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# Post-Harvest Intensification in Late Pleistocene Southwest Asia: Plant Food Processing as a Critical Variable in Epipalaeolithic Subsistence and Subsistence Change

by Michèle M. Wollstonecroft

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Thesis submitted in fulfilment of the degree of PhD Institute of Archaeology University College London 2007 UMI Number: U592469

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### ABSTRACT

The objective of this dissertation is to investigate how developments in *post-harvest systems* may have influenced hunter-gatherer subsistence change during the Epipalaeolithic (23,970-11,990 <sup>14</sup>C yr BP cal) of Southwest Asia. The term *post-harvest system*, as it is used here, refers to the knowledge, technology and co-ordination of labour that are necessary to convert raw plants into edible products and/or storable yields. It is argued that post-harvest systems promote increased abundance in four ways: i) permitting a wider variety of plants or plant parts to be added to the diet; ii) transforming a single plant part into several forms of food; iii) producing physical or chemical changes that improve the nutrient value; and iv) reducing spoilage and/or transforming seasonally available resources into to year-round staple foods.

Moreover, it is argued that the development of post-harvest systems entailed more than simple increase: that it transformed hunter-gatherer productive systems. A schematic model is presented to illustrate how developments in post-harvest systems would be expected to transform hunter-gatherer production systems. The links between food processing intensification and resource selection, during periods of resource scarcity and of resource abundance, are also considered.

This study is multidisciplinary, bringing together the archaeological and ethnographic records and data from food science and botany. A case study was carried out on the harvesting, processing and nutrient analyses of the mature tubers of sea clubrush *Bolboschoenus maritimus* (L.) Palla. Sea club-rush was selected, from among plants recovered from Epipalaeolithic contexts, because it is widespread at early sites, its occurrence has significant archaeological time depth and no previous research of this type has been undertaken on this plant.

The results of the case study show that the potential yields and nutrient values of sea club-rush tubers are comparable with those reported for other wild root foods. Like many other wild and domesticated edible roots, the tubers were found to require extensive processing to make them edible. A model is presented which suggests the technological and environmental conditions in which the intensification of sea club-rush tubers is tenable.

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### **CHAPTER I: THE RESEARCH PROBLEM**

The purpose of this study is to investigate how developments in food processing could feasibly have impacted on ancient human food-production systems. In this thesis I argue that food processing was a critical variable in the changing patterns of Epipalaeolithic (23,970-11,990<sup>14</sup>C yr BP cal) hunter-gatherer subsistence systems, and that it impacted on all aspects of those systems e.g. land use, resource exploitation and mobility patterns. This argument is based on the widespread archaeological and archaeobotanical evidence that during the Late Pleistocene of Southwest Asia significant advances in food processing and food preservation occurred in tandem with increased exploitation of wild plant resources (Bar-Yosef 1996; Bar-Yosef and Belfer-Cohen 1989; Colledge 1991, 2001; De Moulins 1997; Flannery 1969; Hillman 1996; Hillman et al. 1989; Hillman, Madeyska and Hather 1989; Watkins 2004; Wright 1994, 2005). Plant assemblages recovered from Early Epipalaeolithic sites suggest that some groups had replaced generalised foraging strategies with intensive plant collecting practices (Kislev et al. 1992). Certainly, the tools that are thought to indicate the intensive processing of plant foods, the deep vessel mortar and elongated pestle, first appeared in the Early Epipalaeolithic (c. 23,970<sup>-14</sup>C yr BP cal) (Wright 1994, 2005). Also, from the beginning of the Epipalaeolithic there were sequential increases in the numbers and types of other groundstone tools, types of hearths, and pit features, as well as the first evidence for camp re-occupation (Goring-Morris and Belfer-Cohen 1998). Through time, the production of food processing tools and features accelerated in quality, tempo and extent such that by the Late Epipalaeolithic, there were exponential increases in the numbers of groundstone tools, as well as a trend towards grinding technology and more elaborate cooking features (Table 1.1.) (Richerson et al. 2001; Wright 1994, 2005).

Epipa laeo lithic complex	Date <sup>14</sup> C yr BP cal*	Clima te	Mo bil ity Pa tte rn	Ground stone Tools
Ea rly Epipa laeo lithic	23,970 - 17,400	Se vere cold & dry, in creased seaso nal ex tre mes	Mobile: circulating?	Deep vessel mortars & elongated pestles introduced
Middle Epipa laeo lithic	17,400 - 14,730	Warmer & wetter than previously	Mobile: circulating?	In crease in ty pes & quantities of grinding & pounding tools
(early) Late Epipa laeo lithic/ Early Natufian	14,730 - 13,130	Warm & wet	Semi- sedentary/ sedentary radiating?	Significant rise in frequency of ground stone tools, and numbers of sites in which they occur, especially mortars
(late) Late Epipalaeolithic/ Late Natufian	13,130 - 11,990	Dry & cold	Lo gistical, se mi- se den tary / se den tary radiating ?	Apparent increase in grinding technology

Table 1.1. Summary of trends in mobility and groundstone tools during the Epipalaeolithic (Byrd 1998; Goring-Morris and Belfer-Cohen 1998; Hillman 1996; Lieberman 1993; Wright 1992, 2005).

\*Calibration of dates based on INTCAL (Reimer et al. 2004)

Our knowledge of Epipalaeolithic economies, and the changes that occurred throughout this 10,000-year period, are hampered by questions about land use and the geographic distribution of critical resources over the landscape. At present, little is known about the relationships between movements/mobility patterns of Epipalaeolithic hunter-gatherers and the distribution of critical plant and animal resources (Baruch and Bottema 1991; Hillman 1996, 2000; Munro 2004; van Ziest and Bottema 1982). In part, this is because we are only beginning to understand the distribution of vegetation over Southwest Asia during the Late Pleistocene (see Hillman 1996, 2000; Willcox 2005).

Studies indicate that broad spectrum economies, *i.e.* those based on a wide range of resources (Flannery 1969), were well established by the Early Epipalaeolithic, possibly beginning as early as the Middle Palaeolithic (Albert *et al.* 1999, 2003; Madella *et al.* 2002 but see also Dayan and Kaufman 1999; Edwards 1989a; Hillman 1996; Rosen 2003; van Zeist and Bakker-Heeres 1984; Weiss *et al.* 2004b). Indeed, more than 250 wild plant taxa have been identified from seeds, parenchymous tissue, charcoal, phytoliths and pollen retrieved from Epipalaeolithic sites (Colledge 1991, 2001; Hillman 2000; Kislev *et al.* 1992; Martinoli and Jacomet 2004a; Piperno *et al.* 2004; Savard *et al.* 2006; Weiss *et al.* 2004a). Significantly, the patterns suggest that shifts in subsistence practices during the Epipalaeolithic did not necessarily involve a change of resources as much as a change in the ways that those resources were utilised, and probably a change in emphasis on select species and/or plant parts.

Given the archaeological and archaeobotanical evidence, it is therefore surprising that developments in food processing, and their possible role in the evolution of food production systems, have received little attention from researchers of Late Pleistocene plant intensification. Yet, over the last 20 years, several archaeologists have argued that food processing is equivalent to subsistence intensification because it provides human groups with increased abundance in the form of essential nutrients and greater dietary choice (Speth 2001, 2004; Stahl 1989; Yen 1975, 1980 and see also Peacock 1998; Wright 1994). Citing studies in food and nutrition as well as ethnographic examples, these authors argue that food processing can produce significant energy returns by promoting the edibility of otherwise inedible plants or plant parts, and/or change the physical or chemical form of a food such that it is more easily and more completely digested. In fact, support for these arguments is abundant in the food sciences, particularly recent research into

the physical and chemical effects of processing, mastication and digestion on plant tissue (Brett and Waldron 1996; Ellis *et al.* 2004; Fennema 1996; Loh and Breene 1982; Pfannhauser *et al.* 2001; Vincent and Lillford 1991; Waldron *et al.* 1997; Waldron, Parker and Smith 2003).

Furthermore, the consumption of processed foods has an affect on human diet, health and metabolism. Each type of processing affects a plant tissue in different ways, allowing the production of foods that are distinct from each other in form, texture, and taste. Research by food scientists demonstrates that food processing can promote greater *bioaccessability* of macronutrients (protein, fats, carbohydrates, fibre) and micronutrients (minerals and vitamins) for human consumption and digestion (Fennema 1996; Pfannhauser *et al.* 2001).

Bioaccessability is defined as the fraction of a nutrient that is released from a food matrix during processing and/or consumption, and its potential availability for absorption in the gastrointestinal tract (Parada and Aguilera 2007; Stahl *et al.* 2002). Bioaccessability is an important factor in *bioavailability*, which is the rate and proportion of a food that is absorbed by the digestive system to become metabolically active (Bender 1989; Ellis *et al.* 2004; Verhagen *et al.* 2001). Food processing such as grinding, fermenting or heating can promote the bioaccessability of nutrients because they transform the microstructure of plant tissue by disrupting the cell walls, changing nutrient-matrix complexes and/or transforming tissue substances into more active molecular structures (Parada and Aguilera 2007). Thus, developments of food processing techniques are linked to changes in human ingestive behaviours, which, in turn have implications for evolutionary trends such as dietary selection, brain and body sizes, longevity and disease prevention (Johns 1999).

However, the economic, social, diet and health implications of ancient food processing systems have received surprisingly little attention from archaeologists. With few exceptions (see Lyons and D'Andrea 2003; Leach 1999a; Speth 2004;

Wandsnider 1997; Wright 1994, 2005) questions about food processing are rarely included in archaeological investigations into prehistoric subsistence and subsistence change. This may be due to assumptions that food processing is already known and/or that it is associated with consumption rather than food production (Speth 2004).

Certainly contemporary research into the impetus for food production, which is intently focused on the cultivating and mass harvesting of wild cereals, and the effects of human selection on cereal morphology (*e.g.* Charles *et al.* 2003; Jones *et al.* 2005; Kislev *et al.* 2004; Tanno and Willcox 2006a; Willcox 2005; Weiss *et al.* 2004a, b; Weiss *et al.* 2006) rarely includes investigations of the possible form(s) in which ancient people consumed the wild plants that they exploited. As a result, with the exception of the cereals, at present we know little about the potential food value and possible usable properties of the >250 species of economically useful wild plants that have been recovered from Epipalaeolithic sites.

What is more, the development and evolution of food processing systems by ancient groups has implications for other changes to their subsistence system. Recent ethnographic research into plant processing technology (*e.g.* Leach 1999a; Lyons and D'Andrea 2003; Wandsnider 1997) shows that the performance characteristics of edible plants vary according to the technology with which they are processed. The functional relationship between edible plants and specific technologies may be of significance in light of research by Leach (1999a) that shows that a group's decision to add a particular resource to their diet is based on their ability to process that plant or animal part with the available technology. Thus it can be inferred that decisions about resource selection affect decisions about scheduling and mobility: where and when a group situates its members at different times of the year.

Bearing in mind the potentially transformative effects of food processing on Late Pleistocene economies, I propose that the development of food processing systems provided an avenue of *post-harvest* intensification for Epipalaeolithic groups. The term post-harvest (or postharvest) is adopted from agronomy where it represents a specialised branch of research into the physiology of economically useful plants with a focus on the conditions, technology and information that are necessary in order to prevent loss of quality, quantity and nutrients after harvesting (Wills *et al.* 1998). Post-harvest systems promote abundance because they produce improvements in both quality and quantity. The term post-harvest system, as I am using it here, expands on the term post-harvest to include the skills, knowledge, technology and coordination of labour that are necessary to convert raw plants into edible products and/or preserve them as storable yields, and/or promote the availability of nutrients.

I further argue that developments in food processing and preservation methods during the Epipalaeolithic constitute *post-harvest intensification*. The term post-harvest intensification was coined by Yen (19800) to describe food processing activities that convert raw plants to storable crops, as well as food processing activities that transform a single type of resource into different forms of food. My definition of post-harvest intensification expands on that of Yen to further include i) all food processing activities that promote increased abundance, *e.g.* activities which render inedible plants edible; ii) transformation to the production system, brought about by increases in post-harvest labour, technology, and knowledge.

#### **1.1. RESOURCE INTENSIFICATION**

Archaeologists are in agreement that shifts in hunter-gatherer subsistence practices throughout the Epipalaeolithic were linked to the intensification of abundant wild plant and animal resources (Bar-Oz, and Dayan 1992; Edwards 1989a, b; Garrard 1999; Hillman 1996; Hillman *et al.* 2001; Kislev *et al.* 1992; Munro 2004; Stiner *et al.* 2000; Weiss 2004). Intensification is a term that is frequently used by archaeologists to describe social and economic changes that result from an interplay between land-use and an increase in labour, improved technology and/or changes in task group organisation (Ames 1995; Bender 1981; Brookfield 1972; 2001; de Moulins 1997; Hayden 1990). In itself intensification is not a theory but a growing body of literature on the concept, including the causes, the processes by which it is thought to have occurred, and how it can influence economic and social changes (de Moulins 1997).

For archaeologists, the concept of intensification is a useful theoretical device for studying subsistence change because it provides a means of measuring human labour inputs in relation to land use (Brookfield 2001; Leach 1999b; Morrison 1994, 1996). Subsistence intensification, or the intensification of production, as the term is used here, defines a phenomenon wherein a group achieve greater efficiency in their subsistence practices due to their increased productivity per unit area of land exploited (Boserup 1965). Common to these studies is that land is a constant against which a second variable, *e.g.* labour inputs or organizational changes, can be measured in terms of energy [or other types of measures] (Morrison 1994: 115). Intensification occurs when that variable is substituted for land, "so as to gain more production from a given area, use it more frequently, and hence make possible a greater concentration of production" (Brookfield 1972: 31).

Hunter-gatherer intensification is typically characterised as the increased emphasis of time and labour on specific resources, accompanied by increased specialisation in procurement and processing methods and certain types of risk aversion systems such as physical storage (Price and Brown 1985). Essentially hunter-gatherer intensification involves new ways of using and managing resources, which may entail changes in group organisation and possibly shifts towards increased cultural complexity; and/or may entail introducing specialised strategies such as innovations in the harvesting and preservation of seasonally available resources (Ames 1985; Brookfield 1972, 2001; Hayden 1992).

However, by definition the intensification of production is more than simply

increase (Morrison 1994, 1996). Rather, it describes a transformation of the overall productive system because the increasing energy inputs that are associated with increased production will necessitate a reorganisation of the system (Brookfield 1972).

### 1.2. PLANT PROCESSING AS A POTENTIAL AVENUE OF EPIPALAEOLITHIC INTENSIFICATION

Among the first to recognise plant-processing technology as an avenue of intensification of Epipalaeolithic hunter-gatherers was Wright (1994). Following Stahl (1989), Wright "(1994: 257) observed that processing permitted these groups to "...maximise the value of plant foods from limited areas, permitting the same (or shrinking) harvests to support more people. She proposed that plant-food intensification first occurred during the latter part of the Epipalaeolithic (the Natufian) when groups shifted to grinding technology.

While I agree with Wright's (1994) general hypothesis, my argument diverges in that I propose that plant intensification occurred as early as the onset of the Early Epipalaeolithic, at c. 23,970 (<sup>14</sup>C yr BP cal) when deep mortars were first incorporated into human food-production system and grinding and pulverising technology began to be used in conjunction with cooking features (hearths) (Piperno *et al.* 2004). Grinding and pounding, as well as thermal treatments and different regimes of soaking and leaching, are all tools of intensification because they can promote greater abundance per unit area of land exploited.

The basis of my argument is that, quality and quantity of food are improved by post-harvest techniques, which include all types of processing, preservation and storage. The four main points that are of importance here are:

 i) processing permits the consumption of a wider range of plants and/or plant parts;

- ii) processing permits the production of a wider range of food products from a single type of plant part, *e.g.* the tubers of yam (*Dioscorea* spp.) and potato (*Solanum toberosum*) can be fried, mashed, boiled and/or baked and subsequently eaten as a vegetable, pounded into flour that can be boiled into a pudding or baked into bread, cakes, and dumplings or utilised as thickening agents in soups or stews;
- iii) processing promotes increased food value in cases where it promotes the bioaccessability of energy and macronutrients (carbohydrates, protein and fatty acids) and micronutrients (vitamins, iron, calcium) (as noted above: bioaccessablity is the proportion of a nutrient that is released from a food matrix );
- iv) processing for the purposes of preservation constitutes intensification because it extends the shelf-life of foods, thus promoting abundance by preventing loss due to spoilage, and making available a greater quantity and greater variety of foods which can be used over a longer time period (than in the fresh state).

Processing may simply entail fracturing the food into particles that are small enough to be chewed and swallowed; and/or it may entail more complex processes such as heating and fermenting that make the edible tissue more amenable to the abilities of the human mouth and the gastrointestinal tract (Vincent and Lillford 1991). In addition, in some circumstances processing can lead to intensification without necessitating changes to the resource base: *e.g.* in cases where processing permits a group to add to their diet the (otherwise inedible) parts of plants that are already used for non-food purposes; and, in cases where new processing techniques promote increased bioaccessability of nutrients in resources that are already part of the diet (Stahl 1989; Yen 1975). These latter points provide plausible explanations for how Epipalaeolithic subsistence change may have occurred without a change of resources.

Moreover, I argue that processing was an important variable in the evolution of Epipalaeolithic production systems and sequential changes to those systems: new tasks, labour demands, technology, technical and ecological knowledge and changing criteria for resource selection, would accompany developments of post-harvest techniques. Significantly, the ability to transform inedible plants into edible products, and to preserve and store seasonally available resources would allow a group to obtain more productivity from an area of land, and achieve a greater concentration of production (as per Brookfield 1972, see Chapter II, this volume).

Arguably, some evidence of food processing has been identified at pre-Epipalaeolithic sites (see Madella *et al.* 2002; Rosen 2003). However, the patterning in the archeological record suggests it was during the Epipalaeolithic that processing (post-harvest) systems became incorporated into human subsistence settlement systems in Southwest Asia. The introduction of these new systems entailed more than simply a new form of technology.

Thus, in this thesis I argue that the addition of post-harvest systems to the existing subsistence strategy introduced a whole new suite of factors that impacted on all components of the production system. These new factors included the knowledge, technology and labour inputs required to convert raw plants into edible products and/or preserve them as storable yields, as well as to promote the bioaccessability of nutrients. These new factors impacted on the production system because they necessitated changes in subsistence activities and/or changes in emphasis of how group members spent their time, and also expanded the available resource options, potentially influencing resource choice, diet, land use and scheduling, *i.e.* where and when people situated themselves at particular places on the landscape.

### **1.3. THESIS OBJECTIVES AND RESEARCH FRAMEWORK.**

Based on the view that, if we are to understand the economic decisions of prehistoric hunter-gatherers, we need to know a great deal more about their individual resources, the present research entails a case study on the effects of rudimentary processing methods that were probably known to Epipalaeolithic hunter-gatherers, *i.e.* heat, pounding, and moisture regimes, on the otherwise inedible mature tubers of sea club-rush, Bolboschoenus maritimus (L.) Palla, also known as Scirpus maritimus L. Sea club-rush is a semi-aquatic perennial with edible seeds, tubers and shoots, found in saline and fresh-water wetland environments throughout temperate latitudes (Davis 1985; Townsend and Guest 1985). This plant was selected from among species recovered from Epipalaeolithic contexts because it is widespread at early sites, its occurrence has a significant time depth, and no previous research of this type has been carried out on this species. Sea club-rush has been recovered from Late Pleistocene sites dating from 19,000 years ago and from Epipalaeolithic sites in Mesopotamia, the Levant, North Africa, and Anatolia (Figure 1.1.). Moreover, because the mature tuber cannot be eaten in the raw state, it provides an ideal subject for processing experiments and questions about the potential role of processing in the intensification of production.

### 1.3.1. Thesis objectives

This study is multidisciplinary, employing numerous lines of data including recent archaeological, botanical, ecological and environmental, and ethnographic reports as well as recent advances in food science. The principal objectives of the present study are i) to develop a schematic model to explain how developments in food processing could feasibly have impacted on Epipalaeolithic hunter-gatherer production systems; ii) to carry out a case study to investigate the effects of food processing techniques known by Epipalaeolithic groups on one of the plants that they exploited.







Figure 1.1. Map showing the Epipalaeolithic and aceramic Neolithic sites in Southwest Asia where sea club-rush (*Bolboschoenus/Scirpus maritimus*) has been identified (see Chapter 4 this volume). Note: archaeological sites that produced plant remains which have been identified to the genus only (*Scirpus* sp), and/or other species of *Scirpus*, are not shown here.

Other objectives of the case study were to identify the technological and ecological conditions within which sea club-rush tubers can be intensified, and to assess how this plant might respond to routine exploitation by humans. To best address these questions, a holistic approach was adopted that entailed observations on harvesting as well as processing the tubers, and investigating whether they contain sufficient utilisable carbohydrates, energy and/or other nutrients to be of economic value. Fieldwork, conducted in south-central Turkey and East Sussex, England, entailed harvesting and processing experiments to gather data on effective yields and to obtain samples for the processing experiments and laboratory analyses. To establish the nutritional potential of sea club-rush tubers, and to make observations, using microscopy, about how these root foods are affected by rudimentary processing techniques, physical and chemical studies were conducted in the Department of Biochemistry (formerly the Department of Life Sciences) King's College London, and at the Institute of Archaeology, University College London.

#### **1.3.2. Research Framework**

Both experimental and observational strategies were employed during the case study. Experimental studies included controlled and replicated trials that were used to determine the nutrient profile of *B. maritimus*; to identify food-processing techniques that would transform the otherwise inedible tubers into a palatable food. Observational studies entailed measuring, by way of controlled comparisons, the effects of one or more variable, *i.e.* pounding, moisture and/or heat and time, on the experimental materials. The details of the field and laboratory methods are fully explained in Chapters V, VI and VII.

Harvesting experiments were conducted to assess the relationship between effective yields and human labour inputs, and their implications for resource selection and land-use practices. The principal question of interest was: Can enough tubers be collected to make harvesting worthwhile? The harvesting trials, which took place over three years, also provided opportunities to observe the growing habits of this plant and to note "windows of opportunity" and "limiting factors" for collecting (see Munsen 1984). This would include, for example, the ease/difficulty of uprooting the tubers, the response of sea club-rush stands to the potentially beneficial effects of digging, and whether the tubers are available in sufficient quantities year after year.

Nutrient analysis was carried out to measure whether sea club-rush tubers contain enough nutrients and/or energy (calories) to make harvesting worthwhile. Sea club-rush tubers were analysed for energy, moisture, dry matter, protein, lipids, carbohydrates, and total and individual mineral content. Based on the gross production rates of the harvesting trials, harvesting rates (g/h/person and kcal/h/person) were subsequently calculated for each of the nutrients, and compared with those estimated for other wild root foods. A second objective of the nutrient analyses was to identify seasonal shifts in sea club-rush nutrients and the best time of year for harvesting. Tubers collected in March, April, June, July and October were analysed.

Food processing experiments were conducted to test whether mature sea clubrush tubers are "intensifiable" (*i.e.* suitable for intensive human exploitation) according to one of three criteria: i) if it is possible to transform the otherwise inedible mature tubers into an edible product; ii) if a range of different foods can be made from this single resource; iii) and/or whether processing promotes an increase in the nutritional value of the tubers. Microscopy provided the main vehicle for these observations. Three types of microscopy were used: compound light microscopy (LM), transmission electron microscopy (TEM), and scanning electron microscopy (SEM). Each type produces a different kind of image; used together they can provide a more complete picture.

To assess the economic potential of sea club-rush, the interpretative framework entailed comparisons of the results of the harvesting, processing and
nutrient analyses with those reported for other root foods. The interpretative framework was based on the assumption that metaphor (analogy) is an indispensable interpretative tool in archaeological explanation and prediction. In particular, the observational, experimental and interpretative frameworks draw on ethnographic examples of plant uses, many of them from outside Southwest Asia. The arguments for and against the uses of metaphor in archaeological explanation and prediction are comprehensively explained elsewhere and therefore I will not repeat them here (see Gould and Watson 1982; Hodder 1983; Stahl 1993; Wylie 1985) but point out that there is wide-scale support for the use of ethnographic analogy in archaeobotanical studies. For example, Hillman (1973) and Pearsall (1989) maintain that most modelling of prehistoric plant use is based on ethnographic analogy; and Watson (in Gould and Watson 1982), Wylie (1982, 1985) and Stahl (1993) further argue that most archaeological inference is metaphorical, and that metaphor itself is an important tool in practically all scientific research.

#### **1.4. THE ORGANISATION OF THIS THESIS**

The chapters are organised into three groups: background research, field and laboratory experiments and the summary and conclusion.

Chapters II – IV summarise literature reviews of Epipalaeolithic archaeology, intensification theory, and the study plant. Chapter II outlines the evidence for Epipalaeolithic food processing and plant uses, with a focus on the Levant. Chapter III discusses the concept of intensification, how it has been used in archaeological model-making, reviews existing theories about the types of plants that can be intensified, and presents a model of post-harvest intensification. Chapter IV provides biological and ecological information about the study plant, sea club-rush, and describes its ethnographically known uses.

Chapters V - VIII describe the field and laboratory experiments. For the sake

of clarity, instead of a single chapter on methods, a methods section is included within each of these three chapters. Chapter V describes and explains the harvesting methods and quantifies and assesses the results. Chapter VI describes and explains the nutrient analyses and quantifies, evaluates and discusses the results. Chapter VII describes the food processing experiments, and presents and analyses micrographs of the processed sea club-rush tissue.

Chapter VIII summarises the results of the case study and assesses the implications of the results for Epipalaeolithic plant intensification.

# CHAPTER II. DEVELOPMENTS IN PLANT PROCESSING DURING THE EPIPALAEOLITHIC (c. 23,970 – 11,990 <sup>14</sup>C yr BP cal) OF SOUTHERN ANATOLIA AND THE LEVANT

The Epipalaeolithic encompassed one of the most significant transformations in human prehistory: in many parts of Southwest Asia, mobile hunter-gatherer groups assumed less mobile lifeways, eventually establishing village economies, self-sufficient permanent or semi-permanent settlements in which members co-operated to obtain critical resources (see Bar-Yosef 1996; Byrd 1998). This shift from fully mobile subsistence to semi-sedentary or sedentary villages is of great interest to prehistorians because it encompassed radical changes, both economic and cultural, in land use, resource exploitation and labour organisation, and ultimately created logistical, ecological and social conditions that were favourable for plant domestication (Boyd 2006; Henry 1983; Dayan and Kaufman 1999).

But to complicate the picture, the mobility patterns of Late Pleistocene groups are heavily debated (Bar-Yosef and Belfer-Cohen 1989; Bar-Yosef and Valla 1991; Boyd 2006; Edwards 1989b; Hardy-Smith and Edwards 2004; Kaufman 1992; Rosenberg 1998). For example, Lieberman (1993) argues that, up to the Late Epipalaeolithic, groups followed a circulating mobility pattern (*i.e.* a *forager* system, as defined by Binford 1980), in which the entire group moved to resource-procurement areas, a strategy that involves opportunistic gathering of foods for immediate consumption; and that Late Epipalaeolithic/Natufian groups adopted a radiating pattern (*i.e.* a *collector* system as per Binford 1980) in which groups establish semi-sedentary base camps, and, through the division of labour such as specialised task groups, collect seasonally available resources and bring them back to the base camp where some foods are preserved and stored for later use. Alternatively, Kaufman (1992, 1993) and BarYosef and Meadow (1995) argue that circulating and radiating strategies are not mutually exclusive and that throughout the Epipalaeolithic groups used both strategies but with diverse and shifting degrees and emphasis. Boyd (2006) recently added to the debate, refuting the principal categories of evidence that are equated with Late Epipalaeolithic sedentism, categories which include: the thickness of archaeological deposits, stone architecture, heavy-duty material culture, storage pits, cemeteries, the presence of commensal faunal species, and inferences about the seasonality of hunting based on cementum increments on gazelle teeth.

Thus many questions remain about the factors that motivated the resource and mobility decisions of Epipalaeolithic groups. The most common theory is that shifts in mobility patterns were in direct response to a reduction in the availability of critical resources due to changing climatic conditions of the Late Pleistocene (Hillman 1996; Hillman *et al.* 2001; Richerson *et al.* 2001). Indeed, there is strong evidence that environmental change was linked temporally and spatially to shifts in Epipalaeolithic mobility and settlement patterns (discussed in section 2.3.). See Table 1.1.

Furthermore, variations between contemporaneous archaeological assemblages provide evidence for separate local and chronological traditions among the cultural histories throughout this vast region, indicating that there were social and economic differences between coeval Epipalaeolithic hunter-gatherer groups (Bar-Yosef 1996; Byrd 1998; Goring-Moris and Belfer-Cohen 1998). Thus most archaeologists agree that environmental conditions must be examined alongside other factors such as the distinct social and historical contexts within which these changes occurred (Blumler 1986; Boyd 2006; Edwards 1989b; Byrd 1998; Goring-Morris and Belfer-Cohen 1998; Harris 1986; Sheratt 1986; Willcox 2005). It is beyond the scope of this study to elaborate on the many separate local and chronological traditions among Epipalaeolithic cultural histories. Rather, for the purpose of addressing questions about developing post-harvest practices during the Late Pleistocene, this chapter focuses on the types of plant remains recovered from Epipalaeolithic sites, and on general trends in food-processing technology. It begins with an outline of the physical landscape and climate and vegetation of the study area. Subsequently the Epipalaeolithic temporal sequences are discussed.

Unless otherwise stated, all dates in this chapter are calibrated <sup>14</sup>C yr BP. Calibrations are based on INTCAL (Reimer *et al.* 2004).

#### 2.1. THE PHYSICAL LANDSCAPE

The descriptions of the physical landscapes of Anatolia and the Levant presented in this chapter are taken from Bar-Yosef (1996, 1998), Hillman (1996, 2000), van Zeist and Bottema (1991) and Zohary (1973).

Southwest Asia is composed of diverse landscapes with a predominance of mountains, plateaus and alluvial plains which are intersected by wetlands, lakes and rivers (Figure 2.1.). Lands along the Mediterranean are characterised by narrow coastal plains that are bordered on the inland side by high mountains and/or hills. The interior landscapes include rolling hills, plateaus and plains interspersed by lone mountains or small mountain ranges.

Anatolia (Asia Minor) is dominated by mountain ranges that surround a vast, relatively high altitude (c. 900-1200 m asl) inland plateau known as the Central Anatolian Plateau. In northeastern Anatolia, the Anadolu Mountains, which run eastwest, separate the plateau from the Black Sea. In the south, the Taurus Mountains, which stretch from the Agean Sea to the Zagros Mountain range, separate the plateau



Figure 2.1. Map showing the physical terrain of Southwest Asia (redrawn from Moore, Hillman and Legge 2000, page 4, Figure 1.1).

from the Mediterranean coastal plain. The Anatolian plateau itself is composed of enormous expanses of plains, rolling hills, steep river valleys and shallow depressions with salt flats and salt lakes. The high plateau lands in the east, situated at 500 - 2000 m asl, are interrupted in places by volcanic peaks. In southeastern Anatolia, at the base of Taurus foothills are the broad river valleys of the Tigris and Euphrates and their tributaries. These valleys are of particular archaeological significance as they were home to the oldest known sedentary villages in Anatolia, Late Epipalaeolithic Cayönü and Hallan Cemi.

The Levant, a region dominated by desert steppe and desert landscapes, stretches over a north-south axis of >1000 km, from the Taurus Mountains in the north to the Sinai Peninsula in the south; and eastward for c. 250-350 km (Bar-Yosef 1998). Two chains of parallel north-south running hills and mountains, which are divided by the rift valley, stretch between the Orontes River in the north and the Gulf of Aqaba in the south. These chains are known as the eastern and western hills. From north to south, the western hills include the Jebel Ansariye, the Mountains of Lebanon and the Central Highlands of Palestine; and the eastern hills include the Jebel Zawiye, the Anti-Lebanon Mountains and the Transjordan Plateau. These upland regions have the most temperate climate in the Levant and support mesic woodland vegetation.

To the east of the rift valley is the Transjordan Plateau. Here the landscape changes abruptly into steppe and desert landscapes dissected by eastward running wadis. In the eastern part of the plateau (now northeast Jordan), there is an internal drainage system known as the Azraq Basin. The Basin, which covers >12,000 km<sup>2</sup>, has particular archaeological significance as some of the largest sites of the Early and Middle Epipalaeolithic have been found here (Garrard 1998). The landscape is composed of limestone, chalk, sandstone, chert and marl, except in the northeast where

dense layers of basalt cobbles and boulders form the Black Desert. Further south, the Azraq springs area supports wadis, marshes, mudflats and playas.

The Syrian and Arabian deserts span the regions between the eastern Levant and Mesopotamia, extending to the Negev and Sinai in the south-west, and Arabian Sea in the southeast. Various hill zones with relatively temperate upland micro-climates and mesic vegetation occur throughout the desert steppe regions including the Jebal Abdul Aziz in northern Syria and the Jebal Druze of northern Jordan, and Negev Highlands.

# **2.2. CLIMATE AND VEGETATION**

According to Zohary (1973) the present day climate and vegetation of the study area can be grouped into two general phytogeographical regions, classifications which are based on the types of environments that would exist without the otherwise damaging effects of disturbance by humans and livestock. The first is the Mediterranean, which encompasses the coastal lowlands and surrounding mountain/hilly areas of southern Anatolia and the Levantine corridor. It has a mild climate and the dominant vegetation is mesic forest and woodlands. Because they have a greater carrying capacity than the steppe and desert regions, throughout the Late Pleistocene and early Holocene the Mediterranean woodland zones were more heavily populated by human groups than the more arid, inland regions.

The second zone, known as the Kurdo-Zagrosian/Indo-Turanian, has a more continental climate than the Mediterranean zone, and includes the arid inland regions of central Anatolian, Syrian, and Iranian steppes and the northern Mesopotamian steppe. It encompasses steppe, desert-steppe and desert, and open forests in hilly areas including the northern Taurus–Zagros oak forest and the southern Zagros pistachio (terebinth)-almond forest.

#### 2.2.1. Late Pleistocene climate and climatic change

Climatic fluctuations, with increasingly harsh conditions, are known from the Late Upper Palaeolithic (Goring Morris and Belfer-Cohen 1998). Conditions became increasingly difficult with the arrival of the Late Glacial Maximum at about 28,000 years ago. This climate period, which lasted until about 19,000 years ago, brought a shift from cold and wet to cold and dry conditions, as well as pronounced seasonal extremes of hotter and drier summers, and colder and wetter winters (Hillman 1996; Lieberman 1993).

During the Late Glacial Maximum forests retreated to the western Levant, western Anatolia and possibly the northern Zagros (Figure 2.2.) and inland regions became dominated by xeric steppe vegetation such as grasses (Poaceae/Graminae), wormwoods (Artemisia), and chenopod (Chenopodiaceae) shrublets (Baruch and Bottema 1991; Hillman 1996; van Zeist and Bottema 1982). Hillman (1996) maintains that although this dry steppe was low in potential caloric yields when compared with later developments, there was an enormous diversity of potential plant foods, primarily perennial species, including xeric-adapted geophytes and mesic-adapted plants with edible seeds, the latter being restricted to moister habitats found in gullies, wadi banks and lacustrine environments. Among the potentially available xeric-adapted edible species Hillman (1996: 178) states that the seeds of wormwoods (Artemisia sp.) would have been the most universally available over the steppe. Other potential foods include the seeds of joint-pine (*Ephedra*) and the large spiny *Gundelia tournefortii*, as well as the swollen roots and tubers of cream-flowered cranesbill (Biebersteinia multifida), the hairy storksbill (*Erodium hirtum*), and wild salsify (*Scorzonera*). Edible mesic species, occurring in moister patches, would have included the perennial feather grasses (Stipa





spp. and *Stripagrostis* spp.) and certain types of legumes including the large-seeded sainfoins (*Onobrychis* spp) and the small-seeded fenugreek (*Trigonella* spp.).

Following the Late Glacial Maximum, conditions improved during the Late Glacial Interstadials that began between *c*.19,000 and 18,300 (<sup>14</sup>C yr BP cal), bringing increasingly warm and wet conditions (Hillman 1996). Hillman (1996 and see also Hillman 2000) has interpreted three main trends in woodland development from the Late Glacial Maximum to the Holocene based on the patterns in two pollen diagrams, the first published by van Zeist and Bottema (1982) from samples collected from Ghab in northwest Syria, and the second published by Baruch and Bottema (1991) from samples collected from Hula in Northern Israel.

- i) between c.18,300 and c.13,130 (<sup>14</sup>C yr BP cal), an expansion of oakterebinth park-woodlands over the Taurus/Zagros zones (Fertile Crescent), and of terebinth-almond park-woodland-steppe over the inland regions;
- ii) beginning between approximately 13,130 and 12,900 and (<sup>14</sup>C yr BP cal)
  a halt in woodland development that was triggered by an abrupt change at
  the onset of the Younger Dryas stadial, which as characterised by cold,
  dry harsh conditions similar to those of the Late Glacial Maximum.
  During this stadial there was a reduction of woodland cover and mesicadapted herbaceous species;
- iii) at c. 11,500 (<sup>14</sup>C yr BP cal) the early Holocene brought warmer and wetter conditions.

These three main trends are illustrated in Figures 2.3. - 2.6, below.



**Figure 2.3.** Map of the estimated distribution of vegetation by *c*. 18,300 (<sup>14</sup>C yr BP cal) (map redrawn from Moore, Hillman and Legge 2000, page 79, Figure 3.18). Sites mentioned in this chapter, from the Middle Epipalaeolithic/Geometric Kebaran, are indicated.



Figure 2.4. Map of the estimated distribution of vegetation at the start of the Younger Dryas at c. 12,900 ( $^{14}$ C yr BP cal) (map redrawn from Moore, Hillman and Legge 2000, page 79, Figure 3.18). Sites mentioned in this chapter, from the early phase of the Late Epipalaeolithic and the Early Natufian, are indicated.



Figure 2.5. Map of the estimated distribution of vegetation at c. 12,500 ( $^{14}$ C yr BP cal) as after 500 years of Younger Dryas climate conditions (map redrawn from Moore, Hillman and Legge 2000, page 80, Figure 3.18). Some Late Epipalaeolithic and Late Natufian sites are indicated, including those mentioned in this chapter.



**Figure 2.6.** Map of the estimated distribution of vegetation in the early Holocene at *c*. 10,700 (<sup>14</sup>C yr BP cal) (map redrawn from Moore, Hillman and Legge 2000, page 80, Figure 3.18). Some aceramic Neolithic sites that have produced significant plant assemblages are indicated.

#### 2.2.2. Effects of Late Pleistocene climatic change on vegetation

Significantly, following the onset of warmer and wetter conditions brought by the Late Glacial Interstadials, the rainy season lasted longer and evaporation rates were relatively low, which meant that moisture was more available in the soil as well as in rivers, streams, lakes and marshland areas. The rise in rainfall and higher temperatures coincided with a global rise in atmospheric  $CO_2$ , which created atmospheric conditions that advantaged C3 plants, and promoted woodland expansion and the increase of wetlands over south-west Asia (Hillman *et al.* 2001; Richerson *et. al* 2001).

Due to improving climate conditions food-rich habitats became more widely distributed over the landscape, particularly after *c*. 15,300 (<sup>14</sup>C yr BP cal) (Garrard 1999; Hillman 1996, 2000; Price and Gebauer 1995; Richerson *et al.* 2001). The spread of oak-terebinth woodlands created environments composed of open stands of xeric oak (*Quercus*), terebinth/pistachio (*Pistacia*), and shrubs and trees of the Rose family including almond (*Amygdalus*), hawthorn (*Crataegus*), possibly pear (*Pyrus*), as well as maple (*Acer*), buckthorn (*Rhamnus*), and Christ's thorn (*Paliurus spina-christi*).

Significantly, there was an increase in the distribution of economically useful legumes and grasses that are native to oak-terebinth park-woodland and terebinthalmond woodland-steppe. These include wild cereals such as einkorn (*Triticum boeticum*) which is native to Anatolia; emmer (*Triticum diococcoides*) which is native to the Levant; and barley (*Hordeum*) which is native to both regions. Hillman (1996) argues that large stands of cereals would have been available for the first time. Willcox (2005) argues otherwise that wild cereal stands may not have been as large or widespread as previously thought, and probably had a more patchy distribution given their preferences for specific edaphic, rainfall, and temperature conditions as well as vulnerability to competition from other plants.

Byrne (1987, and see also Blumler 1996) pointed out that, despite the improved conditions that began after c. 15,300 (<sup>14</sup>C yr BP cal) the climate continued to fluctuate up to the Holocene, with pronounced seasonality and unpredictable inter-annual shifts in rainfall and temperatures with possible increased periods of drought. Fluctuating conditions such as these are favourable for herbaceous species with underground storage organs (geophytes) such as the purple tartar lily (*lxiolirion tartaricum*), wild tulips (*Tulipa*), star-of-Bethlehem (*Ornithogalum*), grape hyacinths (*Muscari* and *Bellevalia*) and barley grass (*Hordeum bulbosum*) as well as various Asteraceae/Compositeae (Hillman 1996).

Currently there is disagreement about the effects of the Younger Dryas, which lasted for about 1,000 years (c. 12,900 - 11,900 <sup>14</sup>C yr BP cal), on the density and distribution of vegetation. Hillman (1996 and see Hillman 2000) maintains that a dramatic decrease in wild cereals occurred together with the reduction of woodlands, which he argues was the incentive for the first cereal cultivation (see Figure 2.5). Willcox (2005) provides a different view, arguing that although the Younger Dryas brought cooler and less stable climate conditions, it probably did not cause major changes in the vegetation cover that could not be accommodated by hunter-gatherers with their existing resource exploitation strategies.

Certainly, the distribution of vegetation and associated animals over the different regions, and temporal changes in the availability of economically important plants and animals throughout the Late Pleistocene would have affected carrying capacity (person/km) and therefore have a bearing on the mobility patterns of different huntergatherer groups within the different vegetation zones. Noting that vegetative and animal biomass decrease in the steppe and desert steppe regions Bar-Yosef (1998: 160-161) estimates that the optimum hunter-gatherer territory within the Mediterranean

vegetation belt would be c. 300-500 km<sup>2</sup>, while that of groups living in the steppe/desert-steppe regions would need to be much larger, c. 500-2,0000 km<sup>2</sup>. In times of increasing resource distribution and density, *e.g.* the Middle Epipalaeolithic and Early Natufian, sufficient amounts of critical resources were probably found in proximity to each other, such that reduced mobility and more intensive exploitation of a narrower geographical range would have been possible. In times of resource decline, such as those of the Late Glacial Maximum and the Younger Dryas, people would have needed to travel further to obtain critical resources; and/or find ways to obtain more productivity from the land (Boyd 2006; Halstead and O'Shea 1989).

# 2.3. THE EPIPALAEOLITHIC CULTURAL SEQUENCES

The Epipalaeolithic of the Near East encompasses an enormous span of time and space: almost 10,000 years, and diverse temporal and regional archaeological entities. A range of terms, based on stylistic trends in the chipped stone industries, have been used to distinguish the different cultural developments throughout the Epipalaeolithic (see Byrd 1998 and Goring-Morris 1995). For the sake of simplicity, following Byrd (1998) three general temporal classifications are used here (in calibrated <sup>14</sup>C yr BP): the Early Epipalaeolithic (23,970 – 17,400 BP), Middle Epipalaeolithic (17,400-14,730 BP) and Late Epipalaeolithic (14,730 – 11,990 BP) (see Table 2.1). However, sites within the Levant only are classified as: Kebaran (23,970 – 17,400 BP), Geometric Kebaran (17,400-14,730I BP) and Natufian (14,730 – 11,990) (Byrd 1998). The Late Epipalaeolithic/Natufian is further divided into two periods: early (14,730 – 13,130 BP) and late (13,130 -11,990 BP).

The cultural sequences, as well as important archaeological sites and developments in climate, are summarised in Table 2.1.



#### Table 2.1. Late Pleistocene & early Hololocene archaeological sites mentioned in this chapter

<sup>1</sup> **REFERENCES:** Bar-Oz *et al.* 1999; Bar-Yosef 1996, 1998; Byrd 1998; College 2001; Garrard 1999; Hillman 1996; Kislev *et al.* 1992; Moore, Hillman and Legge 2000; Martinoli and Jacomet 2004a; Piperno *et al.* 2004; Rosenberg 1994; Rosenberg and Davis 1992; Sellars 1998; van Zeist and de Roller 1995. Also consulted was the database compiled as part of AHRB/C funded project, based at the Institute of Archaeology, UCL (2001-4): The origin and spread of Neolithic plant economies in the Near East and Europe' (PIs: Professor Stephen Shennan and Dr James Conolly; RA: Dr Sue Colledge) Several authors (*e.g.* Belfer-Cohen 1991; Goring-Morris 1995) have pointed out that the differences between Epipalaeolithic groups and their Late Upper Palaeolithic antecedents were not sudden or revolutionary changes, but shifts in emphasis and scale, and the increasing tempo of change, for example Epipalaeolithic groups used many of the same tools as Late Upper Palaeolithic groups, but appear to have applied them to new purposes and/or improved and elaborated on the existing technology. This pattern of shifting emphasis and scale, and the relatively rapid tempo, characterise the nature of change throughout the different Epipalaeolithic temporal sequences.

In the sections below the three major cultural sequences of the Epipalaeolithic are discussed. The study area and the geographic locations of sites mentioned in the text are illustrated in Figures 2.1. - 2.6.

# 2.3.1. The Early Epipalaeolithic/Kebaran (c. 23,970 – 17,400 <sup>14</sup>C yr BP cal)

The Early Epipalaeolithic emerged during the cold and dry conditions of the Late Glacial Maximum, a period in which prime foraging and hunting areas had been reduced to pockets of refugia (Bar-Yosef 1996; Goring Morris 1995). In the Levant, Kebaran sites were established primarily within the coastal areas, with fewer occurring at inland oases (Bar-Yosef 1998). Like Upper Palaeolithic hunter-gatherers, Kebaran groups were highly mobile and occupied small sites. However, unlike those of their Upper Palaeolithic predecessors, Kebaran sites are more numerous, and were reoccupied on a seasonal basis. The lithic industries also differ, with those of Kebaran groups being dominated by high frequencies of backed bladelets and microliths. More is known about developments in the Early Epipalaeolithic of the Levant than Anatolia and the Zagros but research by Otte and Yalçinkaya (Otte *et al.* 1995; Martinoli and Jacomet 2004a) at Öküzini and Karain in the foothills of the Taurus mountains in south-

central Turkey suggests that similar settlement/mobility patterns and shifts in lithic industries are also true of that region.

In conjunction with a greater emphasis on stylistic elements of the material culture, the new mobility patterns are thought to indicate increased territoriality between Early Epipalaeolithic groups due to competition over favourable pockets of land (Bar-Yosef and Meadow 1995; Goring-Morris 1995; Henry 1989; Lieberman 1993). Population pressure undoubtedly arose due to a reduced overall carrying capacity with human groups congregating in environments that had the most abundant resources, such as the hill zones (see Rosenberg 1998).

It is thought that Early Epipalaeolithic hunter-gatherers living in the hill zones were aware of the advantages offered by the vertical zonation of habitats, as well as aspect, *i.e.* different habitats occurring at the same altitude on the north and south sides of hillsides. In the Levant, for example, due to the east-west altitudinal diversity, there is a vertical zonation of environments such that a range of different plant and animal habitats can be found within short distances (Bar-Yosef 1998). Groups are thought to have followed the sequential ripening of edible plants as it occurred throughout the different elevation zones (Kislev *et al.* 1992).

Early Epipalaeolithic groups appear to have based their economies on a wide range of locally available plant and animal resources (Bar-Oz and Dayan 1999; Bar-Yosef and Meadow 1995; Edwards 1989a; Goring-Morris 1995; Martinoli and Jacomet 2004a, b; Otte *et al.* 1995; Stiner *et al.* 2000). In the Taurus/Zagros zones wild goat (*Capra*) and sheep (*Ovis*) dominate the Early Epipalaeolithic faunal assemblages. In the Levant gazelle (*Gazella*) are dominant although fallow deer are more common at sites located in the Lebanese mountains, and wild ass (*Equus*) and gazelle occur in relatively equal frequencies at sites in the steppe regions. Other prey include aurochs

(*Bos*), wild boar (*Sus*), small animals such as hare (*Lepus*), reptiles, particularly tortoises (*e.g. Testudo graeca*), and molluscs. Birds are present in small numbers, particularly migrating waterfowl, becoming more common in the Late Epipalaeolithic.

# Indirect evidence of plant food processing

This section is focused on groundstone tools rather than cooking features because temporal and spatial developments in early cooking features are not well studied. As observed by Wright (2005: 36), less is known about ancient cooking features because archaeologists rarely distinguish hearths according their construction or frequency of use. Depending on their use, fire features vary in shape, size and materials; they may be wide or narrow in diameter, deep or shallow, stone-bordered or borderless, lined with stones or unlined, and may be used repeatedly or only once (Pokotylo and Froese 1983; Wright 2005).

Evidently fire features became more spatially structured during the Early Epipalaeolithic than previously (Wright 2005). Also, Early Epipalaeolihtic hearths are more commonly found in association with other plant processing tools than previously, *e.g.* at the Kebaran site of Ohalo II (23,000 <sup>14</sup>C BP) a paved hearth was found in spatial and temporal association with a grinding slab (Piperno *et al.* 2004). (See below on for further a discussion on Ohalo II).

The term groundstone, as defined by Wright (1991:21) describes heavy stone tools that are manufactured by combinations of flaking, pecking, pounding, grinding and incising. Wright (1991) classified groundstone tools from Near Eastern archaeological sites as grinding slabs/querns, mortars, handstones, pestles, pounders, stone vessels and multiple tools. Examples are illustrated in Figures 2.7. – 2.10.



Figure 2.7. A range of groundstone tools recovered from Epipalaeolithic sites: (a-c) Upper Palaeolithic grinding slabs and handstones; (d-h) Kebaran and Geometric Kebaran mortars, handstones and pestles; (i-m) Early Natufian mortars, pestles and handstones; (n) Late Natufian grinding slab (redrawn from Wright 1994, page 214, Figure 2).



Figure 2.8. Middle Epipalaeolithic groundstone tools found at the Geometric Kebaran site of Neve David (c. 15,300 <sup>14</sup>C yr BP cal), in the Mt. Carmel region of present-day Israel: (a) shallow bowl; (b) deep mortar (from Kaufman 1989, page 285, Figure 2).



**Figure 2.9.** Late Epipalaeolithic groundstone mortars, pestles and handstones from the Early Natufian site of Wadi Hammeh (c. 12,000 <sup>14</sup>C yr BP cal), in the foothills of the Jordan Valley in present-day Jordan (from Hardy-Smith and Edwards 2004, page 277, Figure 19b).



**Figure 2.10.** Basalt querns from the Late Epipalaeolithic village of Abu Hureyra (*c*. 13,300 <sup>14</sup>C yr BP cal), located in the Middle Euphrates region of present-day Syria (from Moore, Hillman and Legge 2000, page 117, Figure 5.16).

Ethnographic and archaeological studies show that people have used groundstone tools for a range of plant processing purposes, such as dehusking, mashing and the production of fine-grained flours (Kraybill 1977; Hillman 2000). Kraybill (1977: 490) provides a useful classification of groundstone tools according to their most common function, which is shown here in Table 2.2. However, tool function is not always clear-cut, and grinding tools have sometimes been used for pounding and viceversa (Kraybill 1977; Wright 1991, 1994).

 Table 2.2. Common types of groundstone tools (from Kraybill 1977: 490)

POUNDING			
lower stone	upper stone		
mortar	pestle, pounder, or percussion muller		
anvil	rounded hammer-anvil, "pitted" anvil stone		
GRINDING			
lower stone	upper stone		
grain-rubber	rubber		
grinding stone	grinder		
grinding slab	handstone		
mealing stone	mealing stone		
quern	muller		
grinding dish	grinder		
saddle-quern	muller		
milling stone	hand millstone		

Groundstone tools were known to Upper Palaeolithic groups who apparently used them for grinding ochre (Wright 1991, 1992, 1994), a practice that appears to have continued at least up to the Neolithic (Bar-Yosef 1996). The first direct evidence of the use of groundstone tools for processing edible plants dates from the Early Epipalaeolithic. Early Epipalaeolithic groups expanded on groundstone technology with the invention of elongated pestles and deep vessel and bedrock mortars.

Wright (1991) reports that, in the Levant, approximately 14% of Early Epipalaeolithic (Kebaran) sites contained groundstone tools. They are less common at sites in the arid zones where they are usually represented by small and portable handstones, slabs, pestles, mortars (Goring-Morris 1995; Wright 1991), *e.g.* the terrace site of Ein Aqev (c. 21,268 <sup>14</sup>C yr BP) in the Negev, which contained several basin-shaped grinding slabs (Krabill 1977). Some of the earliest examples of bedrock mortars have been found at Kebaran sites in the Negev.

It is thought that Early Epipalaeolithic sites which have both groundstone tools and evidence of frequent re-occupations were located in proximity to favourable plant harvesting areas, such as the former Kebaran lakeside camp of Tor at-Tariq (*c*. 20,000 <sup>14</sup>C yr BP) in west-central Jordan where bedrock mortars and heavy, non-portable groundstone were prominent (Neeley *et al.* 1997).

#### Archaeobotanical evidence of plant use

Archaeobotanical assemblages have been recovered from very few Early Epipalaeolithic sites. These include Öküzini and Karain caves in the Taurus foothills of southcentral Anatolia, and the open-air sites of Ohalo II in the Mediterranean Forest Zone, and Jilat 6 in the Azraq Basin (see Table 2.3.). The Wadi Kubbaniya sites, located on the Upper Nile, are also included here because they produced some of the earliest evidence of Late Pleistocene plant collecting and processing.

#### Archaeobotany of the Mediterranean woodland zones

As noted above, greater frequencies of ground stone tools are found at sites in the Mediterranean forest zones than at sites in the arid regions (Wright 1991). In contrast, direct archaeobotanical evidence is more often recovered from sites outside the Levantine Mediterranean/forest region where the recovery of plant remains is hampered by poor preservation due to a combination of soil and weather conditions (Bar-Yosef and Meadow 1995). A notable exception is the Kabaran site of Ohalo II which was preserved in anaerobic conditions below the water of the Sea of Galilee.

Öküzini <sup>2</sup>	Ohalo II	Jilat 6	Wadi Kubbaniya
EEDS OF FLESHY	FRUITS:		
Celtis	<u> </u>		
	Crataegus		
	Niteria schoberia		
D	Olea europea		
<i>Pyrus</i> group**	cj. Pyrus spp.		
vitis sylvestris	Vills Villfera Zizinhus sping abristi		
unidentified fruit flesh/t	issue**		Hyphaene thebaica
HITC			nyphaene mebalea
Amvadalus group*	Amvadalus		
Pistacia	Pistacia atlantica		
Tistacia	Ouercus		
FFDS OF CEDEAL	SAND OTHER CRAS	SEEC	
EEDS OF CEREAL	Aegilops genicullataperio	orana	
	Alopercurus spp	, and	
	Avena spp.		
	Arundo/Phraymites		
	Bromus spp.	cf. Bromus	
	Catabrosa aquatica	5	
		Echinaria	
	Hordeum spp.		
	Puccinellia		
		cf. Stipa	
D	Triticum dicoccoides	D	
Poaceae spp.	Poaceae spp.	Poaceae spp.	
<u>'ULSES</u>			
	Lens		
Vicieae	Vicieae		
EEDS OF OTHER	HERBACEOUS SPEC	<u>IES</u>	
Alkanna			
	A A	4	Athemidae
	Atriplex	Atriplex sp.	
	Compositae	Compositae	
		Cruciferae Cyperaceae spp <sup>4</sup>	
	Frodium <sup>3</sup>	Cyperaceae spp.	
Galium <sup>3</sup>	Galium <sup>3</sup>		
Gunum	Julian		Liliaceae <sup>4</sup>
	Malva		
			Nymphaceae⁴
	Potamogeton spp.		
Rumex			
		cf. Sophora	
Scirpus*	Scirpus littoralis		
	C. (7*** 1)	Schoenus nigricans	
	Styrax officinalis		
	Umbelliferae	Vanhaan	
		verbascum	
<u>'ISSUE OF EDIBLE</u>	<u>ROOTS</u>		

# **Table 2.3.** List of plants identified from charred seeds and plant tissue from Early Epipalaeolithic sites discussed in this chapter<sup>1</sup>

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<sup>1</sup>References: Colledge 2001; Kislev *et al.* 1992; Martinoli and Jacomet 2004a, 2004b; Weiss *et al.* 2004a. <sup>2</sup>Species with asterisks (\*\*) were also recovered from Early Epipaleolithic Karain Cave

unidentified parenchyma\*\*

<sup>3</sup>According to Colledge (2001:86-91) these taxa have edible roots, and because they can be harvested in all seasons, the presence of seeds could result from root gathering.

<sup>4</sup>Some plants in these families have edible roots, so their occurrence may also indicate root gathering.

Scirpus maritimus-Type tuber

unidentified parenchyma

Dating from 23,000 (<sup>14</sup>C yr BP) Ohalo II appears to have been semi-permanent encampment. Composed of six brush huts, several fireplaces and a burial, the site is thought to have been occupied on a multi-season basis (Nadel and Werker 1999; Nadel et al. 1994). This Kebaran group had a diversified economy based on gathering, hunting and fishing. The site is well known for its remarkable archaeobotanical assemblage of >90,000 well-preserved seeds representing >140 taxa, many of them edible, such as the small and large-seeded wild cereals, e.g. alkali-grass (Puccinellia sp.), several species of barley (Hordeum spp.) and an emmer (Triticum dicoccoides) (Kislev et al. 1992; Kislev et al. 2004; Weiss et al. 2004a). The range of plant species recovered here (Table 2.3.) indicates that despite the harsh conditions of the Late Glacial Maximum, the occupants of Ohalo II were able to obtain a wide variety of edible plants from local habitats within valley and upland habitats, e.g. wild cereals were collected from park-forest and saline habitats (Weiss et al 2004a). Grasses and wild cereals dominate the archaeobotanical assemblage (although, at the time of writing, a full list of taxa had not been published). The presence of storksbill (Erodium) and galium (Galium) in the plant assemblage indicates that geophytes were collected, although only seeds are reported thus far.

Two distinct lines of archaeobotanical evidence from Ohalo II suggest that postharvest systems were part of the occupants' subsistence strategy. In the first case, starch granules, identified as barley, were found on a grinding slab which was recovered *in situ* on the floor of the oldest of the brush huts, Hut 1 (Piperno *et al.* 2004). A nearby, contemporaneous paved hearth feature appears to have been used for roasting barley as well as other seeds and fruit. From the relative association of this hearth and the grindstone, as well as the fact that barley was directly associated with both, Piperno *et al.* (2004) inferred a possible processing sequence of roasting and/or pounding and grinding and/or baking to prepare primarily wild cereals. Certainly the data suggest that this hunter-gatherer-fisher group had developed a food processing system to help them obtain more food value, be it quantity or quality, from starch-rich seeds.

The second line of evidence for post-harvest systems is an assemblage of fragments of twisted stems, thought to be the remains of cordage. Made from monocotyledon stems, these fragments were found in association with piles of fish bones which were recovered from the floor of one of the Ohalo II huts. The site excavators (Nadel *et al.* 1994) inferred that the stems represented the remains of cord nets or bags used as above-ground storage for fish. If Nadel *et al.* (1994) are correct, this is the earliest example of preservation and storage in Southwest Asia. Significantly, it suggests that this Kebaran group practiced delayed-return (as *per* Woodburn 1980, see Chapter III this volume), which is regarded as the first step towards economic and cultural complexity.

#### Archaeobotany of the desert and steppe zones

Despite the comparatively 'marginal' environments of the steppe and desert steppe zones in the eastern and southern Levant, these regions were continuously occupied throughout the Epipalaeolithic (Byrd 1998; Garrard 1998; Goring-Morris 1995). Experiments with thermal food processing have been inferred from an unusual hearth found at Uwaynid 18 (*c*. 23,000 <sup>14</sup>C yr BP), in the desert steppe regions south of the Azraq Basin (Figure 2.2). This feature contained more than 200 basalt cobbles, possibly indicating the use of heated rocks in cooking (Wright 1992).

The earliest plant assemblage from the steppe and desert-steppe regions of the Levant is the Azraq Basin site of Jilat 6 (c. 21,268 <sup>14</sup>C yr BP). This site is thought to be the largest Early Epipalaeolithic site in the Levant (Garrard 1998). Located in the former marshlands of the Azraq Basin, Jilat 6 produced 13 plant taxa, representing arid

zone species that grow in moist and/or wetland environments (Table 2.2.), including several wild grasses, chenopods, Compositae, a crucifer (mustard), a sedge and two other unspecified Cyperaceae (Colledge 2001). Plant processing has been inferred from the presence of four groundstone artefacts that were found *in situ* in the upper phase of the site.

Sites in the Nile Valley of Upper Egypt, at Wadi Kubbaniya near present-day Aswan, are also relevant to the discussion because, along with Ohalo II, they are among the few early sites where food processing tools and edible plants have been directly linked by residue/and or starch analysis (Hillman, Madeyska and Hather 1989a, 1989b). Sixteen Late Upper Palaeolithic sites were excavated at Wadi Kubbaniya representing occupations from *c*. 21,300-18,300 (<sup>14</sup>C yr BP) during the hyper-arid climatic period. The wadi is presently dry for most of the year but when the sites were occupied the area would have been a river floodplain. In fact, Hillman Madeyska and Hather (1989) argue the river flood plain, which was surrounded by relatively barren desert, offered the only food-rich option.

Despite preservation and recovery problems, more than 25 charred plant types were recovered from four of the Wadi Kubbaniya sites and in association with groundstone tools. Further evidence of food processing came from charred seeds, including one SCR seed, found in charred human coprolites recovered from the same four sites. The seeds had been charred prior to consumption, which suggests that some plant foods were roasted before consumption. One of the sites, Wadi Kubbaniya E-78-3 (*c*. 21,300<sup>14</sup>C yr BP) produced 27 lower grindstones and 28 handstones and pounders (Roubert 1989) and charred fragments of the tubers of SCR and wild nut-grass (*Cyperus rotundus*), as well as the mesocarp fragments of dom palm (*Hyphaene thebaica*) (Hillman, Madeyska and Hather 1989). Other taxa recovered from the Wadi Kubbaniya

sites included a chamomile (Anthemidae), several possible Liliaceae (from site E-78-3) and the seed of a water lily (Nymphaceae).

Subsequent studies of the organic residues on the working surfaces of three of the grindstones from three of the four Wadi Kubbaniya sites where plant remains were recovered, showed traces of cellulose and/or starch and an absence of protein. Hillman, Madeyska and Hather (1989) inferred that these grindstones were used for processing root foods because tubers typically contain higher levels of cellulose and starch than seeds. Notwithstanding biases due to problems in preservation and recovery, the data suggest that these hunter-gatherers processed plants for the purpose of increasing the edibility and/or food value of the various plant parts (seeds, fruit, stems, rhizomes, tubers) of a narrow range of species.

#### Archaeobotany of south-central Anatolia

Few Early Epipalaeolithic sites in Anatolia have been excavated, and until recently none had been sampled for plant remains. Martinoli and Jacomet (2004a, 2004b) recently examined Early Epipalaeolithic deposits in Öküzini Cave (dating from c. 20,200 - 17,400 <sup>14</sup>C yr BP) and Karain Cave (dating from c. 17,000 <sup>14</sup>C yr BP), located in the foothills of the Taurus Mountains, about 30 km north of the Mediterranean coast. They found that wild nuts were an important component in the diet of these steppe-forest groups (Table 2.3.). The caves, which are about 1 km apart, appear to have been inhabited on a seasonal basis by highly mobile groups. The plant species recovered from the caves suggest late summer and autumn occupations, while the patterning in the faunal remains indicates spring and early summer occupations. The principal hunted fauna were wild goats and sheep (Otte *et al.* 1995).

Almond and pistachio dominate the Early Epipalaeolithic plant assemblages, and acorns appear around the Middle Epipalaeolithic. Other edible species include

fleshy fruits: wild pear, grape hackberries, and several small seeds of herbaceous species including unspecified sedges, grasses and small-seeded legumes. Unidentified charred parenchyma tissue, thought to represent tubers and bulbs, was recovered from all sampled Epipalaeolithic contexts at both caves, occurring in the greatest amounts in earlier levels and decreasing through time.

Food processing at Öküzini and Karain can be inferred from the associated hearths, grinding slabs and hammer-stones (Otte *et al.* 1995) and the relatively large amounts of almonds that were recovered (Martinoli and Jacomet 2004a, 2004b). Wild almonds, which are high in cyanide, usually need to be detoxified before they can be eaten. However, Martinoli and Jacomet (2004b) argue that people could have eaten the almonds raw because humans can ingest certain amounts of cyanide without harm.

The plant assemblages from Öküzini and Karain are composed of a narrow range of locally available arboreal woodland species. The identified taxa represent steppe forest environments of the type that were increasing in the Taurus region at this time (see section 2.3. above). Plants from the Mediterranean coast and higher plateau are absent. However, salt-water shells were found in the caves, indicating that these groups had contact with coastal groups and/or travelled, possibly to and from the coast.

# 2.3.2. Middle Epipalaeolithic/Geometric Kebaran (17,400 - 14,730 <sup>14</sup>C yr BP cal)

The Middle Epipalaeolithic/Geometric Kebaran is relatively short and less is known about it than the Early and Late Epipalaeolithic. Shifts in group mobility patterns and increased variability in material culture suggest that the tempo of cultural and technical change accelerated during this period (Byrd 1998). Larger site sizes, and greater numbers of hearths at each site indicate that people were organizing themselves into larger groups, possibly composed of several families (Goring-Morris 1995). Middle Epipalaeolithic/Geometric Kebaran sites are identified by the high frequencies of geometric-shaped microliths among the chipped stone assemblages. Chipped stone assemblages of this type are found at sites in the Mediterranean forest, eastern and southern steppe regions. This trend occurs in south-central Anatolia as well as the Levant (Goring-Morris 1995; Otte *et al.* 1995).

In the Levant, Geometric Kebaran groups expanded outwards from Mediterranean forest territories inhabited by their ancestors, to also occupy lowland areas. Large increases occur in the number of sites found in the formerly marginal steppe and desert-steppe areas, environments which had become more lush due to climatic amelioration. In the Negev particularly, there were exponential increases in the number of sites and also significant increases in the frequencies of groundstone tools (Goring-Morris 1995; Wright 1991).

In general, Middle Epipalaeolithic groups appear to have been highly mobile and movements appear to have been seasonal, with the larger, winter camps established in lowland areas (Goring-Morris 1995). However movement patterns varied and some probably incorporated various combinations of mobility strategies (Bar-Yosef and Meadow 1995; Neeley *et al.* 1997), *e.g.* in the Mount Carmel area groups continued to occupy relatively narrow geographic ranges within which they utilized larger, long-term camps and small transitory camps (Kaufman 1989). These changes in mobility patterns appear to have been linked to the increasing improvements in climate due to the onset of the Late Glacial Interstadials (at *c.*19,000 years ago) which resulted in a rise in critical plant and animal resources over the landscape (see Figures 2.3. and 2.4.) (Bar-Yosef and Meadow 1995; Hillman 1996, 2000; Henry 1989; Kaufman 1992; Lieberman 1993). Goring-Morris (1995) suggests that, because potentially exploitable land was increasing, population pressure was relaxed and therefore groups may have engaged in less intergroup competition, and had less need to delineate territorial boundaries. Others (e.g. Wright 1994) have suggested a continuation of a pattern of territoriality which began in the Early Epipalaeolithic.

# Indirect evidence of food processing

Middle Epipalaeolithic groups appear to have continued the broad spectrum subsistence strategies know to their Early Epipalaeolithic antecedents. Plant processing appears to have become more widespread. Substantial increases occur in the number of sites with ground stone tools, as well as the number of tools found at individual sites (Gorring-Morris 1995; Wright 1991).

Advances in thermal technology and techniques are suggested by new types of hearths, larger hearths, and stone-filled roasting pits (Goring-Morris 1995; Krabill 1977; Wright 1991). It is interesting that a human burial at the site of Neve David (15,300 <sup>14</sup>C yr BP) was found interred with fragments of a mortar and a milling stone, which are illustrated here in Figure 2.8 (Kaufman 1989). This suggests that, by the Middle Epipalaeolithic, some hunter-gatherer group regarded food processing as having social and symbolic significance.

Henry (1989:170) stated that the Middle Epipalaeolithic sites of Hefsibah, Neve David and Ein Gev IV show a greater emphasis on stored food, although permanent storage features do not occur until the Late Epipalaeolithic/Natufian. Nevertheless, the preservation of plant and animal foods by dehydration undoubtedly pre-dated archaeologically visible storage features. Therefore it is possible that some preservation and storage techniques were practiced by Middle and/or Early Epipalaeolithic groups, as suggested by evidence of the possible use of twine bags to air-dry and store fish at the Kebaran site Ohalo II (Nadel *et al.* 1994; and *see* also Cane 1989; Edwards 1989a).

# Archaeobotanical evidence of plant uses

The only published information on archaeobotanical material from the Middle

Epipalaeolithic is again from Öküzini Cave in south-central Anatolia (Martinoli and

Jacomet 2004a, 2004b) described in Table 2.4.

Table 2.4. Plant remains r	ecovered from	Middle Ep	pipalaeolithic	contexts	of Öküzini	Cave in
Anatolia <sup>1</sup>						

Öküzini Cave
SEEDS OF FLESHY FRUITS:
Celtis
Crataegus
Pyrus group
Rosa
Vitis sylvestris
unidentified fruit flesh/tissue
<u>NUTS</u>
Amygdalus group
Pistacia
Quercus
SEEDS OF CEREALS AND OTHER GRASSES
small-grained Poaceae
<u>PULSES</u>
Vicieae
SEEDS OF OTHER HERBACEOUS SPECIES
Galium <sup>2</sup>
$Rumex \text{ spp}^2$
Scirpus spp. <sup>3</sup>
TISSUE OF EDIBLE ROOTS
unidentified parenchyma
<sup>1</sup> References: Martinoli and Jacomet 2004a, b;
<sup>2</sup> According to Colledge (2001:86-91) these taxa have edible roots, and because they can be harvested in
all seasons, the presence of seads could indicate root athering

all seasons, the presence of seeds could indicate root gathering.

Compared with earlier contexts from this cave (see Table 2.3 above) there is an increase in the emphasis on nuts, including species that were already part of the diet, almond and pistachio, with the addition of acorn (Quercus) and the fleshy fruit of hawthorn (Crataegus), apple or pear (Malus/Pyrus), and possibly rosehips (Rosa), and several small seeded species including vetch (Vicieae). Martinoli and Jacomet (2004a) attribute the increase in nuts and a decrease in charred vegetative tissue to the expansion

of woodland and parallel reduction of habitats suitable for herbaceous steppe species (see Figures 2.2 and 2.3).

# 2.3.3. Late Epipalaeolithic/Natufian (14,730 – 11,990 <sup>14</sup>C yr BP cal)

The Late Epipalaeolithic/Natufian is better known than the Early and Middle periods, in part because of the larger number of sites, but also due to the scholarly interest in the origins of agriculture. More interest has been focused on this period because it is thought that experiments in plant cultivation by Late Epipalaeolithic hunter-gatherers laid the foundation for the appearance of the domesticated 'founder' crops of the Neolithic period (Bar-Yosef 1996, 1998; Hillman *et al.* 2001; Zohary 1989): emmer (*Triticum dicoccum*), einkorn (*T. monococcum*) and barley (Hordeum vulgare/sativum) as well as flax (*Linium usitatissimum*), lentil (*Lens culinaris*), pea (*Pisum sativum*), bitter vetch (*Vicia ervilia*) and chick pea (*Cicer arietinum*) (Colledge *et al.* 2004), as well as broad bean (*Vicia faba*) (Tannno and Willcox 2006b).

The Late Epipalaeolithic is divided into two periods, early and late. The early part, dating between approximately 14,730 and 13,130 (<sup>14</sup>C yr BP cal), was established during the relatively favourable climatic conditions of the Late Glacial Interstadials. The late period, which began at *c*. 13,130 (<sup>14</sup>C yr BP cal ) corresponds with the arrival of the Younger Dryas, which (as has already been mentioned) brought a return to severe, cold, dry conditions similar to the Late Glacial Maximum (Bar-Yosef 1996; Byrd 1998; Garrard 1999; Hillman 1996).

During the early part of the Late Epipalaeolithic there was a general trend towards decreased mobility and increased populations throughout southeastern Anatolia, the Middle Euphrates and the Levantine corridor. The first permanent architecture, villages typically composed of semi-subterranean circular or oval houses began to appear (Bar-Yosef 1996; Moore, Hillman and Legge 2000; Rosenberg and
Davis 1992). Evidence of food processing is more frequent in Late Epipalaeolithic than at earlier sites, with increases in groundstone tools and charred plant assemblages and more elaborate hearth features (Wright 1994, 2005). Pits found at Late Epipalaeolithic sites have been interpreted as storage features although other uses have not been ruled out (Boyd 2006;Valla 1995).

The most widely known of the Late Epipalaeolithic cultural complexes is the Natufian, a relatively homogenous culture which emerged out of the Geometric Kebaran within the Mediterranean woodland zones of the Levantine Corridor (Bar-Yosef and Valla 2001; Garrod 1932; Henry 1998). The Natufians are particularly famous for their large settlements with stone structures and associated cemeteries, bone and ground stone implements and innovations in finely carved bone and art moblier, all of which are common at Early Natufian sites (Belfer-Cohen 1989; Bar-Yosef and Meadow 1995). The practice of including groundstone tools in burials, first observed in the Middle Epipalaeolithic of the Levant, became common in the Natufian, suggesting that by then food processing had attained widespread social and symbolic importance.

Late Natufian sites are fewer in number and were less intensively occupied than in the Early Natufian, and site abandonment is evident, which together suggest increased mobility (Bar-Yosef 1998; Munro 2004). It is thought that Late Natufian groups became more mobile to cope with the Younger Dryas. However, there is some debate about Natufian sedentism and it is likely that even in the Early Natufian groups were more mobile than previously thought (Boyd 2006). In fact, Bar-Yosef (1998; Bar-Yosef and Meadow 1995) suggests that throughout the Late Pleistocene groups combined both residential and logistical movements.

Some authors include groups from the Late Epipalaeolithic Middle Euphrates area within the Late Natufian (*e.g.* Bar-Yosef and Meadow 1995; Willcox 2005) while

others (*e.g.* Moore, Hillman and Legge 2000) regard sites on the Euphrates as distinct. For example, Moore, Hillman and Legge (2000: 184) argue that Late Epipalaeolithic Middle Euphrates groups, such as those of Tell Abu Hureyra and Mureybit, differ from the Natufian in almost all aspects of their material culture including: the structure of their architecture, lithic tool typologies, the absence of fine carving on bone tools, and significantly the presence of grinding dishes, which are rare at Natufian sites.

These early village economies appear to have been based on semi-sedentary, logistical foraging strategies. Groups living in the Eastern Taurus region of southeastern Anatolia, although building semi-sedentary villages similar to those of their contemporaries in the Levant and Middle Euphrates, appear to have had closer cultural affinities with mobile hunter-gatherer groups in the Zagros region (Bar-Yosef and Meadow 1995; Rosenberg and Davis 1992). At the same time groups living in the central Anatolian Plateau, the Zagros, and the desert regions of the Levant, continued to be highly mobile.

The effects of the Younger Dryas, which brought about approximately 1,000 years of severe, cold, dry conditions, are still not understood with certainty. Hillman (1996, 2000; and see also Hillman *et al.* 2001) proposed that the Younger Dryas caused a radical reduction in edible plants native to oak-terbinth park-woodland and terebinth-almond woodland-steppe habitats. It has already been stated (section 2.2.2 above) that, based on his study of Tell Abu Hureyra, in the Middle Euphrates, Hillman argues that prior to the Younger Dryas, Late Epipalaeolithic groups situated their sites at the nexus of several rich plant habitats, including those of wild cereals, and that during the Younger Dryas groups began to cultivate wild cereals as to offset the demise of wild stands (see Figure 2.5.).

Willcox (2005) argues otherwise that the Younger Dryas only mildly affected the distribution of wild cereals and moreover, that hunter-gatherers were able to cope with these shifts using existing logistical strategies. Willcox proposed that the prime factor influencing the choice of a settlement location by Late Pleistocene groups was the presence of perennial water sources, not the proximity of wild cereals. In fact he argues that wild cereals had always been patchily distributed and, like other wild resources, were obtained by logistical forays to productive patches, *e.g.* the Middle Euphrates site of Mureybit, which was probably located at a distance from wild stands but where wild rye and einkorn have been identified among the plant remains (van Zeist and Bakker-Heeres 1984). Willcox argues that it is unlikely that hunter-gatherer groups began to cultivate to offset a dramatic decrease in wild cereals caused by the Younger Dryas.

#### **Resource exploitation and post-harvest systems**

Common to the Late Epipalaeolithic economies of the Eastern Taurus, the Middle Euphrates and the Levant was a tendency towards diversified yet increasingly more specialised subsistence practices (Belfer-Cohen 1991; Wright 1992; Steiner *et al.* 2000). For example, in the Levant, although a wide variety of animals were exploited, there was a greater focus on gazelle as well as small, fast moving animals such as birds and rabbits (Edwards 1989a; Stiner *et al.* 2000). These patterns suggest that Late Epipalaeolithic groups devised increasingly sophisticated hunting strategies, skills and technology, such as were needed to target fast moving lagomorphs and birds (Munro 2004; Stiner *et al.* 2000); and to build drives and surrounds to corral large numbers of gazelle (Cope 1991; Legge and Rowley Conwy 1987, 2000).

Plant-food processing appears to have taken on greater importance during the Late Epipalaeolithic. An exponential rise in plant exploitation has been inferred from the patterning in groundstone tools: pulverising and grinding tools are found at more

sites and also, in greater numbers at individual sites (Moore, Hillman and Legge 2000; van Zeist and Bakker-Heeres 1984; Wright 1994). Wright (1991) estimates that the frequency of Late Epipalaeolithic Levantine sites with groundstone tools (49%) is triple that of the Early and Middle Epipalaeolithic. More grinding technology and fewer heavy pounding tools occur, although mortars and pestles still dominate the groundstone assemblages (Wright 1992). Furthermore, new groundstone tool types appear, including shallow stone bowls found in sites in southern Anatolia and the Middle Euphrates, *e.g.* Hallan Çemi and Abu Hureyra (Moore *et al.* 2000; Rosenberg and Davis 1992). These bowls appear to have been used for grinding, and are also charred, suggesting use over a hearth, possibly as a kind of griddle (see Lyons and D'Andrea 2003). Wright (2005) reports that Natufian hearths are more elaborate than those of earlier peoples, sometimes including pits lined with stone. Likewise, Moore, Hillman and Legge (2000) report several different types of hearths in contemporaneous layers at the Middle Euphrates site of Abu Hureyra I, features that vary in size, shape and depth, with some being stone-ringed.

**Table 2.5a.** List of fruit and nuts recovered from Late Epipalaeolithic Abu Hureyra, Mureybit Iand II, and Wadi Hammeh 27

Abu Hureyra Ia	Mureybit I and II	Wadi Hammeh 27	
Capparis <sup>2</sup> spp.	Capparis <sup>2</sup>		
Celtis tournefortii			
	Ficus		
	Olea		
Pistacia atlantica	Pistacia	Pistacia spp.	
Pistacia khinjuk			
Prunus			
Pyrus spp.			

Abu Hureyra Ia	Mureybit I and II	Wadi Hammeh 27
Avena sterilis		
		cf. Aegilops
Bromus spp.	Bromus	Bromus
Crithopis spp.		
Cutandia spp.		
Cynodon-Type		
	Echinochloa	
	Eremopyrum	
Hordeum spp.	Hordeum spp.	Hordeum spp.
Lolium rigidum-Type		Lolium
Oryzopsis cf. holciformis		
Paniceae spp.		
Poaceae spp.	Poaceae spp.	Poaceae spp.
Secale spp.		
	Setaria-Type	
Stipa spp.		cf. Stipa
Titicum spp.	Triticum spp.	
Vulpia-Type		

# Table 2.5b. List of seeds of cereals and other grasses recovered from Late Epipalaeolithic Abu Hureyra, Mureybit I and II, and Wadi Hammeh 27

**Table 2.5c.** List of pulses recovered from Late Epipalaeolithic Abu Hureyra, Mureybit I and II,and Wadi Hammeh 27

-

Abu Hureyra Ia	Mureybit I and II	Wadi Hammeh 27	
	Cicer		
Lens spp.	Lens cf. orientalis		
	Pisum		
Lathyrus/ Vicia	Lathyrus cf. cicera		
Leguminosae spp.		Leguminosae spp.	
	<i>Medicago<sup>2</sup></i>		
Trifolieae spp.			
	<i>Trigonella</i> -Type <sup>2</sup>		
Vicia ervilia	Vicia spp.		

Abu Hureyra Ia	Mureybit I and II	Wadi Hammeh 27
Aizoon hispanicum		
	Androsace maxima	
	Alyssum	
	Amaranthus	
Arnebia decumbens <sup>2</sup>	Arnebia decumbens <sup>2</sup>	
Arnebia linearifolia <sup>2</sup>	Arnehia linearifolia <sup>2</sup>	
Ascleniadaceae		
$Asparagus spp^2$	$Asparagus^2$	
Asphodelus <sup>3</sup>	1000 4810	
Asphouetus	$Astragalus^2$	
Atripler spp	Atrinlar-Type	
Rellevalia	Rellevalia	
Dellevalla Prassing spp	Denevana	
Bualossoidas spp.		
Composition Spp.		
Caryophynaceae spp.	Continue True?	
Chananadiaaaaa	Centaurea-Type	Channe diama/Cana ania
Chenopodiaceae	Chenopoaium album-Type	Chenopoaium/Capparis
Citrullus colocynthus		
Compositae <sup>2</sup>		
	Convulvulus-Type-	
	Cuscuta	
Erodium spp. <sup>2</sup>	2	
	Fumeria <sup>2</sup>	
Glychyrrhiza spp		
Gypsophilia <sup>2</sup>	Gypsophilia <sup>2</sup>	
Heliotropium spp.	<i>Heliotropium</i> spp.	
Juncus spp.	Juncus	
<b>Krascheninn</b> ikovia		
<i>Lepidium</i> spp.		
		Liliaceae <sup>3</sup>
	Linum	
	Lithospermum arvense <sup>2</sup>	
	Lithospermum tenuiflorum	
	Lepidium-Type	
	Malva	
	Micromeria	
Moltkia coerulea		
Muscari		
Plantago major		
Polygonum	Polygonum	
	Portulaca	
	Potamogeton	
Potentilla spp	0	
Proposis stephaniana		
Rubiaceae		
Rumex <sup>2</sup>		
Salvia		
Scirpus maritimus <sup>3</sup>	Scirpus maritimus <sup>3</sup>	
son pas nai unius	Silene	
	Solanum-Tupe	
Sparaularia Tupa	solution-Type	
Sperguiaria-Type Suanda	Sugada	
бишеши	Thumalaaa	
7 1 11 6 1	inymeiaea	

Zygophyllum fabago <sup>1</sup>References cited: Colledge 2001; Hillman 2000; van Zeist and Bakker-Heeres 1984. <sup>2</sup>According to Colledge (2001:86-91) these taxa have edible roots thus may indicate root gathering. <sup>3</sup>These plant families/genera also include species with edible roots thus may indicate root gathering

Greater numbers of Late Epipalaeolithic sites produced plant assemblages than their predecessors (Table 2.5.) which may be due to preservation and sampling, or to an increase in cooking practices during the Late Epipalaeolithic, such that plants were more likely to become charred (Colledge 2001; de Moulins 1997). More plant remains have been recovered from Late Epipalaeolithic sites in south-eastern Anatolia and the Middle Euphrates than in the Natufian homeland area. This is attributed to many Natufian sites having been excavated prior to the introduction of archaeobotanical recovery methods, and/or their occurrence in Mediterranean woodland belt where preservation is poor (Bar-Yosef and Meadow 1995). Two Early Natufian sites have produced plant assemblages: Wadi Hammeh 27 in the foothills of the north Jordan Valley, and Hayonim Cave in the Mount Carmel area of Israel, both dating from about 14,500 <sup>14</sup>Cyr BP. Four taxa were identified at Hayonim Cave, including wild barley, almonds, a pea and large proportions of lupin (Lupinus pilosus) seeds (Hopf and Bar Yosef 1987). Wadi Hammeh 27 produced one of the largest and most varied groundstone tool assemblages of the Early Natufian, suggesting that substantial amounts of plant processing took place here. However, a surprisingly small charred plant assemblage was recovered (Colledge 2001).

#### 2.4. DISCUSSION

It is commonly assumed that it was not until the Late Epipalaeolithic that foodprocessing systems took on importance and plant intensification first occurred. Wright (1994), for example, argues that although pre-Natufian foragers had the technological means to intensify plant foods [through processing] they were not under pressure to do so. Such pressures includes a suite of possible factors: increased populations; growing social demands; restrictions on mobility due to semi-sedentism; and after about 13,000 BP, sharply reduced forging territories due to the sudden shift to the cold and dry conditions of the Younger Dryas. These pressures were compounded by the fact that emigration to other areas was not a viable choice because the entire region was suffering the same conditions and/or other groups already occupied the most favourable areas (Hillman *et al.* 2001).

But it can be argued that the pressures experienced by Early Epipalaeolithic/Kebaran groups were in many ways similar to those experienced by Late Epipalaeolithic/Natufian groups. These pressures included the need to obtain more edible products from significantly reduced foraging and hunting territories, due to the environmental impact of the Late Glacial Maximum on environment, and demographics. In the Levant, for example, during the Late Glacial Maximum groups moved into the coastal hill zones where the carrying capacity of the land was better than in other areas. In conjunction with the declining resource base, the movements of people into more favourable areas would have increased population pressure on the carrying capacity, a pattern that is confirmed by archaeological evidence that there was increased territoriality between Early Epipalaeolithic groups (Goring-Morris 1995). At that time, extensification and/or migration out of the hill zones into areas would not have been a viable choice because the entire region was suffering the same conditions and/or habitable areas were already occupied by other groups. I argue that, to tackle these pressures, Early Epipalaeolithic groups experimented with ways to obtain more edible products from the available resources within their territories, in many cases from species that were already part of the economy. One of the ways that they achieved this was by processing plants and plant parts that were previously considered inedible or less palatable.

The fact that many Early Epipalaeolithic groups situated their plant processing sites adjacent to areas that were rich in plant resources indicates the growing importance of plants in their economies. Moreover, it suggests a growing knowledge of plant physiology: that reducing the time between harvesting and processing will lower post-harvest losses of both quality and quantity (Wills *et al.* 1998). Immediate return strategies (Woodburn 1980, see Chapter III this volume) were probably more common at this time, although small quantities of easily preserved surpluses may have been hoarded and possibly cached (see Cane 1989). Evidence from Ohalo II suggests that Kebaran group had adopted some techniques to preserve and store critical resources. But no similar evidence for plant preservation has been reported from that time period.

Although some of the pressures on Early, Middle and Late Epipalaeolithic groups were similar, each cultural sequence faced a different set of conditions. Middle Epipalaeolithic/Geometric Kebaran groups appear to have had new opportunities brought by improving climatic conditions and decreasing demographic pressures. The Middle Epipalaeolithic emerged during the Late Glacial Interstadials, when food-rich habitats had become more widely distributed over the landscape, particularly after about 15,300 (<sup>14</sup>C yr BP) (Garrard 1999; Hillman 1996, 2000; Price and Gebauer 1995; Richerson *et al.* 2001). C3 plants with carbohydrate-rich seeds and underground storage organs were increasingly more available over large areas of the Southwest Asia, and post-harvest technology also appears to have become more widespread. Together the existing processing technology and increasing plant abundance may have permitted more specialized plant exploitation practises, possibly focused on a few preferred species. On the other hand, continuing annual and inter-annual climate fluctuations may have meant that resource availability could not be predicted, so it was necessary for

people to maintain knowledge about the processing performance characteristics of a wide range of plants and/or to develop delayed-return strategies.

Indeed, it was during the Middle Epipalaeolithic that circumstances triggered the feasibility of, and need for, storage. These circumstances included: i) periods in which edible resources were abundant and available in large quantities; ii) contrasted by periods in which there were resource shortages; together with, iii) the existence of basic post-harvest systems. In other words, it is argued here that, building on their existing post-harvest expertise, Middle Epipalaeolithic people developed ways to transform seasonally available resources into year-round staple foods (Halstead and O'Shea 1989; Woodburn 1980, see Chapter 3, this volume).

That is not to say that Early Epipaleolithic groups did not practise some plant preservation and storage. Indeed, plant-rich areas of refugium probably did occur during the Glacial Maximum, as suggested by the rich archaeobotanical assemblage from Ohalo II (Kislev *et al.* 1992; Weiss 2004; Piperno *et al.* 2004; Weiss *et al.* 2004a; and see also Hillman 1996). But current interpretations of Late Pleistocene climate and vegetation suggest that, on a widespread basis, storage was only feasible during the Middle Epipalaeolithic, when carbohydrate rich seed plants and geophytes were more extensively distributed over Southwest Asia, and occurred in stands of sufficient size for mass harvesting (see section 2.3. above).

Late Epipalaeolithic/Natufian groups faced entirely different sets of problems than Early and Middle Epipalaeolithic groups. During the early part of the Late Epipalaeolithic, groups benefited from increasingly favourable climatic conditions and abundant resources but also experienced increasing social and demographic pressures. From the archaeological evidence, it appears that Early Natufian groups had become more territorial and less mobile than their predecessors, and more socially more complex. By this time, food processing had been part of the Late Pleistocene subsistence systems for at least 8,000 years. Therefore, through the transmission of knowledge between generations, Late Epipalaeolithic groups would have inherited knowledge about the processing performance characteristics of the available plants and plant parts. Significantly, food processing appears to have taken on symbolic or social significance by the Early Natufian (Wright 2005).

During the Late Natufian/ latter Late Epipalaeolithic, groups were faced with severe climatic conditions and diminishing resources. In particular there was a decline in critically important park-woodland and woodland-steppe plants (Hillman 2000). In the Levant Late Natufian groups appear to have become more mobile (Bar-Yosef 1998; Munro 2004). However, in the Middle Euphrates, *e.g.* at Abu Hureyra, groups appear to have found local solutions. One such solution was to focus on habitats that were not in decline, in this case the moist valley bottoms, from which they obtained the starch-rich seeds of two species: sea club-rush and knot-grass (*Polygonum corrigioloides*) (Hillman *et al.* 2001). Sea club-rush tubers may also have been exploited but no evidence exists to support this. Hillman *et al.* (2001) further argue that another local solution adopted by this group to counter the effects of the Younger Dryas was to begin cultivating legumes and cereals.

#### **2.4.1. Epipalaeolithic post-harvest systems**

The archaeological and archaeobotanical data suggest that Late Pleistocene processing systems were based on varying sequences of pulverising and heating techniques and the addition or removal of moisture. The development of food processing systems during the Epipalaeolithic may also have included bone boiling. As early as the Plio-Pleistocene homind groups are thought to have obtained marrow from bones by fragmenting them, but the extraction of bone grease, a more complex process involving pulverising followed by boiling, is first suggested in the Epipalaeolithic (Munro and Bar-Oz 2005; Speth 2004). Munro and Bar-Oz (Munro and Bar-Oz 2005; Bar-Oz and Munro 2007) found that there may be a relationship between gazelle bone survivorship at Epipalaeolithic sites and the processing for bone grease. Munro and Bar-Oz (2005) argue that processing methods that renders the bone more prone to preservation may account for the large frequencies of gazelle bones recovered from Epipalaeolithic sites. They propose that bones could have been boiled in containers made from organic materials (*e.g.* animal skins) which were filled with water and heated either by adding hot stones or by suspending over a hearth. They analysed the faunal assemblages of four Epipalaeolithic sites dating from the Kebaran through to the Natufian, and inferred that bone boiling had occurred throughout the Epipalaeolithic. They speculate that these techniques may have been known as early as the Late Upper Palaeolithic. This suggests that boiling of edible plants was also feasible from at least the Early Epipalaeolithic.

With respect to preservation and storage, seeds are considered a more likely candidate than roots and tubers because they have a lower water content, low metabolic processes, and are less prone to damage by bruising and pitting due to their mechanical strength (Coursey and Booth 1977; Wills *et al.* 1998). Indeed, as is shown in Tables 2.4 – 2.6 above, seed foods appear to have been important in Epipalaeolithic Southwest Asia (see Colledge 2001; Savard *et al.* 2006; Hillman 2000; van Zeist and Bakker-Heeres 1984). But this pattern might be due to the lack of data on roots and tubers. More archaeobotanical sampling and analysis of parenchymous remains are necessary to determine the role of root foods in the Epipalaeolithic.

Today root foods are of more importance in the tropical countries. However there is archaeological and ethnographic evidence from various parts of the world that hunter-gatherers living in the temperate and arid zones have preferred root foods over seed foods (see Cane 1989; Hunn 1981; Kubiak-Martens 2002; Turner 1992; Turner *et al.* 1990). For example, in arid interior regions of the Pacific Northwest of North America complex hunter-gatherer groups exploited carbohydrate-rich geophytes more often than carbohydrate-rich seeds (Hunn 1981; Turner 1995, 1997). Moreover, these groups were able to rely on geophytes particularly root foods in the Asteraceae/Compositae and Liliaceae families, as year-round staples because they were able to preserve them. These plants were mass harvested and processed in large roasting pits, which were situated near the root harvesting grounds (Alexander 1992; Lowen 1998; Peacock 1998; Pokotylo and Froese 1983; Turner 1990; Thoms 1989).

#### 2.4.2. Food processing and broad-spectrum resource exploitation

Several authors (*e.g.* Bar-Yosef 1998; Weiss *et al.* 2004) have proposed that the shift to broad-spectrum plant exploitation (Flannery 1969) occurred during the Early Epipalaeolithic. If that is the case, then the origins of the broad-spectrum pattern in plant exploitation can be temporally as well as regionally linked to the beginning of food-processing systems. Post-harvest preservation techniques may have been developed to prevent loss to quality and quantity of herbaceous parts collected for immediate consumption *e.g.* edible leaves and stems that begin to decay soon after they are severed from the parent plant (Wills *et al.* 1998). Most of the carbohydrate-rich seeds that were recovered from Early Epipalaeolthic sites (see Tables 2.4-2.6) cannot be chewed in the raw form due to being too tough for the mechanics of the human mouth (*e.g.* seeds of cereals and sedges), or have a bitter taste or are poisonous (*e.g.* certain legumes, wild almonds). To produce food products from these plants it would have been necessary to learn about the distinct functional properties of each species, *i.e.* the specific techniques and/or sequences of processing necessary to transform each species

into an edible form (Lyons and D'Andrea 2003; Wandsnider 1997). In other words, plant-processing systems were probably critical for people to subsist diet comprising a broad-spectrum of plants and plant parts.

Evidence from Ohalo II suggests that, by the Early Epipalaeolithic, some huntergatherers were already heavily exploiting cereals. The attractiveness of cereals has been attributed to their high caloric content, ease of harvesting and the fact that they can be easily stored (Burton 1982; Garrard 1999; Hillman 1996; Wright 1994). Although these attributes are important, the functional properties of cereals may have been of more consequence. The grains of the grass family can be processed into a range of edible and highly palatable and satisfying food products, including gruels, bulgar-type foods and breads. Moreover the larger seeded cereals that contain gluten respond particularly favourably to heat (Lyons and D'Andrea 2003).

Weiss *et al.* (2004b) argue that after the Late Glacial Maximum there was a sequential narrowing in the spectrum of plants used by hunter-gatherer groups, with a shift away from small-seeded grasses towards large-seeded cereals. But no such narrowing is evident in plant assemblages recovered from Late Epipalaeolithic contexts of sites in south-eastern Anatolia and the Middle Euphrates, *e.g.* Hallan Cemi (Savard *et al.* 2006) and Tell Abu Hureyra (Hillman 2000). For example >100 species were identified from the seed assemblage recovered at Abu Hureyra (Hillman *et al.* 2001) (see Table 2.6). In fact Hillman *et al.* (2001) argue that the wide range of small-and large-seeded carbohydrate-rich seeds may have served as staple foods at Abu Hureyra, including those of sea club-rush, as well as the wild wheats, ryes, feather grasses (*Stipa* spp.), knot grasses (*Polygonum* spp.) and chenopods.

It remains unclear whether the increase in grinding technology during the Late Epipalaeolithic resulted from a shift towards the intensified use of cereals or whether it represented principally a change in processing techniques (Garrard 1999; Wright 1991). On the other hand, it is possible that groups replaced stone mortars with wooden ones which seldom survive archaeologically (for arguments about the advantages of wooden tools, see Hillman, Madeyska and Hather 1989: 223). The possible manufacture of wooden tools might be inferred from the increase in potential wood-working tools, picks and axes; and the increasing abundance of woodlands. As shown in Figures 2.4 - 2.6, by the Late Epipalaeolithic and into the Neolithic, woodlands had expanded to cover large areas of Southwest Asia, including the Taurus/Zagros zones and in the Rift Valley. Raw materials for wood-working would have been more available at this time than over the previous ten millennia.

The archaeological record suggests that developments in species selection and food processing that began in the Epipalaeolithic were continued and intensified by Neolithic groups. De Moulins (1997) compared temporal trends in the flotation samples from three early Neolithic (PPNB) village sites located within the Euphrates drainage area of northern Syria and south-eastern Turkey. She found that the heavy use of wild pulses and cereals, which began in the Epipalaeolithic, continued well into the Neolithic. Tanno and Wilcox (2006a) argue that cultivation was probably taking place but without the appearance of morphologically domesticated varieties. They propose that groups may have begun cultivating wild cereals as early as 12, 509 <sup>c</sup>14 yr BP (cal; 10,500 <sup>c</sup>14 yr BP uncal), but that domestication was slow and therefore took more than two thousand years for domesticated varieties to emerge (see also Fuller 2007).

The (above) observations by De Moulins (1997) and Tanno and Wilcox (2006a) are supported by recent analyses of tooth wear and dental pathology of Late Epipalaeolithic and Neolithic groups. Eshed *et al.* (2005) found that differences in the condition of the teeth of Natufian and Neolithic skeletal populations can be attributed to

shifts in food-preparation techniques rather than significant changes in resource selection. Eshed *et al.* (2005) maintain that although these two populations may have differed in their ecosystem management, in the gathering vs the growing of cereals, the types of plant foods that they consumed were the same.

Altogether the data indicate that, from the Epipalaeolithic to the Neolithic, plant intensification occurred without a major change in the resource base, although there may have been changes in species emphasis. In other words, rather than changing the types of plants that were eaten, changes were made in the ways that the plants were obtained (cultivating, planting, harvesting) and prepared into foods (new technology, techniques, recipes).

# 2.4.3. The potential effects of food processing on the subsistence/mobility system

The pattern in the archaeobotanical, zooarchaeological, and artefact data suggest that, from the Early Epipalaeolithic hunter-gatherers used increasingly specialised food procurement and processing technology yet maintained a diversified resource base, which included a wide range of plants and mammals, fish, birds, molluscs, lizards and amphibians (see Bar-Oz and Dayan 1999; Edwards 1989a; Stiner *et al.* 2000). Specialisation implies technological, biological and ecological skills and knowledge essential for obtaining and processing specific resources. At present there is no direct evidence that Early and Middle Epipalaeolithic hunter-gatherers practised environmental management, but it is not unlikely that, prior to the Late Epipalaeolithic, groups used techniques such as controlled burning and incipient planting, and/or weeding to encourage the growth of economically important species (Hillman 1996).

Organizational changes, and shifts in land-use practices and new approaches to resource scheduling would necessarily accompany developments in post-harvest technology. Scheduling would be adjusted to correspond with the ripening of specific resources, *e.g.* Kislev *et al.* (1992) proposed that groups in the Levant took advantage of the vertical zonation in resources, following the sequential ripening of cereals up the hillsides. Scheduling would also be necessary to obtain perennial root foods before and/or after flowering when they have optimal flavour and/or nutrition, and before the annual die back of their aboveground parts, when they become less visible (see Turner 1988). Given the unpredictable climatic conditions during the Epipalaeolithic, groups may have based their movements on sets of environmental conditions rather than specific seasonal changes, a pattern that Cane (1989) has observed among Aboriginal groups in Australia. More regular visits to specific localities, and longer occupations at places with seasonally abundant plant resources, would be expected.

Organizational changes would have included incorporating new tasks into the routine and/or more regular performance of certain tasks; the possible development of task groups and/or changes to existing task groups; the scheduling of specific harvesting and processing activities to take advantage of the fluctuating windows of opportunity that characterised the period from the Late Glacial Maximum, through to, and including the Younger Dryas. Henry (1989) suggested that, by the late Epipalaeolithic groups may have become dependent on stored resources. This raises questions about surplus, and who controlled the group's access to stored foods, and how that might influence the social structure.

### 2.4.4. Why did post-harvest systems not develop earlier?

The archaeological data beg questions: if it is true that post-harvest systems developed in the Early Epipalaeolithic, why did they not occur earlier? Certainly the technology for roasting and pulversing was in place at least by the Upper Palaeolithic. Human use of fire dates from the Lower and Middle Pleistocene (Goren-Inbar *et al.* 86 2004; Stahl 1984) and there is evidence that Upper Palaeolithic groups sometimes processed plant foods, *e.g.* the assemblage of charred peas recovered from hearths at Kebara Cave dating from *c*. 60,000 years ago (Bar-Yosef *et al.* 1992). Furthermore, in the Levant groundstone tools, such as pestles and bedrock and portable mortars first appear, although in small numbers, in the Upper Palaeolithic (Krabill 1977; Wright 1991).

Cognitive arguments that Neanderthals and Early Modern humans had neither the "abilities nor propensities" for more complex relationships with plants and animals prior to the Upper Palaeolithic (Mithen 1996: 226) have recently been challenged with evidence of Neanderthal plant-use from several rock shelters and cave sites in Israel (Albert et al. 1999, 2003; Madella *et al.* 2002; Rosen 2003). For example, phytolith evidence from Amud cave suggests that Middle Palaeolithic groups used a wide range of plants for diverse purposes, including bedding, fuel and possibly food (Madella *et al.* 2002). Moreover faunal studies (*e.g.* Bar-Oz *et al.* 1999; Edwards 1989a) have demonstrated that broad-spectrum hunting strategies date from the Middle Palaeolithic, and that the same range of taxa recovered from Epipalaeolithic sites in Southwest Asia is found in sites dating from the Middle Palaeolithic.

Nevertheless there is evidence of increasing human social and economic complexity such as changes in hunting strategies at the end of the Late Pleistocene that permitted the capture of fast moving animals and the mass capture and kill of wild herds of gazelle (Munro 2004; Legge and Rowley-Conwy 1987, 2000). Stiner *et al.* (2000) propose that humans devised better means of resource exploitation to meet the needs of growing populations, while Watkins (2004) suggests that a combination of increased human intelligence and experience may have promoted better technology, and that increasing populations were the outcome of this trend. Watkins proposed that a co-

evolution of human cognitive faculties and culture was responsible for the dramatic changes in human settlement and subsistence patterns at the end of the Pleistocene. He believes that the beginning of sedentary communities in the Late Epipalaeolithic marked the first development of fully modern minds.

## **2.5. CHAPTER SUMMARY**

The differences between the subsistence systems of Epipalaeolithic groups and their Late Upper Palaeolithic antecedents, and between Early, Middle and Late Epipalaeolithic groups were not sudden or revolutionary changes, but shifts in emphasis and scale, and the increasing tempo of change. Throughout the Epipalaeolithic groups appear to have maintained diversified subsistence strategies, based on wide range of plant and animal resources, yet at the same time increasingly specialised approaches were used to obtain and process those resources. It is argued here that developments in food processing paved the way for the use of a broad-spectrum of plants. Developments in food processing systems may also have influenced the patterning in the zooarchaeological record. Moreover, the development of food processing and preservation systems permitted increased abundance by promoting the edibility of otherwise inedible plants/plant parts, and by preventing loss of quality and quantity. Preservation permitted the mass harvesting and hoarding of edible plants, which lead to an increasing importance of storage systems. Finally, it is argued that the development of post-harvest systems during the Epipalaeolithic is directly linked to Late Pleistocene change in land use, scheduling and mobility patterns.

# **CHAPTER III: INTENSIFICATION AND ARCHAEOLOGICAL THOUGHT**

In order to clarify the precise meaning of *the intensification of production*, this chapter begins with a discussion about the ways that the term has been defined and applied in the scholarly literature. To build a framework for the types of intensification that hunter-gatherers are likely to adopt, several issues are subsequently examined including questions about how intensification can practicably be incorporated into an annual cycle of hunting and gathering, the development of delayed-return systems, and the types of wild plants that are amenable to production. The arguments about how and why food processing and food preservation can constitute intensification, introduced in Chapter 1, are further discussed, and a general intensification model is presented that considers how food processing promotes increased food production.

#### **3.1. INTENSIFICATION DEFINED**

The geographer Brookfield (1972: 31) defined intensification as follows:

"Strictly defined, intensification of production describes the addition of inputs up to the economic margin, and is logically linked to the concept of efficiency through consideration of marginal and average productivity obtained by such additional inputs. In regard to land, or any natural resource complex, intensification must be measured by inputs only of capital, labour and skills against constant land. The primary purpose of intensification is the substitution of these inputs for land, so as to gain more production from a given area, use it more frequently, and hence, make possible a greater concentration of production"

The *intensification of production* is a process wherein people achieve greater effectiveness in their subsistence practices by investing increasing energy inputs to obtain more productivity per unit area of land exploited (Boserup 1965). In the archaeological, anthropological, economic and geographical literature land is usually designated as the constant against which a second variable such as inputs of labour, capital, and skills can be measured (Brookfield 1972, 2001; Morrison 1994; Stone *et al.* 

1990). Human labour is the variable that is most often proposed as the second variable. The intensification process encompasses substituting that variable for land "...so as to gain more production from a given area, use it more frequently, and hence, make possible a greater concentration of production" (Brookfield 1972: 31). The classic *Boserupian* definition of intensification describes the process as a trade-off in which more energy is extracted from a patch of land, but foraging efficiency declines because individuals must expend more time and energy in obtaining that increase (Boserup 1965; see Stone 2001: 173). Intensification is typically measured by costs: the cost of land, labour and/or capital (Morrison 1994: 113). Yield per plot/time or frequency of cultivation (as *per* Boserup 1965) are the most common ways in which the cost of plant intensification is measured (Lambin *et al.* 2000). Energy (k/cal) is most frequently used to assess yield because ir is the least problematic macronutrient among different classes of foods (Broughton 1999: 8).

#### 3.1.1. The importance of intensification in studies of early agriculture

Most of the literature on prehistoric intensification is concerned with the origins of plant or animal domestication, or changes within established agricultural systems.

As observed by De Moulins (1997), intensification is not in itself a theory but a growing body of literature that in archaeology and anthropology now encompasses a broad range of concerns including the causes of intensification, the processes by which it is thought to occur, and how increased production influences changes in other components of the economic and social system (see also Allen, Ballard and Lowes 2001; Leach 1999b; Morrison 1994, 1996; Peacock 1998; Stone 2001). The intensification of production is regarded as an important theoretical tool for investigating the subsistence decisions of ancient groups. Production, "the making, constructing, or creating actions of human beings – is a primary focus of investigations

into the archaeological record" (Morrison 1994: 114). Increased production is intensification because it alters the overall system, effecting"...transformations in productive strategies designed to extract a greater amount of produce from a given quantity of land and/or labour" (Morrison 1996: 587).

The intensification of production encompasses transformations of productive systems, and is considered a key factor in major shifts in human economies, *e.g.* the development of delayed-return systems, the origins of agriculture, and the industrial revolution in the  $18^{th}$  century (Morrison 1996). The reasoning behind this definition is that the increasing energy inputs that are associated with increased production, be they labour, technology, capital, and/or skills, will always necessitate a reorganisation of the system (Brookfield 1972). Organisational changes will be necessary to fit more into the system, *e.g.* to adapt the work force to increasing labour demands, adjustments in the timing (scheduling) of activities, the addition of new activities.

Stone (2001; Stone *et al.* 1990) has called attention to the fact that labour is of central importance in the intensification of production, and not just a measure of energy expended, but because the costs of increased production are borne by the members of a group. To achieve increased production, individuals must work harder and/or more people must work. Furthermore, labour is embedded within a group's social and demographic systems. Therefore, changing demands on labour can affect the social structure, the age and gender composition of the labour force, and the distribution of people over the landscape (*e.g.* seasonal gatherings and/or dispersals). The labour force is a composite of people, which can vary in numbers from a single individual to households, neighbouring groups, alliance groups, exchange groups, and hired labourers; including individuals who are differentiated by gender and age.

Labour is mobilised within a specific environmental and social and political milieu. It is a process involving human decision-making within specific ecological/environmental conditions, thus "...intensification is a function of the management of physical resources, within the context of prevailing social and economic drivers" (Lambin *et al.* 2000: 329). The costs and benefits of a production system are therefore governed by the interaction of social and political factors with seasons, rainfall, soils, local altitude and topography, proximity to water sources, and the biological characteristics and growing habits of the resources that are being intensified (Stone 2001: 175 and Stone *et al.* 1990: 7-8).

Because the subsistence decisions of human groups are made and carried out within a socio-political milieu, and because social and/or political control over resource distribution is a critical factor in any economy, the study of the intensification of production can facilitate unique insights into the social and/or political structure of a group and into diachronic changes in those structures (Dobres and Hoffman 1994; Lepofsky 1994). Thus investigations into intensification may also shed light on other coeval transformative processes such as changes in land use, mobility, resource scheduling and settlement patterns, changes in social relations and shifts towards social complexity and attitudes towards surplus. For example Hayden (1990) proposed that intensification can influence shifts towards sedentism because increased production improves the density of extractable resources, permitting a group to reduce their range (i.e. the concentration of production as per Brookfield 1972). He further suggested that intensification can promote changes in social organisation because increased labour investments may influence a group to abandon traditional obligatory sharing practices and to embrace the concept of private property, e.g. the concentration of production in specific areas necessitates that the group returns to those places regularly, and may

therefore influence attitudes about land and resource ownership. Indeed ethnographic studies show that groups claim rights over or actual ownership of resources and/or particular patches of land in which they have labour investments (Brumbach and Jarvenpa 1997).

#### 3.1.2. The importance of intensification in hunter-gatherer studies

The smaller, but growing, body of literature on hunter-gather intensification is concerned with distinctly different questions than research into agricultural intensification. One of the key issues is the development of *delayed-return systems* (Woodburn 1980, discussed below) a term that describes the scheduling of subsistence activities for the purpose of harvesting large amounts of critical resource(s) (mass harvesting) for preservation and storage. The shift to delayed-return systems is thought to be the first step towards food production (Chatters 1995; Ford 1985; Harris 1989). Other key issues pertaining to hunter-gatherer intensification include questions about associated shifts towards social complexity, changes in ancient land-use patterns, understanding risk and risk-buffering strategies, and how intensification can practicably be incorporated into an annual cycle of hunting and gathering (Ames 1985; Hayden 1990; Harris 1977, 1989; Hillman 1996; Lewis 1972, 1982; Rowley-Conwy and Zvelebil 1989; Testart 1988; Thoms 1989; Zvelebil 1988).

Ames (1985) judiciously warned that analytical methods that are suitable for investigating agricultural intensification might not always be suitable for investigating hunter-gatherer intensification. However, for the purposes of the present study, many valuable theoretical debates have taken place within the discourse on agricultural intensification, and therefore inform many of the arguments presented in this chapter (*e.g.* Brookfield 1972, 1984, 1986, 2001; Leach 1999b; Morrison 1994, 1996; Stone 2001)

#### **3.1.3.** Theories about the causes of intensification

It is generally agreed that the goals of intensification are to obtain greater abundance from a given patch of land, and to make possible greater concentration of production (Brookfield 1972; Kirch 1994). However the causes of intensification continue to be debated. The most common view is that groups must be motivated by *pressures* to intensify, given that intensification commonly necessitates working harder, and given the assumption of least effort: that human groups will not work harder than they have to, and will thus select systems that offer them the best average return for their labour (Binford 1983; Bender 1978; Boserup 1965; Leach 1999b; Morrison 1994, 1996). However, others (*e.g.* Brookfield 1972, 2001) have argued that under some circumstances groups might be motivated by *opportunities*, *e.g.* increasing production to produce goods for exchange.

#### **Pressures as causal**

Theories about the types of pressures that cause groups to intensify have been widely debated since the economist Ester Boserup (1965) first published her seminal *population stress* model (for a review of these debates, see Brookfield 1972, 1984, 1986; Hayden 1990, 2004; Lourandos 1983, 1984; Leach 1999a; Morrison 1994, 1996; Stone 2001). Boserup (1965) challenged existing Malthusian assumptions that population increases logically followed technological advancement, and that the advantages of technological developments were self-evident (Morrison 1994: 17). Boserup's (1965) intensification model inverted the Malthusian model, proposing that in primitive [sic] agricultural systems population density drove changes in methods and technology; thus in her view population was the independent rather than the dependent variable (Brookfield 1972; Stone 2001). Boserup argued that agricultural intensification

is a unilineal process of increasing labour inputs in the cropping cycle, entailing decreasing intervals of fallow.

Boserup's definition of intensification as involving *increased labour inputs* has endured but in the amended form proposed by Harold Brookfield (1972) as involving *inputs of labour, capital, skills and/or organisational changes*. Brookfield (1972, 2001) further argued that in some cases agricultural intensification might occur as *landesque capital* rather than changes to the cropping cycle. Landesque capital describes labour inputs that irreversibly transform the environment for future generations. Examples of landesque capital in agronomic systems include changes to the soil, terracing, creation of irrigation systems, the removal of forests to create open fields, and the draining of wetlands. But hunter-gatherer also create landesque capital in cases where their resource management practices result in new ecological relationships: *e.g.* controlled burning, irrigation, tilling and weeding and other activities which stimulate preferred wild species, reduce competing species, and cause soil change (Ford 1985; Harris 1989; Peacock 1998; Rindos 1984, 1989). In fact Lewis (1972) suggested that it was these types activities that permitted hunter-gatherers to continue using mobile subsistence strategies while at the same time developing the *in situ* cultivation of wild plants.

Boserup (1965) designed her population-stress model to explain the agronomic practices of extant peoples. Its utility for investigating transformations in past agronomic and foraging systems has been recognised by archaeologists (De Moulins 1997; Morrison 1994). Over the last 40 years studies have confirmed that in non-industrialised societies population is indeed one of the key factors in the intensification of production, but they have also shown that other factors and combinations of factors are also causal, such as: social constraints, environmental conditions, and innovations in technology (Brookfield 2001; Hayden 1990, 2004; Peacock 1998; Richerson *et al.* 

2001). As well as population increases, other types of demographic factors are recognised as critical variables, *e.g.* the distribution of communities over the landscape, and the gender and age composition of communities (Morrison 1994, 1996).

Non-demographic causes of intensification that have been proposed since Boserup (1965) include short short-term pressures, such as periods of famine; long-term pressures such as environmental change; and in tropical areas that experience pronounced dry seasons, as well as temperate zones that experience pronounced cold seasons, intensification may serve as an annual subsistence strategy to provide a more reliable or more diverse diet during seasons of scarcity, *e.g.* the storing of foods (Ames 1985; Goland 1991; Halstead and O'shea 1989; Testart 1988; Woodburn 1980; Yesner 1996). During the 1980's archaeologists moved away from unilinear theories based on prime movers such as Boserup's (1965) population-pressure theory. Her model was subsequently criticized, primarily as over-simplified and underestimating the internal diversity of economies, and also as viewing the environment as spatially undifferentiated and temporally static (Kirch 1994; Morrison 1994).

The usefulness of Boserup's model continues to be debated. Nevertheless critics and proponents are in agreement that it is of importance, partly because it provided the foundation for the development of more complex understandings of the processes that drive economic change (Stone 2001; see also Brookfield 1972; Leach 1999b; Morrison 1994, 1996, 1999).

### Social production and production for trade as causal

Brookfield (1972, 1984, 1986, 2001; and Blaikie and Brookfied 1987) expanded the discourse on the causes of intensification, suggesting that *opportunities* are as likely to motivate intensification as *pressures*. Brookfield proposed that in many cases intensification is driven by socio-political factors and therefore, that the best way to 96 identify the motivations for intensification is to classify production according to its purpose. Accordingly he defined three types of production: *subsistence production* which is driven by basic needs and includes production of goods exclusively for the use of the producer; *social production*, which is production for the use of others and includes the production of ritual and status goods; and *trade production* which is production of goods for sale barter or other means of obtaining an immediately unavailable commodity (and may also serve as a means of creating and maintaining alliances, see Bender 1978, 1981; Hayden 1990, 2004; Halstead and OShea 1989).

Significantly, by separating the pressures for production into these three categories, Brookfield illuminated the fact that intensification may occur in times of abundance as well as in times of scarcity. He further proposed that the resources that a group chooses to intensify during conditions of abundance, such as those for social and trade production, may differ from those that they choose to intensify in times of scarcity:

"[the nature of intensification] will vary between groups according to culturallyspecific norms, and between individuals according to their desire for status and prestige. Inputs may be wildly uneconomic, when measured by calorific returns, yet wholly reasonable when measured against social returns" (Brookfield 1972: 38).

Some scholars (*e.g.* Halstead and O'Shea 1989; Rowley-Conwy and Zvelebil 1989; Yesner 1996) contend that pressures, rather than opportunities, drive social and trade production. The reasoning behind this argument is that social and trade production serve as risk-buffering strategies for coping with uncertainties in the food supply: in societies that practice storage, social demands such as feasting and ritual provide motivations to keep production consistently high so that stored surplus is available and can be diverted to feed the producers themselves in times of scarcity.

Moreover, in this theoretical view, where production is increased to meet exchange obligations, intensification functions as a risk-buffer because reciprocity with alliance partners permits the pooling of resources and access to a wider range of resources.

#### Intensification and recent theoretical directions in archaeological thought

Recent trends in archaeological theory building have shifted away from universal, explanatory models, towards "...more Darwinian, selection-oriented models of cultural [and economic] change in environmental context" (Gremillion 1997: 8). In the social sciences Darwinian selection-oriented models are distinguished by three central processes: i) the innovation of new variants; ii) a means of transmitting the variants among individuals (inheritance); and iii) cultural selection. Greater emphasis is also given to the evolutionary importance of instability and the role of time and place in *selective events*, and *historical contingency* is recognised as a significant factor in shaping evolution and adaptation (Blumler 1996; McGlade and van der Leew 1996; Sherratt, 1996). Thus the study of prehistoric societies must consider "the particular conjunctions of circumstances in particular places at particular times" (Harris 1996: 552). In other words, current directions in archaeological theory encompass the view that human decisions to intensify production, and their decisions about which avenue(s) of intensification to follow, are mediated by ecological, social and historical factors.

In accordance with recent developments in archaeological theory, evolutionary approaches have been incorporated into the discourse on intensification such that there is now greater emphasis on the multivariate character of intensification, and on the internal diversity of economies (Brookfield 2001; Kirch 1994; Leach 1999b; Morrison 1994, 1996; Yesner 1996). Leach (1999b: 321), for example, argues that the process may encompass "...several starting points as well as multiple trajectories, not all leading to the same end-point." Morrison (1996: 583) proposes that understanding the 98 transformative processes of intensification "...requires both specification of variables and more contextual considerations of specific paths of course of change". Significantly, Brookfield, a geographer who has been a leading voice on intensification theory for more than 30 years, and is an important influence on archaeological intensification theory (see Leach 1999b, Morrison 1994, 1996), recently amended his original definition of intensification, stating that change "[but] in no one direction nor along any one dimension" is the normal condition, and warning that simple labour intensification of the same methods on the same land does not lead to progress and can lead to prolonged stagnation (Brookfield 2001: 182).

In recognition of the ecological repercussions of intensification, and the fact that intensification may cause (sometimes irreversible, see Harris 1989) transformations of the landscape, Brookfield further amended his original statement that "intensification must be measured only by capital labour and skills against *constant* land" (Brookfield 1972: 31), to now read "*dynamic* land" [my italics] (Brookfield 2001: 189). Although Brookfield's statement refers to changes in the land due to human intervention, this statement can be expanded to include natural environmental change. Certainly, groups living in the Epipalaeolithic of Southwest Asia were faced with dynamic land. Thus intensification during the Epipalaeolithic entailed investments of labour, skills and knowledge to obtain resources from an ever changing environment.

# **3.1.4.** Problems with the way that the term *intensification* has been applied in the literature

One of the main problems with the way that intensification has been applied in the literature is that the term has been over-used, and in some cases applied so broadly that it obscures rather than clarifies the processes that are being discussed. Another critical concern is the appropriateness of using this single word to describe processes that take place in distinctly different societies and ecological conditions (see Bayliss-Smith 1999; Brookfield 1972, 1981, 2001; Harris 1989, 1996; Leach 1997, 1999b; Morrison 1994, 1996). For example, Boserup (1965) collapsed horticultural and agricultural societies, and Anderson (1993) and Peacock (1998) confuse horticultural techniques and hunter-gatherer environmental management. In hunter-gatherer studies, confusion of this type may, in part, be due to the fact that theoretical approaches to hunter-gatherer intensification are frequently subsumed by investigations into the pathways to agriculture (Leach 1997, 1999a).

Several scholars (*e.g.* Brookfield 1986, 2001; Leach 1999b; Morrison 1984, 1986) argue that the discourse has not progressed beyond Boserup (1965) because archaeologists continue to apply unitary population or environmental stress models to explain intensification (examples include Broughton 1999; Cohen 1981; Hillman 1996; Peacock 1998; Richerson *et al.* 2001). Indeed population pressure and/or environmental change are frequently assumed to be causal, while other potentially important variables, such as social demand and innovations in technology, are routinely treated as *constraints* on decision making rather than possible causes of intensification (see Broughton 1999; 5). Another problem with the discourse is that the range of strategies of intensification, such as specialisation and diversification, are not always explained. Also, intensification is often presented as non-reversible despite the fact that disintensification can occur in cases of population decline and/or shifts to other strategies such as extensification (Brookfield 1972).

Furthermore, as observed by Brookfield (2001), intensification is only one of the paths to resource change, and in some cases other strategies should be considered such as time management, innovation, seizing of opportunity, and expansion. Intensification is frequently confused with these and other strategies such that expansion and

innovation are erroneously discussed as intensification and increased productivity is sometimes mistaken for the intensification of production (Bayliss-Smith 1999; Brookfield 2001; Leach 1999b; Morrison 1996). The following paragraphs discuss how intensification can be distinguished from, and linked with, increased productivity, expansion, innovation, specialization, diversification, and disintensification.

#### Distinguishing intensification from innovation and expansion

In his most recent writings on intensification Brookfield (2001:189) argued that innovation, which he defines as "...bringing the factors of production together in new ways" may be a more important avenue for change than intensification. He (1984: 16) defines innovation as the introduction of qualitative changes into a production system while intensification involves the introduction of quantitative changes. He (1984: 35) further proposed that innovation is distinct from intensification in that it offers the hope of advantage, while intensification is burdensome and is adopted through necessity. In other words, while intensification always involves inputs of labour, capital, skills and/or organisational changes, innovation and expansion do not require these inputs (see also Bayliss-Smith 1999).

Morrison (1994: 111) argues that understanding the multivariate nature of intensification is critical for distinguishing it from expansion or simple increase:

On the other hand, intensification may be promoted by or prevented by innovation and/or expansion, and conversely, intensification may promote or prevent

<sup>&</sup>quot;...the difference between intensification and simple increase involves the introduction of a second variable...Intensification of production refers to an increase in the productive output per unit of land or labour (or some other fixed quantity) [Boserup 1965]. This increase may be achieved in a number of ways. In the archaeological literature, the variable held constant almost always refers to land in reference to food production or hunting and gathering (getting more out of a given area) and labour in studies of craft production (increasing efficiency of production)."

the need for either (Brookfield 1984). For example, Bayliss-Smith (1999: 323) argues that innovation might preclude the need for intensification if it (innovation) causes a system to be more productive, *e.g.* a change in settlement pattern that brings about the reduction of travel times between the main encampment and critical resource patches. Conversely, Leach (1999a, b) demonstrated that in some cases innovation can necessitate increased labour inputs when new types of plant-processing technology promote the intensified exploitation of certain species. Intensification may also be linked to innovation and expansion in cases where groups invest labour inputs into developing new technology that is used specifically for producing surpluses for alliance and trade or to meet the demands of elites (Bender 1978, 1981; Brookfield 1972, 1986; Hayden 1990).

#### Intensification proper, specialisation and diversification

Organizational skills that promote the efficiency of time management are critical components of the intensification of production (Brookfield 2001) *e.g. resource scheduling*, a strategy that permits a group to take advantage of particular temporal and/or spatial opportunities by locating its members in specific places at specific times during the annual cycle (Chatters and Prentiss 2005: 50). Morrison (1996: 587) separated intensification into three classes of organizational strategies: i) intensification proper, ii) specialisation; and iii) diversification. She defines intensification proper as "...the process by which the yield per unit of land and/or labour of an existing resource base is increased." Her examples of intensification proper include practices that are more often associated with agriculture, such as seedbed preparation and more frequent cropping. However, she also includes practises that are frequently associated with both agriculturalists and hunter-gatherers, such as weeding, transplanting, and the construction of soil and water control facilities. She (1996: 587) defines specialisation,

as "...the channelling of resources and/or labour into more restricted avenues..." In other words, what is specialised may be the resource base itself, the type of resource procurement strategy, or both. Resource specialisation, where a group obtains most of their foods from a narrow range of species, is more likely under conditions of abundance (Broughton 1999; Hayden 1992). Intensification of this type entails "specialised use of more costly but more productive resources using more labour and dedicated technology" (Richerson *et al.* 2001: 401). It requires the technology, biological and ecological knowledge essential for locating, collecting and processing specific resources, *e.g.* scheduling and the organisation of specialised task groups to obtain and/or process specific resources (Alexander 1992; Turner 1997; Turner *et al* 1990). Resource specialisation is risky because as a plant or animal becomes more important in the diet, it may be more vulnerable to over-exploitation (Hayden 1992).

Diversification is the "broadening the base of the subsistence system, either by exploiting a wider range of plant and animal species or by exploiting broader and more varied areas" (Halstead and O'Shea 1989: 5). Like specialisation, diversification may occur at organisational level and/or at the resource base. Organisational diversification entails the incorporation of new strategies into the existing subsistence system, and/or modifications of the existing system. The diversification of the resource entails previously unexploited plants and/or animals being added to the existing diet. Morrison (1996: 587) explains the relationship between diversification and intensification as:

<sup>&</sup>quot;...probably the least obvious aspect of productive intensification in that it may involve the addition or elaboration of productive strategies which seem to be *extensive* rather than *intensive* of land or labour. Strategies of diversification may, for example, include the coexistence of multiple fallow regimes, the use of spatially fragmented field locations, extensive arrays of cultigens and wild taxa, maintenance of a range of crop varieties, staggering planting times, and integration of agricultural and non-agricultural activities. Strategies of

diversification might not involve agricultural facilities at all, among the forging of social or other ties and the creation of entitlement across regions."

The shift to a broad-spectrum subsistence is an example of a diversification of the resource base, although, as observed by Edwards (1989a), Hayden (1990), Richerson *et al.* (2001) among others, broad-spectrum economies are not always indicators of intensification, but are the livelihoods of many forager groups. In fact, hunter-gatherer groups use diversification as a cushion against spatial and temporal variability of resources (Rowley-Conwy and Zvelebil 1989). Diversification permits the expanding and contracting of foraging and mobility patterns to most efficiently extract critical resources from the land. Because they typically involve ecological approaches to environmental problems, diversification strategies are particularly advantageous in times of environmental uncertainties.

Thus specialisation and diversification are considered to be separate economic strategies, each with distinct toolkits. Zvelebil (1989) proposed that, due to the investments involved, hunter-gatherers with specialised subsistence systems were more likely to maintain and preserve their traditional economic practices than groups with more diversified systems. For example, he suggested that in Europe, hunter-gatherers with diversified subsistence systems probably adopted farming sooner than did groups with specialised subsistence systems.

However, although specialisation and diversification appear to be inverse strategies, it can be argued that they may be used together, in different combinations. Intensification may occur in circumstances where specialised harvesting and/or processing methods and toolkits permit the expansion of the resource base; or else in circumstances where groups develop specialised relationships with some resources while maintaining non-specialised relationships with others. Rindos (1984), for example, proposed that a group may develop agricultural relationships with some plants, and participate in specialised relationships with others. This theory is supported by Ertug-Yaras' (1997) ethnographic study of an agricultural village in south-central Turkey, in which she observed farmers exploiting a wide range of wild edible plants.

# Disintensification

Disintensification is the reverse of intensification and is most likely to occur in cases of population decline. As Brookfield (1972: 35) states:

"When population declines, it becomes reasonable to shift to a lower technology once average productivity has fallen below its optimum and it becomes a perceived strain on labour resources to sustain the system."

He further suggests that disintensification would meet with less structural resistance than intensification, although there might be resistance from institutions or individuals who have a vested interest in higher production.

In cases where intensification is no longer a viable option, human groups may shift to other strategies such as extensification or innovation. As with intensification, disintensification entails changes throughout the system: *e.g.* the nature and amount of labour requirements may be diminished and technology may shift to lower levels. Likewise demographics, land-use, scheduling, mobility/sedentism may also be affected. Land use would be expected to shift towards less intensive use of traditionally exploited patches, or in the case of extensification, patches may be abandoned for areas further afield. Diminished labour demands will necessitate a reorganisation of the labour force. This could involve groups amalgamating or disbanding, causing new patterns of distribution of people over the landscape to emerge. Gender and status roles may also shift to accommodate less intensive labour demands, new group sizes and/or distributions.
## **3.2. HUNTER-GATHERER INTENSIFICATION**

During the 1960's, concurrent with the introduction of Boserups (1965) theory of intensification, which challenged long-held Malthusian assumptions about technology and demographics, ethnographic studies began to be published which challenged existing assumptions that hunter-gatherer systems required individuals to work harder than agronomic systems. Previously it had been assumed that "progress", such as shifts towards towards agronomic and/or industrial production, brought reductions in labour requirements. However, ethnographic studies, notably Lee and Devore (1968), showed that many hunter-gatherer groups spent fewer hours a day on subsistence activities than farmers. Moreover, ethnographic studies also brought to light the diversity of hunter-gatherer economic strategies (Price and Gebauer 1995).

Archaeologists thus realised that agriculture represents a significant intensification of labour over hunter-gather strategies (Morrison 1994: 118) and, likewise, that hunter-gatherer economies based on delayed-return systems represent a significant intensification of labour over immediate-return hunter-gatherer economies. Intensification was therefore recognised as a key variable in the development of delayed-return systems, which are thought to be the first step towards food production (Chatters 1995: 342). These findings triggered questions about why prehistoric huntergatherers engaged in intensification in the first place (Price and Gebauer 1995: 4).

To investigate this process, researchers attempted to identify the organisational components of hunter-gather societies by classifying groups according to their economic practices, settlement patterns and/or social systems. The most common approach was to classify hunter-gatherers into groups with simple, and groups with complex social and labour relationships (Arnold 1996). Four of the most frequently cited models of hunter-gatherer economies are those of Binford (1980), Hayden (1990),

Testart (1988) and Woodburn (1980), which are summarised in the paragraphs below. Taken together these models outline how archaeologists typically distinguish huntergatherer groups who intensify from those who do not.

## 3.2.1. Woodburn's (1980) immediate-return/delayed-return model

Woodburn's (1980) *immediate-return/delayed-return* model classifies societies into those who immediately consume the products of their labour, and those who conserve them for later (Table 3.1.). This model is distinct in that it links specific landuse practices, including the management and tending of wild resources, with territoriality and ownership which are then related to the concept of assets.

IMMEDIATE-RETURN	DELAYED-RETURN
-activities aimed towards present returns	-activities link past, present and future returns
-no valued assets, people are systematically disengaged from assets, from the potential in assets for creating dependency	-people hold rights over valued assets of some sort, which either represent a yield, a return for labour applied over time or, if not, are held and managed in a way which resembles and has similar social implications to delayed yields on labour
- simple, portable, utilitarian, easily acquired, replaceable tools	<ul> <li>ASSETS:</li> <li>-valuable technical facilities used in production of food gradually over a period of months or years: <i>e.g.</i> boats, nets, artificial weirs, stockades, traps</li> <li>-processed and stored food or materials usually in fixed dwellings.</li> <li>-management and tending of wild resources</li> <li>- rights held by men over their female kin who are then bestowed in marriage on other men</li> </ul>

Table 3.1. Woodburn's (1980) immediate-return and-delayed return model

Immediate-return systems preclude the ownership of land and other assets while delayed-return systems embrace property rights. The immediate-return system, which is comparable with Testart's (1988, discussed below) non-storing system, describes groups who collect and consume available resources on a daily or short-term basis without concern for future situations or past labour investments. Woodburn (1980) argues that groups who practice immediate-return systems are constrained from owning land and taking on agriculture by their social organisation and values. Despite their ability to adjust to the technical aspects of agriculture and pastoralism, they are distinguished from delayed-return systems "by their lack of binding ties needed for agricultural and pastoral co-operation, by their ownership rules and by their rules of sharing and other powerful levelling mechanisms" (Woodburn 1980: 57).

Woodburn (1980) further argued that in immediate-return societies (where intensification is constrained by the social system) extra time produced by improved productivity may be absorbed into social activities thus precluding the accumulation of surplus. Under these circumstances risk aversion is typically maintained through a system of reciprocal relations (sharing). Others, *e.g.* Bender (1981), Hayden (1990), Ingold (1983) and Weissner (1982), have taken this argument further, reasoning that the belief systems and social activities that accompany systems of reciprocal relations shape many aspects of the band society, including economics.

Conversely, the delayed-return system is built on the intensification of production, with labour inputs aimed towards maintaining past investments, and furthering present and future returns. These systems are characterised by territoriality, ownership and assets (see Table 3.1.), which explains the overlap in attitudes towards land ownership that exist between some hunter-gatherers and farmers. Key to understanding delayed-return systems is that fact that:

"...people hold rights over valued assets of some sort, which either represent a yield, a return for labour applied over time or, if not, are held and managed in a way which resembles and has similar social implications to delayed yields on labour" (Woodburn 1980: 32).

Woodburn attempts to correlate these systems with possible causal conditions, suggesting that immediate-return systems, commonly found among groups who are

geographically encapsulated by small-scale farmer and/or pastoral neighbours, might be an adaptation in the face of political or economic threat. He (Woodburn 1980 and also 1988) further proposed that geography and environment might be factors given that delayed-return systems are more common in latitudes with seasonal extremes, and immediate-return systems are more common in regions with more equable conditions.

#### 3.2.2. Binford's (1980) forager/collector model

Binford (1980) proposed that the organisational components of hunter-gatherer societies can be best understood by their subsistence-settlement systems. After conducting ethnoarchaeological work with the Nunamiut in Alaska, Binford constructed his, now well-known, forager/collector model as a way to link the variability in the archaeological record to specific subsistence strategies (Table 3.2.).

FORAGERS	COLLECTORS
-residential mobility	-radiating mobility
-non-sedentary	-semi-permanent settlements
-opportunistic resource procurement strategies	-specialised resource procurement strategies
-simple social structure	-complex social structure
-practices don't overexploit resources	-occasionally overexploit resources
-no storage	-storage
	-surplus and accumulated wealth

 Table 3.2. Binford's (1980) settlement subsistence model

Binford (1980) defined *foragers* as non-sedentary groups practising residential mobility, through a circulating mobility pattern (Table 3.2.). These groups *map on to* resources on a daily basis by way of the entire group moving together or dispersing to resource procurement areas, a strategy that involves opportunistic gathering of food and the absence of storage (like Woodburn's immediate-return system). The advantages to

this strategy are that groups do not overexploit any single area, and if faced with resource fluctuations or shortfalls the entire group can move to new environments.

Binford (1980) defined *collectors* as semi-sedentary people with a main encampment, storage and surplus. They have a more complex social structure than foragers, with social hierarchies based on the accumulation of wealth and/or task specialisation. Binford labels collectors *serial specialists* because their subsistence settlement strategy aims to position the group so that they can best take advantage (through task groups) of a variety of cyclically available resources among diverse environmental zones.

Of particular interest here are the specialised procurement strategies associated with collector subsistence that necessitate logistical mobility. Logistical mobility involves task groups leaving the basecamps to procure specific resources that are in turn transported back to basecamps for later consumption. The advantage of logistical mobility is that it permits diversification so that the group can carry out the concomitant exploitation of diverse environments. The disadvantages of logistical mobility are that nearby resources can be overexploited, and that greater labour investments, and greater amounts of time spent in travelling, are necessary than in the case of forager economies.

Binford sees forager and collector strategies as adaptive responses to environmental conditions (like Woodburn's delayed-return systems). Logistical mobility is thus adaptive in regions with annual extremes in temperature that are more common in higher latitudes:

"Logistical strategies are labor accommodations to incongruent distributions of critical resources or conditions which otherwise restrict mobility. Put another way, they are accommodations to the situation where consumers are near to one critical resource but far from another critical resource" (Binford 1980: 10).

However, as noted by Yesner (1996: 152), latitudinal gradients are not the only factors that cause seasonal variations in resource distribution and the diversity found among hunter-gatherer economies: similar variations may be observed between coastal and interior regions within the same latitudinal belt.

## 3.2.3. Testart's (1988) storing/non-storing model

Testart (1988) put forward a useful economic model that classifies huntergatherer groups into *storing* and *non-storing* communities (Table 3.3.). Non-storing economies comprise societies that are inherently *secure* by way of having year-round available resources. These groups are found in tropical or sub-tropical environments. They practise opportunistic subsistence strategies and occasionally practise storage in small amounts but as a risk-buffer and not as part of their annual subsistence strategy.

NON-STORING	STORING
-found in tropical or sub-tropical	-found in the temperate zones
-year-round available resources	-abundant resources seasonally available
-mobile?	-semi-sedentary,
-egalitarian	-socio-economic inequality
-more flexible economic and social structures	-rigid economic and social organisation
-opportunistic subsistence strategies	-seasonal scheduling of food-getting activities
	-higher populations in comparison
-storage in small amounts as a risk-buffer	-storage as annual subsistence strategy
	-permanent architecture, storage

Table 3.3. Testart's (1988) economic model of storing and non-storing communities

Storing economies are characterised as semi-sedentary or sedentary, having permanent architecture in the form of villages and/or storage features, socio-economic inequality and higher populations than non-storing groups. The storing economy is defined by "a conspicuous seasonal variation in the intensity of food-getting activities" (Testart 1988: 171). They include groups who live in temperate climates such as the Ainu, Gilyaks, Itelmens, and Northwest Coast hunter-gatherers. Because storing societies are usually found in places with seasonal climates, these societies enjoy abundant resources but on a seasonal basis, and may be subject to famine during the winter seasons. Thus they practice seasonal scheduling of resource collection; harvesting and processing resources *en masse*. Edible resources are "stored on a large scale once transformed through appropriate food preservation techniques" (Testart 1988: 171). Testart maintains that the need for scheduling and the mass collection/processing/storing of resources requires that storing societies have more rigid economic and social organisation than non-storing societies.

#### 3.2.4. Hayden's social pressure model

The typological schemes discussed above have been highly criticised for incorporating assumptions that hunting and gathering societies can be characterised by their economic or ecological behaviours without reference to their social, ideological and cognitive practices (Hunn and Williams 1982). Hayden (1990) and Bender (1978, 1980) attempted to address this problem by linking social organisation and economic systems. Hayden's (1990) social pressure model is considered to be the more valuable of the two because it is testable (Keeley 1995: 244). This model links the structure of a group's social organisation, the potential for economic competition, and the nature of the resource base. Hayden (1990) proposes that plant intensification will occur in societies living in environments that are rich in abundant and available resources; groups who are relatively affluent, socially stratified and who engage in competitive feasting. Significantly, he argues that the types of plants that will be intensively exploited (those that are selected for management and/or domestication) are species associated with ritual, feasting and status, rather than species that are nutritional staples.

GENERALISED HUNTER- GATHERERS	COMPLEX HUNTER-GATHERERS
-opportunistic foraging strategies	-exploit abundant and reliable resources
-rely on "K-selected" species: scarce and/or unpredictably fluctuating resources	-rely on "r-selected" species: plants and animals that reproduce frequently and abundantly
-highly mobile	-semi-sedentism, logistical mobility
-low population densities	-larger population densities
-generalised tool kits with little interassemblage variabilty	-specialised food procurement strategies, specialised tool kits, intensified use of certain resources
-egalitarian	-economically based status competition

Table 3.4. Hayden's (1990) social pressure model

Hayden (1990) classifies hunter-gatherers into two groups: generalised hunter/gatherers, which correspond to Binford's (1980) foragers and Woodburn's (1988) immediate-return societies and complex hunter/gatherers which correspond to Binford's collectors and Woodburn's delayed-return societies (Table 3.4). Generalised hunter-gatherers encompass egalitarian groups that use opportunistic strategies, relying on "scarce and/or unpredictably fluctuating resources, resulting in low population densities (ca 0.01-0.1 per km<sup>2</sup>), highly mobile and opportunistic foraging strategies...and generalised tool kits with little interassemblage variability" (Hayden 1990: 32). Complex hunter-gatherers encompass groups that exploit more abundant and reliable resources than generalised hunter/gatherers. Complex hunter-gatherers are semi-sedentary, practice logistical mobility, engage in economically based status competition, are socio-economically differentiated, and usually have higher population densities than generalised hunter-gatherers. Their tool kits and food-procurement strategies are specialised for mass harvesting of specific resources.

Critical to Hayden's model is the argument that generalised and complex huntergatherers target resources that have distinctly different (genetically-inherited) functional responses to predation and disturbance. With reference to the two-strategy *r* and *K*-selection model, borrowed from ecology (MacArthur and Wilson 1967, see Grimes 2001), Hayden proposed that the types of plants and animals that generalised hunter-gatherers exploit are species unsuited to intensive exploitation, whereas those exploited by complex hunter-gatherers can be exploited intensively. In Hayden's model, generalised hunter-gatherers depend on *K*-selected species, which are characterised as organisms that have fewer offspring, long maturation rates and are easy to over-exploit. Thus, for generalised hunter-gatherers, economic competition is maladaptive because it will result in the impoverishment of the economic base.

Hayden argues that economic competition is feasible for complex huntergatherers because they largely exploit *r-selected* resources, which are organisms that are not easily over-exploited. They are organisms that reproduce frequently and abundantly, including many species of fish, insects, rodents and plants including root foods. Overexploitation of these resources is unlikely because exploitation stimulates the growth and reproduction of these resources. Further, exploitation of r-selected resources favours storage, surpluses and economic competition, which are linked to food production, the development of non-egalitarian societies, craft specialisation, slavery, intensive warfare, and generally increasing social complexity. Hayden sees the choice of one strategy over the other as an *adaptive response* to environmental conditions, which is made possible by technological innovations.

From an ecological perspective Hayden's model is problematic. Within ecology the two-strategy r- and K-selection model is controversial because the functional traits of K-selected organisms are uncertain and continue to be debated; and because some of the characteristics attributed to seemingly r-selected species have been observed in organisms outside this class (Grimes 2001: 6). To address these and other problems, in

recent years plant ecologists have shifted away from two-strategy to three-strategy models that consider how the genetically-inherited functional characteristics of organisms interact with local habitat conditions. However, for present purposes Hayden's (1990) generalised/complex model is important because it is one of the few (but see also Hillman 1996; Speth and Spielman 1983; Speth 2001) that considers the relationships between the social and economic organisation of human groups and the biological characteristics, and reproductive habits of the organisms that they exploit.

## 3.2.5. Comments on the above models

Critics argue that models that are based on binary distinctions, such as those of Binford (1980), Hayden (1990), Testart (1988) and Woodburn (1980) are faulty because they do not further our understanding of the internal diversity in hunter-gatherer economies (see Goland 1991; Price and Brown 1985; Hamilton 1982; Stahl 1993, Stark 1993). Furthermore, and of particular relevance here, are arguments that binary models omit a spectrum of plant-human interactions such as the diverse types of wild plants used by humans (Anderson 1993; Hather and Mason 2002; Peacock 1998; see also Lewis 1972, 1982). Nevertheless, these four models cannot be dismissed because they have become embedded in the archaeological and anthropological literature since 1980. Despite attempts to move away from binary distinctions (*e.g.* see Hather and Mason 2002; Ford 1985; Harris 1989; Rindos 1984, 1989) the models of Binford, Hayden, Testart and Woodburn continue to be among the principal the frameworks with which archaeologists interpret social organisation, subsistence-settlement systems and associated land-use and mobility strategies, as well as temporal shifts such as resource intensification.

The value of the four models presented above, as well as others presented in this chapter, is that they provide frameworks that can be tested and/or modified and

developed in order to establish some possibilities, and rule out others. These models were not constructed to be definitive of ancient lifeways, but to provide tools for investigating ancient societies and how they changed. Each of the four models underscores the importance of preservation and storage in shifts to delayed return and complexity. On the other hand, again for the purposes of this thesis, these models do not go far enough in explaining the role of conservation and storage in delayed-return societies because they ignore the transformative potential of post-harvest activities. In part, this is probably due to assumptions that the elements of processing and preservation are already known (Speth 2004).

Instead, in all four models food processing, preservation and storage are regarded as *measures* of intensification, or as surpluses, wealth and sometimes social stratification, rather than as intensification itself (see Morrison 1996; Stahl 1989); or food processing is grouped with food consumption (e.g. Testart 1988 and Woodburn 1980); or food processing is considered *costly* because it promotes losses of nutrients thus lowering the amount obtained from a given quantity of land and/or labour (e.g.Hayden 1990; but see also Kelly 1995 and Thoms 1989). As a result of these omissions, the nature of the energy inputs (labour, technical and organisational components) are missed. Also missed are the potential energy (k/cal) increases obtained by processing plant and animals parts that are otherwise inedible, and gains in other nutrients (protein, lipid, carbohydrate, vitamins and minerals). Finally, ways that innovations in post-harvest strategies may transform the overall production system and impact on hunter-gatherer decisions about resource selection, scheduling, mobility patterns and land use are also missed. These issues are examined in Section 3.6. below, following a brief summary of the ways that intensification is inferred from the archaeological record.

## 3.3. HOW DO WE IDENTIFY INTENSIFICATION FROM THE ARCHAEOLOGICAL RECORD?

This section summarises general archaeological approaches to identifying intensification with a focus on zooarchaeological methods of investigation. Prior to the discussion on zooarchaeological methods, the role of optimal foraging theory in intensification studies is explained. Archaeobotanical approaches to intensification and human plant exploitation are then discussed in section 3.4.

## **3.3.1.** Fine-grained and course-grained research designs

Investigative approaches to intensification fall into two basic categories: finegrained and coarse-grained studies of patterning in material and biological evidence (archaeobotany, zooarchaeology and the analysis of human remains). Course-grained analyses are those that summarise general trends over a spatially broad region, and are typically based on small samples from spatially discrete sites representing different temporal periods. Fine-grained analyses are spatially restricted, involving the careful excavation of the long stratigraphy of one or several well-stratified sites that have significant time-depth (De Moulins 1997: 7; Broughton 1999).

## 3.3.2. Archaeological evidence and inferences about intensification

Intensification is usually inferred archaeologically from evidence of *labour investments*, *e.g.* energy inputs required for technological development such as the production of tools; the construction of irrigation systems and/or terracing; energy inputs required for plant harvesting, tilling, planting and tending; and humanly-induced genetic changes in plants and animals (Brookfield 1972, 2001; Morrison 1996, 1999). Ecological indicators are frequently used as measures of net productivity, such as the size and diversity of resources (Zvelebil 1989; Munro and Bar-Oz 2005).

The models of Binford (1980), Hayden (1990), Testart (1988) and Woodburn (1980) suggest that the intensification of production by hunter-gatherer groups can be inferred from patterns that indicate a reduction in mobility, population increase by way of larger settlements and/or more settlements with a given region, greater amounts of increasingly complex material culture to deal with specialised and diversified resource procurement strategies, and the production of surpluses. The reasoning behind these inferences is that the aim of intensification is to increase the amount of a resource(s) that can be extracted from an area of land. In turn, as the amount of extractable resources increases, so does the carrying capacity of that land, so that there is a reduction in the range size needed to support a family, and therefore a reduction in mobility is feasible (Hayden 1992: 537). Population increases are thought to follow sedentism. Furthermore, a shift towards social stratification is considered a necessary corollary of sedentism, because it provides the means for coping with logistical and spatial problems and inevitable increases in community size. Shifts towards social complexity are assumed to create new pressures on production, such as demands to produce for exchange, ritual elaboration and/or competitive feasting (Bender 1978, 1981; Brookfield 1972; Hayden 1990, 2004; Takahashi and Hoysoya 2002).

Lourandos (1983:82) proposed that hunter-gatherer intensification can best be identified archaeologically from long-term changes in land and resource management strategies including more intensive usage of individual sites, increased establishment of new sites, increased use of marginal environments; and increased complexity of site economy. Ames (1985: 171) presents a similar argument to Lourandos and further suggests that intensification can be recognised from qualitative changes, such as an increasing emphasis on specific resources and on special procurement and processing methods: e.g. the mass harvesting of seasonally available resources should be visible

archaeologically in the form of tools that allow for mass harvesting and/or mass processing such as large cooking features, large basketry or containers for collecting plants. With reference to his research into ancient Northwest Coast societies, Ames (1985) proposed that these types of evidence will be accompanied by indications of the accumulation of wealth, physical assets and land ownership.

Zvelebil (1989: 86) argued that economic intensification is best measured in terms "...of labour and commitment invested in food procurement activities" which include technological investment, settlement location, and the socio-economic organisation of the group. He defined tchnological investments as labour invested in constructing specialised toolkits, either for the exploitation of specific resources, or for the procurement of a broad spectrum of resources. As noted earlier, (Section 3.1.4.) Zvelebil regards specialisation and diversification as distinctly separate subsistence strategies, involving different labour investments and different types of tookits.

Lewis (1972: 216) suggested that, for hunter-gatherer societies the introduction of new resource procurement strategies would have to be tailored to fit in with seasonal patterns of hunting and gathering. Thus, when investigating labour investments in prehistoric societies, we should be looking for evidence of new strategies [or modifications of strategies] that complement, not merely supplement, the primary subsistence and mobility systems. However, the identification of new strategies, such as increased production, from the archaeological record is difficult (Brookfield 1972, 2001; Leach 1997, 1999b; Morrison 1996).

"Indeed, the physical evidence of major site transformation, which is often all that remains to be seen of former intensive practices, represents only one end of a continuum of former intensification, and the archaeological record therefore constitutes only a partial and biased inventory of past practices" (Brookfield 1972: 32) Morrison (1996) cautions archaeologists that our models of intensification may preclude rather than facilitate our ability to identify the transformative processes by which economic shifts occur.

"It may be fair to say that many archaeological conceptions of long-tem history have stressed the additive rather than the transformative nature of change and have viewed human groups as pyramidal arrangements of varying numbers of building blocks in which subsistence strategies constitute the essence of each block and the complexity of the group can be easily measured in terms of the number of blocks in the pile. Hence the great interest in origins, or temporally defined points at which new blocks are introduced" (Morrison 1996: 586).

She argues that many of our models in fact present circular arguments: the models being based on the grouping of certain phenomena into categories, and those categories in themselves have become the measures. In other words, many ostensibly processual models do not actually consider the transformative processes involved.

## **3.3.3. Brookfield's three classes of labour inputs**

Brookfield's early writings on intensification (1972, 1984, 1986) continue to provide the best means of identifying the intensification of production. Noting that the archaeological record "...constitutes only a partial and biased inventory of past practices" he (1972: 32; 1986) advocates identifying the processes as well as products of intensification, and then evaluating the relationships between them. He suggests that the products and processes can be identified from three distinct classes of labour inputs:

- i) labour inputs required to create the capital that provides the conditions of production *e.g.* the construction of residential and storage architecture, the fabrication of specialised tools for specific types of resource procurement, specialised food processing features and equipment;
- ii) labour inputs used to maintain and repair that capital;

iii) labour inputs that are required for production alone, e.g. sowing, harvesting (Brookfield 1986:179).

Brookfield's third class of inputs, *those that are required for production alone*, can be identified only from direct biological evidence: studies of human remains, and the patterning in plant and animal remains. With respect to the Epipalaeolithic, the importance of Brookfield's third class of inputs is echoed by Bar-Yosef and Meadow (1995: 51) who point out that biological evidence can provide more concrete evidence about prehistoric subsistence settlement systems than material remains such as permanent architecture and heavy tools.

Many argue that the biological evidence derived from human, animal and plant remains provide the best evidence for resource change, resource stress, and shifts in mobility/sedentism (*e.g.* Bar-Yosef and Meadow 1995; Edwards 1989b). Certainly the study of human remains provides important information about resource change as well as scarcity and nutritional stress. Enamel hypoplasias in human teeth and Harris lines in human bones are considered archaeological signatures of episodic stress; and diet change can be recognised from temporal changes in tooth wear and dental pathology (see Eshed *et al.* 2005; Molleson *et al.* 1993; Speth 2004; Yesner 1996).

## 3.3.4. Optimal foraging theory and resource intensification

Before moving on to discuss how intensification has been inferred from archaeobotanical evidence (section 3.4, below) and zooarchaeological data (section 3.3.5, below), it is necessary to consider optimal foraging theory because this approach figures prominently in the discourse on hunter-gatherer resource intensification. Optimal foraging models are also used to assess foraging efficiency and evaluate why hunter-gatherers select certain resources over others, and to investigate changes in land

use, the potential effects of changing resource densities on the resource selection of foragers, and the potential effects of human predation on the population densities and productivity of resources (Lambin *et al.* 2000; Winterhalder 1993).

Optimal foraging theory, which is grounded in evolutionary ecology, proposes that individuals will exploit their environment in ways that maximise their reproductive success (Broughton 1999; Winterhalder and Goland 1997). Cost/benefit considerations, energy obtained/energy expended, are at the heart of optimization models which propose that hunter-gatherers forage in ways that the energy return is maximized while the energy outlay is minimized (Hawkes *et al* 1982; Shennan 2002; Yesner 1982). Energy (k/cal) is the most universal measure used to assess foraging returns because it is the least problematic macronutrient among different foods (Broughton 1999: 8).

Several foraging models are used by archaeologists: *prey choice*, *diet breadth* and *patch choice*. Prey choice and diet breadth models predict that foragers will exploit specific resources that give the best returns on their labour investments: animals that are larger and younger are ranked higher than smaller or older individuals which have less meat and/or are less fatty (Munro 2004; Yesner 1996: 164). Likewise, animal products are generally ranked higher than plant foods. These models propose that prey types selected by foragers will be decided by encounter rates with high-ranked resources, and that low-ranked resources will be ignored regardless of their abundance (Shennan 2002). Based on the assumption that resources are randomly distributed over the landscape, in prey choice and diet breadth models search costs are excluded from return rates. Declines in encounter rates are thought to indicate over-exploitation by humans, changes in prey behaviour, or seasonal, climatic, or environmental shifts (Munro 2004: S6). Decreasing encounters with high-ranked prey are identified archaeologically from temporal changes in the ratio of high to low-ranked resources.

The patch choice model is distinct from prey-choice and diet breadth models in that it proposes that prey which aggregate, and therefore require shorter search times, are higher ranked than prey that do not aggregate and require longer search times (Shennan 2002). Patch choice model return rates include search times. Therefore the model predicts that foragers will not pursue resources that occur in patches with high search costs, even if those resources are high ranked species (Hawkes *et al.* 1982: 392).

Optimal foraging models are controversial. Scholarly assumptions about the ranking of hunted and gathered resources have been called into question (Speth 2004; Speth and Spielman 1983; Zvelebil 1989). Optimal foraging models have also been criticised for overlooking the many diverse non-optimal activities that human groups partake in (Lambin *et al.* 2000) such as social, ritual and trade production (see Brookfield 1972; Hayden 1990). Critics also argue that in ethnographically observed situations groups do not always behave in the optimal ways predicted (Shennan 2002)

In terms of the arguments presented in this thesis, optimal foraging models are problematic but also necessary. They are problematic because they give primacy to energy efficiency without considering other critical nutrients and the need for dietary variety (Joachim 1983); and because they consider plant foods, particularly those that require extensive processing, to be low ranked "regardless of their nutritional quality" (Hawkes *et al.* 1982: 394). In fact this approach appears contrary to the basic tenets of the evolutionary biology model because humans require a balance of nutrients, not just calories, to maximise their reproductive success. In most cases, optimisation models are applied despite the fact that little is known about the nutrient properties of the wild plants and animals exploited by ancient peoples. Indeed, many critical macronutrients and micronutrients occur in larger amounts in plants rather than animals, *e.g.* vitamin C. In most latitudes, plant foods are critical for enabling people to obtain the nutrients they need to maximise their reproductive success. Furthermore, in many cases the labour investments required for processing plant and animal foods are necessary to access essential nutrients. Also, the functional properties of the plant and animal parts, and how amenable they are to processing with the existing technology, may be as great an influence on the selection of a species as it rank (Kcal/hr obtained, less Kcal/hr expended) (Leach 1999a; Lyons and D'Andrea 2003).

When applied with caution, optimal foraging models can provide practical frameworks for considering the resource decisions of prehistoric groups, and identifying possible variables involved in resource changes. They may also help to explain how innovations in technology can promote intensification, such as in situations where the introduction of new technology provides more efficient ways to exploit lower-ranked but productive resources (Shennan 2002; Steiner *et al.* 2000). Optimal foraging assumptions are widespread in the archaeological literature, particularly the idea that resources can be ranked from high to low based on their energy potential, and that resources can be rated for cost/benefit. But, if we are to understand the economic decisions of prehistoric hunter-gatherers, we need to know a great deal more about the individual resources themselves. Detailed nutritional studies are needed of the simulated diets of the prehistoric groups in question (Hayden 1992), and detailed biological and ecological studies of the organisms that comprised those diets in order to understand how they respond to routine predation by humans.

## 3.3.5. Inferring resource intensification from zooarchaeological evidence

Four types of analyses are commonly used by zooarchaeologists to investigate prehistoric hunting strategies, and the intensity with which a group exploited the available animals: i) taxonomic composition; ii) prey age structure; iii) prey skeletal part frequency (the parts of the carcass selected by the group under study); and, iv) 124 patterning in fragmentation and cut marks (Broughton 1999; Munro 2004; Speth 2001, 2004; Speth and Spielman 1983). From the temporal trends in taxonomic composition and prey age, shifts in the relative proportions of high- to low-ranked species and species parts can be determined (Munro 2004; Yesner 1996: 164); and prey-processing intensity can be inferred from the prey skeletal part frequency and the patterning in fragmentation and cut marks.

The measurement of *prey processing intensity* is a useful way to investigate intensification because it provides a means of measuring human time and energy inputs in relation to the total energetic returns that were extracted from prey carcasses (Munro 2004: S8). Speth (2004; Speth and Spielman 1983) argues that the analysis of prey processing intensity is the best way to discern the links between ancient human diet and animal abundance. He maintains that, on their own, frequencies of animal remains are not measures of resource abundance because humans can experience starvation in cases where high-ranked prey are abundant and available but low on body fat. Speth and Spielman (1983) emphasise that starvation can occur if humans are forced to depend on lean meat because there are limits to the amount of calories that humans can safely consume from lean meat alone. With reference to ethnographic and ethnohistoric examples, Speth (2004) further argues that in cases where only lean meat is available, humans will seek essential fat and carbohydrates through the intensification of other resources, *e.g.* by exploiting starch-rich edible plant parts, such as root foods and/or the extraction of marrow and/or fat from animal bones.

Prey processing intensity can be assessed from the condition of the animal remains because marrow extraction is achieved by cracking bones open, and bone fat extraction entails bone boiling. In recent years laboratory and statistical methods have been developed to assess faunal assemblages for prey-processing intensity (e.g.

Broughton 1999; Munro and Bar-Oz 2005; Bar-Oz and Munro 2007). The data have been used to assess ancient patterns in intensification and site-use intensity.

Munro (2004: S8) has used two methods of measurement to assess prey processing intensity:

- i) extraction intensity: because processing is intensified as animal products with increasingly high cost/benefit ratios (meat, marrow, then bone grease) are routinely harvested from animal skeletons, determining which of these products were regularly extracted provides a rough measure of extraction intensity;
- ii) marrow and bone grease are differentially distributed throughout an animal's skeleton, so the cost-benefit of processing different body parts varies; comparisons of marrow and grease yields of bone portions with their survivorship, fragmentation rate, and frequency of impact damage, can indicate how intensively humans extracted energy from prey.

By combining data on taxonomic composition, prey age structure, prey skeletal part frequency, and patterning in fragmentation and cut marks, inferences can also be made about site-use intensity (Broughton 1999). For example, Munro (2004) calculated and compared the relative abundance (proportion total NISP) of broad prey groups and small prey groups through five phases of Natufian occupation at Hayonim Cave in Israel. The results showed that, at the Early/Late Natufian margin there was a dramatic shift in the ratio of high- to low-ranked prey, and an increase in the proportion of juvenile to adult gazelles. The results of the prey processing analysis also showed temporal increases in processing intensity. Based on assumptions that declines in encounter-rates occur as a result of over-exploitation of resources, particularly around settlements, Munro (2004) inferred a reduction in site-occupation intensity and increased group mobility during the Late Natufian.

## **3.4. INTENSIFICATION AND HUMAN PLANT EXPLOITATION**

This section begins with a discussion of evolutionary models of plant-human relationships. Next the types of plants that are regarded as intensifiable are considered before archaeobotanical methods for identifying intensification at agricultural and hunter-gatherer sites are described. Plant processing as intensification is discussed in the subsequent section 3.5.

## **3.4.1. Evolutionary models of human-plant relationships**

Rindos (1984), Ford (1985) and Harris (1989) devised Darwinian evolutionary models aimed at explaining how specific human plant-exploitation activities can lead to the outgrowth of different food-yielding systems; as well as explaining the ecological effects of human activities, *i.e.* how human labour inputs set in motion (sometimes irreversible) changes to the environment. Rindos' (1984) co-evolutionary model proposes that humans developed complex relationships with plants as a result of *mutualistic* associations between humans and selected plants. Mutualism is a concept taken from biology that describes an event wherein genetically unrelated organisms develop a symbiotic relationship that is adaptively advantageous for both organisms. In Rindos' view, human-plant exploitation associations, whether they are incidental, specialised or agricultural, are natural biological alliances similar to predator-prey relationships between other species. Because these three stages are arbitrary there is not always a distinct separation between them. People may continue specialised relationships with one species while maintaining agricultural relationships with others. As a result of this symbiotic relationship both organisms increase their fitness and undergo population expansions. Domestication is thus mediated by three factors: i) the morphological adaptations in a plant; ii) the plant's relationship to its environment (autecololgy); and iii) behavioural changes in humans.

Ford's (1985) model, *stages and methods of food production*, describes plant production as "the deliberate manipulation of specific floral species by humans for domestic use or consumption" (1985:2). In this scheme, *foraging* is still distinct from *food production* because, while Ford recognises that *tending* may occur in both foraging and food producing societies, he proposes that only food production encompasses *tilling, transplanting, sowing* and *plant breeding*. Ford identifies two distinct processes of labour inputs:

- i) the expansion and acceleration of tending, tilling, transplanting, and sowing that lead to plant breeding and genetic changes;
- ii) labour inputs that are carried out in the foraging realm. The latter process includes unintentional tending which may stimulate the growth of a species, *e.g.* the intensive gathering of one species and/or the use of implements to harvest wild plants such as digging sticks.

Ford (1985) notes that modifications to the landscape can occur that benefit generations to come, an observation that is similar to the the landesque capital described by Brookfield (1072, 2001), *e.g.* changes to the soil, forest clearance, irrigation systems, raised beds, terracing. Ford (1985) further argues that while unintentional stimulation of wild plants might not influence groups to increase their labour inputs, labour inputs of this sort might have an impact on the landscape by reducing competing species and giving an adaptive niche to selected species. Significantly, both Ford (1985) and Rindos



Figure 3.1. Schematic diagram of an evolutionary continuum of people-plant interactions, by Harris (1989: 17).



**Figure 3.2.** General model of wild plant food production of temperate regions, by Peacock (1998: 80).

(1984) argue that intensification can only occur if the plant(s) in question have traits that are intensifiable.

Harris (1989) took these ideas further with his *evolutionary continuum* model. This descriptive model (Harris 1989: 17), illustrated here in Figure 3.1, identifies four categories of plant food-yielding systems: i) wild plant-food procurement (foraging) which includes gathering, collecting, tending and burning; ii) wild plant-food production (with minimal tillage) which includes replacement planting/sowing, transplanting weeding, harvesting, irrigation and storage; iii) cultivation with systematic tillage; and iv) agriculture. The model describes increasing labour inputs and the ecological effects that accompany each new system. It shows how each new system is born out of the previous one due to a kind of dialectic between human-induced changes in the environment, increases in sedentism, population and social complexity and increasing energy inputs. (Harris intended his evolutionary continuum model to be nondirectional, but that is not clear from his schematic diagram, see Figure 3.1.).

Significantly this model shows escalating human labour inputs culminating in *energy thresholds*, which are portals into new food yielding systems. In an earlier paper, Harris (1977) explored ways that evolutionary differentiation in food yielding systems can take place within forager systems without leading to agriculture; and in more recent papers (*e.g.* Harris 1996) he simplified the evolutionary continuum modeland incorporated a series of animal-exploitation activities into the framework. But for present purposes the 1989 evolutionary continuum scheme is the most useful because it illustrates the transformative nature of plant intensification. What is missing in this (1989) model is the role of food processing, and how processing might influence species selection.

Peacock (1998) built on Harris' (1989) evolutionary continuum model to include plant processing as one of the components of intensification. This causal model, shown in Figure 3.2., proposes that in the temperate zones plant intensification is driven by seasonal and annual fluctuations in resource abundance and availability, and in conjunction with recurrent resource stress. Peacock proposes that human solutions to these stresses are cognitive, technological and social, but that it is the technological components which serve as catalysts for change: environmental management, food processing and storage. She defines three outputs (consequences) of these solutions:

- i) ecological: increases in the reliability, density and distribution of managed resources; and increased seasonal productivity and predictability;
- ii) nutritional: food processing creates calories and other otherwise unavailable macronutrients;
- iii) storage: a means of increasing the abundance and availability of critical resources.

Like Harris' (1989) evolutionary continuum model, Peacock's scheme assumes that sedentism, population and complexity increase as human-plant relationships become more complex. Peacock was careful to draw the continuum of people-plant strategies as non-directional, which suggests that a group may engage in diverse combinations of wild plant food procurement, wild plant food production, cultivation and agriculture. This echoes Rindos (1984) view: that a group may develop agricultural relationships with some species, and participate in specialised relationships with others.

Peacock's (1998) scheme of wild plant food production is the first model of intensification (that I am aware of) to include plant-processing. It usefully summarises

problems and solutions of temperate zone hunter-gatherers under conditions where intensification occurs as a result of external stresses such as environment. It is limited because it proposes a single prime-move (environmental change) as causal, and because it does not consider other types of pressures on production, such as social or trade. Nor does it consider how other types of environmental circumstances, such as conditions of abundance, might influence production (see Hayden 1992). Ultimately this model fails to demonstrate intensification because Peacock confuses increased productivity with intensification (see Figure 3.2.). She overlooks the role of increasing human energy inputs in the transformation from one plant exploitation system to the next (from wild plant-food procurement, to wild plant food-production, to cultivation and agriculture).

## **Comments on evolutionary models**

Evolutionary schemes have greater potential for describing the transformative processes of intensification than binary models. As the same time, evolutionary schemes are difficult to construct due to thorny issues such as: how to effectively illustrate variation, and how to indicate time without implying that change will necessarily move in one direction. Thus models that are intended to be non-directional (*e.g.* Harris 1989) have been criticized for being distinctly directional because the transformation from one stage to the next obscures evolutionary developments that might take place within any of the stages (see Mason 1992). Indeed historic and ethnographic records show that evolutionary differentiation can take place within forager systems without leading to agriculture (Anderson 1993; Harris 1977; Peacock 1998; Thoms 1989; Yen 1975). Yen (1975: 153, see also Stahl 1989: 185) suggests that a group may take pathways other than agriculture if they have appropriate techniques of food processing, *e.g.* the Jomon of Japan who heavily exploited wild plant foods for approximately 10,000 years without turning to agriculture, due to developing techniques

of food processing with simple pottery and water-pooling facilities (Takahashi and Hosoya 2002). Other criticisms of evolutionary models are that they focus too heavily on labour inputs and overlook other developments such as the links between labour, innovation, and social factors, and that they overlook changes at the organizational level (Brookfield 2001; de Moulins 1997).

## 3.4.2. Archaeobotanical studies of intensification

Until recently zooarchaeological analysis has been considered better suited to the investigation of hunter-gatherer resource intensification than archaeobotany because archaeobotanical data are generally lacking (De Moulins 1997). Thus regional assessments of diachronic changes in plant uses are rarely possible. This problem is partly due to the history of archaeological sampling: archaeologists do not always sample for plant remains owing to widespread assumptions that most plant remains do not survive; and because many archaeologists are unaware of the types of insights that can be obtained from archaeobotanical research (Hather and Mason 2002: 9), notwithstanding the fact that archaeobotanical study of root-food exploitation, although improving, has been hampered by taphonomic, sampling and methodological factors (see Hather and Mason 2002; Kubiak-Martens 1999). Furthermore, fine-grained archaeobotanical studies are rare (*i.e.* the careful excavation of the long stratigraphy of one or several well-stratified sites that have significant time-depth), two notable exceptions being the archaeobotanical investigations at Abu Hureyra by Hillman (2000) and De Moulins (1997) (see also Ash and Sidell 1988).

Methodological approaches to the study of agricultural and hunter-gatherer intensification differ. Methods for investigating agricultural intensification are better developed, possibly because they have a longer research history (beginning with Harlan 1967 and Hillman 1973) and have been more widely applied. While studies of 133 agricultural intensification consider qualitative as well as quantitative data, and include ecological approaches to the interpretation of archaeobotanical assemblages, investigations into hunter-gatherer intensification tend to entail exclusively cost/benefit analyses. Examples of these approaches are discussed below. First, however, it is necessary to assess the kinds of plants that are amenable to intensified exploitation.

## What kinds of plants are people likely to intensively exploit?

As stated above, resource intensification is thought to occur when there is a need to meet: i) short short-term pressures, e.g. periods of famine; ii) long-term pressures such as environmental change, population pressure and growing subsistence needs, social or exchange requirements, and/or the demands of authority; iii) or as an annual subsistence strategy to provide an adequate diet during seasons of scarcity, *i.e.* a focus on storable foods. These points suggest that the types of plant-foods that people will intensively exploit are taxa otherwise regarded as *famine* foods, preservable foods, and staple foods. In this context staple foods are defined as dependable resources that constitute significant percentages of the diet in terms of essential nutrients such as carbohydrates, proteins and fats, as well as energy (Clarke 1988; and Jones and Meehan 1989). Availability and abundance are important criteria, such that storable foods will probably include plants that are ripe in particular seasons and/or particular locations. Cereals and legumes, for example, are highly used as staples because they have a relatively high caloric content and a palatable flavour, are easily grown and widely available, often grow in large stands, are relatively easy to collect are easily collected, and store well (Burton 1982; Evers et al. 1999; Garrard 1999; Hillman 1996).

Social factors also need to be considered. For example, Hayden (1990) proposed that social pressure will motivate groups to intensively exploit plants that are status foods. In this scenario species that are high-ranked in terms of energy are not

necessarily selected for intensification. Instead species may be selected that require high labour investments and may therefore represent wealth or have value as trade goods. Other categories are foods used for ritual or ceremony, which include plants that are to be consumed in particular locations and/or in particular seasons (Jones and Meehan 1989: 120). Contemporary religious and religious holiday examples might include unleavened bread, eaten in church during Christian communion rites; and plum pudding, eaten only during the Christmas season.

The exploitation of root foods (edible taproots, bulbs, tubers, corms, *etc.*) is the subject of the case study presented in Chapters 4, 5, 6, 7 and 8. Root foods were among the earliest plants intensively used by past peoples worldwide (Harris 1977; Hather 1994). Some tropical taxa such as yams (*Dioscorea* spp.), taro (*Colocasia esculenta*) and potato (*Solanum tuberosum*) subsequently became very widely cultivated agricultural crops (Hather 1994; Harris 1977; Rindos 1984).

The intensified exploitation of root foods encompasses approaches that differ distinctly from intensified exploitation of seed foods (Thoms 1989; Harlan 1992; Harris 1977; Hather 1994). Rindos (1984), Ford (1985), and Hather (1994) argue that the intensification of any species depends as much on the morphological and biological characteristics of the plant as it does on the human decision to intensively exploit it. Plants selected for their edible seeds, such cereals and legumes, are typically annual speeches, which are stimulated to germinate by planting (Harlan 1992). Conversely, root foods are typically perennials which can be stimulated to grow by harvesting as well as planting because they reproduce vegetatively as well as sexually, *e.g.* in cases where daughter bulbs and tubers are released back into the soil during harvesting. Or, in the case of clonal species, such as sea-club-rush, following predation the clone will seek to attain its former underground biomass (Clevering 1995, and see Chapter V). Thoms (1989) provides a framework for distinguishing the types of *geophytes* (perennial herbaceous plants with underground storage organs) that are suitable for intensive human exploitation. Darby (1996) has shown that Thom's framework is also applicable for distinguishing exploitable *helophytes* (perennial herbaceous marsh plants with underground storage organs such as SCR, which is the subject of the case study presented in this thesis). Thoms' (1989: 82) framework states that root foods must have the following characteristics to be suitable for intensive human exploitation:

- i) storable species rich in utilizable carbohydrates and perhaps other nutrients;
- ii) species must be capable of reproducing sexually and vegetatively, and of responding to the potentially beneficial effects of digging (*e.g.* increased propagation and aeration of the soil);
- iii) the presence of productive and extensive root grounds readily accessiblefrom places where root foods would be consumed, such thattransportation costs are reasonable;
- iv) underground storage organs should also be relatively available in terms of ease of digging;
- v) environmental conditions should be stable enough to insure that plants would be available in sufficient quantities year after year.

Archaeobotanical studies by Hather (1994: 723) reveal that pre-agrarian groups in Europe and Southwest Asia exploited two categories of root and tuber remains, the first being perennial or biennial dicotyledonous taproots which do nor reproduce vegetatively. According to Thoms' (1989) model (above), Hather's first category is unlikely to suitable for intensive human exploitation. The second of Hather's (1994: 723) categories includes various marsh, fen and semi-aquatic plants that have distinct morphological characteristics that permit vegetative production. This category, which includes the study plant SCR, accords with Thoms' (1989) definition of root foods that are amenable to intensive exploitation by humans. Hather (1994) argues that although some of these root foods have the potential for small-scale cultivation, they were never cultivated on a large scale because aquatics and semi-aquatics are difficult to cultivate, often due to a rhizomatous habitat. This suggests that if these types of plants were intensively exploited by people, increased labour inputs would occur in the harvesting and/or post-harvest stages rather than during planting and tending.

#### Archaeobotanical investigations into agricultural intensification

Both direct and indirect methods have been used to identify agricultural intensification. Morrison (1996), for example, took an indirect approach when she examined a combination of pollen, charcoal, archaeological data, and historical records to identify patterns of land use and settlement in pre-colonial southern India. While this method is useful for addressing questions about human impact on the environment, and to investigate human investments into landesque capital, it cannot be used to assess the links between ancient human diet, plant uses and environment. The links between ancient human diet, plant uses and environment can only be determined through archaeobotanical investigation because it entails examining direct evidence of plant exploitation by humans.

Archaeobotanical evidence of agricultural intensification includes:

i) the occurrence of morphologically domesticated cereals and/or legumes, which provide evidence of increased labour inputs of tillage and planting;

- ii) increases in the variety of domesticated species, which provide evidence of increased exploitation of domesticated taxa;
- iii) increases in weeds that are known to thrive under agricultural conditions,which suggest tillage and planting; and,
- (iv) the proportions of weed and wild seeds/domesticated species which can indicate the persistence of wild-plant exploitation alongside, or instead of, incipient agriculture (De Moulins 1997; Jones. 2005).

In fact the study of weeds from archaeobotanical assemblages has provided valuable information about ancient cultivation systems. In recent years archaeobotanists studying the functional ecology of present-day arable weed floras have identified weed attributes that can be applied to archaeobotanical assemblages to identify particular types of ancient husbandry practices, crop sowing times, crop cultivation intensity, and ancient irrigation regimes (see Bogaard *et al.* 2005; Charles *et al.* 2003; and Jones *et al.* 2005).

# Archaeobotanical investigations into agricultural intensification in the study area

De Moulins (1997) conducted a fine-grained archaeobotanical study of the intensification of agricultural practices in Southwest Asia. She analysed charred plant remains from Neolithic contexts of three temporally and contextually similar, but spatially distinct, early village sites: Cafer Höyük, Abu Hureyra and El Kowm. The sites are located within the Euphrates drainage area of northern Syria and southeastern Turkey, encompassing the eastern Taurus highlands and the Syrian plateau and steppe. She (De Moulins 1997: 170) compared temporal trends in the flotation samples by measuring the charred seed assemblages for: i) concentrations of items *per* litre of deposit; ii) ratios and percentages of certain plants in relation to others; iii) the number

of occurrences in the samples of species or species type (presence analysis/ubiquity); and iv) also the intensity of charring, based on the view that throughout the Neolithic, sites produce more plant remains as time progresses because of increasing agricultural activities involving plants being exposed to fire.

For present purposes, an important result of De Moulins (1997) study is that, in the economy of PPNB Abu Hureyra, wild plants were found to be more abundant than domesticated species, although the Epipalaeolithic levels produced some of the earliest examples of domesticated specimens of rye (Hillman 2000; Hillman *et al.* 2001). The patterns in the stratigraphy suggest that, by the PPNB, the necessary labour inputs associated with agricultural production had not increased at Abu Hureyra sufficiently to transform the production system. Thus domestication, and increased production associated with planting and tilling, complemented rather than supplemented the primary hunting and gathering subsistencence system. In other words, cultivation and domestication were probably among several new subsistence strategies that the occupants of the site fitted into their existing seasonal patterning of hunting and gathering.

Another important result of De Moulins (1997) study is that she found significant inter-site diversity in species selection preferences, with large-seeded legumes dominating the domesticated species found at early PPNB Cafer Höyük, while cereals were more important at the other two sites. She also observed that temporal changes differed at each site. She (1997: 178) emphasizes that her results are tentative, and that regional and taphonomic factors may explain the differences between the sites. However, her results highlight the persistence of local economic traditions during the early Neolithic of Southwest Asia. They also highlight the importance of fine-grained methods for investigating intensification, without which local trends and local shifts may be missed.

## Archaeobotanical investigations of hunter-gatherer intensification

Hunter-gatherer plant intensification has more often been inferred from secondary evidence, *e.g.* temporal increases in the number of food processing sites and/or the number and size of food processing features and tools such as roasting pits and bedrock mortars (Hallam 1989; Peacock 1998; Pokotylo and Froese 1983; Wright 1994). Hallam (1989), for example, drew on multiple lines of (non-archaeobotanical) evidence to demonstrate the intensive use of fixed-patch root foods by ancient Aboriginal groups in Southwest Australia. She examined ethnographic, cartographic and botanical information and conducted field surveys and archaeological excavations, and inferred root food intensification from the archaeological remains of processing and other facilities found in proximity to ethnographically known productive root food patches. Likewise, in the Pacific Northwest of North America, Pokotylo and Froese (1983), Thoms (1989), and Peacock (1998), inferred the prehistoric intensification of geophytes from archaeological evidence of temporal increases in roasting pit sites and in the number and sizes of roasting pits found in close proximity to areas reported (ethnographically) to support productive patches of edible geophytes.

Archaeobotanical studies aimed at investigating hunter-gatherer plant intensification typically adopt an optimal-foraging approach, based on cost/benefit assumptions, *e.g.* that nuts have greater return rates than seeds and that larger seeds have greater return rates than smaller seeds (see Barlow and Heck 2002; Weiss *et al.* 2004; Wohlgemuth 2004). However, in most cases researchers (*e.g.* Weiss *et al.* 2004b; Wohlgemuth 2002) identified temporal trends in the *intensity* of use of specific species rather than the intensification of production (see also section 3.1.4. above regarding problems with the way that the term intensification is used in the literature).

However, intensity of use is not intensification.

"...it is important to bear in mind that the subject here is intensification of production, that is [the intensification of] the processes involved, and not intensive practices aimed at improved productivity" De Moulins (1997:2).

This distinction is important because it directly influences the line of questioning that informs the research design, the types of data that are considered to be evidence of intensification, and pattern-searching strategies. Nevertheless, identifying the intensity of use of specific species by ancient groups is central to investigations into human-plant relationships, and is also of prime importance in investigations into the intensification of production (DeMoulins 1997; Harlan 1967, 1989; Hillman 1973, 1981).

In order to investigate the intensification of production several other variables, qualitative as well as quantitative, need to be considered in addition to the species composition of archaeobotanical assemblages, and the intensity of species selection: i) the role(s) of the plant(s) in question within the overall production system; ii) whether the energy investments are sufficient to increase production; iii) whether production is significantly changed by these energy investments, quantitatively and qualitatively. To effectively address these questions, consideration must be given to all plants within a group's economy. Detailed nutritional, biological and ecological studies of the species in question are needed in order to understand the food and nutritional potential of each species, as well as how it responds to routine predation by humans. Studies that have aimed to address some of these issues are summarized below.

Although it is not aimed at discussing intensification, Takahashi and Hoysoya's (2002) paper on Jomon acorn exploitation provides an excellent analysis of the
transformative processes involved. These authors attribute the emergence of delayedreturn systems during the Jomon to increasing labour demands, as well as a need for rigid seasonal scheduling, required to harvest, process and preserve acorns. They argue that throughout time, Jomon hunter-gatherers invested increasing amounts of labour, technology and knowledge into acorn exploitation; these investments entailed acorn harvesting, processing and preservation as well as the construction of acorn processing and preservation features. Takahashi and Hoysoya base their argument on archaeological and archaeobotanical data: sequential temporal increases in acorn storage pits, deep clay pots, and wooden water-pooling features that have been interpreted as acorn acid removal facilities, as well as large numbers of acorns recovered in situ in processing and storage features. They also observe that the Jomon located their acorn processing and storage sites and residences in proximity to each other. This suggests that sedentism or at least semi-sedentism occurred in tandem with a concentration of production on acorn exploitation. They further point out that the narrow season of availability of acorns probably necessitated the reorganization of the labour force, possibly involving communal involvement to optimize efficiency. These authors convincingly argue that the need to concentrate labour in specific places and at specific times to obtain and process acorns, was a critical factor in the reduction of logistic and residential mobility that occurred during the Jomon.

# Archaeobotanical investigations of hunter-gatherer intensification in the study area

In Southwest Asia agricultural intensification is more easily identified archaeologically than in hunter-gatherer subsistence because Neolithic and later sites are easier to locate than Epipalaeolithic sites; and because, throughout the Neolithic, there were sequential increases in activities that create and preserve plant remains (Colledge 2001; De Moulins: 1997).

Barlow and Heck (2002) proposed a persuasive, testable optimal-foraging model for Natufian intensification based on cost/benefit expectations about acorn and cereal exploitation, the natural distribution of cereals and acorns in the Levant, and the necessary harvesting, transport and processing investments. They constructed this model after consulting published reports on experimental harvesting and processing of acorns and cereals, which they used to estimate return rates (kcal/h). In addition they considered the distribution of acorn and cereal habitats throughout the Levant during the Late Epipalaeolithic (based on the reconstructions of Hillman 1996, discussed in Chapter 2 this volume) as well as the locations of Natufian residential sites within those habitats. They also calculated the costs of transporting acorns and cereals from varying distance of origin back to residential sites.

Barlow and Heck (2002) argue that Natufian subsistence-settlement systems were transformed through the development of the acorn and cereal food production systems: that the locations of Natufian residential and specialized processing sites, and the intensity of use of those sites were decided by the requirements of acorn and cereal exploitation systems. Their model proposes that where large acorns are available, they would be ranked higher than cereals, and that cereals would be included or excluded from the diet depending on the availability of acorns and other high-ranked foods. They argue that Natufian groups living in the interior steppe and woodland zones exploited both cereals and acorns, but that cereal and acorn harvesting and processing would have been carried out in different settings. They further propose that Natufian groups situated their residences closer to the grassland habitats so that cereals, which ripen at different times, could be routinely collected, and either processed at their place of harvest or transported to the residences for processing; while acorns, which ripen simultaneously and over a shorter time period would be collected on scheduled seasonal excursions to the more distant park or woodland habitats, and processed at specialised sites adjacent at their collection places. In this case, the high productivity of the large oaks would have necessitated specialised processing sites.

Barlow and Heck (2002) also argue that because Mediterranean maquis oaks produce smaller acorns than inland species, in coastal environments acorn productivity would have been similar to that of cereals. In this case would therefore be more expedient for people to transport acorn harvests back to the residence for processing, rather than constructing specialized processing sites beside acorn groves. Barlow and Heck predicted that residential sites found in Mediterranean maquis areas would contain evidence of both acorn and cereal processing, e.g. a variety of plant processing systems. They further propose that residential sites found in inland regions would contain fewer plant processing systems, with specialized processing sites located closer to the cereal and acorn collection sites.

The least convincing part of Barlow and Heck's argument is their assertion that acorns would be higher-ranked based on the basis of costs/benefits because in fact they report that acorns and wild cereals that are indigenous to Southwest Asia provide similar return rates, approximately 866 - 1335 kcal/h. Other aspects of Barlow and Heck's (2002) argument is supported by the fact that hunter-gatherer nut exploitation, particularly acorns, is well documented, both archaeologically and ethnographically throughout the temperate zones (Mason 1995; Takahashi and Hoysoya 2002; Wohlgemuth 2002). At present there is insufficient archaeobotanical data on Natufian acorn eating to test Barlow and Heck's (2002) model (see Chapter 2 for a discussion of the lack of archaeobotanical evidence from Natufian sites). Furthermore, as observed

by Barlow and Heck themselves, more information is needed about other edible resources that were important in Natufian economies, which would have varied according to local habitat conditions.

# 3.5. FOOD PROCESSING AS INTENSIFICATION

In this section, the ways in which food processing promotes increased abundance and how the development of post-harvest systems could bring about the intensification of production are discussed. Two descriptive models are presented. The first shows how investments in post-harvest systems drive the intensification of production. The second model shows the potential effects of post-harvest intensification on resource selection under conditions of resource abundance and resource scarcity or decline.

As was discussed earlier (in see section 3.2. above), archaeological models of intensification typically classify food processing, preservation and storage as *measures* of intensification, surpluses, wealth and sometimes social stratification, rather than as intensification itself; or processing is grouped with *food consumption*; or else it is considered *costly* because it uses more energy than it provides and/or promotes losses of nutrients, thus lowering the amount obtained. However, in the following sections I put forward an alternative view: that food processing is more than just a measure of intensification; that it *is* intensification because it facilitates "...the extraction of energy [and other critical nutrients] out of existing resources...more intensive use of the hunted [animals and harvested plant] species" Bar-Oz *et al.* (1999:77). In other words: processing is not always costly when considered in terms of the gains that may be achieved (Peacock 1998; Speth 2001, 2004; Stahl 1989; Yen 1975, 1980)

### 3.5.1. Desirable and undesirable changes in foods due to processing

The amount of nutrients that a group obtains from a plant food is influenced by many factors, including how the plant is grown, how it is harvested, and post-harvest treatments. The intake of nutrients is also determined by the group's eating habits, such as how often they eat that plant, in what quantities, and also what other foods they eat with it (Wills *et al.* 1998). Indeed post-harvest treatments, such as washing, peeling, boiling, milling and drying, heat and oxidation, can cause the loss and degradation of proteins and amino acids, lipids, carbohydrates, vitamins and minerals as well as the degradation of colour, flavour and texture (Anese and Nicoli 2001; Taokis and Labuza 1996: 1014). However, these types of losses can be offset by improvements in biological and technical knowledge of the resources in question, and improvements in processing technology (Wills *et al.* 1998).

In the western world today, the effects of processing that are probably of the most concern are those associated with high glycaemic index (GI) foods. The GI is a measure of the effect of a food on the body according to the incremental blood glucose response that it produces (Ellis *et al.* 1996; Truswell 1992). Studies show that high GI diets are linked to diabetes, obesity and heart disease. While numerous food-related factors influence blood glucose, processing (*e.g.* milling) is a major factor. For example, wheat breads are high GI foods but intact wheat grains are low (FAB 2004).

Ultimately, the advantages of processing are greater than the disadvantages because processing makes available a wider variety of nutrients, greater amounts of nutrients, and more stable and safer foods (Anese and Nicoli 2001). For example legumes, low GI foods which are high in proteins but contain mildly toxic and antinutritional substances that are difficult for humans to digest, can be detoxified by soaking and cooking (Hultin and Milner 1978). During consumption many types of raw plant food tissue, such as raw almond and raw carrot, largely pass along the gastrointestinal tract without releasing their nutrients (Ellis *et al.* 2004; Stahl *et al.* 2002). Processing before eating can help to release energy, nutrients and other important compounds (*e.g.* antioxidants) from foods (Johns 1999; Stahl *et al.* 2002). Other positive changes due to processing include ensuring wholesomeness, improving palatability and destroying undesirable compounds (Stahl *et al.* 2002).

Food processing affects the texture and taste of foods. It advantageously changes the mechanical and chemical properties of foods, making them more amenable to the mechanical abilities of the human mouth, as well as promoting their digestibility and absorption in the human gut. For example, processing promotes the digestibility of starch which is influenced by a range of variables including the particle size of the food matrix, the nature of the starch (amylose:amylopectin ratio), the type and degree of processing, and the degree of starch gelatinisation (Vincent and Lillford 1991).

Processing thus has implications for diet and health because, by releasing nutrients from the food matrix in which they are contained, processing by pulverizing, grinding, fermenting, and/or heating, promote greater bioaccessability of macronutrients (*e.g.* starch, protein and fatty acids) and micronutrients (*e.g.* vitamins, minerals *etc*) as well as and critical antioxidents such as vitamin C (Pfannhauser *et al.* 2001). Bioaccessability (the proportion of a nutrient that is released from a food matrix) is an important factor in *bioavailabilty*, which is the proportion of a food or nutrient capable of being absorbed into the human body, such that it is available for metabolic purposes or storage (Bender 1989; Ellis *et al.* 2004; Stahl *et al.* 2002; Verhagen *et al.* 2001).

Each plant or plant part has specific functional properties that work best with specific processing methods (Lyons and D'Andrea 2003). For example Chotineeranat *et al.* (2004) found that the best technique for removing the bitter properties of cassava

(*Maninot esculenta*, also known as manioc) root is grating, which results in 96% reduction in cyanide content; while slicing and chopping removed only 68% and 85% respectively. Even the order in which the stages of food processes are conducted can affect bioaccessability, *e.g.* chopping followed by stearning is usually more effective in promoting the bioavailability of nutrients in vegetables than stearning followed by chopping (Schlemmer *et al.* 2001; Tydeman *et al.* 2001). Combining ingredients by creating composite foods such as cakes, breads, stews also affects food quality. Taste, texture and bioaccessability are highly influenced by interactions with other substances such as fats, proteins, dietary fibre, lectins, tannins, saponins and enzyme inhibitors (Bender 1989; Stahl *et al.* 2002). The addition of spices or vegetable parts, for example, may facilitate the bioaccessability of some nutrients within meats and plant foods (Andersen *et al.* 2001; Konlande and Robson 1972).

### **3.5.2. Preservation and storage**

The aim of preservation and storage is to prevent spoilage: losses of both quality and quantity. In fact, based on the view that preventing loss *after* harvest provides a better return on investments of labour, energy and capital than boosting crop production, a large segment of present-day crop science is devoted to improving post-harvest systems (Burton 1982; Wills *et al.* 1998).

The principles and processes involved in preservation and storage were undoubtedly important components of prehistoric economies. Processing for conservation and storage sets the conditions for increased abundance and preservation which are necessary components of storage and also necessary for delayed-return economies (Halstead and O'Shea 1989). As noted by Testart (1988), in environments of fluctuating seasonality, storage provides a way to transform seasonally available resources into year-round staple foods. Processing and preservation increase the 148 quantity of food available by facilitating the reduction of spoilage and waste, thus improving the net yield from a given land area (Plucknett 1979: 26).

Lewis (1996:200-201) describes preservation methods as "operations involving energy transfer processes". Examples of modern energy transfer processes include: using hot water or steam to pasturize foods, which increases the shelf-life of a food by removing pathogenic micro-organisms; using hot oil to fry foods; chilling and freezing which use cold air and refrigeration to reduce temperatures; and evaporation, using steam to produce a liquid concentrate by removing water. The process of drying, which is the oldest and most widespread method of preservation, involves the removal of water by dehydration, *e.g.* applying hot air, steam or hot water.

Dehydration helps to stabilize plant tissue and to prevent the growth of microorganisms because it lowers water activity (Lewis 1996). Water activity and moisture content are not the same since water activity relates to pressure on unbound water in plant tissue while moisture represents bound water. Unbound water is vulnerable to microbes, molds and yeasts; bound water is protected by the chemical structure of the plant tissue. However, dehydration, which removes bound water, can facilitate the reduction of water activity because it promotes increased binding of the water that remains (Wills *et al.* 1998). Water activity can also be controlled by temperature reduction. Edible plants that have low water activity, such as cereals, are easily stored without the need for prior treatment. In fact it has been argued (*e.g.*Burton 1982) that in the Old World, human groups selected cereals and other grains for domestication due to their ease of preserving them.

The reduction of waste due to food processing is cost-effective because it is a "form of energy conservation" (Lewis 1996: 2000). Because preservation extends the shelf life of foods, it permits groups to extract greater quantities of seasonally available

resources from the land. In other words, preservation permits a group to extract larger amounts of energy from the land than they would if they could not conserve the harvest. The abundance that is created through the labour invested in conservation and storage can nourish a group over a longer period of time. It is curious that Yen (1975: 78-79), while recognizing that cooking and other types of food preparation represent postharvest intensification, stated that storage represents a *technological measure of intensification*, which does not increase yield per unit area, nor per capita, but spreads effective yield over time. The problem with this statement is that it fails to consider the fact that preservation and storage permit larger yields to be extracted per unit area of land. Also, the labour and technical investments of preservation are overlooked because it is assumed that once stored, foods will preserve.

Yet, there is a great deal more to the mechanics of food preservation than simply constructing a storage cupboard. The preservation potential of edible plants is subject to several variables, and can vary between specimens of the same species due to natural factors such as ripeness. Successful preservation requires knowing how to distinguish the preservation potential of edible resources, knowing the best time to harvest them, and knowing which preservation technique is the most suitable. Preservation also requires the construction of storage facilities that are capable of maintaining the plant in its preserved state (Lewis 1996; Wills *et al.* 1998).

Successful preservation and storage of edible plants begins with selection of the specimens that are most amenable to the technology at hand. It requires a biological understanding, that the detached plant organs (fruit, nuts, seeds, stems, leaves and edible roots such as tubers, bulbs and taproots) are living entities, and that each individual species requires preservation treatments that interrupt or suspend the organs' normal biological functions (Coursey and Booth 1977; Lee and Kader 2000; Wills *et al.* 

1998). Accordingly, the preservation requirements of fleshy fruit are not the same as those of edible roots such as bulbs, corms, taproots and tubers. But in all cases, successful preservation requires knowledge of the biological properties and growth habits of the edible plant part. Preservation requires the knowledge and technology needed to slow an individual plant organs' metabolism to prevent maturation and spoilage, to maintain the organ in that metabolic state, and to prevent physical damage as well as spoilage by diseases and pests. To enhance the stability and shelf life of fresh fruit and vegetables, it is necessary to keep them under controlled environmental conditions that facilitate the slowing of their respiration rate, *e.g.* a cool and wellventilated environment (Sanz 2005; Wills *et al.* 1998).

The successful preservation of fleshy fruits entails understanding that, during the stages of physiological development they are at their highest metabolic activity, having a high respiration rate. At maturation (ripening) senescence begins, which is the period when the tissue begins to degrade. Metabolic activity, maturation and senescence continue whether or not the fruit is still attached to the parent plant. After the fruit is separated from the parent plant it continues to respire and transpire (losing water), using up energy and moisture reserves that were previously replenished by the mother plant. Once the fruit is separated from the parent from the parent plant chemical changes escalate e.g. carbohydrates change to sugars. To preserve fleshy fruit in the fresh state, post-harvest treatment is aimed a slowing down senescence from the time that the fruit is picked until it is eaten; it involves keeping the fruit under modified environmental conditions to reduce transpiration and respiration (Hardman 1989; Lee and Kader 2000; Wills *et al.* 1998; Sanz 2005).

A useful example of the links between species selection and choice of processing technique for preservation, is provided by Turner (1997 and pers. comm.

1996) in her description of the harvesting and preservation of the fleshy fruit of saskatoon (*Amelanchier alnifolia*) by Interior Salish groups in British Columbia, Canada. This berry, which is actually a very small pome in botanical terms, was the most important fruit for hunter-gatherer groups living on the British Columbia Plateau. Native people collected Saskatoon berries of different stages of ripeness to use for different food purposes. Turner (1997) reports that the classification schemes that Interior Salish groups use for saskatoon plants are more complex and detailed than that of taxonomists. These classification systems are based on the ripeness, food value and preservation potential of the fruit, as well as the biological and ecological factors that influenced their functional properties (during processing).

"On the basis of habitat, blooming and ripening time, growth form, and size, colour, seediness and taste of the berries, they distinguished many varieties, each with its own particular advantages and disadvantages as food" (Turner 1997: 140).

Saskatoon berries that were at optimum ripeness, having a high water content and therefore being firm, with a crisp texture, were spread on mats and dried individually like raisins. Whole dried berries of this type were used as snacks and to flavour and sweeten other dishes (see also Turner 1992 and Turner *et al.* 1990). Berries that were over-ripe, and therefore softer, were mashed, boiled and kneaded into cakes which were dried over a fire or in the sun. Saskatoon juice was sometimes collected separately and added to the drying cakes or to other foods. Dried cakes provided raw snacks, and were also re-constituted and eaten as a sweet, or mixed into meat stews.

Unlike fleshy fruit, the successfully preservation and storage of edible roots requires harvesting them during dormancy, when they are at their lowest metabolic rate, and maintaining and prolonging the dormant state (Coursey and Booth 1977; Wills *et al.* 1998). For this reason the storage life of root foods is usually longer than that of fresh

fruit. The successful preservation of edible roots begins with understanding that these plant parts are storage organs which contain and maintain energy reserves for the entire plant (*e.g.* carbohydrates such as starch) throughout the different seasons. Prior to the dormant season storage organs collect and conserve energy for shoot growth and propagation during the next years' growing season. During dormancy the metabolic activity of the storage organ slows, providing low but adequate levels of energy to maintain life in the cells of the storage tissues until the growing season resumes.

Once preserved, plant foods require appropriate conservation environments, *i.e.* storage conditions that inhibit maturation and spoilage, such as controlled temperatures, a regulated flow of oxygen, protection from moisture, and also protection from pests and micro-organisms (Taokis and Labuza 1996; Wills *et al.* 1989). Adequate storage of dried foods, for example, requires conditions that prevent hydration and/or rehydration and deter pests. Adequate storage of fresh produce entails the reduction of temperatures, in some cases to just above freezing (3°C), which keeps metabolic processes slow and reduces microbial growth (Wills *et al.* 1998).

Altogether these points demonstrate that a shift towards a delayed-return system is feasible only when a post-harvest system is in place. Moreover, the development of a post-harvest system entails investments of labour, technology and knowledge: the types of knowledge include an understanding of the food processing potential of specific tools and techniques and an understanding of the biological and functional properties of the edible resources in question. Thus an economy that relies on stored foods must have an effective post-harvest system, comprised of effective preservation and storage techniques. Support for this argument is provided by Suttles (1968) in his studies of Northwest Coast subsistence, who argued that the potential presented by a resources' abundance, and the length of time that it is available (window of opportunity) are limited only by peoples' capacity to store that resource. Hayden (1992) likewise observed that large-scale storage is dependent on people having the ability and technology for mass harvesting, as well as the technology for conservation and storing.

### 3.6. SCHEMATIC MODEL OF FOOD PROCESSING INTENSIFICATION

The argument that underpins this thesis is that developments of post-harvest systems are tantamount to the intensification of production in cases where they promote the transformation of the production systems. The terms post-harvest intensification and food processing intensification, as I am using them here, accord with Brookfield's (1972: 2001) definition of intensification in that they encompass increased labour inputs that permit the extraction of greater amounts of edible product, and more metabolisable energy and nutrients from particular plants; and therefore results in the extraction of greater amounts of edible products, metabolisable energy and nutrients from a patch of land. If a species is found to be amenable to food processing intensification, the group may be able to make more frequent use of it, and possibly other resources in that habitat, and hence make possible a greater concentration of production. The concentration of labour implies revisiting the same place on a regular basis and therefore the group will develop ecological knowledge of that area/habitat. It also implies that the habitat may change as a result of human disturbance, tending and/or weeding. If any tending or weeding of plants took place, it may also lead to a perceived ownership of certain resources.

Furthermore food processing intensification can set the conditions for incorporating into the human diet a wider variety of plants or plant parts, animals and animal parts (diversification) e.g. species that were previously considered of low rank, inedible, non-palatable or toxic. Likewise, the group may be able to extract more food

value from species that are already part of the economy, thus increasing production without changing the resource base. A group may add or reject a potential food according to whether or not its functional properties interact favourably with the technology that is available to them (see Bar-Oz and Dayan 1999; Leach 1999b; Lyons and D'Andrea 2003; Stahl 1989; Yen 1980). Accordingly, Stahl (1989: 171) has argued that archaeologists should regard processing "...as an independent variable in our attempts to model the subsistence decisions made by prehistoric populations."

Thus, post-harvest systems can promote increased abundance in four ways:

- i) permitting a wider variety of plant species and/or plant parts to be added to the diet;
- ii) transforming a single plant part into several forms of food;
- iii) producing physical or chemical changes that improve the nutrient value and/or nutrient availability;
- iv) promoting preservation, thus reducing spoilage and permitting a group to harvest greater quantities of seasonally-available resources.

However, by definition the intensification of production is more than just increase (Morrison 1994, 1996). Rather, it describes a transformation of the overall productive system because the increasing energy inputs that are associated with increased production will necessitate a re-organisation of the system (Brookfield 1972). I propose that the development of post-harvest systems accords with the definition of intensification of production in cases where post-harvest systems drive increased production and a necessary re-organisation of the overall production system.

A schematic model is shown in Figure 3.3 to illustrate how a post-harvest system can affect an existing hunter-gatherer system and promote the transformation of



Figure 3.3 Schematic model to illustrate the development of a post-harvest system. The model illustrates a new production system emerging from an existing (former) system. The comonents of the emerging system are shown in green. The components and parameters of the former system are indicated in yellow. The grey arrow symbolises increasing energy inputs, in the form of increasing labour, technology and knowldege, and points to the energy threshold, the place (in time and space) where the post-harvest system emerges. The heavy black arrow symbolises the transformative effect of the emerging post-harvest system on the production system. The individual components form new configurations in relation to each other. Also, new components appear in the emerging system, including storage, specialisation, diversification, as well as new criteria for species selection. As a result of these changes, the emerging system is developing a different shape to the former system; and it may occupy a different space, although it is historically rooted in the former system.

a production system. In the model the increasing energy inputs (shown by the grey arrow) culminate at the energy threshold, which is the point in time and space where increasing energy inputs lead to increased production and the emergence of a new system, in this case the post-harvest system. The black solid arrow indicates the emerging post-harvest system affecting other parts of the production system. This reorganisation of the production system is necessary to fit in post-harvest activities, technology and knowledge, as well as other associated components, such as specialisation, diversification and storage.

In Figure 3.3 the parameters of the existing or former system are shown in yellow while those of the emerging system are shown in green. By overlapping the new system with the edge of the old system, the model aims to show that the emerging system is historically connected to the existing one. Likewise, historical contingency is suggested by the fact that all the components that existed in the old system also exist in the new system. However the emerging system has some new components including storage, diversification and specialisation.

Based on the view that in non-mechanised societies, such as those discussed in this study, energy inputs will be borne by the labour force (Stone 2001), intensification begins in Figure 3.3 with increasing energy inputs, indicated by the grey arrow at the top of the sphere. In this model, the increasing energy investments include the labour, technology and knowledge required to successfully carry out post-harvest activities.

Increasing labour inputs may be in the form of individuals doing more work, and/or more individuals working. As observed by Stone *et al.* (1990: 7-8), labour is context-related, as are the cost-benefits of increased production: labour and production operate within specific environmental and cultural constraints that include seasons, rainfall, soils, and the biological characteristics and growing habits of the resources that

are being intensified, as well as the socio-political structure of the group. Moreover, the labour force may be divided by age groups or gender, and include varying numbers of people, from single individuals, to households, neighbouring groups, alliance groups, exchange groups, *etc.* (This model does not deal with a specific group or the specific environmental, social and political conditions within which the labour force is embedded. Therefore, for the sake of simplicity, in this scheme social relations, belief systems, gender and demographics are depicted as individual components rather than as integral parts of all components.)

Changes in labour organisation will necessitate different demands on individuals, and possible changes in power dynamics, factors that might involve shifts in socio-political relations, *e.g.* status, and age or gender roles. Certainly the development of conservation and storage raises issues such as who controls the stored goods, who decides how and when stored goods are to be used, and who decides how much is allotted to individual members of the group, relatives, allies and trade partners. It also raises issues about how post-harvest production is integrated into the sociopolitical and belief systems.

New technology, technological innovation and/or new ways of using existing technology, and investments in the construction and repair of technological material culture can promote intensification (following Brookfield 1972). Increasing knowledge may be in the form of new ways of managing labour organisation, and/or increasing investments in ecological and/or technological knowledge, *e.g.* improved monitoring of edible resources and improved techniques of minimising loss of harvested crops. Moreover, the development of a post-harvest system is likely to promote changes to species selection. Previously ignored/avoided species or parts of species previously used for other, non-food economic purposes, could be added to the diet as a result of the

group's newfound ability to process them (see Leach 1999a; Lyons and D'Andrea 2003). Alternatively, improvements in post-harvest techniques might permit a more intensive exploitation of a narrow range of preferred species. Within-species selection may also be influenced by concerns about preventing loss after harvesting. Specimens may be chosen or rejected because they have specific characteristics which will enable them to better preserve and/or better survive processes such as washing, peeling, boiling, milling and drying, *e.g.* degree of ripeness, size, lack of bruising (Turner 1992, 1997; Wills *et al.* 1998).

Whether intensification facilitates resource diversification or specialisation depend on interactions of ecological and socio-political factors. Figure 3.4 illustrates how selection might differ under conditions of abundance and conditions of resource scarcity or decline. In both cases the goals of intensification are the same: "the substitution [of labour] for land, so as to gain more production from a given area, use it more frequently, and hence, make possible a greater concentration of production" (Brookfield 1972: 31). Also in both cases, food processing provides the means to achieve increased abundance. But the factors that drive groups to intensify are different under conditions of abundance and conditions of resource scarcity/decline. The types of resources intensified would also be expected to differ.

In the first situation, which occurs under conditions of abundance, intensification is driven by social and/or political pressures, *e.g.* demands for surplus production or to meet trade obligations. Innovations in food processing provide opportunities to meet those demands. Under conditions of abundance both resource specialisation and diversification are possible. But intensification to meet social/political/trade demand would be expected to encompass the increased production of a narrow range of high-ranked, preferred species (specialisation). In the second



Figure 3.4. Schematic model showing how resource selection is expected to differ when driven by different pressures and incentives to intensify.

situation, which occurs under conditions of resource scarcity/decline, intensification is driven the need to meet subsistence requirements, and innovations in food processing provide opportunities to meet those needs. Under these conditions a trend towards resource specialisation is unlikely, and the groups would be expected to increase the diversity of its resource base by making more frequent use of low-ranked and previously ignored species. In both situations increasing energy inputs (labour, technology, knowledge) are necessary to achieve an increased production of edible products, and both it will be necessary to make organisational changes in the overall production system to accommodate post-harvest systems.

Returning to Figure 3.3, other components of the system that are most immediately affected by shifts in resource selection are land use and scheduling. Changes to these components would affect other components, including patterns of mobility-settlement, labour organisation, demographics and social relations. Changes in land use may entail a group making heavier and/or more frequent use of previously exploited patches within their territory, and/or the exploiting of previously unused patches. In other words, it entails the concentration of production within those patches, and the necessary revisiting of them on a regular basis. As a result, group members will develop ecological knowledge of those patches; habitat conditions will possibly be altered by human predation, tending and/or weeding. If the group invests in tending, weeding, irrigation or other activities that enhance the resources in that patch and/or create landesque capital, they may claim ownership of it.

Changes in species selection and land use may influence decisions about resource scheduling, *i.e.* where and when the group locates its members over the landscape. Scheduling demands, such as the timing of harvesting and post-harvest treatments, may further necessitate changes in labour organisation, *e.g.* members may separate into smaller task groups to take advantages of simultaneously occurring 'windows of opportunity'. Or separate groups may join up for periods of time, or permanently, to provide a larger pool of labour.

### **3.7. CHAPTER III SUMMARY**

In this chapter it was explained how post-harvest systems, encompassing food processing, preservation and conservation, are tantamount to the intensification of production when they promote abundance and lead to transformations of production systems. The intensification of production is defined as a process wherein a group achieves greater effectiveness in their subsistence practices due to their obtaining more productivity from each unit area of land exploited (Boserup 1965: Brookfield 1972). Food processing was shown to increase production in four ways: i) by permitting a wider variety of plant species and/or plant parts to be added to the diet, e.g. species that, in the raw form, are toxic or too hard for the mechanics of the human; ii) by transforming a single plant part into several forms of food with different textures and tastes; iii) by producing physical or chemical changes that improve the palatability, nutrient value and/or nutrient availability; and iv) by promoting preservation thus reducing spoilage and loss, permitting a group to harvest greater quantities of seasonally available resources than they would for immediate-return purposes, for the purpose of sustaining the group during periods of resource shortages. Post-harvest intensification was shown to entail more than simply increased abundance. It encompasses a transformation of the entire production system. Moreover, it was argued that the shift to a delayed-return economy would only be possible in cases where a group had an established post-harvest system.

# CHAPTER IV. THE STUDY PLANT, Bolboschoenus maritimus (L.) Palla

This chapter reviews the archaeological and biological literature on sea clubrush (SCR), with a focus on characteristics that are relevant to the research questions. It summarises the archaeological evidence for human uses of SCR during the Late Pleistocene, outlines the biological and ecological characteristics that might limit or promote the potential of SCR for intensification; and addresses questions about the effects of environmental fluctuations, human disturbance, predation and the potential of SCR to be managed. Subsequently ethnographically reported uses of SCR by human groups are outlined.

### **4.1. INTRODUCTION**

*Bolboschoenus maritimus* (L.) Palla, also known as *Scirpus maritimus* L., is a semi-aquatic perennial of the sedge (Cyperaceae) family. SCR is classified as a *helophyte*, which describes a semi-aquatic plant in which the perennating (vegetatively reproductive/storage) organs, tubers, rhizomes and rootlets, lie in soil or mud below the water level, while the aerial shoots (stems, leaves, florets) protrude above the water (Allaby 1992: 192). SCR is a *clonal* species, reproducing and expanding through its underground network of rhizomes and tubers. Like other Cyperaceae, SCR shares a number of morphological similarities with rushes (Juncaceae) and grasses (Poaceae), having solitary stems (culms), grass like, elongated leaves, and small brownish flowers in the form of spikelets or panicles (Figure 4.1) (Davis 1985; Townsend and Guest 1985).

In accordance with recent taxonomic developments, the nomenclature Bolboschoenus maritimus has become accepted worldwide, although many researchers



Figure 4.1. *B. maritimus.* (a) plant; (b) tuberous stem base; (c) junction of leaf-sheath and blade with stem; (d) leaf tip; (e) spikelet; (f) glume; (g) flower; (h) nutlet, filaments and hypogynous bristles (from Townsend and Guest 1985, page 377, Plate 87).

continue to use nomenclature *Scirpus maritimus*. Following the systematic texts of Southwest Asia, the *Flora of Turkey* (Davis 1985) and the *Flora of Iraq* (Townsend and Guest 1985), in the present study SCR is classified as *Bolboschoenus maritimus*. The genus name *Bolboschoenus* describes a group of tuberous bulrushes. It comes from the Greek words *bolbos*, meaning bulb and *schoinos*, meaning rush-like plant (Townsend and Guest 1985). The species name, *maritimus*, which means "growing by the sea", is due to the fact that in Western Europe this plant is frequently found in coastal areas (Stern 1998). The common name *club-rush* refers to the shape of the flowers (Parish *et al.* 1996: 353). Among the other common names are: alkali bulrush, bayonet grass, perennial nutsedge, prairie bulrush, purua grass, saltmarsh bulrush, seacoast bulrush, and tule (Kantrud 1996).

# **4.2. THE ARCHAEOLOGICAL DISTRIBUTION OF SEA CLUB-RUSH THROUGHOUT EPIPALAEOLITHIC SITES OF SOUTHWEST ASIA**

SCR was selected from among the plants recovered from Epipalaeolithic contexts because it is widespread at early sites throughout the study area (Figure 1.1) and its occurrence has significant time depth, extending from at least the Early Epipalaeolithic into the Neolithic (Table 4.1). The present-day distribution of SCR includes the entire study area except the Negev and Sinai (see Townsend and Guest 1985). It is likely that SCR was similarly widely distributed Middle Epipalaeolithic, when conditions had become more favourable for C3 plants. SCR seeds and tubers are absent from sites the southern Levant although this region is within the SCR distribution range (see Townsend and Guest 1985), a pattern that may be due to taxonomic problems (see section 4.3.) and/or the fact that non-seed, non-wood archaeobotanical materials are rarely identified. Colledge (2001) reported that

**Table 4.1.** Late Pleistocene and early Holocene sites in Southwest Asia where the tubers and seeds of *Bolboschoenus maritimus/ Scirpus maritmus* and/or other *Scirpus* species have been found.<sup>1,2</sup> *Scirpus* other than SCR are included here to account for possible misidentifications due to taxonomic problems

Early Epipal. Late Epipal. PPNA	PPNB	PN
23,000 <sup>14</sup> C yr BP	iting of all the solutions	7,430 <sup>4</sup> C yr BP cal
Bolboschoenus maritimus/ Scirpus maritimu	S	eely and all of the
Abu Hureyra I (S)	Abu Hureyra IIA, IIB (S) Ali Kosh (S) Asikli Höyük (S)	Abu Hureyra IIC (S)
	Tel Aswad (S) Bouquras (S)	Tel Aswad (S)
Hallan Cemi (S)	1	
Mureybit I, II, III (S)	Mureybit IV (S)	
Cayönü Ia (S)	Cayönü Ib,c,d (S) Can Hassan III (S)	Cayönü II (S)
	Catalhöyük (T) (S)	Catalhöyük (T) (S)
	Ganj Dareh Tepe (S) Ghoraife (S)	Erbaba (S)
	Tell Ramad (S) Tell Ras Shamra (S)	

### Scirpus maritimus Type

Wadi Kubbaniya (T) (S)

### Scirpus littorialis

Ohalo II (S)

Scirpus spp.

#### Azraq 31 (S)

El Kowm II (S) Magzalia (S) Duweila (S)

Magzalia (S) Nabata Playa, Egypt (T)

Öküzini I – IV (T?) (S)

Tepe Abdul Hosein (S)

Wadi Jilat 13 (S)

### $^{1}(T) = Tubers, (S) = Seeds$

<sup>2</sup>**Reference:** Colledge 2001; Hather 1995; Hillman, Madeyska and Hather 1989; Martinoli and Jacomet 2004a; and the database compiled as part of AHRB/C funded project, based at the Institute of Archaeology, UCL (2001-4): 'The origin and spread of Neolithic plant economies in the Near East and Europe' (PIs: Professor Stephen Shennan and Dr James Conolly; RA: Dr Sue Colledge).

unspecified vegetative tissue has been recovered but not identified from a number of late Natufian, aceramic Neolithic and Neolithic sites within the southern Levant.

SCR seeds are more commonly recovered than tubers, a pattern that may more about archaeobotanical sampling and the fragility of archaeobotanical tuber tissue than prehistoric plant-use. Until recently archaeobotanical studies rarely included the analysis of non-wood vegetative tissue. Yet recent studies, pioneered by Hather (1993, 2000), and including Kubiak-Martens (2002), Perry (1999) and Wollstonecroft (2002), have been successful in the recovery and identification of archeological parenchyma.

Vegetative tissue is more vulnerable to destructive depositional and taphonomic processes than seeds, and is also more prone to fragmentation when exposed to most archaeological recovery methods *e.g.* wet sieving (Hather 1993).

"Remains of vegetative plant tissue have a greatly reduced chance of being preserved in the archaeological record compared with those of seeds, nutshells, or the stony endocarps of many fruits. This is to a certain extent due to the fact that soft tissues are often rich in water or oil and are therefore very susceptible to damage when exposed to fire, and later to fragmentation during the period of their incorporation into archaeological deposits and during the process of recovery from archaeological sites. Another reason is that many vegetative plan parts (especially leaves and young shoots) were collected for immediate use and were not stored, and their preparation for consumption involved little (or no) contact with fire. Finally these remains, if recovered are often not recognised as such, and furthermore are difficult to recognise" (Kubiak-Martens 2002: 23).

SCR seeds are not included in the case study. Nevertheless the presence of SCR seeds in Late Pleistocene/Early Holocene sites is of relevance because it suggests that hunter-gatherer groups of Southwest Asia used this plant. Table 4.1 summarises the occurrence of SCR seeds and/or tubers at Late Pleistocene and Early Holocene sites. To account for possible taxonomic problems that may have obscured the visibility of SCR, sites where other species of *Scirpus* have been recovered are also listed in Table 4.1.

### 4.2.1. Late Pleistocene/Early Holocene archaeobotanical evidence of SCR

The earliest, and only direct evidence of human groups eating SCR seeds, and possibly the tubers, was recovered from three Upper Palaeolithic sites at Wadi Kubbaniya, on the Nile River in northern Egypt (Figures 4.2 and 4.2.). At this site Hillman, Madeyska and Hather (1989) identified the seeds of *Scirpus maritimus* (Figure 4.3.) from specimens found embedded in a fragment of charred human coprolite. They inferred that the seeds had been roasted prior to eating.

They also identified SCR-Type tuber tissue (*Scirpus maritimus* Type) and that of another sedge, *Cyperus rotundus* L., from charred fragments of vegetative tissue found at Wadi Kubbaniya (Figure 4.2). Fragments of charred tissue were recognised as stem tuber (rhizome tuber, see below) tissue from several anatomical and morphological features including: the randomly placed vascular strands, the position of the buds and rhizome attachments, and the overall external shape. Fragments of a *Scirpus maritimus*-Type were subsequently distinguished from those of *C. rotundus* based on differences in size, details in external morphology and internal anatomy.

"One sizeable piece of parenchymatous tissue was isolated which clearly originated from a tuber-like organ larger than all the others represented in the remains. Apart from its size, the fragment had two major features which identified it as of the Scirpus maritimus type rather than Cyperus. First, despite their poor preservation, the scars left by the detached rhizomes are much larger than equivalent scars on any of the other tuber remains and match the relatively thick rhizomes of Scirpus rather than the thin, wiry rhizomes of Cyperus rotundus and C. esculentus. Second, the distribution of the numerous scars of adventitious roots resembles that found in Scirpus rather than in Cyperus species" (Hillman, Madeyska and Hather 1989: 239).

SCR seeds have been recovered from other late Epipalaeolithic sites in the Middle Euphrates as well as sites in the Eastern Taurus regions. Savard *et al.* (2006) report that SCR dominates the seed assemblages of Late Epipalaeolithic and PPNA



**Figure 4.2.** *Scirpus maritimus* type: archaeological tuber fragment recovered from the Late Pleistocene sites of Wadi Kubbaniya, Egypt (from Hillman, Madeyska and Hather 1989, page 192, Figure 7.13).



**Figure 4.3.** Nutlets of *S. maritimus* type embedded in charred fecal material recovered at the Late Pleistocene Site E-81-1 at Wadi Kubbaniya (from Hillman, Madeyska and Hather 1989, page 197, Figure 7.17).

contexts of Hallan Cemi and Demirköy in the eastern Taurus. Given that the seeds are so highly represented, in both ubiquity and relative proportions, Savard *et al.* (2006) argue that SCR was a staple food of these early villagers (*i.e.* constituting a significant percentage of the total diet in terms of energy and/or other critical nutrients, see Clarke 1988 and Wills *et al.* 1998).

Archaeobotanical evidence from the Middle Euphrates suggests that SCR seeds were also heavily exploited in that region. Hillman *et al.* (2001) reported that at the site of Abu Hureyra, the seeds of SCR and the Euphrates knotgrass (*Polygonum corrigioloides*) maintained high frequencies in archaeological levels that represent temporal periods that correspond with the Younger Dryas climate period (see Chapter II for a summary of trends in climate and vegetation in Southwest Asia throughout the Late Pleistocene and Early Holocene). All other edible plants declined steeply in archaeological levels of the site that correspond with this the Younger Dryas. Hillman *et al.* (2001) attribute the continued abundance of these two valley-bottom species during this climate period to high river levels and regular seasonal flooding due to high discharges of sediments into the river headwaters.

SCR seeds have also been recovered in large amounts from Neolithic contexts on the Anatolian plateau, including Hacilar, Asikli Höyük; and Çayönü (see Helbaek 1970; van Zeist and de Roller 1991 – 1992, and 1995). Of note is the Neolithic site of Çatalhöyük where both the tubers and seeds of SCR are found in significantly high frequencies (Asouti *et al.* 1999; Fairbairn *et al.* 2002; Hastorf *et al.* 2000). However, whether the charred *B. maritimus* seeds at Çatalhöyük represent the remains of human food or else animal dung burnt as fuel, remains in question (Fairbairn *et al.* 2002).

### 4.2.2. Problems with identifying SCR intensification

With few exceptions, *e.g.* Hillman (1996, 2001), Hillman, Madeyska and Hather (1989), Savard *et al.* (2006) archaeobotanists have shown little interest in the seeds of SCR and other wild plants which they typically classified as "weedy species". Questions about the role of SCR in Epipalaeolithic economies are hampered by the fact that most scholarly reports on the archaeobotanical assemblages do not include information on contextual origins of SCR seeds and tubers included (*e.g.* van Zeist and Bakker-Heeres 1986; van Zeist and de Roller 1995). While the temporal (stratigraphic) layer in which individual species were deposited is usually reported, the spatial (horizontal) relationship(s) between associated plants, archaeological features and artifacts are rarely explained. Consequently, it is not possible to discern the patterning of SCR among the different temporal layers, *i.e.* within and between features. Nor is it possible to understand the spatial relationships between SCR and other plants.

Our understanding of the possible economic uses of SCR, and its potential for intensification are further hindered by problems in the ethnographic sources, including errors in species identification (discussed in section 4.5.), and the fact that the ethnographic record is incomplete. In many cases it is not clear which species of sedge was eaten, at what stage of their development they were collected (immature, ripe, overripe), and how they were consumed (raw, boiled, baked, mixed with other ingredients or eaten alone *etc*). Nor do we know if this plant is worthwhile harvesting in the first place, let alone intensively exploiting. These problems are partly because it is only recently that ethnobotanists and archaeologists have collaborated to design ethnoarchaeological research approaches to addressing archaeological and archaeobotanical questions (*e.g.* Erkal 1999; Ertug-Yaras 1997; Turner 1992).

Furthermore, despite the existing published ecological and biological reports on the nutrient content of SCR, its value as a human food is unknown because laboratory methods used for answering biological and environmental questions may not be adequate for answering questions pertaining to the parts of the plant that people eat, and the ways that they are eaten. Therefore the harvesting trials, nutrient assays and processing experiments, which are described in Chapters V, VI, and VII, were designed to assess whether or not this plant is worth harvesting, in terms of the nutrients and energy (kcal) obtained; how amenable it is to food processing techniques that were probably known by Epipalaeolithic groups; and whether those processing methods promoted the bioaccessability of critical nutrients, *i.e.* starch.

Questions about wild plant intensification cannot be answered by simply noting changes or increases in the numbers of certain taxa over time (see Chapter III, this volume). It is also necessary to understand how a species could feasibly have been used as food and/or for other economic or cultural non-food purposes (see section 4.10.1) and how those activities might have resulted in that plant becoming become charred and preserved in archaeological sites (or not). It is also necessary to consider other, non-economic ways that the plants could have arrived at archaeological sites, *e.g.* carried in on clothing or by animals. Finally, it is necessary to understand how the discreet ecological and biological characteristics and growth habits of a species may favour or hinder its economic usefulness. In the present case ethnographic and biological reports are available, and are summarized in the sections below.

### 4.3. Bolboschoenus maritimus (L.) Palla, PHYSICAL DESCRIPTION

*Bolboschoenus maritimus* (L.) Palla is a *helophyte*, a semi-aquatic plant in which the perennating organs, which includes rhizomes, tubers and roots, lie in soil or mud below the water level, but the aerial shoots protrude above the water (Allaby 1992: 192). The *above-ground* (aerial) parts of SCR include stems, leaves and flowers; the *below-ground* parts include rhizomes, tubers and rootlets. The *culms* (stems) are upright and solitary, triangular in cross-section, sometimes curved along the length, and typically reach 60-100 cm tall, although they can grow as high as 150 cm (Davis 1985) (Figure 4.1a). The leaves are long-sheathing, and have elongated blades that come to a point at the tip (Figure 4.1a, c, d). The inflorescence is a terminal umbel that is composed of small, reddish brown glumes that are spirally arranged into solitary spikelets of 1-2 cm in length (Figures 4.1e, f). An inflorescence may have as many as 30 spikelets, and as few as three; the flowers are hermaphrodite, with 2 - 3 stigmas (Figures 4.4 and 4.5) (Charpentier *et al.* 2000; Townsend and Guest 1985).

The fruit is a nutlet that is rich in endosperm. It is light to dark brown in colour, broadly obovoid in shape, and includes trifid specimens that are more triganous, and bifid specimens that are more lenticular (Figures 4.1g and 4.5f). Nutlets measure  $0.9 - 3.3 \times 0.5 - 2.3$  mm in length and width and weigh approximately 5.61 mg. They have smooth, waxy seed coats that prevent them from imbibing water and help them float during dispersal. Seen under high magnification, this smooth surface is composed of isodiametric cells (Clevering 1995; Davis 1985; Townsend and Guest 1985).

SCR is a *clonal* species, meaning that it forms stands of genetically identical individuals, known as *ramets*, by vegetative reproduction (Figures 4.6 and 4.7.) SCR clones reproduce and expand vegetatively through an underground network of *rhizomes* 



Figure 4.4. B. maritimus culm, leaves and inflorescence.



**Figure 4.5.** *B. maritimus* flowers and fruit (nutlet): **(a-e)** inflorescence; **(f)** nutlet (abaxial side); **(g)** transversal cross section of nutlet: ex = exocarp, m = mesocarp, en = endocarp, s = endosperm-rich seed(from Hroudová *et al.* 2001, page 14, Figure 6).



Figure 4.6. Clonal growth of *B. maritimus* (from Charpentier et al. 1998, page 109, Figure 1).



Figure 4.7. Chains of *B. maritimus* (SCR) tubers and rhizomes, collected in Pevensey Marshes, East Sussex, England.



Figure 4.8. From left to right: mature, young and old SCR tubers collected in the Pevensey Marshes.



Figure 4.9. Maturation of SCR. (a) young tubers form at the end of rhizomes; (b) as the tuber matures the outer layers darken in colour and begin to form a thickened endodermis and cortex; (c) cross section of young (left) and mature (right) tubers; (d) mature tuber; (e) older tuber.
(horizontally creeping underground stems) and *tubers* (swollen vegetative organs consisting largely of starch-bearing *parenchyma*, which is non-specialised plant tissue that performs various physiological functions) (Fahn 1990: 83; Hather 1994). This network functions as a physiologically integrated system, allowing the transport of water, mineral nutrients, carbohydrates and hormones between ramets via the rhizomes and tubers (Charpentier *et al.* 1998). Following Hather (1994), SCR tubers are classified here as perennial rhizome tubers in that they form as swollen areas at the ends of rhizomes. In SCR plants, the average between-tuber rhizome length is 4 - 12 cm but tubers may be separated by rhizomes as long as 20 cm, or else grow directly attached to larger specimens with no rhizome separation (Kantrud 1996).

In this study I classify SCR tubers into immature, mature and old (Figures 4.8. and 4.9). Immature tubers, the current seasons growth, are white in colour and soft in texture, being composed of an outer, thin epidermis, which appears as whorls of transparent leaves or scales that surround an innermost central white pith composed of parenchyma tissue. During the initial stages of development, tubers reach their maximum size, between 1 and 3 cm in diameter. Starch is absent from the parenchyma cells of immature tubers (see Chapter VII, this volume).

As the tuber matures the outer layers darken in colour and a thickened cortex and endodermis form between the epidermis and pith (Figure 4.9c, d) (Bowes 1997; Fahn 1999; Hather 1993; Sugden 1984). The innermost layer, the pith, is composed of parenchyma tissue that is interlaced by a network of vascular tissue (Hather 1993; and see Chapter VII this volume). By the time that the tuber reaches maturity, the parenchyma cells have become filled with starch granules (again, see Chapter VII, this volume). Rootlets and axillary buds, in the form of reduced leaf axils, are visible on the tuber surface (Figure 4.9). With *senescence* (advancing age, death) the entire tuber softens, the outer layers darken to almost black (Figure 4.9.e), and the pith turns a brownish colour.

# 4.4. GEOGRAPHIC DISRIBUTION AND HABITAT CHARACTERISTICS

SCR inhabits low to mid elevations throughout the temperate zones of the Northern and Southern hemispheres. It grows in Europe, the Balkans, Turkey, the Caucasus, Iran, Pakistan, Afghanistan, India, China, Malaysia, Australia, east and west tropical Africa, South Africa and North America (Tackholm and Drar 1950; Townsend and Guest 1985). Apparently it is one of the most widely distributed plants in the Northern Hemisphere (Kantrud 1996). The fact that SCR is so widely distributed is attributed to its ability to adapt to a range of soil and water conditions (Bassett 1978; Clevering 1995; Kantrud 1996), although there are arguments that this plant is in fact two distinct species which have different geographic distributions; one species being adapted to saline environments, and the another adapted to fresh water habitats (Browning *et al.* 1995; and Hroudová *et al.* 1998) (see section 4.5. on taxonomy).

SCR occurs in well-lit environments that have high summer temperatures. It grows on mud banks, and/or dry zones around saline wetlands or else partially submerged, within a wide range of saline and brackish wetlands, including: coastal saltmarshes, lagoons and pools, as well as along inland lakeshores, marshlands and backwaters (Bernasor and DeDatta 1986; Kantrud 1996; Townsend and Guest 1985). This plant is frequently found in *emergence* marshlands, habitats within the upper (*littoral*) zones of salt marshes that are periodically but not permanently submerged (Allaby 1992; Kantrud 1996). It survives well in agricultural areas, especially those that are continuously wet such as rice fields. It also colonises and thrives in areas that have

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been dredged, such as ditches and irrigation canals. SCR is reported to prefer clay sediments but grows in soil types varying from fine clay to silty loam and sand; it does not grow in rubble, boulder or stone ground (Interagency Riparian/Wetland Project, n.d.; Kantrud 1996). It is tolerant of higher levels of salt than most other *macrophytes* (large semi-aquatic plants), and occurs in salinity ranging from 0.7 to 4.6% (Bassett 1978; Clevering 1995; Lieffers and Shay 1980).

SCR typically forms homogeneous stands, but also grows in mixed reed beds alongside other macrophytes such as *Juncus*, *Typha*, *Phragmites* and other *Scirpus*. In mixed reed beds, SCR is found growing in the outer margins of the reed beds, nearest to open water (Clevering 1995), probably to avoid being shaded out by taller macrophytes such as *Phragmites* and *Typha* species.

# 4.5. TAXONOMY, NOMENCLATURE AND SPECIES IDENTIFICATION

Taxonomic pitfalls continue to hamper the study of SCR, a problem that is attributed to disagreements over species boundaries, misapplication of names, probable hybridisation, the introduction of species, and infraspecific variation (Kantrud 1996). Species misidentification is common in the ethnographic literature, a problem that may also impact on the identification of archaeobotanical species (Gordon Hillman, pers. comm. 1999). In part this is due to taxonomic problems, which are discussed below, but confusion over local uses of common names as well as linguistic errors are also contributing factors, *e.g.* in the Pacific Northwest of North America, the accurate identification of economically important sedges is hampered by the problem that: "Most sedges are simply classified [by native groups] in a general category with grasses and grass like plants" (Turner 1998: 106); or else, that groups apply the name "bulrush" to cattail and to several semi-aquatic sedges (Nancy Turner pers. comm. 1998). This problem is relatively widespread, *e.g.* Mabey (1996) reports that in England several semi-aquatic species are known by the common name "bulrush", including plants in both the sedge and Typhaceae families.

# 4.5.1. Taxonomic problems

The genus *Bolboschoenus* is distinguished from other bulrushes by morphology, anatomy and embryology, and distinctions between species and sub-species are based on differences in floral parts and fruiting structures (Browning *et al.* 1995; Hroudová *et al.* 2001). *Bolboschoenus* is distinguished by its tuberous rhizomes, pubescent floral scales, lack of ligules, and spikelets that are often greater than 1.5 cm long (Haines 2000). Nevertheless within-species variations and inter-species overlaps continue to impede the classifications of *Bolboschoenus* species and sub-species.

At different times and places SCR has been classified into one of three separate genera: *Scirpus* (*e.g.* Fernald 1950), *Schoenplectus* (*e.g.* Haines and Lye 1983; Strong 1993, 1994) and also *Bolboschoenus* (*e.g.* Browning *et al.* 1995; Hroudová and Zakravsky 1995). It is more often identified as *Scirpus* but under various species names, including *Scirpus paludosus* A. Nels, *S. cyperoides* Lamark, *S. tuberosus*, and *S. glaucus* and as a subspecies of *B. maritimus* (subsp. *maritimus* (Desf.). J. Sojak; and subsp. *tuberosus* (Desf.) T Koyama) (Browning *et al.* 1995; Hillman, Madeyska and Hather 1989; Kantrud 1996; Longchamp 2000).

To further complicate matters, the same Latin name has been applied to a number of other species, *e.g.* in Southeast Asia the name *Scirpus tuberosus* (a synonym for *S. maritimus* according to Kantrud 1996) is applied to both SCR and the edible Chinese water chestnut (*Eleocharis dulcis* (Burm. f.) Trin. ex Henschel) (*e.g.* Nadkarni 1954; Tackholm and Drar 1950; Tanaka 1976). Gott (1982) reports that in Australia, a

plant formerly known as *S. maritimus* has been reclassified into two taxa: *Scirpus medianus* V.J. Cook, Marsh, and *S. caldwellii* V.J. Cook. Both species have rhizomes and tubers, the latter plant being distinguished by its smaller size, that it inhabits saltier environments and has a wider distribution. From Gott's descriptions and photograph of these tuberous species, it is likely that they are two species of *Bolboschoenus*.

Many biologists argue that this species (*B. martimus*) is actually two morphologically similar *Bolboschoenus* that have different geographic distributions and grow under different aquatic conditions: *B. maritimus* (L.) Palla; and *B. glaucus* (Lam.) S.G. Smith (Browning *et al.* 1995; Hroudová *et al.* 1998). Hroudová *et al.* (1998) explain that *B. maritimus* inhabits saline environments while *B. glaucus* inhabits fresh water environments, typically river floodplains. These authors maintain that *B. maritimus* occurs throughout the northern regions of Europe; that both *B. maritimus* and *B. glaucus* inhabit the more southerly latitudes, *e.g.* Italy, Yugoslavia, Bulgaria and Greece; and that *B. glaucus* and is widespread in Asia and Africa.

Hroudová *et al.* (2001) have shown that *B. maritimus* and *B. glaucus* can be differentiated by the morphological characteristics of their fruit. These authors distinguish *B. maritimus* nutlets by their triangular to lenticular shape; size of approximately  $3.2 \times 2.5 \times 1.4$  mm in length, width and thickness respectively; and relatively thick exocarp and proportionately narrow bands of mesocarp and endocarp (Figure 4.10a). They further distinguish *B. glaucus* by the triangular nutlet, which is smaller than that of *B. maritimus*, measuring  $2.3 \times 1.5 \times 1.00$  mm in length, width and thickness respectively; and the pericarp with a thick mesocarp situated between the proportionately narrow exocarp and endocarp (Figure 4.10b). However, there are also differences in shape and anatomy at the sub-species level that may result in similarities



**Figure 4.10. (a)** *B. maritimus* nutlet; **(b)** *B. glaucus* nutlet (from Hroudová *et al.* 2001, pages 14 and 1, Figures 6 and 1, respectively).



**Figure 4.11.** Variations in longitudinal fruit (nutlet) shape and cross section of *B. maritimus* subsp. *compactus* (from Hroudová *et al.* 2001, page 100, Figure 9).

between the nutlets of the two species (see below) (Hroudová *et al.* 1998). In fact, significant differences in nutlet shape can occur within one species, as exemplified in Figure 4.11 which shows variations of both longitudinal and cross-section of B. *maritimus* subsp *compactus*.

Kantrud (1996: 4) suggests that, in the warmer regions of the Old World, especially the Middle East, species identified as *Scirpus maritimus* and *S. tuberosus*, are probably *B. glaucus*. In fact Gordon Hillman (pers. comm. 2005) and van Zeist and de Roller (1991-1992: 85) observed that SCR growing in Near East today produce nutlets that are significantly smaller than those of Western European plants, and typically grow in fresh water, which supports arguments that this species is *B. glaucus*. Moreover, charred SCR seeds recovered from ancient sites in the Southwest Asia most closely resemble the smaller, triangular-shaped nutlets described as *B. glaucus* by Hroudová *et al.* (2001). (See Hillman, Madeysaka and Hather 1989: Figure 7:17; and van Zeist and de Roller 1991-1992: Figure 11.3).

Other biological and taxonomic research (*e.g.* Charpentier *et al.* 2000; Hroudová *et al.* 1998; Townsend and Guest 1985) shows that, even at the sub-species level, floral and fruit shapes frequently vary (see Figure 4.11), and furthermore variations often occur even within a single clone. Nevertheless, Hroudová *et al.* (1998) maintain that despite the within-plant variations in SCR nutlet shape, a prevailing shape and anatomical structure can be identified, which in turn can be assigned to specific taxa as well as specific ecological conditions. Their analyses of the internal morphology and anatomy of SCR fruit show that nutlet morphology is adapted to suit that plants' dispersal strategies, which in turn, are adapted to its immediate aquatic conditions. For example, SCR that grow in standing water produce seeds that are long-floating, due to a

greater amount of air-filled lacunate tissue within the exocarp (outer 'nut-shell' layer of the *pericarp*). Alternatively, SCR that grow in moving water produce nutlets that are less buoyant, which sink to the bottom quickly, because they have a narrow or negligible exocarp and relatively little air-filled lacunate tissue.

The debate about the taxonomic classifications of this species cannot be resolved here. (For more information on the taxonomic problems, see Kantrud 1996: 2). For the purpose of this study, *Scirpus maritimus* and *Bolboschoenus maritimus* are considered to be synonymous. Furthermore, following Kantrud (1996), and pending further taxonomic studies, all specimens of SCR used in this research are treated as *Bolboschoenus maritimus s. lat.* ("*sensu lato*" or "in a broad sense").

# 4.6. REPRODUCTIVE BIOLOGY AND PRODUCTION

Potential yield, the amount of a plant's usable products that are available to humans, is determined by reproductive biology and biological production. Talalay *et al.* (1984: 340) define *biological production* as the total amount of growth by a plant or by all the plants of that species within a given unit area. Production and reproduction are inherently linked, and because SCR is a clonal species, production is more dependent on below-ground vegetative reproduction than on above-ground sexual reproduction (Clevering 1995).Kantrud (1996) reports that healthy SCR stands have an above-ground biomass of 500 g/m<sup>2</sup> dry weight (dw). Below-ground biomass usually exceeds that of the above-ground biomass, comprising as much as three to six times that of the standing crop. Worldwide, the net below-ground biomass of SCR is reported to vary from 42 g/m<sup>2</sup> to more than 3,000 g/m<sup>2</sup> (dw). Large differences in productivity may occur within a single geographic region, *e.g.* the Camargue marshes where stands range from 665 g/m<sup>2</sup> – 2,348 g/m<sup>2</sup> (dw) in below-ground biomass.



Figure 4.12. Annual growth of B. maritimus (from Lieffers and Shay 1982a, page 120, Figure 2).

The annual growing cycle begins in the spring when the plant draws on energy reserves from over wintering tubers to send up aerial shoots (Figure 4.12.). Depending on the latitude, altitude and local conditions, in the Northern Hemisphere SCR sprout shoots as early as February (*e.g.* in the Mediterranean region) and as late as May (*e.g.* on the Canadian prairies). The cycle follows the following general pattern: i) the first aerial shoot growth serves to increase the total respiration ability of the plant, and to promote photosynthesis; ii) once above-ground growth is established, below-ground growth begins; (iii) at the end of the growing season, which occurs between late August and October in the northern hemisphere (again depending on the latitude, altitude and local conditions), the culms and leaves die back; iv) organic substances translocate from the dying above-ground parts to the below-ground parts to sustain the plant over winter (Charpentier *et al.* 2000; Clevering *et al.* 1995; Kantrud 1996; Lieffers and Shay 1982a; Townsend and Guest 1985).

### 4.6.1. Tuber production

Kantrud (1996) reports that when cultured indoors, a single SCR clone can produce as many as 366 tubers in a season, and a single tuber can produce 4.5 meters of tuber-bearing rhizomes in 40 days. He maintains that most of the underground biomass grows within 20 cm of the substrate surface, although tubers can sprout at 30-40 cm below the substrate surface. Below-ground growth is controlled by apical dominance among the tubers, via rhizomes.

"In general, one auxiliary bud per tuber sprouts to form directly (*i.e.*, without emitting a new rhizome) a new shoot each spring. At the base of the new shoot, constituted by a tuber, one to three rhizomes develop and form new shoots. This iteration can be repeated many times during a single growing season and results in the formation of attached chains of shoots composed of several tens of shoots. Each shoot possesses at the top of the tuber three axillary buds which can sprout to produce directly a new [upright] shoot. However, most of the axillary buds

remain dormant the first year, and the iteration process takes place primarily by rhizome initiations" (Charpentier *et al.* 1998: 108-109).

A clone can persist indefinitely, maintaining itself and also expanding through vegetative reproduction. Individual clones can expand vegetatively as fast as 3 m/year, and attain a maximum diameter of 24m (Kantrud 1996). A single clone is typically composed of several generations of ramets. Although the lifetime of SCR tubers is not known, studies with a related species, suggest that some generations of tubers may live as long as seven years (Hroudová and Zákravsky 1995).

# **4.6.2.** Nutlet production

Nutlet production can fluctuate considerably from year to year, especially in SCR stands with low numbers of clones that are lacking outcross pollen and/or are self-pollinated (Charpentier *et al.* 2000). Lieffers and Shay (1981) found that nutlet production is also affected by water depth. In deeper water, there is a shift from vegetative to seed production. Studies of managed SCR stands have shown that maximum nutlet production is 100 g/m<sup>2</sup> (Kantrud 1996).

Fertilised seeds can only germinate in periods of low water levels (< 5 cm deep) or drought, conditions that hinder vegetative reproduction. Seedlings normally cannot mature within established stands because they are out-competed by adults (Clevering 1995). Consequently habitats that are suitable for seed germination are usually at a distance from sites that are suitable for vegetative propagation.

"In mature stands of emergent macrophytes the occurrence of sexual recruitment is rare. In these species sexual reproduction may predominantly serve for longdistance dispersal and long periods of dormancy, whereas vegetative propagation is more suitable for dispersal over short distances and overwintering" (Clevering 1995: 64). Once seedlings are established they can quickly colonise open areas (Lieffers and Shay 1981). After the first aerial shoot is established, the seedling develops a rhizome, followed by an upright culm and tubers. The shoot stem size of seedlings tends to be half of that of shoots of established clones, probably due to the fact that established clones have a greater network of support for supplying water, mineral nutrients, carbohydrates and hormones (Clevering 1995; Lieffers and Shay 1982a). Seedlings do not produce an inflorescence during the first year (Kantrud 1996).

# 4.7 RESPONSES TO INTER-ANNUAL AND ANNUAL FLUCTUATIONS, COMPETITION BY OTHER SPECIES, HUMAN DISTURBANCE AND PREDATION

Due to its adaptable reproduction and production habits SCR is resilient to many types of environmental fluctuations, human disturbances and predation (Clevering 1995; Kantrud 1996; Lieffers and Shay 1981). Because it propagates asexually as well as by seeds, this clonal macrophyte spreads relatively easily and can withstand and/or regenerate after extensive periods of drought and flooding. Long or short-term fluctuations in water levels can be accommodated because sexual and vegetative reproduction usually occurs within opposite conditions: increasing water depth promotes a shift from vegetative reproduction to seed production. On the other hand, vegetatively propagated shoots can better tolerate flooding than can seedlings, seeds are better adapted to germinate during drought.

# **4.7.1.** Environmental fluctuations, competition by other species

With respect to production, SCR can withstand environmental fluctuations and changing habitat conditions due to its ability to store and metabolise carbohydrates, as well as its ability to adjust below-ground and above-ground biomass allocations (Clevering *et al.* 1995; Grace 1989; Kantrud 1996; Lieffers and Shay 1982b). For

example, Podlejski (1981; cited in Kantrud 1996) found that above-ground morphology is affected by substrate composition, *e.g.* plants growing in sediments composed of high concentrations of nitrogen and organic matter produced thicker stems and broader leaves. Also, Lieffers and Shay (1982b) found that the tubers can sprout on dry and saline ground, producing short, non-flowering stems. Furthermore, SCR is unique among emergent macrophytes because it can tolerate anaerobic (oxygen deprived) conditions for relatively long periods (eight or nine weeks), conditions that are frequent during the winter months when the underground parts are sometimes buried in heavy mud (Barclay and Crawford 1982; Clevering *et al.* 1995; Clevering and van Gulik 1997). Alternatively, SCR can persist for many years in drained soils of former wetlands (Bassett 1978). It is also fire-tolerant; in fact studies have shown that burning promotes its growth and increases its protein content (Smith and Kadlec 1985).

The outright destruction or reduction of stands more often occurs when several factors come into play simultaneously such as combinations of flooding, damming, draining, changes in salinity, the reduction of nutrients and/or fertility of the substrate, erosion of the substrate, severe storms, cattle grazing, cattle trampling, predation by geese and other waterfowl, muskrats and insects and the invasion of competing macrophytes (Bassett 1978; Clevering *et al.* 1997; Kantrud 1996; Lieffers and Shay 1981, 1982a). For example, Clevering and van Gulik (1997: 230) describe how the damming of Dutch tidal estuaries in 1970 led to the demise of formerly dense stands of SCR. They explain that between 1970 and 1988 the total area of SCR decreased from 500 hectares (ha) to less than 1 ha. These authors attribute the demise of these stands to the loss of the intertidal zones in conjunction with the erosion of the river banks, the affects of which were compounded by the grazing of the rhizomes by geese (*Anser*).

*anser*). In another example, Smith and Kadlec (1985) found that on its own burning promotes growth, and on its own grazing by waterfowl or muskrats does not severely reduce stands, but that burning followed by predation on the rhizomes leads to a significant reduction in total annual production. Likewise, Kantrud (1996: 39) reports that cattle grazing on the stems and leaves does not damage stands, but cattle grazing followed by predation on the rhizomes by geese will damage stands.

Water depth, salinity levels, and the availability of light, significantly influence the above- and below-ground productivity of SCR and its ability to compete with other species. The below-ground biomass of SCR is optimal in water depths of 25 to 35 cm. Rising water levels may promote growth because increased water circulation can help improve the nutrient supply (Lieffers 1984). In deeper water, below-ground biomass decreases and instead the plant lengthens its above-ground shoots (Lieffers and Shay 1981). With increasing water levels, salinity is typically reduced, which creates conditions that are more favourable for other emergent species such as *Phragmites australis* (Cav.) Trin ex Steudel, *Scirpus lacustris*, and *Typha angustifolia* L. (Clevering *et al.* 1995). The availability of light is a critical factor. Taller plants that are adapted to deep water, *e.g. Phragmites*. and *Typha*, shade out SCR (Kantrud 1996).

Under some conditions, the effects of disturbance and competition may be mitigated by other environmental factors. For example, damage to established stands that results in open spaces may create conditions within which seedlings can germinate, providing that other conditions are suitable such as shallow water and low salinity (Anne Charpentier pers. comm. 2003). SCR can colonise areas where *Typha* and other macrophytes have been reduced by cattle grazing (Kantrud 1996)

#### 4.7.2. Predation

SCR stems, leaves and tubers provide food for mammals such as cattle, horses, wild boar and muskrats, as well as waterfowl such as geese (Kantrud 1996; Smith and Kadlec 1985). Predation on the rhizomes by geese is thought to be a threat to wild stands only if the clones are already fragile because of other environmental factors, *e.g.* changes in water levels, extreme drought, or as noted above, in conjunction with erosion and loss of habitat. Loosjes (1974, cited in Clevering and van Gulik 1997) estimates that SCR can tolerate predation by up to 200 geese per hectare if underground productivity is such that each remaining tuber produces 40 new tubers. However, cattle grazing is more destructive for SCR than that of geese, therefore Pehrrson (1988, cited in Kantrud 1996: 39) proposes the rotation of cattle-grazing areas and non-grazing areas, with intervals of several years between.

A benefit of predation is that it counteracts the accumulation of below-ground plant parts (Loosjes 1974). At the end of the growing season, many dead stems and leaves sink, forming a dense mass of debris, thus, some forms of predation might help avert crowding, a factor which negatively affects production in aquatic plants (Boyd and McGinty 1981).

Moreover, predation can stimulate new tuber growth (Clevering *et al.* 1995; Clevering and Van Gulik 1997). Because predation on the below-ground parts causes rhizome severing, it can stimulate dormant tubers to sprout. Charpentier *et al.* (1998) explain that dormant tubers represent a bank of perennating material that the clone can draw on after damage. Because sprouting of buds along the rhizome and tuber chains is controlled by apical dominance, in undisturbed stands most tubers remain dormant and only a fraction of the over-wintering tubers sprout. Rhizome severing releases tubers from dormancy, and also fragments the clone such that some ramets may become independent of the established stand.

Intact clones, *i.e.* those that maintain physiological connections between ramets, will sprout both *consolidating* and *colonising* chains of rhizomes and tubers. Consolidating chains have shorter rhizomes and many small tubers and function to consolidate the plant within the area it already occupies. Colonising chains function to populate new areas by producing longer rhizomes and tubers of different of sizes. Tuber size increases successively along these colonising chains because new growth benefits from the translocation of nutrients from the entire plant. In other words, in colonising chains the tubers and rhizomes function to move resources from other parts of the plant outwards to the newly-formed tubers. These chains benefit from the resources supplied by the mother plant, and the resulting new below-ground "architecture" will include tubers of various sizes, growing successively larger along the sequence of the chain.

"In *S. maritimus*, the contribution of each tuber to the next ramet generation depends not only on its size but also on the other tubers connected to it. ... The maintenance of physiological connections among over wintering tubers could have several benefits in terms of genet persistence. As long as tubers were connected it appears that rhizomes permit resource translocation between tubers. The total biomass produced by the sprouting of a connected tuber chain was more strongly related to the total biomass of tubers, *i.e.* sprouted plus dormant tubers, than to the biomass of sprouted tubers only. So, at least part of dormant tuber reserves seems to be used by sprouted tubers to produce a new ramet generation" (Charpentier *et al.* 1998: 114).

Conversely, fragmented, independent ramets, *i.e.* those that have become separated from the mother plant through rhizome severing, produce consolidating chains of rhizomes and tubers that are composed of shorter rhizomes and large numbers of similar sized, small tubers. Clevering *et al.* (1998) found that more than one third of

tubers from intact clones weighed between 1 and 3 g (dw) while independent ramets did not exceed 1.25 g (dw).

## **4.8. POTENTIAL FOR MANAGEMENT**

The term *management* is used here to describe the modification of the environment by people for the purpose of increasing the productivity of selected plants. No information was found on the management of SCR for food or other economic purpose. However, SCR has responded well to numerous methods of wetland management conducted by ecologists and plant population biologists, including control of water levels and salinity, the sprouting and re-planting of seedlings, the protection of seedlings from predation during early growth, the weeding of species known to outcompete this plant (Clevering and van Gulik 1997; Kantrud 1996). Clevering and van Gulik (1997) report that SCR can be successfully planted outside an existing macrophyte belt as long as waterfowl do not overgraze the rhizomes. Furthermore, controlled burning of SCR and other sedges has also been shown to promote vegetative production and reduce competing species (Cane 1989; Smith and Kadlec 1985).

# 4.9. PUBLISHED INFORMATION ABOUT NUTRIENT COMPOSITION

SCR has been subjected to various types of nutrient assays for biological and environmental purposes. These data are summarised in Table 4.2. Laboratory methods used for answering biological and environmental questions may not be adequate for answering questions pertaining to the parts of the plant that humans eat, and the forms in which they are eaten. Therefore I conducted new laboratory assays (described in Chapter VI, this volume) to determine the nutrient content of SCR tubers.

Nevertheless, prior to the laboratory assays, Kantrud's (1996) nutrient summary provided a means of establishing whether or not SCR is suitable for research into

Species and plant	Moisture (% fw)	Energy kcal/g	Protein (% dw)	CHO (% dw)	Lipid (% dw)	Ash (% dw)	Ref. <sup>1</sup>
WILD SPECIES:			<u> </u>				
Bolboschoenus maritimus (SCR) TUBER	88	4.80	5.0	86	<1	4.4-6.4	6
Cyperus esculentus (yellow nutsedge) TUBER	n/a	n/a	15.0	60	15	2.0	3, 8
Camassia quamash BULB	83	3.59	5.3	87	<]	4.7	1, 8, 12
Wild yams: D. hispida D. cf. glabra, D. transversa TUBER**	cf. 738 1	3.68	7.9	86	0.8	2.7	2, 4, 5
<i>Erythronium grandiflorum</i> BULB	89	3.59	4.2	92	tr	2.7	9
<i>Lewisia rediviva</i> TAPROOT	76	3.85	6.4	89	0.4	4.3	1,7
<i>Lomatium canbyi</i> TAPROOT	67	3.84	7.8	87	1.1	4.3	1,7
<i>Lomatium cous</i> TAPROOT	67	3.85	3.0	91	1.2	4.6	1
Lupinus nootkatensis RHIZOME	82	3.94	11.0	82	2.2	4.4	8
Potentilla pacifica ROOT	77	3.88	7.0	85	1.3	6.1	8
<i>Pteridium aquilinium</i> RHIZOME***	68	n/a	39.1	<i>cf.</i> 58	n/a	n/a	9
Sagittaria latifolia TUBER	68	3.22	14.7	80	<1	4.7	7, 8
Trifolium wormskioldii RHIZOME	84	3.89	11.3	81	1.9	5.6	8
DOMESTICATED SPEC	TIES:						
Cyperus esculentus var sativus (chufa) TUBER	10-30	4.00	12.0	55	30	1.2	3, 10
<i>D. alata-</i> type (yam) TUBER **	78	3.68	9.4	87	0.8	2.7	2, 4, 5
<i>Eleocharis dulcis</i> TUBER	73-80	3.30-4.60	5.3-7	52-90	0.4-1.0	4.1	4, 5
<i>Solanum tuberosum</i> TUBER	80	3.80	9.5	85	<1	4.5	11

**Table 4.2.** Nutrient composition reported in the literature for SCR tubers and various other wild and domesticated root foods that are mentioned in this thesis\*

<sup>1</sup>**References: 1.** Benson *et al.* 1973; **2.** Chu and Figueiredo-Ribeiro 1991; **3.** De Vries 1991; **4.** Haytowitz and Matthews 1984; **5.** Holland *et al.* 1991; **6.** Kantrud 1996; **7.** Keely 1980; **8.** Kuhnlein and Turner 1991; **9.** Lowen 1998; **10.** Pascual *et al.* 2000; **11.** Woolfe 1987; **12.** Yanofsky and Kingsbury 1938.

\*Key: cf = my estimate based on the references cited; n/a = data not available; tr. = trace

\*\*Because nutrients in yams vary widely from species to species (Chu and Figueiredo-Ribeira 1991), mean nutrient concentrations were estimated from values reported for both wild & domesticated species.

\*\*\*Carbohydrate values of *Pteridium aquilinium* were estimated by subtraction, based on values reported by Kuhnlein and Turner (1991).

intensification, *i.e.* whether the raw tubers contain sufficient amounts of carbohydrates, and perhaps other nutrients, to make harvesting worthwhile. Table 4.2. summarises Kantrud's data on SCR macronutrients, as well as that of eight other edible roots, wild and domesticated species that have been used as staple or important foods in different parts of the world. SCR tubers appear to contain similar amounts of macronutrients to these other 15 species.

# 4.10. ETHNOGRAPHICALLY REPORTED USES

There are many ways that charred seeds and other plant parts might arrive at archaeological sites, including: i) as food; ii) as a component of wild crops; iii) as bedding; iv) as fodder; v) as condiments or implements used in processing; vi) as matting, thatching or building materials; vii) as fuel or in dung which is burnt as fuel; viii) accidentally brought in on clothing (Hillman 1984; Colledge 1991; Turner 1992). To assess how ancient people may feasibly have used SCR, this section considers ethnographically reported uses of SCR plants. Due to the taxonomic confusion surrounding SCR (discussed in section 4.5.1.) and the known and unknown repercussions of these taxonomic problems on the ethnographic literature, human uses of other Cyperaceae are also discussed.

This summary is not intended to provide an exhaustive list of the ethnographies and ethnohistories (for more information about the uses of sedges, the reader is recommended to see Ebeling 1986, Mabey 1996; Moerman 1998; Simpson and Inglis 2001; Turner 1998), but to demonstrate the range of economic and cultural uses that SCR plants have served. To avoid confusion, in this section, the scientific plant names and their authors adhere to those in ethnographic reports from which they are taken.

#### 4.10.1. Food uses

Tubers, shoots, stems and seeds of a number of Cyperaceae species have been exploited as foods by human groups. The paragraphs below summarise ethnographically and historically reported economic uses of SCR plants, as well as those of other Cyperaceae.

#### Sea club-rush tuber consumption

According to Arora and Pandey (1996) and Royale (1839 cited in Hedrick 1919), up to recently, in parts of India the tubers of *B. maritimus* were used as bread flour. They do not explain whether SCR tubers provided staple or famine foods, nor whether they are still used as food today. The English used SCR tubers as a famine food, processing them into flour, according to Bryant (1783). He wrote in his *Floral Dietica* (1783) that the flour was consumed during times of scarcity but does not explain how the flour was cooked and eaten, *e.g.* baked into bread or eaten as gruel. The use of SCR as a food is not reported elsewhere among English ethnobotanies (*e.g.* Mabey 1996) and, curiously, the 19<sup>th</sup> century edition of Culpeper's *Herbal* (see Culpeper 1997: 137) describes sedges as "good for nothing".

Tanaka (1976: 670) reports that Native Americans ate the rhizomes of *S. paludosus*, a species that is now classified as *S. maritimus* (see Kantrud 1996). Evidently the rhizomes were eaten raw or pounded into flour that was used to make bread. The Blackfoot of the Canadian prairies also ate the tubers of this species (*S. paludosus*) which they dug in the autumn (Johnston 1987). Moerman (1998) also notes that the *Pomo*, a group living in the American mid-west, ate the tubers and shoots of *S. robustus* Pursh (now classified as *Bolboschoenus robustus* Pursh) a species that is closely related to SCR (Kantrud 1996).

In Oceania, the tubers of species known as *S. maritimus* (more recently classified into two separate species *S. medianus* and *S. caldwelli* but most likely two species of *Bolboschoenus*) were eaten by Aboriginal groups of southern Australia (Gott 1982). The tubers were roasted and then pounded with stones into a thin cake. And, Johnson (1989) reports that the *Maori* of New Zealand occasionally ate the underground parts of a species formerly identified as *Scirpus maritimus* L. var. *fluviatilis* (now classified as *Bolboschoenus fluviatilis* (Torey) Sojak).

#### Food uses of other sedges

Today, probably the most widely known economically useful Cyperaceae are the yellow nutsedge, (*Cyperus esculentus* L.), and the Chinese water chestnut (*Eleocharis dulcis*) and *Cyperus papyrus*. These species are discussed in the following paragraphs, as well as other less-known sedges that have served as food.

#### Yellow nutsedge: Cyperus esculentus

The tuber of yellow nutsedge, also known as *Mediterranean chufa* and *tiger nut*, is popular for its sweet taste and the fact that it contains high amounts of oil and starch (Kay 1987; Pascual *et. al.* 2000). In West Africa it is served as a confectionery and in Spain it is used to make a milky drink known as *horchata*. Yellow nutsedge tubers have also been used as coffee and cocoa substitutes, and the extracts are used for the production of oil, starch, flour and alcohol (Kay 1987; Pascual *et al.* 2000).

Culinary uses of yellow nutsedge and also papyrus have a long time-depth. Both these plants figure in art and sculpture of Egyptian tombs, and are mentioned as Egyptian foods by Classical scholars such as Herotodus (5<sup>th</sup> century B.C.), Theophrastus (321-287 B.C.) and Pliny (A.D. 23-79) (Darby *et al.* 1977; Negbi 1989). The tubers have been recovered from Egyptian tombs dating from the fifth millennium BC, and apparently been found in the intestinal contents of pre-dynastic bodies (Darby *et al.* 1977; Pascual *et al.* 2000). The Greek Philosopher, Theophrastus (cited in Darby *et al.* 1977: 650) wrote that the Egyptians consumed yellow nutsedge tubers as a sweet meat, after boiling them in barley beer. Pliny (cited in Negbi 1992: 65) wrote that they were roasted in the fire and then eaten.

#### Purple nutsedge: C. rotundus

Today the purple nutsedge (*Cyperus rotundus* L.) is widely regarded as a noxious weed (Negbi 1992). However, this species, which is closely related and morphologically similar to *C. esculentus*, bears discussion here because, like SCR, the human use of this plant have significant time depth. As noted, the tubers were recovered from the Upper Palaeolithic sites at Wadi Kubbaniya on the Nile; small numbers have also been found in Egyptian tombs (Negbi 1992).

The culinary uses of purple nutsedge cover a wide geographic area including: Southwest Asia, Southeast Asia, parts of Africa, Australia (for a comprehensive summary of the food uses of this plant, see Hillman Madeyska and Hather 1989). The classical scholar Theophrastus remarked on the edibility of the young tubers (cited in Negbi 1989: 35). Although Hillman, Madeyska and Hather (1989) argue that purple nutsedge tubers may have served as a carbohydrate staple of the group(s) who inhabited the ancient Wadi Kubbaniya sites, ethnographic reports more often describe it as a famine food than as a staple, *e.g.* Bhandari (1974) wrote that groups living in the Rajasthan Desert ate the tubers during times of famine. He reported that Rajasthan Desert groups prepared purple nutsedge tubers into a flour that was consumed as bread:

"In times of scarcity the roots are easily dug up for human food. The fibre and the dark cuticle being removed, the solid part of the root is dried, ground and made into bread. A little flour is sometimes mixed with it. The accompanying specimen

of bread I got from a man who, with his family, was making a dinner of it" (Bhandari 1974: 78).

# Papyrus: C. papyrus

*Cyperus papyrus* is more famous worldwide for its papermaking properties than as a food. However, its stems, culm bases and rhizomes are also known as foods in Tropical Africa and Egypt (Darby *et al.* 1977; Peters 1999). The stems, culm bases and rhizomes of *C. papyrus* are eaten by groups living in Tropical Africa and Egypt (Darby *et al.* 1977; Peters 1999). Moreover, the use of this plant as food has significant timedepth: Theophrastus wrote that the Egyptians chewed papyrus "...both raw, boiled and roasted; they swallow the juice and spit out the quid" (cited in Darby *et al.* 1977: 645). Diodorus commenting on the diet of Egyptian children, said:

"...they give them such stalks as the byblos plant as can be roasted in the coals, and the roots and stems of marsh plants, either raw or boiled or baked..." (Diodorus, cited in Darby *et al.* 1977: 645).

Peters (1999) experimented with eating various raw parts of this plant and found that the only the raw heart of the *C. papyrus* rhizome is edible:

"...[the rhizome consists] of slightly aromatic, sweet tasting succulent fibrous tissue, and the pith of the culm base...consists of a moist spongy tissue, only somewhat fibrous, with a mild starch flavour which is also very faintly sweet" (Peters 1999: 491).

#### Chinese water chestnut: Eleocharis dulcis

Chinese water chestnut (*Eleocharis dulcis*) corm is an important vegetable ingredient in the cuisine of many East Asian countries today. In China it is also regarded as important source of extractable starch (Kay 1987). This species shares many physical and probably chemical properties with SCR (discussed in Chapter VII, this volume). A species of *Eleocharis* was also exploited by Aboriginal groups in

Northern Queensland, Australia who ate the raw tubers of and also baked, pounded and made them into cakes (Jones and Meehan 1989; Thozet 1866).

## Miscellaneous other sedges

Many other sedges have been of economic importance in various parts of the world. In fact, Simms (1987: 128) carried out seed harvesting experiments on a number of Great Basin plants and found *Scirpus* yields to be comparatively high: 800-1000 kcal/h (excluding search time).

Native American groups, particularly those living in the arid regions of North America, *i.e.* the Great Plains, Great Basin, and California, the Canadian Prairies and castern woodlands, are reported to have eaten the rhizomes and/or tubers as well as seeds, pollen, stem bases, and/or shoots of various sedges including *Scirpus acutus* Muhl. ex Bigelow; *S. nevadensis* S. Wats; *S. americanus* Pers., *S. pungens* Vahl; *S. tahernaemontani* K.C. Gmel. (Ebeling 1986; Moerman 1998).

"They ate the young [S. acutus] shoots raw or cooked. When the bulrush was in flower, they collected the pollen and mixed it with meal to make bread, mush, or pancakes. Later, the seeds were beaten off into baskets or pails, ground into a meal, and used in the same way as the pollen" (Ebeling 1986:34).

The *Paiute* of the Great Basin, "ate the large, bulbous rhizomes of the bulrush [*S. americanus*] or pounded them into flour for mush" (Ebeling 1986: 118). *S. acutus* was widely used across North America. Ebeling (1986) writes that native groups living in the arid regions used all parts of this plant: the young shoots, pollen seeds and tubers were eaten, and the stems were used as raw material for mats:

The scaly rootstocks, available at all seasons, were eaten either raw or cooked. They might also be dried and pounded into a kind of flour. Indians made a sweet syrup by bruising the rootstocks, boiling them for several hours, then pouring off the sweet liquid." (Ebeling 1986:34).

Kuhnlein and Turner (1991) report that groups living in the Canadian far north exploited several aquatic sedges. They explained that the *Inuit* collected the stem bases and corms of the tall cottongrass (*Eriophorum angustifolium*) in the early summer, but the corms were also collected again in the spring and/or fall, prior to winter freeze-up. The corms were prepared by first dousing in boiling water to facilitate the removal of the outer layers. They were then eaten raw or boiled and eaten with seal oil, apparently having a sweet flavour. The corms were also stored by drying or preserving in seal oil.

Sedge tubers were also used as food in South America. According to Christine Hastorf (pers. comm. 1999) there is both ethnographic and archaeological evidence that groups living in the Andes ate the tubers of the wetland species *S. riperius*. Today these tubers are regarded as starvation food but their stems are valued as raw materials for weaving and building. The fact that *S. riperius* stands are tended and owned by Andean groups attests to their continuing economic importance in that region.

Cane (1989) lists the sedge *Fimbristylis oxystachya* among the preferred seed foods of Aboriginal groups of the Western Desert. He maintains that this species is suitable for intensive and mass seed harvesting because it is widely distributed throughout the region, regenerates quickly after fire, grows in dense stands and produces large numbers of seeds which are easily stripped from the plant by hand. He reports that Aboriginal women prepare the seeds by dehusking, winnowing, sieving, and soaking, before grinding them into a paste. Apparently the paste is either eaten raw or else as baked cakes, the latter being shaped into small loaves and baked hot ashes.

### 4.10.2. Medicinal uses

The tubers, roots and/or rhizomes of numerous Cyperaceae are reported to have both medicinal and aromatic properties. In many cultures sedges are also reported to have had a role in women's reproductive health and birth control.

# Sea club-rush

In traditional Chinese medicine SCR is regarded as an astringent and as a diuretic (Chopra *et al.* 1956) and the closely related species *Bolboschoenus yagara* (Ohwi) Y.K. Kang & M. Zhan as a treatment for blood clotting (David Simpson pers. comm. 1999). Pharmaceutical analyses of SCR nutlets revealed that they contain bioactive compounds that might be used against some forms of leukaemia (Powell *et al.* 1987). Chemical analyses, conducted primarily for taxonomic purposes on SCR and other Cyperaceae, indicate that alkaloids are present in the whole plant, and that the flavonoids luteolin and tricin are present in the leaves (Harborne 1971; Powell *et al.* 1987). Flavonoids, which are ubiquitous in the plant kingdom, are responsible for pigments in plant tissue (Fahn 1990; Lindsay and Astley 2002). Recent biomedical research has shown that some flavonoids contained in edible plant parts may function as dietary antioxidants which have the affects of improving human health and aiding disease prevention (Lindsay and Astley 2002).

### Medicinal uses of other sedges

Purple nutsedge (*C. rotundus*) tubers were valued by Egyptian priests and Mycenean perfume manufacturers as an aromatic ingredient for perfumed oils and ointments (Negbi 1992; Theophrastus cited in Negbi 1989: 35). The Chinese traditionally regarded the tubers as a painkiller and indeed recent phytochemical analyses have identified compounds in this plant that have analgesic (pain-killing) properties (Jeong *et al.* 2000). Scientific research has shown that purple nutsedge also contains constituents that have anti-inflammatory and anti-pyretic (anti-fever) effects (Gupta *et al.* 1980; Jeong *et al.* 2000).

Culpeper's 1826 *Herbal* (1997: 137) provides a recipe in which the underground parts of a sedge are "...boiled in water, to the consumption of one-third" to treat a cough. Nevertheless this text gives a disdainful account of the medicinal properties of rushes:

"There are remedies enough without them for any disease, and therefore, as the proverb is, 'I care not a rush for them;' or, rather, 'they will do you as much good as if one had given you a rush" (Culpeper 1997: 137).

In India, astringents were made from the underground parts of *Scirpus grossus* L. and *S. lacustris*; a treatment for diarrhoea and vomiting was made from the tubers of *S. kysoor* Roxb.; the root of *S. articulatus* L. was used as a purgative, and the tuber of Chinese water chestnut (*E. dulcis*) was used as a laxative (Chopra *et al.* 1954; Nadkarni 1954). The Ancient Egyptians used *Cyperus papyrus* externally, as a caustic remedy, and *C. esculentus* to treat eye problems, as an enema, for ointments and dressings, and as a fumigant for clothes and houses (Darby *et al.* 1977).

Moerman (1998) listed several native American groups as using *Scirpus acutus* Muhl. ex Bigelow, and *S. tabernaemontani* K.C. Gmel externally to stop bleeding, and internally as emetics. The root of *S. microcarpus* was evidently used in different ways to treat various ailments *e.g.* it was made into a gargle for sore throats, and pounded into a poultice to treat abscesses. Moerman also reported an unspecified *Scirpus* used as a sedative for children

#### Sedges, women's reproductive health and contraception

The anti-fertility properties of the tubers, rhizomes and/or roots of various Cyperaceae are known in the folk medicine of England, West Africa, the Americas, Southeast Asia, and the Pacific (Bouchard and Turner 1976; Cambie and Brewis 1997; Garbarino *et al.* 1985). Cyperaceae are also widely regarded as treatments for womens' reproductive health, *e.g.* as an antidote for amenorrhea, and to counteract excessive bleeding during menstruation (Bouchard and Turner 1976; Cambie and Brewis 1997; Culpeper 1997; Garbarino *et al.* 1985

"The seed of the soft rushes ...being drunk in wine and water, stays the last and women's courses, when they come down too abundantly; but it causes headache; it provokes sleep likewise, but must be given with caution" (Culpeper 1997: 137).

In the Pacific Northwest of North America S. *microcarpus* was used as a treatment for venereal disease and by women as an anti-fertility treatment (Bouchard and Turner 1976; Turner *et al.* 1990. In England, for example: Other Cyperaceae reported to have anti-fertility properties are the purple and yellow nutsedges as well as *Cyperus corymbosus* Rottboll, *C. longus, Kyllinga memoralis* (J.R. & G. Forst.) Dandy, and *Scleria ciliaris* Nees (Cambie and Brewis 1997; Garbarino *et al.* 1985). The plant parts were typically processed into a decoction and ingested orally, *e.g.* Bouchard and Turner (1976) report that (Northwest Coast) Squamish women drank a beverage made from the underground parts of *S. microcarpus* as a contraceptive and abortive. Chemical analyses of purple nutsedge and some *Scleria* species confirm that anti-fertility properties and other medicinally effective compounds are present in these plants (Cambie and Brewis 1997; Garbarino *et al.* 1985).

# 4.10.3. Sedges as raw materials for construction, household gear and implements

On a worldwide basis today, it is the stems of sedges that are known for their economic usefulness (Simpson and Inglis 2001). From at least the Early Epipalaeolithic to the present, in regions as far apart as the Mesopotamia and the Andes, groups have

used sedge stems as raw materials for a multitude of purposes, *e.g.* the ethnographic record shows that throughout the world sedge stems are widely used as raw materials for making mats, baskets, and clothing; as stuffing for pillows and mattresses; burned as fuel; strewn as floor coverings; as materials to build dwellings and watercraft.

#### Sedges as raw materials for constructing buildings and watercraft

In south Central Turkey today, both the stems and tubers of sea club rush are regarded as useful raw materials for constructing buildings and walls. Villagers of the steppe village of Küçükköy, the closest village to the Neolithic village of Çatalhöyük, in the Konya Basin, make a brick for building garden walls from mud containing SCR tubers (Figure 4.13) (Erkal 1999; Wollstonecroft and Erkal 1999). Küçükköy residents explain that the tubers serve as a binder, making the bricks stronger. Interestingly, when older garden walls begin to crumble and fall onto the garden paths and outdoor cooking areas, the desiccated tubers and other debris are swept up and tossed into a garden hearth that is normally used for cooking food. Under these circumstances, the tubers are burned simply for the purpose of rubbish disposal.

From Sumerian times groups living in Mesopotamia have constructed dwellings from reeds (Roux 1992). The Marsh Arabs, made famous by Thesiger (1967), continued this tradition up to the recent present, living on reed islands in the marshes of what is now southern Iraq, where they constructed large domestic buildings and animal compounds from reeds, as well as boats which they used to travel around the marshes.

According to a passage in the Bible (Isaiah 18: 1-2), and numerous depictions found in Egyptian tombs, papyrus boats of various sizes have been used by Nilotic groups since at least the second millennium BC (Hepper 1990; Darby *et al.* 1977).



**Figure 4.13.** Ethnographically observed use of SCR: tubers used as a structural material for a mud-brick wall, in the village of Kuçükköy, in the Konya Basin of Turkey. Evidently the tuber serves to strengthen the mud-brick.



**Figure 4.14.** Ethnographically observed use of SCR stems as fibre in mat-making. This example is from the village of Adakale in the Konya Basin, Turkey, where mats of this type are placed under carpets in living rooms to make them more comfortable for sitting (Aylan Erkal, pers. comm.).

Small skiffs made of reeds are still used along the Nile as well as on Lake Chad, in sub-Saharan Africa (Hepper1990: 30). They are constructed from bundles of tightly-bound sedge stalks, which are joined together like planks to form the body of the craft. The boats are not watertight, but stay afloat due to the buoyancy of the stalks (Hepper 1990).

In the Americas, Andean groups in the lake Titicaca region continue a similar tradition today, living on reed islands, and constructing buildings and boats from the stems of *Scirpus riparius* (Christine Hastorf pers. comm. 1999). Also, the Pomo Indians of California were using reed boats at European contact (Moerman 1998).

# Sedges as fibre for cordage, textiles, bedding, basketry

Sedges are universally preferred for mat-making purposes because the stems are flexible, lightweight and strong (Ebeling 1986; Erkal 1999; Moerman 1998; Simpson and Inglis 2001). The use of sedges as fibre continues today in the Konya Basin of Turkey, *e.g.* in the village of Adakale women use the flattened stems to weave large mats which they place beneath wool carpets within their sitting rooms (Figure 4.14) (Wollstonecroft and Erkal, 1999). Adakale villagers explained that SCR stems are preferred for matting because they are softer than other reeds. Erkal (1999) further reports that women from the Konya Basin village of Küçükköy use sedge straw as a stuffing for pillows.

The earliest evidence of sedges fibers in Southwest Asia is the cord fragments recovered from the floor of a hut at Early Epipalaeolithic/Kebaran Ohalo II (23,000  $^{14}$ C yr BP cal). The fragments are thought to represent rope, basketry or netting (Nadel *et al.* 1994; see Chapter II this volume, section 2.4.1.2.). The earliest evidence of sedge woven baskets in the study area is from the Neolithic site of Catalhöyük in the Konya Basin of Anatolia (Asouti *et al.* 1999).

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Mabey (1996) reports that sedge cutting was once a commercial industry in England. The stems of "common club-rush" and/or "bulrush" were harvested for weaving baskets, chair seats and mats. Furthermore, loose sedge stems were strewn on the floors of churches and chapels, in the absence of floorboards and carpets, and also on slippery surfaces such as those found on bridges and in barns.

The *Menomini, Meskwaki and Ojibwe*, of the region of North America that is now Wisconsin, regarded soft-stemmed bulrush *Scirpus validus* as the best material for making mats because the stems are not easily crushed when used, due to the small diameter of the stem and the small internal pith (Smith 1923, 1928, 1932). In the Pacific Northwest, both the soft stemmed-bulrush and the hard-stemmed bulrush (varieties of *S. acutus*) were used by Coastal and Interior groups for making mats because the stems are relatively tall and lightweight, have good insulation capacity, and, once woven, the mats could be easily rolled longitudinally into a bundle (Turner 1998).

Andean groups today use *S. riparius* stems to make baskets, mats and furniture (Christine Hastorf. pers. comm. 1999). North American Native groups traditionally used the flattened stems of sedges fibres to make mats that they sewed together with nettle or hemp fibre (Bouchard and Turner 1976; Parish *et al.* 1996: 355; Turner 1998). Sedge mats provided seating; surfaces for preparing and drying food, windbreaks, and coverings for doors, walls and floors. Sedges were also used to weave baskets and storage sacks and to make clothing such as hats, capes, skirts, and sandals. The loose straw was stuffed into moccasins as insulation, and used to stuff mattresses and pillows (Ebeling 1986; Moerman 1998; Turner *et al.* 1990; Turner 1998). Apparently the *Pomo* Indians used the underground parts of some species to decorate baskets (Ebeling 1986).

#### 4.10.4. Sedges used as fuel

In places where arboreal resources are scarce, sedges are sometimes used as fuel. In Mediterranean countries, both the underground parts and the stems of several sedges are reported to have been used as fuel, *e.g. Cyperus papyrus* and *C. auricomus* Sieber *ex* Sprengel (see Darby *et al.* 1977; Negbi 1989). Erkal (1999) otherwise found that in the Konya Basin today, SCR stems are used as tinder, but not as fuel because they burn too quickly. Erkal (1999) also observed that villagers do not intentionally burn the tubers as fuel, or use them in any way associated with preparing foods.

Van der Veen (1999) lists SCR among the saltmarsh plants used as fuel by Roman-period inhabitants of Morton Fen, in Lincolnshire England. Mabey (1996) reported that in more recent times in Cambridgeshire, England sedges served as fire lighting material as well as fuel. Apparently, during the 17<sup>th</sup> century, sedges were the preferred fuel for the bake house ovens of colleges of Cambridge University: "Every college had a 'sedge loft' and the servants, like the cutters, wore special gloves to protect their hands whilst handling the plant" (Mabey 1996: 391).

## 4.10.5. Sedges as materials to facilitate food-preparation and food storage

Turner *et al.* (1980) and Turner *et al.* (1990) explain that Native groups living in the Plateau regions of British Columbia, in the Pacific Northwest, preferred the stems and leaves of sedges for layering pit-ovens because these materials do not impart flavours into foods. Plateau groups also used *Scirpus* stems as raw materials for making implements and containers for collecting, preparing and storing foods. Woven sedge baskets were used for collecting roots and berries; sedge mats were used as surfaces for drying berries, and filleting and drying fish and meat. Loose stems provided covering and lining for berry baskets and cache pits (Turner *et al.* 1980, Turner *et al.* 1990).

## 4.10.6. Sedges in belief systems: symbolic and ritual uses

Mabey (1996) lists sea club-rush as one of the sedges used in English "rush-

bearing" ceremonies that occurred annual up to the 19<sup>th</sup> century, usually for the purpose

of renewing the floor covering in churches and chapels.

"Every part of the parish contributed its quota of sweet-smelling rushes, sometimes carried in bundles by young women in white, but more often piled high in decorated harvest wains, and held in place by flower-covered ropes and high harvest-gearing. The best horses in the village were chosen to draw the cart. Morris dancers usually preceded them, and children and young people walked beside them, carrying garlands that were hung in the church after the new rushes had been laid down. Often the procession perambulated the parish in the morning, stopping outside the great houses of the district where the Morris-men danced; and then, the long round ended, the whole company came to the church, to the sound of pealing bells, and there were strewed the rushes on the floor (and sometimes on the graves as well), and hug up their garlands in the appointed places" (Christina Hole, cited in Mabey 1996: 389-390).

Apparently rush-bearing ceremonies continue in the Lake District today, taking place in July or early August. In Cornwall, a similar ritual, in which sedges are strewn on the floors of official buildings, is part of the Mayor-making ceremonies (Mabey 1996).

In North America sedges were used for a number of ritual and symbolic purposes. Turner *et al.* (1990: 116) report that among some Native groups of the Pacific Northwest *Scirpus microcarpus* was known as a protection against the mythological trickster Coyote. Also in this region, the headdresses of certain Native doctors were woven from *S. acutus* (Turner *et al.* 1990). Moerman (1998) reports that in the American southwest the hard-stemmed bulrush (*S. acutus*) is regarded as a symbol of water by both the Hopi and the Omaha Indians. The *Navaho* drank *S. pallidus* (Britt.) as a ceremonial emetic. And, Moerman (1998) also notes that *Potawatomi* women of present-day Wisconsin regarded the flowers of *S. tabernaemontani* as a love medicine. Apparently the Northern Cheyenne used *S. nevadensis* in the Sun Dance Ceremony (although Moerman does not explain the specific use of this sedge in the ceremony). There are a few reports of sedges being linked with the dead. Human images constructed from *Scirpus tabernaemontani* stems were made to represent deceased persons for *Kawaiisu* (of Utah, in the U.S.) ceremonies for the dead (Moerman 1998). *Cyperus papyrus* bundles are extensively represented in tomb and temple carvings by the Egyptians (Darby *et al.* 1977). Purple nutsedge (*C. rotundus*) tubers were used in embalming and other methods of preparing human corpses for burial in the Mediterranean regions (Tackholm and Drar 1950). This practice apparently continues in parts of the Aegean region of western Turkey today (Wollstonecroft 1998).

# 4.10.7. Sedges as trade goods

The fact that SCR has served as a trade commodity suggests that this plant has, in some circumstances, attained an economic value beyond immediate subsistence requirements. Trade of the raw stems continues in the Konya Basin today.

"I found that *Scirpus* has been one of the most important exchange materials until recently. People in wetland areas used to exchange wood for bulrush with people in forest areas. This may explain why it is also possible to see *Scirpus* used as building materials or mats in forest areas where the species does not grow" (Erkal 1999).

Turner (1998) reports that mats made from *S. acutus* were traded between the *Coast Salish* of southern British Columbia, Canada.

# 4.10.8. Ethnographically reported season of harvest and methods of collecting

The best season of harvest for sedges depends on which part of the plant is

desired. The optimum periods for collecting sedge tubers do not necessarily coincide

with the optimum periods for harvesting the nutlets or the stems.

# Harvesting the tubers

From an analysis of SCR carbohydrate utilisation by Clevering *et al.* (1995) it can be inferred that the tubers would be at their highest carbohydrate levels twice annually: in the early spring, when some (albeit diminished) reserves remain in overwintered tubers; and again in late summer and autumn, after above-ground growth has stopped. Indeed, a rare reference to the season of tuber harvest by Johnston (1987) indicates that on the Canadian prairies the tubers of *S. paludosus* (a synonym for *B. maritimus*) were collected in autumn. Likewise, Moerman (1998) reports that Native groups of Montana collected the tubers of *S. robustus* in the autumn. And, according to Kuhnlein and Turner (1991), in the Canadian north Inuit groups harvested the corms of *Eriophorum angustifolium* in the spring or fall, but apparently more often collected them in late fall from the winter caches of tundra mice and voles.

#### Harvesting the seeds

Simms (1987) found that, in the Great Basin, *Scirpus* seeds have a very long season such that stands that were harvested in late July could be harvested again in mid October. However Simms' observations cannot be considered universal because the timing and length of the *Scirpus* fruiting season depends the fruiting habits of the species, and the latitude, altitude, and habitat conditions in which it grows (Charpentier *et al.* 2000; Kantrud 1996; Lieffers and Shay 1981; Townsend and Guest 1985).

#### Harvesting the stems

According to Turner (1998) Native groups in the British Columbia region of the Pacific Northwest collected sedges for mat-making and basketry in late summer or early fall, after the stems had turned brown and are easier to break off or cut. Mabey (1996) writes that in England, sedge stems used for making baskets, chair seats and mats, were
harvested in June or July, before they became too woody to easily work. On the other hand, he also observed that stems collected for rush-bearing ceremonies are harvested in late July or early August.

Erkal (1999) observed that present-day Konya Basin groups harvest SCR stems by cutting them at the culm base, so that the underground parts remain in the soil. Likewise, Turner (1998) reports that in British Columbia, native mat-makers broke off or cut the stems at the base. However, Smith (1928: 1932) observed that, to obtain the maximum stem length *Meskawaki* and *Objibwe* matt-makers harvested *S. validus* by uprooting, rather than cutting. This observation is important as it provides an alternate, non-food, explanation of how sedge tubers might arrive in archaeological sites.

## 4.10.9. Ecological and economic significance of wetland plants

The ecological and economic importance of wetlands has long been recognised by human groups (Kantrud 1996; Smith and Kadlec 1985; Turner *et al.* 1990; Yamakana 1975). Apparently, in North America, native hunters in search of game, such as waterfowl, regarded bulrushes as environmental indicators of game availability (Moerman 1998; Turner *et al.* 1980; Turner *et al.* 1990). In archaeological sites, numerous wetland resources been recovered in association with SCR, *e.g.* Wadi Kubbaniya, Abu Hureyra, Mureybit (Hillman, Madeyska and Hather 1989; Hillman 2000; van Zeist and Bakker-Heeres 1984). The fact that the Neolithic Catalhöyük village was established in the midst of wetland composed of marsh and riverine habitats (Roberts *et al.* 1999) suggests that wetland resources were of importance to that group.

In Europe and North America today marshes are valued because they produce significant amounts of rich organic dry matter and nutrients that can be used by aquatic and terrestrial plants and animals (Kantrud 1996; Smith and Kadlec 1985; Yamakana 1975). Wetland vegetation is valued because it provides food for cattle, wild boar, muskrats, and food and habitation for numerous waterfowl, well as fish, frogs, and a multitude of insects and minute water creatures. In North American and Europe today, SCR is recognised as an important plant for wetlands restoration (Clevering 1995; Clevering *et al.* 1997; Kantrud 1996; Smith and Kadlec 1985).

## 4.11. DISCUSSION AND CHAPTER SUMMERY: IS THERE EVIDENCE THAT SEA-CLUB RUSH COULD SERVE AS AN INTENSIFIABLE RESOURCE?

This section assesses the likely prehistoric economic and cultural uses of SCR. Subsequently the potential of this plant for management is discussed. The chapter finishes with a discussion about the effects of predation on SCR stands.

## 4.11.1. Potential economic and cultural uses

The literature cited above provides a substantial body of biological and cultural evidence in support of the economically useful properties of SCR. All parts of this plant have economic uses, including the fruit, the stems, the rhizomes and tubers; many of the parts have multiple uses; the seeds and tubers are carbohydrate-rich; the reproductive systems of this species are well adapted to regular churned soil; it is resilient to environmental fluctuations and predation; and, up to recent times, when wetlands were drained for agricultural and other purposes, dense stands of these plants were widely distributed throughout Eurasia (Clevering *et al.* 1997; Eken 1998; Mabey 1996; Gordon Hillman pers. comm. 1999).

From the archaeology and ethnographies we know that human use of SCR has a significant time depth and covers a wide geographic area. SCR and other sedges have been used for a multitude of purposes worldwide: as food, medicine, as building materials, to make mats and baskets and other household implements, to make food

collecting, processing and preservation equipment, as fuel, as animal fodder, as symbols in the belief systems, for trade goods, and as environmental indicators. In North America and Europe today, SCR is recognised as an important plant for wetland restoration (Clevering 1995; Clevering *et al.* 1997; Kantrud 1996; Smith and Kadlec 1985). The few reports that discuss harvesting practices indicate that the best time for collecting the tubers for consumption is early spring and/or early autumn.

Turner (1988: 276-277) suggests that humans are attracted to individual plants by their *ecological salience* and *perceptual salience*: ecological salience being the frequency and distribution of a species within a group's territory; and perceptual salience being whether or not that plant is conspicuous and easy to recognise. Based on the biological, ecological, archaeobotanical and ethnographic literature on SCR, it can be inferred that, in regions where it was widespread and existed in large stands, SCR had both ecological and perceptual salience: this plant is conspicuous and easy to recognise because it grows in relatively tall, dense, and often monospecific, stands; if the stands are healthy, and the clones are productive, harvesters should have been able to collect several kilograms of tubers within a small area (see section 4.5.). SCR is accessible without the need for watercraft or special tools because it grows in relatively shallow water. Because these tubers are perennial they are available, and possibly edible, year-round thus conceivable could have provided a staple source of carbohydrate during the lean seasons (*e.g.* fall to spring). Also, SCR produces large numbers of edible seeds that can be easily stripped from the plant by hand.

Questions remain about how SCR was used by prehistoric groups in Southwest Asia: *i.e.* whether or not these plants had culinary uses or whether they served other purpose. Fairbairn *et al.* (2002) argue that charred SCR seeds found at the Anatolian Neolithic village of Catalhöyük represent dung burned as fuel; likewise Miller (1996, 1997) proposed that seeds of non-cultivated species found at Late Epipalaeolithic and early Neolithic sites in Southwest Asia were from burning the dung of wild herbivores as fuel. Savard *et al.* (2006) and Hillman *et al.* (2001) otherwise argue that Late Epipalaeolithic and early Neolithic groups living in the east Taurus and Middle Euphrates used these seeds as foods, and moreover, that SCR seeds may have been *staple* foods (*i.e.* constituting a significant percentage of the total diet in terms of energy and/or other critical nutrients, see Clarke 1988 and Wills *et al.* 1998).

If Late Pleistocene and Early Holocene people consumed the seeds and tubers of SCR as food, questions remain about the importance of these foods in the diets of these hunter-gatherer and farmer groups. With the exception of the *S. maritimus* seeds found in charred faecal material at Wadi Kubbaniya (Hillman, Madeyska and Hather 1989), there is little archaeological evidence to show that this plant had any role in Epipalaeolithic diets. The seeds are commonly found in Late Pleistocene and Early Holocene archaeological sites within the study area, but the largest numbers of SCR tubers were recovered from a single site, from domestic contexts of the Neolithic and Chalcolithic contexts of Catalhöyük, albeit this pattern is probably highly influenced by sampling methods, *i.e.* up to recently archaeobotanical research has been focused on seeds and charcoal but not parenchymous tissue.

More information is known from the ethnobotanies which attest to the fact that SCR seeds and tubers can both be eaten several ways. After being prepared by parching and then grinding into a flour, seeds can be consumed as mush or else baked into cakes or bread, sometimes along with other ingredients. The tubers can be made into a flour to be used in any number of ways (Cane 1989; Ebeling 1986; Hillman 2000; Hillman Madeyska and Hather 1989; Moerman 1998). Among the advantages of adding SCR tubers to the diet are that they can be prepared and eaten in several different ways, thus contributing to culinary diversity. According to various ethnographic reports (discussed above), in various parts of the world people have consumed whole SCR tubers raw (probably young specimens), baked or boiled. However, SCR tubers are more often reported to have been eaten as bread or a mush, after first being ground into flour and baked or boiled (Arora and Pandey 1996; Bryant 1783; Hedrick 1919; Hillman Madeyska and Hather 1989; Moerman 1997).

The use of SCR tubers as food is not reported in the ethnographies as frequently as the food uses of other Cyperaceae. But our knowledge of human uses of SCR and other Cyperaceae are hindered by problems in the ethnographic sources, including errors in species identification, such as those discussed earlier (section 4.5.) and the fact that the ethnographic record is incomplete. Therefore it is not always clear which species of Cyperaceae and which parts were eaten, and how they were eaten. This problem is due to the fact that it is only recently that ethnobotanists and archaeologists have collaborated (*e.g.* Erkal 1999; Ertug-Yaras 1997; Turner 1992;) to design ethnoarchaeological research approaches to addressing archaeological and archaeobotanical questions.

Recent ethnographic work in Central Anatolia, including Erkal's (1999) study in the Konya Basin, and Ertug-Yaras' (1997) research on the Melendiz Plain in the province of Aksaray, indicate that neither the seeds nor tubers of SCR are recognised as a food in this region today. Instead, the stems and tubers are valued as raw materials for building and other household purposes. Consequently, if we are to learn how prehistoric groups utilised this plant, we must also consider ways that these tubers may have been introduced into hearths or fires at archaeological sites for non-food purposes, e.g. seeds and tubers may have accidentally been introduced when the stems were harvested for building and/or matt-making *etc*.

The potential non-food uses of SCR are numerous. From the ethnographic record we know that SCR and several closely related species are regarded as having medicinal properties, particularly as astringents and diuretics, and some Cyperaceae are regarded as having anti-fertility uses. The medicinal potential of SCR tubers is not known because very little chemical and pharmacological research has been done on this species. Pharmacological research on the nutlets indicates that they have potential medicinal properties. SCR and other sedges have also served as forage for animals and as environmental indicators for hunters, as tinder and fuel, in food preparation, and for ceremonial and symbolic purposes. On a worldwide basis, SCR and other sedges are most widely exploited for their stems, which provide raw materials for construction and for household items such as mats and basketry (Ebeling 1986; Erkal 1999; Mabey 1996; Moerman 1997; Turner *et al.* 1980; Turner *et al.* 1990). Evidently sedge stems are highly valued in some regions today, *e.g.* in the Konya Basin in southcentral Turkey they are valued as exchange goods; in Lake Titicaca in the Andes, where they are used as raw materials in building, people claim rights over the wild stands that they tend.

Furthermore, despite the existing body of research on the nutrient content of SCR, its value as a human food is unknown because laboratory methods used for answering biological and environmental questions may not be adequate for answering questions pertaining to the parts of the plant that people eat, and the ways that they are eaten. For example, many of the nutrient reports cited by Kantrud (1996; summarised in Table 4.2) provide little information about the individual plant parts because the

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laboratory assays analysed the combined underground parts, or else the combined above- and below-ground parts (*e.g.* Boyd and McGinty 1981; Yamanaka 1975). Also, the data provided by these reports are not always reliable. For example, Yamanaka's (1975: 47, 118) results from ash and nitrogen assays were highly variable, which Yamanaka himself attributes to inconsistencies during sample preparation due to varying amounts of mud and silt adhering to plant materials.

Also unknown is the bioaccessability of the nutrients of SCR tubers, and the effects of different preparation methods on bioaccessability of nutrients as well as food texture, taste and preservation potential. These factors are important because, as observed by Wills *et al.* (1998), the nutritional contribution of a plant food to the diet is highly influenced by how that food is harvested and processed and eaten, also how often it is eaten, in what proportions, and what else it is eaten with.

Knowing the methods and times of harvest may help us to assess which plant parts were intentionally brought to the site, and which were introduced accidentally. While it is possible that SCR seeds were accidentally introduced to archaeological sites in the mid-to-late summer when the stems were collected, it is unlikely that the tubers would have been accidentally introduced in the same manner. Most ethnographic studies report that when SCR stems were harvested for weaving, people cut them at the stem base, leaving the tubers in the ground. But we cannot rule out the possibility that, in some cases, the tubers were unintentionally introduced to sites for non-food purposes *e.g.* by matt-makers who uprooted entire plants to obtain the maximum length of stems (see Smith 1928), or in cases where tubers within mud-brick were deposited and charred in hearths as a part of regular cleaning and rubbish disposal activities (Erkal 1999).

#### **4.11.2.** Potential for management

It is also important to consider the potential of SCR for management because management has important ecological, social and economic implications. For example, it is well known to both biologists and hunter-gatherers that controlled burning not only stimulates the growth of certain plants growth, but certain animals and birds are attracted to burned areas (Lewis 1982; Smith and Kadlec 1985; Turner 1991). Worldwide, management is associated with groups, both hunter-gatherer and agricultural, claiming ownership of patches of wilderness (Erkal pers. comm.; Kelly 1995; Palmer 1975). In the Lake Titicaca region of the Andes, for example, groups claim to own the wild stands of *S. riparius* that they tend (Hastorf pers. comm. 1999).

Hather (1994) argues that in Southwest Asia and Europe, groups selected seed plants over root foods for management and subsequent cultivation because, among the plants that grow in these regions, those with carbohydrate-rich seeds provide a more sustainable and productive resource than those with carbohydrate-rich roots and tubers. He agrees that some root foods eaten by prehistoric groups in this region, such as SCR, are capable of successful vegetative propagation and therefore, small-scale management and cultivation of these species might be possible. But he argues that the growth habits and morphological characteristics of these plants make them unsuitable for cultivation:

their potential, however, to become major carbohydrate-producing staples is likely to be hampered by difficulties in cultivating aquatics and semi-aquatics, especially with a rhizomatous growth habit and possibly low yield" (Hather 1994: 723.

On the other hand, recent studies show that management of SCR for ecological purposes can be successful. For example, Clevering and van Gulik (1997) succeeded in planting SCR outside its traditional habitat conditions. Also, Lieffers and Shay (1981, 1982b) demonstrated that control of water levels can promote below-ground productivity, and Smith and Kadlec (1985) found that controlled burning promotes growth. While the aims of plant management for ecological purposes differ in many ways from the aims of plant management for human consumption, ethnographic reports from the Americas and Australia suggest that similar management methods were known to hunter-gatherers, *e.g.* water control, burning, the weeding out of competing species, and the clearing of areas of debris such as dead growth and rocks (see Anderson 1993; Peacock 1998; Steward 1933; Turner 1991; Turner *et al.* 1990; Yen 1989). Steward (1933), for example, reports that the Owens Valley *Paiute* irrigated stands of wild hyacinth. In another example, Christine Hastorf (pers. comm. 1999) observed that Andean groups today continue to manage *S. riparius*, which they harvest exclusively for their stems, plants that were also used as root foods in this region in ancient times.

#### 4.11.3. Potential effects of intensive human harvesting on stands of SCR

The long-term effects of intensive harvesting by human groups on SCR stands also remain unknown. Research suggests that, depending on the part of the plant that is taken, SCR responds to predation in different ways. The harvesting of seeds would have negligible effects on the whole plant (although the effects of human selection on SCR seed morphology has not been studied). Predation on the stems may sometimes lead to a change in above-ground morphology, for example cattle-grazed shoots tend to be shorter and thicker (Kantrud 1996). Below-ground parts can rapidly re-colonise after predation due to having a bank of reserves stored in dormant tubers (Charpentier *et al.* 1998). Rhizome severing stimulates the release of tubers from dormancy, and the production of new growth. However, under some circumstances predation might seriously damage these plants, *e.g.* where cattle grazing on the stems is followed by geese grazing on the rhizomes or changes in water levels or salinity. Whether or not SCR clones benefit from intensive rhizome severing also depends on the resulting change in size-number relations of the newly isolated, fragmented ramets (Charpentier *et al.* 1998). Fragmented ramets are more vulnerable to other types of environmental fluctuations because they no longer benefit from the support of the mother plant. Alternatively, the creation of open spaces due to damage by predation can create conditions in which new seedlings might become established. Recent research suggests that regular rhizome severing promotes an increase in tuber production, but that it does not always lead to the production of larger tubers. An established clone responds to rhizome severing by sprouting otherwise dormant tubers, producing both consolidating and colonising below-ground networks with rhizomes of varying lengths and tubers of varying sizes. Fragmented ramets, those that become isolated from the mother plant through rhizome severing, no longer benefit from the translocation of nutrients from other parts of the clone. They typically respond to rhizome severing by producing consolidating below-ground networks which are composed of smaller tubers which grow at the ends of shorter rhizomes.

People would probably seek out plants that produce larger tubers. For example De Vries (1991) suggests that the variety of yellow nutsedge that was taken into cultivation (*Cyperus esculentus* var. *sativus*) was selected because it produces larger tubers than other wild varieties. Larger SCR tubers probably provide greater overall return rate (Kcal/hr) because they have higher relative carbohydrate contents than smaller specimens (Clevering *et al.* 1995). But isolated ramets may, under some circumstances, provide a better return rate because the tubers are consolidated closer to the stem base and within a smaller area, thus being potentially easier to locate and uproot. Again De Vries (1991) provides an example, he suggests that another reason

that yellow nutsedge (var. *sativus*) was preferred over other weedy varieties is that the rhizomes are characteristically shorter, such that the tubers are closer to the shoot base.

Rhizome severing also affects the character of above-ground growth. It is therefore possible that the growth habits and morphological features of SCR were known to prehistoric foragers, and used as indicators of plants with larger tubers and/or larger numbers of tubers. Charpentier *et al.* (1998) found that the ramets of established clones produce denser above-ground growth than plants that have become isolated through rhizome severing, that plants with taller shoots produce longer rhizomes and more numerous tubers than isolated ramets. Clevering *et al.* (1985) found that, although tuber size did not affect the length increment of shoots, larger tubers produced greater overall (above-ground and below-ground) biomass.

The information presented in this chapter suggests that if people were to intensively harvest SCR tubers, and on a regular basis, they would learn to distinguish which SCR plants have high below-ground productivity by observing the density of above-ground growth and associated morphological characteristics of the above-ground parts. The information also suggests that, if people were to intensively harvest SCR tubers, stands would need to be rotated to prevent overly fragmenting the clones, to allow mother plants to re-establish themselves, and to permit recently newly-severed, isolated clones to consolidate and enlarge their underground networks. Seasonal harvesting of the tubers, in the spring and late summer/autumn, appears to be the most productive collecting strategy, but opportunistic harvesting can be done at other times of the year. From the botanical and ecological literature it can also be inferred that intensive human harvesting of SCR may affect local wetland ecology, possibly altering the composition of semi-aquatic and aquatic flora.

# CHAPTER V. HARVESTING: QUANTITATIVE ANALYSIS (PRODUCTION RATES) OF Bolboschoenus maritimus TUBER YIELDS

The principal aim of the harvesting experiments was to assess the relationship between effective yields and human labour inputs. These experiments were necessary because, although the biological production potential of sea club-rush underground biomass is known and reported to vary from 42 g/m<sup>2</sup> dw to >3,000 g/m<sup>2</sup> (dry weight) (Kantrud 1996), questions remained about how much of that biomass is accessible to human harvesters. The most important question is: Can enough tubers be collected to make harvesting worthwhile? The harvesting experiments also provided opportunities to observe the availability and accessibility of the tubers, seasonal windows of opportunity and factors limiting their harvest.

## **5.1. HARVESTING SITES**

Two sets of timed harvesting trials were conducted. One was conducted in the Pevensey Marsh in East Sussex, England, and the other in the Konya Basin, on the South-Central Anatolian Plateau in Turkey.

#### 5.1.1. Konya Basin

In Turkey the harvesting experiments were carried out in collaboration with the Çatalhöyük Research Project (Wollstonecroft and Erkal 1999). Çatalhöyük is a Neolithic village site, situated on the Konya Plain about 60 km southeast of the presentday town of Konya, at 37°06′N, 32°08′E and ca 1000m asl (Figures 5.1, 5.2.). The Çatalhöyük Research Project, led by archaeologist Ian Hodder, includes archaeological excavation, ethnographic research and experimental projects. SCR is of particular interest to the Çatalhöyük research team because a relatively large number of the tubers



Figure 5.1. Map showing the location of Çatalhöyük in the Konya Basin. The site is situated on the Çarsamba alluvia fan delta (redrawn from Yakar 1991, page 18, Map IV).



Figure 5.2. Konya Basin landscape.

a b

**Figure 5.3.** Akgol which (**a**) up to the 1990s was the site of more than 7,000 acres of marshlands. (**b**) Akgol today (Eken 1998, page 98).





**Figure 5.4.** (a) Hotamiş Gölü in the 1970s (photo courtesy of Gordon Hillman); (b) Hotamiş Gölü today. The Epipalaeolithic rockshelter sites of Pinarbaşi in the background.



Figure 5.5. The Konya Basin irrigation canal harvesting site. Note that SCR grows in mono-specific stands throughout the canal.



**Figure 5.6.** SCR growing in the irrigation canal (Konya Basin). The substrate is a fine sand and the water depth is about 20 cm at the bank, deepening to about 50 cm in the centre of the canal.

have been recovered from domestic contexts at this site (Asouti *et al.* 1999; Fairbairn *et al.* 2002; Hastorf *et al.* 2000).

Although this region is a dry, steppe landscape, until recently lakes, wetlands and reed marshes flourished in areas where fresh water flowed into the Konya Basin (De Meester 1970; Roberts *et al.* 1999; Yakar 1991). These wetlands supported numerous semi-aquatic plants such as grasses, reeds, and rushes. Up to the 1990s, SCR was common in Konya Basin wetlands. It grew in dense stands within dikes and ditches around Ereğli, and the Selereki and Çarçamba fans, and in vast stands around the edges of Hotamiş Gölü (lake), particularly the western shores (G. Hillman pers comm.). During the 1990's these wetlands were lost due to increased drain-off of fresh water for agricultural purposes (Eken 1998). As a result, habitats that supported SCR were significantly reduced and by 1998 the former marshes near Ereğli and Hotamiş Gölü were almost completely dry (Figures 5.3. and 5.4).

We (Wollstonecroft and Erkal 1999) harvested SCR from an irrigation canal that runs through agricultural lands within the Çarçamba alluvial fan-delta, located approximately 600m east of the Çatalhöyük site. The irrigation canal habitat was chosen for our harvesting trials because it was the only reed bed within the area where we found SCR growing in, what we judged to be, sufficient amounts to support repeated harvesting. This habitat consists of homogenous stands of SCR which grow throughout the length of the canal (Figures 5.5 and 5.6). These stands are separated at intervals by spaces of open water and/or stands of cattail (*Typha domingensis* Pers.). Dock (*Rumex*) grows on the banks along the water's edge. The canal substrate is fine sand. Water depth ranged from 30 cm at the banks to > 50 cm in the middle of the canal.

#### 5.1.2 The Pevensey Marsh

In England I collaborated with Professor Gordon Hillman to carry out the SCR harvesting trials. We collected SCR tubers from an irrigation ditch within the Pevensey Marsh in East Sussex ( $50^{\circ}47^{\circ}N - 52^{\circ}54^{\circ}N$ ,  $0^{\circ}14^{\circ}E - 0^{\circ}28^{\circ}E$ ) (Figure 5.7). At present the landscape is composed of lowland grazing marshes for cattle and sheep, encompassing grassland, marshes and ditches. Up to Roman times saltmarshes covered the area for several hundred hectares. Since Roman times the marshlands have been drained by construction of creeks and ditches, to reclaim land for agricultural purposes. There has also been a reduction in salinity because many parts of the marsh are pump drained (Sussex Wildlife Trust 2002; Thompson 2001).

Numerous pockets of *refugium* persist within the Pevensey Marsh, habitats in which salt marsh plants, including SCR, continue to thrive despite changes in the surrounding environment (Thompson 2001). Our harvesting site is one of a number of small (approximately  $3 - 4 m^2$ ) patches of SCR that grow along the edges of an irrigation ditch. The substrate of the ditch is loamy, composed of sand, silt and small amounts of clay. Over the four years of the harvesting trials (1998 – 2001), we observed that water levels fluctuated considerably, from 40 - 80 cm in depth, due to seasonal, annual and inter-annual flooding.

This habitat is a mosaic of semi-aquatic plants, particularly reeds and grasses (Figure 5.8). SCR is locally dominant, growing on the open water side (Figure 5.9). A species of *Phragmites* is abundant and increasing; reed sweetgrass (*Glyceria maxima* C. Hartm.) and great pond sedge (*Carex riperia* Curtis) are frequent/abundant; branched bur-reed (*Sparganium erectum* L.) is frequent/locally abundant; and occasional species are quackgrass (*Agropyron repens* (L.) Pal. Beauv.), American waterplantain (*Alisma*)



Figure 5.7. Map showing the location of the Pevensey Marshes in East Sussex, England.



Figure 5.8. The Pevensey Marshes harvesting site is a mosaic of semi-aquatic plants, particularly reeds and grasses.



**Figure 5.9.** SCR growing in the Pevensey Marshes harvesting site. Here SCR is locally dominant, growing along the open water side of the habitat.

plantago aquatica L.), common scouring rush (Equisetum hyemale, L.), hard rush (Juncus inflexus, L.) and cattail (Typha latifola. L.).

## 5.2. METHODS

For the sake of brevity, in the paragraphs below the Konya Basin trials are designated as KB and the Pevensey Marsh trials as PM.

The PM timed harvesting experiments included eight individual trials which took place between September 1998 and September 2001: one in spring, two in the summer and five in the autumn. The KB timed trials encompassed eight individual harvests which took place in August 1999. In both sets of trials, specimens were uprooted by hand (Figures 5.10 and 5.11). Whole plants were collected, and prior to quantification, the tubers were washed, air dried and the stems, leaves, rhizomes and rootlets removed (Figure 5.12).

## 5.2.1. Verification of species identification.

Bearing in mind the taxonomic debate surrounding SCR (discussed in Chapter IV), I prepared voucher specimens of specimens collected in the UK and in the Konya Basin. To verify the species identification, these specimens were shown to Cyperologist David Simpson of the Royal Botanic Gardens at Kew. The English specimens were tentatively identified as *B. maritimus* var. *martimus* and the Turkish specimens *B maritimus* var. *tuberosus*, which correspond with recent taxonomic classifications as *B. maritimus* and *B. glaucus*, respectively (Hroudová pers. comm. and also Browning *et al.* 1995). However, as noted in Chapter IV, all specimens of SCR used in this research are treated as *Bolboschoenus maritimus s. lat.* ("*sensu lato*", or "in a broad sense").



**Figure 5.10.** Harvesting SCR in the Pevensey Marshes. Annual and inter-annual fluctuations in water levels ranged from (a) water depth of 40 cm; (b) water depth of 80 cm.





Figure 5.11. Harvesting SCR in the Konya Basin.



Figure 5.12. We uprooted the plant by hand, pulling up entire ramets (stem, leaves, tubers and roots).

### 5.2.2. Measurements, documentation and descriptions

In the field, the tubers were separated into mature and immature, and those that were deemed too old (rotten) for use were discarded. The number (n) and fresh weight (fw) of mature and immature specimens were both recorded for each harvesting trial, as well as the area ( $m^2$ ) covered by each harvester. For each trial the *number of specimens collected per hour* (n/h) and *production rate* (g/h) were measured. Production rate is defined here as a measure of *effective yield* in relation to *human labour input*, where effective yield is that part of the total crop which can be harvested by human collectors (Talalay *et al.* 1984). Human labour input is equal to one hour of harvesting. Immature tubers were counted separately and their frequency documented, frequency being the proportion of the gross return rate (% n).

#### **5.3. RESULTS: AVAILABLE YIELDS**

Table 5.1 summarises the results of the harvesting trial. The PM harvests consistently produced greater numbers of tubers (n/h) and larger production rates (g/h) than the KB harvests. The PM production rates and numbers were found to be 1271.8 g/h/person and 367 n/h/person, respectively. The KB production rates and numbers were found to be 521.8 g/h/person and 226 n/h/person, respectively. Means and coefficients of variation (CV) were calculated so that variations of the data obtained for the two sets of trials could be compared. The CV data were found to be high. Variations in the mean production rates were the same for both sets of trials, *i.e.* 49% CV. The CVs for the number of tubers obtained per hour were similar, 44% and 51% for KB and PM harvesting sites, respectively. Together these data suggest that effective yield, that part of the total crop which can be harvested by people, differed between the two harvesting sites but that labour inputs were consistent in both sets of trials.

Date specimens harvested	Harvester <sup>1</sup>	Number obtained: n/hr/person	Production rate: <sup>2</sup> g/hr/pers (fw)*	Area covered (m <sup>2</sup> /h)	
KONYA BASIN TRIALS;					
August 5, 1999	BB	292	676.00	2.00	
August 8, 1999	BB	242 519.20		0.90	
August 24, 1999	BB	125	288.00	0.44	
BB mean and CV		220 (39%CV)	<u>494.4 (39% CV)</u>	<u>1.11 (72% CV)</u>	
August 5, 1999	MW	192	2.00	2.00	
August 8, 1999	MW	300	0.77	0.77	
August 15, 1999	MW	382	0.52	0.52	
August 19, 1999	MW	193	0.97	0.97	
August 24, 1999	MW	79	0.44 0.44		
MW mean and CV:		229 (50% CV)	<u>538.3 (55% CV)</u>	<u>0.94 (67% CV)</u>	
KB: overall mean and CV:		226 (44% CV)	521.8 (49% CV)	1.01 (64% CV)	
PEVENSEY MAR	SH TRIALS	<u>:</u>			
Sept. 24, 1998	GH	433	1,344.80 0.50		
October 1, 1998	GH	294	912.40 0.60		
GH mean:		<u>363**</u>	1,128.60	<u>0.55</u>	
Sept. 24 1998	MW	575	2,300.00 0.50		
Oct. 1 1998	MW	485	1,946.40 0.60		
June 23 1999	MW	628	1,573.48 2.8		
March 31 2000	MW	156	629.96	1.00	
July 31 2000	MW	166	166 673.33 n		
Sept. 13, 2001	MW	198	794.00	n/a	
MW mean and CV:		<u>368 (60% CV)</u>	<u>1,319.6 (54% CV)</u>	<u>1.23 (87% CV)</u>	
PM: overall mean and CV:		367 (51)% CV	1,271.8 (49% CV)	1.00 (90% CV)	

Table 5.1. Results of the KB and PM harvesting trials: mature SCR tubers only

<sup>1</sup>Harvesters: BB = Basak Boz; MW = Michèle Wollstonecroft; GH = Gordon Hillman

<sup>2</sup>Specimens were washed and the stems, roots and rhizomes removed prior to weighing.

\*fw = fresh weight

\*\*No CV as two trials only.

Measurements of the areas covered by the harvesters during one hour of harvesting (shown in the right hand column of Table 5.1) indicate that, although more than twice the number and weight of tubers were obtained from the PM habitat than the KB habitat, similar areas were covered during both sets of trials. However, there are wide variations between the individual harvests, the CVs were 65% and 90% KB and PM, respectively. These patterns suggest that the differences between the rates of production of the KB and PM habitats are due to variations within each habitat, *i.e.* effective yield, rather than between-worker differences. One possible explanation for the CVs being higher in the PM trials is that the PM habitat contains several other semi-aquatic species, unlike the KB habitat, which is composed of homogenous SCR stands.

Date of Harvest	Harvester	Frequency: % total harvest	Number obtained:	Production rate:
mar vest		70 total halvest	n/h/person	g/m/person (iw)
KONYA B	ASIN TRIAI	<u>_S</u>		
Aug 5,	BB	9.9	32	96.4
Aug 8	BB	4.0	10	42.9
Aug 24	BB	4.6	6	19.1
Aug 5,	MW	5.9	12	92.4
Aug 8	MW	5.7	18	83.5
Aug 15	MW	n/a*	n/a*	n/a*
Aug 19	MW	9.4	20	26.8
Aug 24	MW	20.2	20	11.1
KB: mean	and CV:	8.5% (66%CV)	16.7 (54% CV)	53.2 (122% CV)
PEVENSEY MARSH TRIALS				
Sept 24	GH	3.8	17	52.0
Oct 1 1998	GH	4.5	14	44.5
Sept 24	MW	7.7	48	191.6
Oct 1 1998	MW	15.8	91	366.6
June 23	MW	16.5	124	196.7
Mar 31	MW	n/a*	n/a*	n/a*
July 31	MW	11.2	21	85.8
Sept 13	MW	10.8	24	97.3
PM: mean	and CV:	8.8% (57% CV)	48.4 (89% CV)	147.8 (77% CV)

Table 5.2. Results of KB and PM harvesting	z trials:	immature SCR tubers only
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<sup>1</sup>Harvesters: MW = Michèle Wollstonecroft; BB = Basak Boz; GH = Gordon Hillman.

<sup>2</sup>Specimens were washed and the stems, roots and rhizomes removed before weighing.

\* n/a = data not available

Table 5.2. shows the number of specimens collected (n/h) and production rates (g/h) of immature specimens, as well as the proportion of the overall harvest that they represent. Both sets of harvesting trials yielded similar frequencies of immature tubers, with numbers of immature specimens constituting mean values of 8.5 - 8.8%. Nevertheless, the frequencies (%) of immature tubers were widely dispersed for both sets of trials, with CV's of 57 - 66%, patterns that can only be attributed to natural factors such as time of year and habitat conditions.

## 5.4. DISCUSSION: CAN ENOUGH SCR TUBERS BE COLLECTED TO MAKE HARVESTING WORTHWHILE? HOW AVAILABLE AND ACCESSABLE IS SEA CLUB-RUSH, AND WHAT ARE THE LIMITING FACTORS?

The principal question behind the harvesting trials is whether or not the harvesting of SCR tubers is "worthwhile". In the present study worthwhile is defined as: returns that are suitable and/or sufficient for the labour inputs invested (albeit a group may consider harvesting to be worthwhile for other reasons, *e.g.* associated social and ritual activities and/or the exchange value of the tubers). Due to the subjectivity of this term, I searched the ethnographic literature for data on the types of harvesting returns different groups have considered suitable and/or sufficient for various types of wild root foods. The assumption here is that the ethnographic record can provide a reasonable baseline analogue for what groups consider worthwhile (suitable and sufficient), against which the PM and KB harvesting returns can be measured. Ethnographic studies were chosen that report on the number of specimens harvested (n/h) and/or rates of production (g/h) for wild root foods of economic importance.

The discussion begins with an assessment of the harvesting trial results, and comparisons with other published experimental harvesting studies. Subsequently, the question of whether enough mature and immature tubers can be collected to make 239

harvesting worthwhile is addressed. Finally, with an aim of identifying tuber availability, accessibility and seasonal windows of opportunity for harvesting, biological productivity and effective yields are considered. Following Munson (1984) and Turner (1988) accessibility and limiting factors are evaluated according to:

- i) geographic distribution and habitat characteristics, with a focus on the size (area in m<sup>2</sup>) of stands necessary to support intensive annual harvesting;
- ii) degree of visibility;
- iii) ease of uprooting;
- iv) time of year; and
- v) any other conditions that make collecting easier or more difficult.

### 5.4.1. Evaluating the data

As a first step in evaluating the results of the harvesting trials, the results were compared with those reported for wild arrowhead (*Sagittaria latifolia*) tubers. Comprehensive data on arrowhead yields are available thanks to research by Darby (1996). There are similarities in the habitat and harvesting conditions of SCR and arrowhead: both are indigenous to the temperate latitudes and are semi-aquatic, occurring in the emergent zones of wetlands.

Darby (1996) conducted six harvesting arrowhead harvesting trials. She reported rates of production of 608 - 2964 g/h (fw), with a mean of 1592 g/h (fw). These values are higher than those of SCR reported here (fresh weights of 522 g/h for KB, and 1272 g/h for PM).

On the other hand, similar numbers of specimens (n/h) were obtained in the SCR and arrowhead harvesting trials: SCR = 79 - 628 n/h (Table 5.1) and arrowhead = 88 - 352 n/h (Darby 1996). This suggests that the comparatively low KB and PM production

rates are due to tuber *size*, not the number of accessible specimens. Indeed Darby (1996) reported arrowhead weights of 4.6 -10.2 g/tuber with a mean of 7.8 g/tuber. SCR ranged in weight from 0.5 - 7 g (fw) with mean values of 2.3 g/tuber (KB) and 3.45 g/tuber (PM).

Significantly, when compared with weights of SCR tubers recorded by other researchers, the mean KB and PM values are notably low, less than half the weight. Clevering *et al.* (1995: 106) for example, report that specimens collected in The Netherlands weighed 6.8 - 19 g (fw) and similar mean weights are reported by Lieffers and Shay (1981) for specimens collected on the Canadian Prairies.

According to the biological literature, these discrepancies can be explained by habitat conditions and clone size, although researchers disagree about which variables have the greatest effect on SCR tubers size. Lieffers and Shay (1981, 1982a) argue that water depth is the most significant factor: that tuber size is greater in water depths of <20 cm, and significantly reduced when water levels rise above 30 cm. Clevering *et al.* (1995) otherwise suggest that clone size has more influence on size than water depth, and that large SCR clones produce larger tubers than small clones. Significantly, the habitat conditions and clone sizes of both the KB and PM harvesting sites accord with each of the above criteria for small tuber production: water depths were >30 cm, and the clones were small, covering only a few  $m^2$ .

The fact that other researchers report SCR tuber sizes that are more than twice the size of those collected from the KB and PM habitats indicates that the results of the harvesting trials (Tables 5.1. and 5.2.) represent only part of the picture. Thus, for the purpose of addressing questions about potential production rates, it was necessary to find a way to assess the types of yields that could be obtained from stands with larger tubers. Also, due to practical concerns about logistics and time, it was necessary to 241 make this assessment without additional fieldwork. Therefore, based on the assumption that the number of SCR tubers (n/hr) we obtained during the harvesting experiments were adequate and reasonable yields but that the specimens that we harvested were particularly small, potential production rates (g/h/person) were calculated using the actual numbers (n/h) in combination with larger tubers sizes reported in the literature. Potential production rates were calculated from the actual number of specimens collected in the KB and PM trials (from Table 5.1.) multiplied by the two weight classes reported by Clevering *et al.* (1995): *small*,  $8.9\pm 2.6$  g (fw); and *large*,  $16.2 \pm 2.8$ g (fw). These values are shown in Table 5.3.

From Table 5.3, it can be inferred that, if the tubers are within these size classes, and the n/h is comparable with those reported for the KB and PM habitats, production rates will range from 703 – 6188 g/h/person (fw), and 1388.4 - 10,173 g/h/person (fw) respectively. Because clones produce tubers of varying sizes, in Table 5.3 the mean weights of the small and large specimens were averaged to obtain estimated production rates of: 2831.6 g/h/person (fw) and 4605.8 g/h/person.

These calculations suggest that, to obtain 1 kg tubers, with the production rates of the actual harvesting trials (Table 5.1.), a KB worker must work for almost two hours, and a PM harvester for almost one hour. But when production rates are calculated using the tuber size classes reported by Clevering *et al.* (1995), as shown in Table 5.3, the amount of time harvesting is reduced significantly. Therefore, a KB worker could obtain 1 kg tuber in about 16 minutes and a PM worker in 10 minutes.

Date harvested	Harvester <sup>1</sup>	Actual number of tubers obtained <sup>2</sup> (n/h)	Estimated production rates small tubers g/h (fw): return rates x 8.9g	Estimated production rates large tubers g/h (fw): return rates x 16.2g
KONYA BASIN 1	<u>CRIALS</u>			
August 5, 1999	BB	292	2,598.8	4,730.4
August 8, 1999	BB	242	2,153.8	3,920.4
August 24, 1999	BB	125	1,112.5	2,025.0
August 5, 1999	MW	192	1,708.8	3,110.4
August 8, 1999	MW	300	2,670.0	4,860.0
August 15, 1999	MW	382	3,399.8	6,188.4
August 19, 1999	MW	193	1,717.7	3,126.6
August 24, 199:	MW	79	703.1	1,279.8
Overall KB mean:		224 (n/h)	2,008.1 (g/h)	3,655.1 (g/h)

**Table 5.3.** Potential rates of production (g/h fresh weight) for SCR based on two classes of mean tuber weights reported by Clevering *et al.* (1995)

KB mean estimated production rate for both size classes combined: 2,831 (g/h fw)

PEVENSEY MARS	H TRIALS			
Sept. 24, 1998	GH	433	3,853.7	7,014.6
October 1, 1998	GH	294	2,616.6	4,762.8
Sept. 24 1998	MW	575	5,117.5	9,315.0
Oct. 1 1998	MW	485	4,316.5	7,857.0
June 23 1999	MW	628	5,589.2	10,173.6
March 31 2000	MW	156	1,388.4	2,527.2
July 31 2000	MW	166	1,477.4	2,689.2
Sept 13, 2001	MW	198	1,762.2	3,207.6
Overall PM mean:		367 (n/h)	3,265 (g/h)	5944.4 (g/h)

## PM mean estimated production rate for both size classes combined: 4,604 (g/h fw)

<sup>1</sup>Harvesters: BB = Basak Boz; MW = Michèle Wollstonecroft; GH = Gordon Hillman <sup>2</sup>Table 5.1.

# 5.4.2. Comparisons of the results with ethnographically reported wild root food harvests

Ethnographic studies from around the world report that people invest significant amounts of time and labour to harvest wild and/or cultivated root foods when using non-mechanised methods (see Couture *et al.* 1986; Chikwendu and Okezie 1989;

Coursey and Feber 1979; Darby 1996; De Vries 1991; Hallam 1989; Hawkes 1989; Hunn 1981; Jones and Meehan 1989; Lowen 1998; Peacock 1998; Thoms 1989; Turner et al. 1990; Ungent et al. 1984, Ungent et al. 1986; White 1989). Of course the amount of time that people spends on harvesting depends on a number of factors, including the role of that species in the subsistence system of the group and the characteristics of the plant itself. But, in all cases the harvesting of wild root foods appears to be labour intensive. For example, a 19<sup>th</sup> century explorer travelling in northwest and Western Australia (Grey 1841, cited in Hallam 1989: 142), observed Aboriginal women uprooting yams (Dioscorea spp) with digging sticks, and wrote that "...they dig with great rapidity. But the labour, in proportion to the amount obtained, is great." Evidently a single yam can take from several minutes to several hours to uproot. Hallam (1989: 125) reports that in Northern Australia "Skilled [Gidjingali] women were able to obtain about 2 - 3kg of long yam (D. transversa) in about one hour of hard work." In her research in Thailand, White (1989) found that a wild yam known as Man nok (probably D. glabra), which weighed 200 g (fw) and measured about 8 cm in length, can be uprooted in about 10 minutes; whereas it took about 2.5 hours to obtain Man hoerp (a wild type similar to the cultivated Dioscorea alata), which weighed 4 kg (fw) and was >2 m long.

Few ethnographic reports were found that document the harvesting return rates of wild root foods. Indeed those of domesticates, particularly seed foods, are more often and more precisely documented. But cultivar yields cannot be compared with those of wild species because they have larger edible parts and/or are easier to uproot than wild varieties. For example, White (1989: 157) reports that certain species of wild and domesticated yams have similar weights, but cultivated varieties are easier to uproot because they form at shallower depths than the wild species. While cultivated yams can be uprooted in 10 - 30 minutes, wild yams require up to two hours of digging. In another example, De Vries (1991) found that domesticated varieties of yellow nutsedge (*Cyperus esculentus* L. var. *sativus* Boeck) are consistently larger than those of their wild counterparts, as well as being easier to uproot due to having shorter rhizomes so that the tubers lie closer to the foot of the plant. Likewise, Seiler (1990) reports that domesticated varieties of Jerusalem-artichoke (*Helianthus tuberosus* L.) produce larger tubers, which cluster near the main stem, while wild varieties produce smaller tubers at the ends of long rhizomes.

Harvesting production rates for 15 wild edible roots, species that are indigenous to North America, Thailand and Australia, are shown in Table 5.4. The purpose of Table 5.4 is to provide a range of values with which the KB and PM data can be compared, and not to provide an exhaustive list of wild root food yields. The production rates of the 15 comparative species, shown in Table 5.4, was found to range from 50 – 1350 g/h/person (dw), with an overall mean of 508 g/h/person (dw). To compare the production rates of SCR with those of the 15 wild edible roots, it was necessary to convert them to dry weights, thus both fresh and dry weights are shown in Table 5.4. This step was necessary in order to standardise the data because water (moisture) content varies significantly between species.

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Taxon	Region Estin	mated production rate (g/h/person)		<b>Ref.</b> <sup>1,2</sup>
Geophytes		fw	dw <sup>3</sup>	
Camassia quamash bulb	Pacific Northwest, North America	3,694	628	1, 3, 7
Dioscorea alata type tuber	Northeastern Thailand	1,600	352	8
Dioscorea cf. glabra tuber	Northeastern Thailand	1,200	324	8
Dioscorea hispida tuber	Northeastern Thailand	5,000	1350	8
Dioscorea transversa tuber	Northern Australia	2,500	675	8
Erythronium grandiflorum bulb	Interior, Pacific Northwest North America	450	50	6
Lewisia rediviva taproot	Interior, Pacific Northwest, North America	2,589	621	1, 3
Lomatium canbyi taproot	Interior, Pacific Northwest, North America	1,931	637	1, 3
Lomatium cous taproot	Interior, Pacific Northwest, North America	2,408	795	1, 3
Lupinus nootkatensis rhizomes	Northwest Coast	1,250	225	5
Potentilla pacifica roots	Northwest Coast	750	173	5
Pteridium aquilinium rhizomes	Northwest Coast	1,000	320	5
Trifolium wormskioldii rhizomes	Northwest Coast	500	80	5
Semi-aquatics				
Eleocharis dulcis tuber	Northern Australia	3,260	880	4
Sagittaria latifolia tuber	Northwest Coast	1,592	509	2
Mean production rate for all species:			508	

 Table 5.4. Estimated harvesting production rates (g/h/person) for 15 economically important species of wild edible roots

<sup>1</sup>References for production rates only: **1.** Couture *et al.* 1986; **2.** Darby 1996; 3. Hunn 1981; 4. Jones and Meehan 1989; **5.** Lepofsky *et al.* 1985; **6.** Lowen 1998; **7.** Thoms 1989; **8.** White 1989.

<sup>2</sup> See Table 4.2 for an explanation of the moisture and dry matter composition of each species

Figure 5.13 shows the actual and estimated KB and PM production rates (from Tables 5.1 and 5.3 respectively) alongside those of the 15 ethnographically documented species listed in Table 5.4. Again, comparisons are made on a dry weight basis. SCR dry weight values, based on a moisture content of 23.3% (see Chapter VI) were calculated to be: 122g/h and 296 g/h (dw) for the actual KB and PM trials respectively; and 659 and 1,072 g/h (dw) for the estimated KB and PM production rates, respectively.



**Figure 5.13.** Comparison of the SCR harvesting production rates (from Tables 5.1 and 5.3.) with the production rates of 15 other edible wild roots (from Table 5.4.). KB-A and PM-A denote the actual KB and PM production rates; and KB-E and PM-E denote the mean SCR production rates calculated from the tubers size classes observed by Clevering *et al.* 1995 (from Table 5.3. above). All values represent dry weights.

All SCR production rates, including the actual (KB-A and PM-A) and estimated values (KB-E and PM-E) are within the range of values delimited by the 15 comparative species. Moreover, while the actual SCR production rates are at the lower end of the scale, the estimated production rates are among the highest values on the chart: the PM-E value is second only to *Dioscorea hispida*; the KB-E value is greater than those of 11 of the 15 comparative species. Therefore, it can be concluded that SCR tubers are potentially worthwhile harvesting, when worthwhile is defined by the range of production rates known for economically important wild root foods.

#### 5.4.3. Is it worthwhile collecting only the immature SCR tubers?

Immature tubers were quantified separately. The reason for this is that immature are texturally different than mature tubers, and can be eaten raw, which suggest that mature and immature tubers may have been used as different foods. Given that immature SCR tubers can be eaten without processing, questions arose about whether ancient groups may have harvested SCR solely to obtain immature specimens.

Date of Harvest	Harvester <sup>2</sup>	Actual number of tubers	Estimated production rate (g/h) small tubers:	Estimated production rates (g/h) large tubers:
		obtained	Keturn rate X 8.9g	Keturn rate X 16.2g
KONYA BAS	IN TRIALS			
Aug 5, 1999	BB	32	284.8	518.4
Aug 8 1999	BB	10	89.0	162.0
Aug 24 1999	BB	6	53.4	97.2
Aug 5, 1999	MW	11	97.9	178,2
Aug 8 1999	MW	18	160.2	291.6
Aug 15 1999	MW	n/a*	n/a*	n/a*
Aug 19 1999	MW	20	178.0	324.0
Aug 24 1999	MW	20	178.0	324.0
Average mean	values:	16.7 (n/h)	148.8 (g/h)	270.8 (g/h)
KB mean esti	mated produc	ction rate for be	oth size classes combined	: 209.8 (g/h fw)
PEVENSEY N	MARSH TRL	ALS		
Sept 24 1998	GH	17	151.3	275.4
Oct 1 1998	GH	14	124.6	226.8
Sept 24 1998	MW	48	427.2	777.6
Oct 1 1998	MW	91	809.9	1474.2
June 23 1999	MW	124	1,103.6	2,008.8
Mar 31 2000	MW	n/a*	n/a*	n/a*
July 31 2000	MW	21	186.9	340.0
Sept 13 2001	MW	24	213.6	388.8
Average mean	values:	48.4 (n/h)	431.4 (g/h)	784.5 (g/h)
PM mean estimated production rate for both size classes combined: 607.9 (g/h fw)			: 607.9 (g/h fw)	

Table 5.5. Potential production rates (g/h fw) for immature tubers based on two classes of mean
tuber weights reported by Clevering <i>et al.</i> $(1995)^1$

<sup>1</sup>Small size class =  $8.9 \pm 2.6$ g (fw). Large size class of tubers includes specimens of  $16.2 \pm 2.8$ g (fw). <sup>2</sup>Harvesters: BB = Basak Boz; MW = Michèle Wollstonecroft; GH = Gordon Hillman <sup>3</sup>See Table 5.2.

n/a = data not available

Table 5.5. shows the estimated potential production rates of immature tubers when calculated from the size classes reported by Clevering *et al.* (1995). Using these figures, the estimated potential KB production rate is 53.4 - 518.4 g/h (fw); and the estimated potential PM rate of production is 124.6 - 2008 g/h (fw). Given that a clone

will produce tubers of varying sizes, the mean values were averaged to produce estimated potential return rates of 210 g/h (KB) and 608 g/h (PM).

From the actual production rates of the harvesting experiments (Table 5.2) it can be estimated that to obtain 1 kg immature SCR, a KB harvester must work for as much as 12 hours and uproot more than six kg tubers of all ages, whereas a PM harvester must work for nearly seven hours and uproot almost nine kg tubers of all ages.

Dry weights were subsequently calculated. Based on a 6.3% dry matter content (see Chapter VI), the actual return rates were calculated to be 3.4 g/h (dw) (KBi-A) and 9.3 g/h (dw) (PMi-A, and the estimated production rates were calculated to be 17.1 g/h (dw) (KBi-E) and 38.3 g/h (dw) (PMi-E) for KB and PM, respectively.



**Figure 5.14.** Comparison of immature SCR production rates (from Tables 5.2 and 5.5) with those of 15 other wild root foods (from Table 5.4.). KBi-A and PMi-A denote the actual immature SCR production rates; KBi-E and PMi-E denote the estimated immature SCR production rates, values that were calculated from the tubers size classes observed by Clevering *et al.* 1995 (Table 5.5. above). All values represent dry weights.

Figure 5.14 summarises the estimated and actual dry weight production rates of immature SCR tubers alongside those of the 15 comparative species listed in Table 5.4. In Figure 5.14 the immature specimens are at the lowest end of the scale, falling outside
the parameters of the 15 ethnographically documented examples. This suggests that it is not worth harvesting SCR tubers only for the purpose of utilising the immature specimens. Immature specimens might be collected on an opportunistic basis but do not occur in quantities large enough to provide a staple food.

Moreover, because the frequency of immature tubers varies widely, constituting 4-25% of the overall harvest, with CVs of 54-75\% (see Table 5.2.) even in productive habitats the return rate of immature specimens cannot be predicted. Therefore it can be inferred that the immature tubers can be used as an occasional food but cannot provide a staple. That is not to say that immature tubers might not be valued for other qualities, *e.g.* they can be eaten raw, without processing, so there are no post-harvest costs; and, due to their unique taste and texture, they provide a separate food.

# **5.4.4.** What size SCR stand (area in m<sup>2</sup>) is necessary to support intensive harvesting?

To estimate the size of SCR stand that would be necessary to support intensive harvesting, it was first necessary to consider how many days people would need to spend harvesting if SCR was an important food. Ethnographic examples from the Interior Plateau of the Pacific Northwest, the temperate zones of present day British Columbia, Canada, and Oregon and Washington, U.S.A., were selected as appropriate analogues for how many days might be spent harvesting. Like SCR, the wild edible roots discussed here are temperate zone species. Unlike people living in the tropical, arid or semi-arid zones (see Hallam 1989; Jones and Meehan 1989; and White 1989) people in the temperate regions must concentrate harvesting into a relatively short growing season (Darby 1996; Hunn 1981).

# How many days annually might a group spend harvesting in the temperate zones?

Wild edible roots were of major economic importance for Native groups living in the Interior Plateau of the Pacific Northwest. For example, Thoms (1989) estimates that a family could harvest enough camas (*C. quamash*) bulbs in one season to supply 20% of that family's annual energy intake. Hunn (1981) and Keely (1980) maintain that, taken together, the combined contribution of various root foods provided 50% or more of the minimum daily energy requirements of some Pacific Northwest groups.

Native groups of the Fraser-Columbia Plateau apparently spent anywhere between 14 - 60 days per species in the harvesting of root food, depending on the group and the plant. Lowen (1998: 107) estimates that Native families set aside 10 - 14 days to collect their winter supply (approximately 90 kg) of *Erythronium grandifolium* bulbs. Hunn (1981: 130) reports that people spent 30 - 40 days on the harvesting of wild *Lomatium* spp. taproots and up to 60 days in the harvest of *Lewisia rediviva* taproots. Thoms (1989: 46) estimates that Columbia Plateau people spent about 28 days collecting a winter supply of *Camassia quamash* bulbs. He states that they typically harvested 1,000 kg fresh weight during this period. Unfortunately, in most of these reports, it is not clear exactly how many people were involved in harvesting, nor how many people the 1,000 kg was expected to feed.

Table 5.6. summarises the ethnographic data, and calculates the mean number of days, 35, and mean amount of edible root, 908 kg, collected during that period. Based on the ethnographic data cited in Table 5.6, 35 days and 908 kg are considered reasonable guidelines for the amount of time and size of harvest that might be required by a family (e.g. two adults, two children) on an annual basis.

Taxon and plant pa	art (	Estimated number of lays collected annually <sup>1</sup>	Annual yield per family kg (fw)	Ref.s <sup>2</sup>
<i>Camassia quamash</i> (bulb)		21-28	1,000	3, 5
Erythronium grandiflorum (bulb)		10-14	90	4
<i>Lewisia rediviva</i> (taproot)		60	1,818	1, 3
L. canbyi (taproot)		30-40	1,050	1,3
Lomatium cous (taproot)		30-40	1,000	1,3
Sagittaria latifolia (tuber)		44	633	2
	Mean:	35 days	908 kg (fw)	

 Table 5.6. Estimated annual yields (kg) of root foods collected per family, for preservation and storage in temperate zones of North America

<sup>1</sup>Some species may well have been available and accessible for longer times than listed here, *e.g.* Darby (1996: 101) suggests that *S. latifolia* are available for at least 250 days a year.

<sup>2</sup>References: 1. Couture *et al.* 1986; 2. Darby 1996; 3. Hunn 1981; 4. Lowen 1998:107; 5. Thoms 1989.

Table 5.7. shows that, based on the actual harvesting trials (Table 5.1.), to obtain 908kg SCR tubers would take anywhere from 89 - 190 days for an individual harvester working for eight hours daily.

Harvesting trial	Hourly rate of production g/h	Daily rate of production g/8hr*	Number of days required to obtain 908 kg.
KB actual <sup>1</sup>	521.8	4.17	218
PM actual <sup>1</sup>	1271.8	10.2	89
KB estimated <sup>2</sup>	2831.6	22.7	40
PM estimated <sup>2</sup>	4604.3	36.8	25

 Table 5.7. Estimated number of days required per person to obtain 908 kg sea club-rush

1.Table 5.1.

2. Table 5.3.

In productive habitats, such as those reported by Clevering *et al.* (1995) and Lieffers and Shay (1981, 1982a) harvesting to collect 908 kg sea club-rush would take anywhere from 25 - 40 person days, if a harvester worked eight hours daily. Again, the number of days would be significantly reduced if several people were involved.

It is important to note that a period of eight hours is used here to standardise the data, for the purposes of calculating how many days a group would need to harvest SCR stands to obtain an annual supply. Again an annual supply is estimated to be 908 kg tubers (see Table 5.6). Whether or not people harvested for eight hours daily is possibly an exaggeration given that ethnographic reports show that hunter-gatherers participate in a range of other activities while harvesting wild foods, *e.g.* Thoms (1989: 461) points out that in the Pacific Northwest, during the camas harvest native groups spent at least 20% of the time on social and religious activities. Moreover, the number of hours and/or days of harvest would be reduced significantly if more than one person were involved.

# Estimated size of SCR stands (area in m<sup>2</sup>) that would be necessary to support intensive harvesting.

Table 5.8. provides estimates of the size of stands (area in m<sup>2</sup>) that would be required for 35 days of annual, intensive harvesting. The estimates shown in Table 5.8 are hypothetical. Nevertheless they provide useful guidelines for the minimum size stand that would be required if SCR tubers were to be used as a staple food. Given that 608 kg sea club-rush would provide for a family's annual needs, and that 608 kg could be obtained by one harvester with eight hours of harvesting daily, for 35 days annually, allowing for three and four year rotations an area of about one ha<sup>2</sup> would be required. Therefore, SCR stands that cover several hundred square hectares, such as those reported by Clevering (1995) and Kantrud (1996) could feasibly support regular harvesting by larger groups, such as several families, or even villages. On the other hand, access to numerous pockets of smaller stands which contain large clones, might also be sufficient.

KB and PM <sup>1</sup>				
Mean per person area covered in KB & PM harvesting trials <sup>1</sup> (m <sup>2</sup> )	Estimated area covered in 8 h daily (m <sup>2</sup> )	Estimated area covered in 35 days* (m <sup>2</sup> )	Estimated area required for 3-year rotation (m <sup>2</sup> )	Estimated area required for 4-year rotation (m <sup>2</sup> )
1	8	280	840	1120

Table 5.8. Estimated minimum size (area in m<sup>2</sup>) of SCR stands that would be necessary to support intensive harvesting in habitats with effective yields comparable with those of KB and PM<sup>1</sup>

<sup>1</sup>From table 5.1.

\*From the mean value from ethnographic data, (Table 5.4.).

# 5.4.5. Availability and accessibility of SCR tubers

The aim of this section is to discuss the growth habits and habitat requirements from the perspective of the harvester, rather than of a biologist (for a summary of the biological characteristics, growth habits and habitat requirements of SCR, see Chapter IV). Following Munson (1984) and Turner (1988), availability, accessibility and limiting factors were evaluated according to geographic distribution and habitat characteristics with a focus on the size (area in m<sup>2</sup>) of stands that are necessary to support intensive annual harvesting, degree of SCR plant visibility, ease of uprooting the tubers, best time of year for harvesting, and any other conditions that made collecting easier or more difficult.

### Geographic distribution and habitat conditions

The geographic distribution of a plant is important to consider because it influences that plant's *ecological salience*, which is the frequency and distribution of that species within a group's territory (see Turner 1988). Geographic distribution will influence how regularly the plant is encountered within the course of a group's daily and yearly routines.

Ecological salience undoubtedly influenced the use of SCR plants by prehistoric groups. The frequency of the seeds and/or tubers in Epipalaeolithic and Neolithic sites in Southwest Asia (Table 4.1.) suggests that during the late Pleistocene and early Holocene people encountered this plant often. It would be expected that SCR would be better represented at archaeological sites that, during the period that they were occupied, were in proximity to wetlands. Moreover, it can be inferred that intensified exploitation of this species is likely to occur where groups had accesses to productive stands. But the question remains: What size (m<sup>2</sup>) stands would be necessary to support the use of these tubers as staple foods?

Calculating the relationship between biological production and effective SCR tuber yield is beyond the scope of this project. Nevertheless, some conservative estimates can be made about the size of stands that would be necessary to support intensive harvesting. To do this, the following sections consider: i) under what conditions sea club-rush could withstand regular harvesting; and ii) how many days a year a group might spend on harvesting.

#### Under what conditions could sea club-rush withstand regular harvesting?

Beginning with the first question, no published studies on the effects of human harvesting on SCR stands were found, but reports are available on the effects of predation by birds and cattle. Ecological studies show that SCR can tolerate predation by up to 200 geese per hectare if underground productivity is such that each remaining tuber produces 40 new tubers (Clevering and van Gulik 1997). Ecological studies further suggest that a fallow period of several years should be allowed after heavy predation to allow existing clones to re-establish underground biomass, and to permit fragmented plants to develop a new network of tubers and rhizomes (Kantrud 1996). Diminishing return rates were observed during the harvesting trials (see Tables 5.1 and 5.2) which supports the argument that a fallow period is necessary between intensive harvests/predation. The number of specimens collected per area (n/h) and rate of production (g/h) diminished by more than 50% between the first and last trial in both the KB and PM harvesting experiments. These decreasing returns cannot be attributed to the fact that accessible specimens were collected during the earlier harvests because, in both sets of trials, harvesters collected specimens from different parts of the stand. Again, the KB harvests took place over a three week period, but the stands had been harvested a number of times in previous years by the Çatalhöyük Archaeobotany team for research purposes. The PM trials took place over several years, leaving time for new growth between trials.

On its own predation does not appear to have a negative impact on SCR tuber production, but it can be detrimental when combined with certain biological and environmental factors, such as changes in water levels or salinity *etc*. (see Chapter IV). Because so many variables affect tuber growth, it was not possible to pinpoint the cause of the diminishing returns in the KB and PM trials. Nevertheless, this trend has implications about this plant's potential role in a group's subsistence system, suggesting that intensification is possible only where groups had access to habitats large enough that harvesting patches could be rotated from year to year.

#### Degree of visibility and ease of uprooting

The degree of visibility of a plant is linked to its *perceptual salience*, which is defined as whether or not it is conspicuous and easy to recognise (Turner 1988: 277). During the growing season, March – September, SCR is easy to recognise because it occurs in relatively dense and often monospecific, stands, is relatively tall and has

unique florets. In mixed reed beds SCR stands are sometimes hidden from view by taller plants but because they tend to grow on the open waterside of the habitat, they are fairly easy to locate. During the winter months SCR plants can also be easily seen by their dead, standing stems.

Because SCR occurs in relatively shallow water, it is easily accessible to humans without the need for watercraft or special tools. I experimented with harvesting tools but found that sea club-rush tubers are best uprooted by hand-pulling, which accords with observations by other researchers about the harvesting of semi-aquatic root foods, e.g. *Typha* spp. and *Saggitaria lattifolia* (Darby 1996; Hillman, Madeyska and Hather 1989). On the other hand, it is possible that SCR growing in habitats with low water levels, such as mud-flats, or in the dry zone around saline wetlands, are more easily uprooted with a digging stick than hand-pulling. Geophytes such as *Camas, Erythronium,* Asteraceae, *Lomatium,* and *Dioscorea* spp. are usually uprooted from the soil with a digging stick (Thoms 1989).

SCR tubers require strong pulling to tear the rhizome in order to break off the ramet and/or pull the roots out of the substrate. In deep water, to locate and uproot the tubers the harvester must stand in (sometimes waist-deep) water, bend over and reach below the water, feeling into the muddy substrate for the tubers.

Given the effort that is required to uproot the tubers, it is unlikely that their occurrence in archaeological sites is due to accidental or natural factors. However, as noted in Chapter IV, the ethnographic literature reports several non-food reasons why people might choose to uproot the whole plant (including the tubers), *e.g.* when harvesting sedge stems to be used in weaving, people sometimes uproot the entire plant to maintain the full length of stems.

# Time of year

Harvesting, for the purposes of collecting samples and/or conducting timed trials, was carried out at different times of the year between 1998 and 2001. We found that the tubers were more easily obtained between March and October than during the winter months. There is some suggestion in the ethnographic record that, in dryer climates, harvesting is better in the spring, before wetlands dry up and the ground becomes hard (Chapter IV).

SCR were easily located during the winter month because some of the dead aboveground stems remain standing and are visible above the water's surface. Nevertheless, freezing conditions and high water levels made it extremely uncomfortable for the harvester to remain standing in the water for very long periods of time, let alone to find the tubers in the substrate below the water. In fact, after 15 or 20 min in the cold winter water our fingers became too numb to locate and uproot the tubers from the muddy substrate. In habitats with shallow water levels, such as mud flats, winter harvesting would probably by easier, especially if a digging stick of some type could be used, as suggested above.

Another problem during the winter was flooding, which inundated the Pevensey Marshes during October and November 2000. During such periods harvesting was impossible. Water levels were so high that the reed beds were only accessible by boat. However, even with a boat, SCR stands would have been difficult to locate due their ariel parts being submerged below the water.

#### **5.5. CHAPTER SUMMARY**

From the harvesting trials, and the comparison of SCR production rates with those reported for other wild tubers, it was inferred that SCR tubers are worthwhile harvesting. The effective yields of raw SCR tubers were found to be similar to those reported for wild root foods that have served as staple foods.

SCR is widely accessible to people due to its extensive geographic distribution, high degree of visibility, that it occurs in relatively shallow water, and that it can be uprooted without watercraft or tools. The tubers and rhizomes require a good deal of physical exertion to dislodge them from the mud/sand substrate, not unlike other wild root foods discussed in this chapter.

Harvesting was found to be easier during the warmer months, between March and September/October. But, in shallow areas, such as mud flats or dry zones around saline wetlands, it might be possible to use a tool to uproot the tubers. In that case, it might be feasible to harvest SCR tubers during the winter months.

It was observed that human uses of this plant might be limited by some SCR stands were found to be significantly more productive than others. Effective yields were found to range from a low of 522g/hr/person (fw) to an estimated high of 4604g/hr/person (fw). It was also concluded that biological production of the tubers, and tuber size are related to distinct habitat conditions, and that some of these conditions can be easily recognised, *e.g.* larger tubers occur in habits with greater numbers of clones and low water levels (Chapter IV this volume).

Another limiting factor in the intensive exploitation of SCR tubers is that the clone produces smaller tubers after being subject to predation and/or other types of disturbance that cause rhizome severing. Published reports suggest that heavy predation should be followed by a rotation period (see Chapter IV).

Calculations, based on the harvesting experiments and factoring in a rotation period of 3-4 years, show that stands of one hectare square could support regular annual harvesting, of up to 30-days by one harvester. It was estimated that a 30-day harvest 259 could provide enough SCR to meet the annual needs of a family, therefore can be inferred that stands of 91 - 500 ha, such as those reported by Clevering (1995) and Kantrud (1996) could support regular harvesting by small groups of people.

The calculations discussed in this chapter are based on the relative gross yields of SCR and other root foods in their raw, unpeeled form. Chapter VI assesses the nutrient composition of sea club-rush to determine if it has enough food value to make it worth harvesting.

# CHAPTER VI: QUANTITATIVE ANALYSIS OF NUTRIENT COMPOSITION OF Bolboschoenus maritimus TUBERS

This chapter deals with the food value of raw SCR tubers. Laboratory assays were conducted to determine the moisture, nitrogen, protein, lipids, carbohydrate, energy, vitamin C (ascorbic acid), total minerals (ash), and several individual minerals including calcium, magnesium, copper, iron, and zinc. Studies of the nutrient constituents of SCR tubers have been published (*e.g.* Clevering *et al.* 1995; De la Cruz and Poe 1975; Kantrud 1996; Yamanaka 1975), but were designed to answer biological and environmental questions. Therefore, in the present study the nutrient analyses were designed to address questions that are relevant to human consumption of the tubers: their potential food value and the best time(s) of the year for harvesting.

The chapter begins by explaining the general framework for compiling the data. The next section explains the individual laboratory materials and methods. Subsequently the results are presented and discussed. Comparisons are made with nutrient values reported for other wild edible roots in order to investigate whether or not SCR tubers can be considered worthwhile harvesting.

# 6.1. GENERAL FRAMEWORK FOR NUTRIENT DATA COMPILATION

Laboratory procedures were performed in the Department of Life Sciences and Nutrition in King's College, London. All procedures described below are known to produce accurate and reproducible results and are accredited by food chemists such as the American Association of Cereal Chemists (AACC) and Association of Official Analytical Chemists (AOAC). This section explains why specific nutrients were selected for analysis, the types of measurements that were used to compile the data, and the framework for interpreting the data.

# 6.1.1. Decisions about which nutrients to analyse

Decisions about which nutrients to analyse were based on archaeobotanical and archaeological questions. Carbohydrate, protein, and lipid are of particular interest here because they are the primary sources of energy in foods. Moreover, because ethnobotanical and archaeological publications on ancient and indigenous foods typically discuss foods in terms of energy, protein, and/or carbohydrates, these measurements are useful for comparison and discussion.

Prior to analysing the carbohydrate, protein, lipids, minerals, and energy of SCR tubers, the moisture was assessed. The importance of knowing the water (moisture) and *dry matter* (dm) contents of the food in question cannot be overemphasised. Dry matter is the material that remains after the moisture is removed, and contains the ash, carbohydrates, lipids and protein. Water is usually the main constituent in plant foods. It is standard procedure in nutrient analyses to report the moisture content of a foodstuff because the proportion of water directly affects the proportions of the other nutrients (Food Standards Agency and Institute of Food Research (FSAIFR) 2002; Kirk and Sawyer 1991).

The moisture content of plant foods is a factor in human dietary selection, past and present. The amount of moisture in a plant tissue affects how it reacts to different food processing techniques and how well a plant preserves under different storage conditions (Kirk and Sawyer 1991; Wills *et al.* 1998). In some cases high moisture levels might be desired, *e.g.* human groups typically harvest fruit and vegetables that are at maximum water content because it gives a more appealing "crisp" texture (Wills *et al.* 1998). In other cases low moisture levels might be desired, *e.g.* Burton (1982: 17) proposed that ancient peoples favoured cereals as staple foods because grains are low in moisture and therefore easily preserved and stored. Fruit and vegetables typically contain >90% moisture, whereas starchy tubers and seeds usually have significantly less (Wills *et al.* 1998). Keely (1980), for examples, found that the edible underground parts of wild geophytes (dryland plants), including those in the Compositeae, Liliaceae and Umbellifarae families, typically contain between 51 and 83 g/100g moisture, with an average of 65 g/100g. Semiaquatic root foods are known to range widely from species to species, *e.g. Typha latifolia* contains 9 g/100g moisture, *Sagittaria latifolia* has 68 g/100g and *Eleocharis dulcis* has 80g/100g (Holland, Unwin and Buss 1991; Turner and Kunhlein 1991). Kantrud (1986) reports that SCR tubers contain 87.5 g/100g moisture which seems high compared with values known for other wild edible roots. However, Kantrud did not specify whether they separated mature and immature tubers, the relative amounts of which are likely to influence the moisture content of the sample analysed (see section 6.2.).

Energy describes the amount of heat released when a sample is completely oxidised through combustion (Miller and Payne 1959). Lipids, protein, carbohydrates and alcohol provide the energy that is obtained from foods. Energy value is measured as kilocalories (kcal) and/or kilojoules (kJ), protein produces 4 kcal/g (17kJ/g); lipids (fats) 9 kcal/g (37kJ/g;) carbohydrate 3.75 kcal/g (16kJ/g); and alcohol 7 kcal/g (29kJ/g) (FSAIFR 2002).

Knowing the carbohydrate content of SCR is of particular importance to this study because, for many human peoples, past and present, carbohydrates provide the primary source of energy (Duyff 2002; FSAIFR 2002; Hunn 1981; Jerome 1977; Kuhnlein and Turner 1991). After water, carbohydrates are the most abundant constituents in food plants, typically comprising around 75% of the dry matter (Fennema 1996; Wills *et al.* 1998). Moreover, because carbohydrates contribute to the

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structural and storage components of the different plant parts, they play a part in the ways that plant products respond to food processing (Hultin and Milner 1978).

The term *carbohydrate* describes a group of compounds that are constructed from the same "monosaccharide building blocks" and are classified according to their degree of polymerisation: *monosaccharides* and *diasaccharides* are the simple sugars, their components contain 1 - 2 sugar units; *oligosaccharides* are carbohydrates with 3 to 9 sugar units of polymerisation; and *polysaccharides* are defined as polymers containing ten or more monosaccharide units (FAO 1998). In plants, carbohydrates occur as *reserve energy, structural compounds* and *naturally occurring polysaccharides*. Starch (discussed in more detail in Chapter VII) is the most common reserve carbohydrate in plants (Fahn 1990). Non-starch polysaccharides (NSP) include the structural carbohydrates (cellulose, hemicelluloses and pectic material) which form the cell wall and vascular tissue, and naturally occurring polysaccharides (gums and mucilages) that perform numerous functions such as responding to tissue damage (BNF 1990; Waldron, Parker and Smith 2003).

Although protein typically occurs in small amounts in plant tissue, it is one of the major constituents of the dry matter, along with carbohydrate, ash, and lipid. Protein was calculated from the nitrogen using the AACC Method 46-18 conversion factor (protein = nitrogen x 6.25, discussed below). Therefore it was necessary to calculate the nitrogen concentrations. Nitrogen is composed of proteins and non-protein compounds. In plants protein amino acids serve functional purposes, *e.g.* as enzymes for growth and development. Non-protein amino acids contribute to the colour, aroma and taste of plants (Evers *et al.* 1999; Fennema 1996). Plants usually contain low concentrations of protein. Pulses, seeds and nuts have relatively high levels, between 3 - 25 g/100 g (fw); while cereals (grains) contain 7 - 12 g/100 g (fw); fleshy fruit contain 0.5 - 3 g/100g (fw); and leafy vegetables have 5 - 7 g/100g (fw) (Fennema 1996: 947). Underground plant parts, such as tubers, corms, taproots and bulbs, usually contain lower protein levels than shoots, stems and leaves (de la Cruz and Poe 1975; Keely 1980).

There are several reasons why the crude fat (lipid) content of plants eaten by ancient peoples may be of interest to archaeologists, including understanding the relationship between prehistoric dietary selection, food processing and health. Lipids not only provide energy, they also promote the palatability of a foodstuff and act as enhancers of absorption of other nutrients such as fat-soluble vitamins and fatty acids (FSAIFR 2002; Woolfe 1987). Moreover when processed by heat, lipids bind with other nutrients, which affects the physical and chemical form of the foodstuff, and may also affect the bioavailability of macronutrients and micronutrients (Fennema 1996; FSAIFR 2002; Wills *et al.* 1998). Crude fat consists of a number of lipid substances, a combination of triacyglycerols, phospholipids, glycolipids, sterols and related compounds (Fennema 1996; FSAIFR 2002). Triacyglycerols, for example, form the main reserve material in oily nuts and seeds, and in pulses and cereals (Fennema 1996). Most fruit and vegetables contain less than 1 g/100g lipids, although pulses and seeds contain 1 – 18 g/100g, nuts 2 - 70 g/100g, and cereals 2 - 6 g/100g.

The term *ash* describes the inorganic constituents found in the dry matter. It is considered a rough measure of the total mineral content of the plant (Fahn 1990). In foods ash is determined from the inorganic residue that remains after the organic matter has been burnt off (Kirk and Sawyer 1991). Knowing the ash concentration is important because ash is one of the principal components of the dry matter of plants, along with protein, lipid and carbohydrate. Ash typically occurs in small concentrations in plants, ranging from 0.1 to 5.0 g/100g (fw).

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Several micronutrients that are common in plants, vitamin C (ascorbic acid) calcium, magnesium, iron, zinc and copper, were also assessed to investigate how SCR tubers might have contributed to prehistoric diet and health. Ascorbic acid (AA) was assessed to investigate if SCR may have contributed to prehistoric diet and health. AA is an anti-oxidant and helps with disease prevention. It is also important for bioavailability as it acts as an enhancer of absorption of other nutrients, such as iron (FSAIFR 2002).

Although root foods contain low concentrations of vitamin C compared with leafy vegetables or fleshy fruit, when eaten on a regular basis, root foods such as potato, cassava and yam, can provide the main source of ascorbic acid. In fact, the potato is the main staple source of vitamin C in Europe and North America (Kirk and Sawyer 1991; Tannahill 1973; Woolfe 1987). This can be explained by the fact that obtaining the daily requirements of necessary vitamins and minerals depends more on the amount of a food that is eaten than on the concentrations available in a food (Wills *et al.* 1998: 27-28). Moreover, the vitamin levels of root foods remain relatively stable for weeks after the plant is harvested due to the low metabolic rate of underground plant parts, whereas the vitamin levels of fruit and leafy vegetables quickly diminish after harvesting.

Calcium, magnesium, iron, copper and zinc were selected for analysis because they are among the most common minerals in plants. On a daily basis people need minerals in very small amounts. Trace minerals, such as copper, iron and zinc, are needed in amounts of less than 250 mg daily. Major minerals are required in greater doses, such as calcium (1000 mg daily) and magnesium (300 – 400 mg) (Duyff 2002). Minerals are essential nutrients that humans require for growth, development and health. Moreover they are necessary constituents of bone, teeth, muscles and blood and other tissue, and serve as part of body enzymes that regulate different types of body function. Although they do not directly contribute to the energy that we obtain from food, minerals do contribute to the processes that produce energy, *e.g.* zinc which helps the body to use protein, fat and carbohydrate (Duyff 2002). As well as being a necessary part of the human diet, minerals have other desirable effects that are of interest here, such as influencing how well a plant part will preserve during storage, *e.g.* higher levels of calcium can improve the shelf life and quality of certain vegetable foods (Fennema 1996).

# 6.1.2. Methods of measurement

In the laboratory, measurements were taken on a dry weight (dw) basis. For the sake of comparison with other studies, fresh weights (fw) were also calculated. Measurements are reported as g/100g in accordance with standard UK food tables (*e.g.* FSAIFR 2002). To obtain a mean and measure sample variability, three replicates per batch were assessed. Sample variability is presented as a coefficient of variation (CV) so that the relative dispersion of two or more assays of the same type, or two or more samples, can be easily compared.

To validate the mean values and evaluate the variability in the results, comparisons were made with data on SCR from other sources, primarily the published reports of Clevering *et al.* (1995) and Kantrud (1996). When information on SCR was lacking, or seemed inadequate, comparisons were made with published data on similar types of assays on similar types of edible plant parts, *e.g.* other tuberous Cyperaceae, semi-aquatic species, and/or other types of wild edible root foods. While such reports cannot be used to verify the accuracy of the laboratory results, they do provide a basis for assessing whether or not the data are reasonable. In other words, they provide a standard for delimiting the boundaries between wholly acceptable and unacceptable means and variations (see Thomas 1986).

# 6.1.3. Methods of interpreting the data

To address questions about the potential for SCR to be intensively exploited by people, production rates are calculated and compared with those estimated for other wild root foods (based on published ethnographic and nutrient studies). Again, the production rate represents effective yield in relation to human labour inputs, where effective yield is the part of the total crop which is available to human collectors (Talalay *et al.* 1984: 348) and human labour inputs are measured by one hour of harvesting. As described in Chapter 5, the effective yield was measured by the amount of fresh tuber obtained per harvest. In this chapter the effective yield is measured by the amount (g) of protein, lipid, carbohydrate and energy (k/cal).

#### **6.2. MATERIALS AND METHODS**

This section describes in detail the materials and techniques used, including sample collecting, sample (batch) preparation and the moisture, protein, lipid, ash, carbohydrate, energy, vitamin C and minerals assays.

#### 6.2.1. SCR sample selection

All tubers used for the nutrient analyses were collected from a single population of SCR growing in the Pevensey Marshes in East Sussex (see Chapter V). (As noted earlier, species identification was validated by Cyperologist Dr. David Simpson, of the Royal Botanical Gardens at Kew.) The choice of the Pevensey Marsh habitat was governed by convenience and practical considerations: concerns about the integrity of the samples, but also concerns about logistics and the time and expense that were necessary for repeat sampling. The Pevensey Marsh is particularly suitable as, in addition to having healthy stands of SCR, it is located close to London and samples could be transported to the laboratory within two or three hours after harvesting. It is important to minimise the transport time as much as possible because after harvesting 268 plants continue living and their nutritional components begin to change. Post-harvest changes are both physical and chemical, affecting the nutrient levels and preservation potential of a plant food, as well as its taste, texture, colour and the ways that it can be prepared and eaten (Sanz 2005; Wills *et al.* 1998).

For practical reasons it was not possible to subject all the samples to all the analyses. To profile the maximum high and low nutrient levels of SCR tubers, priority was given to tubers collected in March and July. Published reports suggest that SCR nutrients are highest in March and lowest in July (Boyd and McGinty 1981; Clevering *et al.* 1995; de la Cruz and Poe 1975). Samples collected in these two months were prioritised for the full set of assays: moisture, nitrogen, protein, lipids, carbohydrate, total and individual minerals and energy. To obtain additional information about changes in nutrients over the growing season, samples collected in April, June and October were subjected to a more limited set of assays, in this case moisture, lipids and energy. Repeat experiments were conducted when necessary.

# **6.2.2.** Preparation of the sample into a powdered form (batch) that is suitable for a series of nutrient assays.

The term *sample* is used here to indicate a specific group of tubers that were harvested from the same habitat in one episode. The term *batch* describes a portion of a sample that was, in one procedure, prepared into a powdered form that is suitable for a series of nutrient assays. The purposes of batch preparation are to reduce the sample particle size and to transform it into a representative, homogeneous, and thoroughly blended mixture. Methods were chosen that minimise, as much as possible, chemical changes to the samples that might affect the accuracy and precision of the subsequent nutrient assays (Kirk and Sawyer 1991; Pomeranz and Meloan 1980).

#### Estimating an adequate batch size

Batch size must be calculated prior to batch preparation. Kirk and Sawyer (1991) recommend preparing 200 - 400 g (dw). However, as noted by Kuhnlein (2000: 651) it is not always possible to obtain a sample of this size when analysing wild plant foods. In the present study, the minimum batch size that would yield valid results was found to be 46.5 g (dw) (Table 6.1.). This value was calculated from the total number and types of assays to be conducted, and the minimum amount of material required for each assay, multiplied by the number of replicates per assay, as shown in Table 6.1.

prepared sample needed per assay			
ASSAY TYPE	AMOUNT NEEDED PER REPLICATE (g)	x 3 REPLICATES PER ASSAY (g)	
Moisture	I	3	
Nitrogen/protein	1.5.	4.5	
Lipids (fats)	3	9	
Total energy (kcal)	1	3	
Ash (total minerals)	1.5	4.5	
Calcium	1.5	4.5	
Magnesium	1.5	4.5	
Copper	1.5	4.5	
Iron	1.5	4.5	
Zinc	1.5	4.5	
	TOTAL:	46.5	

**Table 6.1.** Calculating the required batch size (g dw) based on the minimum amounts of prepared sample needed per assay<sup>1</sup>

<sup>1</sup>Samples for vitamin C (AA) are not included here as they required different treatment during harvesting and batch preparation.

To obtain a batch size of 46.5 g from the mature tubers, it is necessary to prepare about 185 g fresh weight (fw) of peeled specimens. To obtain 46.5 g from the immature tubers it would be necessary to prepare approximately one kg fresh sample because immature specimens contain very low amounts of dry matter (section 6.2.3. below). For example, Batch 1, composed of immature specimens collected in July, provided enough . dry matter only for the nitrogen and energy assays. Therefore samples were pooled, immature tubers collected at different times of the year were mixed (Batch 5) to provide adequate material for the moisture, lipid, and energy assays. In this case, it was thought that season would not be a factor as the immature tubers are still in a state of growth. Whenever possible, excess batches were prepared to provide for contingencies such as repeat experiments, periodic moisture checks, and loss of material due to spillage *etc*.

#### **Batch preparation: materials and techniques**

Freshly collected tubers were frozen at  $-20^{\circ}$ C, in a raw unpeeled form, from arrival at the laboratory up to the time that they were prepared into batches. To facilitate the production of a sufficiently fine particle size, researchers (*e.g.* Pomeranz and Meloan 1980; Wang 1997) recommend that foods with high moisture content, such as SCR tubers, be desiccated prior to grinding. In addition to being easier to grind, desiccated foods have a longer shelf-life because they are less vulnerable to oxidative changes and microbial attacks. Freeze-drying was used here because it is rapid and conducted at low temperatures, conditions that are necessary for minimising enzymic modifications that can occur during batch preparation (Kirk and Sawyer 1991; Pomeranz and Meloan 1980). Steps in batch preparation are outlined below:

#### Steps in batch preparation:

- The tubers were washed and the stems, rootlets and rhizomes were removed, as well as the coarse outer layers of mature specimens (epidermis, cortex and endoderm).
- The tubers were ground to a coarse particle size (≤ 0.5 cm) with a laboratory mill (type 643 Moulinex).
- 3. The ground samples were put into cellophane bags and frozen for 24 h.

- 4. The cellophane bags containing the samples were removed from the freezer; perforated with a pin to allow air to escape during freeze-drying, and placed into a Christ Alpha 1-5 System freeze drier until dried, from 48
   72 h (depending on the amount of material in the freeze drier).
- After freeze-drying, the sample was again ground with the laboratory mill (type 643 Moulinex).
- 6. To obtain an acceptable fineness, the ground sample was sieved with a 1.00 mm mesh (Pomeranz and Meloan 1989; Seiler 1990; Wang 1997). Once the batch had reached a particle size of <1.00 it was not ground again.</li>

#### **Storage of batches**

Batches were stored at room temperature in screw-top clear glass containers, and kept in a darkened locker. Because prepared batches are known absorb atmospheric moisture (Kirk and Sawyer 1991), prior to use they were tested for moisture that had been re-absorbed during preparation and/or storage (using AACC method 44-15A, see section 7.2.3.2 below). Because moisture change affects the proportion of solid in the sample, it must be accounted for to prevent inaccuracies in calculating nutrients on a dry weight basis. Stored SCR batches were found to contain between 5 and 12% moisture.

#### 6.2.3. Moisture assay: materials and techniques

Five batches made from mature tubers were analysed, and these represent samples collected in March, April, June, July and October. One batch of immature tubers was analysed, Batch 5, which was composed of pooled samples that had been collected at different times of the year.

Gravimetric, distillation, chemical and instrumental methods of determining moisture are among the most common used by food chemists (see Kirk and Sawyer 1991). In the present study a two-stage gravimetric method was used, involving a drying process in which the sample weight was recorded before and after dehydration, and the moisture content calculated from the weight change (AACC Method 44-01).

The first stage of the moisture assay is similar to batch preparation. In the first stage the tubers were ground into coarse particles and freeze-dried. This stage served to control for moisture losses that might occur during initial grinding and to prevent enzymic changes to the samples. In the second stage of drying the tubers were further ground into a fine powder and subsequently fan-oven dried at 103° C (AACC Method 44-15A). Fan-oven drying is considered the best oven method because it gives consistent results and an increased rate of drying (Kirk and Sawyer 1991).

#### Stage one, freeze drying

- The tubers were washed and the stems, rootlets and rhizomes were removed, as well as the coarse outer layers of mature specimens (epidermis, cortex and endoderm).
- The tubers were ground into course particles (≤ 0.5 cm) with a laboratory mill (type 643 Moulinex).
- 3. The ground samples were weighed.
- 4. The samples were put into cellophane bags and frozen for 24 h.
- 5. The cellophane bags containing the samples were removed from the freezer; perforated several times with a pin to allow air to escape during freeze-drying, and placed into Christ Alpha 1-5 System freeze until dried, 48 72 h (depending on the amount of material in the freeze dryer).
- 6. The samples were removed from the freeze dryer, following AACC method 44-01, the samples were weighed and the moisture loss calculated at:

% moisture = 100 x loss of moisture/original weight of sample

#### Stage two, fan-oven drying:

- 7. Prior to the analysis, for each sample, three aluminium dishes and their lids (dimensions: approximately 55 mm diameter, 15 mm height), were sterilised and dried by washing, rinsing with distilled water, drying in the air oven and cooling in a desiccator with a silica gel drying agent.
- 8. The freeze-dried sample was ground with the laboratory mill and sieved through a 1 mm mesh.
- Each aluminium dish and lid were weighed; a measure of ≥1 g tuber flour was placed into the dish, the lid replaced, and the total weighed.
- 10. Each aluminium dish containing the sample was placed in the air oven at a temperature of 103°C, the lid was removed (remaining in the oven).
- 11. After 12 h, the covered dish was removed from the oven, placed into a desiccator until cooled, and subsequently weighed. (Note: a sample is considered dry once it reaches a constant weight).
- 12. Moisture loss was calculated according to AACC 2000 method 44-01:
- % moisture = 100 x loss of moisture/ original weight of freeze-dried sample
- 13. Total % moisture was calculated as:

moisture loss of stage 1+ moisture loss of stage 2

#### 6.2.4. Determining the nitrogen and crude protein content

The purpose of the assay was to determine the amount of organic nitrogen (N) and crude protein within the dry matter of the tubers. It was essential to determine the

nitrogen so that crude protein and metobalisable energy could be measured (section 6.2.7. below).

Mature samples collected in March and July, and one immature sample collected in July, were analysed. Organic nitrogen was measured using the improved Kjedahl method copper-titanium dioxide catalyst modification (AACC Method 46-16). The improved Kjedahl method copper-titanium dioxide catalyst modification method (AACC Method 46-16) is a two stage procedure involving first, digestion of the sample in a concentrated sulphuric acid, aided by a catalyst; and second, the distillation and titration of that solution with a Markham Steam Distillation Apparatus. The first stage, digestion (wet combustion) reduces the organic N in the sample to ammonia (NH<sub>3</sub>), which is converted and retained in solution as ammonium sulphate,  $(NH_4)_2SO_4$ ) (Kirk and Sawyer 1991). The solution is made alkaline by adding sodium hydroxide NaOH. The second stage, distillation (steaming) of the solution, releases the trapped ammonia, which is measured by titration.

The improved Kjedahl method is considered the most reliable procedure for determining organic nitrogen (Kirk and Sawyer 1991). Nevertheless, there are drawbacks to using this method to determine protein. The principal problem is that the results may contain some non-protein nitrogen because plants are high in non-protein nitrogen (Fennema 1996; Kirk and Sawyer 1991). Direct protein assays, such as the formalin titration, colorimetric (dye binding), direct distillation and spectroscopic methods are considered more exact methods for assessing protein (Kirk and Sawyer 1991). One trial with a dye binding method (Bradford 1976) was conducted but the results, which are not reported here, were questionable probably because the batch material did not digest well. In contrast, the improved Kjedahl method is easier to

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perform because the acid digests all the cellulose. Moreover, food chemists continue to consider this method acceptable for assessing protein.

# Improved Kjedahl method copper-titanium dioxide catalyst modification method (AACC Method 46-16)

# **Digestion:**

- A 1.5 g portion of batch was weighed onto N-free paper and the entire parcel put into a digestion tube.
- 2. One Kjeltab CTC catalyst tablet  $(K_2SO_4)$  was added to raise the boiling point of the reaction. Anti-bumping granules were also added to the digestion tube to prevent spillage and/or splashing.
- 3. The digestion tube was transferred to a fume cabinet. For every gram of sample, 20 ml of concentrated sulphuric acid  $(H_2SO_4)$  was added and mixed by swirling.
- 4. 5 ml of a 30% concentrated sulphuric acid-hydrogen peroxide ( $H_2SO_4/H_2O_2$ ) was added in drops.
- 5. Digestion occurred when the water was added. To further digest the mixture, the digestion tube was inserted into a heating apparatus and heated until clear, and for an additional 20 min to ensure all ammonia was converted to ammonia Sulphate. The mixture was considered digested when the solution turned light green, in this case after 2 h.
- 6. Approximately 50 ml distilled water was added while cooling the tube under cold running water.
- The solution was poured into a 100 ml volumetric flask and made up to 100ml with distilled water.

# Distillation

- 8. A series of standards were prepared consisting of 50 ml boric acid/indicator solutions. One of these was diluted with 10 ml water to provide a colour check at the end.
- 9. To prevent contamination, the Markham Steam Distillation Apparatus was steamed (flushed) out between each distillation.
- 10. A 5 ml portion of digest was pipetted into the sleeve of the steam jacket, followed by 5 ml water.
- 11. 10 ml of 40% solution of sodium hydroxide (NaOH) was added to the sleeve of the steam jacket to convert the solution to alkaline.
- 12. The indicator solution was added to the titration beaker, below the tip of the condenser, with the condenser tip under the liquid so that it trapped all the ammonia  $(NH_3)$  from the distillate.
- 13. A bunsen burner was placed under the steam generator to boil the water.
- 14. The steam generator and steam jacket were connected with a hose to begin distillation. When the indicator turned green, the tip of the condenser was removed from the liquid and distillation continued for 2 min.
- 15. The bunsen burner was removed to allow the steam jacket to cool, and produced a vacuum that served to draw the distillate out of the steam jacket.
- 16. The distillate was collected in a titration beaker.

#### **Titration:**

17. Boric acid was pipetted into the beaker until the distillate colour changed to match that of the indicator solution. Three titrations were made for each trial and the mean of the three was accepted as the correct value.

17. N was calculated by:

a. The titration value of the standard (indicator solution) multiplied by the titration value of the 5 ml sample (batch) = A.

b. Total mg N in 100 ml sample,  $B = A \times 20$ 

- c. Total mg nitrogen per gram of sample: N = B/sample weight (dw)
- 18. Crude protein was calculated with AACC Method 46-18 using a

conversion factor of 6.25:

Protein = 
$$N \times 6.25$$

### 6.2.5. Determining the lipid (crude fat) content

Five batches derived from mature specimens collected in March, April, June, July and October, and one batch from immature specimens collected at different times of the year, were analysed.

Lipid determination methods include solubilisation extraction, volumetric and physical assays. In the present study, lipids were determined by petroleum ether extraction (AACC Method 30-26), a distillation process of petroleum spirit (60-80°). This is a type of gravimetric method (calculated from weight changes) involving a direct, hot solvent extraction assay, otherwise known as a *soxhlet* method. This method is widely used by food chemists because it is expedient, precise and reproducable (AACC 2000). Soxhlet procedures involve heating the petroleum ether (pet ether) in a glass beaker over a water bath. A heated water bath is used for heating because pet ether is highly flammable and must be heated by an indirect method. The distillation apparatus, which sits over the water bath within a fume cupboard, is composed of a set of tubular glass condensers. Each condenser sits on, and drains into a glass beaker, and is hooked up to a cold-water tap for cooling.

Once heated, the pet ether becomes a gas that rises into the attached glass condenser. When this vapour comes into contact with the condenser tube, which is cooled by cold water, it turns from a gas back to a liquid. The (now liquid) pet ether drips onto the sample, contained within a cotton thimble at the base of the condenser tube, and causes the lipids within the sample to liquefy. The lipid/pet ether mixture then drips into the beaker below. The amount (%) of lipid is determined from the weight gain of the glass beaker and/or the weight loss of the cotton thimble.

### The soxhlet method:

- In preparation for the assay, glass beakers were washed, dried and weighed, and a set of paper thimbles were dried in the muffle oven and placed in a desiccator.
- 2. A paper thimble was removed from the desiccator and weighed before adding a portion of  $\geq 3$  g batch to the thimble that was again weighed.
- 3. The thimble was placed into a glass condenser within a fume cupboard.
- 4. Pet ether was placed into the glass beaker.
- 5. The beaker was put into the fume cupboard, over a water bath, and coupled to the condenser containing the thimble.
- 6. The pet ether was heated to boiling point.
- 7. When heated, the pet ether became a gas and rose up from the beaker and into the condenser.

- 8. Lipids were considered extracted once the solution around the thimble became clear, usually after about 72 h.
- 9. The flasks were cooled and weighed.

#### **6.2.6.** Determining the ash (total minerals) content

Ash was determined by a gravimetric method in which the sample is incinerated in a muffle oven, AACC Method 08-01. Mature tubers, collected in March and July. were analysed for ash content. Unfortunately it was not possible to assess the immature tuber samples due to scheduling of the assays and the sample material that was available at the time.

#### Ash, AACC Method 08-01:

- $1. \ge 1.5$  g batch was weighed into a porcelain crucible.
- 2. To reduce the time in the muffle oven, the replicates were charred on a hot plate for 1 h.
- The replicates were incinerated in a Gallenkamp Muffle Oven overnight at 450°C until a constant weight was achieved, in this case 24 h.
- 4. The crucibles were cooled in a desiccator.
- 5. The crucibles were weighed again, the weight of the residue being equivalent to the weight of ash.
- 6. Ash was calculated:

% Ash = 100 x (<u>weight of residue</u>) original weight of batch portion

# 6.2.7. Determining the carbohydrate content

The most precise to way to determine carbohydrates is to analyse the simple and complex sugars individually, using chemical methods, and then to add the results (FAO

1998). However, the subtraction method, which was used here, is widely used by food chemists because of its expediency. Furthermore, this method is commonly used to address archaeological and ethnographic research questions about carbohydrates and/or soluble sugars (see Keely 1980; Lowen 1998; and Peacock 1998). Carbohydrate levels were ascertained by calculating the difference:

100% - (% protein + % lipid + % ash) = carbohydrate (dw)

Therefore, the carbohydrate content can be calculated for all samples that have been analysed for protein, lipid and ash.

#### **6.2.8.** Determining the energy (kcal/kJ)

Five batches of mature tubers were analysed, representing samples collected in March, April, June, July and October. One batch of immature tuber was also analysed (Batch 5), representing pooled samples.

In the laboratory, energy (kcal/kJ) was determined using a Ballistic Bomb Calorimeter CB 370. In this procedure, the sample is placed into the casing of the bomb calorimeter and ignited (oxidised). The amount of heat released at the time of oxidisation is measured by deflection on a galvanometer. It calibrates the change in conductivity of the thermocoupler that is attached to the top of the casing of the bomb calorimeter (containing the material being oxidised). Prior to assessing the sample materials, a blank (bl) was tested in the deflection on the galvanometer, and the galvanometer was calibrated by bombing a sucrose standard (x three replicates).

The bombing of the samples encompassed the following steps:

#### **Steps in Ballistic Bomb Calorimetry**

1. Approximately 0.5 g (dw) batch was weighed into a silica crucible.

2. The crucible was placed on the pillar in the bomb calorimeter.

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- 3. A cotton thread (length: approximately 7 cm) was placed between the platinum filament and the material being oxidised.
- 4. The chamber was shut and the sample ignited.
- 5. The value was read off the galvanometer and the gross energy calculated by calibrating that value with the value obtained from the sucrose standard (Miller and Payne 1959).
- 6. Metabolisable energy (ME) was calculated from the gross energy using a standard formula (Miller and Payne 1959).

# 6.2.9. Determining the Vitamin C (AA)

Sample collecting and preparation were different for the Vitamin C analysis than the other assays used in this study. Fresh samples were collected specifically for vitamin C analyses. They were harvested in January, at the height of plant dormancy, and in July, at the height of photosynthesis. Specimens were frozen immediately after harvesting on dry ice (carbon dioxide snow). They were kept frozen during transport to London and subsequently stored in the freezer at  $-20^{\circ}$ C until used. Sample preparation did not involve dehydration, consequently the AA concentrations are reported on a fresh weight basis.

Vitamin C was assessed with a titration method, encompassing an extraction procedure (AACC Method 86-10). Using a pestle and mortar, samples were macerated with a solution of metaphosphoric and acetic acid, which prevents oxidation and has a stabilising effect (Kirk and Sawyer 1991:). The filtered extract was titrated against a standard made with crystalline indophenol dye.

### Stage 1: prior to the vitamin C assay

- A dye was prepared by adding 100 mg crystalline indophenol dye to 100 ml boiled distilled water.
- 2. An ascorbic acid standard was made from a mixture of 50 mg ascorbic dissolved in 100 ml metaphorphoric and glacial acetic acid and made up to 1000 ml with water.
- 3. The crystalline indophenol dye solution was calibrated by titrating it against a 5 ml portion of the ascorbic acid standard.

# **Stage 2: the assay**

- 4. Samples were removed from the freezer and ground with sand in a solution of 15 g metaphosphoric acid in 20-glacial acetic acid and 450 ml water.
- 5. The mixture was filtered through muslin cloth into a 100 ml flask.
- 6. The extract was made up to a standard amount (100 ml) with distilled water.
- 7. Portions of 5 ml extract were decanted against the indophenol dye.

### 6.2.10. Mineral assays: calcium, magnesium, copper, iron, and zinc

Mature SCR tubers collected in early March and July were analysed for calcium, magnesium, copper, iron, and zinc. A wet ashing method was used to digest the sample. It eliminates the organic constituents and producing a residue that can be analysed with an atomic absorption spectrometer. Wet ashing involves oxidising (digesting) the batch in a solution of concentrated Nitric acid, and heating the digest over a sand bath in order to reduce it to less than 5 ml. Nitric acid is used in this process because has an acidity that is comparable to the samples when they emerge from the wet ash, and also because it prevents micro-organisms from growing in the digest.

The digest was measured with a Unicam Solar AA 929 atomic absorption spectrometer. This apparatus assesses the colour of absorbed light emitted by the atomised digest to determine the amount of an element that is present in the digest.

#### **Digestion:**

1. A batch portion of 1.5 g was weighed onto nitrogen-free paper.

- The sample and nitrogen free paper were transferred to a 100 ml conical flask, 20 ml concentrated nitric acid (HNO<sub>3</sub>) added and the mixture swirled gently.
- The flask was place on a hot Gerhardt sand bath, within a fume cupboard, to digest the solution by boiling.
- 4. Digestion took approximately 2 h. The mixture was considered digested when the fumes changed from a deep brownish colour to a whitish colour, and the volume of acid in the conical flask was reduced to less than 10 ml.
- 5. The flask was removed from the sand bath and cooled in a fume cupboard.
- 6. The liquid from the conical flask was transferred with a pipette into a 10 ml volumetric flask and made up to 10 ml with de-ionised water.

#### **Measurement:**

6. Wet ash was measured with a Unicam Solar AA 929 Spectrometer. For Calcium only, a 10% lanthum chloride (Lacl.) was added to the digest (125 microliters) to prevent an interface due to silicates, which can interfere with a reading. 7. For each element, standards were read prior to and after each group of samples were analysed.

# 6.3. RESULTS OF THE LABORATORY ASSAYS

## **6.3.1. Moisture assay: results**

The results of the moisture assay (Table 6.2.) show that over the growing season the moisture content of mature SCR tubers fluctuates from a low of 71.4 g/100g (April) to a high of 78.4 g/100g (July), with a mean of 75.9%. Immature tubers were found to contain 93.7 g/100g moisture.

ВАТСН	MONTH HARVESTED	MEAN MOISTURE <sup>2</sup> : g/100g	MEAN DRY MATTER: (dm) g/100g	
Immature t	ubers			
5,1	Year-round	93.7	6.3	
Mature tub	ers			
3,8	March	76.7	23.3	
9	April	71.4	28.6	
7	June	75.6	24.4	
2.4	July	78.4	21.6	
6	October	77.5	22.5	
Matu	re tuber MEAN	75.9	24.1	

Table 6.2. Results: mean moisture and dry matter in SCR tubers<sup>1</sup>

<sup>1</sup>To obtain a mean, three replicates were assessed for each batch analysed (n = 3).

<sup>2</sup>For the immature tubers, the results of the first stage of analysis (freeze drying) had a coefficient of variation (CV) of <0.2; and 1 - 3.4% for the second stage (oven drying). Mature tubers produced a CV of <0.7 for the first stage of the assay, and 0.6 - 2.8% for the second stage.

#### Evaluating the results of the moisture assay

The results of the moisture assays were relatively homogeneous: replicates produced CVs of  $\leq 3.4\%$ . The mean moisture values reported here are approximately 10% lower than the 87.5 g/100g reported by Kantrud (1996). However, the moisture values of individual plants are known to vary substantially between studies due to natural factors as well as methods of sampling and laboratory procedures (see Keely
1980; Lowen 1998). For example, Keely (1980) collected seven samples of wild *Lomatium canbyi* roots from different regions in Washington State, and found them to vary from 61 to 71 g/100g moisture.

The moisture content of plants is highly influenced by genetic and biological factors, humidity, temperature, rainfall prior to harvest, season of harvest, crowding in stands; as well as post-harvest circumstances such as handling and storage (Boyd and McGinty 1981: Wills *et al.* 1998). Although published studies on SCR nutrients (*e.g.* Kantrud 1996; Yamanaka 1975) do not detail their methods of sample collecting and analysis, some differences between their methods and those used here can be inferred from their reports. For example, in the present study, the mature and immature SCR tubers were analysed separately, and prior to batch preparation the rootlets and rhizomes were removed; whereas Kantrud's (1996) report does not distinguish between immature and mature tubers, nor separate the tubers from roots, and rhizomes. This probably explains why his results were higher than those reported here.

#### 6.3.2. Nitrogen and protein: results

Immature SCR were found to contain 1.1 g/100g (dw) nitrogen and 6.7 g/100g (dw) protein (Table 6.3.). Mature SCR tubers were found to contain nitrogen concentrations of 0.7 - 1.2 g/100g (dw) with a mean of 1.0 g/100g; protein was calculated to be 7.8 g/100g (dw) in March and 4.6 g/100g (dw) in July, with a mean of 6.2 g/100g.

BATCH	MONTH	NITROGEN <sup>1</sup>		PROTEIN <sup>2</sup>	
	HARVESTED	g/100g (dw)	CV	g/100g (dw)	g/100g (fw)*
Immature	tubers <sup>3</sup>				
1	July	1.07		6.7	0.4
Mature tu	bers				
3	March	1.2	2.9%	7.8	1.8
4	July	0.7	3.4%	4.6	1.0
Mature	tuber MEAN:	1.0		6.2	1.4

Table 6.3. Results: mean nitrogen and protein in SCR tubers<sup>1</sup>

<sup>1</sup>To obtain a mean and CV, three replicates were assessed for each batch analysed (n = 3). For Batch 1 (immature tubers) no CV could be calculated because only two replicates were made.

<sup>2</sup>Following AACC 200: 46-18, a conversion factor of 6.25 was used to calculate protein.

\*Fresh weights are based on Table 6.2.

#### Evaluating the results of the nitrogen assay

The results of the nitrogen assay were relatively homogeneous, with replicates producing CVs of 2.9 - 3.4%. CVs were not calculated for the samples of immature SCR assays since only two replicates were assessed, due to a shortage of sample material. The nitrogen concentrations of SCR reported here correspond with those reported in the literature: 0.8 - 1.2 g/100g (Kantrud 1996). No published reports were found on the protein content of SCR tubers. From the published nitrogen values (see Kantrud 1996), and using the recommended conversion factor of 6.25 (AACC Method 46-18) SCR tuber protein was estimated as 5.3 - 7.4 g/100g (dw), which compares favourably with the values obtained here.

These values are also similar to protein concentrations in the below-ground parts of several related semi-aquatic species reported by de la Cruz and Poe (1975) *e.g.*, *Scirpus americanus*, 7.2. g/100g (dw); and *S. robustus*, 5.5 g/100g (dw).

# 6.3.3. Lipid (soxhlet) assay: results

Over the growing season lipid concentrations in the mature SCR tubers were found to range from 0.5 - 1.5 g/100g (dw), with a mean of 1.0 g/100g (Table 6.4.). Immature specimens were found to contain 0.8 g/100g (dw).

BATCH	MONTH		MEAN LIPID CO	ONTENT	
	HARVESTED	g/100g (dw)	CV	g/ 100g (fw)*	
Immature tubers					
5	Year-round	0.8	72%	<0.1	
Mature tubers					
3,8	March	1.5	38%	0.4	
9	April	0.5	21%	0.1	
7	June	0.9	12%	0.2	
2,4	July	1.2	50%	0.3	
6	October	0.8	48%	0.2	
Mature tube	er MEAN:	1.0		0.2	

**Table 6.4.** Results of the lipid assay: mean lipid levels in SCR tubers<sup>1</sup>

<sup>1</sup>To obtain a mean and CV, three replicates were assessed for each batch analysed (n = 3). \*Fresh weights are based on moisture analyses shown in Table 6.2, above.

#### Evaluating the results of the soxhlet (lipid) assay

The mean lipid concentrations presented in Table 7.4 are similar to the value reported in the literature: **O.8** g/100g (dw) (Kantrud 1996). The results of the present study also accord with lipid levels known for other wild root foods, which typically range between 0.4 - 1.2% (dw) (Appendix A).

However, the results of the lipid assays were highly dispersed, with replicates obtaining CVs of 12 - 72%. To check the accuracy of the initial results, specimens collected in March and July were subjected to repeat assays. These repeat assays confirmed the results of previous soxhlet analyses, and also produced widely variable replicates (up to 50% CV). Further assays of samples collected in April, June and October, also produced highly dispersed results (12 – 48% CV). This might be due to an uneven distribution of lipids within the batches, a problem that might, in part, be

addressed by grinding the batches into a finer particle size,  $e.g. \le 750 - 500 \ \mu\text{m}$ . As noted above, the SCR batches analysed here were ground to  $\le 1.00 \ \text{mg}$ . On the other hand, it might be that the lipid is differentially distributed within the tuber, and that the batch was not mixed sufficiently. Comparisons with results published by Keely (1980) and Kuhnlein (2000) suggest that this erratic pattern may be the norm for all plants where the lipid values are low.

#### 6.3.4. Ash (total minerals): results

Mature SCR tubers were found to have ash concentrations of 3.5 g/100g (dw) (March) and 3.3 g/100g (dw) (July), with a mean of 3.5 g/100g (dw) (Table 7.5).

Tuble 0.01 IV	coulds. mean ash levels in mata	le ben taben					
BATCH	MONTH HARVESTED	MEAN ASH CONTENT					
		g/100g (dw)	CV	g/ 100g (fw)*			
3	March,	3.5	3.7%	0.8			
4	July	3.3	1.8%	0.7			
Ma	ature tuber MEAN:	3.4		0.8			

Table 6.5. Results: mean ash levels in mature SCR tubers<sup>1.2</sup>

<sup>1</sup>To obtain a mean and CV, three replicates were assessed for each batch analysed (n = 3).

<sup>2</sup>Due to the scheduling of assays, and sample that was available at the time, immature tubers were not assessed for ash.

\*Fresh weights are based on moisture analyses shown in Table 6.2.

#### Evaluating the results of the ash (total mineral) assay

The results were relatively homogenous, with replicates having CVs of 1.8% and 3.7%. However, the SCR ash concentrations reported here are notably lower than those reported in the literature: 4.4 - 6.4 g/100g (Kantrud 1996). This discrepancy may be due to natural factors, between-worker or inter-laboratory variations, and/or differences in sampling methods. For example, Yamanaka (1975: 47) stated that his SCR ash values were unquestionably too high due to the fact that mud was not entirely removed from the tubers prior to analysis.

On the other hand, the ash composition of plants is highly influenced by environmental conditions, so it is likely that there were real differences between the samples analysed in this study, and those reported by other analysts. Keely (1980:36), for example, analysed seven different samples of the wild edible root *Lomatium canbyi*, collected at the same time of year, and found the ash content to vary by almost 1%, ranging from 1.0 - 1.9 g/100g (fw).

# **6.3.5.** Carbohydrates : results

Using the subtraction method (Table 6.6.) the total carbohydrates (starch and NSP such as structural and naturally occurring polysaccharides) of mature SCR tubers were determined as 87.2 - 90.9 g/100g (dw). Immature specimens were determined to contain 89.1 g/100g (dw).

BATCH	MONTH	PROTEIN	LIPID	ASH _	CARBO	<u>CARBOHYDRATE</u>		
	HARVESTED	g/100g (dw)	g/100g (dw)	g/100g (dw)	g/100g (dw)	g/100g (fw)		
Immature tubers <sup>3</sup>								
5	Year-round	6.7	0.8	3.4	89.1	5.6		
Mature tu	bers							
3	March	7.8	1.5	3.5	87.2	20.3		
4	July	4.6	1.2	3.3	90.9	19.6		

**Table 6.6.** Calculation of mean total carbohydrates by difference<sup>1.2</sup>

<sup>1</sup>Dry weight calculated as: carbohydrate = 100 - (ash + protein + lipid)

<sup>2</sup>Fresh weight calculated as: carbohydrate = 100 - (moisture + ash + protein + lipid)

<sup>3</sup>Because immature specimens were not assessed for ash, the carbohydrate concentrations of immature specimens were estimated using the mean ash values of mature tubers from Table 6.5.

#### Evaluating the results of the carbohydrate calculations

No published data on the total carbohydrates of SCR tubers were found.

Comparisons with a closely related semi-aquatic, Bolboschoenus robustus, showed

similarities: *B robustus* contains 86 g/100g (dw) carbohydrate (Kantrud 1996).

The reserve carbohydrates of SCR (*e.g.* starch) have been assessed by other authors, including Barclay and Crawford (1983) and Clevering *et al.* (1995). They reported that SCR reserve carbohydrates fluctuate from a high of 57 g/100g (dw) in early spring (March) to a low of 10 g/100g (dw) in mid summer (June/July). Crude fibre concentrations are reported to be approximately 10g/100g (dw) (Kantrud 1996).

Interestingly, Clevering *et al.* (1995) found that larger SCR tubers, specimens weighing  $16.2 \pm 2.8$  g (fw), contain greater proportions of reserve carbohydrate than smaller tubers, specimens weighing  $8.9 \pm 2.6$  g or less (fw). They attribute these variations to the different volume-to-surface ratio of large and small specimens. This suggests that the overall carbohydrate values calculated here (Table 6.6) may be conservative, as the samples were comparatively small, weighing <7 g (fw).

#### 6.3.6. Energy: results

The mature tubers were found to range in energy over the growing season from a low of 3.55 kcal/g dw (April) to a high of 3.78 kcal/g (dw) (July), with a mean of 3.74 kcal/g (dw) (Table 6.7.). Immature specimens were found to have 3.8 kcal/g dw.

ратси	MONTH		PGV kcal /a	MEANENI	MEAN ENERGY/100~		
DAICH	HARVESTED	kcal/g (dw)	CV	kcal (kJ) (dw)	kcal (kJ) (fw)*		
Immatu	re tubers						
5	year-round	3.80	5.0%	380 (1590)	24 (67)		
Mature	tubers						
8	March	3.75	3.6%	375 (1569)	88.5 (370)		
9	April	3.55	1.5%	355 (1485)	103.0 (430)		
7	June	3.67	3.8%	367 (1535)	90.3 (378)		
4	July	3.78	4.3%	378 (1581)	81.2 (340)		
6	October	3.77	2.8%	377 (1577)	85.5 (358)		
	Mature tuber mean:	3.74		374 (1564)	89.7 (375)		

 Table 6.7. Results of bomb calorimetery: mean energy (kcal/kJ) of SCR tubers<sup>1.2</sup>

<sup>1</sup>To obtain a mean and CV, three replicates were assessed for each batch analysed (n = 3).

<sup>2</sup>Kilojoules were calculated using the conversion factor: 4.184 kJ/kcal (FSAIFR 2002: 9).

\*Fresh weights are based on moisture analyses shown in Table 6.2., above.

### **Evaluating the results of the energy assay**

The results of the replicates were narrowly dispersed, mature tubers having CVs of 1.5 - 4.3% and immature tubers 5% (CV). The values reported here are lower than the 4.8 kcal/g (dw) SCR energy values reported in the literature, (Kantrud 1996). However, results of the present study are comparable with published data on other root foods, which typically range between 3.5 - 3.9 kcal/g dw (see Table 4.2.).

Energy provides an independent line of evidence for verifying the results of the other nutrient analyses. In other words, seasonal shifts in energy should correspond with trends in the overall nutrient profile. Thus, to validate the results of the bomb calorimetry, the energy values for the March and July samples. Following the metabolisable energy conversion factors published by FSAIFR (2002: 9), energy was calculated from the proportions of macronutrients, using the following equation:

Energy (kcal) = (g protein x 4) + (g lipid x 9) + (g carbohydrate x 3.75)

_	ENERGY k	.cal/100g (fw)	
	March <sup>2</sup>	July <sup>2</sup>	
NUTRIENT COMPONENT <sup>1</sup>			
Protein (at 4kcal/g)	7.2	4.0	
Lipid (at 9 kcal/g)	3.6	2.7	
Carbohydrate (at 3.75 kcal/g)	<u>76.1</u>	<u>73.5</u>	
Total energy kcal/100g (dw)	86.9	80.2	
<b>RESULTS OF THE BOMB CALORIMETRY:</b>	88.5	81.2	

Table 6.8. End	ergy (kcal/1	00g) calculated	d from prop	ortions of	f protein,	lipid and	carbohydi	rate of
matur	e SCR tuber	rs collected in I	March and	July				

<sup>1</sup>Reference for energy values of protein, lipid and carbohydrate: FSAIFR 2002: 9.

<sup>2</sup>March energy values based on: 1.8 g protein, 0.4g lipid, 20.3 g carbohydrate; July energy values based on: 1 g protein, 0.3 g lipid, 19.6 g carbohydrate (see Tables 6.3., 6.4. and 6.6).

The results of these calculations (Table 6.8) are virtually identical to those obtained by bomb calorimetry, the differences being within the CVs reported in Table 6.7.

# 6.3.7. Vitamin C: results

Mature SCR tubers were found to contain 0.45 – 1.18 mg/100g (fw) vitamin C

(Table 6.9.). Immature tubers were found to contain

0.42

mg/100g (fw).

Table 6.9. Results: mean vitamin C concentrations per 100g (fw) SCR tuber <sup>1</sup>								
MONTH HARVESTED	mg/100g (fw)	CV	% RDI/100g* (fw)					
Immature tubers								
July 30, 2000	0.42	4.8%	0.70					
Mature tubers								
January 23, 2001	0.45	10.1%	0.75					
July 30, 2000	1.18	41.0%	1.95					
Mature tuber mean:	0.82		1.35					

<sup>1</sup>To obtain a mean and CV, three replicates were assessed for each batch analysed (n = 3).

\*RDI (Recommended Daily Intake) is 60mg, based on values published by the American Dietetic Association (Duyff 2002).

### **Evaluating the results of the AA assay**

There was considerable variability between the replicates of the mature tubers, with the July sample producing a CV of 41%. Other studies of the AA of wild edible plants (*e.g.* Keely 1989; Kuhnlein 2000) also report considerable variability in the results but offer no explanations for these patterns. In the present study, the wide dispersion may be due to an uneven distribution of AA within the prepared sample. Indeed, during laboratory preparation the SCR tubers were found to be very tough, and required extensive processing to break open the cells and release the cell contents.

#### **6.3.8.** Minerals: results

The results of the mineral analyses are shown in Table 6.10.

MINERAL	<u>SA</u>	MPLE	RESU	JLTS: mea	an values	<u>% RDI/100g (fw)*</u>	
	Batch	Month	mg/100g	CV	mg/100g	Adult	Adult
		harvested	(dw)		(fw)	female	male
calcium (Ca)	3	March	55	11.0%	14	1.4	1.4
	4	July	47	9.4%	11	1.1	1.1
magnesium	3	March	108	6.9%	27	8.4	6.8
( <b>Mg</b> )	4	July	109	11.5%	25	8.1	6.3
copper (Cu)**	3	March	4	17.5%	1.0	111	110
	4	July	4	25.0%	0.9	100	100
iron (Fe)	3	March	91	17.0%	24	133	300
	4	July	84	13.3%	21	117	263
zinc (Zn)	3	March	4	27.5%	1.0	8.3	6.7
	4	July	6	25.0%	1.4	11.7	9.3

 Table 6.10. Results of the wet ashing: mean values for calcium, iron, zinc, magnesium and copper in mature sea club -ush tubers<sup>1</sup>

<sup>1</sup>To obtain a mean and CV, three replicates were assessed for each batch analysed (n = 3).

\*RDI is based on values published by the American Dietetic Association (Duyff 2002).

# **Evaluating the results**

The SCR calcium values reported here, 0.47 - 0.55 mg/g are somewhat higher than those seen in the literature which are reported to be 0.3 - 3.6 mg/g (dw) (Kantrud 1996). The SCR magnesium values reported here, 1.08 - 1.09 mg/g are within the range of those reported in the literature: 0.6 - 1.6 mg/g (dw) (Kantrud 1996). No published data were found on the copper, iron and zinc concentrations of SCR. Comparisons with other wild root vegetables suggest that SCR has relatively high levels of the copper, iron and zinc, but such concentrations are known for several species of wild edible roots (Keely 1980; Kuhnlein 2000; Seiler 1990) The results of the present study were highly dispersed, with replicates having CVs of 6.9 - 28%. Nevertheless, the variations among the replicates are low compared those reported for mineral assays of other wild edible plants (*e.g.* Keely 1980, Kuhnlein 2000, and Seiler 1990).

# 6.4. DISCUSSION: SEASONAL TRENDS, POTENTIAL FOOD VALUE

To briefly review, the timing and the length of the growing season of SCR vary with latitude, altitude, hours of sunlight, and other climate conditions (Lieffers and Shay 1982a, and Townsend and Guest 1985). In the Pevensey Marsh the annual growing season for the above-ground parts of SCR was observed to last from March through September, a pattern that is typical for this species in western European habitats (Clevering *et al.* 1995).

# 6.4.1. Seasonal trends and their implications for human subsistence strategies

Biologists classify the SCR growing season into two main phases: *submerged* and *emerged* (Clevering *et al.* 1995). The submerged phase, which lasts for approximately nine weeks, between March and May, is the period when shoots sprout from over-wintered tubers and begin to grow up towards the water's surface. Below-water leaves form and begin photosynthesis. The *emerged* phase of annual growth, which begins in June, occurs when the shoots have surpassed the water's surface and photosynthesis is transferred to newly formed above-water leaves. In the emerged phase the above-ground organs pass through the vegetative, flowering, and fruiting stages of maturity, reaching senescence in the autumn. Perennial below-ground growth begins after above-ground biomass has reached its optimum, typically in June, or July, although some below-ground growth occurs earlier as new tubers are produced as early as March.

Clevering et al. (1995) have shown that fluctuations in the concentrations of reserve carbohydrates (i.e. starch) in SCR tubers correspond with shifts from submergence to emergence. They observed that starch is at its highest level in the early spring (March), prior to initial (submerged) shoot growth. They further observed that reserve carbohydrates are depleted by more than 50% during submergence, beginning in April; and gradually replenished during emergence, after June, due to the translocation of newly produced photosynthates. Significantly, Clevering et al. (1995) demonstrated that changes occur in the quality of carbohydrates in SCR tubers throughout the growing season. They analysed exclusively the reserve carbohydrates (i.e. starch) of SCR tubers and observed that concentrations were about 57% (dw) in March and dropped to <18% (dw) by mid-May. Concentrations began rising again after emergence (July), with the translocation of newly-produced photosynthates. Other authors have shown that maximum below-ground biomass is achieved in the autumn, after aboveground senescence, when tuber growth is enhanced by the translocation of nutrients from the dying above-ground leaves and stems (see Kantrud 1996). Together, these studies suggest that the stages of submergence, emergence and the maturity of the aboveground SCR organs can serve as indicators of the nutritional quality of the below ground parts.

Barclay and Crawford (1982, 1983) found that, due to metabolic processes that are unique in this species, SCR tubers conserve energy during protracted oxygen-free periods, *e.g.* covered in deep mud and/or deep water during the winter months. These authors report that reserve carbohydrates are as high as 34% of the dry matter during the winter. This suggests that SCR may offer a good source of carbohydrate during the winter and early spring months when other edible plants are depleted of carbohydrate, or are unavailable. The results of the present study are consistent with Clevering *et al.*'s (1995) results which shows that fluctuations in lipid, moisture and energy can also be linked to the submerged and emerged stages of growth. Moreover, the present study supports Barclay and Crawford's (1983) findings that SCR tubers conserve energy over the winter months by showing that the tubers contain high levels of lipid, protein, ash, carbohydrates and energy (kcal) in the early spring (March).

The most abrupt change in tuber macro-nutrient concentrations were observed to occur in the interval between March and April, the first weeks of the submerged phase. Moisture, lipid, and energy decreased substantially during this period (Tables 6.2, 6.4 and 6.7) together with a decrease in starch (according to Clevering *et al.* 1995). In fact, concentrations dropped to their lowest annual levels during this period.



Figure 6.1. Summary of macronutrients in March and July samples

The total macronutrients in March and July samples are summarised in Figure 6.1. On a fresh weight basis, all macronutrients are shown to be higher in the March samples than the July samples, with the exception of moisture. On the other hand, Figure 6.1. shows that, on a dry weight basis, tubers collected in July contain higher 297 levels of carbohydrates than tubers collected in March. This increase in carbohydrates occurs in tandem with a steady rise in lipid and energy concentrations that began in June (Tables 6.4 and 6.7.) and corresponds with the emergence stage of growth. In fact, the lipid concentrations were second only to those of the March samples.

But how much do these shifts in nutrients affect the food value of SCR tubers? Certainly, compared with annual fluctuations (g/100g dw) in nutrient concentrations reported for other root foods, those of SCR appear relatively small. As shown in Table 6.11, the annual fluctuations of micronutrients are much narrower in SCR than in Jerusalem-artichoke (*Helianthus tuberosus*) and the bulbs of yellow glacier lily (*Erythronium grandiflorum*).

**Table 6.11.** Observed maximum amount of fluctuation, g/100g dw, over the growing season, including the vegetative, flowering and fruiting stages

	Moisture g/100g (fw)	Protein g/100g (dw)	Lipid g/100g (dw)	Ash g/100g (dw)	CHO g/100g (dw))	Energy (kcal/g)
SCR	7.0 <sup>a</sup>	3.1 <sup>b</sup>	1.0 <sup>a</sup>	0.2 <sup>b</sup>	2.5 <sup>b</sup>	0.1 <sup>b</sup>
Yellow glacier lily <sup>1</sup>	24.0	0.1	n/a*	3.9	4.0	0.2
Jerusalem- artichoke <sup>2</sup>	22.0	4.3	n/a*	n/a*	n/a*	n/a*

<sup>a</sup>Value calculated from five pooled SCR samples, collected in March, April, June, July and October. <sup>b</sup>Calculated from two SCR samples, collected in March, and July.

<sup>1</sup>From Lowen 1998: 145

<sup>2</sup>From Seiler 1990: 324-325

\*n/a = data not available

But, Clevering *et al.* (1995) demonstrated it is quality of the SCR carbohydrates that must be considered, rather than the total amount of carbohydrate that is present. They found that starch, which had declined substantially in SCR tubers collected during initial submerged growth in April, from 57% to 10%, are only beginning to increase in July. This suggests that the increase in total carbohydrates observed here in the July samples (Figure 6.1 and Table 6.6) may be due to increases in other types of carbohydrates, *e.g.* non-starch polysaccharides (NSP). Similar fluctuations in reserve carbohydrates have been reported for wild yams (*Dioscore a* spp.) by Chu and Figueirdo-Ribeiro (1991: 473). They observed that during the dryer periods of the year, starch concentrations decrease because reserve carbohydrates are utilised for building structural tissue. They also noted increases in moisture concentrations during this period which they attribute to the plants' need for water reserves during drier periods.

These patterns are interesting in that they may explain, in part, why SCR tubers are reported ethnographically to have been collected in spring or autumn, but there are no reports of them being collected in the summer (see Chapter IV). People may have found that tubers collected in the spring and/or autumn provided a more satisfying food.

SCR samples collected in October should contain nutrient concentrations similar to or greater those of the March samples given that, at the end of the growing period, growth is boosted by the translocation of nutrients from the above-ground organs (Kantrud 1996). But the October samples analysed here, which were collected October 9, produced lower values than expected, which suggests that they were collected too soon to exhibit significant increases. From this it can be inferred that belowground growth may continue later into the autumn, possibly into early winter (November). However annual growth is probably influenced by local conditions and may possibly vary from year to year, depending on climate conditions. People who collected SCR tubers in the autumn, *e.g.* the Blackfoot on the Canadian prairies (Johnston 1987), may have found the growing habits of SCR to be advantageous because harvesting could be accomplished after other resources, such as those with narrower seasons of ripeness, had been collected. On the other hand, an early onset of winter on the Canadian prairies might see the tubers inaccessible by November, due to the freezing of wetlands.

#### 6.4.2. Potential food value of SCR

To assess whether SCR tubers contain adequate food value to make harvesting worthwhile, this section compares their macronutrients and micronutrient levels with those reported for other wild edible roots. The discussion begins by quantifying the production rates of the SCR macronutrients and comparing them with those estimated for other wild roots. It is important to note that nutrient composition tables, such as those presented in this thesis, represent the mean concentrations of nutrients within a food, but do not indicate the fraction of the nutrient that is released from the food matrix during processing and consumption (bioaccessibility) (Ellis *et al.* 2004; Parada and Aguilera 2007). Thus, nutrient composition tables do not indicate the amount of the nutrient that is actually available for digestion, absorption and metabolic purposes (bioavailability). Put more precisely, nutrient (chemical) assays such as those carried out in this thesis, define the nutrient composition of a food, but do not indicate the fraction of the nutrient composition of a food.

# Are SCR tubers worthwhile harvesting in terms of macronutrients and energy?

Based on the results of the harvesting experiments (Chapter V) and the laboratory assays (this chapter), potential production rates were calculated for the amount of protein, lipid, carbohydrate and energy obtained in a one hour harvest of SCR. Potential production rates for the macro-nutrients of sea club-rush are calculated for both the *actual* and the *estimated* values of fresh mature and immature specimens, as determined in Chapter V (Tables 5.1. and 5.4). Again, *actual* rates of production represent the real g/h/person collected during the harvesting experiments, and *estimated* rates of production represent the same number of tubers as the actual rates, but their weights were calculated from the mean of the two classes of tuber weights in Table 5.4.

	Es	stimated pro	oduction rat	tes of macro	onutrients	(g/h/person	)
Species & type	Fresh weight	Dry weight	protein (dw)	lipid (dw)	ash (dw)	CHO	kcal
<u> </u>	weight	weight	( <i>uw</i> )	( <i>uw</i> )	( <i>uw</i> )	( <i>uw</i> )	( <i>aw</i> )
immature tuber	53	5	0.2	<0.1	0.1	3	13
Pmi-Actual: immature tuber	148	9	I	0.1	0.3	8	35
Kbi-Estimated: immature tuber	210	13.	1	0.1	0.5	12	50
Pmi-Estimated: immature tuber	608	38	3	0.3	ł	34	146
KB-Actual: mature tuber	522	122	8	1.8	4	106	456
PM-Actual: mature tuber	1,272	296	19	4.4	10	258	1,111
KB-Estimated: mature tuber	2,832	660	51	9.9	23	575	2,474
PM-Estimated: mature tuber	4,604	1,073	84	16.1	38	935	4,023
C. quamash	3,694	628	33	3.77	30	546	2,255
D. alata Type	1,600	352	33	2.82	10	306	1,295
D. cf. glabra	1,200	324	26	2.59	9	279	1,192
D. hispida	5,000	1,350	107	10.80	36	1161	4,968
D. transversa	2,500	675	53	5.40	18	581	2,484
E. dulcis	3,260	880	47	3.52	36	792	2,904
E. grandiflorum	450	50	2	tr.	1	46	180
L. rediviva	2,589	621	40	2.48	27	553	2,391
L. canbyi	1,931	637	50	7.01	27	554	2,446
L. nootkatensis	2,408	795	24	9.54	37	723	3,061
L. nootkatensis	1,250	225	25	4.95	10	185	887
P. pacifica	750	173	12	2.25	11	147	671
P. aquilinum	1,000	320	125	n/a	n/a	186	n/a
S. latifolia	1,592	509	75	3.05	24	407	1,639
T. wormskioldii	500	80	9	1.52	4	65	311

**Table 6.12.** Potential production rates (g/h/person) of macro-nutrients of unprocessed SCR tubers and 15 other wild edible roots<sup>1. 2</sup>

<sup>1</sup>The macronutrient profiles of each of the 15 comparative species are explained in Table 4.2.

<sup>6</sup> Calculated from SCR production rates, Tables 5.1, 5.2, 5.3 and 5.5, and mean nutrient values shown in Tables 6.2-6.10.



Figur 6.2. Comparison of estimated SCR protein production rates with values reported for other wild edible roots (see Table 6.12). Arrows indicate estimated minimum & maximum potential SCR production rates.



Figure 6.3. Comparison of estimated SCR lipid production rates with values reported for other wild edible roots (see Table 6.12). Arrows indicated estimated minimum & maximum potentials SCR production rates.



**Figure 6.4.** Comparison of SCR carbohydrate production rates with values estimated for other wild edible roots (see Table 6.12). Arrows indicate estimated minimum and maximum potential SCR production rates.



**Figure 6.5.** Comparison of SCR energy (kcal) production rates with values estimated for other wild edible roots (see Table 6.12). Arrows indicate estimated minimum and maximum potential SCR production rates.

Given the subjective nature of the term "worthwhile", in this section comparisons are made with the 15 economically important wild root foods discussed in Chapter V. These comparisons are shown in Table 6.12. Figures 6.2 to 6.5. illustrate how the production rates of SCR protein, lipid, carbohydrates and energy (kcal) compare with those calculated for the other edible roots described in Table 6.12 (The macronutrient levels of each of the comparative root foods are explained in Table 4.2.). Again, these plants are known to have been important foods for indigenous groups in the temperate zones of North America, and the arid and tropical zones of Australia and Southeast Asia. The rationale behind these comparisons is that the ethnographic record can provide a reasonable baseline analogue for what groups consider worthwhile.

The mature tuber production rates are well within the range provided by the 15 comparative species. While the KB-actual and PM actual production rates among the lower values shown in Figures 6.2.- 6.5, they are nevertheless similar to those of several other edible roots. Significantly, the KB-estimated and PM-estimated production rates are among the higher values in Figures 6.2. – 6.5. In particular, the lipid production rates of the PM-estimated values are the highest (Figure 6.3).

Immature SCR were found have the lowest production rates for all macronutrients (Table 6.12) and are therefore not included in Figures 6.2. – 6.5. The data suggest that immature specimens are not worthwhile harvesting when worthwhile is defined by protein, lipid, carbohydrate and energy. (Although, immature tubers may be considered worthwhile for other reasons, *e.g.* specific culinary uses.)

# Are SCR tubers worthwhile harvesting in terms of micronutrients (vitamin C and minerals)?

In this section the micronutrient levels of sea club-rush are assessed by their contribution to the daily Recommended Daily Intake (RDA) instead of comparisons

with other edible roots. This approach was adopted because there are often wide variations between samples of a single species obtained from different sources, particularly calcium, iron, magnesium and zinc (Bensen *et al.* 1973; FSAIR 2002; Keely 1980). Evidently the mineral concentrations of plant foods are heavily influenced by external factors such as climate, habitat conditions, and the amounts of other minerals in the plant tissue. In fact, Keely (1980: 50) found iron to vary as much as 400% among plants grown from the same seed source but grown in different locations.

## Vitamin C

The AA levels of mature SCR were found to range from 0.45 - 1.18 mg/100g. SCR, which is 0.75 to 1.95% of the recommended daily intake. Compared with AA values reported for other wild root foods (Table 6.13), the SCR AA values are low.

Species	Plant part	mg/100g fw	%RDI <sup>1</sup> /100g fw	Ref. <sup>2</sup>
Wild				
Immature SCR	tuber	0.42	0.70	Table 6.9
Mature SCR	tuber	0.82	1.35	Table 6.9
Wild onion (Allium spp.)	bulb	15 - 17	25 - 28	4
Camas ( <i>C. quamash</i> )	bulb	4	7	1
Jerusalem-artichoke (H. tuberosus)	tuber	4	7	4
Bitterroot (Lewisia rediviva)	root	27	45	1
Desert parsley (Lomatium canbyi)	taproot	20	67	1
Biscuitroot (L. cous),	taproot	17	28	1
Wapato (S. latifolia)	tuber	5	8	4
Domesticated				
Taro ( <i>Colocasia esculenta</i> )	corm	16	27	3
Yam ( <i>Dioscorea</i> spp.)	tuber	17	28	2,3
Water chestnut (E. dulcis)	tuber	4	7	2,3
Jerusalem-artichoke (H. tuberosus)	tuber	4	7	2
Sweet potato (Ipomeoea batatas)	tuber	23 - 26	38 - 43	3,5
Cassava (Manihot esculenta)	tuber	36	60	5
White potato (Solanum tuberosum)	tuber	20	33	2,5

 Table 6.13. Contribution to the recommended daily intake of vitamin C of various wild and domesticated edible roots.<sup>1</sup>

<sup>1</sup>Recommended Daily Intake is 60mg, based on values published by the American Dietetic Association (Duyff 2002).

<sup>2</sup>References: **1**.Benson *et al.* 1973; **2**. Haytowitz and Matthews 1984; **3**. Holland *et al.* 1991: **4**.Kuhnlein and Turner 1991: 352-363; **5**. Woolfe 1987: 24,

Given that SCR tubers weigh between about 2.5 and 16 g (fw), a person would need to eat the equivalent of approximately 16 large or 30 small tubers just to obtain 1.35% RDI. Thus even if they are eaten on a regular basis, SCR tubers would not provide an important source of vitamin C. Although the vitamin C concentrations of SCR tubers were found to be low, they may function to facilitate the absorption of other nutrients, *e.g.* iron. (Vitamin C concentrations in plants are highly affected by preharvest and post-harvest factors, see Lee and Kader 2000).

# Minerals

Table 6.12 shows that 100g fw SCR tubers provide the necessary daily intakes of copper and iron, as well as contributing to the necessary amounts of magnesium and zinc. The lowest SCR values in terms of RDI are those of calcium. Again, the contribution of a food to the daily intake of minerals, vitamins and other nutrients will depend on how often, and in what amount, that food is consumed.

Teeommended da	ing make	provided in	Too g (TW) SCR tubers		
	SAMPLE INFORMATION			<u>% RDI/100g (fw)*</u>	
MINERAL		Month		Adult	Adult male
	Batch	harvested	mg/100g (fw)	female	
calcium (Ca)	3	March	14	1.4	1.4
	4	July	11	1.1	1.1
magnesium (Mg)	3	March	27	8.4	6.8
	4	July	25	8.1	6.3
copper (Cu)**	3	March	1.0	111	110
	4	July	0.9	100	100
iron (Fe)	3	March	24	133	300
	4	July	21	117	263
zinc (Zn)	3	March	1.0	8.3	6.7
	4	July	1.4	11.7	9.3

**Table 6.14.** Potential contribution of minerals in mature SCR to the human diet: percent of recommended daily intake provided in 100 g (fw) SCR tubers

\*RDI is based on values published by the American Dietetic Association (Duyff 2002).

# **6.5. CHAPTER SUMMARY**

This chapter discussed the results of the nutrient analyses of SCR tubers and how the nutrient profile compares with that of other edible roots. The results suggest that mature SCR are as worthwhile harvesting as a number of other species, if worthwhile can be defined by the protein, lipid, carbohydrate and energy yields known for economically important wild root foods. Moreover, SCR tubers growing in productive habitats, represented here by the KB-estimated and MP-estimated values, were found to be highly worthwhile harvesting, having production rates that are comparable with those of other high yielding species, such as yams and arrowhead. Again, the nutrient values reported in this chapter are measures of the concentrations within the plants and do not indicate the fractions (amounts) of the nutrients that people actually obtain during consumption and digestion.

Notwithstanding other reasons why immature specimens might be harvested, in terms of nutrient values their yields were found to be outside the limits of what constitutes worthwhile. On a dry weight basis the nutrient profile of the immature specimens was similar to that of mature specimens. However, because immature specimens contained significantly higher amounts of moisture, on a fresh weight basis they contain very little dry matter (<7%).

SCR collected in the autumn (collected October 9) were not subjected to all the nutrient assays, but from those assays that were carried out: moisture, lipid and energy, it was concluded that the samples were collected too soon to reflect annual highs in nutrient levels. This suggests that the underground parts keep growing well into late October or November, after many other edible plants have diminished. For people who used this plant, this growing habit may have been an attractive characteristic because SCR could feasibly be harvested after other resources, with shorter seasons of availability, had been collected.

SCR macronutrients were found to be highest in mature tubers collected in the early spring (March). This can be explained by the fact that SCR tubers maintain their nutrient concentrations over the winter due to metabolic processes that are unique in this species, which allow them to conserve energy under anaerobic conditions (Barclay and Crawford 1983). This characteristic might be of great value to human groups. SCR tubers could, during the winter months, provide carbohydrates when other sources are unavailable or difficult to locate.

The present study builds on earlier research by Clevering *et al.* (1995) and Barclay and Crawford (1983), showing the shift in macronutrients over the growing season correspond with visible changes in the aboveground organs. Significantly, the stages of maturity of the aboveground parts are conspicuous and easy to recognise. This suggests that the stages of maturity of the above ground growth might serve as environmental indicators, providing human groups with a visual gauge of the food quality of the tubers.

# Ch VII. PROCESSING: OBSERVATIONAL STUDIES OF THE FUNCTIONAL PROPERTIES OF Bolboschoenus maritimus TUBERS

Based on the assumption that food processing is tantamount to intensification (Chapter III this volume), SCR food processing experiments and structural studies were carried out to address the following questions: i) Can the otherwise inedible mature SCR tubers be transformed into an edible form using processing techniques similar to those known to Epipalaeolithic groups? ii) Can more than one food product can be made from this single plant part? iii) What are the effects of the selected processing methods on the physical properties of the tuber tissue?

This segment of the study involved several different types of procedures and analyses. Thus, to facilitate reading, this chapter is ordered differently than the two other experiment chapters (Chapters V and VI). Rather than having a single methods section followed by the results and discussion, this chapter is organised into two main parts, each with a methods and results section. The first part presents the SCR food processing experiments. It explains the experimental methods, and describes the tastes and textures of the resulting foodstuffs. The second part presents the microscopy studies. It describes the techniques used to characterise the structure of the native and processed SCR, and illustrates and discusses the results. The properties of plant cell wall, and the effects of processing on SCR cell wall are examined first. Subsequently, the properties of starch and the effects of processing on SCR starch are examined.

# 7.1. SCR FOOD PROCESSING: EXPERIMENTAL METHODS

The processing experiments encompassed qualitative rather than quantifiable observations. Field experiments were conducted to observe the performance

characteristics of the mature SCR tubers when exposed to pulverising with a mortar and pestle, and/or thermal treatment. The objective was to produce three types of food from the tubers: bread, gruel and a steamed/boiled vegetable. The processing experiments also provided opportunities to taste the food products, and to observe the types of labour, technology and knowledge that are necessary to transform the mature SCR tubers into edible products.

# 7.1.1. Experiment locations, date, sample collecting, and species identification

Three sets of food processing trials were conducted. The first, which took place at the Primitive Technology workshop (Primtek) run by the Institute of Archaeology in East Sussex, September 1998, encompassed two pit-steaming experiments. The second, which took place at the Catalhöyük project in Turkey, August 1999, included bread baking and pit steaming. The third, conducted in London in September 2000, encompassed experiments in boiling, bread baking, and making a mush (gruel/porridge). With the exception of the Bread 1 experiment (see section 7.1.8. below), the ingredients used in the experiments included exclusively mature SCR tubers and water. For the Bread 1 experiment, SCR flour was combined with bread-wheat (*Triticum aestivum*) flour as well as water.

#### 7.1.2. Choice of experimental methods

The choice about which food processing techniques to use in the experiments was made after examining ethnographic reports in which SCR processing is mentioned, as well as reports that describe the processing of other types of wild edible roots. Most references that I found which discussed SCR tuber processing provided general rather than explicit information. In all cases, it was noted that the SCR tubers were first

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pulverised to the consistency of a flour or meal, and subsequently baked into bread or boiled as mush (Bryant 1783; CSIR 1972; Gott 1982; Tanaka 1976). Two studies provided somewhat more detailed information. The first of these, CSIR (1972: 258), reported that in India the SCR flour was mixed with barley flour to produce a bread, and that the tubers were peeled and dried before grinding into flour. In the second study, Gott (1982) reported that in Australia the tubers were roasted prior to pulverising into a flour. From these examples it was inferred that SCR can be eaten as a bread or mush after pulverising into a flour or meal. Following Lyons and D'Andrea (2003: 515), bread is defined as a pancake, a flatbread, or a loaf that is baked, fried or steamed.

However, consideration was also given to the fact that many other wild and domesticated root foods simply require baking, boiling or steaming prior to consumption, *e.g.* the potato (*Solanum tuberosum*). The most universally known traditional apparatus for cooking root foods is the earth-oven (Konlande and Robson 1972; Lowen 1998; Peacock 1998; Spier and Sapir 1930; Wandsnider 1997). The root food tradition of the Pacific Northwest of North America provides a good case in point. Groups living in that region steamed many types of wild edible roots in earth ovens, including the bulbs of *Allium cernuum* and *Erythronium grandiflorum*; the taproots of *Balsamhoriza sagittata, Lewisia rediviva* and various species of *Lomatium*; the rhizomes of *Pteridium aquilinium* and *Trifolium wormskioldii*; and the tubers of *Sagittaria latifolia* (Darby 1996, Lowen 1998, Peacock 1998, Turner 1992, 1997; Turner and Kunhlein 1982; Turner *et al.* 1990). In many cases the root foods were consumed as steamed or baked vegetables, without further processing, although in some cases additional processing was necessary (Dering 1999; Lowen 1998; Peacock 1998; Teit 1900, 1909). From these examples it was inferred that it would be useful to test

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whether or not SCR tubers could be eaten as a vegetable after being processed simply by boiling or pit steaming.

Accordingly, a series of processing experiments was designed with the objectives of producing bread, gruel and steamed/boiled vegetables from SCR tubers. The processing techniques used in these experiments included dehusking the tubers, pulverising them with a mortar and pestle and/or thermal treatment. These techniques are described and illustrated in the sections below.

## 7.1.3. Peeling the tubers

The tubers were washed and air-dried and then the outer layers (endodermis, cortex and epidermis) were removed (Figure 7.1. and see Figure 4.9). To remove the outer layers I experimented with several methods including soaking, immersing in boiling water for a minute, and charring in the fire, followed by hand rubbing the tubers and peeling with a small knife or shears. Peeling with a knife or shears was found to be the most effective method, although time-consuming. Soaking, immersing in boiling water, charring in the fire and hand rubbing had no significant effects.

### 7.1.4. Pulverising with a mortar and pestle

Samples prepared into bread and gruel were first pulverised into flour using wooden mortars and pestles. Human groups have used mortar-and-pestle technology since at least the Upper Palaeolithic where it appears to have been used primarily for pounding ochre. In Southwest Asia the first archaeological evidence of pounding technology being used on a regular basis to process food plants dates from the Early Epipalaeolithic. This phenomenon increased during the Middle and Late Epipalaeolithic (Wright 1992, 1994).



Figure 7.1. Peeled SCR tubers, as prepared for pit-cooking, boiling and pounding.



Figure 7.2. SCR tubers pounded into flour, as prepared when making bread and gruel.



**Figure 7.3.** Pulverising tools used in processing experiments: (a) wooden and limestone mortars; (b) Aylan Erkal pounding with the oval mortar and mallet; (c) Aylan Erkal pounding with the taller mortar and a pestle. The wooden mortars were purchased second-hand in Konya, Turkey. The limestone mortar was recovered from Neolithic levels of Çatalhöyük. (Images b and c are from Wollstonecroft and Erkal 1999). 314

To pulverise the tubers, I purchased two second-hand mortars in Konya, Turkey in 1999. Apparently mortars similar to these (Figures 7.2 and 7.3) were used in the recent past for pounding wheat by Konya Basin families who were unable to pay for mechanised milling (Wollstonecroft and Erkal 1999). Mortar 1 (Figure 7.2, 7.3 a, b) is oval-shaped, both internally and externally. The inside basin is wider at the top than at the base, narrowing in width from 17 cm to 10 cm, and narrowing in breadth from 13 cm to 8 cm (Table 7.1). It was used with a wooden mallet, Pestle 1, which has a curved head with a pounding end of 5 cm in diameter. The second mortar, Mortar 2, differs in size and (Table 7.1) and shape from the first, being cylindrical in external and internal shapes and the base of the internal basin is flat (Figure 7.3 a, c). A straight wooden pestle, Pestle 2, with a pounding end of 7 cm in diameter, was used with Mortar 2.

Table 7.1. Dimensions of two monars used for purvensing the SCR tubers					
	External dimensions	Internal dimensions			
	(height x width x breadth)	(depth x width x breadth)			
Mortar 1	17 x 26 x 19 cm	15 x 13 x13 cm			
Mortar 2	24 x 18 x 18 cm	12 x 14 x 14 cm			

Table 7.1. Dimensions of two mortars used for pulverising the SCR tubers

While carrying out the processing experiments at the Catlahöyük project, I also experimented with a limestone mortar with external dimensions of approximately 25 x 24 x 12; internal dimensions  $17 \times 17 \times 5$  cm (as shown in Figure 7.3 a, lower right). I preferred the wooden mortars because they are deeper, and therefore the tubers did not fly out during pulverising. However, that is not to say that a limestone mortar with a deeper bowl would not have proved useful. Also I found the wooden tools to be easier to manoeuvre than the limestone mortar, and as well as being easier to carry from one place to the other.

The pulverised tubers (flour) were subsequently used in the bread and gruel experiments. For bread flour, to obtain a fine particle size, the tubers were sieved through a 500  $\mu$ m mesh after pulverising. For making gruel, the tubers were pounded into the consistency of a meal, which was not sieved. In the experiments carried out in Turkey in 1999, Aylan Erkal and I did most of the pulverising of the tubers, but we were also assisted by members of the project (Wollstonecroft and Erkal 1999). In the experiments carried out in England, I did the pulverising on my own.

# 7.1.5. Thermal processing

Both wet and dry thermal processing experiments were conducted (Table 7.1.).

experiments to coo			
Cooking method	Apparatus	Cooking time	Temp. (°C)
Hydrothermal (water add	ed)		
Pit-steaming whole	Earth-oven	12-15 h	85-50*
boiling whole and sliced	Smeg SUK61 60 cm gas cooker	30 min	100
boiling as gruel	Smeg SUK61 60 cm gas cooker	10 min	100
Dry thermal (no water ad	ded)		
baking (Bread 1)	Tandir (circular mud-brick oven)	20 min	433**
baking (Bread 2)	Smeg SUK61 electric oven	30 min	250
derest.		1 1 (50% C) C 1	

 Table 7.2. Methods, apparatus, cooking time and temperatures used in the thermal processing experiments to cook SCR tubers

\*Pit-oven temperature range indicates readings at the beginning (85°C) and end (50°C) of cooking.

\*\*  $433^{\circ}$ C is the temperature of the heated tandir walls; at the fuel source the temperature was  $620^{\circ}$  C.

Hydrothermal methods (heat processing involving water) included pit steaming and boiling. Dry methods included baking. However, due to the high moisture composition of the SCR (native and processed) dry thermal techniques did involve a hydrothermal process. Temperatures were measured with an RS 53 K-type handheld digital thermometer, with a range of -50°C to 1300°C, coupled to an external measuring probe. These experiments are described below.

# 7.1.6. Earth-oven (pit-oven) cooking

An earth oven, also known as pit oven or roasting pit, is a shallow pit, with a depth of between <0.1 m to 1.5 m, which is heated by hot stones, lined with leaves and/or leafy boughs, and covered in matting and/or soil (Figure 7.4). The usefulness of the earth-oven is that it permits slow baking or steaming at moderate to high temperatures, heat levels that are required to cook raw plant and animal foods into forms that are digestible by humans.

Today earth-oven cooking is used primarily by groups living in the Pacific regions (Ishinge 1997; Sillitoe 1997). However, earth ovens are reported in ethnographic and historic accounts of 19<sup>th</sup> and 20<sup>th</sup> century explorers travelling in the Americas, Pacific Islands and Far East, and has been identified at prehistoric hunter-gatherer sites in many parts of the world, particularly in the arid zones (Dering 1999; Di Piazza 1998: Peacock 1998; Teit 1900, 1909; Pokotylo and Froese 1983). It is also likely that Mesolithic groups in northern Europe used earth ovens, given the apparent importance of root foods in that region (Kubiak-Martens 2002).

There is both archaeological and ethnographic evidence that ancient and modern people living in Southwest Asia pit cooked some foods, although at the time of writing, no evidence was found to show that this method was used to process plant foods. Ethnohistoric records of 19<sup>th</sup> century nomadic groups living in what is now Syria, report the cooking of small animal prey, such as rabbits, in small earth ovens (Moore *et al.* 2000: 88). Stone-filled earth ovens appear to have been introduced to Southwest Asia during the Middle Epipalaeolithic (Goring-Morris (1995: 162). A number of unusual hearth features have been identified from the Late Epipalaeolithic sites, which may also



**Figure 7.4.** Pit-steaming. (a) schematic drawing of the type of earth oven used in the present, based on pit-ovens used by Plateau peoples in British Columbia, Canada (redrawn from Lowen 1998, page 109, Figure 3.5). (b) pit-steaming experiment at the Çatalhöyük project, Çumra, Turkey; this image shows the earth-oven after 12 hr of cooking, prior to re-opening; note the temperature probe in the lower right hand corner, and extinguished embers of the fire that was on top of the oven. (c) pit-steaming experiment at Primtek, East Sussex, England; this image shows the earth-oven at the time of re-opening, after 12 hr of cooking, the overlying earth and matting have been removed to expose the top layer of vegetative lining. 318



**Figure 7.5.** Unpeeled SCR tubers prepared for pit-cooking. (Strings and tags were attached to groups of tubers to monitor changes in weight due to pit-cooking.)



Figure 7.6. SCR tubers peeled and diced in preparation for boiling.

have been used for pit cooking, such as the relatively deep fire pit feature found at Epipalaeolithic/Neolithic Mureybit, on the North Syrian Euphrates River (van Zeist and Bakker-Heeres 1984); and the comparatively large hearth, measuring 1.5 m<sup>2</sup>, found at Mushabi V, a Mid-Late Epipalaeolithic open-air site in the northern Sinai (Henry 1989).

In the present study, the structure and components of the experimental earth ovens were based on ethnographically reported examples from western North America. Pit-oven technology from that region is well documented both ethnographically and experimentally (see Dering 1999; Lowen 1998; Peacock 1998; Pokotylo and Froese 1983; Teit 1900, 1909; Turner *et al.* 1990). Significantly, root foods were highly important in these economies, and pit-cooking technology was regarded as essential for root-food consumption.

Ethnographic and archaeological reports from the Pacific Northwest region describe pit-ovens that ranged in diameter from  $<1 - 7m^2$ , and between < 0.1 - 1.5 m in depth (Alexander 1992; Dering 1999; Lowen 1998; Peacock 1998; Pokotylo and Froese 1983; Teit 1900, 1909; Wollstonecroft 2002). The depth and diameter (in plan view) of the pit, as well as the amount and types of lining materials and sediment piled on top, varied according to the quantity and type (s) of food that the group is cooking, and on the size of the group using the pit. Foods that needed longer cooking times required larger pits with more heated stones. Another factor affecting pit size is the quality of the soil found at the processing site, such that smaller pits are more likely in hard-packed or rocky soils (Alexander 1992). In recent times Native families used smaller earth ovens to process wild roots, the pits measured about 1 m<sup>2</sup> in diameter and 0.8 m in depth (Lowen 1998; Peacock 1998).

Earth-oven construction is aimed at creating a feature that will heat up to, and maintain, moderate to high temperatures (55-95°C) for long periods of time without burning the food (Wandsnider 1997). Construction entails digging the pit, arranging its component heating elements, and lining it with herbaceous materials. The purposes of the lining are to support the foods that are to be cooked, and to keep them from touching the hot rocks at the base of the pit. At the same time, the lining should not be too heavily packed to prevent hot air and steam from circulating throughout the pit during cooking (Figure 7.4a).

In the Pacific Northwest, plant materials used as lining include grasses, leafy branches of bramble, leaves of herbaceous plants, and/or fir boughs (Turner 1998). The lining is layered over the bottom of half the pit, and the foods that are to be cooked, which are usually wrapped in leaves or mats, are placed on top of the lining, and subsequently other layers of branches, leaves *etc* are placed over the foods. Once the pit has been lined and filled with the foods to be cooked, it is covered, usually with matting and then earth. A fire is sometimes lit on top of the earth oven.

The pit may be used to dry bake or steam the foods. The only difference in constructing a pit for steam cooking is that it is necessary to add water. In that case, the vegetative materials that are used to line the pit are soaked in water before use, and/or a hole small is created during pit filling so that water can be poured in after everything else is in place. In the Pacific Northwest, a method used to make the hole is to hold a thick stick (about 5cm in thickness) upright within the pit during the layering stages. Once the pit has been filled and covered with matting and earth, the stick is removed and several litres of water are poured in through the hole, which is subsequently plugged (Lowen 1998).
In the present study, the main aims of the pit-cooking experiments were to test whether the SCR tuber can be processed into a steamed vegetable, and to collect samples for microscopy. Three pit-steaming experiments were conducted. The first two were carried out in Sept 1999 at Primtek and the third as part of the experimental studies that I carried out at Çatalhöyük in August 1999.

Fresh mature SCR, which had been collected the previous day, were processed. Peeled and unpeeled SCR specimens were pit cooked (Figures 7.1 and 7.5. above). Temperatures were measured at regular intervals. To provide standards for assessing the functional properties of SCR during cooking, white potato (*S. tuberosum*) was pitsteamed alongside SCR tubers. It was selected for comparison because, like SCR it is a stem tuber and therefore has similar physical characteristics.

The following steps were used to construct and fill the earth oven:

# Creating a heating element: heating the rocks

- 1) Rocks were collected from the surrounding fields.
- 2) Rocks were heated in a fire at 600°C for 1 h, 15 min.

# **Digging and firing the pit-oven**

- 3) A circular hole was dug measuring  $1 \text{ m}^2 \times 0.8 \text{ m}$  deep.
- 4) A fire was lit within the pit to bake the walls.
- 5) Once the fire died down, the burnt debris was removed from the pit.

#### Lining and filling the pit

- 6) The hot rocks that had been heated in an adjacent fire and were piled over the bottom of the pit. Branches of wood were used as tongs and prods to move the hot rocks from the fire into the pit.
- 7) A thin layer of moistened soil was spread on the heated rocks.

- 8) A stick was placed into the pit, and held in an upright position.
- 9) Water-soaked branches of pine (*Pinus*) and *Rosa* or *Rubus* were placed over the heated rocks.
- 10) The foods, peeled and unpeeled fresh SCR tubers and unpeeled potato(S. tuberosum), were laid on top of the damp foliage.
- 11) Temperature probes were placed into the pit, with their tips aligned alongside the tubers.
- 12) More leafy branches were layered over the tubers.
- 13) The pit was covered with a canvas mat.
- 14) The stick was removed and four litres water were added to the pit through a small opening in the canvas mat.
- 15) The opening in the canvas cover was closed prevent the steam escaping, and soil was piled on top of the canvas mat.
- 16) A fire was built on top of the pit.
- 17) The tubers were left in the pit-oven for 11 15 h.

## 7.1.7. Boiling

The main purpose of the boiling experiments was to produce samples for thinsection microscopy, *i.e.* to allow assessment of the structural changes during hydrothermal treatment. Because no thin-section samples were collected during the pitoven experiments, SCR and potato tubers were boiled and sampled to obtain LM and TEM images. Boiling and steaming are known to have identical effects on the structure and chemistry of plant tissue (Konlande and Robson 1972; Loh *et al.* 1982).

From the Epipalaeolithic faunal evidence, several authors have inferred that groups routinely practiced bone boiling (Chapter II and II, this volume). Therefore it is likely that Epipalaeolithic groups also boiled plant foods. There is no archaeological evidence that ceramic containers capable of being heated at high temperatures were used at this time. However, it has been proposed (e.g. Munroe and Bar Oz 2004) that boiling may have been done in animal skins or other types of containers made other types of perishable materials.

The boiling experiments were conducted in London, England on September 14, 2001. SCR samples were harvested from the Pevensey Marsh the day before. This experiment was conducted twice. In the first trial the tubers were peeled and boiled whole (Figure 7.1). Because the tubers remained impenetrable after boiling for 30 min, a second trial was conducted in which fresh tubers were peeled and cut into wedges prior to boiling (Figure 7.6, above). Boiling was done in a 2-litre glass saucepan on a Smeg SUK61 60 cm gas cooker, using a large gas burner with a 3.0 (kW) nominal heat capacity and a 750 W net heat capacity.

For comparative purposes, small new potatoes (Charlotte variety) were also boiled. Potatoes of this variety are the same size as large SCR tubers. Potato was selected for comparison because, like SCR it is a stem tuber and therefore has similar physical characteristics. Furthermore, it has similar potential food uses and there is an extensive literature on the functional behaviour of potato (*e.g.* Mudahar and Jen 1991).

Samples of both SCR and potato were collected after 5, 10, 30 min boiling and fixed in a concentration of gluteraldyhyde and phenol/ethanol.

#### **Boiling methods**

1) Specimens of  $\geq 3$  cm in diameter were selected for boiling.

 The fibrous outer layers (endodermis, cortex and epidermis) were removed.

- 3) The SCR tubers were sliced into wedges and placed in water in a 2 I glass saucepan.
- 4) The tubers were boiled at  $100^{\circ}$ C.

# 7.1.8. Gruel (pulverising followed by boiling)

The aims of this experiment were to produce a fine-ground mush with the consistency of a gruel/porridge, and to extract samples for microscopy. This experiment was conducted in London, England on September 14, 2001. Fresh SCR were used that had been harvested from the Pevensey Marsh the previous day.

The SCR tubers were peeled, pounded into a meal, and water added. The mixture was composed of 2 parts SCR meal to 5 parts water. Cooking was done in a 2-litre glass saucepan on a Smeg SUK61 60 cm gas cooker, using a large gas burner with a 3.0 (kW) nominal heat capacity and a 750 W net heat capacity.

#### Steps in making gruel

- 1) Prior to pulverising, the fibrous outer layers (endodermis, cortex and epidermis) were removed.
- 2) The peeled tubers were pounded in Mortar 1 with Pestle 1 for 15 min.
- 3) 40 g SCR flour (meal) was produced.
- 4) 100 ml water was added to the SCR flour.
- 5) The mixture was cooked in a 2-l glass saucepan at 100°C until the mixture thickened and a gruel-like consistency was obtained (10 min).

Samples for light microscopy (LM) and transmission electron microscopy (TEM) were extracted after 10 min cooking and fixed in the gluteraldyhyde and phenol/ethanol mixture-. Portions of the mixture were then allowed to be charred in the saucepan to obtain charred material for scanning electron microscopy (SEM).

# 7.1.9. Bread 1: SCR flour mixed with bread-wheat (*Triticum aestivum*) and water and baked in a tandir.

The main aim of this experiment, which took place in Küçukköy Turkey, was to produce a loaf of bread from SCR flour, using local non-mechanised methods. Following Lyons and D'Andrea (2003: 518) a bread *loaf* is defined as leavened or thick bread made from dough or else batter that is shaped in moulds. In the present study dough was prepared and baked in a tandir, which is a domed, semi-subterranean oven (Figure 7.7.). Tandirs are widely used throughout Asia and North Africa to bake bread and/or cook meat. The advantage of this type of oven is that it produces high temperatures (>450° C) and foods can be cooked quickly.

In the archaeological record, tandirs date from c.5,000 years ago (Lyons and D'Andrea 2003: 521). Although no evidence of tandirs has been found at Epipalaeolothic sites, similar shaped mud-brick ovens have been identified in Neolithic sites where SCR tubers and seeds have also been recovered, e.g. ovens with domed superstructures are found in domestic contexts of Neolithic Çatalhöyük (Hodder and Catalhöyük Research Trust 1999), and Jarmo (Braidwood *et al.* 1983).

There are numerous variations in the tandir style and size and, they are situated indoors or outdoors, depending on the people using them. Two styles found in the Konya Basin are shown in Figure 7.7a and 7.7c. Tandir ovens are typically constructed of clay or mud brick and heated by burning fuel in the centre of the oven base. To bake the bread, raw loaves are pressed directly onto the heated inside walls of the tandir, to which they adhere and bake (Figure 7.7b).

The SCR tandir bread-baking experiment was a collaboration between myself, the Çatalhöyük ethnobotany team, and two local women, Madine Tokyaksun and her daughter-in-law Fatima Tokyaksun. The Tokyaksuns facilitated the baking at their farm



Figure 7.7. Bread baking in the tandir. (a) cone-shaped mud-brick tandir observed in a courtyard of one of the villages in the Konya Basin, Turkey. (b) loaves of bread baking in the tandir, the raw loaves have been pushed onto the hot inner walls to which they adhere, allowing them to bake; note the burning dung, used for fuel, at the base of the oven. (c) Bayan Tokyaksun baking bread on her doughnut-shaped mud-brick tandir, in her garden in Küçükköy, Turkey; note the unbaked loaf in Bayan Tokyaksun's hands, as she prepares it for the oven, and the freshly baked loaves piled up to cool, visible on the left of the photograph.



**Figure 7.8.** Preparing Bread 1 for baking in tandir: (a) mixing a dough from a combination of SCR flour, water and bread wheat (*Triticum aestivum* Linn.) flour; (b) kneaded and shaped loaf, ready for placing on the wall of the tandir.



**Figure 7.9.** Preparation of Bread 2. A batter was made from SCR flour and water. It was subsequently baked in an electric oven.

in Küçukköy. Their tandir, which is mud-brick, is situated outdoors, halfway between the farmhouse kitchen and the vegetable garden. This area is used for various types of food preparation, and includes a shaded patio where we did much of the tuber peeling and pulverising. The tandir is adjacent to the garden wall, out in the open air. Also located in this area is a small horseshoe-shaped hearth, also made from mud-brick, which is covered with a small grille. Boiling, grilling and re-heating of water and foods are done over this hearth.

The Tokyaksuns' tandir is doughnut-shaped, measuring about  $2 \text{ m}^2$  and approximately 60 cm high (Figure 7.7c). The oven roof is relatively flat, but mounded towards the central opening, which serves as a door to the oven. During baking this opening is covered with an aluminium tray. The Tokyaksuns use the oven roof as a work surface during bread baking. The baker sits on the oven roof and reaches into it through a hole in the top to place uncooked loaves onto the walls or to remove the baked bread (Figure 7.7c).

The first steps in bread making were to pre-heat the oven. The Tokyaksuns use cattle dung as fuel, which is placed in the bottom of the tandir. While the tandir was heating, we prepared the dough. SCR flour (prepared earlier, section 7.2.2. above) was mixed with water until it formed a thick dough. The mixture was then kneaded into shape (Figure 7.8). During kneading, Madine Tokyaksun observed that the SCR dough did not have an appropriate consistency to adhere to the walls of the tandir. To resolve this problem, she added bread-wheat (*T. aestivum*) flour. (Gluten, which is a necessary component in successful tandir bread baking, does not occur in SCR. See Lyons and D'Andrea 2003). The final dough was composed 200 g SCR flour, 100 g bread-wheat flour, and 220 ml water. The kneaded dough was shaped into eight small loaves

measuring approximately  $10 \ge 12 \ge 1.5$  cm; an example is shown in Figure 7.8b (above).

#### **Steps for making Bread 1**

1) 200 g SCR, 100 g bread-wheat flour and 220 ml water were mixed.

- 2) The mixture was kneaded into dough, and shaped into loaves.
- 3) The loaves were baked in the tandir for 20 min on walls heated to 433°C, with the temperature at the fuel source (dung) reaching 620°C.

During baking, one loaf fell off the wall onto the oven floor and was charred. This and one other loaf were kept for subsequent SEM analysis; one loaf was treated with a preservative by the conservator and kept in the Çatalhöyük archive. The remaining loaves were broken into pieces and tasted by the Çatalhöyük field team.

# 7.1.10. Bread 2: SCR flour and water baked in an electric oven

The main aim of the Bread 2 experiment was to produce baked SCR tissue samples that could be observed with thin-section microscopy. As noted, Bread I had been sampled for SEM microscopy only. The Bread 2 experiment further provided the opportunity to test if it was possible to produce bread from SCR flour alone, with no other ingredients added (other than water). Again, bread is defined as a pancake, flatbread or loaf that is baked, fried or steamed. The absence of rising agents and/or gluten determined that the proposed product would be a flatbread. Lyons and D'Andrea (2003: 518) provide a precise definition of flatbread as "...either an unleavened or slightly leavened bread, less than three centimetres thick, made with dough or batter".

The Bread 2 experiment was conducted in London, England on September 14, 2001. Fresh tubers were used that had been harvested from the Pevensey Marsh the previous day. A batter was made from 80 ml water and 230 g SCR flour. The resulting

mixture formed a batter from which three flatbreads were prepared (Figure 7.9). With a goal of obtaining an even bake, inside and out, these flatbread batters were baked at a lower temperature (250°C) and for a longer time (30 min) than Bread 1. Ideally a clay or stone griddle or mould is best for flat breads (Lyons and D'Andrea 2003). However, bearing in mind that the objective of this experiment was to produce samples for microscopy, for practical reasons Bread 2 was poured onto aluminium foil and baked in an electric Smeg SUK61 oven with 48 litre size capacity and 3.19 (kW) heat capacity.

## **Steps for making Bread 2:**

- 1) Prior to pulverising the SCR, the fibrous outer layers (endodermis, cortex and epidermis) were removed.
- 2) The tubers were pounded in Mortar 1 to produce 230 g flour.
- 3) To assure a fine particle size, the flour was sieved through a 500  $\mu$ m mesh.
- 4) The 230 ml of SCR flour was mixed by hand with 80 ml water for 10 min.
- 5) The mixture was left to soak for 20 min.
- 6) The mixture was poured onto an aluminium foil wrapped metal baking sheet and baked at 250°C for 30 min (Figure 7.9, above).

After 15 min baking, the bread was removed from the oven and checked. As it was not cooked it was returned to the oven for another 15 min. Samples for microscopy (LM and TEM) were taken after each stage of processing: i) after 20 min of pounding; ii) after soaking for 20 min; and iii) from the final, baked, product. SEM samples were also taken from the final (baked) product.

# 7.2. QUALITATIVE RESULTS OF THE FOODSTUFF EXPERIMENTS

This section begins with a discussion of the texture and taste of the food products. The techniques entailed in each processing method and the waste products produced are then summarised. Micrographs of the raw and processed tuber tissue, and the discussion about the physical properties of the SCR tissue are presented and discussed in section 7.3.

#### 7.2.1. The products: qualitative observations about taste and texture

Figure 7.10 shows the SCR food products. The experiments that were the most successful were the bread and gruel (mush), which resulted in foods that were easily chewed and swallowed, with acceptable tastes and textures. Each of these foods was prepared with a sequence of techniques, including pounding, soaking and thermal treatment. Experiments that involved only one technique, the pit-steaming and boiling trials, did not result in edible products. SCR tubers prepared in these ways were too hard to bite into. The textural characteristics and estimated hardness ratings of these foods are summarised in Table 7.3 and 7.4.

## Pit-cooked and Boiled SCR: taste and texture

I estimated that the raw, boiled whole and pit-steamed (Figure 7.7a) mature SCR had a hardness value >9 (Table 7.4.) because they were impossible to fracture by chewing. The sliced boiled tubers (Figure 7.7b), which were estimated to have a hardness value of 8-9 (Table 7.4.), appeared to be less hard than the whole boiled specimens. A possible explanation for this is that smaller slices were more manageable for the mechanics of the mouth than the whole boiled and whole pit-cooked tubers. However, they were still extremely difficult to chew and had no apparent flavour.



**Figure 7.10.** Results, the products: (a) pit-steamed peeled SCR tubers and unpeeled potatoes; (b) sliced and boiled SCR tubers; (c) SCR gruel; (d) SCR Bread 1; (e) SCR Bread 2.

Food product	Mechanical characteristics	Physical characteristics	Other characteristics
Raw immature	crisp, firm	cellular, aerated	highly moist; white
Raw mature	Very hard, impenetrable	solid ball	
Gruel	soft with chewy, slightly gummy substances throughout	viscous, containing fibrous, gritty substances	moist, starchy flavour; cream colour
Bread 1 (mixed with wheat flour)	hard, brittle, crusty on outside, soft on inside	Coarse on outside; gritty & fibrous on inside	slightly moist on inside; brown outside, cream colour inside
Bread 2 (SCR only)	brittle and crumbly throughout; soft on inside	flaky inside & out, & somewhat puffy	burnt on edges; medium brown outside, cream colour inside
Pit-steamed	impenetrable	solid ball	
<b>Boiled whole</b>	impenetrable	solid ball	
Boiled sliced	firm, rubbery, difficult to bite into	solid wedge	like bamboo shoots; cream colour

Table 7.3. Mechanical & physical characteristics of raw & processed SCR tubers

<sup>1</sup>Table based on texture evaluation classifications provided by Lewis (1996:140).

1401C 7.4. L3	timated relative naraness of matur	e bert tubers, tuw und processed	
Hardness	Product	SCR tubers, raw and processed	
1 2	Philadelphia cheese cooked egg white		
3	Frankfurters, cream cheese	Bread 1 inner layer	
4	processed cheese,	SCR gruel & Bread 2 inner layer	
4.5	boiled and pit-steamed potato	,	
5	pickled olives	Bread 2 crust	
5.5.	steamed Chinese water chestnut		
6	peanuts	Bread   crust	
7	carrot (raw)		
8	peanut brittle, candied peanuts,	SCR sliced & boiled	
9	rock candy	,	
>9		raw mature SCR	
		SCR boiled whole,	
		SCR pit-steamed whole	

Table 7.4.	Estimated relative	hardness of	mature SCR	tubers raw	and processed
1 and 1.4.	Lonnated relative	naruness or	mature SCR	tubers, ram	and processed

<sup>1</sup>Table based on texture evaluation classifications provided by Lewis (1996: 140).

Surprisingly, the pit-cooked SCR tubers seemed even harder after cooking than before. Gordon Hillman (pers. comm. 1999) observed a similar increase in SCR tuber hardness in specimens that had been baked in ash, at the base of a fire. Not surprisingly, potatoes, which were pit steamed and boiled with the same methods and for the same time as the SCR tubers, were found to have a pleasant flavour and texture, and were easily chewed and swallowed. Clearly the relative hardness (Table 7.4.) is an important determinant of the sensory properties of foods.

# SCR Gruel: taste and texture

The gruel (Figure 7.10.c) had a sweet but starchy flavour, which suggests that the starch was undercooked (Light 1990), an inference that was later confirmed by the microscopy (Section 7.5, below). The texture of the gruel was viscous and paste-like, but somewhat gritty (Tables 7.3). The estimated hardness value was 3-4, comparable with that of cream or processed cheeses (Table 7.4). The taste and texture reminded me of hot breakfast cereals such as fonio (*Digitaria* sp.), porridge or other puddings made from root foods such as tapioca (cassava). Only one other person aside from myself tasted the gruel. She said that she liked the flavour and texture, which reminded her of a hot breakfast cereal such as cream of wheat.

#### SCR Breads: taste and texture

Bread 1 (Figure 7.10.d), the tandir-baked bread, had a firm and brittle, darkcoloured crust, with a soft, moist but grainy interior texture (Tables 7.3). The hardness values of the crust and interior layer were distinctly different: the crust having an estimated hardness of 6; while the interior had an estimated hardness of 3 (Table 7.4). The flavour was sweet. The other women involved in making this bread, Madine Tokyaksun, Fatima Tokyaksun and Aylan Erkal, also commented on its sweetness (Wollstonecroft and Erkal 1999).

The large number of people working at the Çatalhöyük project, and the many different nationalities represented, provided the opportunity to obtain a range of opinions about Bread 1 from a number of individuals representing a cross-section of cultures. Five of the Bread 1 loaves were broken up and tasted by the Çatalhöyük field team. Of the more than 30 Çatalhöyük team members who tasted Bread 1, three people said that they did not like it. Negative comments were focused on the texture, that the "inside layer of the bread was too gritty, had too much fibre". However, most people said that they liked it and/or that the recipe had promise. Comments included those of a Turkish team member who stated that it reminded her of Turkish village bread; a Dane who said that it was similar in taste and texture to traditional Danish bread; an Australian who said that the flavour was reminiscent of molasses; and another American who commented that she liked the thickness and "nutty" texture. Overall, the most common comments were:

-the texture was fibrous, gritty and/or grainy (n 11);

-the flavour was sweet = (n 7);

-the well-cooked crust was preferable to the softer, grittier inside (n 6);

-the bread needed other ingredients, e.g. salt, fruit (n 4);

-the bread left a distinctly gritty aftertaste (n 4).

- the chewiness was satisfying (n 3).

Like Bread 1, Bread 2 (Figure 7.10e) had a sweet and malt flavour. But the texture was distinctly different, being more like a flaky oatmeal cookie than a loaf. It

did not hold together as well as Bread 1, as it was thinner than Bread 1 and lacked a distinct crust. The texture was crumbly on the outside and flaky both inside and out (compare Figures 7.10d and e). The hardness values of the outer and inner layers were similar, with estimated values of 5 and 4, respectively (Table 7.4.). The inner layer was less gritty and more evenly cooked throughout than the inner layer of Bread 1, except at the edges, which were burned. Aside from myself, one other person tasted Bread 2; she stated that she liked the flavour and texture, which reminded her of puffed wheat.

#### 7.2.2. Labour, technology, knowledge and waste products

The intensification model put forward in Chapter III (Figure 3.3.) proposes that, during the Epipalaeolithic, post-harvest intensification was driven by the evolution of post-harvest systems, entailing escalating investments in labour, technology, and knowledge. However, because techniques of non-mechanised food processing, be they ancient or present-day, are poorly documented, we can only speculate on the actual labour, technology and knowledge Epipalaeolithic groups invested in food processing. Several authors (*e.g.* see Lyons and D'Andrea 2003) attribute this paucity of documentation to the fact that cross-culturally women are the food processors, and that ethnographers, historians and other academics typically treat women's activities as nontechnical.

Therefore, the food processing experiments were regarded as opportunities to observe and record the techniques associated with different types of food processing; the types of labour, technology and knowledge that were involved. Moreover, these experiments provided opportunities to identify the types of archaeological correlates might be produced by each of the processing experiment, *e.g.* features, tools, and debris. Labour inputs were only roughly measured because, given the lack of experience of the people involved in processing, it was thought that the values were inflated and therefore unrealistic. Nevertheless, the *types* of labour inputs were recorded for each processing experiment, including the time spent, features, tools, problems and other considerations, as well as waste products. These are summarised in Tables 7.5-7.11, and discussed in the paragraphs below.

## Cleaning and dehusking: summary of techniques and waste products

Regardless of whether the tubers were newly harvested or air-dried, dehusking was highly labour intensive, *e.g.* using small knives and shears, it took several hours to peel 144 g (fw) of SCR tubers. However, by the time I finished the experiments, I was able to peel 144 g in about 1 hr. The steps used in dehusking are described in Table 7.5.

<sup>1</sup>Mortars and pestles may be used (Gordon Hillman pers. comm. 2006)

Dehusking the SCR tubers by peeling with a knife was found to be awkward; it was difficult to manoeuvre the blade over the relatively small SCR tuber surface. Larger specimens were found to be easiest to peel. Nevertheless, the average peeling production rate, approximately 144 g/h, appears realistic compared with an ethnographic example of cassava reported by Williams (1979). According to Williams (1979: 342-344), peeling is one of the most time-consuming steps in cassava root processing by Nigerian women. Williams observed that a small group of village women (the number is not reported) spent 93 hours processing 103 kg cassava, and that

approximately 65% of this time was spent peeling the tubers. Hypothetically, if this group were made up of five women, and each did the same amount of work, each woman would have processed 20.6 kg in 93 hours, which is 221.5 g/h/person. Given that 65% of that time was spent peeling, each woman would have peeled approximately 145g per hour, which is similar to the SCR peeling times shown in Table 7.5.

However, Gordon Hillman (pers. comm. 2006) recently found that SCR tubers can be efficiently de-husked by pulverising them in a deep mortar. Based on traditional methods of rice and wheat dehusking that he had observed in villages in Turkey during the 1970s, Hillman used a mortar with a curved (internal) bowl, and a pestle with a curved end, to dehusk SCR tubers.

## Pulverising: summary of techniques and waste products

The pulverising techniques, and waste products are summarised in Table 7.6.

Table 7.6. Tuber pulverising: summary of techniques, time and waste products
Tools: hands, mortars and pestles, mat (placed under the mortars), a container for the flour
Other plants parts used: if the mat placed below the mortar was made from vegetative materials such as reeds or grasses
Number of people required: variable
Approximate time taken/production rate: 200 g/h person
Waste products: fragments of raw SCR parenchyma tissue

Pulverising the tubers into flour that was fine enough to pass through the 500 $\mu$ m sieve was time consuming. During the initial experiments we produced 25g/h/person. This low production rate was undoubtedly due to the inexperience of the people involved. Over time I became more adept and produced about 200g/h. During pulverising small amounts of parenchyma tissue spilled flew out of the mortar. We resolved this problem by placing a mat below the mortars (Figure 7.3) and periodically sweeping fragments from the mat back into the mortar.

Even though the flour made for the bread was screened through a  $500\mu$ m sieve, the breads were somewhat fibrous (gritty) in texture. Gordon Hillman (pers. comm. 2006) had similar results when using a deep wooden mortar with a flat base and a pestle with a flat end, to pulverise the SCR tubers into flour. He stated that this flour, which was not screened but simply formed into a pancake and cooked into flatbread, exhibited a fibrous texture.

# Pit cooking: summary of techniques and waste products

The tasks involved in pit cooking are listed in Table 7.7. Including pit construction, pit cooking involved four sets of tasks: i) collecting rocks, fuel and herbaceous materials to using in lining the pit; ii) digging and firing the pit, heating the rocks in a separate fire; iii) filling the pit, adding water, covering the pit and lighting a fire on top; iv) emptying the pit after cooking is finished.

Because the experimental pit ovens were small, we were able to collect the rocks, fuel and herbaceous materials to line the pit in about 2-3 person hours. Collecting was done opportunistically in Turkey and in England because we did not have previous knowledge of where to find suitable materials. We used locally available rocks as heating elements: in the Turkish experiments limestone; and in the UK, a chalk-rich material. Nevertheless in all pit-oven experiments we achieved the temperatures that we required ( $c. 85^{\circ}$  C).

The times taken to collect the rocks and pit-lining materials are reasonable compared with ethnographic reports from North America. These reports (*e.g.* Alexander 1992; Turner 1992) indicate that the collecting of rocks, fuel and vegetative lining can take several days, depending on the quantity of food to be pit-cooked, and size of the pit(s), and other activities taking place at the same time.

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# Table 7.7. SCR pit cooking: summary of techniques, time and waste products

# **Collecting rocks, herbaceous lining materials, and fuel for three fires:**

Tools: sacks for packing & carrying

Other plants parts used: yes if the sacks were made from vegetative materials

Number of people required: variable

Approximate time taken: 2 -3 person hours

# Digging and firing the pit; heating the rocks in a separate fire:

Tools: hands, mortars and pestles, mat (placed under the mortars), a container for the flour

Features created: pit, adjacent hearth

Fire: in pit (to bake walls), & in adjacent hearth (to heat rocks)

Other plants parts used: stems of wood & twigs as fuel

Number of people required: variable

Approximate time taken: 15 – 20 min to lay & light each fire

## Filling the pit and lighting the fire on top:

**Tools:** sticks/branches (to move hot rocks from adjacent fire), hands (to line & fill pit), mat (to cover pit & provide base for soil piled on top); stick to create hole for water

Features created: pit containing rock, vegetative lining, foods, mat and soil on top.

Water: 4 I poured into pit before closing

- **Other plants used:** herbaceous materials to line the pit, wrapping for the foods being cooked, mat covering for the pit.
- **Number of people:** 2-3. At least two: one person to hold the stick upright during pit layering; the other to layer and fill the pit.
- Approximate time taken: 30 min to fill & close the pit; plus 15 -20min to lay and light the fire on top; 11 15 h. cooking

# **Emptying the pit after cooking:**

- **Tools:** shovel &/or hands to remove the extinguished fire and soil; hands to remove foods and pit lining.
- Features: empty pit, with stones on bottom and adjacent pile of soil and plant parts from lining removed from the oven

**Other plants used:** herbaceous materials to line the pit, herbaceous wrapping for the foods cooked, straw or woven mat covering for the pit.

Number of people required: variable

Approximate time taken: 30 min

#### Waste products:

Fire-altered rock, soil, charred and uncharred leaves &of branches of bramble & pine, charcoal and ash; and if spillage occurred, fragments of foods that are being cooked, possibly fragments of a mat used in covering the pit.

Turner et al. (1990) observed that specific plants were selected as pit lining

which did not impart an unpleasant flavour. Konlande and Robson (1972) otherwise

suggested that certain species of plants and plant parts were selected as lining because they facilitated the cooking of root foods. They proposed that the plants selected as lining released volatile acids during heating, which promote the hydrolysis of certain carbohydrates.

In all three pit-oven experiments, at the time that the pit was closed, temperatures in the centre of the pit were between 81 -85°C. In all three experiments it had dropped to 50-52°C (in the middle of the feature) by the time the pit was opened. The temperatures and times taken of our pit-cooking experiments agree with those in published reports (*e.g.* Wandsnider 1997). However the fact that the tubers were not softened by pit steaming for 12 h suggests that they may have needed longer cooking and/or pulverising after pit-cooking, and/or possibly additional cooking of the pulverised meal. A number of ethnographic reports describe processes in which plant foods are treated with further processing, following pit cooking (see Alexander 1992; Dering 1999; Peacock 1998; Turner 1992).

Debris created by pit cooking include fire-altered rocks, soil, charred and uncharred leaves and branches of brambles and pine, charcoal and ash. No tubers were found among the debris. In fact, the foods that are being cooked are rarely recovered from archaeological pit-ovens (Peacock 1998; Pokotylo and Froese 1983; Wollstonecroft 2002). In part this is an archaeological sampling problem, but probably also because the foods were wrapped, and unless spillage occurred, specimens did not become charred and deposited in the feature. The techniques, time and waste products entailed in constructing and cooking with the earth oven are summarised in Table 7.7.

## Boiling whole and sliced: summary of techniques and waste products

This experiment was conducted for the primary purpose of producing samples for microscopy, and therefore a modern hob was used instead of a hearth. This experiment involved simply peeling and boiling the tubers (Table 7.8).

 Table 7.8. Boiling whole: summary of techniques, time and waste products

 Peeling

 Tools: hands, small knives and shears, & containers for the peeled tubers<sup>1</sup>

 Water: for washing the soil from the fresh tubers

 Number of people required: variable

 Approximate time taken/production rate: 144 g/h/person

 Waste products: fragments of roots, rhizomes & husk (endodermis, cortex, epidermis)

 Boiling

 Tools: heat-resistant container

 Water: for boiling

 Number of people required: 1

 Approximate time taken: 30 min boiling (but did not soften the tuber tissue).

 Waste products: possible burnt parenchyma tissue

Human labour inputs that would be required when non-mechanised methods were used would include: collecting fuel, building a fire or stove apparatus, and constructing or improvising a heat-resistant container. The tubers were not softened by boiling. This suggests that longer boiling times and/or pulverising after boiling, and possibly additional cooking of the pulverised meal, were necessary to cook the tubers.

Waste products were created during peeling. Spillage or burning would create waste. When rudimentary cooking methods were used, the features, tools and debris may include a hearth, stone or clay vessel and may create ash, burnt wood or dung.

## Gruel (mush): summary of techniques and waste products

The basic steps of gruel making included peeling, pulverising, mixing with water and boiling. These techniques are summarised in Table 7.9.

Again, a modern hob was used instead of a non-mechanised heat source such as a hearth. In cases where non-mechanised methods are used, human labour inputs would include: collecting fuel, building a fire or stove apparatus, and constructing or improvising a heat-resistant container. Waste products were created during peeling, and would also be created if spillage or burning occurred. In addition, non-mechanised cooking methods would create ash, burnt wood and/or dung.

 Table 7.9. Pulverising and boiling to produce a gruel: summary of techniques, time and waste products

#### Peeling

Tools: hands, small knives and shears, and containers for the peeled tubers<sup>1</sup>

Water: for washing the soil from the tubers after harvesting

Number of people required: variable

Approximate time taken/production rate: 144 g/h/person

Waste products: stems, fragments of raw roots, rhizomes and husk (SCR endodermis, cortex, epidermis)

## Pulverising

Tools: hands, mortars and pestles, mat (placed under mortars), a container for the flour

Other plants parts used: if the mat placed below the mortar was made from vegetative materials such as reeds or grasses

Number of people required: variable

Approximate time taken/production rate: 10-15 min to pulverise 40 g

Waste products: raw fragments of raw SCR parenchyma tissue

# **Boiling**

Tools: heat-resistant container

Features, appliances: heat source capable of boiling water

Water: 100 ml added to the tuber meal (flour)

Number of people required: one

Approximate time taken/production rate: 10 min to boil

Waste products: charred fragments of SCR parenchyma tissue (if spilled or burned during cooking)

## Tandir baking: summary of techniques and waste products

The tasks and waste products of tandir baking are summarised in Table 7.10.

Tandir baking requires two types of technical knowledge and labour inputs, namely that

which is needed to construct the oven, and that which is needed to cook foods in the

oven. Tandir construction was not observed in the present study. However, it can be inferred that the principal tasks involved in tandir construction would include: i) collecting materials for oven construction; ii) forming/shaping bricks and/anther type of building framework for the walls; and iii) constructing the feature. Once built the feature would have been re-usable, probably requiring occasional repair.

**Table 7.10.** Tandir baking: summary of techniques, time and waste products

#### Peeling

**Tools:** hands, small knives and shears, and containers for the peeled tubers<sup>1</sup>

Water: for washing the soil from the tubers after harvesting

Number of people required: variable

Approximate time taken/production rate: 1 h. 20 min to peel 200g

Waste products: stems, fragments of roots, rhizomes and husk (SCR endodermis, cortex, epidermis)

# Pulverising

Tools: hands, mortars and pestles, mat (placed under the mortars), a container for flour

**Other plants parts used:** if the mat placed below the mortar was made from vegetative materials such as reeds or grasses

Number of people required: variable

Approximate time taken/production rate: 1 h to pulverise 200g

Waste products: fragments of SCR parenchyma tissue

# Mixing, Kneading and shaping

Tools: hands, containers for water, flour and mixing

Number of people required: one

## Approximate time taken: 20 min

Waste products: none

#### **Baking**

Tools: hands,

Features: tandir

Use of fire: dung-fuelled, at base of tandir

Number of people required: variable

Approximate time taken/production rate: 20-25 min, including placing the breads in oven and baking them

Waste products: fragments of charred SCR parenchyma tissue, dung

The principal tasks entailed in making bread are peeling, pulverising, shaping

and baking (Table 7.10). Baking includes pre-heating the oven and collecting fuel to

heat the oven. Each stage of processing took place in a different location: peeling and pulverising were carried out on the shaded patio; mixing and kneading were done indoors; baking was done outdoors. Potential waste products include charred fragments of dung and bread.

# Flat-bread baking: summary of techniques

Flat-bread baking techniques are summarised in Table 7.11.

<b>Table 7.11.</b> Flat-bread: summary of techniques, time and waste products	ad: summary of techniques, time and waste products
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## Peeling

**Tools:** hands, small knives and shears, and containers for the peeled tubers<sup>1</sup>

Water: for washing the soil from the tubers after harvesting

Number of people required: variable

Approximate time taken/production rate: 144 g/h/person

Waste products: stem, fragments of root, rhizome, husk (endodermis, cortex, epidermis)

#### Pulverising

Tools: hands, mortars and pestles, mat (placed under the mortars), a container for the

Other plants parts used: if the mat placed below the mortar was made from vegetative materials such as reeds or grasses

Number of people required: variable

Approximate time taken/production rate: 200g/h person

Waste products: fragments of SCR parenchyma tissue

## **Mixing and shaping**

Tools: hands, containers for the flour, water and mixing

#### Number of people required: one

Approximate time taken: 5 min

Waste products: none (unless spillage)

#### Baking

Tools: hands, (potentially a mould of some kind)

Features: oven (potentially a hearth)

Use of fire: no, in this case an electric oven (potentially a hearth)

Number of people required: one

Approximate time taken/production rate: 20 - 30 min

Waste products: fragments of charred SCR parenchyma tissue

Again this experiment was conducted more for the purpose of creating microscope samples rather than exploring traditional cooking technology. But observations were made about techniques and waste products. The principal steps were peeling, pulverising, mixing with water, pouring/shaping and baking.

Hillman (pers. comm. 2006) recently found that SCR flatbread can be baked by cooking it directly in a hearth. In his experiment the principal steps were dehusking by pulverising, pounding into flour, mixing with water, shaping into a pancake, and baking. The pancake was baked in the fire by placing it on a hot rock and covering it with embers from the fire. He described the cooked pancake as having a sweet taste and grainy, fibrous texture similar to that reported here for Bread 2.

## 7.3. MICROSCOPY METHODS

Following the processing experiments, a series of laboratory observations (microscopy) was conducted to observe the effects of pulverising and heat treatment on the physical properties of SCR tuber parenchyma tissue. This methodological approach, entailing experimental food processing and microscopy for the purposes of addressing archaeological questions, was pioneered by Samuel (1994, 1996a, 1996b) in her investigations into Egyptian beer and brewing methods.

In the present study, the original objectives of the microscopy were: i) to identify and record the physical features of raw SCR tuber tissue; and ii) to observe and record any changes to the tissue caused by the different processing techniques; and iii) to observe whether an increase in nutrient bioaccessability can be predicted. Given the results of the processing experiments, another objective was added: iv) to investigate why, among the different processing methods tested, only those involving a sequence of techniques were found to transform SCR tubers into an edible form. The results of the microscopy may also have wider archaeobotanical applications than addressing the research questions presented here. The past decade has seen an expanding interest among archaeobotanists in the properties of vegetative tissue. The recovery and identification of charred or waterlogged parenchyma tissue from ancient archaeological sites is recognised as a means of identifying human uses of non-seed vegetative materials, and is particularly relevant to the study of ancient root food traditions (*e.g.* Hather 1993, 1994; Hillman Madeyska and Hather 1989; Kubiak-Martens 2002; Perry 1999; Wollstonecroft 2002). The present study builds on Hather's (1993: 126) observations of the anatomical characteristics and charring behaviour of SCR tuber tissue, by examining processing alters those characteristics.

The microscopy also provided opportunities to make observations on the general effects of the different processing techniques on the intracellular starch. Starch is of importance because it is the major storage polysaccharide in the human diet (BNF 1990). Starch is of relevance here because its functional behaviour during processing also influences the taste, texture, palatability and digestibility of the final food product. Moreover, starch provides an ideal subject for observation with microscopy because its physical properties are more obvious with microscopy than those of other macronutrients (Hultin and Milner 1978).

Although the reliability of current techniques in ancient starch recovery and analysis is controversial (see Haslam 2004), starch analysis is proving to be a useful method for identifying human uses of edible roots at prehistoric sites, particularly tubers. Starch is of interest to archaeologists because, like parenchyma tissue, it is increasingly recovered from archaeological sediments, as well as from residues on stone tools (*e.g.* Barton *et al.* 1998; Cortella and Pochettino 1994; Piperno and Holst 1998;

Piperno *et al.* 2004). Therefore it was hoped that, in addition to addressing the present research questions, the observations presented in this study will contribute to our knowledge about the tuber starch morphology, and its functional properties. However, given the complexity of starch and how it behaves when heated (Atwell *et al.* 1988; Buléon *et al.* 1998; Whistler and BeMiller 1997), only general observations are made here about SCR starch morphology and how it changed during processing.

Three types of microscopy were used to identify and record the characteristics of the raw and processed tissue: compound microscopy (LM), transmission electron microscopy (TEM), and scanning electron microscopy (SEM). Each type provides a different kind of image and, used together they provide a more complete picture. Micrographs of LM, TEM and SEM views of SCR tissue, raw and processed, were recorded and are presented below. The reader should note that these micrographs are of particular importance because they comprise the data of interest here, and are not merely illustrative of the text.

# 7.3.1. Compound light microscopy (LM)

Compound microscopy is a light absorption method that produces a twodimensional image. The advantage of this method is that thin sections of plant tissue can been viewed at high magnification. I carried out the compound microscopy (LM) in the department of Life Sciences, King's College London, using a *Zeiss Axioskop 2 mot plus* microscope, with a magnification rage of 100-400X. These images were recorded electronically, in colour.

Samples to be viewed by LM must be cut into thin sections and mounted on transparent glass slides (sectioning and mounting techniques are described in detail by Flint 1994). Mounted slides are treated with a stain to make the sample visible and/or

to highlight specific components. John Pacy of the Microscopy Unit of King's College London prepared the thin sections. He prepared two sets of slides: one set stained with a Toluidine Blue to highlight all the features of the cells, and a second set stained with Schiff's method, which highlights the carbohydrates in red (Flint 1994; Kiernan 1990).

# 7.3.2. Transmission electron microscopy (TEM)

TEM is a type of thin-section microscopy that it is electron illuminated. The advantage over compound microscopy is that it provides significantly greater magnification and higher resolution such that the internal structure of cells can be viewed in more detail. Because electrons will only pass through extremely thin samples, TEM samples must be sectioned to an ultramicron, the typical section thickness being 80 nanometers (nm). Sectioned samples are fixed, processed and embedded in resin prior to scanning. All TEM microscopy and thin section preparation was carried out by John Pacy in the Microscopy Unit of King's College. The TEM images were recorded onto b/w negative film.

## 7.3.3. Scanning electron microscopy (SEM)

The third type of microscopy used here is SEM. The advantage of this high magnification, high-resolution method of microscopy is that it produces a 3-dimensional picture. It uses a focused electron beam to scan the surface of the samples, providing a view of the topography of the specimen surface. Prior to SEM scanning, samples are mounted on aluminium stubs and coated in gold. SEM is particularly useful for archaeobotanical analysis because whole objects up to 1 cm, such as a seed, can be viewed, as well individual morphological and/or anatomical features of the object that require much greater magnification (Hather 1993, 2000).

Two sets of SEM images are included here. The first was photographed by the author on a Hitachi S-570 scanning electron microscope, at the Institute of Archaeology, UCL. An Edwards Sputter Coater S150B was used to gold coat the specimens, and the images were recorded on Ilford HP5 plus b/w negative film. The second set of SEM images was produced according to my specifications by Dr. Tony Brain of the Microscopy Unit of King's College London with a Philips SEM501B.

# 7.3.4. Microscope methods for studying the effects of thermal processing on the physical properties of starch

Two methods can be used for studying the effects of thermal processing on the physical properties of starch. In the first method, the starch is extracted from the raw plant tissue, placed into a dilute aqueous suspension and, with the aid of a microscope and heating source, such as a microscope heating stage, the physical effects of heating can be observed (see Flint 1994; Samuel 1994; and Xu and Shoemaker 1986). The advantage of this method is that the stages of granule gelatinisation (melting) can be viewed and photographed as they occur. Thus this method is useful for assessing the gelatinisation temperature range because temperature is the only variable. The drawback of this method is that the starch granules are viewed in isolation and so do not necessarily respond as they would when other substances are present (Samuel 1994).

In the second method, which was used in the present study, the starch is examined as a component of a processed food. The advantages to this method are: i) that the starch is observed in the form that it will be consumed; and ii) its behaviour is a result of synthetic processing conditions.

It is possible that the physical condition of the starch (granule morphology) can be used to discern how a food was processed. However, the variables responsible for the changes in the starch may not be obvious because, during processing starch is 351 affected by a complex set of factors, including heat, time and other substances within the processed food, such as lipids and protein (Colonna *et al.* 1992; Evers, Blakeney and O'Brien 1999; Samuel 1994; Singh *et al.* 2005). Determining if the physical appearance of the starch is indicative of the processing techniques that were used, or is an artefact of subsequent cooling and storage, would require a different set of experiments than were conducted here, and therefore is beyond the scope of this project.

Nevertheless, it is possible to make observations about the similarities and differences in starch of SCR that has been treated in different ways. Light (1990) summarised the morphological characteristics of cooked starch granules, including features that can be seen under the microscope when the starch is properly cooked, overcooked or undercooked. He (Light 1990) observed that undercooked granules appear slightly swollen but their structure is still intact and they continue to exhibit crystallinity. Undercooked starch can also be discerned by taste as it imparts a starchy flavour on the food. Overcooked starch granules, when viewed under the microscope, appear fully ruptured and in fragments, having lost their structural integrity. Properly cooked starch granules have good viscosity, have lost their crystallinity and become pasted, and merged into a continuous substance, which may contain a small percentage of granules that are not fully ruptured, *e.g.* during bread baking, wheat starch granules retain some granular identity as well as birefringence (Gray and Bemiller 2003).

#### 7.3.5. Obtaining and preparing samples for microscopy

With the exception of the tandir-baked bread, which was made from tubers collected in August, all tubers used in the processing experiments were collected in September. Therefore, the anatomical structure of the tuber tissue should be comparable for all the prepared foodstuffs. At this time of the year the tubers are substantially replenished with nutrients due to the dying of the aboveground parts and the translocation of nutrients from those dying parts to the tubers (see Chapters IV and VI).

Samples collected for thin-section (LM, TEM) microscopy were fixed at the time that they were harvested and/or processed. Specimens were fixed in solution of gluteraldyhyde and phenol/ethanol (mixed). Samples were sectioned, fixed and/or stained for LM and TEM viewing using standard laboratory methods (Buschmann *et al.* 2002; Flint 1994; Kiernan 1990).

During laboratory preparation of thin sections of mature and immature SCR for TEM and LM, we found that it was extremely difficult to section raw SCR tubers and to obtain adequate fixation and infiltration of the resin into the cells. This problem did not occur with pounded and cooked SCR nor with the raw and cooked white potato and Chinese water chestnut. Turning to the literature, similar difficulties with sectioning and fixation were found reported for certain species of raw edible roots in which the parenchyma cell wall (cw) has high levels of starch, lignin, suberin, tannin, lipid and phenolic materials, the most notable being cassava tubers (Buschmann *et al.* 2002). A similar chemical composition might be found in SCR parenchyma tissue, which might explain the problems that we encountered in specimen preparation.

# 7.4. OBSERVATIONS OF THE PHYSICAL PROPERTIES OF THE RAW SCR TISSUE AND THE EFFECTS OF PROCESSING

To address questions about food processing intensification it was necessary to examine the physical properties of SCR tuber tissue, particularly the characteristics of the cw, because it is the physical and chemical properties of the cw that ultimately determine the texture of a plant tissue, and regulate the stability of the tissue during heating, pulverising, mastication and digestion (Waldron *et al.* 1997; Waldron, Parker and Smith 2003). Moreover, and significantly, it is the stability of the cw that regulates bioaccessability by providing physical barriers to the intracellular contents, nutrients that include starch, lipids, proteins and phytochemicals such as phenolic compounds (Brett and Waldron 1996; Loh and Breene 1982; Loh *et al.* 1982; Vincent 1991). As stated earlier, one way that food processing (*e.g.* grinding and heating) can promote the bioaccessability of nutrients is by disrupting the cw (Parada and Aguilera 2007).

However, this chapter only examines the structural properties of SCR tissue. It does not assess bioaccessability or bioavailability. Bioaccessability and bioavailability can only be measured by *in vivo* (experiments involving humans) or *in vitro* (simulated experiments performed in the laboratory) (Parada and Aguilera 2007: R3.).

# 7.4.1. Analysing the structural properties of plant tissue

Before examining the physical properties of SCR tuber tissue, which are discussed below in section 7.4.2, this section provides background information on the physical properties of plant tissue. A useful summary of the mechanical properties of a plant organ is provided in a schematic model published by Waldron *et al.* (1997) and Waldron, Parker and Smith (2003), which is shown in Figure 7.11. This model describes five distinct hierarchical levels of the plant organ that interact to produce the discrete mechanical properties (toughness, strength) of the organ. At the base of the structure are polymers (complex molecules), which are the principal components of the cw. The cw itself forms the next level of the hierarchy, providing mechanical strength and thickness. The whole cell, which provides shape, is the third level of the structure. The penultimate level is the tissue, in which the cells are cemented together by the pectin-rich middle lamella. The fifth and ultimate level is the organ, which is composed of various types of tissue including epidermal, vascular and parenchyma.



**Figure 7.11.** Schematic model of the levels of structure that contribute to the mechanical properties of plant tissue (from Waldron *et al.*2003: 103).





According to Brett and Waldron (1996), and Waldron, Parker and Smith (2003) the effects of food processing and/or mastication on this hierarchical structure are many and vary between species and even between different tissue types within a plant. The ways that plant tissue responds to different processing techniques, mastication and physiological changes such as ripening, are highly influenced by the chemical and physical architecture of each level of the hierarchical structure, and how these different levels interact with each other, *e.g.* cell size influences tissue strength because smaller, more densely packed cells create a tougher tissue that is less prone to cw fracture and loss of turgor than tissue composed of large cells (see Vincent and Lillford 1991: 26).

However, the most important variables governing the receptivity or resistance of an edible plant organ to thermal and/or other processing techniques, are the physical and chemical composition of the cw. In comparison, turgidity, cell size, cw thickness, and/or cell content have minor roles in thermal softening (Brett and Waldron 1996; Loh and Breene 1982; Loh *et al.* 1982; Vincent 1991). Significantly, it is the physical and chemical properties of the cw that govern the mode of fracture at the fracture surface, whether it is by *cell rupture* (breakage) and/or *cell separation*.

Cell rupture (Figure 7.12a) describes a fracturing process in which the tissue remains intact and the cw is broken open to release its contents. Cell rupture occurs in cases when the mechanics of the middle lamella dominate. In other words, it occurs when the adhesive holding the cells together is stronger than the cw. Crunchy textured raw vegetables and juicy fruit are typical examples of foods that are prone to cell rupture during mastication and/or processing.

Cell separation (Figure 7.12b) describes a fracturing process where whole intact cells become detached from each other, such that the tissue is disrupted. Separation occurs when the cw is stronger than the adhesive forces of the middle lamella that hold the cells together (Waldron, Parker and Smith 2003). Cell separation further promotes cell rupture because individual, separate cells are more easily fractured than cells that are incorporated within tissue (Vincent and Lillford 1991). Foods that are prone to fracture by cell separation include mealy fruits and cooked vegetables.

Thermal softening of plant tissue is usually the result of cell separation. However, some species are inherently resistant to thermal softening because the chemical properties of the middle lamella of the cell promote cell adhesion during heating, *e.g.* Chinese water chestnut (*E. dulcis*) and beets (*Beta vulgaris*). In other words, the amount and rate of softening during cooking depends primarily on whether the innate tendency of the cw is towards adhesion or cell separation (see Brett and Waldron 1996; Loh and Breene 1982; Vincent 1991).

#### 7.4.2. Characteristics of raw SCR tissue

The SCR tuber is composed of a solid central pith that is covered by three outer layers, the endodermis, cortex and outermost layer, the epidermis (see Figure 4.9c). These outer layers were removed during most of the processing experiments in order to get at the pith. It is the central pith that is of interest here. Following Hather (1993: 126), SCR tuber pith can be described as solidly parenchymous tissue with vascular bundles occurring randomly throughout. Intracellular starch (discussed below in section 7.5) is abundant. The raw SCR parenchyma tissue is shown in Figures 7.13 and 7.14. It is composed of uniform sized, tightly-packed cells, characteristics that may contribute to the toughness of this tissue (see Vincent and Lillford 1991).


**Figure 7.13.** Thin-section microscopy: raw mature SCR tuber parenchyma tissue. (a) LM view of tissue stained with Schiff's method to accentuate the carbohydrates. With this stain, cell wall carbohydrates appear as pinkish lines and the intracellular starch granules appear as purple/dark pinkish clusters within the cells. (b) LM view of the tissue stained with Toluidine blue to emphasize the characteristic polygonal shape and thin walls of the cells and draw attention to the simple and compound intracellular starch granules. (c, d) TEM views of the parenchyma cell wall and cell contents. Examples of an assortment of starch granule shapes are visible in (d);and lipid droplets are also visible in (c). (Note: In TEM view the starch grains are wrinkled due to shrinkage caused by the fixative, and in (d), the lines in the cell wall are caused by the sectioning process.)





a

-130 µm b



**Figure 7.14.** SEM microscopy: raw SCR tuber parenchyma tissue: (**a**, **b**) sample collected in the Konya Basin; (**c**, **d**) sample collected in the Pevensey Marsh. Shown here are the characteristically small (35 - 50  $\mu$ m) and tightly packed parenchyma cells, small intercellular spaces (2 - 5  $\mu$ m), cell wall pitting (**a**, **b**), and abundance of intracellular starch. Examples of several compound starch granules are visible in images **a**, **b** and **d**. **Key:** cw = cell wall, i = intercellular space, sg = simple starch grain, csg = compound starch grain, ml = middle lamella, p = cell wall pitting.



**Figure 7.15.** Thin-section microscopy: raw immature SCR tuber tissue. (a) LM view of parenchyma tissue stained with Schiff's method to reveal cell wall carbohydrates and intracellular starch. Little carbohydrate is visible, small dots of pink along the inside edges of the cell walls indicated with *s*?, as in the circled area, suggest initial starch development. (b, c) TEM views. Intracellular lipid droplets (*l*) and possible amyloplasts (*a*?) can be seen in (b), and the formation of starch granules within amyloplasts is visible in (c). Key: *a* = amyloplast, *a*? = possible amyloplast, *cw* = cell wall, *i* = intercellular space, *l* = lipid droplet, *ml* = middle lamella, *s*? = possible starch granule, *v* = vascular tissue.

There is also uniformity in the size of the intercellular spaces that are interspersed throughout the tissue, which measure 2 - 5  $\mu$ m. The cells themselves are isodiametrically polygonal in overall shape, a characteristic of parenchyma cells in general (see Fahn 1990). The cells measure 35 - 50  $\mu$ m and have a cw thickness of 1- 2  $\mu$ m. In SEM view (Figure 7.14) cw pitting is visible on the inside of the cells, again a characteristic that is typical of parenchyma cells in general (Fahn 1990).

#### Parenchyma cells of immature SCR tubers

Thin sections of immature SCR tuber tissue are shown in Figure 7.15. In comparison with that of the mature tubers (7.13a), the parenchyma cw of immature specimens is thin (Figure 7.15a). Staining with Schiff's method (Figure 7.15a) revealed that little intracellular and cw carbohydrate are present in the parenchyma tissue of immature specimens. Like the mature tubers, immature specimens were found to be difficult to thin-section. This suggests that the physical and chemical properties that cause toughness in the mature tissue (*e.g.* high levels of starch, lignin, suberin, tannin, lipid and/or phenolic materials) are already present in the parenchyma cw in the early stages of tuber development.

# Comparison of raw SCR parenchyma cells with those of potato and Chinese water chestnut.

To provide standards for assessing the characteristics of the raw and processed SCR tissue, Chinese water chestnut and white potato (*S. tuberosum*) were also examined with LM and TEM (Figure 7.16.). These two tubers were chosen for comparison for a number of reasons, beginning with the fact that SCR, potato and Chinese water chestnut have similar potential food uses, including boiling as a



Figure 7.16. LM views of raw parenchyma tissue of (a, b) SCR; (c, d) Chinese water chestnut (*E. dulcis*); (e, f) potato (*S. tuberosum*). Of note are the differences in cell size, most obvious in the tissue stained with Toluidine blue, shown in the left column (a, c, e); and differences in starch granule size and shape, most obvious in tissue stained with Schiff's method, shown in the right column (b, d, f). Key: cw = cell wall, i = intercellular space, sg = starch granule.

vegetable and, as in the case of the potato, pulverising into flour. Like SCR, both the potato and Chinese water chestnut are stem tubers and therefore have the same general anatomical structure as SCR (for a comprehensive explanation of the anatomical characteristics of edible roots and tubers, see Hather 1994 and 2000). Moreover, there is an established literature on the heating performance characteristics of the parenchyma tissue of both potato and Chinese water chestnut. In the raw form they are of similar physical properties and chemical composition as each other, and also have comparable texture in terms of tensile strength and toughness (Mudahar and Jen 1991; Loh and Breene 1982, Loh *et al.* 1982).

Figure 7.16 shows LM views of potato, Chinese water chestnut and mature SCR tubers. In comparison with the cells of potato and Chinese water chestnut, which are up to 100  $\mu$ m in length, SCR parenchyma cells are small (35 – 50  $\mu$ m). As noted earlier, the relatively small SCR cell size, along with the uniformity of cell size throughout the tissue, may contribute to the toughness of this parenchyma tissue (Vincent 1991).

Several similarities between the parenchyma tissue of SCR and that of its close relative the Chinese water chestnut can be observed in Figure 7.16 a-d, including the uniformity of cell size, cw thickness and in the size of the intercellular spaces. Despite the differences in cell sizes, SCR and Chinese water chestnut have similar cw thickness, measuring  $1 - 2 \mu m$ . However the intercellular spaces of Chinese water chestnut are larger than those of SCR measuring up to  $10 \mu m$ .

Compared with SCR and Chinese water chestnut, the cells of the potato parenchyma tissue are less uniform in size. Furthermore the potato cw is slightly thinner, measuring  $1 - 1.5 \mu m$ , and there is less uniformity in cw thickness (see Mudahar and Jen 1991). SCR and potato have similar sized intercellular spaces, while

those of Chinese water chestnut are larger, measuring up to 10  $\mu$ m. In all three species the parenchyma cells are packed with starch (see section 7.5. below).

# 7.4.3. The effects of thermal processing on SCR tissue: pit cooking and boiling

This section considers why SCR tubers were not softened by boiling or pit steaming. Given the above information on mechanical properties of a plant organ, taken from Waldron *et al.* (1997) and Waldron, Parker and Smith (2003) (Figures 7.11 and 7.12), it would be expected that the insufficient softening of SCR tubers during pit-cooking and boiling can be explained by a thermal stability of the parenchyma tissue: when heated SCR cw is prone to adhesion rather than cell separation. Indeed, viewed with SEM, LM and TEM microscopy, as shown in Figures 7.17 and 7.18, no cell separation is evident in pit-steamed and boiled SCR tubers. The tissue appears to have remained intact, and no spilling of intracellular materials has occurred. However the intracellular starch appears gelatinised (disordered) which indicates that the moisture and heat have permeated the tissue, and/or that heat only has permeated the tissue and the moisture inside the parenchyma cells has been heated. Together these processes have caused swelling and loss of structural integrity of the starch granules (discussed below in section 7.5.4).

Increased boiling time did not promote cell separation. SCR tissue collected after 30 min of boiling show no more cell separation than tissue collected after 5 and 10 min of boiling (Figure 7.18). Moreover, in the pit-cooked samples, shown in SEM view ' in Figure 7.17, there is no visible difference in the cw adhesion of samples that were peeled before pit cooking and samples that were not peeled. Altogether these patterns demonstrate that cw adhesion was not reduced when SCR tubers were exposed to



**Figure 7.17.** SEM views of pit-steamed SCR: (a, b) tubers not peeled before cooking; (c, d) tubers peeled before cooking. In both samples, no cell separation or deformation is apparent. However, in both samples the cell walls are swollen and the intercellular spaces appear to have enlarged (compare these images with SEM views of raw SCR, shown in Figure 7.14). The only visible difference between the two samples is that the starch of the peeled tubers (c, d) is fully gelatinised and pasted, while that of the unpeeled tubers (a, b) appears only partially gelatinised. Key: cw = cell wall, i = intercellular space, s = starch.



Figure 7.18. Thin-section microscopy of SCR peeled, diced and boiled for (a) 5 min; (b, d) 10 min; (c, e) 30 min. Microscopy: upper row (a-c) LM view of Toluidine blue stained tissue; lower row (d-e) TEM view. No significant changes in cell wall adhesion or integrity are apparent after 30 min; the intercellular spaces have widened in some places. Starch gelatinisation appears to have occurred, and in some cells the intracellular starch has collected within one area.

thermal processing at temperatures between 85-97°C, and for periods of time ranging from 5 min to >12 h.

Although it did not influence cell separation, heating does appear to have promoted changes in SCR cell shape and cw thickness. The pit-cooked cells are significantly rounded compared to the polygonal shape of cells of the raw tissue (compare Figure 7.17b and d with 7.14a and c). The cw appears thickened/swollen in SCR samples that were boiled for 30 min (Figure 7.18c) and samples that were pitcooked for 12 h (7.17b, d). Also, in the pit-cooked samples the walls between adjacent cells appear more robust, as though fused along the middle lamella (see 7.17b, d).

For the sake of comparison potatoes were boiled for 10 and 30 min and sampled for microscopy. Again, taste tests of pit-cooked and boiled potato samples had determined that potatoes were adequately cooked with these techniques, which suggests that cell separation and/or cell rupture had occurred. Potato boiling experiments by Loh, *et al.* (1982) demonstrate that indeed, tissue softening begins immediately because cell separation occurs after only one minute in 100°C steam, followed by cell rupture. Cell rupture is likely to follow cell separation because individual, separate cells are more easily fractured than cells that are incorporated within tissue (Vincent 1991).

Figure 7.19 shows LM and TEM views of boiled potato. In contrast with the thermal behaviour of SCR tubers, potatoes that were boiled 10 min (Figure 7.19b and e) sustained both cell separation and cell rupture. After 30 min potato cw appears swollen and distorted. In comparison the cw of SCR, boiled for the same period appears to have retained its integrity (compare Figure 7.18c and e with 7.19e and f). Cw swelling is common to both the potato and SCR boiled for 30 min and SCR pit-cooked for 12 h (compare Figure 7.18 c and e and Figure 7.19c and 7.19f). Loh *et al.* (1982)



Figure 7.19. Thin-section microscopy of raw and boiled potato (*S. tuberosum*) parenchyma tissue. Left column (a, d) raw tissue; middle column (b, e) tissue boiled 10 min; right column (c, f) tissue boiled 30 min. Changes during thermal treatment include cell separation, cell rupture, and, visible in (c), cell wall swelling and the enlargement of intercellular spaces. The gelatinised starch is relatively viscous compared with that of the boiled SCR samples (see Figure 7.18). Microscopy: upper row (a-c) LM view of tissue stained with Schiff's method; lower row (d-f) TEM. (Note: The starch granules in (a, d) are wrinkled due to shrinkage caused by the fixative.) Key: cw = cell wall, i = intercellular space, s = starch.

attribute the tendency of the potato cw to swell to a hydration of the matrix materials in potato cw and/or adhesive material in the middle lamella.

Factors that might contribute to the different thermal responses of potato and SCR include the larger and less uniform potato cells, and the fact that potato cw is marginally thinner than that of SCR (1 – 1.5  $\mu$ m vs. 1 - 2  $\mu$ m, respectively). But these differences do not explain the difference in the ways these two tubers behave when heated. Again, the amount and rate of softening during cooking depends primarily on whether the innate tendency of the cw is towards adhesion or cell separation (Brett and Waldron 1996; Loh *et al.* 1982; Parr *et al.* 1996).

Interestingly, the thermal behaviour of SCR is more similar to that reported for its relative, the Chinese water chestnut. Like SCR, Chinese water chestnut tissue does not soften during heating because the cells do not separate. This species has a remarkable and unusual thermal stability, retaining a firm and crunchy texture after cooking. Thus, to better understand the thermal behaviour of SCR tissue, it is useful to discuss the previous reports on the functional properties of Chinese water-chestnut tissue. Food scientists have been studying Chinese water chestnut since the 1980's to identify the physical and chemical characteristics that contribute to its unusual textural properties (Brett and Waldron 1996; Loh and Breene 1982; Loh *et al.* 1982; Parr *et al.* 1996; Waldron *et al.* 1997).

For present purposes, it useful that several published studies compare the thermal behaviour of Chinese water chestnut with that of the potato. Evidently, in the raw form, the tissues of these two species are similar in chemical composition and have comparable tensile strength and toughness (Loh and Breene 1982, Loh *et al.* 1982). In fact, compression studies by Mudahar and Jen (1991) revealed that, in the raw state, the

potato is slightly harder (tougher) than Chinese water chestnut, and has a higher degree of tensile strength (structural integrity). However, the structural properties of these two species respond very differently to heating (Mudahar and Jen 1991; Loh and Breene 1982, Loh *et al.* 1982). The cw of the potato quickly separates while that of Chinese water chestnut does not. Moreover, after 10 min boiling in water, the degree of structural integrity retained by the potato cw diminishes from 100% to about 15%; in the same period the degree of structural integrity retained by the Chinese water chestnut diminishes by 10%. After 30 min boiling the degree of structural integrity retained by the potato diminishes to 0% while that of the Chinese water chestnut diminishes to no more than 65% (Mudahar and Jen 1991).

In fact Waldron *et al.* (1997) report that the tensile strength and toughness of Chinese water chestnut actually increase slightly during cooking, a tendency that Gordon Hillman (pers. comm. 2000) and I each independently observed in SCR tubers that were baked in ash and pit cooked, respectively. The perceived increase in hardness of SCR tubers that had been pit cooked and cooked in the embers of a fire may be linked to the apparent cw fusion that was noted for the pit-cooked SCR in the SEM images (Figure 7.17).

Recent studies (Parker *et al.* 2003; Waldron *et al.* 1997) have revealed that the thermal behaviour in Chinese water chestnut is due to the presence of specific phenolic substances in the cw. These phenolic substances, known as ferulic acids, cross-link the polysaccharides of adjacent cw, promoting cell adhesion during heating. Ferulic acids are more common in monocotyledons, particularly grasses (Poaceae/Gramineae) but also occur in several economically important dicotyledons, *e.g.* beetroot (*Beta vulgaris*).

In species that thrive in wet conditions, such as SCR and Chinese water chestnut, ferulic acids may serve to protect the tubers from pathogens (Parr *et al.* 1996).

It is therefore highly possible that a chemical analysis of the cw of SCR tubers would reveal the presence of phenolic or other substances that promote cell adhesion during heating. If that is the case, then processes other than heating are necessary to soften SCR tissue. For example, Parker *et al.* (2003) recently reported that Chinese water chestnut can be softened with prolonged extraction in cold alkali, which brings about an increase in the ease of cell separation. In their analysis of the wall-bound phenolics of Chinese water chestnut they observed that it was necessary to reduce most ferulic acid moieties before tissue strength could be reduced. But significant tissue softening only occurred with the loss of one particular substance known as 8,8'-diferulic acid, aryltetralin form.

These reports on the physical and chemical properties of plant tissue (*e.g.* Brett and Waldron 1996; Loh and Breene 1982, Loh *et al.* 1982; Parker *et al.* 2003; Parr *et al.* 1996; Waldron *et al.* 1997) have many implications for food processing, ancient and modern, particularly for food processing intensification. They demonstrate that between-species difference in functional properties of plants cannot be predicted from the morphology of plant tissue, even when the different levels of the hierarchical structure are observed microscopically. Put more precisely, the functional properties of edible plants cannot be predicted with the naked eye. Thus, the acquisition or invention of a heating technology that cooks one type of plant tissue does not automatically bestow people with the ability to cook all other available plants. Again, heating can have opposite effects on the functional properties of different plant tissue and, heating alone is not enough to soften some types of plant tissue. Accordingly, human groups that are heavily reliant on processed plants will need to have obtained prerequisite knowledge of the functional properties of critical plant resources, and between-species differences. Experimentation, involving trials of different technologies on single species, and/or different species on single technologies, is a prerequisite for developing a diet based on cooked foods. Moreover, knowledge of the functional behaviour of edible plants is highly essential for complex cooking *e.g.* preparing recipes that involves two or more ingredients (see Loh *et al.* 1982).

In the case of SCR tubers, heating alone was not sufficient to soften the tissue because the tendency of SCR cw is towards *increased* adhesion. With reference to schematic model of a plant organ (Waldron *et al.* 2003, seen here in Figure 7.11), in conjunction with studies of the related species Chinese water chestnut (Brett and Waldron 1996; Loh and Breene 1982, Loh *et al.* 1982; Mudahar and Jen 1991; Parker *et al.* 2003), the thermal behaviour of the SCR tuber appears to be due to the chemical and structural characteristics of the polymers that form the cw, the possible presence of phenolic substances which cross-link the polysaccharides of adjacent cw causing adhesion during heating. Thus, the fact that SCR tubers were observed to become even tougher after heating can be explained by genetically-determined chemical and structural properties.

#### 7.4.4. The effects of pulverising on SCR tissue

Heating alone did not cause SCR tissue softening, but tissue that was pulverised prior to heating did soften. Thus pulverising was recognised to be an important step in SCR tissue softening. SCR tissue was pulverised into flour for the bread and gruel experiments.







**Figure 7.20.** SCR tissue pulverised for 5 min. Cells that are fragmented by cell rupture are visible in (a), (b), and (c). Cells that are fragmented by cell separation are visible in (d). In all images the starch grains are slightly swollen due to having absorbed moisture from the air. **Key:** csg = compound starch granule; cw = cell wall; ml = middle lamella; s = starch granule; sc = separated cell; v = vascular tissue. 373 Figure 7.20 shows four SEM views of SCR tissue that was pulverised for 5 min. The cells are primarily fractured by cell rupture, such that the cell walls are broken open and the intracellular contents are able to spill out (Figure 7.20a, b, c). The tissue is fragmented into clusters of densely packed cells (Figure 7.20a). Fragments range from a few  $\mu$ m to a maximum length, width or depth of about 300  $\mu$ m. In most cases the tissue is fragmented in clusters of tissue with ruptured cells on the outside that enclose (contain) intact tissue within Figure 7.20a. In most cells the cw appears deformed, in some cells it is flattened as well as ruptured (Figure 7.20b and c).

However, cell separation along the middle lamella has also occurred, although to a lesser degree (Figure 7.20d). Furthermore, cracks and fissures along the middle lamella are visible throughout the tissue, between cells that are still joined to the tissue. There is a predominance of cell adhesion over cell separation and many cells appear tightly bonded after pulverising, including those cells that are partially separated along the middle lamella by fissures.

SCR tissue prepared for gruel was pounded for 15 min to render the tubers into a meal-like consistency, while SCR tissue that was prepared for each of the breads was pounded for about 20 min to obtain a finer consistency. Figures 7.21 and 7.22 show the sequences of gruel and bread making. Microscope views of SCR tissue pounded for 5 min (Figure 7.20) and tissue pounded for 15 and 20 min (Figures 7.21a, c, e and Figure 7.22a and d) show no significant differences in cw deformation. This suggests that increased time spent on pounding causes increased fragmentation at the tissue level, with more areas of the tissue being broken into smaller clusters of cells, rather than increased deformation of individual cells. However, by causing more surface area to be

exposed, increased pulverising would have promoted the vulnerability of the cells to fragmentation by tissue rupture and cell separation.

Based on the schematic model of the hierarchical levels of the plant organ, shown in Figure 7.11 (from Waldron *et al.* 1997; and Waldron, Parker and Smith 2003), and in conjunction with the images shown in Figures 7.20 - 7.22, it can be inferred that pulverising causes SCR tubers to fracture at both the tissue and at the cell levels of the hierarchy because it causes cell rupture, and to a lesser degree cell separation. Moreover, additional weakening of the tissue occurred in the form of fissures along the middle lamella, although complete cell separation does not always occur.

#### 7.4.5. Gruel: the effects of pulverising followed by boiling on SCR tissue.

Gruel making entailed two stages of processing: pounding for 15 min, followed by boiling for 10 min. SCR gruel was sampled for microscopy after each of the two stages. SEM, LM and TEM views are provided in Figure 7.21.

Samples collected after the first stage of the sequence, pulverising for 15 min, are shown in the left column of Figure 7.21. Samples collected after the second stage, boiling for 10 min, are shown in the right hand column. After Stage 1, the pulverised tissue (Figure 7.21a, c, e,) is changed in several ways, including: a deformation of cell shape; cw rupture; the fragmentation and flattening of the cw tissue; the increased exposure of cw; the spilling of the cell contents from ruptured cells and some cw separation. Fissures along the middle lamella of cells that have not separated were also observed (Figure 7.21d).

Sample collected after Stage 2, boiling, (Figure 7.21b, d, and f), shows increased deformation of the cell shape and the cw thickness is diminished (compare Figure 7.21 with Figures 7.11 and 7.12). There is no obvious increase in cw separation



Figure 7.21. Microscopy: sequence of SCR gruel production: Stage 1, raw tissue pounded 15 min, is shown in the left column: (a) SEM (c) LM and (e) TEM. Changes after pounding include deformation of the cell walls and cell rupture, and separation of compound starch granules (compare with Figures 7.13 and 7.14). Stage 2, boiled 10 min, is shown in the right column: (b) SEM (d) LM and (f) TEM view. Changes after boiling include shrinkage in cell wall thickness (b, d) and incomplete as well as full starch gelatinisation, most obvious in (b). (Note: Starch granules in (e) appear wrinkled due to shrinkage in the fixative.) Key: cw = cell wall, i = intercellular space, ml = middle lamella, p = cell wall pitting, s = starch, v = vascular tissue.

along the middle lamella after boiling, over that of tissue that was pulverised only. However, a swelling of the cw is apparent in TEM view, when Figure 7.21f is compared with 7.13c.

In SEM view (7.21b), cw pitting is no longer visible because substances contained within the cells (*i.e.* starch) have melted, spilled out and coated the cw surface (compare the SEM view shown in Figure 7.21b with those of Figure 7.14). This coating appears to have spread into an even covering over the cells. Comparisons of SEM views of the gruel (Figure 7.21b) with SEM views of the pit-cooked SCR tissue (Figure 7.17) reveal differences between these processed tubers in both cell shape and cw thickness. The gruel cells are deformed, having lost the characteristic polygonal parenchyma shape, yet retaining an angular overall shape in which the cw is somewhat folded in on itself. In contrast, the pit-cooked SCR cells have lost their angularity and become more oval. The cw of the gruel appears to have narrowed significantly, becoming folded in on itself; in contrast the cw of pit-cooked SCR parenchyma tissue has swollen and the walls between adjacent cells appear more robust, as if they have fused along the middle lamella. Pulverising and soaking, prior to cooking, promoted a more effective thermal response in SCR tissue than simply heating the tubers by boiling or pit steaming.

### 7.4.6. Bread: the effects of baking, after pounding and soaking

Bread making involved three main stages of processing: i) pulverising for 20 min; ii) adding water and soaking for 20 min; and iii) baking at high temperatures. In the case of Bread 2, the second step entailed simply mixing SCR flour with water; while in the case of Bread 1 the second step entailed mixing SCR flour, bread-wheat flour, water and kneading. LM and TEM views of the three stages of Bread 2 processing are shown in Figure 7.22. SEM images of Bread 1 and Bread 2 are shown in Figure 7.23.



Figure 7.22. Microscopy: sequence of SCR Bread 2 production. Stage 1, raw tissue pounded for 20 min, shown in the left column (a, d); cell wall rupture and deformation have occurred, as well as a spilling of starch granules from fragmented cells. Stage 2, tissue soaked for 20 min, is shown in the middle column (b, e); there is an increase in cell wall deformation and the intracellular starch has collected within one area of each cell. Stage 3, baked for 30 min at 250°C is shown in the right column (c, f); no further cell wall changes are apparent, while the starch has gelatinised. Microscopy: upper row (a-c) LM view of Toluidine blue stained tissue; lower row (d-f) TEM. Key: csg = compound starch granule, cw = cell wall, gs = gelatinised starch, i = intercellular space, s = simple starch granule.



 A3368 SEI 15KY B Scirpus burnt "cookie"
 3/2

**b** Figure 7.23. SEM microscopy of Bread 1 and 2. Bread 1 (a) was made from SCR flour, water and bread wheat (*T. aestivum*), and Bread 2 (b) was made from SCR flour and water. Compared with raw tissue shown in Figure 7.14, the cell walls and intercellular spaces of Bread 1 (a) appear relatively unchanged, with the exception of a broken fragment of cell wall visible in the lower left corner. In Bread 2 (b) the cells appear to have collapsed/folded, the cell walls are shrunken in thickness, and the intercellular spaces are reduced. In both samples, the starch has gelatinised and formed a thin layer over the cell wall surface, concealing cell wall pitting, but the starch of Bread 2 appears more "melted" than that of Bread 1, covering both the inside and outside the cells. Key: cw = cell wall; f = cell wall fragment, i = intercellular space, s = starch. 379 Tissue collected after the first stage in the sequence of making Bread 2, *i.e.* 20 min pulverising to pass through a 500  $\mu$ m mesh, is shown in LM and TEM in Figure 7.22a and d (see also Figure 7.20 for SEM images of tissue pulverised for 5 min). Tissue that was pulverised for 20 min (Figure 7.22a, d) demonstrates: a deformation of cell shape; cw rupture; a fragmentation and flattening of the cw; an increased exposure of cw; a spilling of the cell contents from ruptured cells, and some cell separation along the middle lamella. Fissures along the middle lamella of cells that have not separated were also observed (Figure 7.20d). In fact these changes, including cell separation along the middle lamella, were shown to occur after only 5 min of pulverising (Figure 7.20). Again, this suggests that increased time spent on pounding causes increased fragmentation at the tissue level, with more areas of the tissue being broken into smaller clusters of cells, rather than increased deformation of individual cells.

Samples collected after the second stage of processing, 20 min soaking, are shown in Figure 7.22b and e. Changes include an increased deformation of the cell shape and a reduction of cw thickness. No significant increase in cell separation is evident compared with tissue that was pounded only but there does seem to be increased swelling/distortion along the middle lamella in some places. Ruptured cells appear to have been emptied of their contents, while the contents of intact cells appears to have aggregated.

Samples collected after the third stage of bread making, 30 min baking, are shown in LM and TEM views Figure 7.22c and f, as well as Figure 7.23. There are no visible changes from the previous stage in terms of cell shape and cw integrity, but the intracellular contents are greatly changed, having become more disordered in

appearance, *i.e.* the loss of structural integrity. In (Figure 7.22c) broken fragments of cw have lodged within some of the ruptured cells. No cell separation is visible.

SEM views of the final products, Bread 1 and Bread 2 are shown in Figure 7.23. As observed above these two breads tasted like very different foods, and were prepared in different ways: Bread 1 contained one more ingredient (bread wheat flour), less water, was baked at a higher temperature, and for a shorter period of time. Nevertheless, when viewed with SEM, the breads appear similar to each other in that the cells have partly retained their geometric, angular shapes, the cw appears narrowed, and the intracellular substances appear to have "melted" and coated the cw so that no cell-wall pitting is visible (compare with Figure 7.14).

Nevertheless several differences between Bread 1 and Bread 2 are evident (compare Figure F7.23a with 7.23b). The cells of Bread 2 appear more deformed and flattened than those of Bread 1. Also, the Bread 2 parenchyma cw appears thinner than that of Bread 1. Dehydration might be partly responsible for this change. In fact, the shape of the Bread 2 cells and the consistency of the cw are more similar to that of the gruel (see Figure 7.21). Again these differences are not surprising as Bread 2 had a higher water content than Bread 1, was baked for longer and at a lower temperature, and was not mixed with a third ingredient, as was Bread 1.

Comparisons of SEM views of the SCR Breads (Figure 7.23) with SEM views of the pit-cooked SCR tissue (Figure 7.17) reveal differences in cell shape and cw thickness. In both Breads 1 and 2 the polygonal parenchyma cell shape is retained, although in Bread 2 some cells while cells appear to have collapsed inwards; in the pitcooked SCR the cells have lost their geometric shape and become more oval. In both breads the cw appears to have narrowed; the cw of pit-cooked SCR parenchyma tissue has swollen and the walls between adjacent cells appear more robust, as if they have fused along the middle lamella. Again, as observed for the gruel, it can be inferred that pulverising and soaking prior to cooking, are important steps in promoting adequate cooking of SCR tissue. Moreover, pulverising and soaking prior to cooking are more effective than simply heating.

## 7.5. OBSERVATIONS OF THE PHYSICAL PROPERTIES OF SCR STARCH

This section begins with a general description of starch, and a summary of its characteristics, and then describes and discusses raw and processed SCR starch. Starch is of interest here because: i) it is the major storage polysaccharide in the human diet; ii) its functional behaviour during processing influences the taste, texture, palatability and digestibility of the final food product; and iii) the starch granule provides an ideal subject for observation with microscopy because its physical properties are more obvious with microscopy than those of other macronutrients (BNF 1990; Englyst *et al.* 1992; Hultin and Milner 1978). Given the complexity of starch and how it behaves when heated (Atwell *et al.* 1988; Buléon *et al.* 1998; Whistler and BeMiller 1997; Shamekh 2002) only general observations are made about SCR starch morphology and how it changed during processing.

#### 7.5.1. Starch: description and development

Starch, which is usually the primary component of plant cells (Fahn 1990) occurs in the form of granules (grains). Starch granules are essentially parcels of sucrose polymers, and characteristically quasi crystalline, slightly hydrated and insoluble in water (Cortella and Pochettino 1994). Starch is a polysaccharide, the granules being composed of two organic polymers, amylose which is essentially a linear molecule with a very small level of branches, and amylopectin, which is highly 382

branched. The relative proportion of amylose:amylopectin, which is genetically determined, affects the functional behaviour of the starch during processing, and ultimately influences the taste, texture, palatability and digestibility of the final food product. Most starches contain 20-30% amylose but tuber starches are typically high in amylopectin, which may comprise up to 85% of the starch (Atwell *et al.* 1988; Buléon *et al.* 1998; Englyst *et al.* 1992; Whistler and BeMiller 1997).

Starch granules originate within specialised organelles known as chloroplasts and amyloplasts, from a point known as the hilum. During starch formation the hilum is covered by layers that appear as striations. Granules have birefringence under the hilum appearing as a Maltese cross. The shape and placement of the hilum varies among plant species (Flint 1994).

Starch granule shape and size also varies among plant species, as well as the part of the plant in which they occur. Shapes vary from oval or elliptical to angular, polygonal. Sizes range from  $1 - 100\mu$ m, again depending on species but also depending on whether they are *transitory* or *storage* starch. Transitory starch is a temporary form of carbohydrate storage that is produced during the daylight hours, when the plant is photosynthesising, and depleted during the night when it serves as energy for normal metabolic processes (Haslam 2004: 1722). It develops in chloroplasts, organelles found in stems and leaves, where photosynthesis takes place. Transitory starch granules are typically smaller than those of storage granules, normally measuring  $2 - 5 \mu$ m (Therin *et al.* 1999).

Storage starch, which is the subject of interest here, serves as an energy reservoir for the plant, allowing it to survive during periods of dormancy and/or unfavourable environmental conditions. Storage starch occurs in many plants parts that

humans use as food, *e.g.* tubers, corms, roots, rhizomes, corms, seeds and fruit (Haslam 2004: 1716). Storage starch granules develop within amyloplasts, which are specialised organelles within plant cells devoted to starch development and storage (Fahn 1990). Storage starch granules are typically larger than those of transitory granules, measuring  $>5 \ \mu$ m, *e.g.*, cassava, 10 – 30  $\mu$ m; Zea maize kernels, 10 – 15  $\mu$ m; and wheat, 25 and 6  $\mu$ m (Therin *et al.* 1999).

Starch size, as well as shape, is an important diagnostic feature in the visual identification of archaeological starch. Among the controversies within current archaeological starch research is the fact that analysts frequently dismiss small starch grains, specimens of  $<5\mu$ m, on the assumption that they are transitional granules and therefore represent general vegetation rather than plant foods (Haslam 2004). However, as Haslam (2004) has shown, the size ranges of transitional and storage starch granules overlap, and many plant foods have exceptionally small starch granules *e.g.* the taro (*Colcasia esculenta*) corm has granules of  $<5\mu$ m; the kernel of rice (*Oryza sativa*) contains granules of  $5 - 8 \mu$ m; and the kernel of oat (*Avena sativa*) is 3-10  $\mu$ m (Flint 1994; Shamekh 2002). Furthermore, in some plants starch granules are bimodal, occurring in two size/shape groups, such as wheat kernels, which have small granules of  $6 \mu$ m and large granules of 25  $\mu$ m (for a comprehensive and concise description of wheat starch, see Evers *et al.* 1999).

### 7.5.2. The effects of processing on starch granules

Activities such as pounding and grinding, which cause cw rupture, improve the availability of starch for consumption and absorption by eliminating physical barriers and exposing the granules (BNF 1990). Fracturing also promotes starch availability and bioaccessability because it causes mechanical damage to the grain, which increases the susceptibility of the starch molecules to chemical and physical processes and promotes interactions between the starch and other substances (BNF 1990). Likewise, kneading and fermentation promote interactions between starches and other elements and ingredients. Interactions between starch and other elements can facilitate changes in the physical structure of a food, *e.g.* the structure of a bread loaf (Evers, Blakeney and O'Brien 1999).

Heating causes four main physical transformations of starch granules: i) an increase of the surface area to volume ratio in the solid phase; ii) swelling; iii) a modification of the crystallinity, and; iv) depolymerization of starch macromolecules (Colonna *et al.* 1992). The (genetically-determined) ratio of amylose:amylopectin in the granule influences the functional properties of a starch. But the amount of swelling and solubilisaton of a granule depends on the species. Starch that is composed of a greater proportion of amylopectin will become more viscous while starch that is composed of a greater proportion of amylose will form a more firm gel (BNF 1990). It has been reported that only amylose is leached from barley and wheat starches while both amylose and amylopectin are leached from oat starch (Shamekh 2002: 11).

Dry and moist thermal heating each have different effects on the starch that ultimately influence the texture and taste of the final food product. Dry thermal processing promotes dextrinisation. Moist thermal processing promotes gelatinisation. Dextrinisation is a form of depolymerisation, involving a chemical degradation of starch. Unlike gelatinisation, during dextrinisation granules do not swell or leach their contents but instead, a decrease in granule cohesion occurs, which causes a loss of paste viscosity and gel strength. In some food products starch is both gelatinised and dextrinised, *e.g.* breads, where the baked crust becomes dextrinised and serves to keep

moisture inside the loaf thus promoting gelatinisation (Colonna *et al.* 1992; Whistler and BeMiller 1997). Dextrinisation is associated with changes in taste, smell and colour such as the formation of a crust during the baking of bread or non-enzymic browning during cooking such as the Maillard reaction (Colonna *et al.* 1992).

Gelatinisation is a non-reversible process that occurs when starch molecules are exposed to both heat and water. It involves a modification of crystallinity in which the granular structure is altered irreversibly (Atwell *et al.* 1988; Buléon *et al.* 1998; Englyst *et al.* 1992; Evers, Blakeney and O'Brien 1999; Whistler and BeMiller 1997). Irreversible swelling typically begins at 60°C. Gelatinisation is distinct from natural, reversible swelling that can happen at room temperature when there is an increase of starch water absorption. Gelatinisation and pasting involve the formation of gels and pastes and are associated with thickening in cooking. Gelatinisation begins when water is imbibed into the granule during heating, causing swelling, deformation, rupture, splitting, leaching of the molecules, and, in the later stages of the process, collapse, and loss of structure. The process of collapse and loss of structure, total disruption and dissolution of the granule, which occurs in the later stages of gelatinisation, is known as *pasting*. Gelatinisation and pasting involve the following processes:

- i) The granule imbibes water during heating and swells.
- ii) The swollen granule tears at the hilum with fissures running lengthwise.
- iii) The molecular components leach out.
- iv) There is a collapse and loss of structure of the granule (Atwell *et al.*1988; Evers, Blakeney and O'Brien 1999; Whistler and BeMiller 1997).

Gelatinisation transforms starch into a form that is more easily digested by humans (Englyst *et al.* 1992). Depending on the species, and the food matrix within which the starch is located, gelatinisation begins at around 60 - 70°C, *e.g.* Chinese water chestnut gelatinises at slightly higher temperatures than potato starch (Table 7.12). The process occurs over a temperature range (Table 7.12).

**Table 7.12.** Gelatinisation ranges of potato and Chinese water chestnut starches (from Xu and Shoemaker 1986)<sup>1. 2</sup>

	Gelatinisation temperature °C		
	To	T <sub>p</sub>	T <sub>p</sub>
Potato	58	61.2	68
Chinese water chestnut	59	65.8	69

<sup>1</sup>The gelatinisation range represents the temperature range needed for the gelatinisation of 90% of the granules (Flint 1994).

<sup>2</sup>Gelatinisation onset (To), peak (Tp) and, conclusion (Tc).

However, the actual temperature in which gelatinisation temperatures are influenced by a number of conditions including the other ingredients that are in the food (Light 1990). Therefore, temperatures obtained during the pit cooking (55-85°C), boiling (97.7°C) and baking (250-433°C) experiments are adequate to gelatinise starch (although when baking at 433°C, starch in the crust of the bread will be dextrinised).

#### 7.5.3. SCR Starch

Starch is abundant in the parenchyma cells of raw mature SCR tubers (Figures 7.13 and 7.14). It occurs in individual and compound (aggregated) form. Individual granules measure 3 - 7  $\mu$ m and have assorted shapes: triangular, polyangular, cubic, crescent, round and half cap. It was inferred that individual granules are actually disaggregated compound grains because in transverse view the grains appear triangular or wedge-shaped, which according to Flint (1994) is a characteristic of grains derived from compound granules, due to a flattening on the attachment faces. Significantly, the relatively small size of SCR individual starch granules, like those of taro corms and rice kernels, does not fit with typical size range of storage starch (discussed above in section 387

7.5.1). SCR granules illustrate Haslam's (2004) argument that there is an overlap in the granule sizes of transitional and storage starch, and the importance of including granules that are >5  $\mu$ m in archaeological starch sampling and analysis.

Compound granules, which measure 9 - 11  $\mu$ m, are composed of 3 - 8 individual grains. Examples of intact compound SCR starch granules are visible in Figure 7.14d.

Little starch is visible in the tissue of immature SCR tubers (Figure 7.15). The first stages of starch development within amyloplasts are visible in Figure 7.15c.

There appeared to be greater numbers of starch granules in SCR cells than those of the potato and Chinese water chestnut. However, SCR starch grains are small relative to those of the other two species. Potato starch grains are relatively large, measuring up to 100  $\mu$ m, and occur in two size/shape grain types: >30  $\mu$ m ovoid and 10 - 30  $\mu$ m rounded (Figure 7.16e, f; see Flint 1994). Chinese water chestnut granules occur in a similar assortment of shapes to SCR, but are larger and do not occur in compound form (Figure 7.16b and c). They are round, half cap, polyangular and cubic shaped, and measure approximately 5 – 40  $\mu$ m (see also Xu and Schoemaker 1986).

#### 7.5.4. The effects of pit cooking and boiling on SCR starch

Pit-cooked SCR were examined with SEM only. SEM views of tissue from both peeled and unpeeled pit-cooked tubers are shown in Figure 7.17. In the peeled tubers the starch appears to be fully gelatinised and pasted, while in the unpeeled tubers it is gelatinised but not pasted. The starch of the peeled pit-cooked tubers (Figure 7.17d) appears to have fully disintegrated, merged and evenly spread over the insides of the cells. In contrast, the starch of the unpeeled pit-cooked tubers (Figure 7.17b) appears to retain much of its native morphology, with many granules still intact, although swollen

and slightly melted. SEM views of the overall tissue (Figure 7.17 a and c) show that these patterns are uniform throughout the tissue of each of the pit-cooked tubers.

These results suggest that the outer layers of the SCR tubers (the peel) functioned to prevent moisture and/or heat from getting into the parenchyma tissue. Certainly, the absence of adequate moisture would explain the lack of pasting of the starch (Atwell *et al.* 1988; Whistler and BeMiller 1997). This functional behaviour is probably due to biological reasons: for tuberous plants that grow in wet environments, such as SCR, the outer layers of the tuber would have a function in water regulation and exclusion. Therefore, it is necessary to remove the outer layers to allow moisture into the parenchyma tissue to properly cook the starch.

Significantly the starch in the unpeeled potatoes was properly cooked by pit cooking for 12 h. This suggests that, unlike SCR, its outer layers did not prevent moisture from getting into the pith and permeating the tissue. Again, this functional property was probably due to biological reasons: the potato is a geophyte and the outer layers may function to absorb moisture from the surrounding soil. Thus, removal of the outer layers of the potato was not necessary for starch gelatinisation and pasting.

Figure 7.18 shows SCR that has been peeled and boiled for 5,10 and 30 min. Figure 7.19 shows LM and TEM views of potato tissue that was also peeled and boiled for 10 and 30 min. After 10 min cooking SCR starch has swollen and formed clumps (Figure 7.18b, d, also, compare Figure 7.13c with Figure 7.18d), which are not fully merged. These clumps fill less of the parenchyma cells than the starch does when in the native state (compare Figure 7.13b and d with Figure 7.18b, d). It is likely that the clumps are compound granules undergoing the gelatinisation process. In comparison, after 10 min boiling potato starch appears more gelatinised than that of SCR boiled for the same period of time, particularly in TEM view (compare Figure 7.18b, d with Figure 7.19b, e). Although in the raw state potato starch fills only half the cells (Figure 7.19a, d) after 10 min cooking it has swollen to fill the cells, and the granules are fully collapsed and have merged (Figure 7.19b, e). However, in LM view the potato starch appears to retain network-like structure, which probably represents the boundaries of the gelatinised and ruptured granules.

SCR starch, after 30 min boiling (Figure 7.18c and e), appears to have expanded and merged, such that it now fully fills many of the cells. In TEM views (compare Figure 7.19f and e) the physical condition of the potato starch seems unchanged after 30 min boiling from 10 min boiling. However, seen in LM view it appears less networklike after 30 min boiling than it did after 10 min, the boundaries of the granules have collapsed and granules are less distinct in form (compare Figure 7.19c and b). Also in LM view the starch appears less tightly packed within the cells and is somewhat lighter in colour than after 10 min boiling, which suggests an increased leaching of carbohydrate (starch molecules). This inference seems reasonable given that the increased swelling and rupture of the potato cw after 30 min boiling (discussed in section 7.4.3. above, and visible in Figure 7.19c and f, respectively).

Seen in TEM view (compare 7.18e with 7.19f) SCR and potato starch appear to have very different structures. That of SCR appears more organised than that of the potato. However, although it is necessary to note this observation, it cannot be considered diagnostic because the apparent structure of a gelatinised starch may be related to the ratio of starch content to cell volume, and as well as other physical and chemical factors such as the ratio of amylopectin to amylose (Loh *et al.* 1982:337).

Comparisons of gelatinised Chinese water chestnut starch, and that of the potato by Loh *et al.* (1982:337) revealed that the Chinese water chestnut starch appeared as a more organised, networklike versus random, structure than that of the gelatinised potato starch. Nevertheless, these authors cautioned that this observation might not be diagnostic because the difference in the network structure of gelatinised starch is related to the ratio of starch content to cell volume and other physical factors.

### 7.5.5. The effects of pounding on SCR starch

SCR tissue that has been pounded for 5 min is shown in SEM view in Figure 7.20. SEM, LM and TEM views of tissue pounded for 15 and 20 min are shown in Figures 7..21 and 7.22 respectively. Several obvious changes to the starch after pulverising for 5 min include: i) many granules have been released from ruptured cells; ii) a dis-aggregation of compound granules is suggested by the lower number of compound granules seen here than in raw, unprocessed tubers (shown in Figure 7.13 and 7.14); and, iii) in some cases a roughening of the granule surface and fracturing of individual grains into several pieces has also occurred, best viewed in Figure 7.21a and 7.21c (compare Figure 7.21 with Figures 7.13 and 7.14).

Samples that were pounded for 15 and 20 min are shown in LM and TEM view in Figures 7.21 and 7.22 respectively. Cells that were pounded for 20 min show a decrease in starch granules, due to increased cell rupture (best seen in LM view) and have fewer compound granules. The greatest effect of increased pounding time (20 min rather than 5min) appears to be increased cell rupture, *i.e.* a greater number of cells are broken open and therefore a greater amount of the cw barrier has been removed, leaving more granules susceptible to 'damage' in the form of processing and digestion. In LM view (Figure 7.22a, lower left corner) starch that has been released from the cells appears deformed (damaged), whereas starch that is within the cells appears intact (visible also in TEM view, Figure 7.22d).

## 7.5.6. The effects of a sequence of pounding and boiling on SCR starch:

The effects of pulverising, followed by boiling, are shown in Figure 7.21. As observed above, after Stage1, which entailed pounding for 15 min, three changes to the starch are apparent: i) granules are released from ruptured cells; ii) a dis-aggregation of compound granules has occurred; iii) roughening of the surface of individual grains is apparent in SEM view (compare Figure 7.21 with Figures 7.13 and 7.14).

Samples that were subjected to stage 2, boiling in water for 10 min, are shown in the right column, images (b) (d) and (f). Partial gelatinisation as well as some full gelatinisation is apparent. Partial gelatinisation, *i.e.* gelatinisation without pasting, is visible in SEM view (7.21b) where granules appear slightly melted but clustered in lumps, having retained much of their granule shape. Full gelatinisation of some granules is further suggested by the apparent coating over the cw, also visible in SEM.

Compared with the starch of tubers that were simply peeled and boiled, the gelatinised state of the gruel starch falls between that of specimens cooked for 10 min and specimens cooked for 30 (compare Figures 7.21 and 7.18). The gruel starch appears more gelatinised, showing a greater loss of structure than that of SCR tubers that were simply boiled for 10 min, without previous pounding (compare Figure 7.21d, f with Figure 7.18b, d). This suggests that pulverising SCR tubers prior to boiling permits greater amounts of moisture and/or heat into the cells, resulting in faster cooking of the starch than in non-pulverised samples.

Altogether these results suggest that 10 min boiling was not enough to cook the SCR starch, regardless of whether the tubers were whole or previously pulverised. This

observation is supported by previous inferences based on the taste of the gruel (section 7.2.1. above, see also Table 7.3.) in which it was found to have a "starchy" flavour. As observed by Light (1990) undercooked starch typically imparts a starchy flavour.

# 7.5.7. The effects of sequential pounding, soaking and baking on SCR starch: Breads 1 and 2

The Bread 2 experiment is discussed in greater detail here than the Bread 1 experiment because only Bread 2 was sampled for, and examined with all three types of microscopy: LM, TEM and SEM (Figure 7.22 and 7.23). Bread 1 was sampled and examined with SEM only (Figure 7.23).

The Bread 2 experiment involved exclusively SCR tubers and water as ingredients. This experiment entailed a sequence of three stages, namely pounding, soaking, and baking. After Stage 1 in the sequence, pulverising for 20 min, several changes to the starch were observed including: i) granules are released from ruptured cells; ii) a dis-aggregation of compound granules has occurred, such that individual granules are detached from each other, suggested by the lower infrequency of compound granules than in raw, unprocessed tubers (compare Figure 7.20 with Figure 7.13 and 7.14); and iii) in some cases a roughening of the granule surface and fracturing of individual grains has also occurred (discussed above in section 7.5.4.).

After Stage 2 in the sequence, soaking for 20 min (Figure 7.22b, e), the starch appears to be changed in two ways: the granules have collected within one area of the cell; and, there is an increased emptying of the starch from rupture cells (compare Figure 7.22b, e with Figure 7.13).

After Stage 3, baking for 30 min at 250°C, SCR starch appears fully gelatinised and pasted (Figure 7.22c, f and 7.23b). Figure 7.23 shows SEM views of both Bread 1 and Bread 2. Again, Bread 1 was made with one more ingredient (bread wheat) than 393
Bread 2, and baked at a higher temperature but for a slightly shorter period of time, 20 min instead of 30 min (Table 7.1.) In both breads the starch appears to be fully gelatinised and pasted.

# 7.6. SUMMARY OF THE SCR PROCESSING EXPERIMENTS AND POTENTIAL NUTRIENT BIOACCESSABILITY

The results of the processing experiments are summarised in Table 7.13. Three of the experiments produced edible products: the gruel and the two breads. A sequence of techniques was found to be necessary to transform these otherwise tough tubers into edible products: pulverising, the addition of water/and or soaking, followed by thermal processing. On its own, thermal processing was found to promote tuber toughness due to cell adhesion.

The bread products were the most successful SCR foods in terms of both texture and flavour (Table 7.13). However, each of the edible products was observed to need additional work: i) the texture of the breads and gruel could be improved in the first stage of processing by pulverising or grinding the flour to a finer consistency; ii) the flavour of the gruel could be improved by cooking the gruel for longer than the 10 min that was allowed, in order to adequately gelatinise and paste the starch.

Although the cell contents of boiled and pit-cooked tubers were observed to be cooked, the cell contents were unavailable for consumption because the hardness of the tubers increased during cooking, such that the tubers were impenetrable by biting with the human mouth. Pulverising was found to be a necessary step in softening the SCR parenchyma tissue, and to facilitate starch availability for subsequent cooking and consumption. Soaking the pulverised tissue was observed to promote subsequent starch

**Table 7.13.** Summary of the SCR cooking experiments. The two bread experiments, highlighted here in yellow, produced the most success foodstuffs in terms of texture and palatability. The gruel experiment, highlighted here in green, was successful in terms of texture but needed0 longer cooking for full starch gelatinisation to occur. Boiled and pit-cooked tubers were too tough to penetrate by biting, although the intra-cellular starch was cooked.

FORM												
of FOOD	<b>COOKING METH</b>			FOODSTUFF QUALITIES				<b>TISSUE CHARACTERISTICS**</b>				<b>STARCH</b>
	Peeled?	Pulverised ?	<u>Cooking</u> <u>Time</u>	<u>Cooking</u> <u>Temp</u>	<u>Edible?</u>	<u>Mech.</u> <u>features</u>	<u>Flavour</u>	<u>Tissue</u> <u>fracture?</u>	<u>Overall cell</u> <u>shape</u>	<u>Cell wall</u> thickness	<u>Middle</u> <u>lamella</u> visible?	
Pit-steamed (unpeeled) as a vegetable	No	No	12 h	85-50°C	No	too hard to bite into	- print	No	distinctly oval	swollen	fused	Incompletely gelatinised
Pit-steamed (peeled) as a vegetable	Yes	No	12 h	85-50°C	No	too hard to bite into	1	No	distinctly oval	swollen	fused	Gelatinised
Sliced & boiled as a vegetable	Yes	No	30 min	100°C	No	chewy, & tough		No	less angular, towards oval	swollen	not observed	Gelatinised
Boiled as gruel	Yes	Yes, 15 min	10 min	100°C	Yes	soft, viscous, gritty	sweet & starchy	Yes, R, S.F	angular & flattened	thinned	Yes	Incompletely gelatinised
Baked into Bread 1	Yes	Yes, 20 min	20 min	433°C	Yes	brittle,	sweet	Yes, R, S, F	angular & flattened	thinned	No	Fully gelatinised
Baked into Bread 2	Yes	Yes, 20 min	30 min	250°C	Yes	brittle, crumbly, flaky	sweet	Yes, R, S, F	angular & flattened	thinned	No	Fully gelatinised

\* Key: tissue fracture by  $\mathbf{R}$  = cell wall rupture;  $\mathbf{S}$  = cell separation;  $\mathbf{F}$  = cracks, fissures without obvious separation or rupture

gelatinisation because it exposed the starch grains to additional moisture. Cooking was necessary to gelatinise and paste the starch.

# 7.6.1. Time and temperature and the different stages of processing

The relationship between cooking time and temperature was found to be complex. *Time* appears to be an important variable in why the bread making experiments were more successful than the gruel making. Longer periods of time were allowed in each of the three stages of the bread experiments: i) pulverising, ii) soaking and iii) cooking. In the first stage of Bread 2 preparation, prolonged pounding (20 min) probably promoted starch gelatinisation because it broke open more cells and thus permitted greater penetration of water and heat into the cells, as well as causing greater damage, disruption, and dispersal of the granules. In the second stage, prolonged soaking (20 min) probably permitted water to penetrate the ruptured parenchyma cells and thus come into contact with the starch. In the third stage, gelatinisation and pasting occurred because there was an adequate combination of heat, water and time: prolonged heating of 30 min rather than 10, allowed both heat and water to penetrate the cells and come into contact with the starch.

Temperatures that are adequate to cook starch (c. 60-70°C) were easily achieved with pit-cooking, boiling and baking. However, time was an important factor, and it was observed that proper starch cooking requires a certain amount of time, depending on the food matrix within which the starch is embedded, and other factors. It was recognised that 10 min boiling was not sufficient for full gelatinisation and pasting of SCR starch. But, it was also observed that the starch of SCR tubers that were pulverised prior to boiling required shorter boiling times to gelantinse and paste than tubers that were simply sliced and boiled. Increased boiling times did not promote cell separation in SCR parenchyma tissue. SCR tissue collected after 30 min of boiling show no more cell separation than tissue collected after 5 and 10 min of boiling. Moreover, pit-cooked SCR tubers, cooked for 12 h, showed no more cell separation than boiled tubers. Altogether these patterns demonstrate that cw adhesion did not change when SCR tubers were exposed to thermal processing at temperatures between 85-97°C, and for periods of time ranging from 5 min to >12 h.

# 7.6.2. The role of pulverising in successful cooking of SCR

A factor that was observed to highly affect the amount of heat and also moisture that penetrate the cells, and ultimately influence the gelatinisation process, is the physical structure of the tuber itself. The outer layers (endodermis, cortex and epidermis) were found to impede the penetration of moisture and heat into the tissue: the starch of peeled pit-cooked tubers was more completely cooked than that of unpeeled tubers. Observations of tissue from the soaking stage of bread-making (section 7.5.6. above) suggest that the parenchyma tissue also provides a barrier to heat and water. Unless the cw is fractured open, external water cannot permeate the parenchyma cells and come into contact with the starch.

Pulverising appears to have been an important variable in successful cooking of SCR tubers. It promoted tissue softening and the availability of starch for cooking and subsequent consumption and digestion (Table 7.13). Boiling and baking without previous processing did not render SCR tuber tissue edible. In contrast, potatoes, which were boiled and pit-steamed with the same techniques as SCR, were adequately cooked because the thermal behaviour of potato is towards cell separation and cell fracture

when heated. These between-species differences in thermal behaviour can be attributed to genetically determined difference in the cw chemistry.

Thermal processing appeared to cause an increase in the hardness of SCR tuber tissue. SCR tissue demonstrated an unusual thermal stability similar to that of Chinese water chestnut, such that increased cell adhesion was observed in tissue that was boiled and pit-steamed. The most likely explanation for this thermal stability is that, like that of Chinese water chestnut, the cw of SCR parenchyma tissue is probably composed of high levels of substances which create tissue toughness, *e.g.* phenolic materials and/or lignin, suberin, tannin and lipids (Brett and Waldron 1996; Buschmann *et al.* 2002; Loh and Breene 1982, Loh *et al.* 1982; Parr *et al.* 1996; Waldron *et al.* 1997).

After tasting the SCR food products, it could be concluded that pulverising the tubers prior to cooking facilitated a textural softening. This occurred because pulverising fragmented the tissue into particle sizes that are more easily chewed. In other words, pulverising made the tissue more manageable to the mechanics of the human mouth. It was also observed that fracturing the tissue by pulverising exposed the cell contents, making them more accessible for processing, mastication and digestion. However, the examination of the processed tissues under high magnification microscopy, LM, TEM and SEM, showed that pulverising had a number of other desirable effects on the tissue. In addition to causing cell rupture, and some cell separation pulverising was observed to cause cracks and fissures, thus providing avenues for the transmission of heat into the cells which promoted the cooking of starch granules. Moreover pulverising may have loosened the middle lamella of cells that did not actually separate, thus weakening the tissue and rendering the cw more susceptible to the effects of thermal processing. Certainly the thermal behaviour of tissue that was

pulverised prior to thermal treatment appeared different than that of tissue that was exposed to thermal treatment only: the cw of tissue that was pulverised and heated appear thinned and in some cases collapsed, possibly due to dehydration; while the cw in tissue that was heated without prior pulverising is rigid and slightly swollen, possibly having absorbed moisture from within the tissue or from outside the tissue (compare the images in Figure 7.25f and g with those of Figure 25e and h). The fact that SCR tubers that were cooked but not pulverised (pit-cooked and boiled SCR) were inedible yet their starch was highly gelatinised, further indicates that tuber inedibility (poor chewing properties) was due to cw adhesion, and not to changes in the structure of the starch.

### 7.7. CHAPTER VII SUMMARY AND CONCLUSION

SCR tubers were found to be intensifiable (*i.e.* suitable for intensive human exploitation) according to all three criteria set out at the beginning of the study: i) it is possible to transform raw SCR tubers into edible products; ii) it is possible to produce a range of edible products from SCR tubers, in the present case two breads and a gruel were produced, each having a distinct flavour and texture; iii) processing promoted the availability of the starch for consumption and digestion. A sequence of techniques, involving pulverising, soaking and heating, was found to be necessary to transform the tubers into edible products and to promote the availability of the intracellular starch for consumption. Moreover, the experiments demonstrated that the tubers can be processed into food products with non-mechanised techniques and tools similar to those that were available to Epipalaeolithic groups.

Altogether the processing experiments demonstrate that people who depend on processed plant foods will need to have considerable technological knowledge and expertise about the functional properties of each species that they exploit. Furthermore, they will need knowledge and expertise about the most suitable technology, materials, and techniques to use in the preparation of plant foods, *e.g.* pit-lining materials, fuel, feature construction materials. These observations are supported by ethnographic studies on indigenous plant processing (e.g. Alexander, Peacock 1998; Turner 1997; Turner *et al.* 1990; Turner *et al.* 1980) and published reports on the physical and chemical properties of plant tissue (*e.g.* Brett and Waldron 1996; Loh and Breene 1982, Loh *et al.* 1982; Parker *et al.* 2003; Parr *et al.* 1996; Waldron *et al.* 1997). The between-species difference in functional properties of plants cannot be predicted with the naked eye from the morphology of plant tissue. Accordingly, the acquisition or invention of a heating technology that processes one type of plant tissue does not necessarily mean that such technology can be successfully used on all other available plants. As seen in the pit-cooking and boiling of SCR and potato tubers, heating can have opposite effects on the functional properties of different plants. Indeed, in some cases, such as SCR, heating alone is not enough to soften some types of plant tissue.

Labour inputs were only roughly measured because, given the lack of experience of the people involved in processing, it was thought that the values were inflated and therefore unrealistic. Nevertheless, the *types* of labour inputs were recorded for each processing experiment, and each post-harvest method was found to entail a number of tasks in addition to the actual preparation of the foodstuff, including: the collecting of fuel, rocks and vegetative materials with which to process the tubers, the construction of features and manufacture of tools. The processing experiments revealed that transforming these tubers into an edible form was more complicated and labour intensive than expected. On its own no single post-harvest technique was found to be sufficient to render the SCR tubers edible. Instead, a sequence of techniques, involving pulverising, soaking and subsequent thermal processing, was found to be necessary to transform these otherwise tough tubers into edible products. In some cases the techniques that I chose were not the most efficient, *e.g.* dehusking with a mortar and pestle would have been faster than dehusking with knives and shears. Also the types of fuels and heating apparatus (*e.g.* rocks) and vegetation that were used to line the pit oven were possibly not the most appropriate; ethnographic studies suggest that certain vegetative materials and types of fuels are better for cooking specific plant foods than others.

# CHAPTER VIII: POST-HARVEST ANALYSIS: INTERPRETATIONS AND CONCLUSIONS

This chapter integrates the results of the case study on *Bolboshoenus maritimus* (from Chapters IV – VII) with the general theoretical arguments about intensification presented in Chapters I and III, and suggests how the intensification and species selection models presented in Chapter III (Figures 3.3. and 3.4.) can be applied to changing economic practices throughout the Epipalaeolithic. The chapter is divided into two parts. The first part summarises results of the case study and presents a model for the technical and biological conditions in which the intensification of SCR tubers is tenable. The second part of the chapter discusses the implications of the case study and the intensification model with reference to economic and social developments in Epipalaeolithic Southwest Asia.

# 8.1. RESULTS OF THE CASE-STUDY: A MODEL FOR SCR INTENSIFICATION

A major aspect of this thesis is the case study of *Bolboschoenus maritimus*. Field and laboratory studies, as well as literature surveys of archaeological, ethnographic, biological and ecological reports, were conducted to determine whether this species is amenable to intensive exploitation by people; whether the tubers contain sufficient utilisable carbohydrates, energy and/or other nutrients to make harvesting worthwhile; and whether the tubers can be made into an edible food using rudimentary processing techniques, methods thought to be similar to those used by Epipalaeolithic peoples.

# 8.1.1. The raw and the cooked: the potential for intensified SCR tuber exploitation

The processing experiments showed that: i) it is possible to transform raw SCR tubers into edible products; ii) it is possible to produce a range of edible products from SCR tubers, in the present case two breads and a gruel were produced, each having a distinct flavour and texture; iii) processing promoted the availability of the starch for consumption and digestion. Processing the tough, otherwise inedible raw SCR mature tubers into an edible form was more difficult than expected. A sequence of techniques, involving pulverising, soaking and heating, was found to be necessary to transform them into edible products, and to promote the availability of the intracellular starch for consumption. Thermal processing alone, such as pit cooking and boiling of whole and sliced tubers, was not a successful means of softening the tubers. After boiling and pit cooking, the tubers remained too hard for the mechanics of the human mouth.

The experiments demonstrated that SCR tubers can be processed into food products with non-mechanised techniques and tools similar to those that were available to Epipalaeolithic groups. Using the SCR tuber flour, three edible products were produced: two types of bread and a gruel. Two of these products, Bread 2 and the gruel, were made from SCR flour and water. The third product, Bread 1, was made from SCR flour, bread-wheat and water. People who tasted these products generally commented that they found the flavour distinctly sweet and pleasing, and a "satisfying food". However, most people who tasted the food products also stated they were too fibrous and chewy in texture.

The raw and processed tuber tissue was observed with microscopy. The cells were found to contain substantial amounts of starch, which may explain why the cooked food products were perceived to be a "satisfying food". Microscopy further showed that the fibrous texture of the tubers, and the resistance of the tubers to thermal processing, can be explained by the physical structure of the cell wall. Heating alone was not sufficient to soften the tissue because the tendency of SCR cw is towards *increased* adhesion along the middle lamella, rather than cell separation. In fact, the tubers were observed to become even tougher after heating, which was inferred to be due to chemical and structural characteristics.

Heating alone did not cause SCR tissue softening, but tissue that was pulverised prior to heating was significantly softened. Observations with microscopy revealed that pulverising produced both cell separation and cw rupture. Thus pulverising was recognised to be a necessary step in SCR processing because it releases the otherwise encapsulated critical nutrients, *e.g.* starch. However, from the results of the taste tests, combined with the microscopy, it was inferred that the texture of SCR food products would be improved, and greater amounts of otherwise encapsulated nutrients released, if the tubers were pounded or ground to a finer particle size than in the current study, *e.g.* into a particle size that would pass through a 750 - 500 µm mesh.

As stated earlier, the role of any plant in people's diet will in part depend on how regularly it is eaten. Although numerous plants in the Cyperaceae family have served as important foods (see Chapter IV this volume), no archaeological or ethnographic evidence were found to suggest that people have eaten SCR tubers regularly. However, there is some historic evidence to suggest that SCR flour has been used to supplement other types of flour during times of food shortages (Bryant 1783, see Chapter IV this volume). This may have been the case in prehistoric times also. For example, SCR tubers have been found in large numbers at the Neolithic site of Çatalhöyük, and given that this plant was locally available and grew in large stands, it is feasible that it was used to supplement the wheat supply. Thus results of the Bread 1 experiment (Chapter VII), in which SCR flour was mixed with bread-wheat flour to make bread, have possible implications about the ways that SCR tubers might have fit into the diets and economies of ancient people.

As discussed in Chapter IV, there are many other non-food economic ways in which this plant may have been used. On a worldwide basis today, it is better known as a fibre than as a food, the stems being valued as raw materials for basketry and matting. It is possible that ancient groups initially exploited SCR plants for their stems to use as fibres, and began using them as food after processing systems were established. Indeed, evidence from Ohalo II (see Chapter II) suggests that by the Early Epipalaeolithic groups were adept at weaving the stems of reeds, grasses and sedges into matting and possibly netting. Certainly, there would be many advantages in adding a species to the diet that was already exploited for other purposes, *e.g.* narrowing of travel and search time, and concentrating production.

Altogether, the harvesting, processing and nutrient studies showed that SCR tubers meet criteria for an "intensifiable" root food (see Thoms 1989 and Chapter III this volume). Moreover, the plant has several other attractive qualities: it is available year-round, nutrient levels shift minimally throughout the year, and the tubers are high in carbohydrates during the winter months when other sources of carbohydrate are either unavailable or depleted of nutrients. The qualities of SCR tubers that may have made them attractive to people, at different periods in human prehistory and history, include the following:

- i) SCR tubers are rich in energy (kcal) and carbohydrates, and contain considerable amounts of other critical nutrients such as lipids, proteins, and micronutrients.
- ii) SCR tubers are as worth harvesting as other wild edible roots. The harvesting production rates of energy (kcal/h/person), dry matter, carbohydrates, lipids, proteins (g/h/person) and several minerals were found to be similar with those reported for other wild root foods that are ethnographically known to have served as important resources.
- iii) The otherwise inedible SCR tubers can be transformed into an edible form using rudimentary technology similar to that which was available to Epipalaeolithic groups: pulverising, and the addition of moisture and heat.
- iv) Products made with SCR tuber flour have a distinct sweet flavour.
- v) SCR tubers are available and accessible on an almost year-round basis.
- vi) SCR macronutrients are highest between October and March; during the winter months, when carbohydrate-rich resources are scarce and/or depleted, SCR tubers retain notably high levels of carbohydrates;
- vii) SCR clones can withstand intensive predation, other ecological conditions permitting.
- viii) SCR clones respond well to management by humans: planting and tending, and control of water levels and salinity.

Furthermore, extensive SCR stands, which were once common throughout Eurasia, could probably provide staple food crops, other conditions, such as optimal salinity and water levels, permitting. Extensive stands are more amenable to intensive exploitation by humans because they usually contain large clones, and large clones produce bigger tubers than small clones; and, large clones are more resilient to predation than small clones, particularly if patches are rotated from year to year to allow regeneration.

On the other hand, this study demonstrates that some SCR stands are significantly more worthwhile harvesting for the tubers than others. Belowground biomass production ranges widely, from  $42 - >3,000 \text{ g/m}^2$  (dw) (Kantrud 1996). Some stands are more worthwhile harvesting for the nutlets than the tubers. Nutlet and tuber production are advantaged under different habitat conditions. Belowground growth is hindered by conditions that favour sexual reproduction, such as very deep water and drought. Belowground growth is advantaged under conditions of low water depth, fewer hours of light, large clone size and some levels of predation; salinity levels and soil composition are also factors (see Chapters IV and V).

Small SCR patches composed of a limited number of clones, such as those exploited during the harvesting trials (KB and PM habitats, see Chapter V) can probably support occasional exploitation. But, given the comparatively low effective yields of stands comprised of fewer clones, and the fact that smaller clones are more vulnerable to destruction due to ecological stresses, (such as flooding, changes in salinity levels, drought, and/or predation) it is unlikely that individual patches such as the KB and PM habitats could provide a staple annual source of human food. However, low-yielding stands could serve as important food sources in cases where numerous patches occur within a group's territory, and patches are numerous enough to permit inter-annual patch rotation.

### 8.1.2. The model for sea club-rush intensification

The results of the case study indicate that the potential for people to intensively exploit SCR tubers depends on two main variables: i) the existence of an effective processing system; and ii) available yield; the latter being determined by biological production. Table 8.1 suggests six possible interactions of these two variables, and also indicates which of these interactions permit human intensification.

Pote	ntial for intensification	Available yield	People have access to an appropriate food processing system			
a.	very high	highest ( <i>e.g.</i> > $3000 \text{ g/m}^2$ )	Yes: well- developed			
b.	high	highest ( <i>e.g.</i> >3000 g/m <sup>2</sup> )	system Yes: incipient			
c.	low, but feasible if patch	low ( <i>e.g.</i> <1300 g/m <sup>2</sup> )	Yes: well- developed			
d.	not tenable	low ( <i>e.g.</i> <1300 g/m <sup>2</sup> )	system Yes: incipient			
e.	not tenable	lowest ( <i>e.g.</i> 42 g/m <sup>2</sup> )	No			
f.	not tenable	highest $(e.g. > 3000 \text{ g/m}^2)$	No			

 Table 8.1. Suggested conditions within which the intensified exploitation of mature SCR is tenable or untenable

A schematic model to illustrate the conditions in which SCR intensification is tenable is shown in Figure 8.1. The first variable, the existence of an effective processing system, describes a system in which edible products are produced from the tubers. In this case an effective processing system was found to involve pulverising them into a fine flour and adding water and heat, *i.e.* baking or boiling. The processing experiments encompassed qualitative observations about abundance rather than quantifiable measures. Nevertheless, it can be inferred that the abundance and availability of SCR as a food was increased by 100% after processing, because without processing the mature tubers are inedible.



#### INCREASING EFFICIENCY IN FOOD PROCESSING SYSTEM (labour, technology and knowledge)

**Figure 8.1.** Schematic model to illustrate the conditions within which the intensive exploitation of mature SCR tubers is tenable or untenable, depending on the interactions of the two variables *available yield* (biological production) and *the existence of an effective food processing system* (Table 8.1). Points a - f represent six possible interactions of these variables :

*a.* indicates 'tuber intensification' which refers to the circumstances that are the most favourable, where available yields are optimal and a well-developed food processing system exists.

**b.** indicates 'supplemental use' which represents circumstances where available yields are optimal and a food processing system exists but the functional properties of the tubers are not suited to the existing food processing system. In this scenario SCR tubers can be consumed but only if they are processed by mixing them with other ingredients that are better suited to the existing technology.

c. indicates 'patch intensification' which represents circumstances in which a well-developed food processing system is in place but available yields are low and therefore the group intensively harvest all known edible plants in the habitat rather than any one species in that habitat.

*d.* indicates 'opportunistic or occasional use', circumstances where available yields are low and the existing food processing system is inadequate for the functional properties of the tubers. In this scenario SCR tubers can be consumed but only if they are processed by mixing them with other ingredients that are better suited to the existing technology.

e. indicates circumstances where SCR tubers will not be exploited as food because the available yields are too low and no appropriate food processing system exists.

f. indicates circumstances where SCR tubers will not be exploited as food, although available yields are at their highest, because no food processing system exists.

The second variable, available yield, is the amount of the crop that is available to human harvesters. Available yield depends on biological production. As noted earlier, SCR biological production is conditional on several interacting variables, with tuber production being advantaged under conditions such as low water depth, fewer hours of light, large clone size and some levels of predation and possible rotation of harvesting stands. SCR belowground biomass is reported to vary widely from 42 - >3,000 g/m<sup>2</sup> (dw) (Kantrud 1996). No data are currently available on the proportion of that belowground biomass represented by the tubers, nor the proportion of that biomass that is available to human harvesters. For the purpose of the model (Figure 8.1.), available yields are estimated to be between 42 and 3,000 g/m<sup>2</sup> (dw).

The six possible interactions of these two variables, shown in Table 8.1 and Figure 8.1, are designated as contingencies a - f. Three of the contingencies, a-c, describe conditions within which sea club-rush intensification is tenable; and three, d-f, describe conditions within which it is untenable.

*Contingency a* (Table 8.1.), termed here 'tuber intensification' describes the circumstances within which mature SCR tubers are intensifiable and could feasibly become important or staple foods in a group's diet. In this scenario the group has access to highly productive SCR stands and to an appropriate food-processing system comprising labour, technology and knowledge. If a group were to rely on this resource they would exploit stands more often and more heavily, thus concentrating production in particular places and at particular times, a characteristic of intensification described by Brookfield (1972). A potential archaeological parallel for this scenario is the PPNB site of Çatalhöyük where relatively high frequencies of SCR tubers have been recovered, and where the people who occupied the site had pounding and grinding tools,

hearths and ovens and perhaps other cooking technology such as boiling. The fact that the site was adjacent to an extensive marshland indicates that transport costs would have been minimal. It further suggests that the people may have had easy access to large and productive stands, which could have provided a reliable annual tuber crop.

Contingency b, termed here 'supplemental use' also describes a situation where SCR tubers are intensifiable and could make important contributions to the diet. In this scenario the group has access to highly productive stands of SCR and also has a food processing system in place, but the functional properties of SCR tubers are not suited to the available technology. However, an edible product can be produced if SCR tuber flour is mixed and cooked with other ingredients that are better suited to the available technology. Put more precisely, productive SCR stands are available and accessible, and the tubers may become important foods, but their usefulness will be contingent on the availability of the other ingredients. A modern example of a group having a food processing system in place, but one which is not suitable for the functional properties of SCR tubers, is the Bread 1 experiment conducted in Küçükköy, Turkey (as part of the present study, Chapter VII) where SCR tubers were pounded into a flour to be mixed into a dough and baked in the tandir. SCR flour was found to be unsuited for this technology because the dough was neither sticky nor robust enough to adhere to the walls of the tandir. However, once wheat flour was added, a dough was produced which was then successfully baked in the tandir.

Contingency c, termed here 'patch intensification' describes a situation where human groups intensify their exploitation of certain habitats rather than specific species. Contingency c is more likely in cases of resource shortages, where a group needs to diversity the resource base to obtain edible products (see Figure 3.4, Condition b). In

this scenario the group has an appropriate food processing system but the available SCR stands are low in tuber production, *e.g.* where SCR occurs in small stands or large stands in deep water. On its own SCR is not worth harvesting, but taken together SCR and several other species occurring in a patch may provide a worthwhile harvest if they are collected *en masse* and processed and eaten together. The availability of a food processing system thus permits diversification: extracting a range of otherwise inedible resources from the patch, and more frequent use of the patch, thus promoting the concentration of production. As in Contingency b, in this scenario SCR tubers may not constitute a large percentage of the diet in terms of energy (kcal) but if they are consumed on a regular basis, even in small amounts, the tubers may provide staple sources of specific nutrients.

Contingency d, termed here 'opportunistic or occasional use' describes a situation where accessible SCR stands have low tuber production; and although a group has a food processing system in place, the functional properties of mature SCR tubers are not suited to the available technology. In this case, it is likely that SCR tubers will be unimportant in the diet although they may be opportunistically exploited during periods of food shortages and mixed in with other ingredients (as in Contingencies **b** and **c**).

Contingency e describes a case where the tubers will not be exploited for food. Biological production of the tubers, immature and mature, is too low and no appropriate food processing exists. Both Contingency d and Contingency e include cases where local habitat conditions favoured aboveground production and reproduction (sexual), rather than belowground production and reproduction (vegetative). In this situation people may consider the nutlets more worthwhile harvesting than the tubers. Potential archaeological parallels for these scenarios include the Epipalaeolithic sites of Hallan

Cemi or Abu Hureyra, where large numbers of the nutlets have been recovered. Hillman *et al.* (2001: 387) commented that even during the Younger Dryas, water levels remained high in the Euphrates River, which suggests conditions that advantage sexual over vegetative reproduction in SCR stands. Under these conditions it would probably have been more worthwhile to harvest the seed crops than the tubers.

Contingency f describes circumstances where belowground production is high but no appropriate food-processing system exists. In this case the immature young tubers may be intensively exploited but consumption of the mature tubers is not possible.

Figure 8.2. provides a semi-quantitative diagram that shows how the results of the harvesting and processing experiments can be related to Contingencies a - f (Table 8.1 and Figure 8.1.). This diagram illustrates the relative differences in amounts of edible product that can be obtained with appropriate processing technology, and under conditions of high and low abundance, where abundance is defined as the available yield, which is based on biological productivity. For the sake of this model, the harvesting production rates are assumed to be measures of available yields. In other words, because biological productivity was not assessed for the two harvesting sites, in Figure 8.2 relative differences in biological productivity effective yields (*i.e.* the amount of the crop that is available for harvesting) were inferred from the harvesting production rates.



Figure 8.2. Semi-quantitative model, based on the results of the harvesting and processing experiments, showing how the two variables, harvesting production rates and the existence of an appropriate processing system, interact to create a range of possible contingencies with which the intensified exploitation of mature SCR tubers (as food) is tenable or untenable. For the sake of this model, harvesting production rates are assumed to be a measure of available yields. The six possible contingencies a-f are explained in detail in the text and in Table 8.1.

In summary, the results of the case study indicate that the likelihood of people incorporating SCR tubers into their diet is dependent on two main variables: ecological conditions and the availability of an appropriate food processing system. Consideration of these two variables, and how they interact, may explain the factors that influenced ancient groups to exploit SCR tubers in the first place: why some groups exploited the tubers more intensively than other groups, and why some may have chosen to exploit the nutlets or immature tubers only, or else not to exploit this plant for food purposes at all. If people were only able to use SCR tubers as an ingredient in a composite food, *e.g.* combined with wheat to make bread, as in *Contingency* b, above, then the availability of the other ingredients (plants and/or animals) may also have been a critical factor in whether or not people exploited these tubers. Likewise the availability of other wild edible plants and plant parts, which may have been preferred over SCR tubers, must also be considered a critical factor.

# 8.2. EPIPALAEOLITHIC PLANT INTENSIFICATION: THE ROLES OF LABOUR, TECHNOLOGY AND KNOWLEDGE IN POST-HARVEST INTENSIFICATION

Throughout this thesis I have argued that post-harvest intensification was a critical variable in economic changes throughout the Epipalaeolithic. While the results of the present study do not prove whether or not post-harvest intensification had a role in Epipalaeolithic resource change, the results suggest numerous ways that early post-harvest systems may have affected Late Pleistocene subsistence and mobility systems.

The study demonstrates that, for human groups to depend on plants that require processing to make them edible, a balancing of complex sets of ecological, botanical and technological factors must be achieved. Successful plant processing is not simple. It requires significant technological expertise and ecological and biological knowledge. The between-species differences in functional properties of edible plants cannot be predicted from simple observations of the morphological characteristics of potentially edible plant parts: processing methods that work on one species do not necessarily work on others. Thus each plant or plant part must be tested individually.

The establishment of post-harvest systems, although labour intensive, would mean that a greater variety of foodstuffs, and nutrients and energy to be extracted from the land because: i) a greater variety of plants and animal parts could be consumed; ii) a greater variety of food products could be prepared from a single plant part; iii) food processing promotes the accessibility of nutrients for human consumption and digestion; and iv) post-harvest techniques for preservation purposes reduce spoilage, thus promoting an increase in quality and quantity.

With respect to the Epipalaeolithic, the results of this study suggest that foodprocessing systems introduced by Late Pleistocene groups would have promoted increased labour inputs as well as exponential increases technological sophistication and ecological and biological knowledge. Even the most "simple" food-processing techniques known to have been used by Epipalaeolithic hunter-gatherers (*i.e.* pulverising and heating) were shown to require considerable investments of labour, technical expertise and knowledge. As well as the energy inputs required to process the plant into an edible form, labour inputs include expending energy to gather fuel and other plant materials that are necessary to facilitate cooking, and/or raw materials to fabricate cooking features such as hearths or possibly pit-ovens, and processing tools such as the deep mortar.

In addition to labour inputs, the evolution of post-harvest systems required an expanding technological sophistication, entailing technical expertise regarding the

functional properties of individual plants. People had to learn about the types of heat (wet or dry), cooking temperatures and cooking times that are necessary to promote adequate cooking of individual plants, and whether the plant needs additional treatment prior to or after heat processing. In cases where a sequence of techniques is used, successful processing involves knowing the order of the sequence, and the amount of time that should be devoted to each technique in the sequence. It also requires knowledge of the types of fuels and other materials that will promote proper cooking and/or impart pleasant flavours or not impart flavours. The technological expertise required for successful processing, also includes the ability to manufacture and maintain the features and/or tools that are required to process the plant into foodstuff. And last, but not least, in addition to investments of labour and technological expertise, the evolution of post-harvest systems required both ecological and biological knowledge about the resources in question: understanding the growing habits of the plant or plant part in order to select specimens that are suitably mature or suitably ripe for the intended processing method(s); an ability to identify which plants and/or habitats are the most productive, such that the plant part occurs in amounts and/or sizes that are worth harvesting.

Although only general trends in Epipalaeolithic subsistence are discussed in this thesis, several inferences can be made about developments in post-harvest systems during the Epipalaeolithic. These inferences combine the intensification model (Figure 3.3.) and resource selection model (Figure 3.4.) presented in Chapter III with observations made during the harvesting and processing experiments. The main points are:

- i) From the Early Epipalaeolithic significant investments of human labour, technology and ecological, botanical and technological expertise were allocated to post-harvest activities.
- ii) Throughout the Epipalaeolithic, Late Pleistocene groups expanded their technological, ecological and botanical expertise.
- iii) Throughout the Epipalaeolithic, the factors that drove food processing intensification evolved and changed: mainly *need* drove intensification during the Early and Middle Epipalaeolithic, as well as the latter part of the Late Epipalaeolithic (Late Natufian); while mainly *opportunity* drove intensification in the early part of the Late Epipalaeolithic (Early Natufian).
- iv)Throughout the Epipalaeolithic there were changes in the post-harvest processes by which intensification occurred: in the Early Epipalaeolithic groups invested in food processing for immediate-return purposes; during the Middle Epipalaeolithic post-harvest systems expanded to include delayed return processes; during the Late Epipalaeolithic groups improved post-harvest techniques, incorporating more grinding which further increased the food value obtained from yields.
- v) The evolution of post-harvest systems transformed the production systems of Epipalaeolithic hunter-gatherers, influencing shifts in resource selection, and therefore changes in land-use, mobility patterns, and scheduling.
- vi) The evolution of post-harvest systems provided the stimulus to plant cultivation, planting and domestication that occurred in the latter Late

Epipalaeolithic and Neolithic: the need to supply raw materials to support existing post-harvest systems may have driven groups to cultivate.

First and foremost, the arguments that underpin this study are that the development of food processing systems was a critical variable in the emergence of the Epipalaeolithic from the Late Upper Palaeolithic; and, the sequential improvements in post-harvest systems were crucial to the intensification of production throughout the Epipalaeolithic. From the archaeological and archaeobotanical data it can be inferred that, at the end of the Late Upper Palaeolithic, during the harsh climatic conditions of the Late Glacial Maximum, groups experimented with food processing as a means of extracting more edible products from the land. Food-processing intensification began as a way to solve immediate-return problems in order to support existing hunting and gathering systems. Over time, groups allocated increasing amounts of time and energy to food processing. Because the functional properties of plants differ, people would have found some species to be more amenable to the existing technology than others. Therefore it can be inferred that preferences would have developed for specific species based on their positive functional properties, although groups appear to have continued to exploit a broad spectrum of species as a form of risk aversion. The archaeological evidence that food-processing intensification developed in the Early Epipalaeolithic includes the deep vessel mortar, which is considered a principal indicator of the shift to the Epipalaeolithic; and archaeobotanical, starch and groundstone evidence of wild cereal grinding, as well as possibly fish drying and storage, at Ohalo II, a Late Upper Palaeolithic site with Kebaran components (Kislev et al. 1992; Kislev et al. 2004; Nadel and Werker 1999; Nadel et al. 1994; Piperno et al. 2004; Weiss et al. 2004a, b).

During the Middle Epipalaeolithic conditions changed, including the factors that motivated intensification and the processes whereby it occurred. I propose that it was during the Middle Epipalaeolithic that groups began to shift to delayed-return systems. That is not to say that, prior to the Middle Epipalaeolithic groups did not engage in some storage (see Cane 1989 for a discussion of preservation by hunter-gatherers who practice immediate-return subsistence). But it was in the Middle Epipalaeolithic that the prerequisites for mass harvesting were established whereby storage became more generally feasible. These prerequisites include

- i) periods in which resources were abundant and available in sufficient quantities to provide for both immediate- and delayed-return needs; as discussed in Chapter II, it was only post the Late Glacial Maximum that carbohydrate rich seed and geophytes occurred in stands of a sufficient size for mass harvesting (Hillman 2001; Richerson *et al* 2001);
- ii) contrasted by periods of food shortages, which stimulated the need to transform seasonally available resources into year-round staple foods. (Blumler 1996; Byrne 1987).

I propose that Middle Epipalaeolithic groups used two basic risk-aversion strategies in their plant exploitation: i) a continuation of the broad-spectrum pattern established in the Early Epipalaeolithic; ii) a focus on the mass harvesting, conservation and storage of selected species. With the shift to delayed-return subsistence, huntergatherer production systems would have changed in focus, to allocate greater amounts of time, labour, and biological and environmental expertise in obtaining and conserving storable species. Inter-species differences in conservation properties would have influenced which plants were selected most frequently, and in the greatest amounts, and decisions about selection would have affected land use, mobility patterns, and scheduling. At the same time, continued use of a broad-spectrum of plants would insure that, in circumstances when critical preferred resources were not available, a group would know how to exploit a range of edible species.

By the Late Epipalaeolithic both social and environmental conditions had changed. There were again shifts in the factors driving plant intensification as well as the way in which the process occurred. Food-rich habitats were increasingly widely distributed over the landscape, particularly after c. 15,300 ( $^{14}$ C yr BP cal) (see Chapter II). Reductions in group mobility and shifts towards social complexity are thought to have occurred. The exponential increase in groundstone tools suggests that food processing had become widespread by the Late Epipalaeolithic, and also that it was more heavily practiced by individual groups. As observed by Wright (1994), these patterns indicate a new means of intensification because grinding promotes more food value than pulverizing alone. The fact that food preservation was more widely practiced has been inferred from the occurrence of permanent features that are thought to have been used for the storage of edible plants (but see Boyd 2006). It is possible that during the early part of the Late Epipalaeolithic, groups continued to view stored foods as riskaversion measures, although climatic conditions were improved by this period in time. It is likely that some processed and preserved foods had come to signify wealth, being a measure of the group's labour investments, as well as a symbol of their success. In any case, in this scenario, Late Epipalaeolithic food intensification was driven more by opportunity than need.

Following the advent of the Younger Dryas Stadial, Late Epipalaeolithic groups appear to have diversified their resource procurement-strategies, with both

intensification and extensification practiced. Extensification occurred in cases where groups, or some group members, became more mobile for the purpose of obtaining access to more extensive areas, thus substituting land for labour. On the other hand, the continued increase in grinding tools, and also indications of continued bone boiling (Munro and Bar Oz 2004) suggest that food processing continued to be an important means of producing foodstuff. Finally, it was during the final Late Epipalaeolithic that groups began to intensify production by means of cultivation. Hillman (1996; 2000 and Hillman *et al.* 2001) argues that cereal cultivation began as a way of enhancing the food supply from diminishing stands of wild cereals.

The results suggest that the inquiry into Epipalaeolithic post-harvest systems may also be of utility for investigating the origins of food production. Certainly the evolution of post-harvest systems, which appear to have begun with the Early Epipalaeolithic, paved the way for the delayed-return economies that characterise the Neolithic. Accordingly, I argue that the mass harvesting and domestication of wild plants undertaken by Late Epipalaeolithic and Early Neolithic groups was feasible only because post-harvest techniques were already integrated into the subsistence system.

Building on Hillman's argument, I propose that the factors that motivated Late Epipalaeolithic groups to cultivate plants were pressures to meet the demands of their existing post-harvest systems. The reasoning behind this argument is that, by the Late Epipalaeolithic, hunter-gatherers had come to depend heavily on processed plant foods, and were therefore dependent on species that had suitable functional properties for the existing technology such as cereal grains and other small seeds. Moreover, Late Epipalaeolithic economies were based on, and revolved around, the mass harvesting, preservation and storage as well as the daily preparation of edible plants, activities that provided the framework for daily life. In summary, I argue that post-harvest processes, which originally developed as a way of maintaining existing hunter-gatherer systems, came to transform those systems; likewise, cultivation and planting, which were introduced as means of supporting the post-harvest production system, subsequently transformed it again, leading to food production through domestication. To this day agricultural and post-harvest systems continue to be inseparable components of food production throughout the world. Post-harvest technology is of critical concern on a global economic scale, as well as being important in the diet, health, and culinary choices of people around the world.

### **8.3. FUTURE DIRECTIONS**

This research draws attention to the need for more detailed ecological, biological, ethnographic and processing studies of the resources exploited by ancient peoples. It draws attention to the many gaps in our understanding of the diet and resource decisions of ancient peoples. I believe that these gaps can be best addressed by a multidisciplinary approach, that the answers to our questions about the resource decisions of ancient peoples are at the interface of archaeology, biology, food science, nutrition and technology.

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