Factors affecting habitat selection by waterbirds at temporarily abandoned fish farms in the southwestern coast of Taiwan and their application in the restoration of wetlands for conservation

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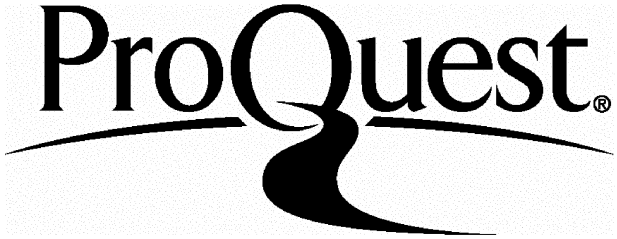

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Abstract

This study aims to identify the environmental factors affecting the habitat selection of waterbirds at temporarily abandoned fish farms in the southwestern coastal area of Taiwan. The results of this investigation are used to make management recommendations to enhance the value of these fish farms for the conservation of wetland birds. Data were collected on the annual pattern and chronosequence of characteristic environmental attributes of 179 sample wetlands. Simultaneously, the biological responses of waterbirds were recorded, including species richness, species composition and abundance. Guilds of waterbirds were identified and their distribution and abundance in sample wetlands, including actively managed aquaculture ponds, temporarily abandoned aquaculture ponds, saltpans and natural wetlands were analysed. Multivariate techniques were used to relate each guild to particular environmental attributes: these relationships are then utilized to recommend appropriate habitat management. Specifically, two types of recommendation are made. First, guidelines are provided to enable conservation site managers to evaluate the present status and potential of aquaculture ponds for the conservation of waterbirds. Second, a protocol is established for the enhancement of aquaculture ponds in terms of habitat use by waterbirds. A manipulation experiment was conducted in which the water level was modified in order to ascertain if guilds of waterbirds responded in the manner predicted by the multivariate analysis. This is one of very few investigations that have simultaneously utilized environmental and biological data for a range of sites and all wetland bird species in order to understand how environmental factors act to determine species distributions and abundance.

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Chapter 1

Introduction and literature review

1.1. Introduction

The Taiwan Strait, situated between Mainland China and Taiwan, is part of the Western Pacific Ocean Flyway for migrant birds (Figure 1.1). This flyway provides a number of stopovers, mainly coastal wetlands, for birds to migrate between Japan, northeastern China or even Siberia and southeastern Asia. Maintenance of habitat suitability in these coastal wetlands for these migrant birds has become an international conservation issue. Tidal mudflats, lagoons and mangroves in this coastal area are among the habitats utilized by these birds. The natural spectacle that results from the stopover and wintering of migrating birds is obvious especially on the western coast of Taiwan, particularly in Tainan and Chiai counties where a series of sand dunes formed as a result of strong sedimentary activity in this area, and many associated brackish lagoons and mud flats occur. These natural wetlands and associated habitats provide shelter and food resources for these migrant birds, which need to refuel immediately after a long journey from Siberia or Northern China. Abundant invertebrates thriving in these natural coastal wetlands attract many tens of thousands of waders, shorebirds, waterfowl and other migrant birds to Taiwan every year.

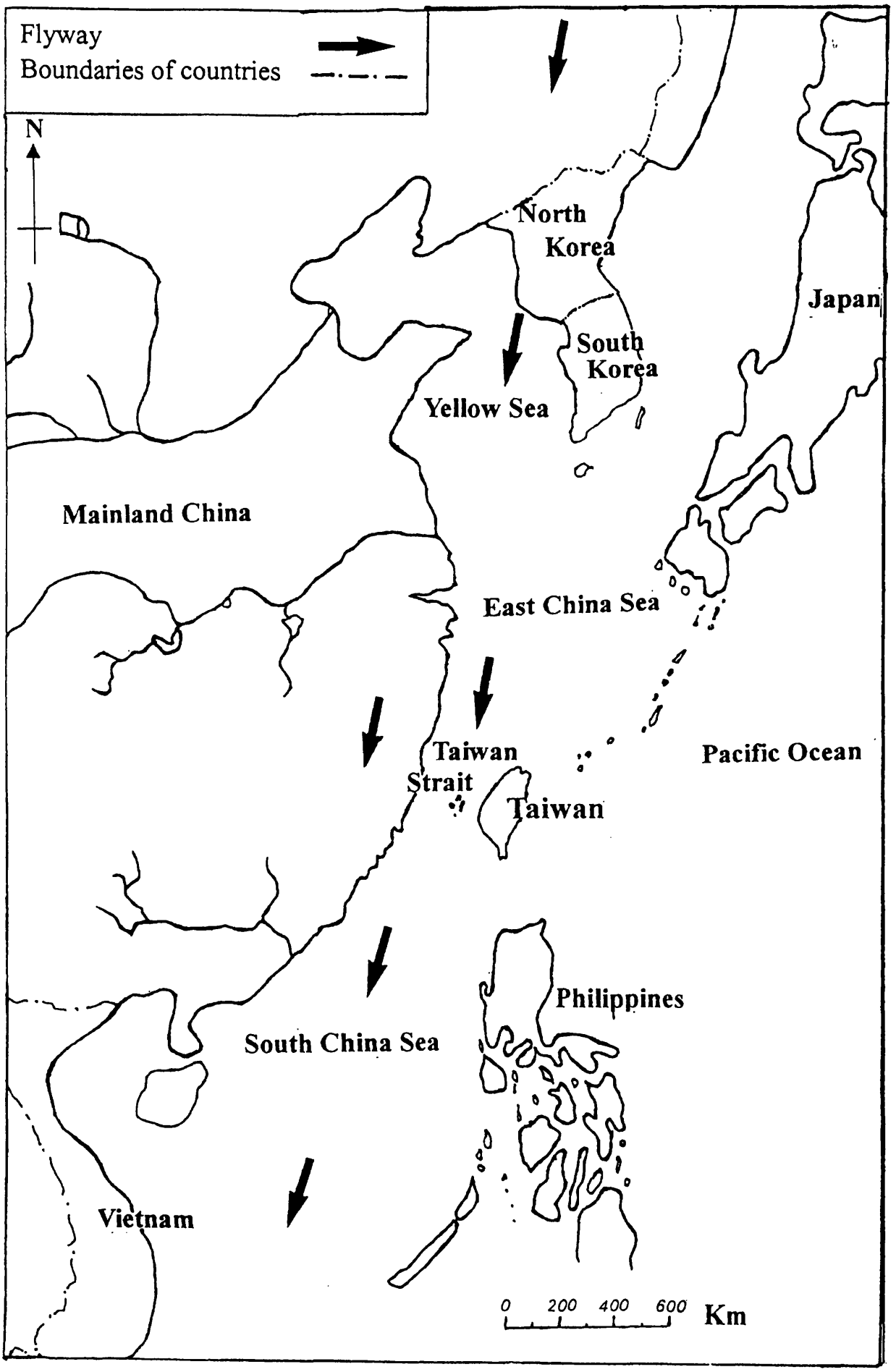


Figure 1.1. Western Pacific Ocean flyway.

In terms of human population, western Taiwan is the most populated region of Taiwan, and development pressures are high. As a result, most of these natural coastal wetlands have been reclaimed for fishery, agriculture and industry. Fishery use, mainly for the creation of aquaculture ponds, has become one of the common land use forms in these coastal counties. According to the annual official statistics of FACOA (Fisheries Administration, Council of Agriculture, Taiwan R.O.C., 2000), the extent of fishery land use in these six southwestern coastal counties is 31.2% by area. In Tainan and Yunlin counties, aquaculture use even exceeds 40% of land use by area. The expanding development in the aquaculture industry has reduced the extent of natural wetlands available to waterbirds.

However, during the last decade, the trend for reclaiming coastal wetlands for fishery use has slowed down for several reasons (SIECLC, 1995). First, in 1988, the cultivation of shrimps, one of the three main species raised in these fish farms, was severely affected by several shrimp diseases. This problem still remains unsolved. Second, high prices and an unstable supply of elvers has greatly limited the profit from the cultivation of eels, which is another of the principal cultivated species in the aquaculture industry. Third, the intensive enforcement of laws of relating to the reclamation of land for aquacultural use, especially on government-owned property, has resulted in the further abandonment of aquaculture ponds. Fourth and possibly the most important reason, is the over use of groundwater, which is used to supply the freshwater for the aquacultural practices in fish farms. This has resulted in a sharp drop of the groundwater table and consequently caused the ground level to subside over a large region due to no adequate support from ground water. More than 2.5 metres ground has subsided in the most seriously-affected area of Taiwan (SUPGS, 2001). In an attempt to relieve the large-scale subsidence of land, the Taiwanese government implemented strict control measures for groundwater use. This situation has resulted in higher costs for freshwater supply and thus a further decrease in the profitability of fishery cultivation.

These four reasons have resulted in an increased trend in the temporary abandonment of aquaculture ponds. According to the official statistics of FACOA (1994, 1995, 1996, 1997, 1998, 1999, 2000) between 1993 and 1999, there has been a high rate of temporary abandonment of aquaculture ponds (Figure 1.2). For instance, an average

of 17.4% of aquaculture ponds were abandoned in 1996. There was even a peak annual value of 22.7% abandonment rate by area of ponds in Tainan County. The numerous abandoned aquaculture ponds offer a remarkable opportunity to compensate for the loss of natural wetland habitats in the past. These defunct ponds could be restored to a state of semi-natural wetland and subsequently integrated with the remaining natural wetland for the benefit of conservation of waterbirds. But in order to restore these man-made fishponds for conservation benefit, it is essential to better understand the habitat use of these ponds by waterbirds. By applying the findings of such ecological studies, restoration of these temporarily abandoned aquaculture ponds could play an important role in habitat conservation and the future of Taiwan's wetland ecosystem.

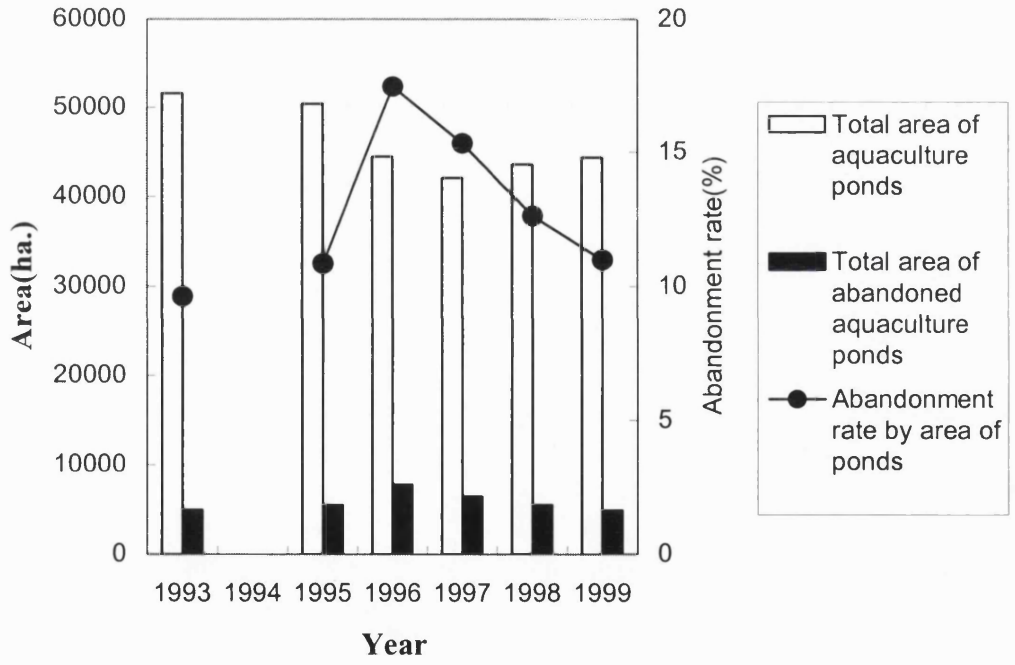


Figure 1.2. Abandonment rate by area of ponds and area of abandoned aquaculture ponds in Taiwan from 1993 to 1999 (Sources: Fisheries Administration, Council of Agriculture, Taiwan R.O.C., 1994, 1995, 1996, 1997, 1998, 1999, 2000).

1.2. Literature review

Many studies of waterbirds have been conducted as a consequence of the awareness of a decline in their population. A review of UK and European studies provides an introduction to the present study. Early studies were often only descriptive, for example studies offering a comparison of waterbird population trends over time (O'Brien & Smith, 1992). Some of these studies provide basic information required for the assessment of habitat quality by nature conservation authorities, site managers or scientists. For example, nationwide inventories such as the National Waterfowl Counts of the Wildlife and Wetlands Trust (WWT); Birds of Estuaries Enquiry of the British Trust for Ornithology (BTO); and Seabird Colony Register of the Nature Conservancy Council (NCC) as well as local inventories such as August peak counts for the passage of each wader species at particular sites (Stewart & Kantrud, 1972; Lloyd *et al.*, 1991; Burgess *et al.*, 1992; Pollitt, 2003; Peck, 1993; Smith, 1994). Early studies and research effort focused on the possible causes for the decline in the number of waterbirds and how different factors influenced their populations. The relationship between prey availability and the population dynamics of predators, namely waterbirds, continues to be a popular research topic. Research was conducted either by solely observing the dynamics of the predominant prey species in the diet of a particular waterbird species and the interaction with the associated environmental factors (Riley & Bookhout, 1990; Euliss *et al.*, 1991; Kalejta & Hockey, 1991; Cronk & Mitsch, 1994[2]; Robarts *et al.*, 1995; Robinson *et al.*, 1997[1]; Robinson *et al.*, 1997[2]; Euliss & Mushet, 1999), or more directly by observing the interaction between the population dynamics (Hudson,1983; Kaminski & Prince, 1984; Tuite *et al.*, 1984; Craig & Beal, 1992; Colwell, 1993; Hill *et al.*, 1993; Fox & Bell, 1994; Savard *et al.*, 1994; Boettcher & Haig, 1995; Dehorter & Tamisier, 1996; Norris *et al.*, 1997; Rehfisch *et al.*, 2000), foraging behaviour (Norris *et al.*, 1997), habitat selection (Norris *et al.*, 1997) and the spatial distribution (Tuite *et al.*, 1984; Boettcher & Haig, 1995) of waterbirds and the associated environmental factors. Some studies analysed a combination of prey, waterbird dynamics and associated environmental factors (Danell & Sjöberg, 1982; Pienkowski, 1983; Pehrsson, 1984[1]; Kalejta & Hockey, 1994).

Several studies focused on the threats to waterbirds by analysing the effect of various

threats on the birds' population dynamics. Such research has successfully identified the main threats to waterbird population such as habitat loss (Bibby & Lunn, 1982; Goss-Custard *et al.*, 1987; Williams & Bowers, 1987; Goss-Custard & Moser, 1988; Partridge, 1988; Goss-Custard *et al.*, 1994; Goss-Custard *et al.*, 1995[1]; Goss-Custard *et al.*, 1995[2]; Yates *et al.*, 1996; Norris *et al.*, 1997; Rehfisch *et al.*, 2000), over-exploitation of waterbirds (Dehorter & Tamisier, 1996), drainage (Kadlec, 1962; Williams & Bowers, 1987; Partridge, 1988), disturbance from recreation (Tuite *et al.*, 1984; Bell & Austin, 1985; Platteeuw & Henkens, 1997) and flooding (Johnsgard, 1956). Research focusing on the impacts of threats on waterbirds inspired experiments in wetland management. Such experiments were designed either to show how the population of waterbirds or the main prey species respond to the manipulation of the features of wetlands or to restore the degraded wetlands to a natural state. Such management-oriented studies are usually confined to several key characteristic parameters of wetlands such as water level (Rundle & Fredrickson, 1981; Murkin *et al.*, 1982; Riley & Bookhout,1990; Velasquez, 1992; Green & Robins, 1993; Erwin *et al.*, 1994; Self *et al.*, 1994; Boettcher & Haig, 1995; Robinson *et al.*, 1997[1]; Robinson *et al.*, 1997[2]), vegetation (Murkin *et al.*, 1982; Huseby, 2000), salinity (Velasquez, 1992) and the hydrological characteristics (Cronk & Mitsch, 1994[1]; Fennessy *et al.*, 1994; Rehfisch, 1994; Self *et al.*, 1994).

Apart from the awareness of a decline in the population of threatened waterbird species, growing demands for natural-tourism after World War II have also stimulated research on waterbirds. Many people are now more likely to spend their spare time observing natural spectacles such as the flocking assemblies of shorebirds on the exposed mudflats at high tide and the aggregation of foraging waterfowl at wetlands. Such leisure pursuits have brought substantial financial reward to those who provide such services. In addition, the obligations coming from legal delegations and conservation interests have stimulated management-related research. For example, grazing management of large herbivores, which can alter the physical environment of grasslands and thus affect waterbirds, is the most popular research topic (Green, 1988; Allport, 1989; Campbell & Mudge, 1989; Burgess *et al.*, 1992; Norris *et al.*, 1997; Welch, 1997). Vegetation management, especially reed bed management, is also popular (Sills, 1988; Burgess & Evans, 1989; Everett, 1989; Tyler *et al.*, 1998). Management-oriented research aims to achieve one or both of the following

objectives: to increase waterbird biodiversity or the population of some rare or common species. The latter is more favoured by most site managers.

Among the management-oriented studies, those conducted by the RSPB (The Royal Society for the Protection of Birds) in their nature reserves are prominent. A great deal of conservation effort has been geared towards changing coastal brackish wetlands into optimal habitat for bitterns (*Botaurus stellaris*), which recolonised the UK in 1911 (Andrews & Ward, 1991; Tyler, 1994). Bittern sites require to be maintained at a particular seral stage with an appropriate cover of reeds by means of periodic reed harvest or flooding. This is expected to increase the prey accessibility and to provide suitable nesting sites for bitterns. Water depth needs to be maintained at 25 cm or less--the optimal water depth to harbour this rare species (Andrews & Ward, 1991; Tyler, 1994). A similar species-based approach prevails at other conservation sites such as for the Wood Stork (*Mycteria americana*) at Kathwood Lake of the National Audubon Society's Silver Bluff Plantation Sanctuary (Coulter *et al.*, 1987) . However, this single species approach has had negative impacts on some non-target species and thereby resulted in conflict between site managers, conservationists and conservation authorities as well as scholars who are concerned about site biodiversity. Unfortunately, management-oriented research often lacks background ecological knowledge and is therefore usually conducted on a trial-and-error basis (Wood, 1996). This is rather risky especially when habitat alteration is more or less irreversible or requires extensive time for recovery from manipulation.

As a result of extensive global industrialization, many natural wetlands have been altered, degraded or lost. At the same time, artificial wetlands have also been created intentionally or unintentionally worldwide, and these artificial wetlands are beginning to play an increasingly important role in the conservation of waterbirds. Consequently, recent studies have focused on the habitat selection of waterbirds in these artificial wetlands. Such studies cover a wide spectrum of research such as the comparison of habitat utilization by waterbirds between natural and man-made wetlands (Ruwaldt *et al.*, 1979; Burger *et al.*, 1982; Fasola, 1986; Hafner, 1986; Wilcox, 1986; Weber & Haig, 1996; Melvin and Webb, 1998), the relationship between the habitat utilization of wetlands by waterbirds and their prey (Hafner, 1986;

Coulter *et al.*, 1987; Kelsey and Hassall, 1989; Euliss *et al.*, 1991; Velasquez, 1992; Rehfisch, 1994; Euliss *et al.*, 1997; Safran *et al.*, 1997), the variations in the habitat use of different types of artificial wetlands by waterbirds (Leschisin *et al.*, 1992; Weber and Haig, 1996), the correlation between the features of wetlands and the habitat utilization of wetlands by waterbirds (Kadlec, 1962; Mack & Flake, 1980; Hudson, 1983; Rumble and Flake, 1983; Davidson & Evans, 1986; Fasola, 1986; Bélanger & Couture, 1988; Breininger and Rebecca, 1990; Leschisin *et al.*, 1992; Boettcher & Haig, 1995; VanRees-Siewert and Dinsmore, 1996; Young, 1998), the effects of wetland management practices on the habitat utilization of wetlands by waterbirds (Rundle & Fredrickson,1981; Rumble & Flake, 1983; Brush *et al.*, 1986; Coulter *et al.*, 1987; Velasquez, 1992; Erwin *et al.*, 1994; Rehfisch, 1994; Euliss and Mushet, 1996; Svingen & Anderson, 1998), the differential habitat use among the guilds of waterbird species (Poysa, 1983), the chronological changes in the habitat use of wetlands by waterbirds (Danell & Sjöberg, 1982; Hudson,1983; VanRees-Siewert & Dinsmore, 1996; Beckerman *et al.*, 1998) and the effects from residues of organic substance on the growth of invertebrate fauna and on the habitat utilization of wetlands by waterbirds (Rumble & Flake, 1983; Weber and Haig, 1996).

The history of wetland research in Taiwan is similar to that in the West but without the benefit of being a member of the international research community. Under the extreme suppression coming from the government of the People Republic of China, Taiwanese government can hardly become a member, or even an observer, of any international conservation NGO or treaty such as *The Convention on Wetlands of International Importance especially as Waterfowl Habitat* (Ramsar Convention on Wetlands). However, the Taiwanese government still attempts to follow the regulations recommended by these international conservation treaties or agreements. In Taiwan, conservation history only goes as far back as 1970, when the first local ecological studies were conducted (Patel & Lin, 1989). During the following two decades the main research emphases were on descriptive studies such as general inventories and spatial distribution studies of biota (Lu & Tsai, 1979; Sa, 1984; Chou, 1985; Wang, 1985[1]; Wang, 1985[2]; Kaoshiung bird society & Cheng-Kung university wild bird society, 1987; Lee, 1987; Wu & Yen, 1989; Chen, 1990; Lu, 1990; Wu, 1990; Wang, 2000; WBSROC, 2000). Studies of the relationship between the habitat utilization of wetlands by waterbirds and associated environmental factors were

conducted more frequently thereafter. This research includes studies such as the inventory of prey species and their seasonal fluctuations in population (Zang, 1986; Chang, 1990; Sei, 1992; Chen *et al.*, 1994; Liu, 1994; Liu & Lin, 1995; Sei *et al.*, 1995; Chou *et al.*, 2000), the relationship between the features of wetlands and the population dynamics of prey species (Pong, 1981; Gao, 1984; Chang, 1994[3]; Lin, 1994; Hwang, 1998) and the relationship between the population dynamics of waterbirds and their prey (Tsai, 1994, Chen & Lin, 1995; Lin & Chen, 1995). These studies can be divided into two prevailing approaches, planning and single-species biological approach. The planning approach comprises principally the studies which aim to establish a new protected area or to monitor an existing conservation site (Lin & Lu, 1985; Lin, 1988; Lee, 1991; Holong Engineering Consultant Company, 1994; ILSTU, 1994; Tyler, 1994; Wong, 1994; Gao *et al.*, 1995; WBSROC, 1996; Gwo, 1997; Yu, 1997; Yu, 1998; Yang, 1999; Chou, 2000). The single-species biological approach consists of studies that investigate the general biology of individual species, mainly waterbird species (Du, 1991; Yen, 1994; Wang & Hu, 1995; Chang, 1997).

However, a major difference between wetland research conducted in Taiwan and the West relates to the absence of management-related studies (not including the research planning to set a particular conservation site aside). In Taiwan, such studies were seldom conducted due to the belief that the best way to manage conservation sites is to "leave them alone".

Any management-related studies were nearly always conducted at natural wetlands. In general, relatively few wetland studies were conducted in artificial wetlands, although studies of saltpans were undertaken. For example, ecological studies in saltpans have been conducted such as the species composition, foraging habitat and general ecology of waterbirds (Hwang, 1984; Chen, 1993; Lin and Chen, 1995; Wong, 1997). Water chemistry and aquatic insects have been studied in rice paddies (Chang *et al.*, 1996; Pong, 1998; Wong *et al.*, 1998). Only two studies have been conducted at the artificial aquaculture ponds. In one of these two studies, the conflict between waterbirds and aquaculture industry was the main concern (Wang *et al.*, 1989; Wang *et al.*, 1990) and in the other study, the species composition of waterbirds was described (Wong, 1997).

Wetland studies are generally conducted on single species and cover only a limited range of associated environmental or biological factors. Surprisingly, few studies deal with several species (or guilds) as well as all aspects of the waterbird habitat requirements. The single-species approach ignores the fact that all wildlife species show individual interactions with other species and their physical environment. Single-species studies that deal with a few key environmental factors are more easily conducted than multiple-species studies and are more likely to obtain public support and research grants from the conservation authorities owing to the clear and direct focus on a few endangered species (Simberloff, 1998). The information obtained from these single-species studies helps site managers to manage their conservation sites, but does not provide sufficient information for them to confidently decide how to protect all species at their sites or to prioritise between species. Partial knowledge about some species and several associated factors is insufficient to support the management of wildlife habitats and is likely to lead to policies that are beneficial to some valued species but may be inadequate for others (Temple, 1997). The complexity of ecological relationships for conservation has shown a strong necessity of overview considerations. Holistic approach such as ecosystem management, landscape ecology and focal species approach, utilized by the majority of site managers in North America, could provide much more useful assistance for the management of conservation sites than the single-species approach. They could, for example, help to enforce connectivity among habitat patches, and target research effort towards understanding the processes and functions of ecosystems (Grumbine, 1994; Agee, 1996; Christensen, 1997). The main advantage of adopting a Holistic approach is that it integrates features of ecosystem functions and processes and therefore provides site managers with an overview of the target habitat on a broader scale. This approach stresses an understanding of the operation of whole systems, rather than several individual flagship species (Grumbine, 1994; Agee, 1996).

The integration of these two approaches, the single-species approach and Holistic approach, could lead to more effective habitat management. Coupled with good knowledge of individual species or particular wetland types from the single-species studies, Holistic approach can have a greater potential for developing more realistic theories and skills for habitat management practices (Grumbine, 1994; Agee, 1996; Christensen, 1997). However, little Holistic research has been conducted, due to the

difficulties encountered during such research such as the challenge of understanding the intricate relationships between the habitat utilization of wetlands by waterbirds and associated factors such as water level, but also because of a lack of background knowledge and efficient analytical techniques.

When complex issues are at stake such as the management of operational systems in order to support a wide range of waterbirds, the use of multivariate techniques to explore and quantify relationships between habitat variables and bird species is potentially advantageous. Many multivariate statistical software packages such as CANOCO and TWINSPAN, have been developed and applied in the last decade. This software can combine two datasets such as an all-inclusive species assembly and a full range of environmental variables into a single analysis (Ter Braak & Prentice, 1988; Ter Braak & Verdonschot, 1995). Many recent studies have been conducted using these analytical tools (Korhola, 1999; Moore *et al.*, 1999; Hall & Grahn, 2001; Weckström & Korhola, 2001). This powerful statistical software has also enabled an enormous amount of data collected during this study to be analysed, and such techniques help to support a more integrated approach to ecosystem management.

1.3. Description and objectives of this study

In this study, multivariate techniques and ordination statistical software, CANOCO version 4.0, have been applied to analyse the overall interaction between the environmental features of aquaculture ponds (both actively managed and abandoned ponds) and the habitat utilization by waterbirds. This study is one of the very few studies that simultaneously investigate a wide range of wetland environmental attributes and all waterbird species at each site and attempts to understand how environmental factors act to determine the distribution and abundance of waterbirds. Environmental parameters comprise most of the potential variables such as water chemistry, vegetation, water depth, age of ponds and wetland density. This integrated research is used to answer the following questions: how many species use these artificial wetlands; what are the chronological and annual changes in species richness, species composition, relative abundance and potential associated environmental parameters; what are the specific habitat requirements for each individual guild or common species; what is the ideal pond for the majority of

waterbirds, for a particular guild of waterbirds or for a particular waterbird species?

A set of objectives of the research relate to needs of conservation managers. Many decisions need to be made by conservation site managers during daily management. They need to know the ideal water depth for certain guild of birds, the timing to trim emergent vegetation, the appropriate kind of environment for a particular managed site: in favour of ducks, shorebirds or a combination of the two, and the ideal proportion of a particular pond type at a conservation site. This study aims to provide answers to these questions by identifying the key environmental factors affecting the habitat selection of each guild of waterbirds. In addition, this study also provides several guidelines and a protocol to enable the conservation site managers to evaluate the present habitat status of their managed sites and consequently to respond rapidly when habitat degradation occurs. These guidelines can also instruct site managers on how to evaluate the potential of aquaculture ponds (either actively managed or abandoned) for the conservation of waterbirds. If suitable abandoned aquaculture ponds are available for habitat restoration, then the recommended protocol for the enhancement of aquaculture ponds in terms of the habitat use by waterbirds can be employed. This protocol allows the restoration of aquaculture ponds to be achieved efficiently and effectively.

Consequently, the research aims of this study are as follows:

- To describe the chronosequences, which are defined as the long-term chronological changes, and annual changes in physical and vegetative attributes of abandoned aquaculture ponds (Chapter 2).
- To describe the chronosequences and annual changes in habitat utilization of abandoned aquaculture ponds by waterbirds after being abandoned (Chapter 3).
- To determine the population dynamics and species composition of bird species in the temporarily abandoned aquaculture ponds and to make comparisons between wetland types (Chapter 4).
- To determine which key environmental features of abandoned aquaculture ponds most affect the habitat use of sample wetlands by all waterbird species, specific guilds and the variation between wetland types (Chapter 5, 6 and 7).
- To provide guidelines for enabling conservation site managers to evaluate the

present habitat status, the potential of aquaculture ponds for the conservation of waterbirds and to monitor the changes of habitat status (Chapter 8).

- To establish a protocol for the enhancement of aquaculture ponds in terms of their attractiveness to a range of waterbirds (Chapter 9).

1.4. The field sites

1.4.1. Geography

Taiwan is situated 160 km from the southeastern coast of mainland China (Longitude: 120° 0'~121° 57', Latitude: 21° 54'~25° 18'; Figure 1.1). Its terrestrial area is approximately 35,960 km^2. Taiwan is meteorologically classified as having a subtropical monsoon climate with an annual average precipitation of 1691 mm in southwestern Taiwan. Tropical storms known as typhoons occur several times during the summer and bring about 65% of the annual precipitation in a period of three months. The dry season starts from October to March when the average monthly precipitation may be as low as 14 mm in November (less than 1% of the annual average precipitation). The monthly average temperature ranges from 16.7℃ in January to 28.7℃ in July.

1.4.2. Site selection

Aquaculture needs intensive labour input to conduct routine practices. The primary practices include maintenance of water depth and salinity through an input of freshwater which mainly comes from underground water and partly comes from rainfall. Regular baiting and the input of pesticide are both main practices. There are two types of aquaculture ponds, namely the deep-small and the shallow-large pond (Figures 1.3 and 1.4). A complete cultivation cycle includes release of young fish into aquaculture ponds, growing-up and harvest. The short-term water drawdown of a few weeks for harvest has provided an opportunity for the foraging of waterbirds. The relatively short cultivation cycle in the shallow-large ponds means that this kind of wetland has been used intensively by waterbirds. A long-term winter water drawdown, of between two to four months, is conducted for sanitation purposes (personal communication with local pond managers) and provides an extra opportunity for foraging by waterbirds.

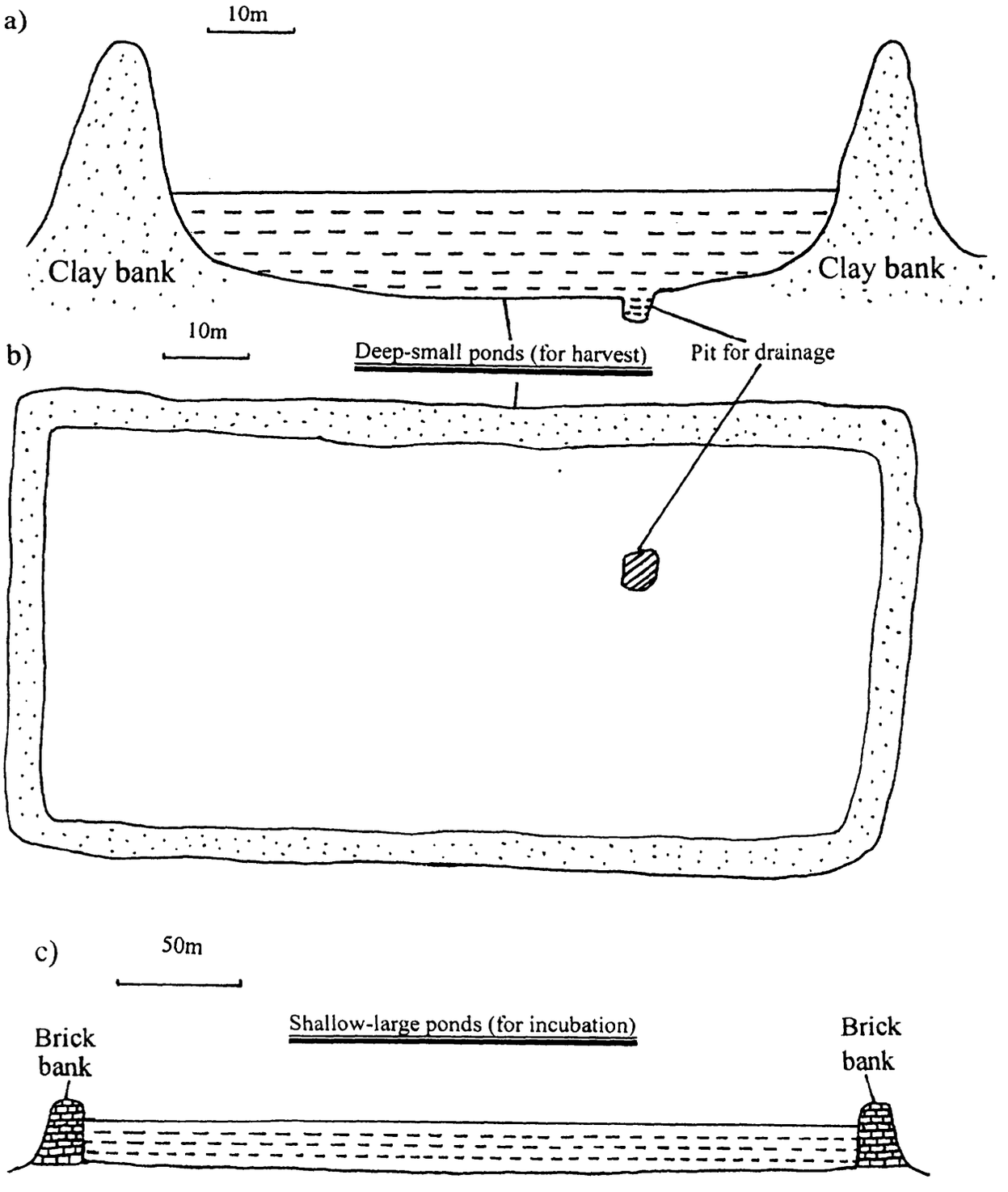


Figure 1.3. Cross-section (a+c) and aerial view (b) of the structure of the two most common types of aquaculture ponds, deep-small ponds (basin area: 3.40 ±2.11 ha, water depth: less than 60 cm with variations from constant manipulation of pond managers) and shallow-large ponds (basin area: 0.81 ±0.72 ha, water depth: more than 2m with variations from constant manipulation of pond managers) in the study area.

Figure 1.4 The two most common types of aquaculture ponds (a) deep-small ponds (top, for harvest), (b) shallow-large ponds (bottom, for incubation) in the study area.

Because aquaculture ponds are considered to be an investment by their owners, they are treated like shares in a stock market. Consequently, the abandonment rate of these commercial fishponds fluctuates inversely with the demand for fish. Owing to the instability of the fish market and the financial state of individual owners, the geographic distribution of temporarily abandoned ponds changes greatly with time and abandoned ponds are distributed unevenly. This makes the task of choosing suitable wetlands as study sites rather difficult. In order to find as many potential sample sites as quickly as possible in a large area like southwestern Taiwan, the most recent aerial photographs and the officials of local conservation and fishery authority were consulted. This greatly facilitated the procedure of site selection. Only 13 sites, which were defined as a place harbouring a group of nearby sample wetlands, were considered to have sufficient available wetlands for the periodic and intermittent observations.

At first, 10 sample sites, which were studied at a 15-day interval (the detailed descriptions and maps are given in Appendix 1), were randomly selected from the 13 suitable study sites. Next, in order to objectively select a series of ponds at each site to fully reflect the whole habitat spectrum of aquaculture ponds and other wetland types, the ponds at each site were selected using a stratified random sampling method (Snedecor & Cochran, 1980). At each selected site, the entire spectrum of representative wetland types, including actively managed aquaculture ponds, temporarily abandoned aquaculture ponds, saltpans and natural wetlands, were chosen at a fixed ratio among these wetland types. Random numbers were then employed in the selection of sample ponds in each wetland type. This kind of sampling method guarantees the efficient use of research resources and sufficient but objective sampling sites to answer the research questions.

Most waterbirds are more or less disturbed by the presence of people. In other words, they are normally less likely to use small ponds (maximum 2 ha.) since a smaller buffering distance for escape is provided by these ponds between the roosting sites of birds and the embankments of ponds, from where predators are most likely to come. Large ponds (minimum 2 ha.) provide a longer buffering distance for escape, and are more likely to harbour a more diverse habitat for feeding, resting, nesting and even raising chicks than small ponds. However, not many large abandoned ponds can be

found in the field. If random numbers had been fully applied to the selection of sample ponds the sampled ponds at many sites could have comprised few or even no large ponds. To avoid the above situation, a fixed ratio of large ponds is guaranteed by selecting every large available pond at a sample site if the ratio in the number of these large ponds to all sample ponds at a site is smaller or equal to the fixed ratio for large ponds. Random sampling was applied to the large ponds only if more large ponds than the fixed ratio occurred at a particular site. Random sampling was separately applied to every category of wetland types. The sampling ratio for each sample pond complex (sample site) is defined as 3: 4: 2: 1: 1 for large abandoned aquaculture ponds : small abandoned aquaculture ponds : actively managed aquaculture ponds : saltpans : natural wetlands. A greater emphasis was placed on abandoned ponds since they are the main focus of this study. Such disproportionate sampling aims to collect the information necessary to restore abandoned aquaculture ponds to a state in favour of waterbirds. In addition, two non-aquaculture-pond types were sampled to offer the opportunity to compare the differential utilization of wetland types by waterbirds.

In the real world, the aforementioned wetland types are distributed in a mosaic of human habitation, artificial wetlands and natural wetlands. These wetland types, which are of a variety of sizes and with differing management histories, often lie close together. Waterbirds obviously use them all. The whole combination of wetlands can actually be regarded as a functional habitat unit. In practice, the sample of ponds at a site is formed by firstly randomly selecting three to four large abandoned ponds and five to six small abandoned ponds and then selecting two of the nearest actively managed ponds, a nearest natural wetland and a nearest saltpan. However, because saltpans and natural wetlands were uncommon in the study area, only those within a reasonable distance (i.e. one km) from the first randomly selected abandoned pond at a given site were sampled.

1.4.3. General description of the sample sites

Locality: Sample sites were confined to the four southwestern counties and city in Taiwan where aquaculture is most popular (Figure 1.5). There were 10 to 20 wetlands per site and 164 sample wetlands in total were sampled among these thirteen sample sites (actively managed ponds, N=56; temporarily abandoned ponds, N=98; saltpans, N= 4; natural wetlands, N=6; see appendix 1 for detail).

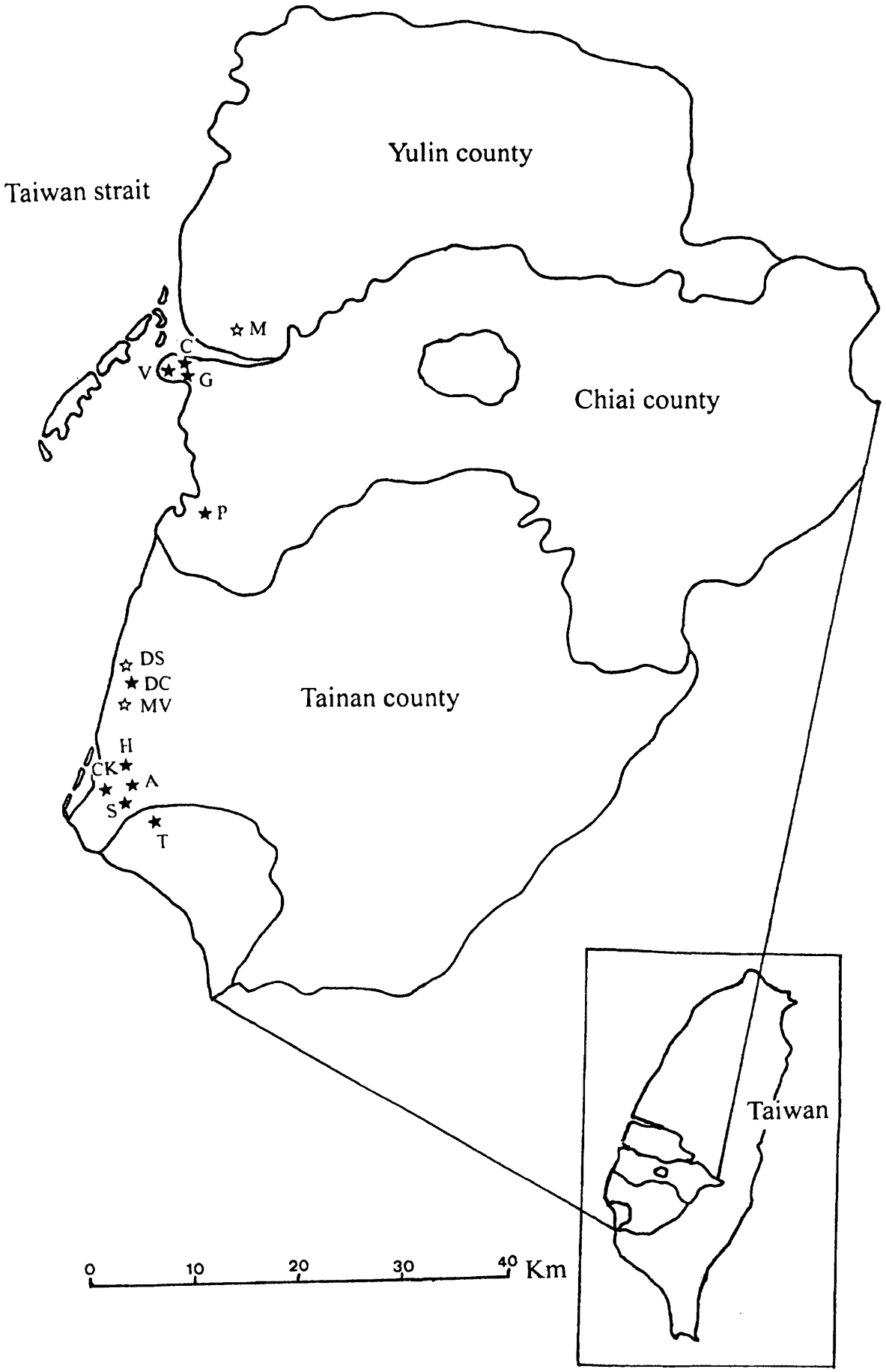


Figure 1.5. A map of study area, showing 13 study sites. Ten intensively studied sites are marked with solid asterisks and three less-intensively studied sites are shown by open asterisks.

Vegetation: In most commercial aquaculture ponds, few trees are allowed to grow to more than three metres in height due to the constant trimming for the occasional access of large construction vehicles. Generally, annual plants, mostly pioneer species in the early seral stages can be found in the aquacultural ponds. *Sesuvium portulacastrum* and *Pluchea indica* dominate their embankment, while *Suaeda nudiflora* and *Arundo formosana* are the common plant species at the bottom area of ponds. *Egeria densa* is the common submerged plant species in the aquacultural ponds.

Structure: The efficient utilization of available land in the study area has resulted in a monotonous appearance in the shape of aquaculture ponds, normally square or rectangular. Triangular or polygonal ponds are occasionally constructed when the local land use does not permit. Two principal types of pond occur in the study area, namely shallow-large ponds for incubation (basin area: 3.40 ±2.11 ha, length: 335.7±59.4 m, width: 138.4±68.5 m, water depth: less than 60 cm with variations from constant manipulation of pond managers) and deep-small ponds for harvest (basin area: 0.81 ±0.72 ha, length: 123.0±75.7 m, width: 59.7±24.9 m, water depth: more than 2m with variations from constant manipulation of pond managers). To reduce the harvest effort, the bottoms of these ponds are typically rather smooth. However, the depth of these ponds increases gradually towards the centre. In addition, a small peripheral pit is constructed for the drainage of water from the ponds. When necessary, the water could be drained through the pit and then pumped out from the ponds (Figures 1.3 and 1.4).

Age of ponds: In total, 98 of the 164 (59.8%) sample ponds are classified as temporarily abandoned aquaculture ponds. However, several ponds (23.9%) were re-used for aquaculture during the study period. The time that had lapsed after being abandoned varies from several months to more than 20 years. Most sample ponds had been abandoned for 1-2 years or 10-15 years (Figure 1.6).

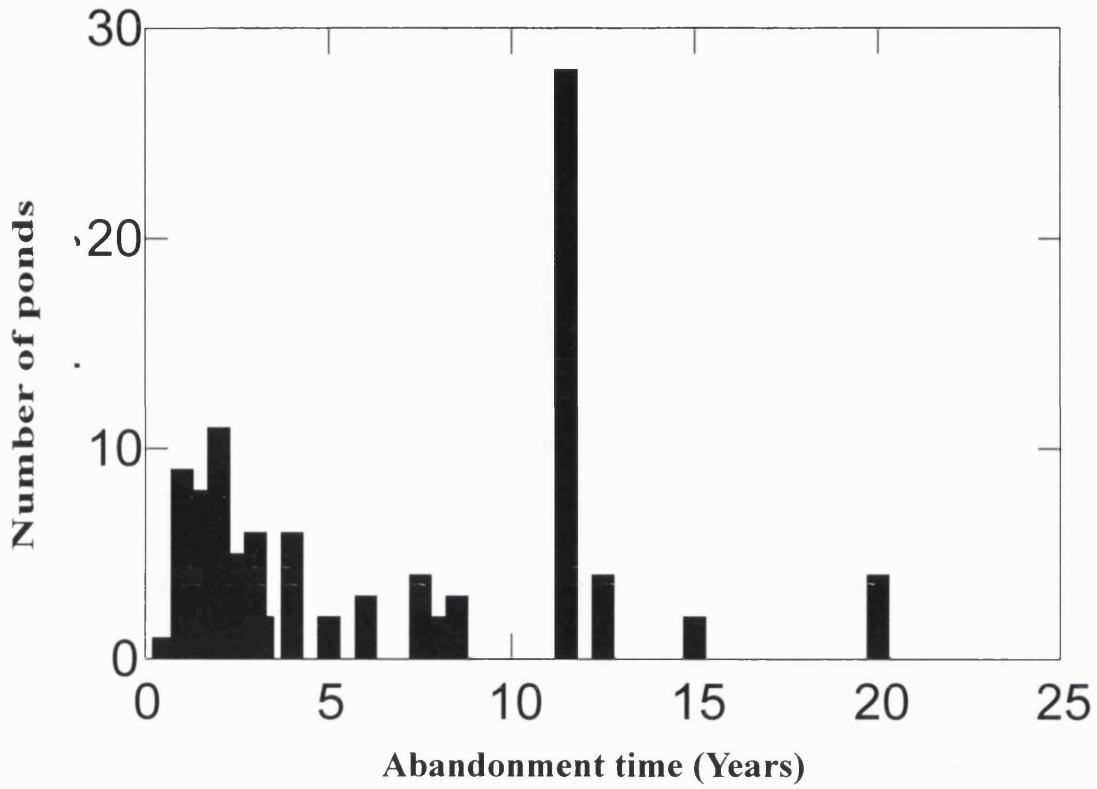


Figure 1.6. Distribution of abandonment time of the sample of temporarily abandoned ponds (N=98).

Chapter 2

Environmental features of abandoned aquaculture ponds: annual pattern and chronosequence

2.1. Introduction

It is important to investigate the annual pattern and chronosequence of the avian community (chapter 3) and the features of temporarily abandoned ponds before attempting to relate the physical parameters of wetlands to the occurrence of waterbird species. In general, many environmental attributes of abandoned ponds may show obvious trends with time as these abandoned ponds gradually dry out due to a lack of irrigation from active aquacultural practices. The surface area of the water body, which is defined as a body of water in which any part of this water body can connect each other, should predictably reduce with time.

However, the strong seasonal variations of rainfall and temperature in the study area means that changes in the features of temporarily abandoned ponds are difficult to predict accurately. The monthly rainfall over a one-year period is not uniformly distributed in the study area during the study period of time (Figure 2.1). The graph indicates that the wet season is from May to July and the dry season covers the remaining months, especially the winter months, i.e. from December to February. Precipitation during the wet season accounts for almost three quarters (73.9%) of the total annual rainfall. Rainfall normally increases rapidly from May and remains high for three to four months during the wet season, then declines to a relatively low level and remains constant for the rest of the year. However, the plot of the average monthly temperature versus time shows a smooth curve that reached a maximum in June and a minimum in February.

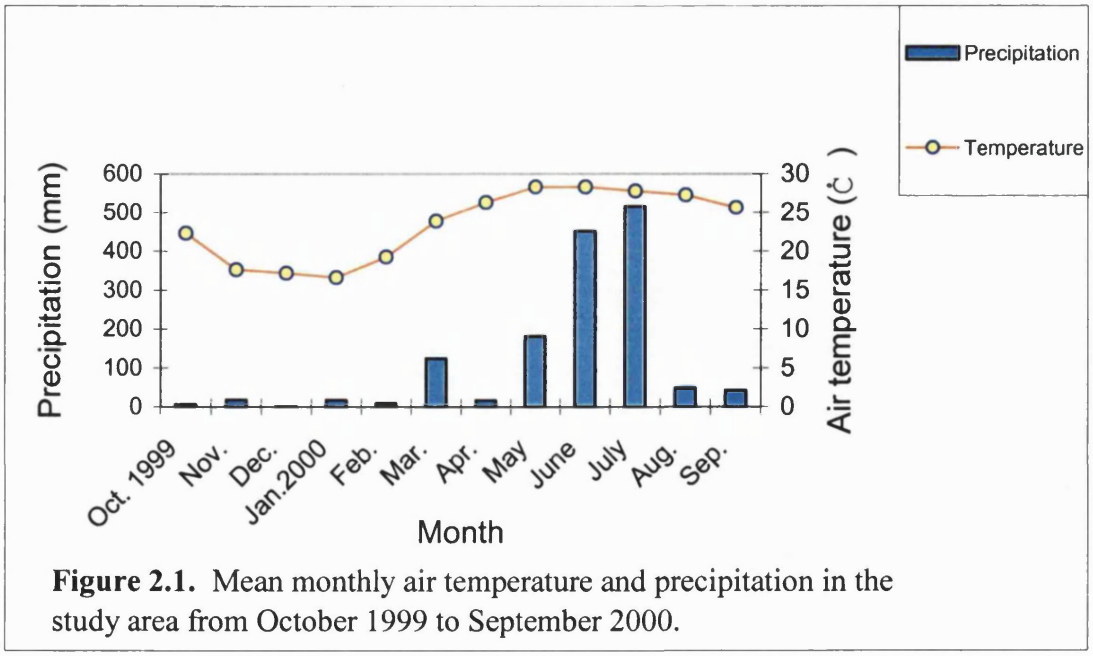


Figure 2.1. Mean monthly air temperature and precipitation in the study area from October 1999 to September 2000.

From the analyses of annual variations and chronosequence in the features of sample wetlands, several relationships are expected to be established, including temporal changes in the features of temporarily abandoned ponds and the variations between the wetland types or between the abandonment age classes. Long-term (chronosequence) and short-term (annual changes) analyses both help to build the systematic knowledge necessary for an in-depth understanding of the evolution of aquaculture ponds after being abandoned. In this chapter, only the features of wetlands are discussed. Avian attributes will be reviewed in the third chapter.

2.2. Methods

2.2.1. Sampling

Only the data collected in the temporarily abandoned ponds were analysed to demonstrate the chronological changes (either long-term chronosequence or short-term year-round changes) in the environmental features of sample wetlands after being abandoned. However, the data collected in other categories of wetlands, namely the actively managed aquaculture ponds, saltpans and natural wetlands, were compared to those in the temporarily abandoned ponds to determine the differences of the year-round chronological changes between wetland types in both avian and environmental characteristics of sample wetlands. This will help to obtain a further detailed understanding into the chronological changes of aquaculture ponds after being abandoned. Furthermore, in order to eliminate the effect of any variation in sampling frequency on the overall results, only the ponds with complete 15-day-interval records over the whole research period were incorporated into the analysis in this chapter (10 intensively-studied sites :107 sample wetlands(actively managed ponds, N=26; temporarily abandoned ponds, N=73; saltpans, N= 3; natural wetlands, N=5)). Environmental variables were measured for an entire year at a fifteen-day interval from October 1999 to September 2000.

2.2.2. Environmental features

2.2.2.1. Vegetation features

Vegetation may offer both food (Cramp & Simmons, 1977, 1980, 1983; Jefferies, 1988; del Hoyo *et al.*, 1992; Belanger & Bedard, 1994; del Hoyo *et al.*, 1996) and shelter (Cramp & Simmons, 1977, 1980, 1983; del Hoyo *et al.*, 1992, 1996)

for adult birds and their broods. In order to describe changes in the vegetation characteristics of sample wetlands with time, two attributes, namely cover and height, were estimated for four vegetation types, including total vegetation, shore vegetation, wall vegetation and emergent vegetation (Hudson, 1983). The cover and height of every vegetation types was all recorded by visual estimation. The height of a fifth category, submerged vegetation, is unlikely to be recorded from merely visual estimation, and needs a thorough investigation to sample ponds. Therefore, only cover was recorded for the fifth vegetation type, submerged vegetation.

Detailed information such as the species composition of vegetation, is not required for future analyses although the dominant species for each vegetation type was recorded during this study. These five vegetation type categories are not totally independent and overlapped to some extent between sample ponds. Total vegetation includes shore, emergent vegetation types and any vegetation between shore and wall vegetation zones. A strip of two-metre width of wall vegetation above the shore is described as shore vegetation if the water body fully covers the basin, which is defined as the area circumscribed by the embankments of ponds. Cover of submerged and emergent vegetation are most likely to overlap among the vegetation types since a water body with emergent vegetation normally also supported submerged vegetation. These two vegetation types normally grow together, and are unlikely to estimate separately without overlapping at many cases. Regarding cover of wall vegetation, the extent of the water body does not generally have a direct influence on its estimation except at those ponds whose basin are covered with 100% water and therefore parts of the embankments of those ponds are covered with water. In this circumstance, the estimation of coverage of wall vegetation is influenced by the extent and depth of the water body.

Shore vegetation was measured within a two metre wide strip encircling the largest water body (Leschisin *et al.*, 1992). Basin area is the only accurate area-related measurement that was measured by the government agencies or calculated using aerial photographs. Other area-related variables were calculated using this measurement and other less accurately estimated measurements such as visual estimation. For example, cover of vegetation was calculated using two

measurements. One is the measurement of basin area; the other is the estimation of percentage cover of a particular vegetation type, which was estimated for every routine observation (at a 15-day interval). These two types of measurements were subsequently combined to calculate the cover of the vegetation types. Regarding the calculation of shore vegetation, the shore vegetation of the largest water body at one particular sample wetland was used as a sample to estimate the extent of shore vegetation of this wetland. In addition, the radius of the largest water body, which was assumed as a perfect round water body, was used to calculate the circumference of the largest water body. Of the five vegetation types, shore vegetation was most changeable. and its absolute coverage (A_{sh}) was calculated using the following formulae with two assumptions:

1. $A_l = A_b \times P_l = \pi \times r_l^2 \rightarrow r_l = \sqrt{(A_b \times P_l / \pi)}$
2. A_{sh}=length of shore vegetation along the largest water body × width of shore vegetation=$2\pi \times (r_l + 1) \times 2 = 2\pi \times (\sqrt{(A_b \times P_l / \pi)} + 1) \times 2$
   $= 4\pi \times (\sqrt{(A_b \times P_l / \pi)} + 1) = \sqrt{(16 A_b \times P_l \times \pi)} + 4\pi$

* the length of central line of the 2-metre wide stripe along the largest water body is viewed as the length of shore vegetation, therefore '$r_l + 1$' rather than 'r_l' was used to calculate A_{sh}.

3. In conclusion,

$$A_{sh} = \sqrt{(16 A_b \times P_l \times \pi)} + 4\pi$$

A_b : basin area of a pond (see definition of basin below)

A_l : area of the largest water body in a pond

A_{sh} : the extent of shore vegetation

P_l : the percentage extent of the largest water body to the basin area of this pond

r_l= the approximate value for the radius of the largest water body in a pond

Length unit: metre

Basin: the area enclosed by the embankments of ponds

Water body: a body of water in which any part of this water body can connect each other.

Two measures were taken to describe the characteristics of vegetation height: the absolute maximum height (A.H.) and the mean height of the dominant

vegetation (M.H.). The tallest individual plant of a particular vegetation type of a pond is defined as A.H. However, some individual plants may grow to be particularly tall, and therefore A.H. is not sufficient to represent the vegetation characteristics of a pond. The mean height (M.H.) of plants at a particular vegetation type of a pond was thus also included to describe its vegetation characteristics.

2.2.2.2. Physical attributes

Certain physical attributes of aquaculture ponds could possibly be key factors that determine the habitat selection of waterbirds. Water quality (Hudson, 1983; Leschisin *et al.*, 1992; Hill *et al.*, 1993; McKinstry & Anderson, 1994; Rehfisch, 1994; Weller, 1994; Weber & Haig, 1996; Greighton *et al.*, 1997; Svingen & Anderson, 1998), water depth (Breininger & Rebecca, 1990; Leschisin *et al.*, 1992; Colwell & Landrum, 1993; McKinstry & Anderson, 1994; Rehfisch, 1994; Weber & Haig, 1996; Safran *et al.*, 1997; Ashkenazi & Dimentman, 1998), the surface area of the water body(Hudson, 1983), basin area(Leschisin *et al.*, 1992; McKinstry & Anderson, 1994; Johnson *et al.*, 1996; VanRees-Siewert & Dinsmore, 1996; Svingen & Anderson, 1998), the distance to a variety of natural and artificial habitats (Hudson, 1983; Leschisin *et al.*, 1992; Colwell & Landrum, 1993) and wetland densities (Leschisin *et al.*, 1992; McKinstry & Anderson, 1994; Naugle *et al.*, 1997) are among the most important potential environmental factors, of which all except the last three factors were measured every half month. The last three factors were measured once in the initial stages of the project. If there were several water bodies in a particular sample unit, water quality was measured from the largest water body.

a. **Water quality:** A 250 ml water sample each sample pond was taken from the shore of its largest water body. These water samples were subsequently used to measure the following water quality related parameters, salinity (ppt), pH, dissolved oxygen content level (mgl^{-1}) and turbidity (Nephelometric Turbidity Unit, N.T.U.). HACH EC10 pH meter was used to measure pH, and WTW microprocessor conductivity meter LF196 was used to measure salinity. Turbidity was measured using HACH 2100P portable turbidimeter, and dissolved oxygen was measured using Consort Z521 oxymeter. All factors were measured at each pond at a fifteen-day interval until May 2000. Thereafter sampling was taken monthly as water quality was found to be

relatively constant. A monthly measurement should provide a sufficient amount of data to demonstrate the patterns of water quality (Table 2.1 and Figure 2.2).

Table 2.1. The sampling frequency and instruments used for measuring the water quality related parameters of sample wetlands in this study.

Parameters	Instruments	Sampling frequency
pH	HACH EC10 pH meter	Once per pond per fifteen days until May 2000, thereafter measuring at a thirty-day interval from May to October 2000
Salinity	WTW microprocessor conductivity meter LF196	The same as above
Turbidity	HACH 2100P portable turbidimeter	The same as above
Dissolved oxygen	Consort Z521 oxymeter	The same as above

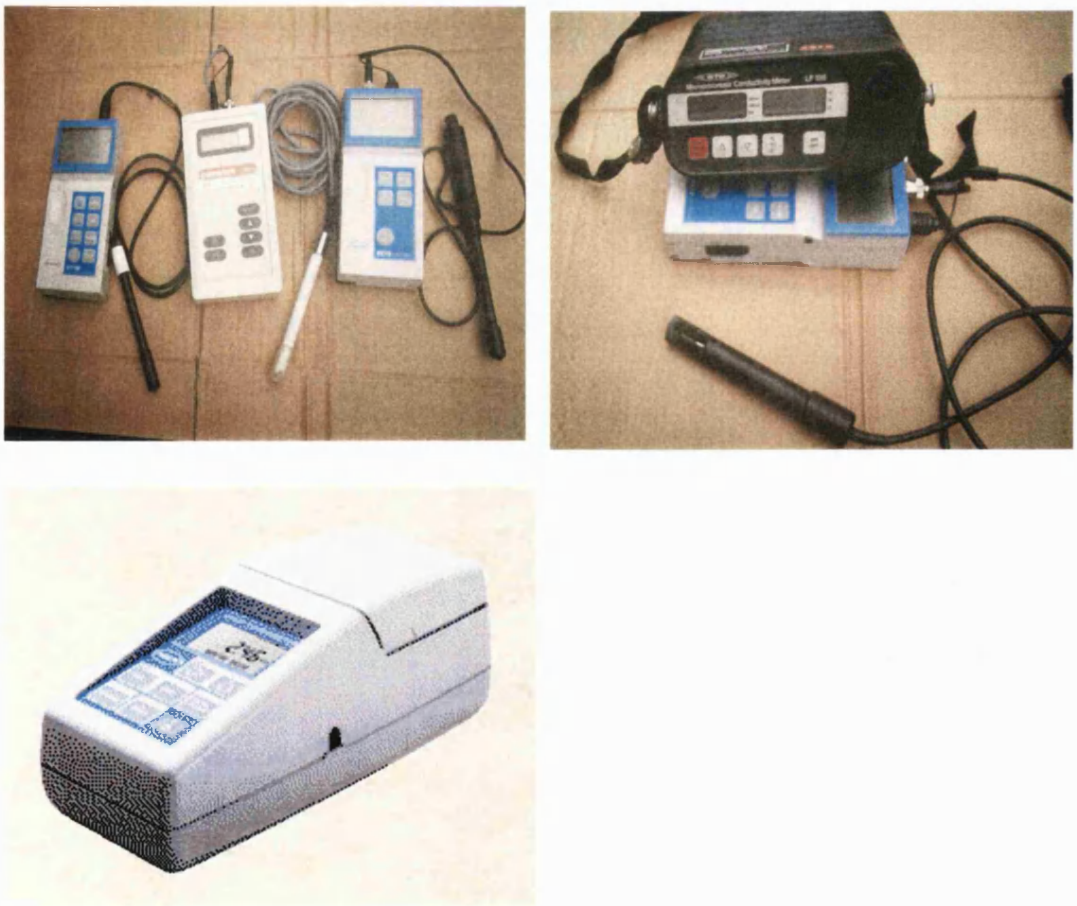


Figure 2.2. Water quality equipment using in this study.

b. **Basin area:** This is defined as the area that is circumscribed by the embankments of a particular pond. For natural wetlands, the most recent aerial photographs are employed to estimate basin area (Hudson, 1983, Leschisin *et al.*, 1992).

c. **Water depth:** The depth of the largest water body was measured and subsequently categorized into five ranges (0-5 cm, 5-10 cm, 10-20 cm, 20-30 cm and >30 cm depth zones). These categories aim to provide detailed information about the microhabitats available to waterbirds. In order to efficiently obtain the estimates of five water depth zones, one measuring wooden stick with marks evenly spaced at a five cm interval was used to measure depth. The investigator walked along an imaginary line, which is perpendicular to the tangent of shore line, from shore to a point at a depth of five cm, say the point W, by probing the 5 cm depth with measuring stick. Then, the distance, say A, from shore to the point W was measured using measuring stick. After that, the investigator walked again from the point W to a point of 10 cm depth, say the point X. Then the distance, say B, from the point W to the point X was measured. The similar process continued until 30 cm depth. As a result, four measurements were obtained, namely A,B, C and D for 0~5 cm, 5~10 cm, 10~20 cm and 20~30 cm. These four measurements were consequently used to estimate the extent of five water depth zones, namely 0-5 cm, 5-10 cm, 10-20 cm, 20-30 cm and >30 cm depth zones. The water body was assumed as a perfect round water body, therefore r_1, see section 2.2.2.1's formula, was deducted by A, A+B, A+B+C and A+B+C+D, to obtain four radii: r_A, r_B, r_C and r_D. Then the extent of >30 cm depth zone is approximately the circle area of a r_D radius, say area r_D. The extent of 20-30 cm, 10-20 cm, 5-10cm and 0-5 cm depth zone is the difference between area r_D and r_C., area r_C and r_B, area r_B and r_A, and area r_A and r_1 respectively (Figure 2.3).

d. **The area covered by open water, largest water body, entire water body and exposed mudflats:** These variables were estimated using the percentage extent of these variables and basin area in a pond, and consequently converted to the absolute extent of the aforementioned variables. The extent of an open water body will be different from the area of the entire water body if emergent vegetation occurs in a pond.

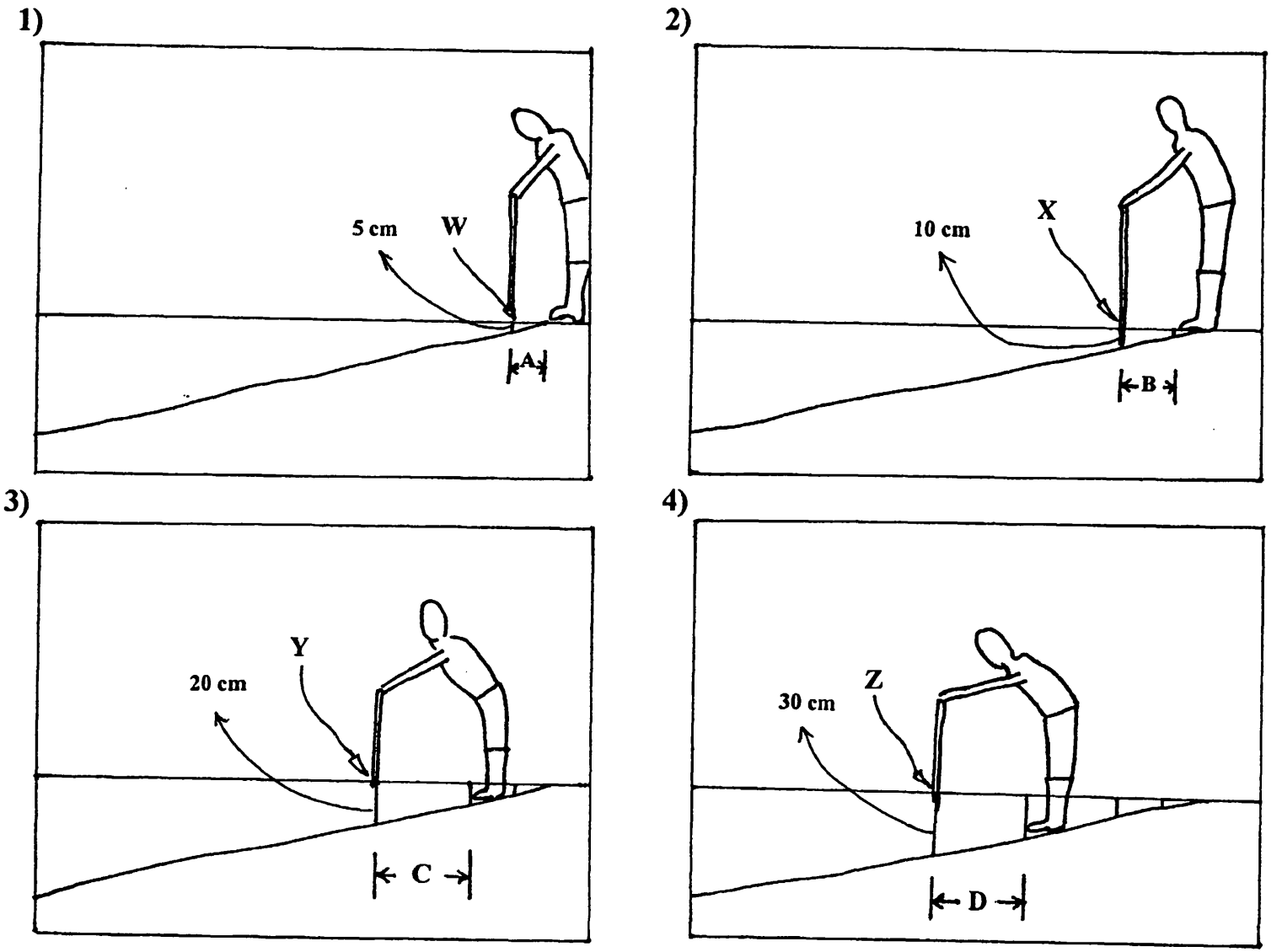


Figure. 2.3. The drawings showing the process for measuring the shortest distance between the pond's shore and the position of one of the four water depths (5, 10, 20, 30 cm).

e. **The distance to seashore, the nearest natural wetland, human habitation and highway or main road** (Hudson, 1983, Leschisin *et al.*, 1992)**:** The presence of natural wetlands and the sea may be positively associated with the use pattern of sample ponds by waterbirds, while the presence of human disturbance may be negatively associated with it.

f. **The density of wetlands or natural wetlands or aquacultural ponds within a one-kilometre radius** (Leschisin et. al., 1992): The overall wetland density includes both natural and artificial wetlands and the density of every recorded wetland type. All densities were calculated within a one-kilometre radius by referring to the most recent aerial photographs.

2.2.2.3. Miscellaneous attributes

2.2.2.3.1. Abandonment history

The study of abandonment history comprised the observations on abandonment time, artificial activities such as fishing and netting, the extent of these artificial activities after being abandoned and the history of cultivated species before abandonment. Some drained ponds are given a "sunbathing treatment", an aquacultural practice whereby a pond is drained and left to bake in the sun in an attempt to sanitize the substrate. This practice was noted during the study period, although these ponds were not considered abandoned. The abandonment history of ponds was obtained either from the records of local authorities or from personal interviews. Some of the ponds had been abandoned many years ago, so the accuracy of their abandonment history is relatively poor.

2.3. Statistical analysis

One-way analysis of variance (ANOVA) was used for the initial statistical test to show if there was a significant difference between the 15-day-interval measurements of each individual environmental attribute of sample ponds. Only those attributes exhibiting significant differences, at least four statistically significant analyses out from 12 analyses (one analysis for all sample ponds, four analyses for four wetland types and seven analyses for seven age classes), were included in further analyses. However, some physical attributes exhibiting significant changes do not display a recognized trend in either annual pattern or chronosequence, and consequently were not included in further analyses. Normality was tested for every investigated attribute of wetlands in this study. Those non-normal distributed attributes were subsequently transformed to new attributes with normal or nearly-normal distribution (Table 2.2).

Table 2.2. Summary of the normality and transformation of investigated attributes of wetlands in this study. One-sample Kolmogorov-Smirnov normality test was applied to every individual attributes to test their normality.

Physical attributes	Transformation	N	Significance (2-tailed)
pH	none	1713	0.002
Salinity	none	1621	0.000
Turbidity	natural log	1435	0.000
Dissolved oxygen	none	1708	0.000
The cover of all vegetation	natural log	2420	0.000
The cover of shore vegetation	none	2371	
The cover of wall vegetation	natural log	2280	0.000
The cover of emergent vegetation	natural log	2381	0.000
The cover of submerged vegetation	natural log	2216	0.000
A.H. of all vegetation*	none	2494	0.000
A.H. of shore vegetation	none	2352	0.000
A.H. of wall vegetation	natural log	2439	0.000
A.H. of emergent vegetation	none	2319	0.000
M.H. of all vegetation**	natural log	2496	0.000
M.H. of shore vegetation	natural log	2354	0.000
M.H. of wall vegetation	none	2443	0.000
M.H. of emergent vegetation	natural log	2324	0.000
Basin area	natural log	178	0.000
0-5 cm depth zone	natural log	2309	0.000
5-10 cm depth zone	natural log	2309	0.000
10-20 cm depth zone	natural log	2307	0.000
20-30 cm depth zone	natural log	2305	0.000
>30 cm depth zone	natural log	2307	0.000
The extent of open water	natural log	2411	0.000
The extent of largest water body	natural log	2062	0.000
The extent of entire water body	natural log	2412	0.000
The extent of exposed mudflats	natural log	2408	0.000
The distance to seashore	natural log	176	
The distance to the nearest natural wetland	natural log	176	0.000
The distance to the nearest human habitation	natural log	175	0.000
The distance to the nearest highway or main road	natural log	175	0.000
Density of wetlands	none	176	0.000
Density of all aquaculture ponds	none	176	0.005
Density of natural wetlands	natural log	176	0.000
Abandonment time	natural log	107	0.000

* A.H.: the absolute maximum height.

**M.H.: the mean height of the dominant vegetation.

2.4. Results

Several types of environmental features of sample ponds were examined every 15 days from October 1999 to September 2000, including water chemistry, vegetation and the extent of the water body and water depth zones. The chronological changes in these environmental features were determined using long-term analysis (chronosequence) and short-term analysis (year-round changes). Environmental attributes measured at a 15-day interval were analysed in four ways: chronosequence with abandonment time and year-round changes in all sample ponds, and the sample ponds of a particular wetland type or age class.

2.4.1. Annual pattern

2.4.1.1.Water chemistry

Several water chemistry-related variables were compared, including pH, salinity, dissolved oxygen content and turbidity. Only pH and salinity are more likely to show an obvious annual pattern in all sample ponds or a particular wetland type or age class. However, each of these four variables display significant differences in all sample ponds and most of the wetland types and age classes with respect to the one-way ANOVA of the 15-day-interval measurements (Table 2.3). Salinity shows a more periodic annual pattern than pH (Figures 2.4 and 2.5). Dissolved oxygen content shows a quite constant pattern with three indistinct peaks, in all sample ponds, a particular wetland type or particular age class (Table 2.3 and Figure 2.6).

Table 2.3. Summary of one-way ANOVAs of salinity, pH and dissolved oxygen with time for all sample ponds, four wetland types and seven age classes from October 1999 to September 2000.

Physical attribute	Wetland type/age class	Degrees of Freedom	F-value	Significance
Salinity	All sample wetlands	2,261	46.87	0.000**
	Actively managed ponds	523	17.12	0.000**
	Temporarily abandoned ponds	1,588	35.48	0.000**
	Saltpans	63	3.33	0.000**
	Natural wetlands	82	9.93	0.000**
	0-1 year age class	128	2.92	0.000**
	1-2 year age class	285	6.10	0.000**
	2-3 year age class	188	1.80	0.018*
	3-4 year age class	164	3.72	0.000**
	4-10 year age class	111	11.20	0.000**
	10-15 year age class	669	19.90	0.000**
	15-20 year age class	95	18.34	0.000**
pH	All sample wetlands	2,247	57.21	0.000**
	Actively managed ponds	513	26.23	0.000**
	Temporarily abandoned ponds	1,585	36.37	0.000**
	Saltpans	66	3.34	0.000**
	Natural wetlands	80	1.44	0.131
	0-1 year age class	128	5.37	0.000**
	1-2 year age class	285	8.46	0.000**
	2-3 year age class	198	6.12	0.000**
	3-4 year age class	164	6.79	0.000**
	4-10 year age class	108	1.49	0.096
	10-15 year age class	668	17.46	0.000**
	15-20 year age class	95	7.69	0.000**
Dissolved oxygen	All sample wetlands	2,242	92.82	0.000**
	Actively managed ponds	512	18.98	0.000**
	Temporarily abandoned ponds	1,581	68.53	0.000**
	Saltpans	66	11.41	0.000**
	Natural wetlands	80	9.98	0.000**
	0-1 year age class	127	11.88	0.000**
	1-2 year age class	284	17.62	0.000**
	2-3 year age class	197	15.51	0.000**
	3-4 year age class	164	22.78	0.000**
	4-10 year age class	108	13.42	0.000**
	10-15 year age class	667	31.30	0.000**
	15-20 year age class	95	38.46	0.000**

P.S.: * means that p-value is no more than 5% and ** means that p-value is no more than 1%.

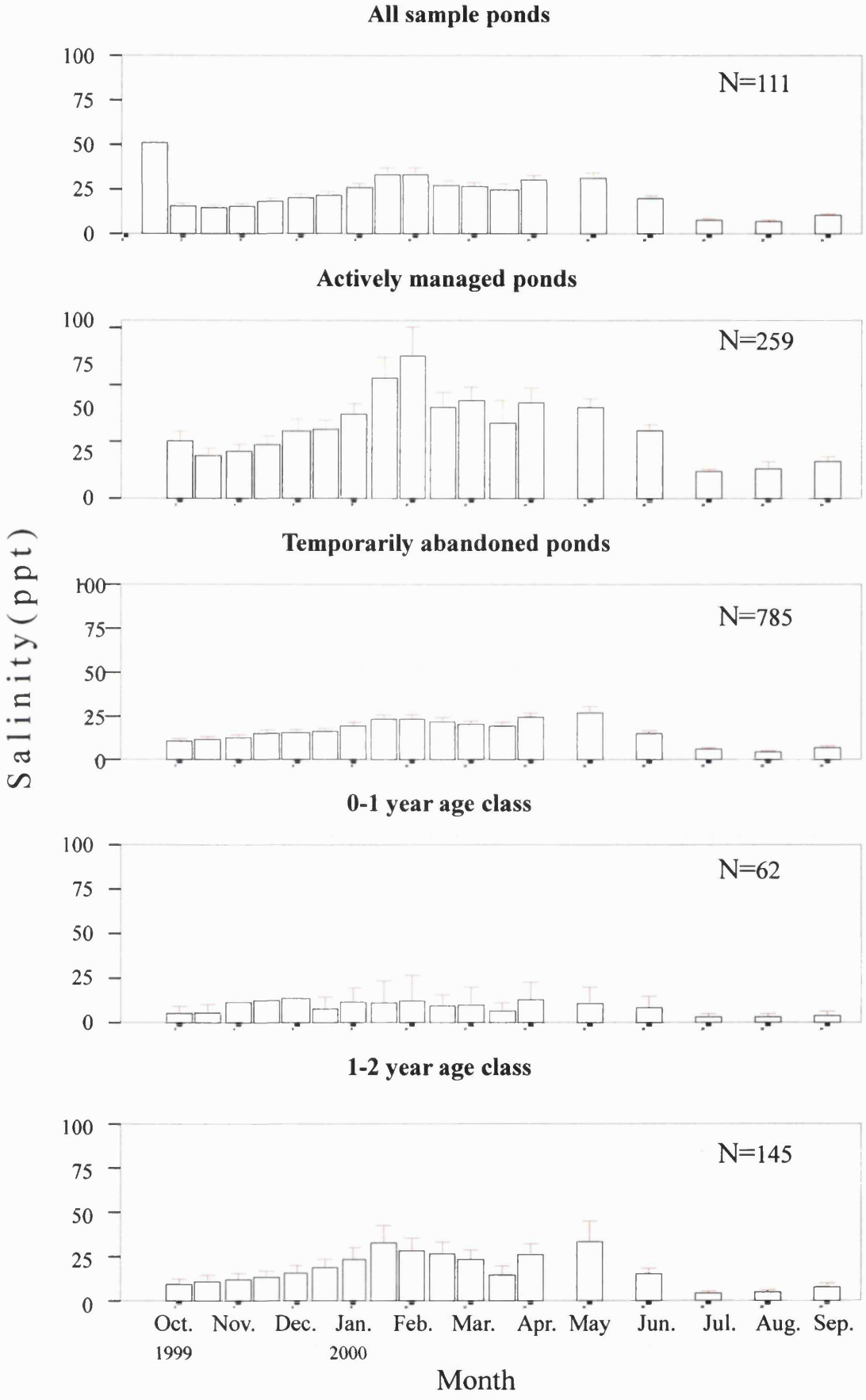


Figure 2.4. Mean salinity at a 15-day interval in all sample ponds and the ponds of two wetland types and seven abandonment age classes from October 1999 to September 2000. Error bars represent the standard error of the mean.

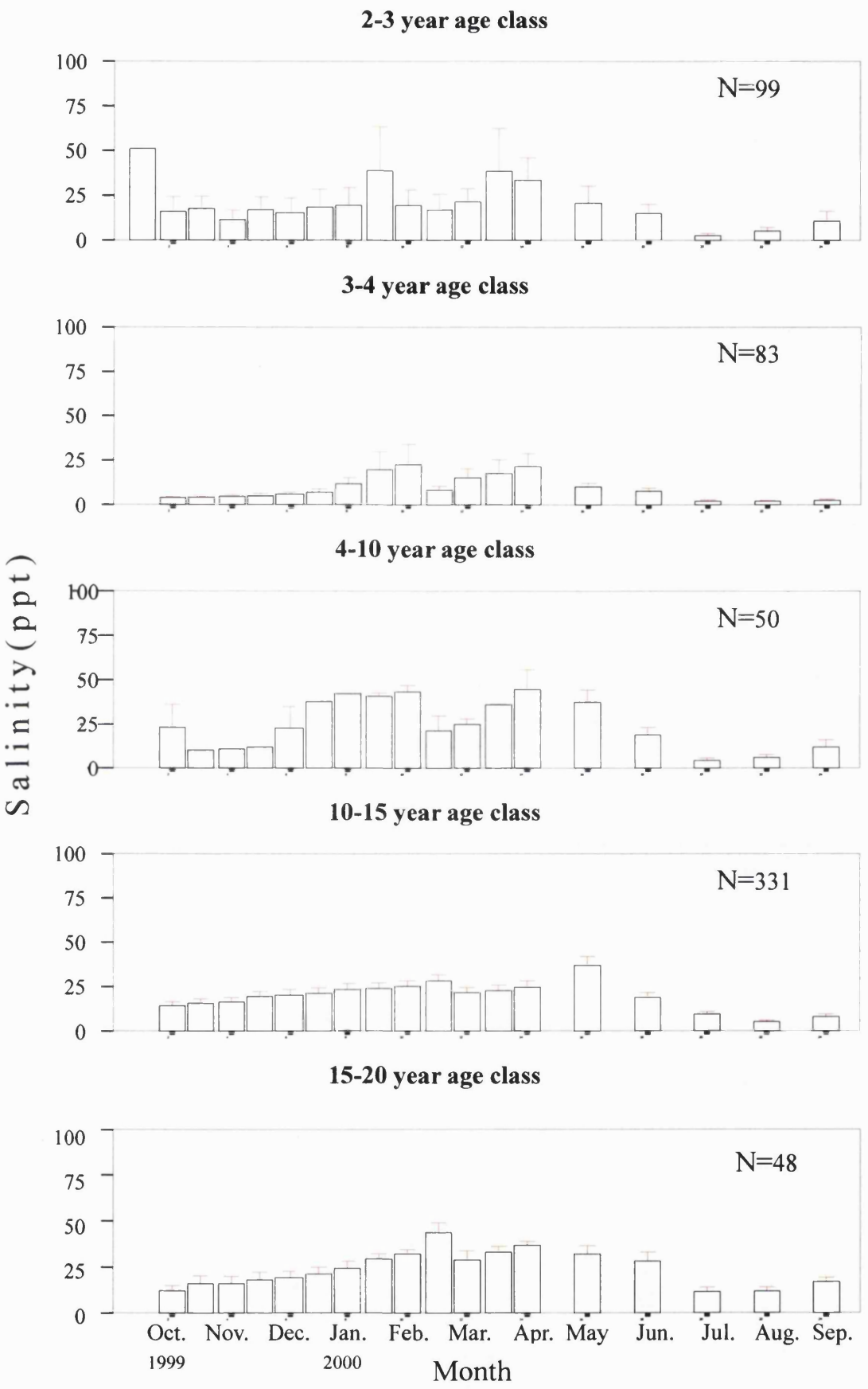


Figure 2.4. (Cont.) Mean salinity at a 15-day interval in all sample ponds and the ponds of two wetland types and seven abandonment age classes from October 1999 to September 2000. Error bars represent the standard error of the mean.

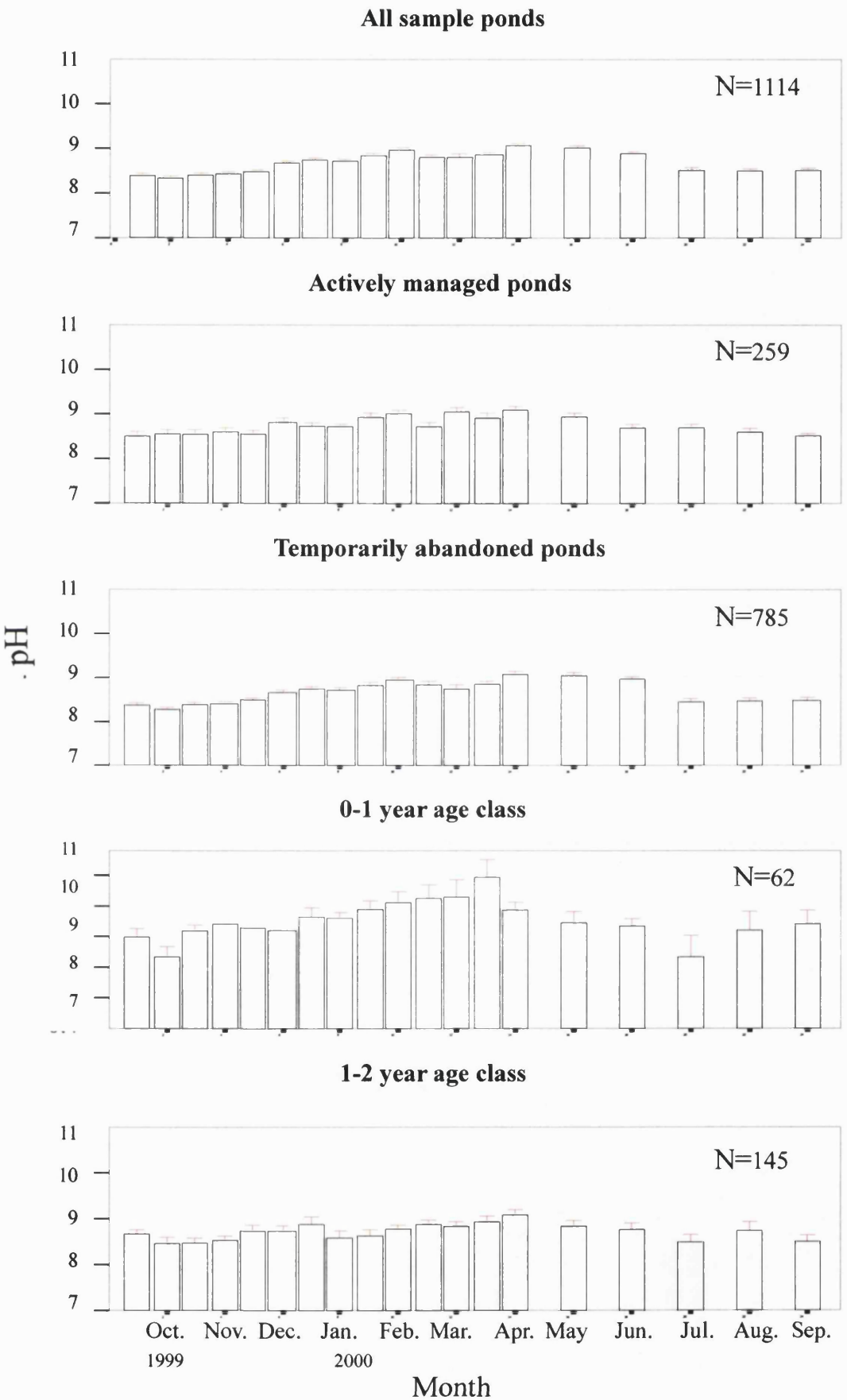


Figure 2.5. Mean pH at a 15-day interval in all sample ponds and the ponds of two wetland types and seven abandonment age classes from October 1999 to September 2000. Error bars represent the standard error of the mean.

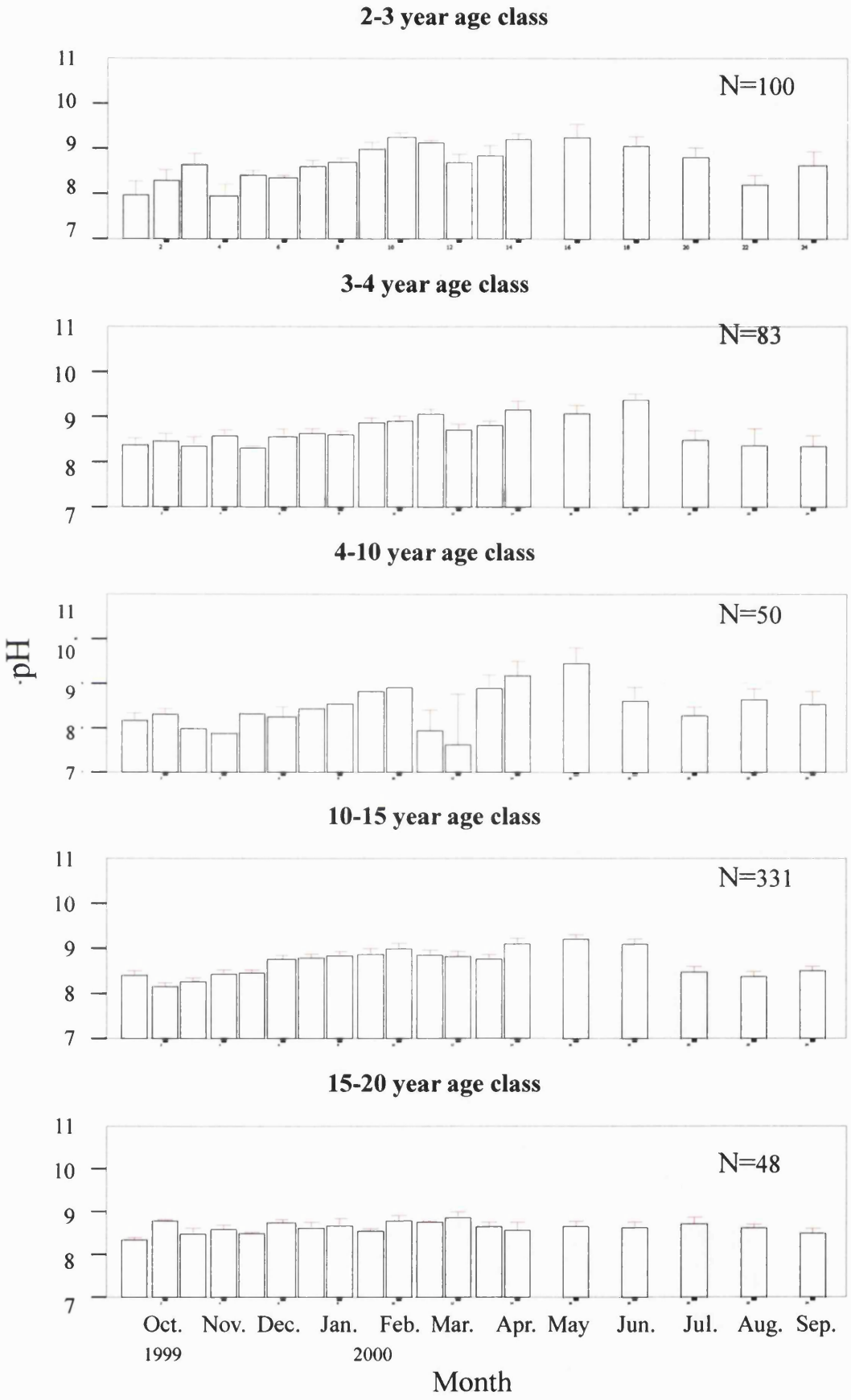


Figure 2.5. (Cont.) Mean pH at a 15-day interval in all sample ponds and the ponds of two wetland types and seven abandonment age classes from October 1999 to September 2000. Error bars represent the standard error of the mean.

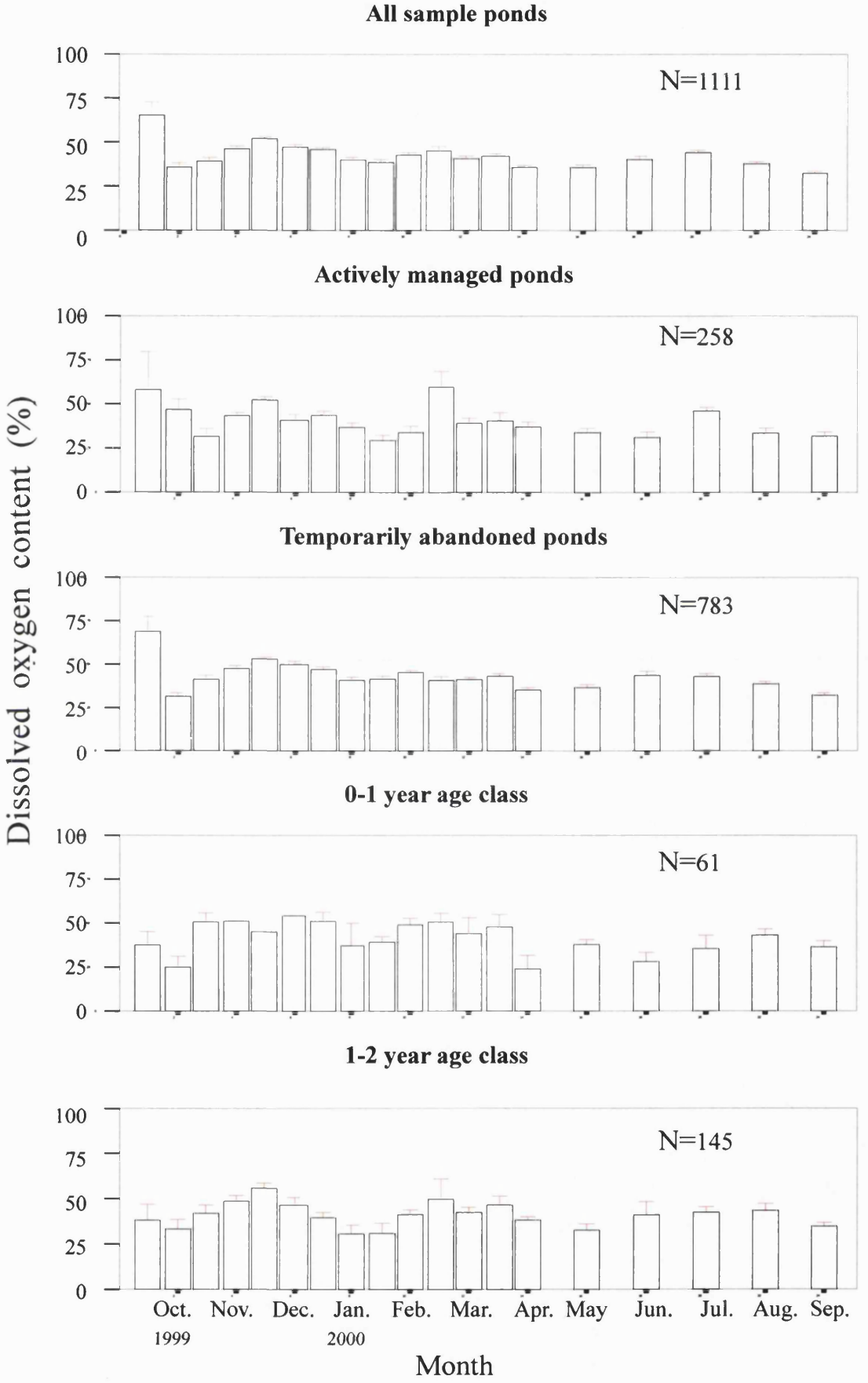


Figure 2.6. Mean dissolved oxygen content at a 15-day interval in all sample ponds and the ponds of two wetland types and seven abandonment age classes from October 1999 to September 2000. Error bars represent the standard error of the mean.

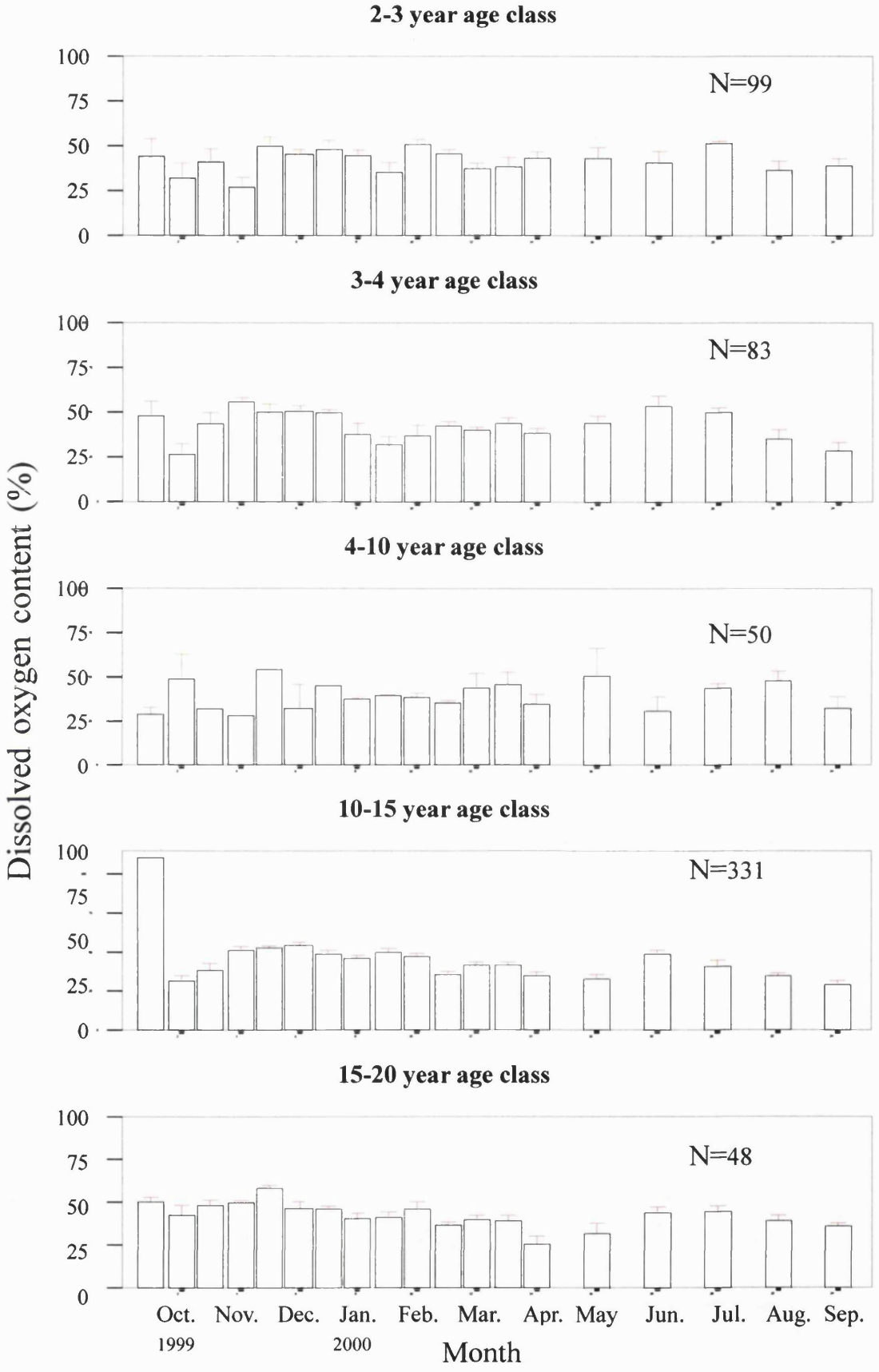


Figure 2.6. (Cont.) Mean dissolved oxygen content at a 15-day interval in all sample ponds and the ponds of two wetland types and seven abandonment age classes from October 1999 to September 2000. Error bars represent the standard error of the mean.

2.4.1.2.The extent of five water depth zones, exposed mudflats and total vegetation

The relative extent of vegetation, exposed mudflat and water depth zones in a pond may provide some initial clues about the habitat environment for waterbirds. These characteristics could be crucial for high-flying waterbirds in search for a suitable feeding ground or roosting habitat, particularly over a mosaic landscape that consists of a mixture of artificial and natural wetlands.

The extent of exposed mudflats and the >30 cm water depth zone were most likely to show a significant annual pattern either in all sample ponds or a particular wetland type or age class (Table 2.4, Figures 2.7 & 2.8). The category of exposed mudflats includes any unvegetated bare ground in a pond, namely mudflat, pebble land, rock and sands. A decrease in coverage of total vegetation could happen rapidly when part of emergent vegetation became submerged vegetation due to a large water input of heavy rain.

Table 2.4. Summary of one-way ANOVAs of the extent of >30 cm water depth zone and exposed mudflats with time for all sample ponds, four wetland types and seven age classes from October 1999 to September 2000.

Physical attribute	Wetland type/age class	Degrees of Freedom	F-value	Significance
>30 cm water depth zone	All sample wetlands	2,398	3.84	0.000**
	Actively managed ponds	575	3.24	0.000**
	Temporarily abandoned ponds	1,683	7.90	0.000**
	Saltpans	62	0.78	0.735
	Natural wetlands	75	0.12	1.000
	0-1 year age class	123	0.96	0.525
	1-2 year age class	301	2.02	0.005**
	2-3 year age class	165	3.37	0.000**
	3-4 year age class	164	3.23	0.000**
	4-10 year age class	160	2.33	0.001**
	10-15 year age class	672	3.32	0.000**
	15-20 year age class	92	0.96	0.524
Exposed mudflats	All sample wetlands	2,499	0.51	0.973
	Actively managed ponds	603	2.51	0.000**
	Temporarily abandoned ponds	1,724	3.70	0.000**
	Saltpans	65	1.11	0.373
	Natural wetlands	104	0.39	0.993
	0-1 year age class	131	0.72	0.815
	1-2 year age class	308	1.68	0.029*
	2-3 year age class	166	1.20	0.255
	3-4 year age class	167	4.69	0.000**
	4-10 year age class	162	1.66	0.039*
	10-15 year age class	689	2.00	0.004**
	15-20 year age class	95	0.92	0.572

P.S.: * means that p-value is no more than 5% and ** means that p-value is no more than 1%.

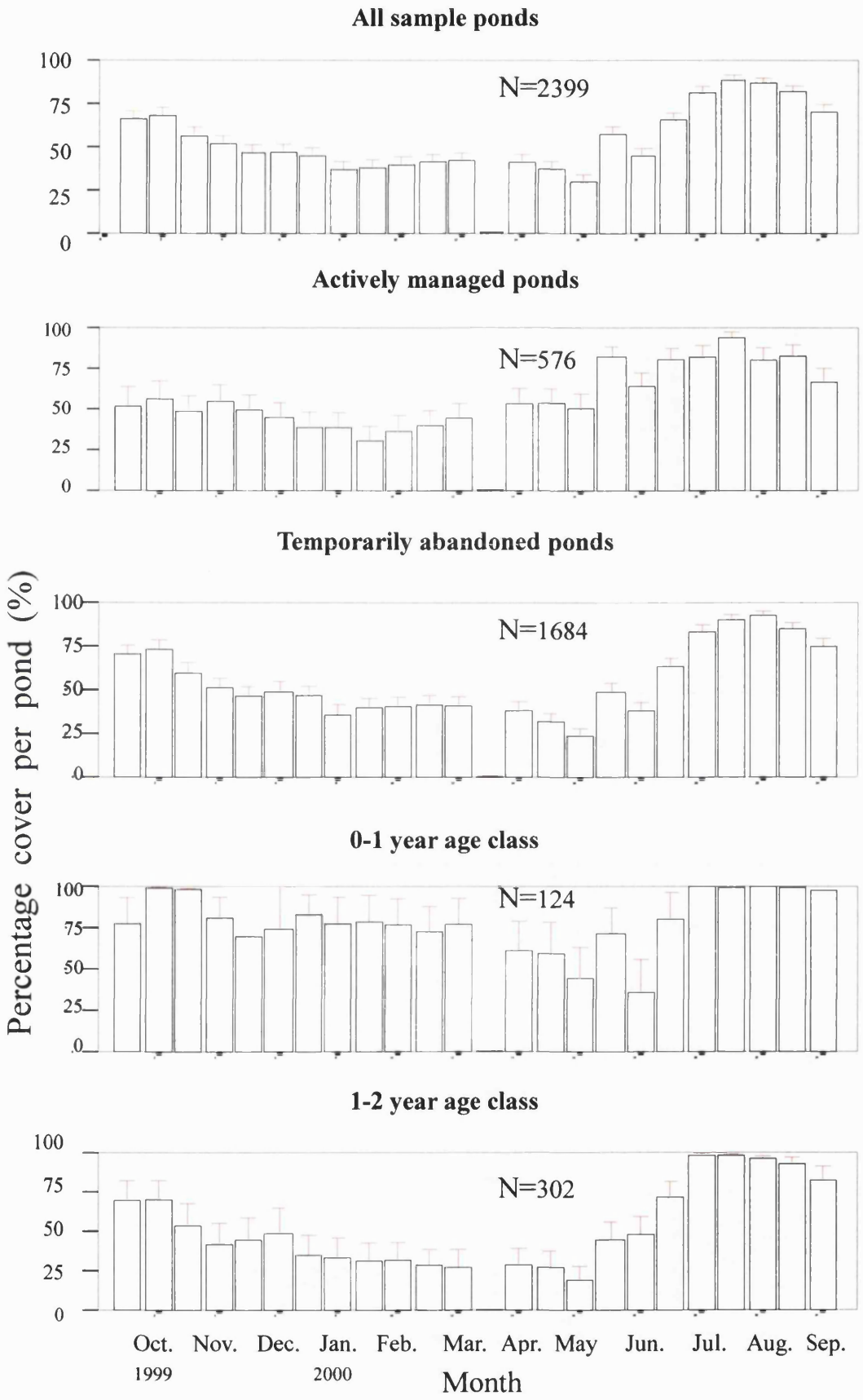


Figure 2.7. The mean extent of the >30 cm water depth zone at a 15-day interval in all sample ponds and the ponds of two wetland types and seven abandonment age classes from October 1999 to September 2000. Error bars represent the standard error of the mean.

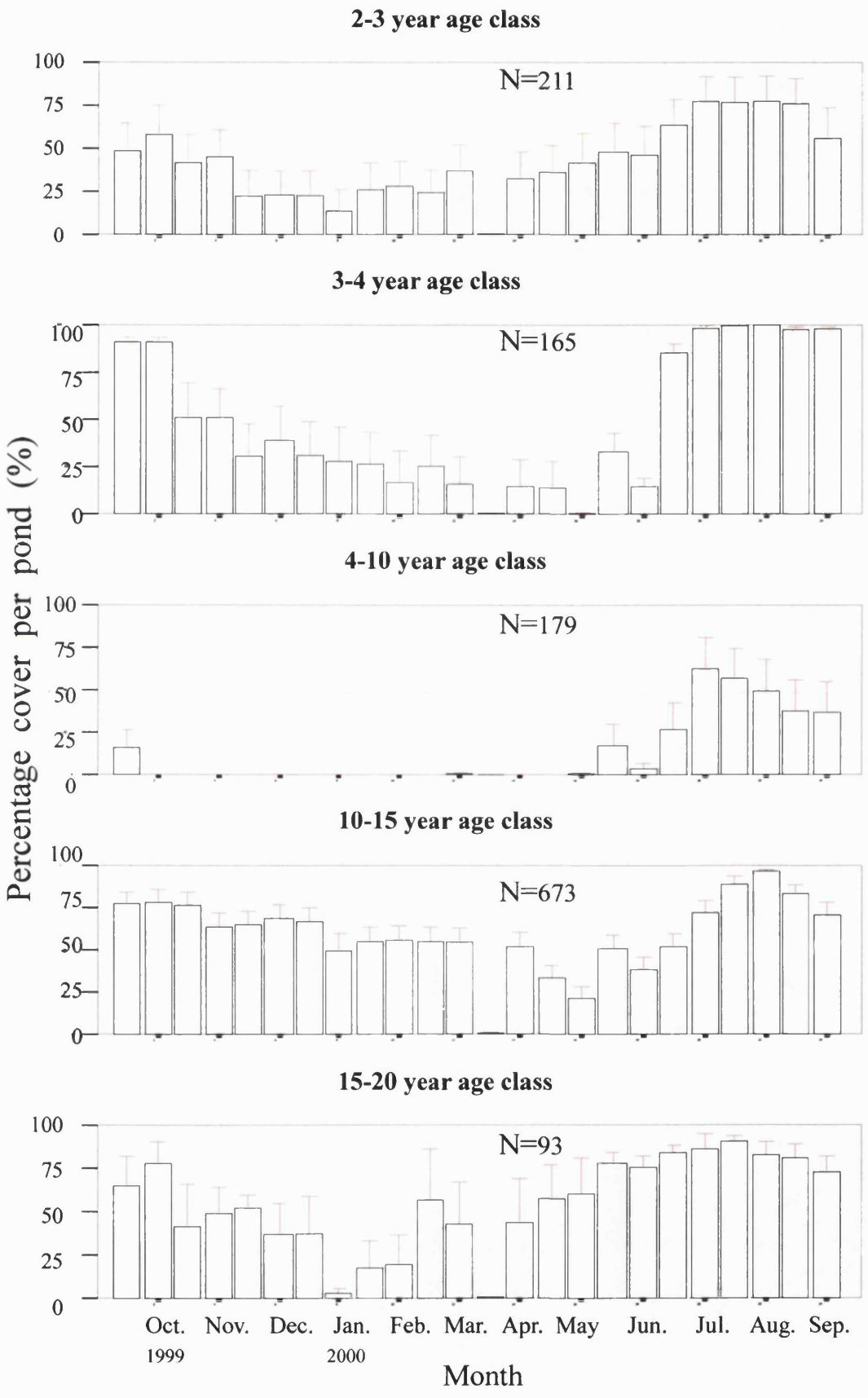


Figure 2.7. (Cont.) The mean extent of the >30 cm water depth zone at a 15-day interval in all sample ponds and the ponds of two wetland types and seven abandonment age classes from October 1999 to September 2000. Error bars represent the standard error of the mean.

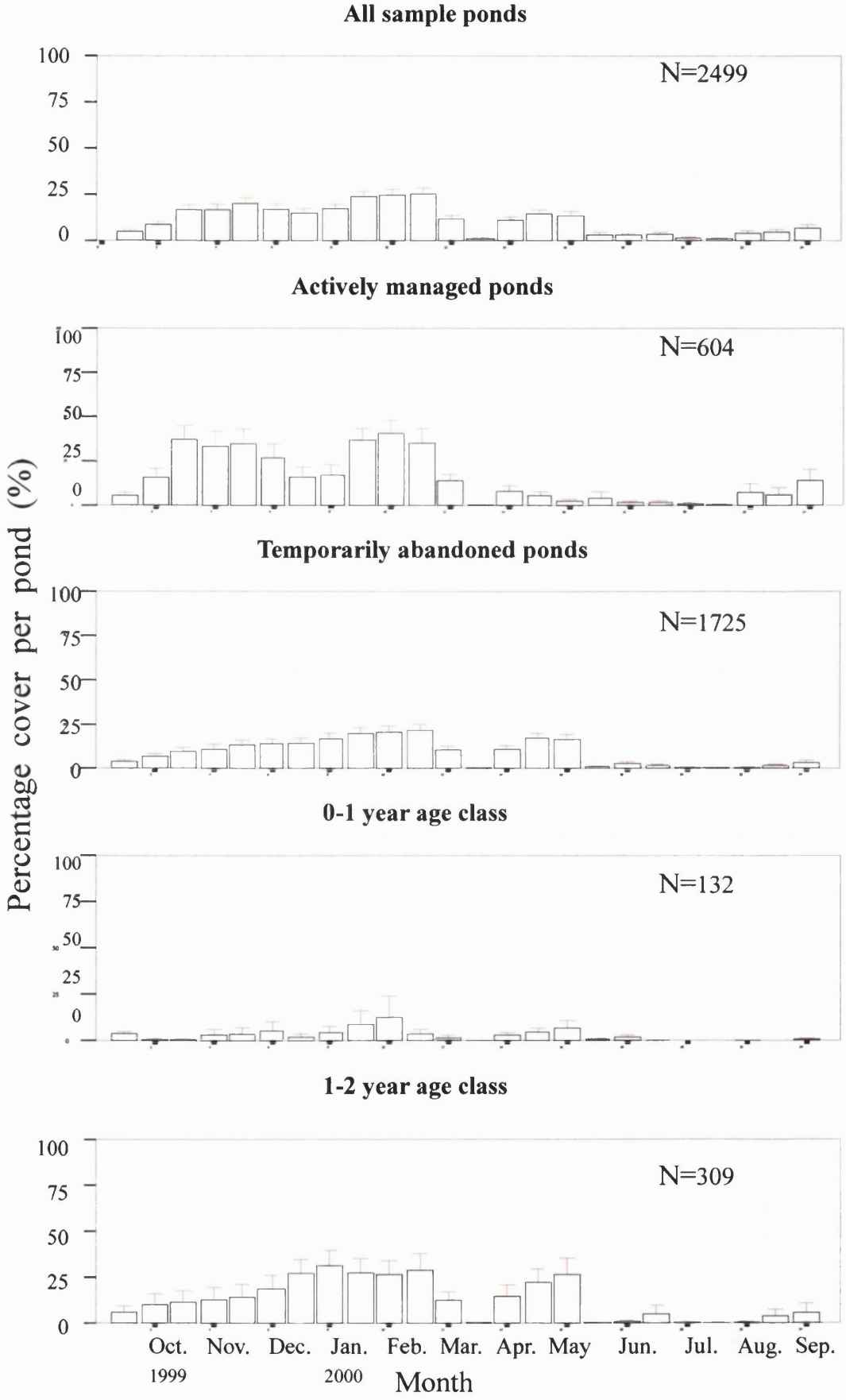


Figure 2.8. The mean extent of exposed mudflats at a 15-day interval in all sample ponds and the ponds of two wetland types and seven abandonment age classes from October 1999 to September 2000. Error bars represent the standard error of the mean.

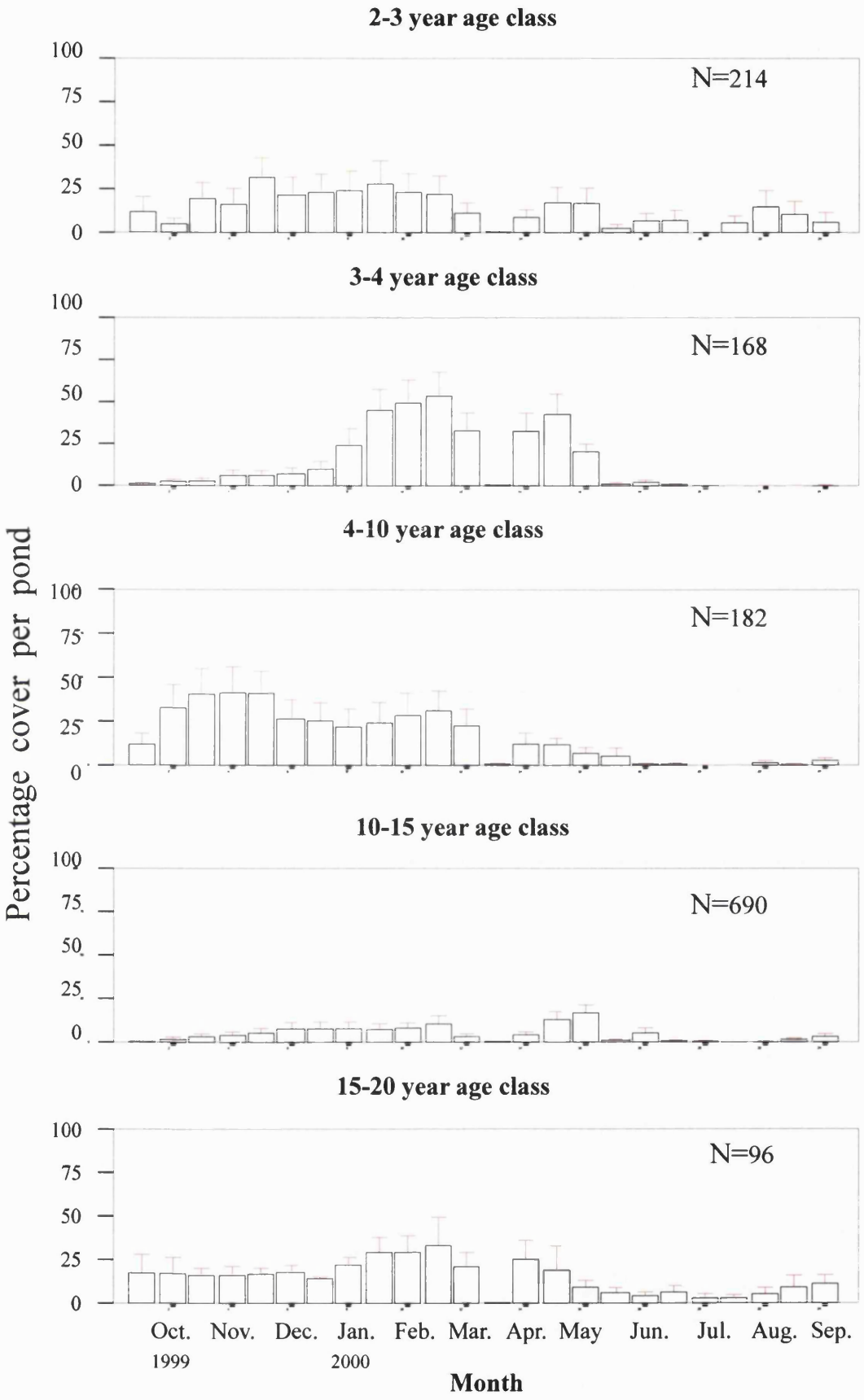


Figure 2.8. (Cont.) The mean extent of exposed mudflats at a 15-day interval in all sample ponds and the ponds of two wetland types and seven abandonment age classes from October 1999 to September 2000. Error bars represent the standard error of the mean.

The extent of exposed mudflats shows a generally reciprocal annual pattern to that of the >30 cm water depth zone (Figures 2.7 and 2.8). Regarding the variation within wetland types, the extent of exposed mudflats in the temporarily abandoned ponds (T.P.) was generally larger than that in the actively managed ponds (A.P.) although the oscillation patterns in the 15-day-interval measurements of these two wetland types are similar to each other (**mean exposed mudflats**: A.P., 0.44 ha / pond, T.P., 0.16 ha / pond; independent samples t-test between A.P. and T.P.: t_{2327}=7.29, p=0.000**). In addition, the ponds of all age classes either completely or almost completely lost the extent of exposed mudflats during the last four months of the study (from June to September, 2000). The oldest ponds were the only exception where some exposed mudflats still remained during the last four months of the study (Figure 2.9).

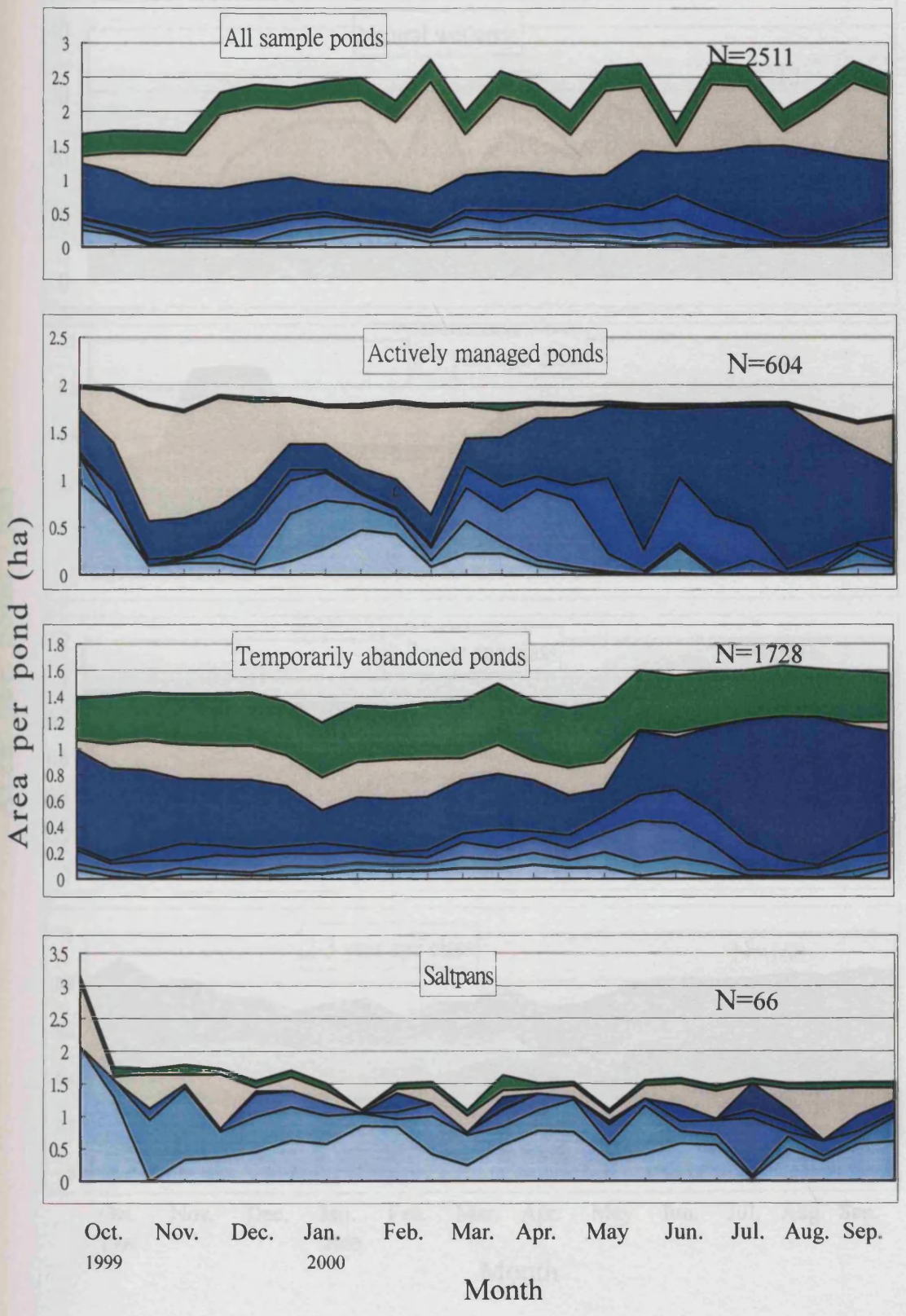


Figure 2.9. The mean extent of five water depth zones at a 15-day interval in all sample ponds and the ponds of four habitat types and seven abandonment age classes from October 1999 to September 2000 (total vegetation, exposed mudflats, >30 cm water depth zone, 20-30 cm water depth zone, 10-20 cm water depth zone, 5-10 cm water depth zone, 0-5 cm water depth zone).

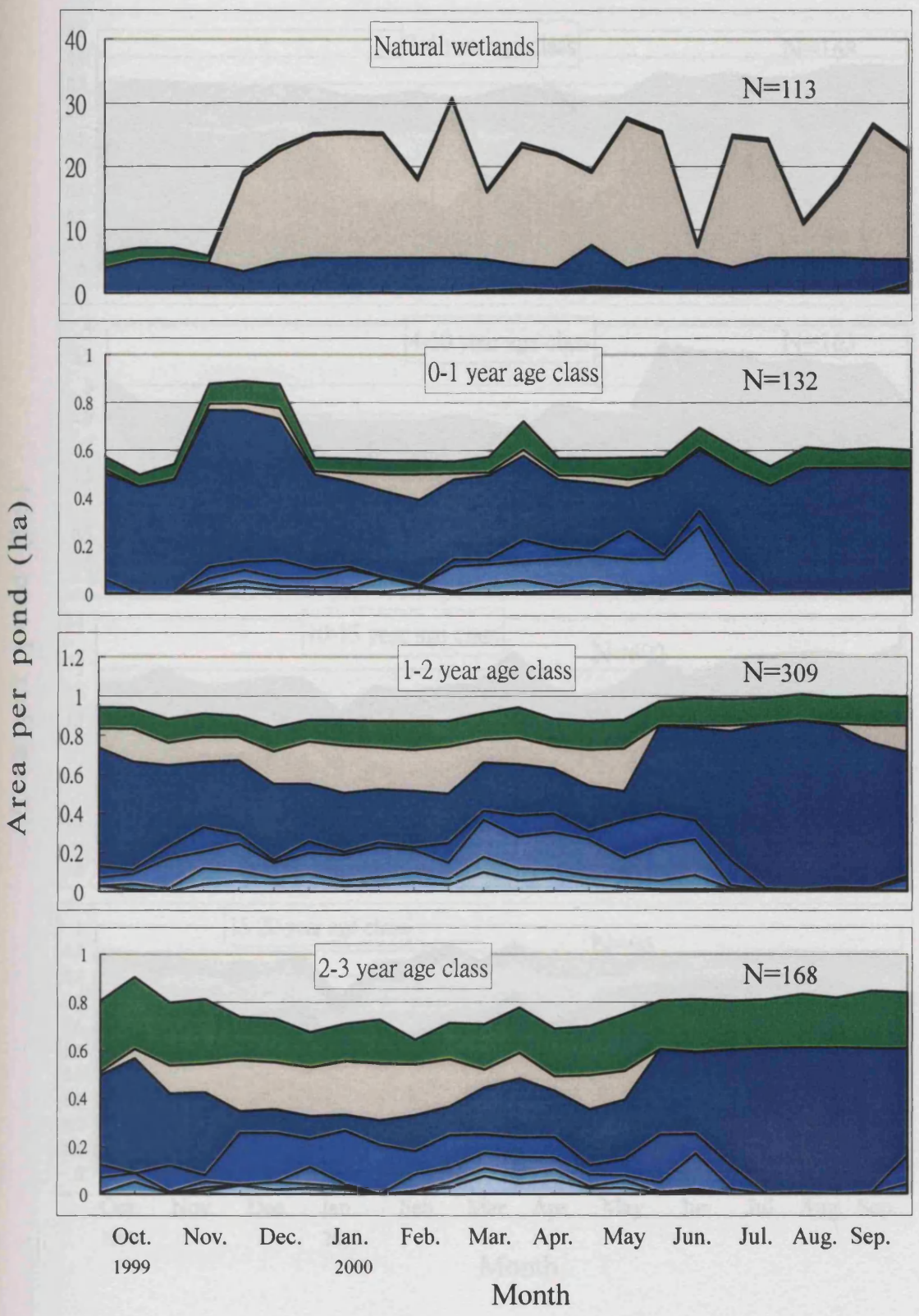


Figure 2.9. (Cont.) The mean extent of five water depth zones at a 15-day interval in all sample ponds and the ponds of four habitat types and seven abandonment age classes from October 1999 to September 2000 (total vegetation, exposed mudflats, >30 cm water depth zone, 20-30 cm water depth zone, 10-20 cm water depth zone, 5-10 cm water depth zone, 0-5 cm water depth zone).

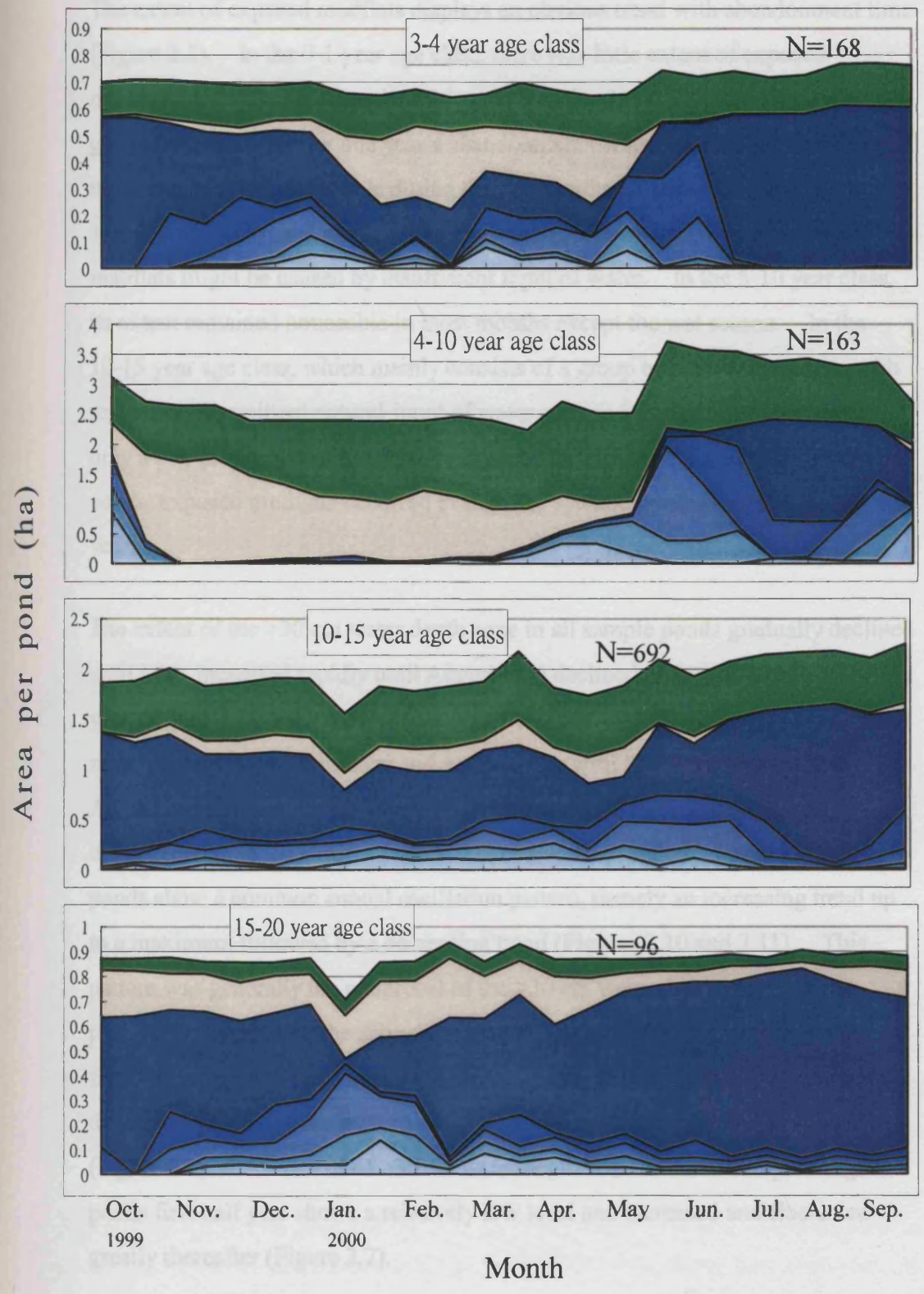


Figure 2.9. (Cont.) The mean extent of five water depth zones at a 15-day interval in all sample ponds and the ponds of four habitat types and seven abandonment age classes from October 1999 to September 2000. (■ total vegetation, □ exposed mudflats, ■ >30 cm water depth zone, ■ 20-30 cm water depth zone, ■ 10-20 cm water depth zone, ■ 5-10 cm water depth zone, □ 0-5 cm water depth zone).

The extent of exposed mudflats displays an obvious trend with abandonment time (Figure 2.8). In the 0-1 year age class, there was little extent of exposed mudflats, probably because plentiful water remained in the ponds. Its extent gradually increased after one year's abandonment till four years old. However, its extent was only noticeable during the dry months of August to February in the 1-2, 2-3 and 3-4 year classes. The gradual increase in the extent of exposed mudflats might be caused by insufficient input of water. In the 5-10 year class, its extent remained noticeable in most months except the wet season. In the 10-15 year age class, which mainly consists of a group of deep-water ponds with regular or intermittent natural-input of water such as seepage of ground water, only a tiny proportion of ponds were exposed throughout the year. In the oldest ponds, exposed mudflats occurred even in the wettest months and throughout the year.

The extent of the >30 cm water depth zone in all sample ponds gradually declined until May, increased rapidly until August then declined to the starting value of the year (Figure 2.7). It indicates that the annual curve of the >30 cm water depth zone displays an asymmetrical and gentle curve with the maximum value in August and the minimum value in May. In contrast, the 15-day-interval measurements in the extent of the two shallowest water depth zones in all sample ponds show a common annual oscillation pattern, namely an increasing trend up to a maximum followed by a decreasing trend (Figures 2.10 and 2.11). This pattern was generally the reciprocal of the >30 cm water depth zone, but not precisely. In general, the actively managed ponds displayed a greater annual fluctuation than the temporarily abandoned ponds in the extent of >30 cm water depth zone, although the pattern of the two wetland types were rather similar (Figure 2.7). The extent of >30 cm water depth zone in the actively managed ponds first half year shows a relatively low level and increased and fluctuated greatly thereafter (Figure 2.7).

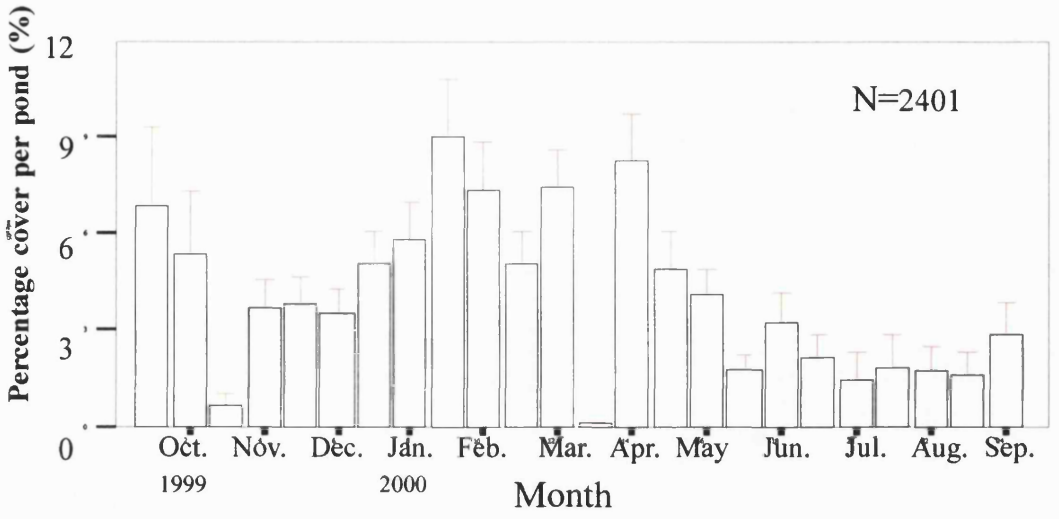


Figure 2.10. The mean extent of the 0-5 cm water depth zone at a 15-day interval in all sample ponds from October 1999 to September 2000. Error bars represent the standard error of the mean.

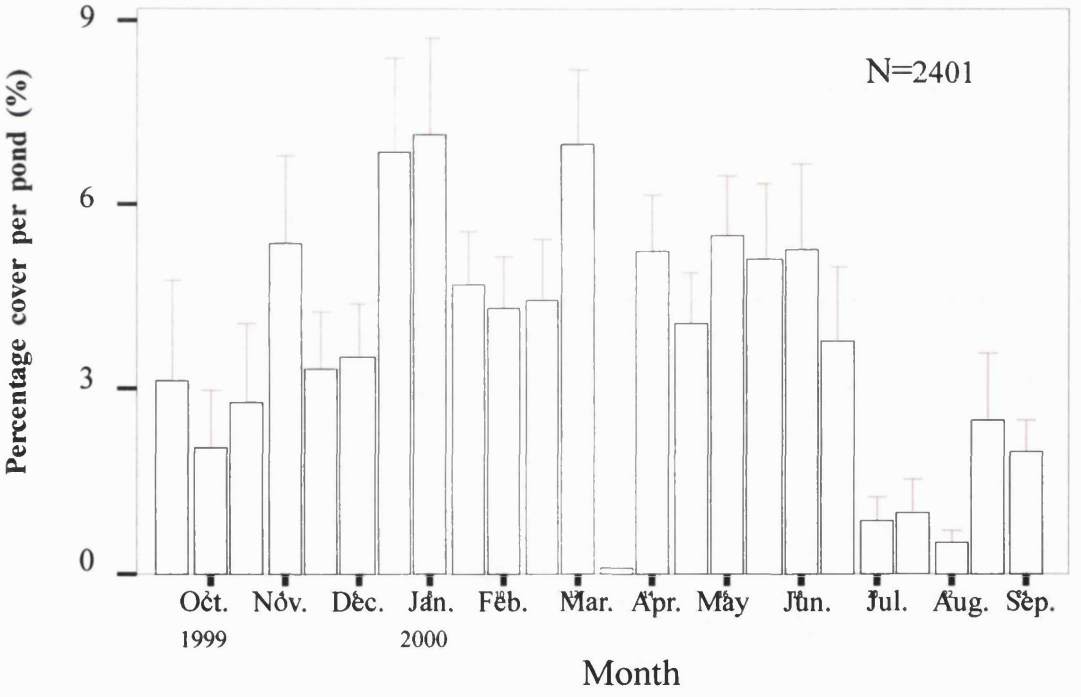


Figure 2.11. The mean extent of the 5-10 cm water depth zone at a 15-day interval in all sample ponds from October 1999 to September 2000. Error bars represent the standard error of the mean.

2.4.1.3. Vegetation

Although vegetation can provide food (Cramp & Simmons, 1977, 1980, 1983; Jefferies, 1988; del Hoyo *et al.*, 1992; Belanger & Bedard, 1994; del Hoyo *et al.*, 1996) and shelter (Cramp & Simmons, 1977, 1980, 1983; del Hoyo *et al.*,

1992, 1996) for waterbirds, dense vegetation may also diminish their ability to detect the presence of predators (Dekker & Ydenberg, 1987; Valone & Lima, 1987; Cresswell, 1996; Ydenberg et al., 2002).

2.4.1.3.1. Cover

The year-round 15-day-interval measurements of the absolute extent in five vegetation types, namely total, shore, wall, emergent and submerged vegetation types, of all sample ponds are presented in Figure 2.12. Amongst these five vegetation types, shore and emergent vegetation types more frequently show a significant annual pattern in the absolute extent of all sample ponds, a particular wetland type or particular age class (Table 2.5, Figures 2.13 & 2.14). These two vegetation types both display a similar oscillation pattern as the >30 cm water depth zone with a slight difference. They rose less rapidly to the starting value of the year after a trough, than the >30 cm water depth zone. In addition, there were variations in the standard deviations of the15-day-interval measurement between shore and emergent vegetation types. The standard deviations of emergent vegetation generally remained low when low coverage of emergent vegetation occurred in all sample ponds, a particular wetland type or particular age class, and vice versa (Figure 2.14). The standard deviations of shore vegetation remained constant throughout the year in all sample ponds or a particular wetland type, but not at a particular age class (Figure 2.13). Two obvious trends in the standard deviations of shore vegetation can be identified. The standard deviations in the 15-20 year age class show a divergent trend toward the starting and the ending of research period of time, while those in the 2-3 and 3-4 year age classes both show an increasing trend toward the centre of the year-round curve of shore vegetation. This indicates that the seasonal variations in the extent of shore vegetation amongst the sample ponds differ between the ponds of these three age classes.

For the variation in vegetation cover among wetland types, the percentage cover of shore vegetation in the temporarily abandoned ponds was greater than that in the active ponds (mean percentage cover of shore vegetation: Active ponds, 48.4%, Temporarily abandoned ponds, 68.5%; independent samples t-test between A.P. and T.P.: $t_{2190}=11.77$, $p=0.000^{**}$). This finding indicates that denser shore vegetation coverage occurs in the temporarily abandoned

ponds than in the actively managed ponds.

Table 2.5. Summary of one-way ANOVAs of the extent of shore and emergent vegetation types with time for all sample ponds, four wetland types and seven age classes from October 1999 to September 2000.

Vegetative attribute	Wetland type/age class	Degrees of Freedom	F-value	Significance
Shore vegetation	All sample wetlands	2,370	12.99	0.000**
	Actively managed ponds	592	5.96	0.000**
	Temporarily abandoned ponds	1,598	12.64	0.000**
	Saltpans	65	0.14	1.0
	Natural wetlands	112	0.29	0.999
	0-1 year age class	131	0.54	0.957
	1-2 year age class	291	5.41	0.000**
	2-3 year age class	152	2.22	0.003**
	3-4 year age class	160	3.88	0. 000**
	4-10 year age class	96	5.78	0.000**
	10-15 year age class	668	2.83	0.000**
	15-20 year age class	94	2.02	0.013*
Emergent vegetation	All sample wetlands	2,366	2.17	0.001**
	Actively managed ponds	589	1.42	0.093
	Temporarily abandoned ponds	1,598	2.47	0.000**
	Saltpans	65	1.65	0.079
	Natural wetlands	111	0.46	0.982
	0-1 year age class	130	1.03	0.436
	1-2 year age class	289	3.01	0.000**
	2-3 year age class	152	0.47	0.982
	3-4 year age class	160	2.36	0.001**
	4-10 year age class	96	1.29	0.207
	10-15 year age class	671	1.02	0.437
	15-20 year age class	94	1.26	0.227

P.S.: * means that p-value is no more than 5% and ** means that p-value is no more than 1%.

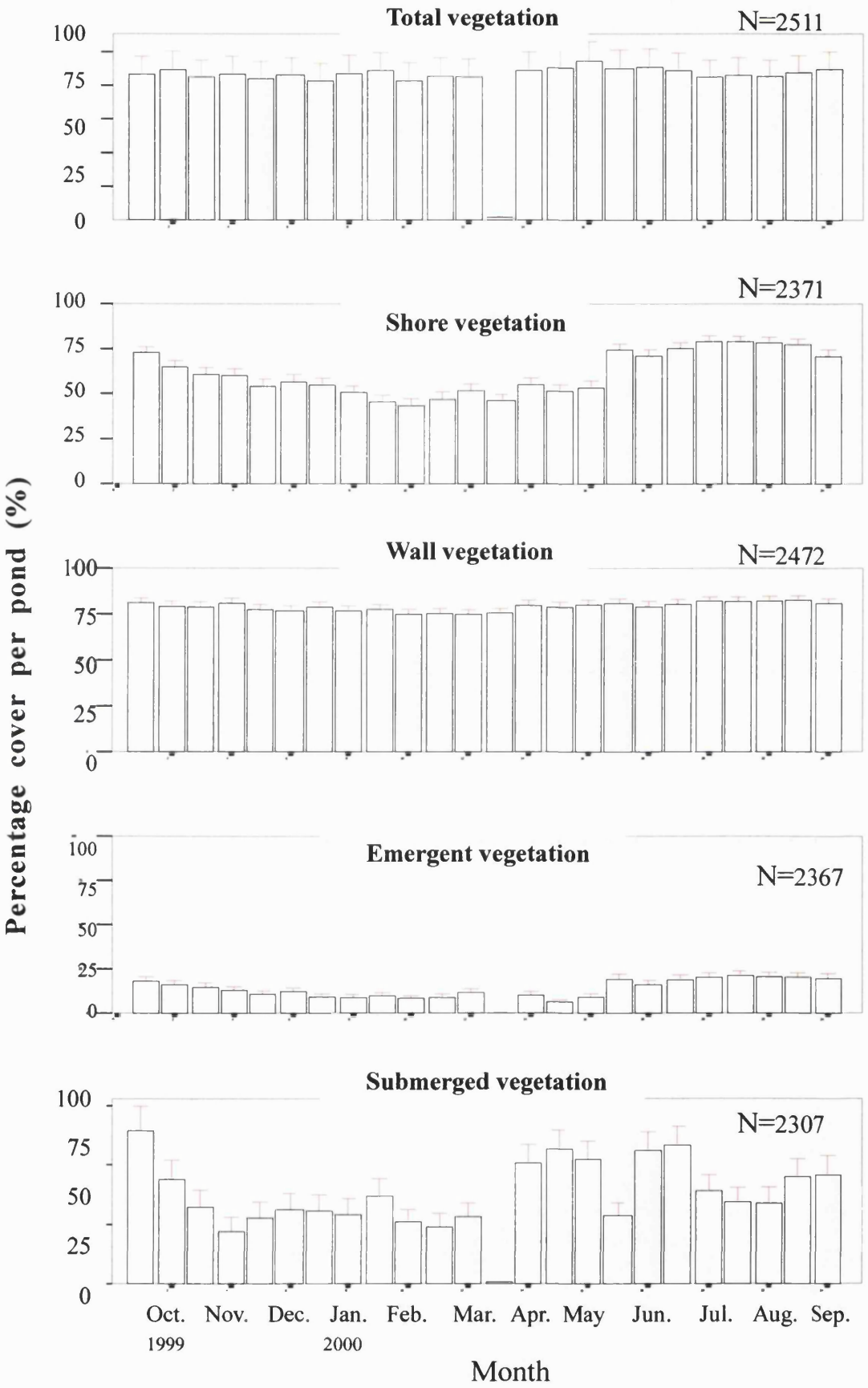


Figure 2.12. The mean cover of the five vegetation types at a 15-day interval in all sample ponds from October 1999 to September 2000. Error bars represent the standard error of the mean.

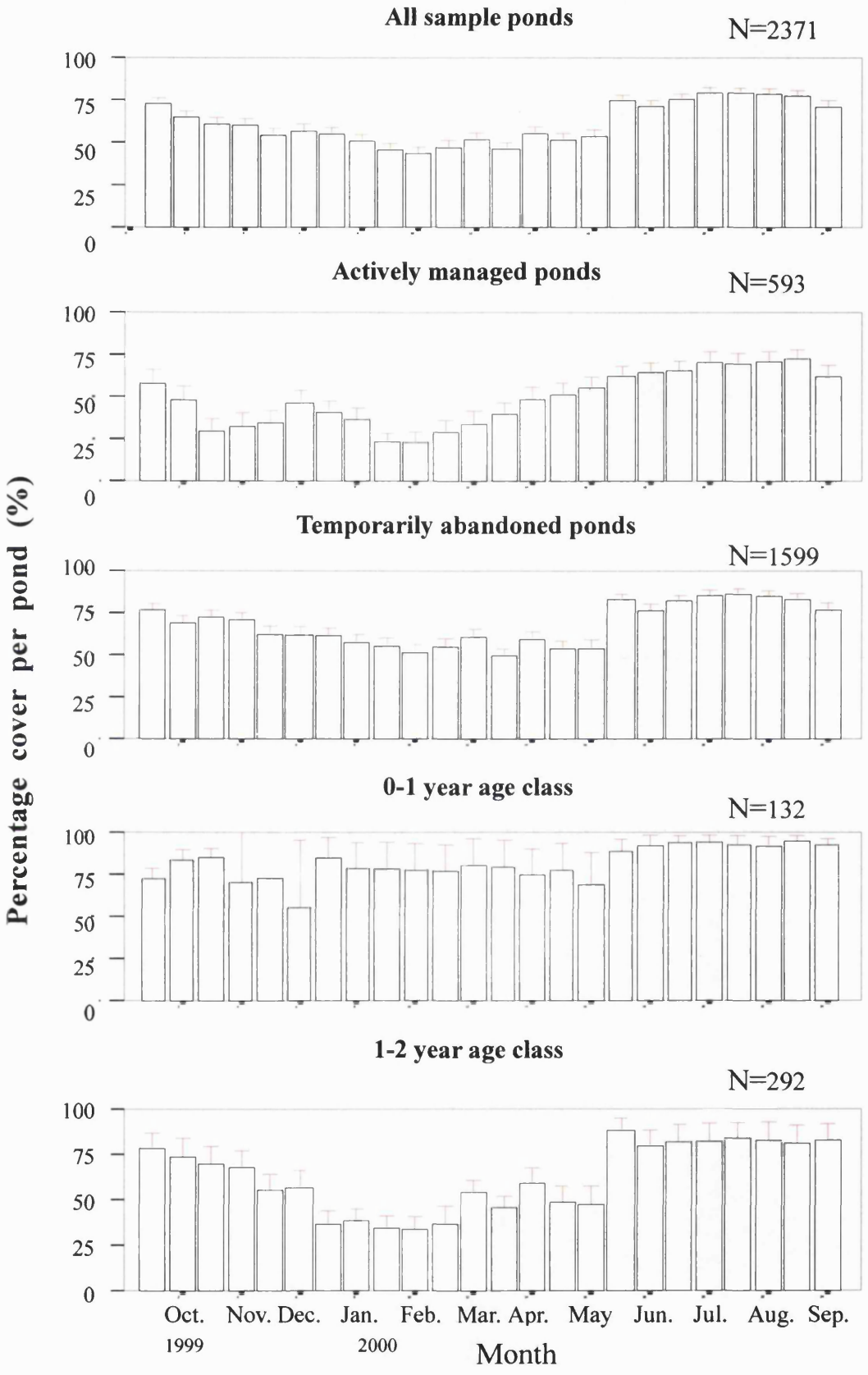


Figure 2.13. The mean cover of shore vegetation at a 15-day interval in all sample ponds and the ponds of two wetland types and seven abandonment age classes from October 1999 to September 2000. Error bars represent the standard error of the mean.

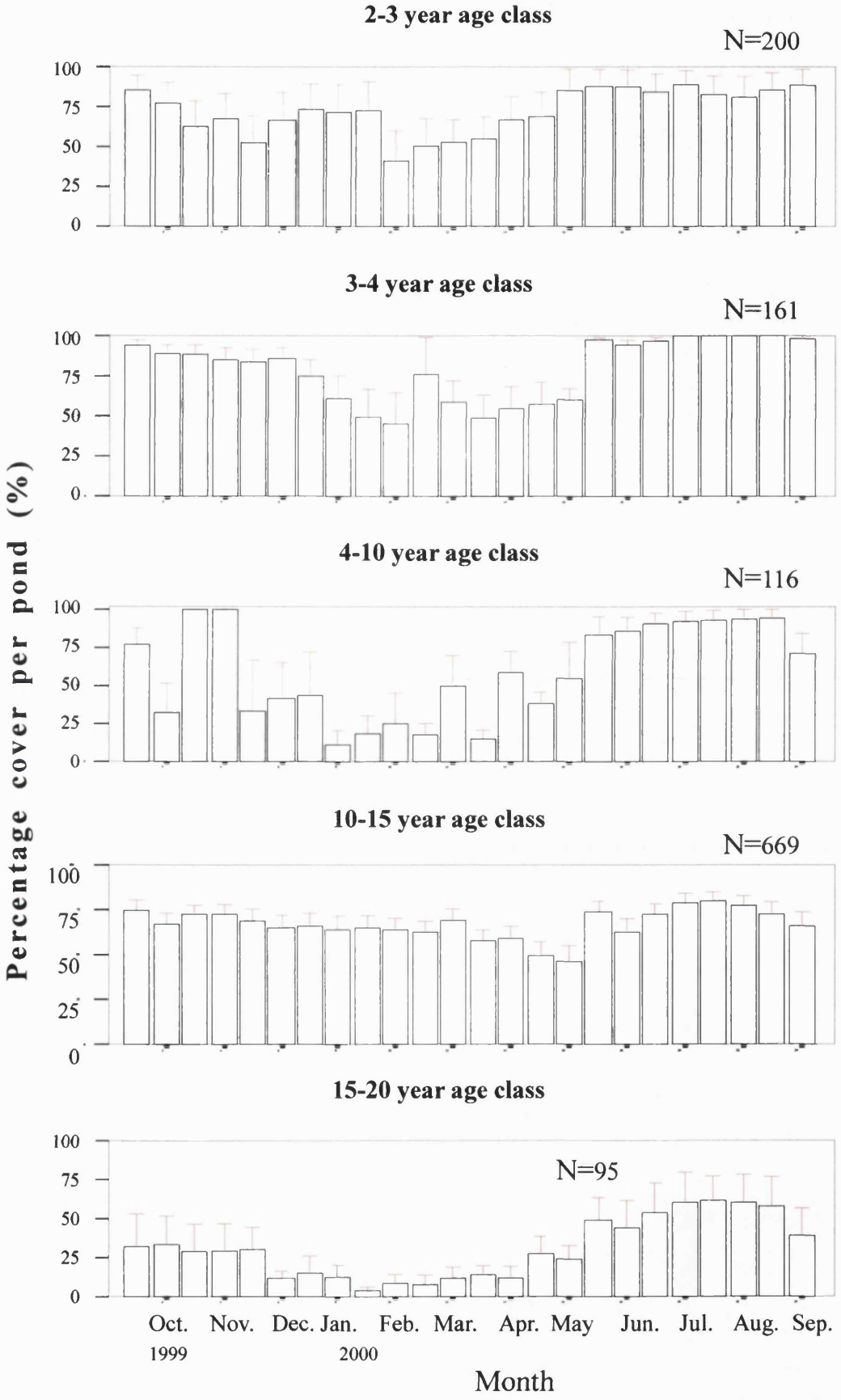


Figure 2.13. (Cont.) The mean cover of shore vegetation at a 15-day interval in all sample ponds and the ponds of two wetland types and seven abandonment age classes from October 1999 to September 2000. Error bars represent the standard error of the mean.

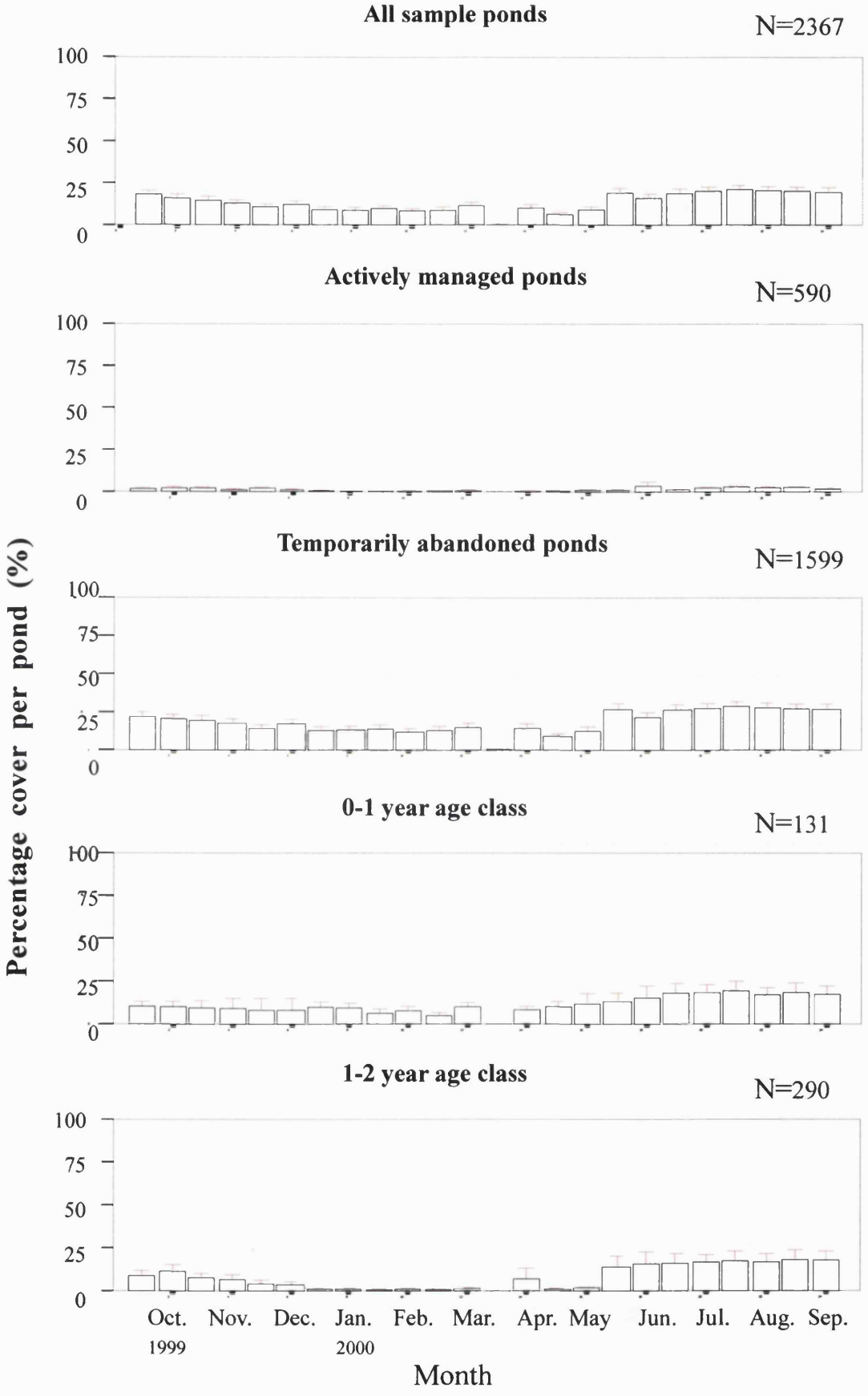


Figure 2.14. The mean cover of emergent vegetation at a 15-day interval in all sample ponds and the ponds of two wetland types and seven abandonment age classes from October 1999 to September 2000. Error bars represent the standard error of the mean.

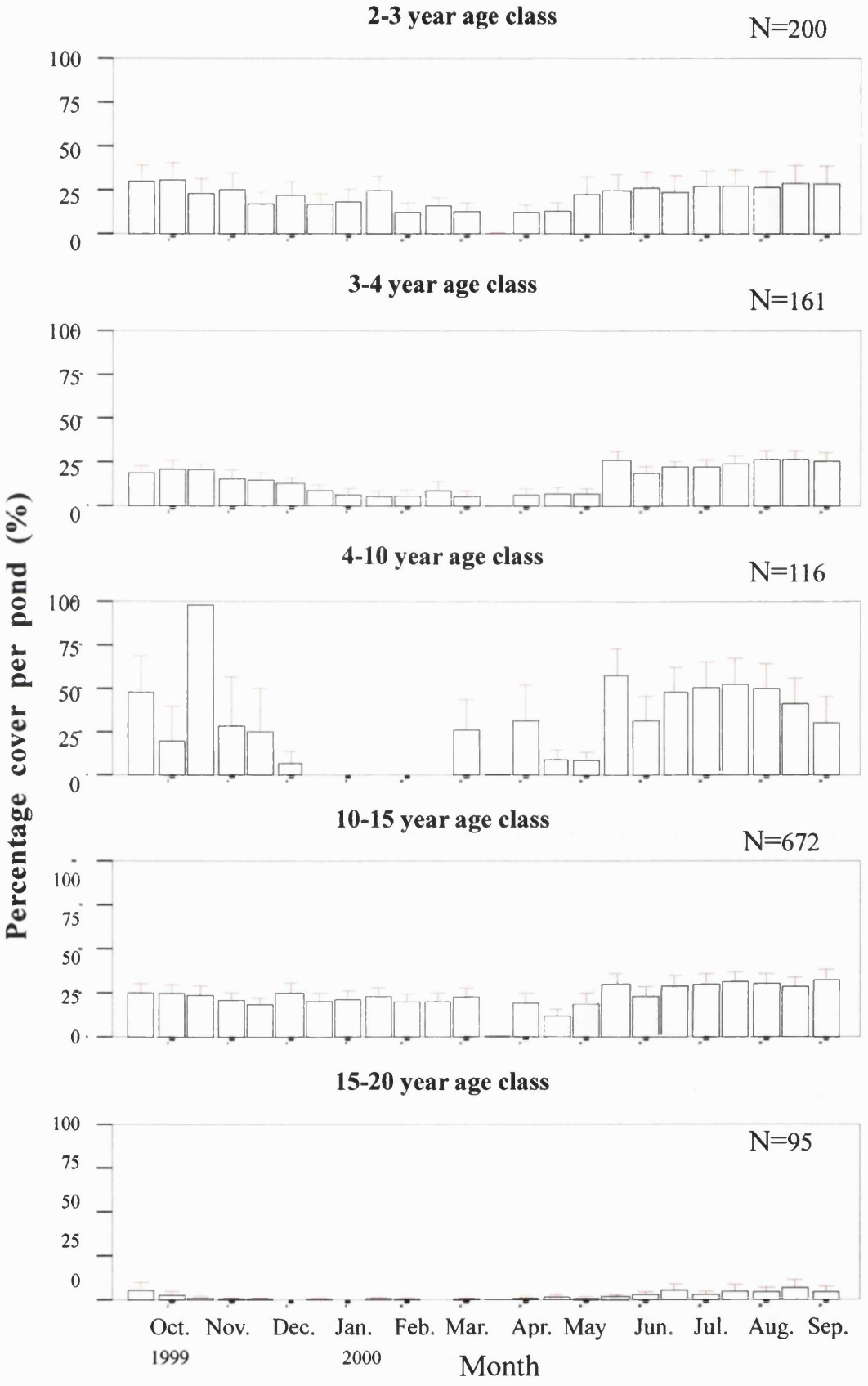


Figure 2.14. (Cont.) The mean cover of emergent vegetation at a 15-day interval in all sample ponds and the ponds of two wetland types and seven abandonment age classes from October 1999 to September 2000. Error bars represent the standard error

of the mean.

2.4.1.3.2. Height

Collecting data for vegetation height provides a record of vegetation growth and could be used as basic information for future studies. Eight vegetation height-related measurements were taken, namely the absolute maximum height (A.H.) and the mean height (M.H.) of total, shore, wall and emergent vegetation types.

Just like the expectation regarding the vegetation growth after the abandonment of aquaculture ponds, the A.H. of most vegetation types, including total, shore and emergent vegetation types, displays an increasing trend over time. The A.H. of total vegetation in all sample ponds shows an obvious increasing trend with time during the year-round research period of time (df=2493, F=3.60, p=0.000** , Figure 2.15). This indicates that vegetation grows higher with time during the study period and might attribute to the continuous growing season in the study area. As to the variation within wetland types, the mean A.H. of total vegetation in the actively managed ponds was much smaller than that in the temporarily abandoned ponds (Table 2.6 and Figure 2.16). This indicates that the height of the vegetation in the temporarily abandoned ponds was greater than in the actively managed ponds.

Table 2.6. Summary of the means of the absolute maximum height (A.H.) of total, shore and emergent vegetation types at both active ponds (A.P.) and temporarily abandoned ponds (T.P.), and their independent samples T-tests between A.P. and T.P from October 1999 to September 2000.

Vegetative attribute	Mean		Degrees of Freedom	T-value	Significance
	Active ponds	Temporarily abandoned ponds			
A.H. of total vegetation	32.1(N=601)	117.9(N=1716)	2,315	27.42	0.000**
A.H. of shore vegetation	32.1(N=584)	117.9(N=1561)	2,143	22.02	0.000**
A.H. of emergent vegetation	32.1(N=589)	117.9(N=1585)	2,172	14.52	0.000**

P.S.: ** means that p-value is no more than 1%.

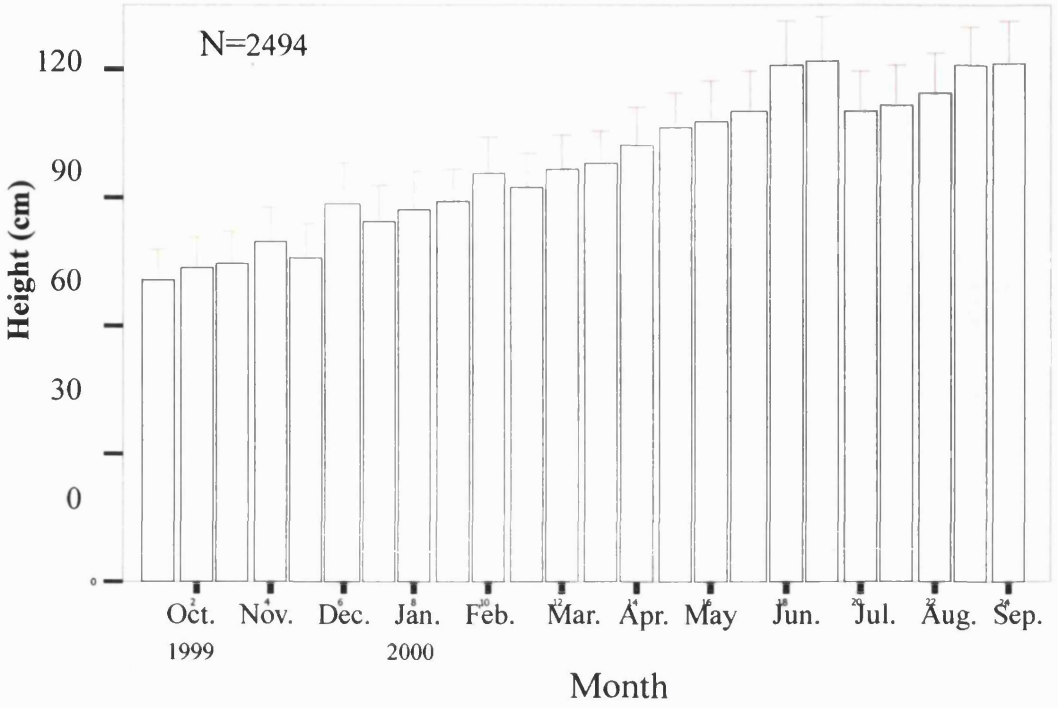


Figure 2.15. The mean absolute maximum height (A.H.) of total vegetation at a 15-day interval in all sample ponds from October 1999 to September 2000. Error bars represent the standard error of the mean.

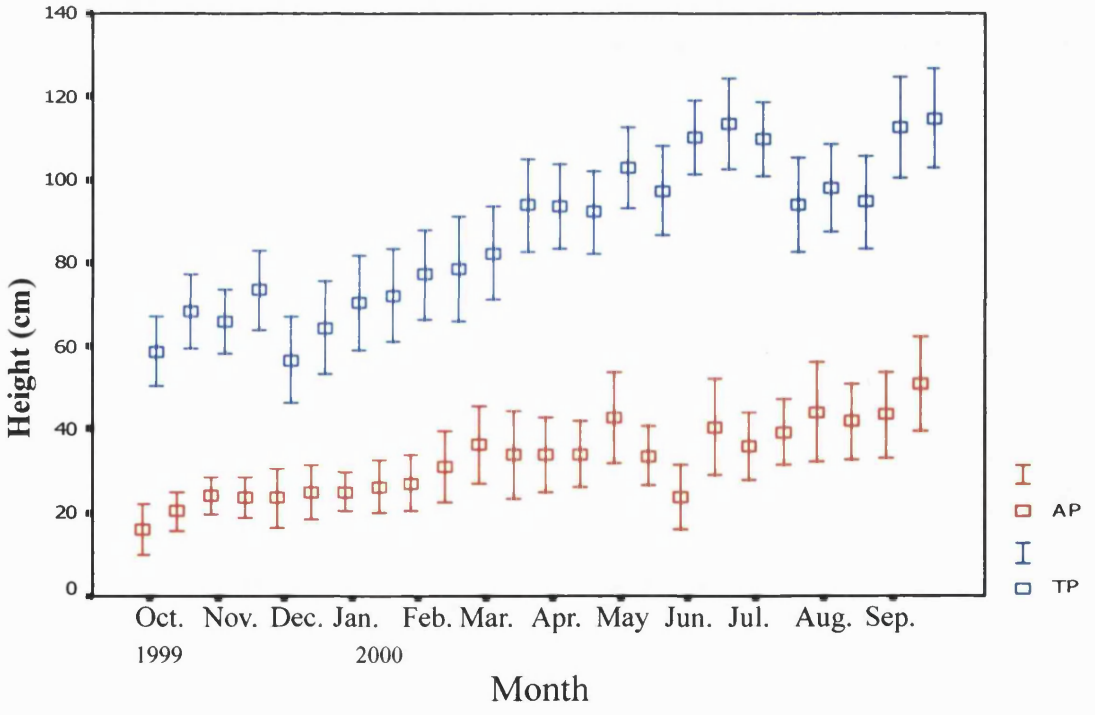


Figure 2.16. The mean absolute maximum height (A.H.) of total vegetation at a 15-day interval in the actively managed ponds (AP, N=601) and temporarily abandoned ponds (TP, N=1716) from October 1999 to September 2000. Error bars represent the standard error of the mean.

The A.H. of emergent and shore vegetation types both display a significant increase, but change more indirectly than the A.H. of total vegetation and display a two-staged increase that generally remained constant until May and then abruptly attained a higher level of A.H. and maintained for four months (Table 2.7 and Figure 2.17). For the variation within wetland types, only actively managed ponds and temporarily abandoned ponds show significant variations in the A.H. of emergent and shore vegetation types (Table 2.7). The mean measurements of A.H. of both emergent and shore vegetation types in the actively managed ponds were shorter than that in the temporarily abandoned ponds (Table 2.6). The 15-day-interval measurements of A.H. of emergent and shore vegetation types in the temporarily abandoned ponds both show two-staged increase similar to that in all sample ponds, while those in the active aquaculture ponds shows a much smoother and continuous change from trough to peak (Figures 2.18 and 2.19). In addition, the standard deviations of emergent vegetation type remained constant in the temporarily abandoned ponds. In contrast, that in the actively managed ponds shows a high value when the 15-day-interval measurement was high, and vice versa.

Table 2.7. Summary of one-way ANOVAs of the absolute maximum height (A.H.) of emergent and shore vegetation types with time for all sample ponds, actively managed ponds and temporarily abandoned ponds from October 1999 to September 2000.

Vegetative attribute	Wetland type	Degrees of Freedom	F-value	Significance
A.H. of emergent vegetation	All sample wetlands	2,318	6.36	0.000**
	Actively managed ponds	583	3.96	0.000**
	Temporarily abandoned ponds	1,560	7.84	0.000**
A.H. of shore vegetation	All sample wetlands	2,351	3.06	0.000**
	Actively managed ponds	588	6.34	0.000**
	Temporarily abandoned ponds	1,584	4.31	0.000**

P.S.: ** means that p-value is no more than 1%.

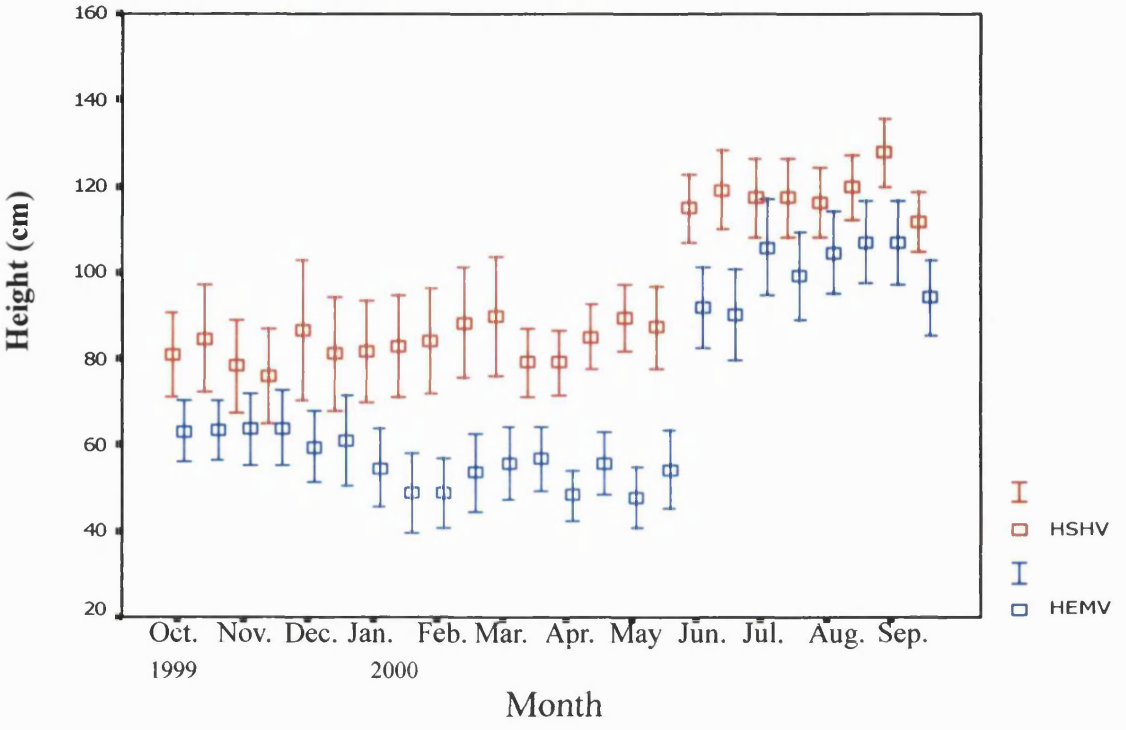


Figure 2.17. The mean absolute maximum height (A.H.) of shore (HSHV, N=2352) and emergent (HEMV, N=2319) vegetation type at a 15-day interval in all sample ponds from October 1999 to September 2000. Error bars represent the standard error of the mean.

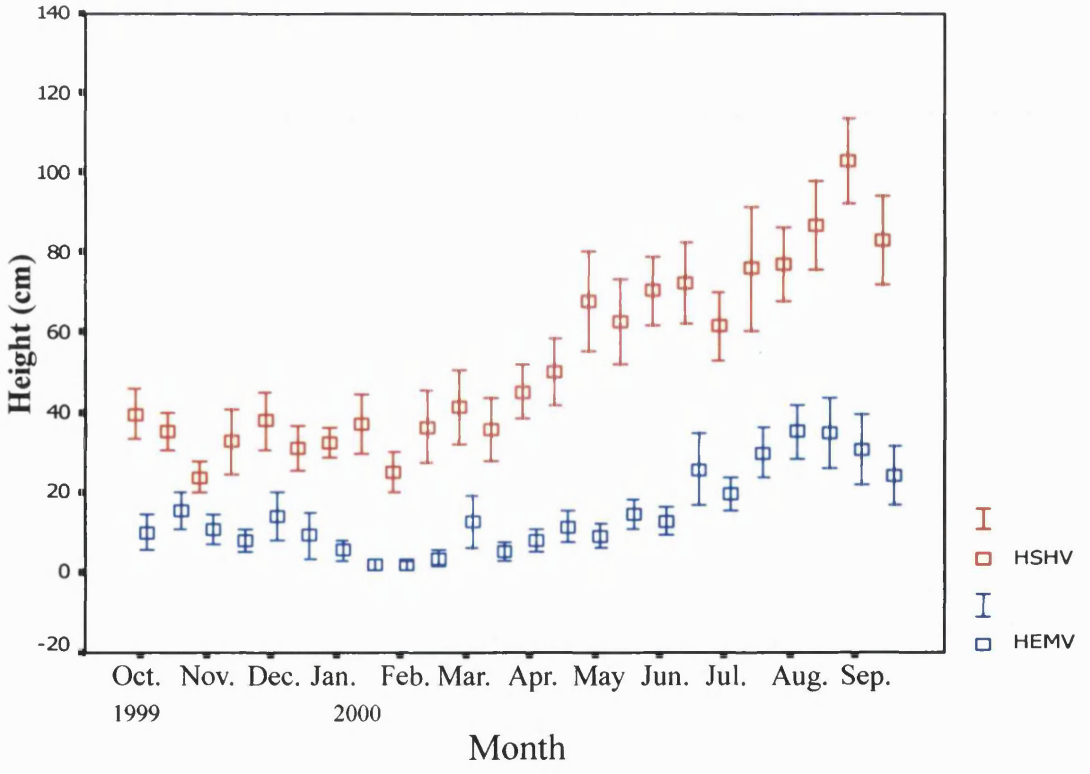


Figure 2.18. The mean absolute maximum height (A.H.) of shore (HSHV, N=1585) and emergent (HEMV, N=1561) vegetation type at a 15-day interval in the temporarily abandoned ponds from October 1999 to September 2000. Error bars represent the standard error of the mean.

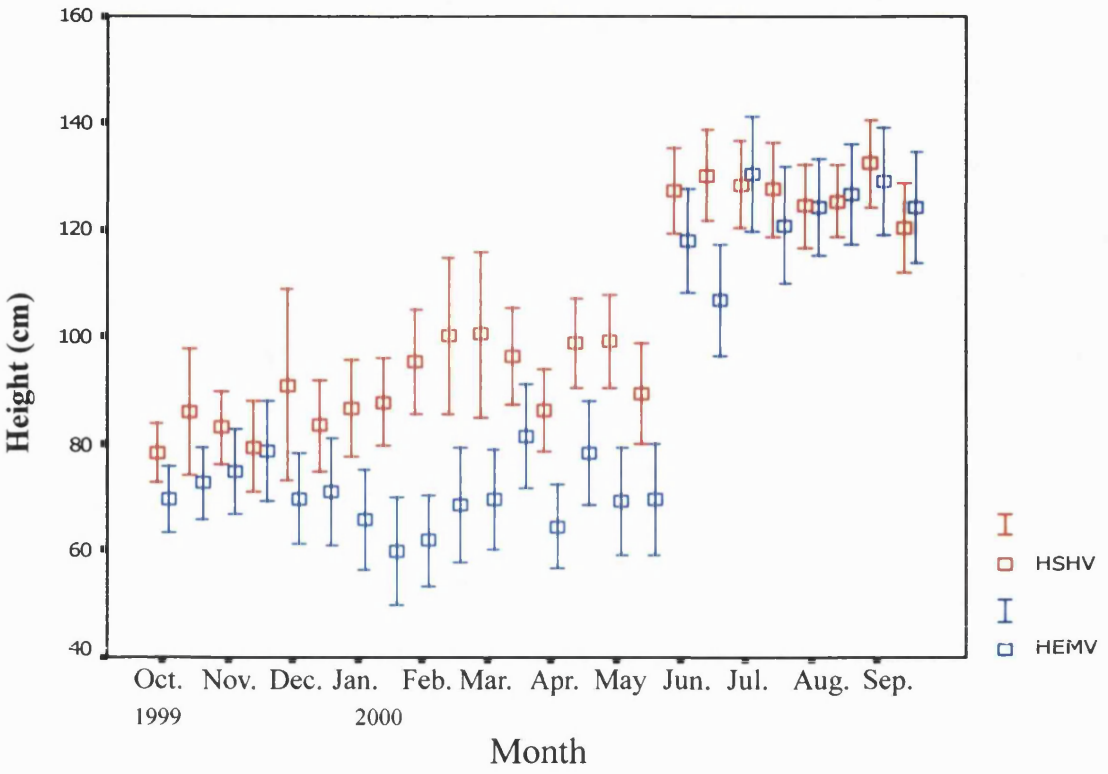


Figure 2.19. The mean absolute maximum height (A.H.) of shore (HSHV, N=589) and emergent (HEMV, N=584) vegetation type at a 15-day interval in the actively managed ponds from October 1999 to September 2000. Error bars represent the standard error of the mean.

2.4.2. Chronosequence

Seven age classes of temporarily abandoned ponds were defined (0-1, 1-2, 2-3, 3-4, 4-10, 10-15 and 15-20 year age classes). There are three reasons for adopting this uneven-interval classification. Based on the results of preliminary study, rapid changes in the physical environment appear to occur mostly in the early abandonment stages. In addition, accurate information regarding abandonment time was more difficult to obtain for the ponds of older categories, except for the 10-15 age class. The range in the abandonment time for a category of ponds was consequently larger when older ponds were grouped. For the 10-15 age class, a large group of government-owned ponds with homogenous physical environment were abandoned at the same time. In spite of the uneven separation of sample ponds within abandonment categories, the sample sizes in each category are still uneven and caused some difficulty in the comparison between categories. In total, 73 temporarily abandoned ponds were categorized into seven age classes, 0-1 (N=6), 1-2 (N=13), 2-3 (N=7), 3-4 (N=7), 4-10 (N=7), 10-15 (N=29) and 15-20 (N=4) year age classes.

Although 34 characteristic attributes of sample wetlands were recorded periodically throughout the year, only a few environmental variables of sample ponds show regular trend with abandonment time, although every recorded environmental variable of sample ponds shows significant variations in the one-way ANOVA. These variables with regular trends include water chemistry-related variables: salinity (Figure 2.20) and turbidity (Figure 2.21) and vegetation-related variables: cover of shore vegetation (Figure 2.22) and A.H. of total and emergent vegetation types and M.H. of total vegetation type (Table 2.8, **total vegetation:** A.H., Figure 2.23, M.H. , Figure 2.24; **emergent vegetation**: A.H., Figure 2.25). Salinity generally displays an increasing trend with abandonment time while turbidity generally shows a decreasing trend (Figures 2.20 and 2.21). These may indicate that aquaculture ponds became increasingly saline and clearer in water quality after being abandoned. The trends of A.H. of total and emergent vegetation types and M.H. of emergent vegetation type generally increase with time (Table 2.8, Figure 2.23, 2.24 and 2.25). This relationship might indicate that vegetation in the sample ponds grows significantly taller with abandonment time. However, the measurements at the 0-1 and 15-20 age classes are different from those of other age classes. This might imply that other factors have more influence on their changes than abandonment time.

Table 2.8. Summary of one-way ANOVAs and linear regression analyses of several physical or vegetative attributes with abandonment time for all sample ponds.

Physical/Vegetative attribute	Degrees of Freedom	F-value	Significance	Gradient coefficient	Intercept	Significance
Salinity	1,620	27.26	0.000**	0.60	10.42	0.000**
Turbidity	1,434	3.84	0.000**	-0.65	26.72	0.000**
Cover of shore vegetation	1,598	28.10	0.000**	-1.05	78.22	0.000**
M.H. of total vegetation	2,495	50.44.	0.000**	2.81	45.13	0.000**
A.H. of total vegetation	2,493	76.20	0.000**	2.99	90.39	0.000**
A.H. of emergent vegetation	2,318	46.32	0.000**	1.95	70.96	0.000**

P.S.: ** means that p-value is no more than 1%.

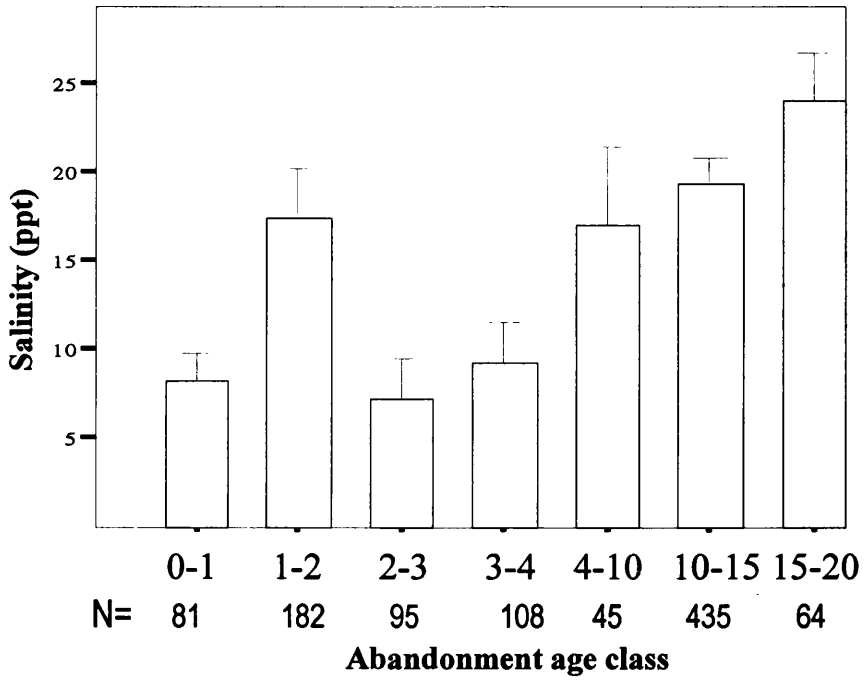


Figure 2.20. Chronosequence of salinity in the temporarily abandoned aquaculture ponds. Error bars represent the standard error of the mean.

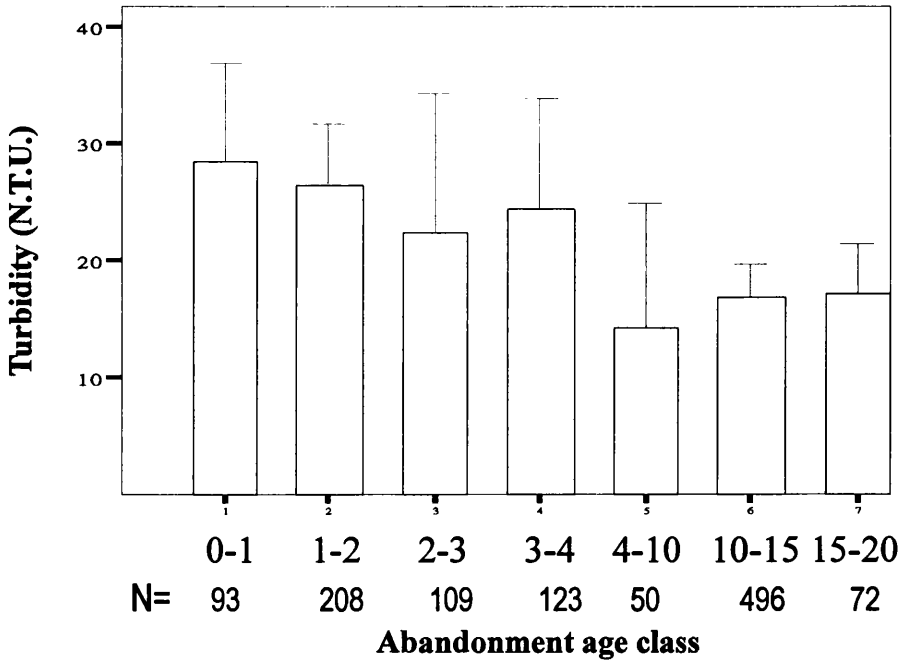


Figure 2.21. Chronosequence of turbidity in the temporarily abandoned aquaculture ponds. Error bars represent the standard error of the mean.

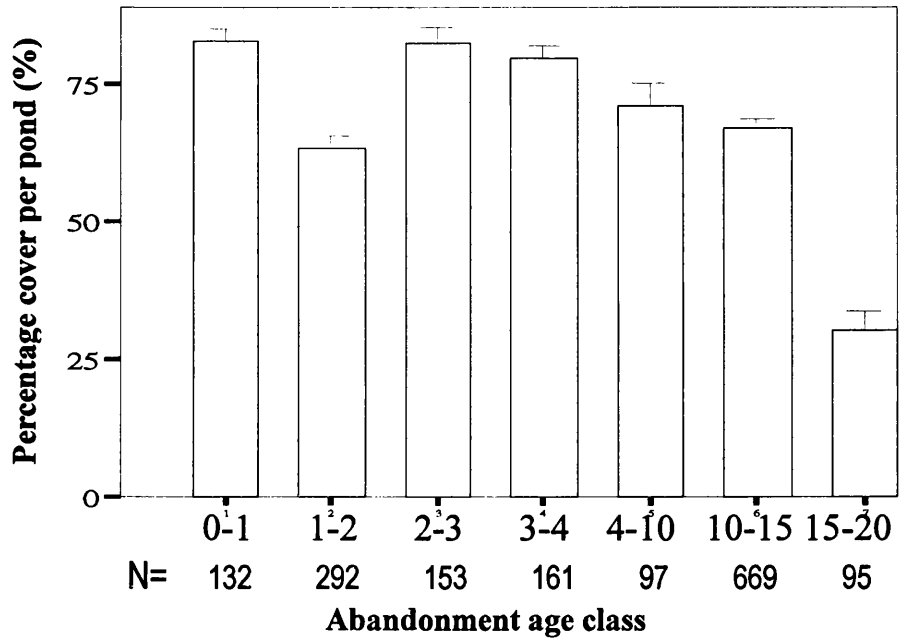


Figure 2.22. Chronosequence of the mean cover of shore vegetation in the temporarily abandoned aquaculture ponds. Error bars represent the standard error of the mean.

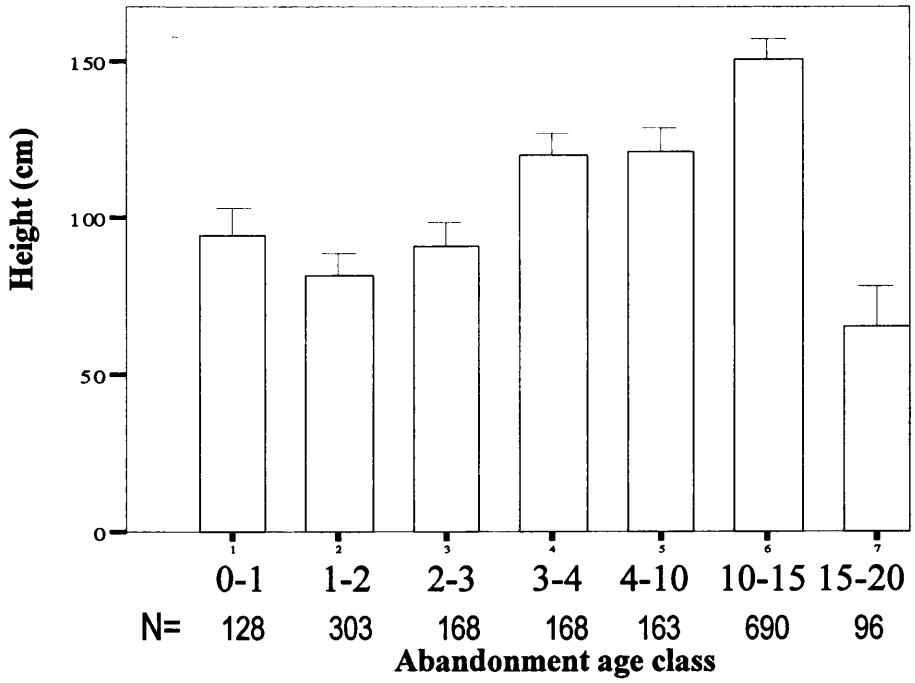


Figure 2.23. Chronosequence of the absolute maximum height (A.H.) of total vegetation in the temporarily abandoned aquaculture ponds. Error bars represent the standard error of the mean.

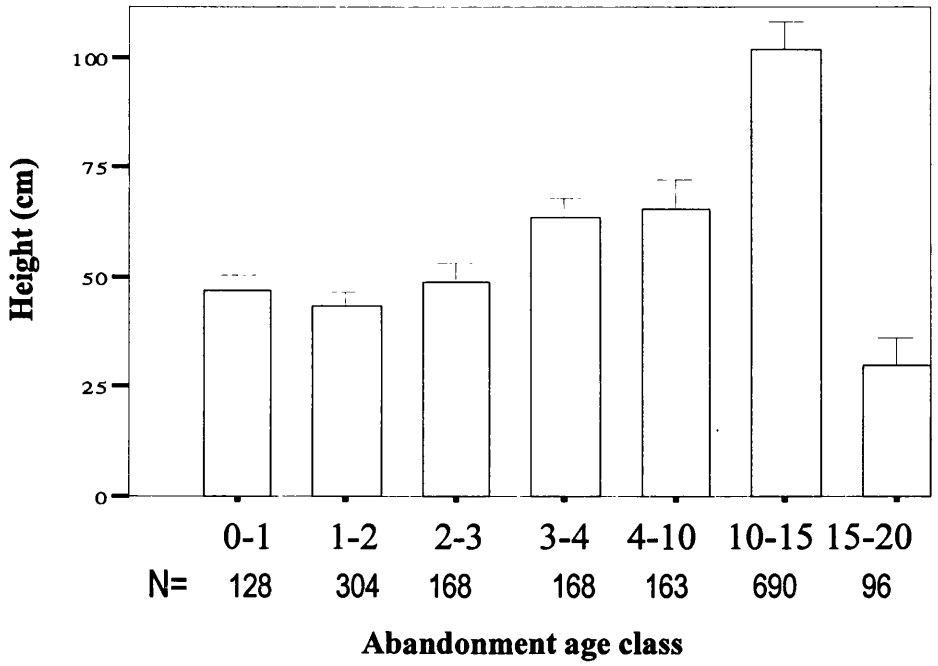


Figure 2.24. Chronosequence of the mean height (M.H.) of total vegetation in the temporarily abandoned aquaculture ponds. Error bars represent the standard error of the mean.

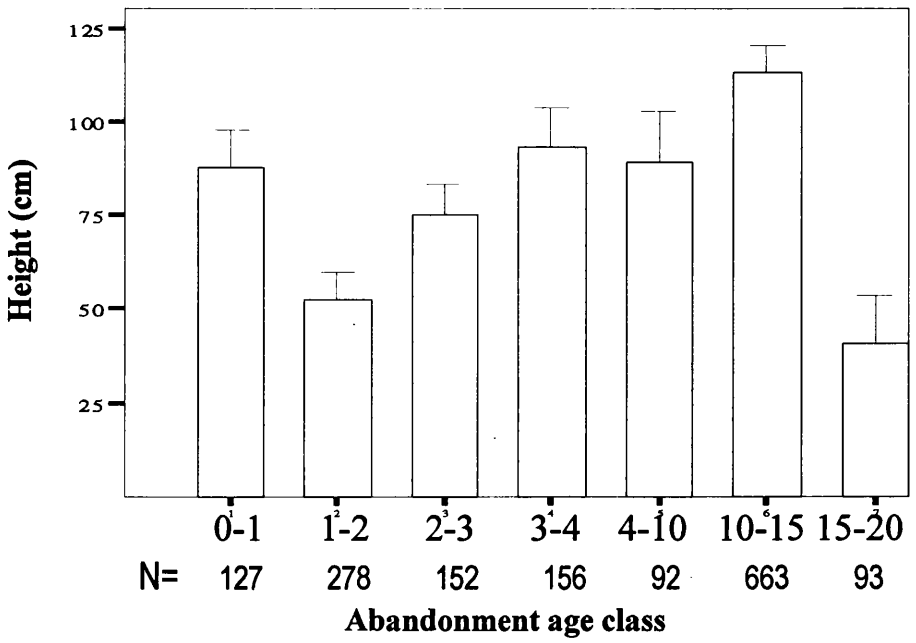


Figure 2.25. Chronosequence of the absolute maximum height (A.H.) of emergent vegetation type in the temporarily abandoned aquaculture ponds. Error bars represent the standard error of the mean.

2.5. Discussion

Several characteristic attributes of sample wetlands showed significant pattern in the year-round observations and chronosequences. These attributes were discussed under five headings, namely water chemistry, the extent of five water depth zones, exposed mudflats and total vegetation, vegetation cover, vegetation height and chronosequence.

Water chemistry

Hydrology and water quality could determine the species composition and abundance of vegetation in a wetland (Clewell, 1997), and consequently could play an important role in deciding the abundance of the principal prey species for waterbirds such as aquatic invertebrates, phytoplankton and macrophytes (Cramp & Simmons, 1977, 1980, 1983; del Hoyo *et al.*, 1992, 1996). Of the four water quality-related attributes under observation, pH and salinity were the variables that most frequently showed significant changes both in the year-round 15-day-interval measurements between wetland types or age classes and in the chronsequences (Table 2.3, Figures 2.4, 2.5 and 2.20). Their significant annual trends fit the typical annual oscillation pattern, in which the initial and final values of the year were similar to each other. Rainfall might be the causal factor behind these fluctuations as the annual precipitation pattern paralleled the changes in pH and salinity. The rainfall in the study area mainly comes during a period of tropical storms known as typhoons. In fact, approximately 50% to 80% of annual rainfall (78.4% in 2000) comes during the typhoon season from June to August. After the typhoon season, the monthly rainfall is relatively low (Figure 2.1). The amount of water in the sample ponds gradually decreased due to the declining input of rainfall. Salinity and pH consequently increased. Because most ponds were already basic, they became even more alkaline. However, rainfall is really acidic (5.7 to 5.8 for the study area, from October 1999 to September 2000, Central Weather Bureau in ROC, 2001) and can therefore slow down the increase in pH. When the heavy monsoon rain arrived in April and May, aquaculture ponds started to show a reverse trend and responded with a sudden drop in salinity and pH. In the typhoon season, the large quantity of water input caused a further decline in salinity and alkalinity.

The extent of five water depth zones, exposed mudflats and total vegetation

The >30 cm water depth zone more frequently to showed a common fluctuation pattern amongst the collective sample ponds, wetland types and age classes (Figure 2.7) than did the other depth zones. This water depth zone represented a principal proportion of the water body and can actually account for the total water body. It is suggested that this fluctuation pattern has a strong link with rainfall just like pH and salinity. Aquaculture ponds, especially the temporarily abandoned ponds, were filled with a large quantity of rainwater during the typhoon season, after which the water body would gradually dry out. After a persistent dry season, the deeper water depth zones reached their lowest cover, while the extent of the shallower water depth zones, exposed mudflats and total vegetation reached their highest extent in April or May (Figure 2.7). The amount of rainfall in May appears to be insufficient to reverse the decreasing trend of the water body although the monthly rainfall was nearly 200 mm. This explains why five water depth zones, exposed mudflat and total vegetation all still displayed the driest state of the year. Only an abundant precipitation in June and July can reverse this drying trend and let the net gains of water become positive (Figure 2.1). During the driest months, some ponds could even dry out completely. In these circumstances, an extra input of water would be necessary since some prey species for waterbirds such as fish, aquatic insects, cannot live without water.

As with fluctuant salinity and pH, the actively managed ponds displayed a greater annual fluctuation than the temporarily abandoned ponds in the extent of >30 cm water depth zone (Figure 2.7). This might again suggest thin the temporarily abandoned ponds are a more stable habitat type than the actively managed ponds.

During the dry season, in the actively managed ponds, a minimum water depth needs to be maintained to raise fish, and a large volume of underground fresh water is pumped into active ponds. When the wet season comes, heavy rainfall will bring substantial water input into active ponds, ponds managers generally prefer holding extra water to let water lose naturally from strong evaporation activity. Consequently, the extent of >30 cm water depth zones fluctuated more or less to match with the fluctuation of rainfall in the study area (Figure 2.1).

Vegetation

Wetland vegetation normally implies shelter (Cramp & Simmons, 1977, 1980, 1983; del Hoyo *et al.*, 1992, 1996) and food (Cramp & Simmons, 1977, 1980, 1983; Jefferies, 1988; del Hoyo *et al.*, 1992; Belanger & Bedard, 1994; del Hoyo *et al.*, 1996) for waterbirds although they might also decrease the detectability of predators (Dekker & Ydenberg, 1987; Valone & Lima, 1987; Cresswell, 1996; Ydenberg et al., 2002). Amongst the four types of vegetation, shore and emergent vegetation were more frequent to show significant annual fluctuation pattern in the vegetation cover. Numerous factors such as frequent heavy rain, strong evaporation and the flat beds of aquaculture ponds, may explain the frequent changes in both cover of emergent vegetation and the location of shoreline. Furthermore, deep water (minimum 1 m) generally deters the colonization of emergent plants. Consequently, various depths in a pond can result in a heterogeneous vegetation cover over the basin of a particular pond. In this situation, the frequent changes in the location of shoreline will greatly influence the coverage of shore vegetation and thereby cause a larger degree of variation in the annual pattern than other vegetation types (Figure 2.12).

Chronosequence

Chronosequences of either the characteristics of the temporarily abandoned aquaculture ponds or population dynamic and species composition of avian fauna are viewed as key information to understand the long-term chronological changes of aquaculture ponds after being abandoned. This information will greatly help researchers and site managers to set the goal and measures for the restoration and management of the abandoned wetlands. However, relatively few attributes of wetlands were identified with significant variations with abandonment time in this study. Sample ponds might include several different types of abandoned aquaculture ponds with distinct characteristics. The data from the different wetland types were put together for analyses, and therefore may mask the real trend in the changes of the characteristic attributes and avian population of wetlands. It is recommended that information pertaining to the separation of different types of abandoned aquaculture ponds is recorded in the future.

Chapter 3

Species richness, abundance and species composition of waterbirds in the temporarily abandoned ponds: annual pattern and chronosequence

3.1. Introduction

When aquaculture ponds are abandoned, the longer the ponds have been abandoned, the more the environmental characteristics in these ponds are expected to be similar to those of natural wetlands. Unlike the annual pattern and chronosequences in the environmental features of aquaculture ponds, it is more difficult to summarize any general trend in temporal changes in avian attributes such as species richness, abundance and species composition. This is primarily because of complex interactions among migrant waterbirds and associated factors during the migratory seasons in the sample wetlands of this study (Tsai, 1998; TCWBS, 1999; BSTP, 2000; Wang, 2000). Additionally, disturbance is expected to diminish in the older wetlands, more shy species might be attracted to these wetlands over a chronosequence.

3.2. Methods

3.2.1.Sampling

Sampling is described the same as 2.2.1. Sampling in chapter 2 (page 46).

3.2.2. Optimal Time for observation

The avian variables in all sample ponds, including species richness, abundance and species composition, were measured for a whole year at a 15 day interval from October 1999 to September 2000. Observations were planned for the period of time when the highest value of species richness and abundance of waterbirds are expected. The time of day and the time of high tide have both been reported to have strong influences on the observations of aforementioned variables, especially for migrant species (Ruwaldt and Flake, 1979; Leschisin *et al.*, 1992; McKinstry and Anderson, 1994). In addition, many observations have been documented which show that waterbirds moved from estuary to nearby wetlands during high tide in this study. Therefore, the observations and counts were conducted during two fixed time periods for each pond at a particular site. One period was between two hours before and after the time of high tide (Observation Time period at High Tide, OTHT). The other was either during the period of time between half an hour before sunrise and 9.00 a.m. (1^{st} priority), or between 3.00 p.m. and half hour after sunset (2^{nd} priority)(Early Morning Or Late Afternoon time period, EMOLA). These two observation time periods for all routine sample ponds were undertaken once for each time period on the same day and were separated by at least an hour.

In other words, when the early morning time period is separated from the OTHT by less than an hour, the avian observations were made during the late evening time period; otherwise, the early morning time period was used. In general, OTHT and EMOLA for each pond at a particular site were completed in a day, otherwise the whole set of observations was restarted (OTHT or EMOLA), if only one observation time period was completed. However, weather conditions on some months were not suitable for completing two observation periods (OTHT and EMOLA) in a day at a particular site. The unfinished observations, either OTHT or EMOLA, were then undertaken on the closest date (maximum two days apart) when weather conditions were appropriate. In addition, observations affected by severe weather conditions, i.e. strong winds and heavy rains, were not included in the data analysis, for such weather could alter the habitat use made by the waterbirds of the sample wetlands. However, data collected in light rain were considered acceptable for data analysis.

3.2.3. Investigation

The number of species and the abundance of each species were recorded every 15 days for each pond, as was the age and sex of waterbirds whenever identification was possible. In general, observations were made along the embankments of sample ponds. The observation record was not considered to be complete for a pond unless every part of it was scanned sufficiently. The scanning time for a given pond varied in accordance with the pond size and cover of vegetation. On average it took approximately 15 minutes to investigate a pond. However, it could require 45 minutes or more to complete the observations on some large natural wetlands. Several waterbird species such as duck species, are extremely shy in the study area and require to be approached exceptionally carefully. In this instance, total abundance was estimated first, then species identification and followed by sex and behaviour. If species identification did not finish in time, the guild name or unknown species would be labeled on this record. These incomplete records were only used in some limited analyses, as for example, the sum of birds occurring in the total ponds at a particular study site.

3.3. Statistical analysis

One-way analysis of variance (ANOVA) was used initially to determine whether there was a significant difference between the 15-day-interval measurements of each

individual avian attribute. Only those attributes that frequently showed significant differences either in all sample ponds or a particular wetland type or abandonment age class were included in further analysis. However, some avian attributes with significant differences in a particular wetland type or age class do not display recognized trends in either annual pattern or chronosequence and consequently were not utilized for further analyses.

3.4. Results

One hundred and twenty nine bird species were recorded during this study. Amongst the species, 38 are terrestrial and 91 are waterbird species. Only waterbird species were used for further analysis in this study. In this chapter, I will discuss temporal changes, including annual pattern and chronosequence, of four avian attributes in the sample wetlands: the mean species richness and abundance per pond, dominance in the abundance of individual waterbird species and species composition. In addition, the variations between the wetland types or abandonment age classes are also discussed. One hundred and sixty six wetlands were observed at diverse observation frequencies. All sampled temporarily abandoned ponds were used to determine the chronosequences of avian attributes. For the analyses of the annual pattern of avian attributes, only sample ponds with complete year-round 15-day-interval records were used (N=107; actively managed ponds, N=26; temporarily abandoned ponds, N=73; saltpans, N= 3; natural wetlands, N=5).

3.4.1.Annual pattern of avian attributes

3.4.1.1. The mean number of species and abundance per pond

The abundance and the number of waterbird species are likely to be the most important characteristics that contribute to the overall understanding in the temporal changes of habitat use of wetlands by waterbirds. Due to the strong relationships between these two variables, they are discussed collectively. Two measurements, the mean 15-day-interval number of species and abundance per pond, were used to represent the two aforementioned study variables. Only the variables with statistically significant variations in one-way ANOVA are discussed in the results section.

The mean 15-day-interval number of waterbirds per pond in all sample wetlands are presented in Figure 3.1 and show a typical annual pattern with a peak value in

October (that is 140.1 birds/pond, 271.7% of the average value). In comparison with the smooth fluctuation pattern of the mean monthly number of birds, the mean number of species per pond shows a fluctuation pattern with much less significant amplitude and shows two obvious peaks in April and September, respectively (that is 3.06 species/pond, 112.0% of the average number; that is 3.55 species/pond, 130.0% of the average number, respectively) (Figures 3.2 and 3.3).

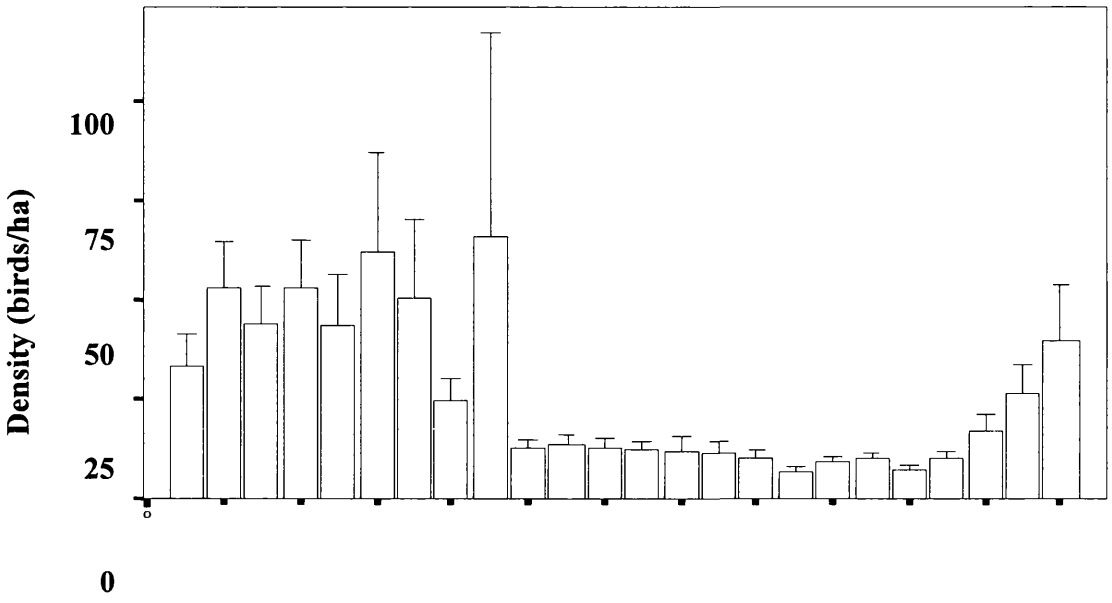


Figure 3.1. The mean abundance of waterbirds per pond at a 15-day interval in all sample ponds. Error bars represent the standard error of the mean..

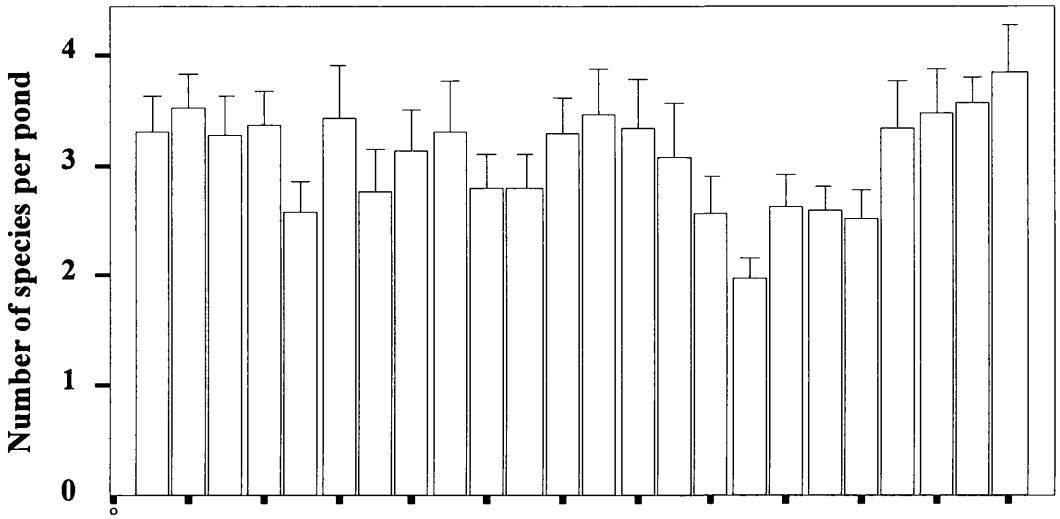


Figure 3.2. The mean number of waterbird species per pond at a 15-day interval in all sample ponds. Error bars represent the standard error of the mean.

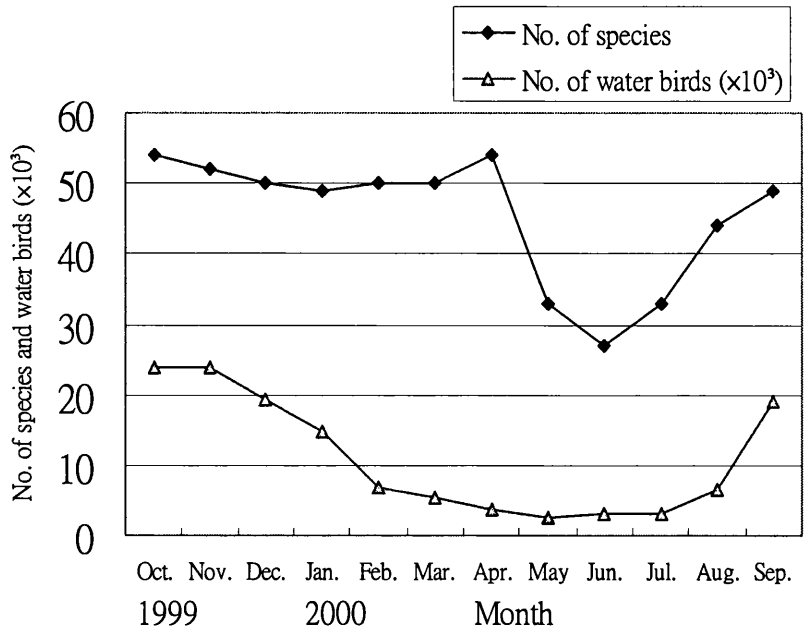


Figure 3.3. The mean number of species and abundance of waterbirds at a 15-day interval at all sample ponds.

3.4.1.1.1. Variations by wetland types

Species richness and abundance of waterbirds were compared to each other among the four wetland types: actively managed ponds, temporarily abandoned ponds, saltpans and natural wetlands. However, due to the small sample sizes in saltpans and natural wetlands, more emphasis was placed on the analyses of the other two wetland types: actively managed ponds and temporarily abandoned ponds.

In general, for any given species, the annual pattern of abundance in the actively managed ponds or temporarily abandoned ponds was similar to those in all sample ponds. Nevertheless, the annual patterns of the mean number of species per pond and total number of birds are somewhat different between wetland types. The annual fluctuations in the total number of birds and mean number of species per pond in the temporarily abandoned ponds were similar to those in all sample ponds (Figures 3.1, 3.2, 3.4 3.5 and 3.6). In contrast, the mean number of species per pond in the actively managed ponds displays trends toward a bowl-shaped variation pattern with a minimum in June (Figure 3.7). Although

the annual pattern of total number of birds in the actively managed ponds demonstrated a similar oscillation pattern to those in all sample ponds, the duration of greater amplitude was shorter (actively managed ponds: three months; total ponds: six months) (Figures 3.1, 3.8 and 3.9).

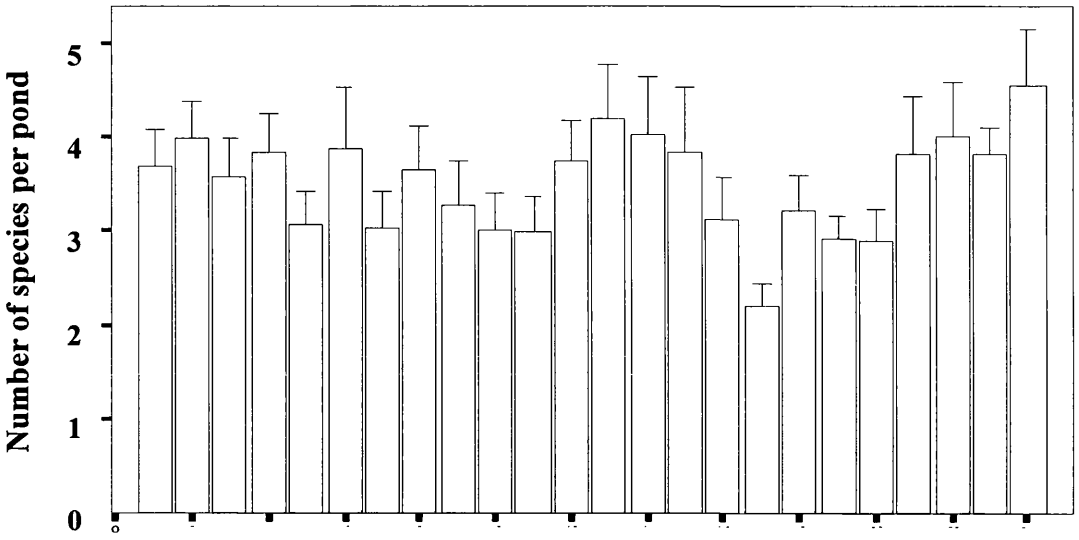


Figure 3.4. The mean number of waterbird species per pond at a 15-day interval in the temporarily abandoned aquaculture ponds. Error bars represent the standard error of the mean.

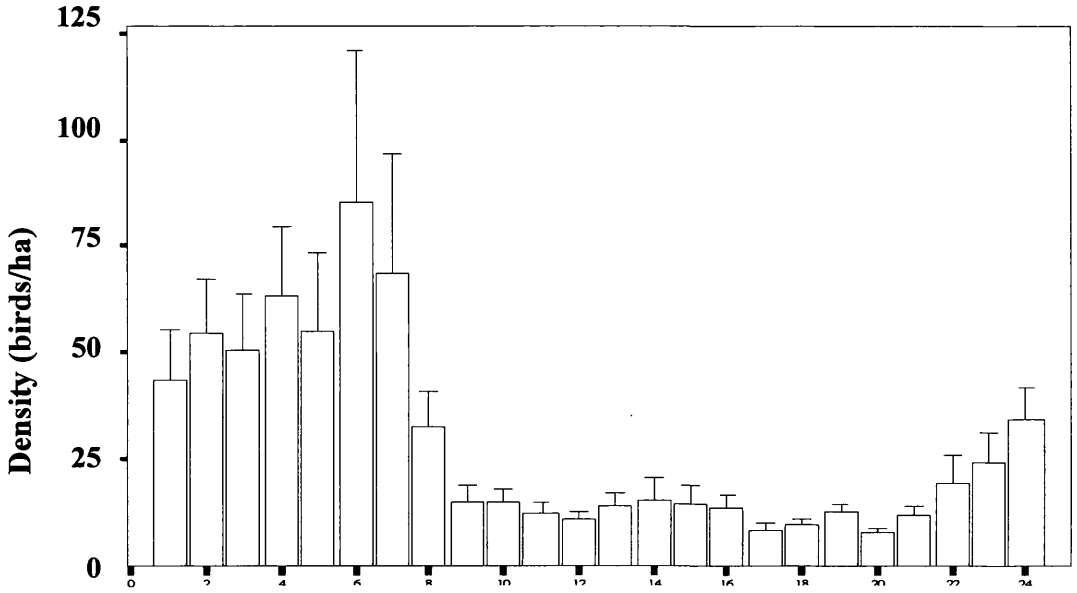


Figure 3.5. The mean abundance of waterbirds per pond at a 15-day interval in the temporarily abandoned aquaculture ponds. Error bars represent the standard error of the mean.

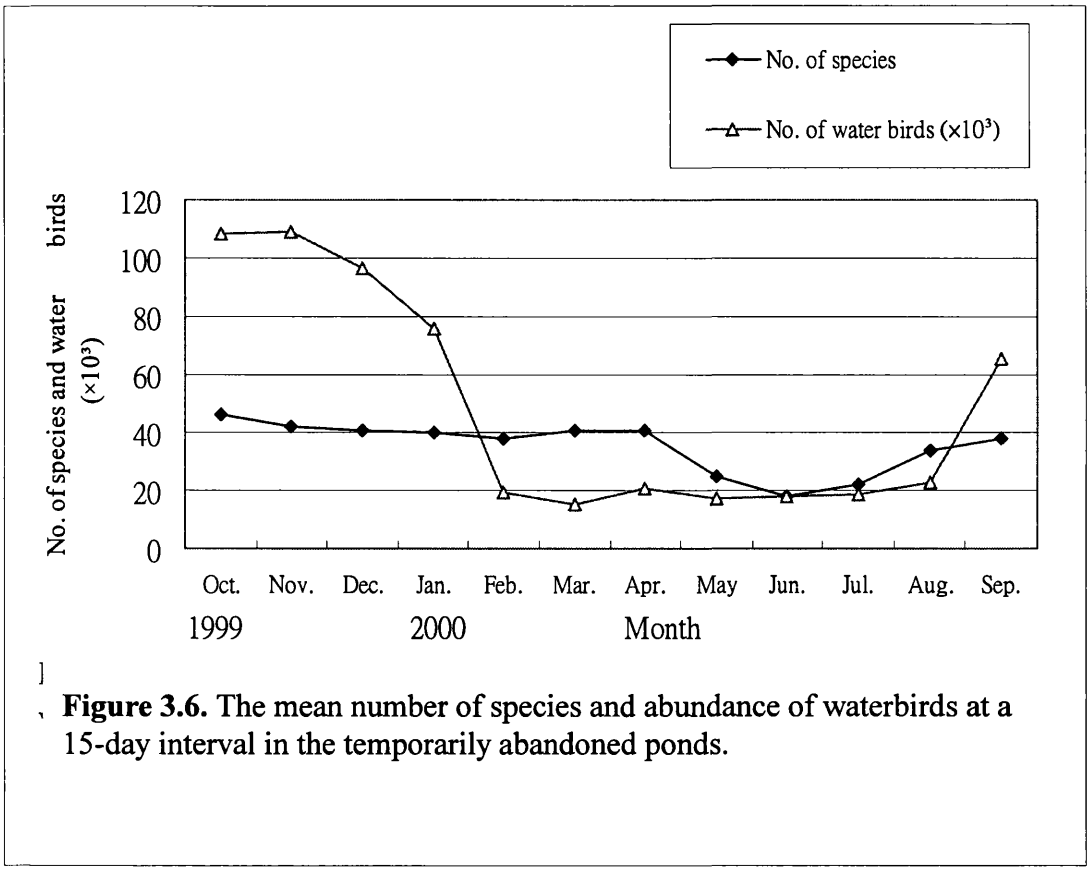


Figure 3.6. The mean number of species and abundance of waterbirds at a 15-day interval in the temporarily abandoned ponds.

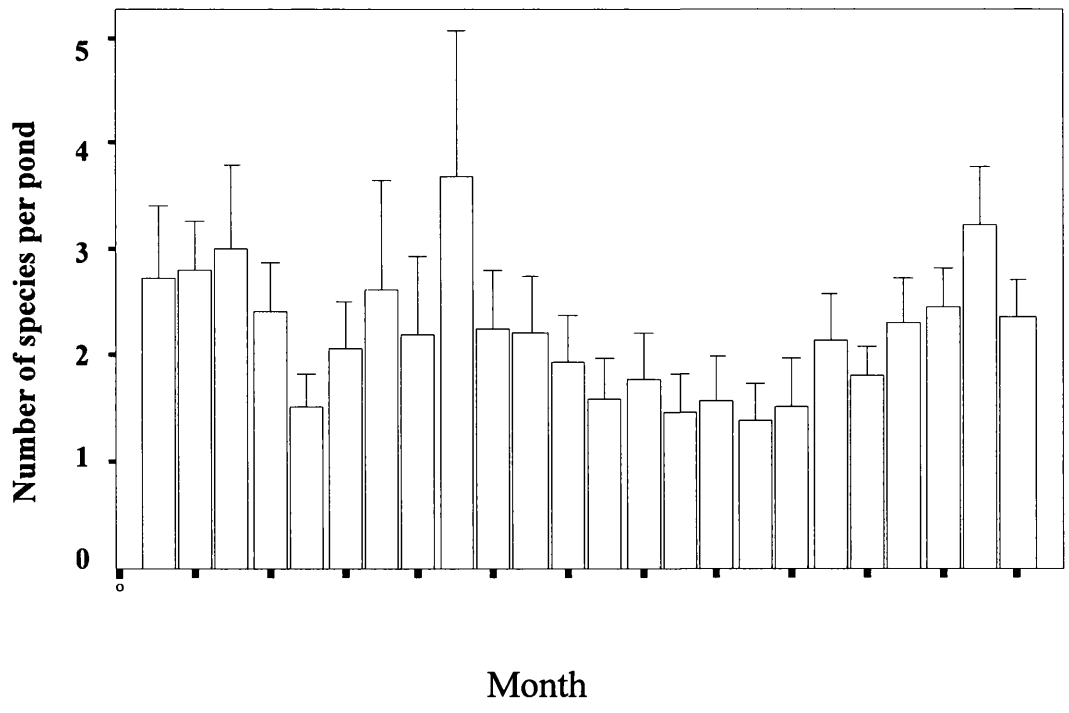


Figure 3.7. The mean number of waterbird species per pond at a 15-day interval in the actively managed ponds. Error bars represent the standard error of the mean.

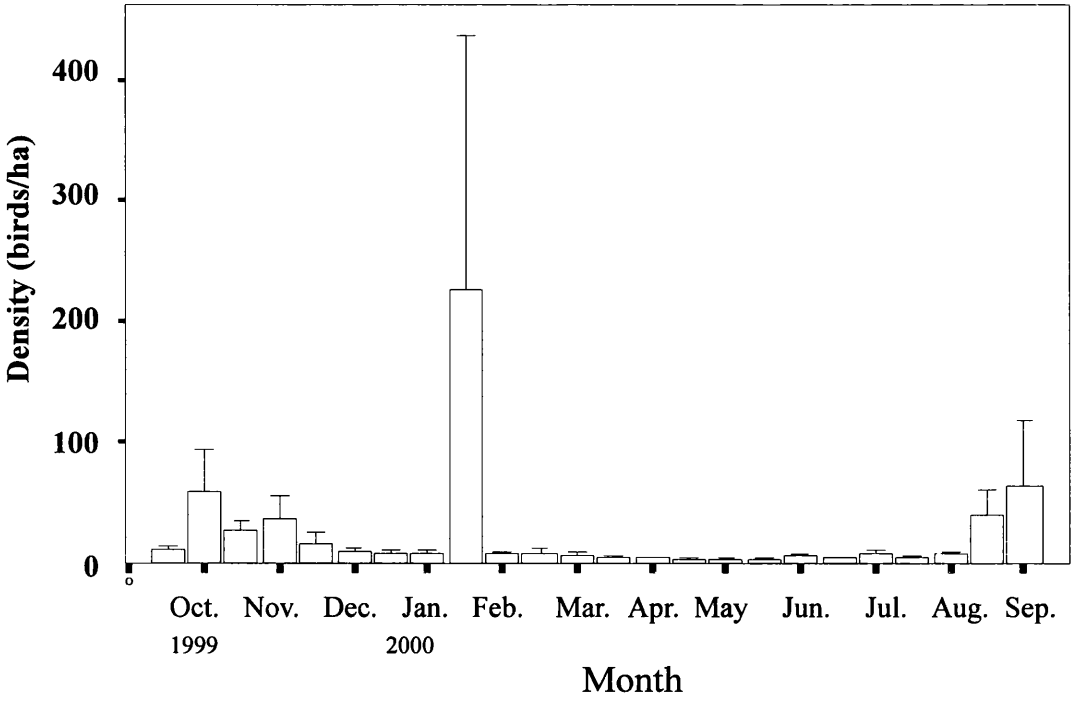
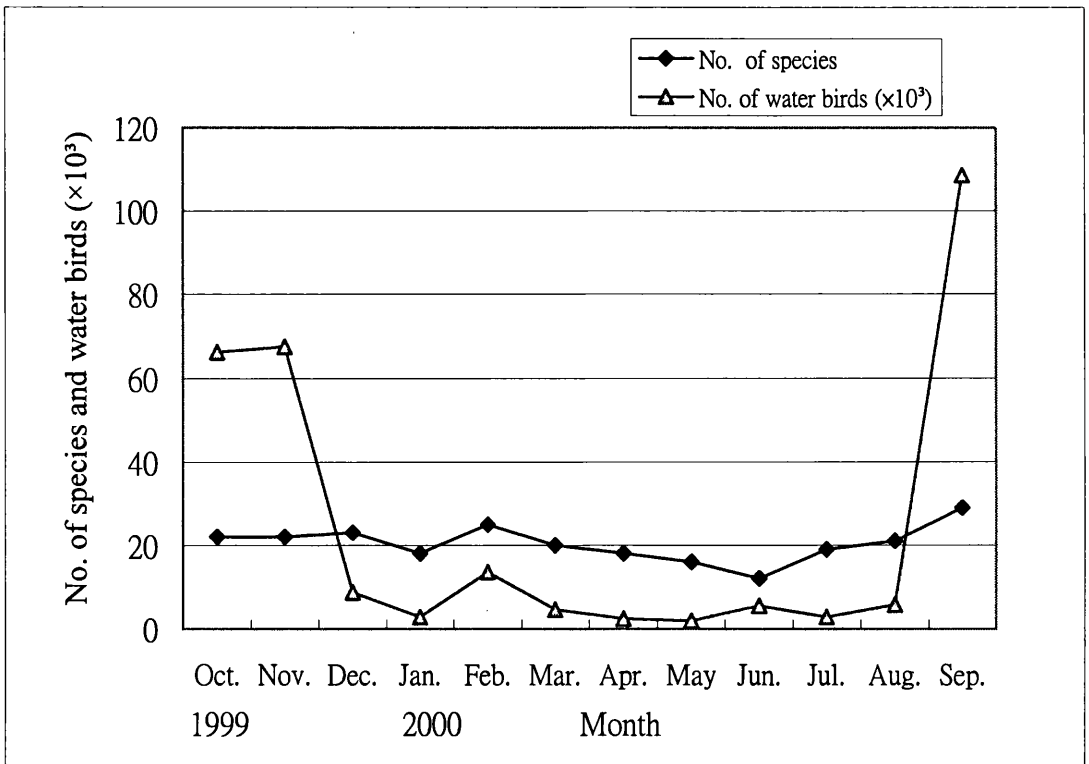


Figure 3.8. The mean abundance of waterbirds per pond at a 15-day interval in the actively managed ponds. Error bars represent the standard error of the mean.



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v **Figure 3.9.** The mean number of species and abundance of waterbirds at a 15-day interval in the actively managed ponds.

The annual pattern of the mean number of waterbirds per pond was quite similar amongst all sample ponds, temporarily abandoned ponds and actively managed ponds. However, large numbers of waterbirds were present for a shorter duration on the actively managed ponds than the temporarily abandoned ponds. High counts were recorded from August in both instances, but were maintained two months longer in the temporarily abandoned ponds than in the actively managed ponds (Table 3.1). This relationship might indicate that a wide range of species of waterbirds have explored every wetland type in the study area, including actively managed ponds and temporarily abandoned ponds during the major southbound migratory season starting in August. After three months' utilization actively managed ponds, are much less used by waterbirds while waterbirds still continue to use temporarily abandoned ponds for another two months. However, only the total number of waterbirds species, not total number of waterbirds, of temporarily abandoned ponds are significantly larger than those of actively managed pond (Table 3.1).

Table 3.1. The mean number of species and waterbirds per pond at a 15-day interval at both active ponds (A.P.) and temporarily abandoned ponds (T.P.), and their independent samples T-tests between A.P. and T.P from October 1999 to September 2000.

Vegetative attribute	Mean		Degrees of Freedom	T-value	Significance
	Active ponds	Temporarily abandoned ponds			
Number of species	2.08(N=624)	2.65(N=1,752)	2,374	5.77	0.000**
Number of waterbirds	47.37(N=624)	33.21(N=1,752)	2,374	1.57	0.117

P.S.: ** means that p-value is no more than 1%.

3.4.1.2. Species composition

Twenty-five out of 78 recorded waterbird species show significant differences in their 15-day-interval occurrence (Table 3.2). This indicates that these species might have seasonal variations in abundance. Most of the 25 species with significant differences have a single peak in abundance (Figures 3.10, 3.11 and 3.12). The peak month mainly occurred in the migratory season, either from September to December (southbound migratory season) or from April to May (northbound migratory season). These species are mostly passage species (Tsai, 1998; TCWBS, 1999; BSTP, 2000; Wang, 2000) and are only present in the study area for one or two months to refuel. Species occurring mainly during the southbound migratory season are as follows, *Bubulcus ibis* (Aug. and Sep.),

Sterna leucoptera (Sep.), *Anas querquedula* (Sep. and Oct.), *Tringa glareola* (Oct.), *Egretta intermedia* (Oct. and Nov.), *Calidris subminuta* (Nov.), *Fulica atra* (Dec.), *Larus ridibundus* (Dec.), *Anas acuta* (Jan.) (Figure 3.10). In contrast, species occurring mainly during the northbound migratory season are as follows, *Calidris tenuirostris* (Apr.), *C. ferruginea* (Apr. and May), *Tringa ochropus* (Apr. and May), *Sterna albifrons* (May), *C. acuminata* (May) (Figure 3.11). Some migrant species were present over a longer period, mainly in the winter and spring time and are classified as wintering birds in the study area. These species are *Calidris alpina and Anas crecca* (Figure 3.12). Few resident species show significant seasonal variations. However, some resident species such as *Egretta garzetta, Nycticorax nycticorax, Ixobrychus cinnamomeus, Gallinula chloropus, Tringa nebularia* and *Tringa hypoleucos* show more or less seasonal fluctuations in abundance (Figure 3.12).

Table 3.2. Summary of one-way ANOVAs of the waterbird species which show significant differences in their 15-day-interval occurrence in the total sample wetlands from October 1999 to September 2000.

Species	Degrees of Freedom	F-value	Significance
Egretta garzetta	2,562	1.99	0.003**
Nycticorax nycticorax	2,562	2.54	0.000**
Egretta intermedia	2,562	1.66	0.025*
Bubulcus ibis	2,562	2.58	0.000**
Gallinula chloropus	2,562	1.76	0.014*
Ixobrychus cinnamomeus	2,562	2.50	0.000**
Ardea cinerea	2,562	1.61	0.033*
Tringa nebularia	2,562	1.58	0.040*
Tringa hypoleucos	2,562	1.84	0.009**
Sterna albifrons	2,562	2.86	0.000**
Arenaria interpres	2,562	1.62	0.032*
Anas acuta	2,562	1.92	0.005**
Anas crecca	2,562	3.82	0.000**
Anas querquedula	2,562	2.95	0.000**
Circus cyaneus	2,562	2.02	0.003**
Calidris acuminata	2,562	4.60	0.000**
Calidris alpina	2,562	1.69	0.021*
Calidris ferruginea	2,562	1.62	0.032*
Calidris subminuta	2,562	2.31	0.000**
Calidris tenuirostris	2,562	1.85	0.008**
Tringa glareola	2,562	2.78	0.000**
Tringa ochropus	2,562	3.28	0.000**
Larus ridibundus	2,562	2.38	0.000**
Sterna leucoptera	2,562	2.99	0.000**
Fulica atra	2,562	1.93	0.005**

P.S.: * means that p-value is no more than 5% and ** means that p-value is no more than 1%.

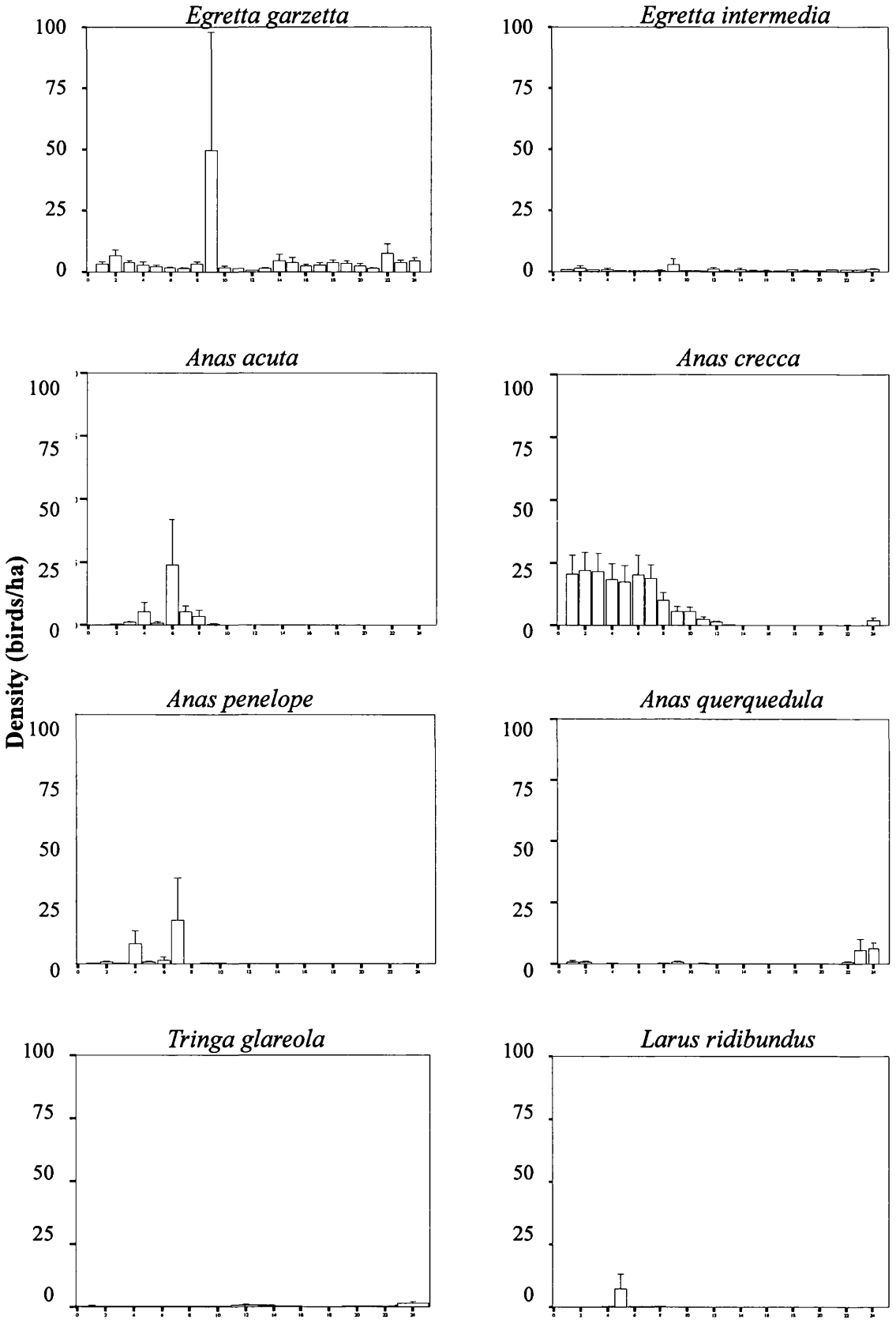


Figure 3.10. The mean abundance of *Egretta garzetta*, *Egretta intermedia*, *Anas acuta*, *Anas crecca*, *Anas penelope*, *Anas querquedula*, *Tringa glareola* and *Larus ridibundus* per pond at a 15-day interval in all sample ponds. Error bars represent the standard error of the mean.

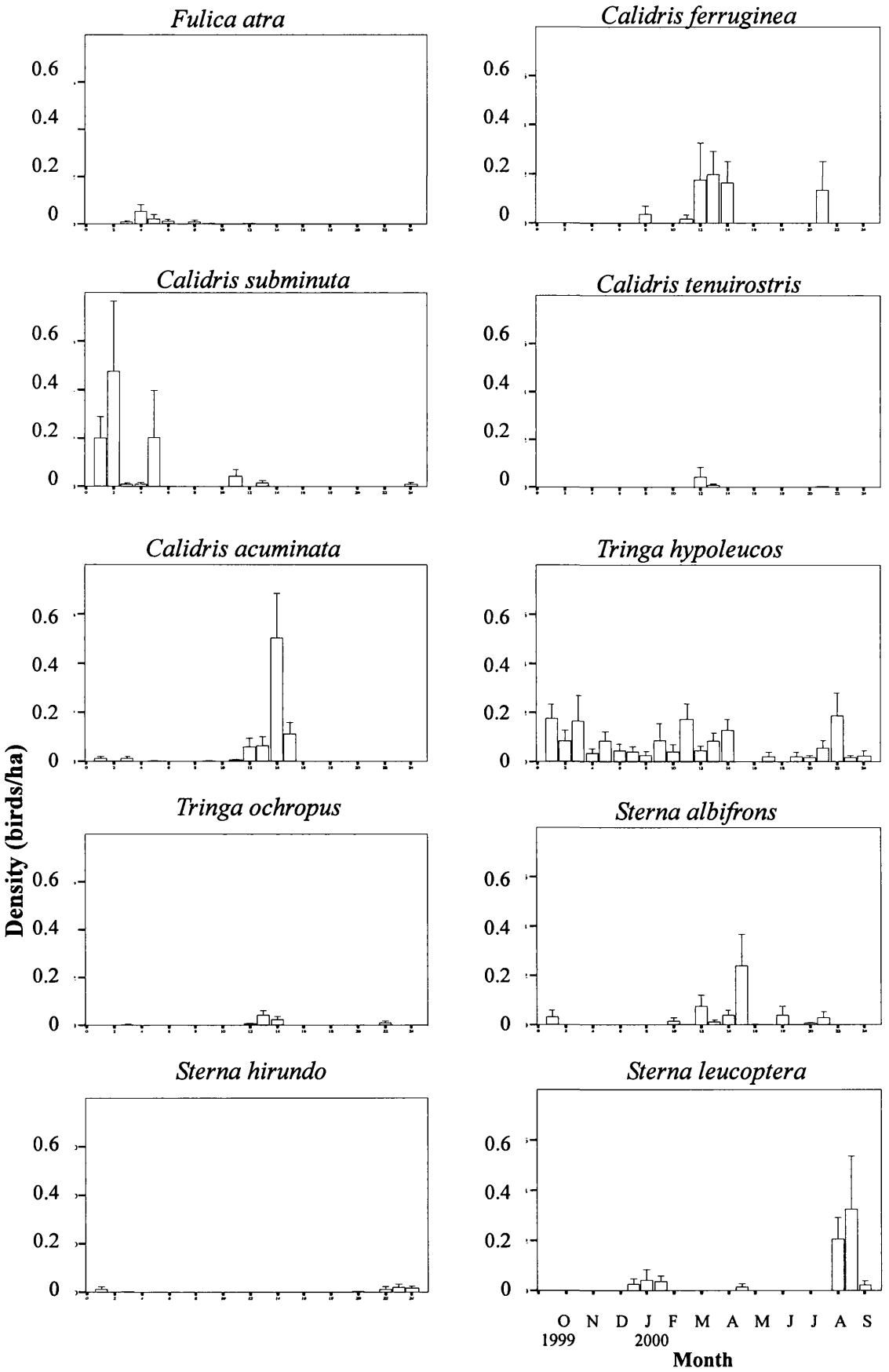


Figure 3.11. The mean abundance of *Fulica atra, Calidris ferruginea, Calidris subminuta, Calidris tenuirostris, Calidris acuminata, Tringa hypoleucos, Tringa ochropus, Sterna albifrons, Sterna hirundo* and *Sterna leucoptera* per pond at a 15-day interval in all sample ponds. Error bars represent the standard error of the mean.

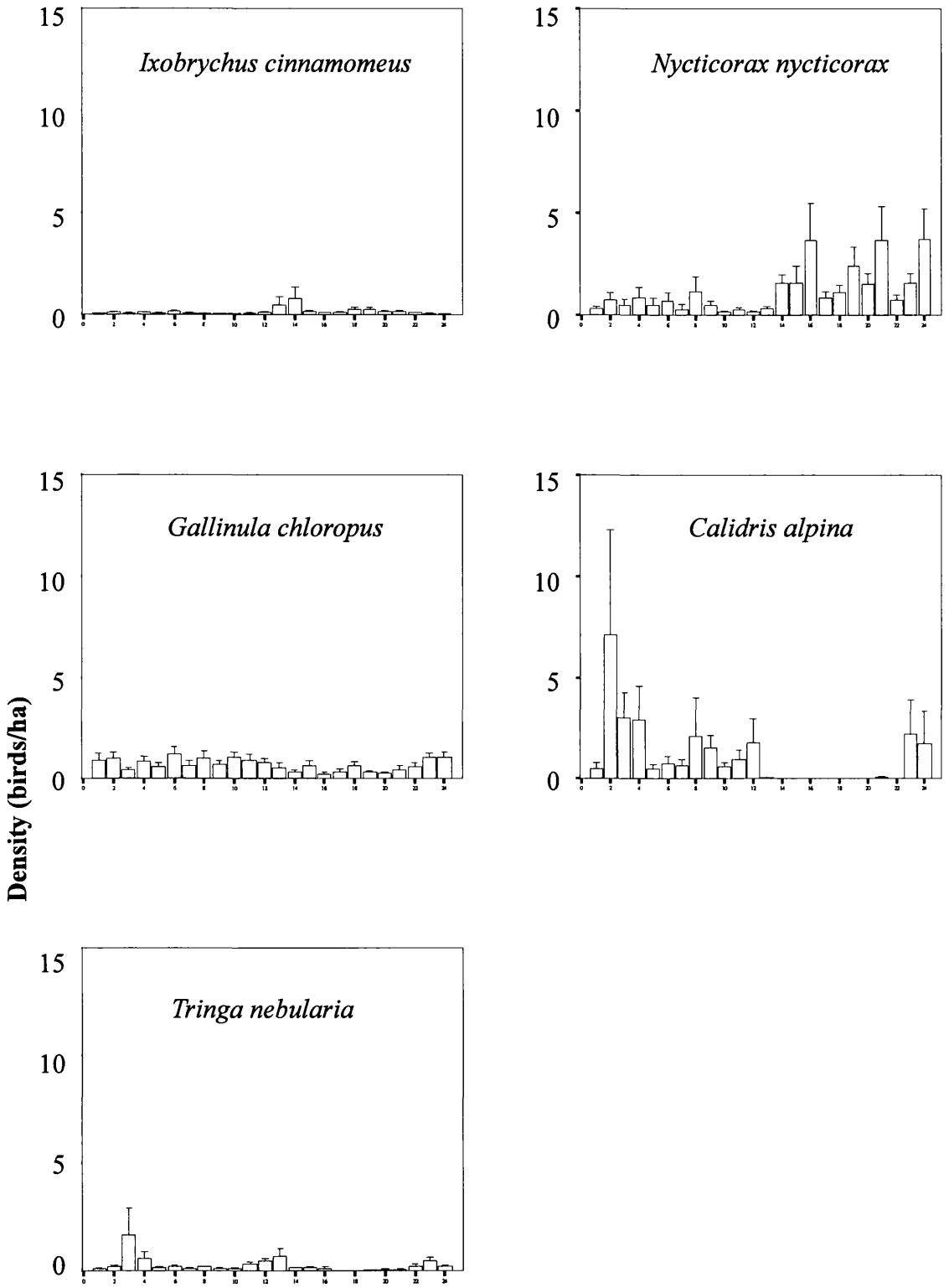


Figure 3.12. The mean abundance of *Ixobrychus cinnamomeus, Nycticorax nycticorax, Gallinula chloropus, Calidris alpina* and *Tringa nebularia* per pond at a 15-day interval in all sample ponds. Error bars represent the standard error of the mean.

Interactions with migrant species might be the main cause of fluctuation in species composition in the sample wetlands (Table 3.3). In August, the early southbound migrant species, mainly wader and tern species, start to occur in the aquaculture ponds. They include *Arenaria interpres*, *Calidris ferruginea*, *Sterna hirundo* and *Sterna nilotica* (Figures 3.11 and 3.13). From September to November, most southbound migrant species start appearing. In September, mainly wader species show their presence. These include most common species such as *Calidris alpina* and *Tringa glareola*, the first duck species, *Anas querquedula* and the largest egret species in Taiwan, *Ardea cinerea* (Figures 3.10, 3.12 and 3.13). In October, the number of newly-arrived species reaches its peak. Aside from wader species, three duck species, *Anas crecca*, *Anas clypeata* and *Anas penelope* appear (Figures 3.12 and 3.13). In November, another two duck species, *Anas acuta* and *Anas strepera*, appeared (Figures 3.10 and 3.13). From December to March, the number of newly-arrived species was outnumbered by departing species. Departing species included duck species, egret species and tern species, but not wader species. This indicates that most southbound migrant non-wader species only appeared for a few months in the sample wetlands. On the contrary, most southbound migrant wader species appeared longer in the study area and could be considered as wintering species. In April, species composition fluctuated to a great extent as many newly-arrived species co-incided with the absence of many other species in the study area. The changing species are principally wader species such as the common species, *Calidris alpina* (Figures 3.12). In addition, the common duck species, *Anas crecca*, was also absent during this month (Figure 3.12). During the following two months, May and June, there was only absence of species but no newly-arrived species in the sample wetlands. As well as the common wintering wader species, *Tringa glareola*, these newly absent species included mostly non-wintering migrant wader species in these two months (Figures 3.10, 3.11 and 3.12). In July, the sample wetlands were used principally by resident species without the involvement of migrant species (Figures 3.10 and 3.12).

Table 3.3. Summary of the newly-arrived and -absent waterbird species in the sample wetlands throughout the year, beginning with the southward migratory season in the study area.

Month	New-arrival	Newly-absent species
August	Wader and tern species: *Arenaria interpres*, *Calidris ferruginea*, *Sterna hirundo* and *Sterna nilotica*.	
September	Most of common wader species: *Calidris alpina*, *Calidris ruficollis*, *Charadrius alexandrinus*, *Calidris temminckii*, *Charadrius dubius* and *Tringa glareola* and the earliest duck species, *Anas querquedula*	
October	Three duck species: *Anas crecca*, *Anas clypeata* and *Anas penelope*	
November	*Anas acuta* and *Anas strepera*	
December to February		Non-wader species, mainly duck species
March to May	Short-stay wader species	Short-stay wader species and common wintering wader species, such as *Calidris alpina*, *Calidris ruficollis* and *Charadrius alexandrinus*
June and July	Smallest number of new-arrival of the year	Lowest loss rate of species of the year

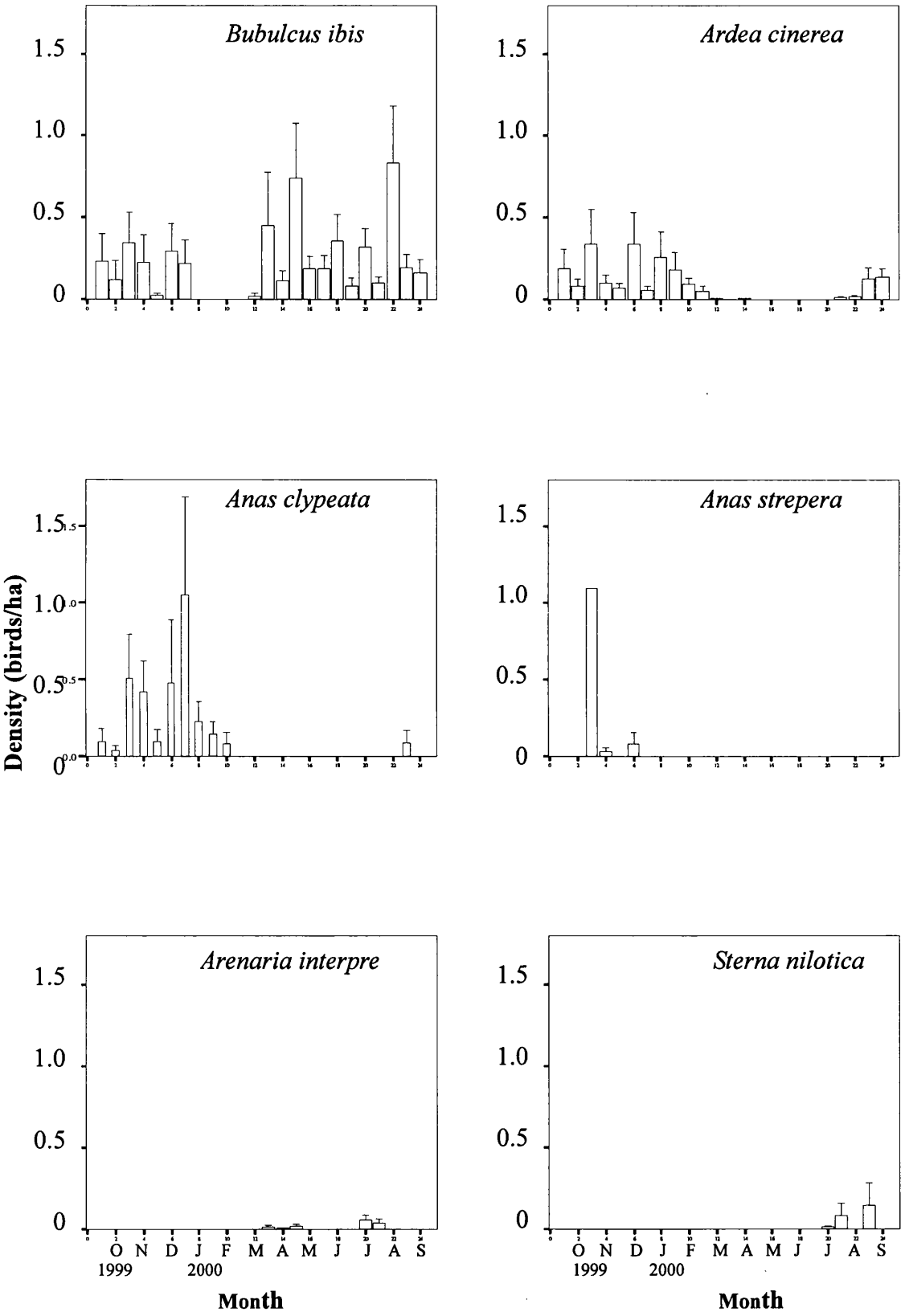


Figure 3.13. The mean abundance of *Bubulcus ibis, Ardea cinerea, Anas clypeata, Anas strepera, Arenaria interpres* and *Sterna nilotica* per pond at a 15-day interval in all sample ponds. Error bars represent the standard error of the mean.

The differences between the southbound and northbound migratory seasons are not only in the number of species and abundance, but also in their species composition and relative abundance of several species. The largest variation occurred in the duck species. Most duck species, including *Anas acuta*, *Anas clypeata*, *Anas penelope*, *Anas strepera* and *Aythya fuligula,* only occurred during the southbound migratory season, while most common migrant species, including *Calidris alpina*, *Charadrius alexandrinus*, *Calidris ruficollis*, *Calidris alpina* abd *Anas crecca,* occurred during both migratory seasons. In contrast, several species are only found in the northbound migratory season, including *Charadrius mongolus*, *Calidris canutus*, *Limnodromus semipalmatus*, *Phalaropus lobatus*, *Sterna albifrons* and *Calidris tenuirostris*.

3.4.1.2.1.Variations by wetland types

The species composition of waterbirds at the wetland types shows obvious variations. In the actively managed ponds, six species were consistently present, including three wader species, *Charadrius alexandrinus*, *Himantopus himantopus* and *Tringa hypoleucos*, an egret species, *Egretta garzetta*, a tern species, *Sterna hybrida* and a grebe species, *Podiceps ruficollis,* and could be considered resident species of the actively managed ponds (Figure 3.14). The remarkable monthly increase in the number of species during the southbound migratory season in the actively managed ponds occurred for a shorter period and a month later than that in all sample ponds. Only two duck species occurred in the actively managed ponds. In addition, the period when duck species were present was later and shorter than that in all sample ponds. *Anas crecca* appeared from October and was present for five months in the actively managed ponds. In addition, its monthly mean abundance per pond remained relatively low compared with that in all sample wetlands (Figure 3.15). Another duck species, *Anas acuta*, was present from January to February (Figure 3.15). No obvious increase was evident in species richness during the northbound migratory season in the actively managed ponds.

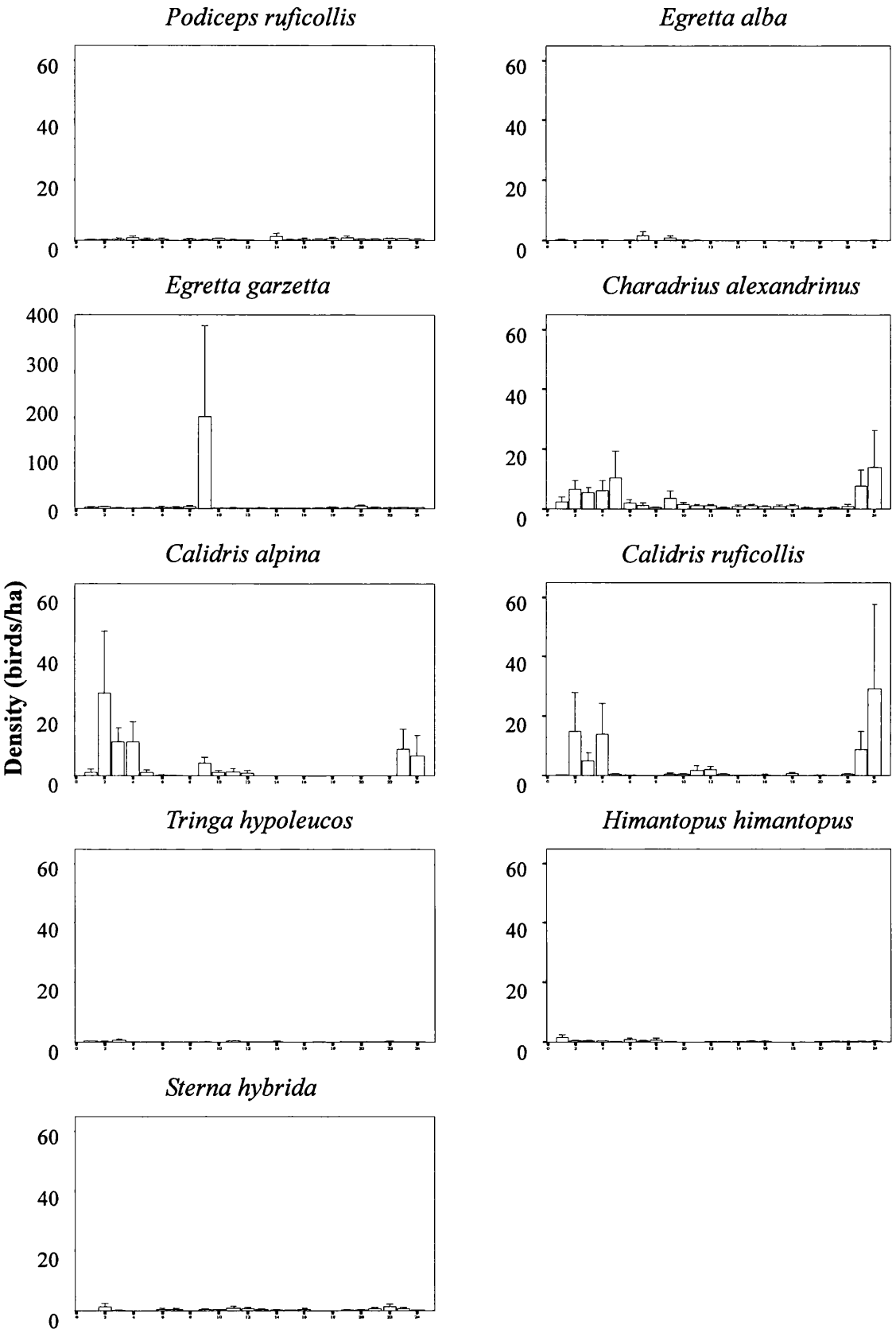


Figure 3.14. The mean abundance of *Podiceps ruficollis, Egretta alba, Egretta garzetta, Charadrius alexandrinus, Calidris alpina, Calidris ruficollis, Tringa hypoleucos, Himantopus himantopus* and *Sterna hybrida* per pond at a 15-day interval in the actively managed ponds. Error bars represent the standard error of the mean.

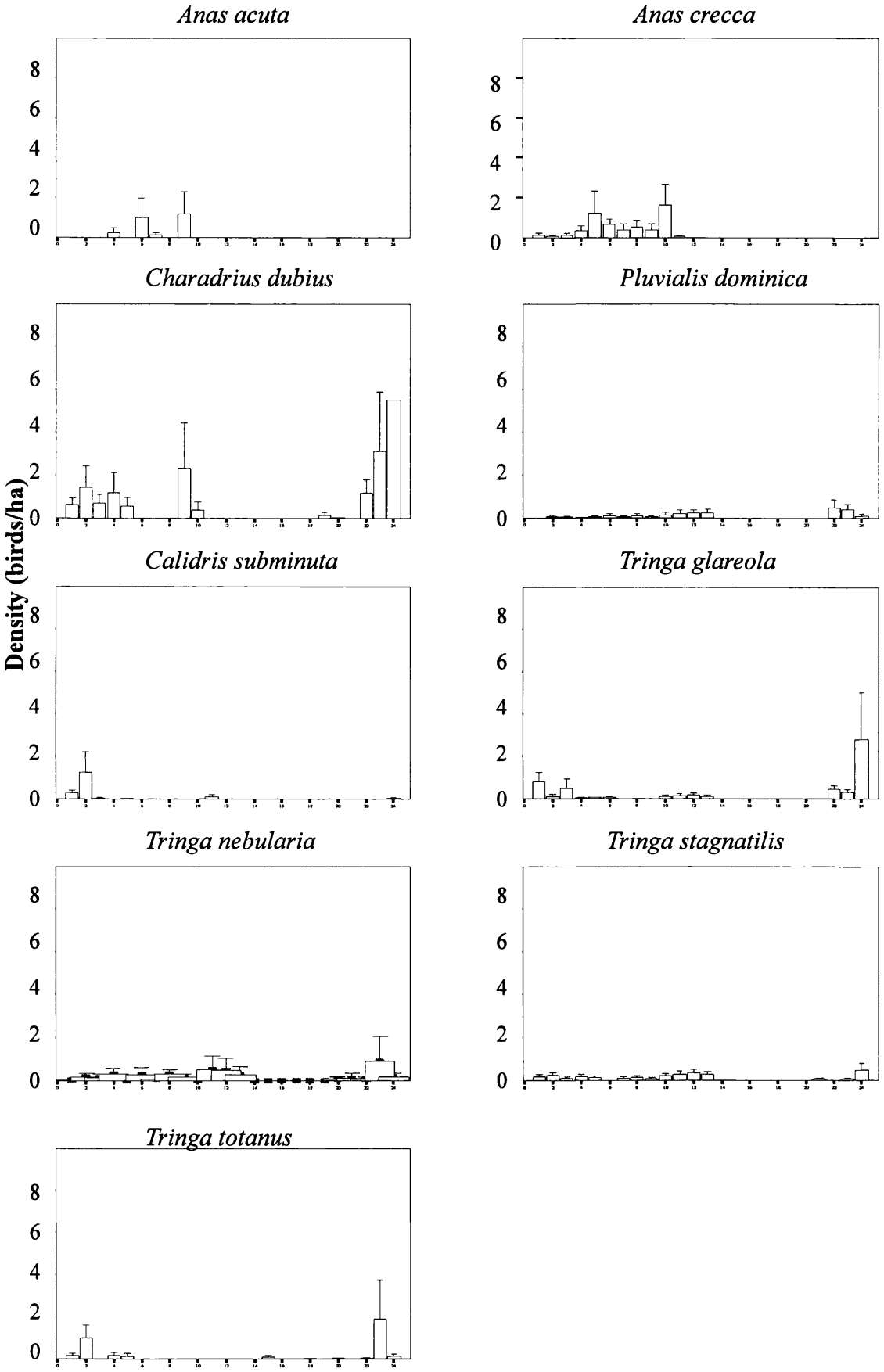


Figure 3.15. The mean abundance of *Anas acuta*, *Anas crecca*, *Charadrius dubius*, *Pluvialis dominica*, *Calidris subminuta*, *Tringa glareola*, *Tringa nebularia*, *Tringa stagnatilis* and *Tringa totanus* per pond at a 15-day interval in the actively managed ponds. Error bars represent the standard error of the mean.

In contrast, the species composition in the temporarily abandoned ponds is similar to that in all sample wetlands. Among the 69 species present in the temporarily abandoned ponds, 14 species consistently occurred in the temporarily abandoned ponds and can be considered to be resident of temporarily abandoned ponds. These species include six egret species, *Egretta garzetta*, *Nycticorax nycticorax*, *Egretta intermedia*, *Egretta alba*, *Ixobrychus cinnamomeus* and *Ixobrychus sinensis*, four wader species, *Charadrius alexandrinus*, *Himantopus himantopus*, *Tringa stagnatilis* and *Tringa nebularia*, two rail species, *Gallinula chloropus* and *Amaurornis phoenicurus* and two other species, *Alcedo atthis* and *Podiceps ruficollis* (Figures 3.16, 3.17 and 3.18).

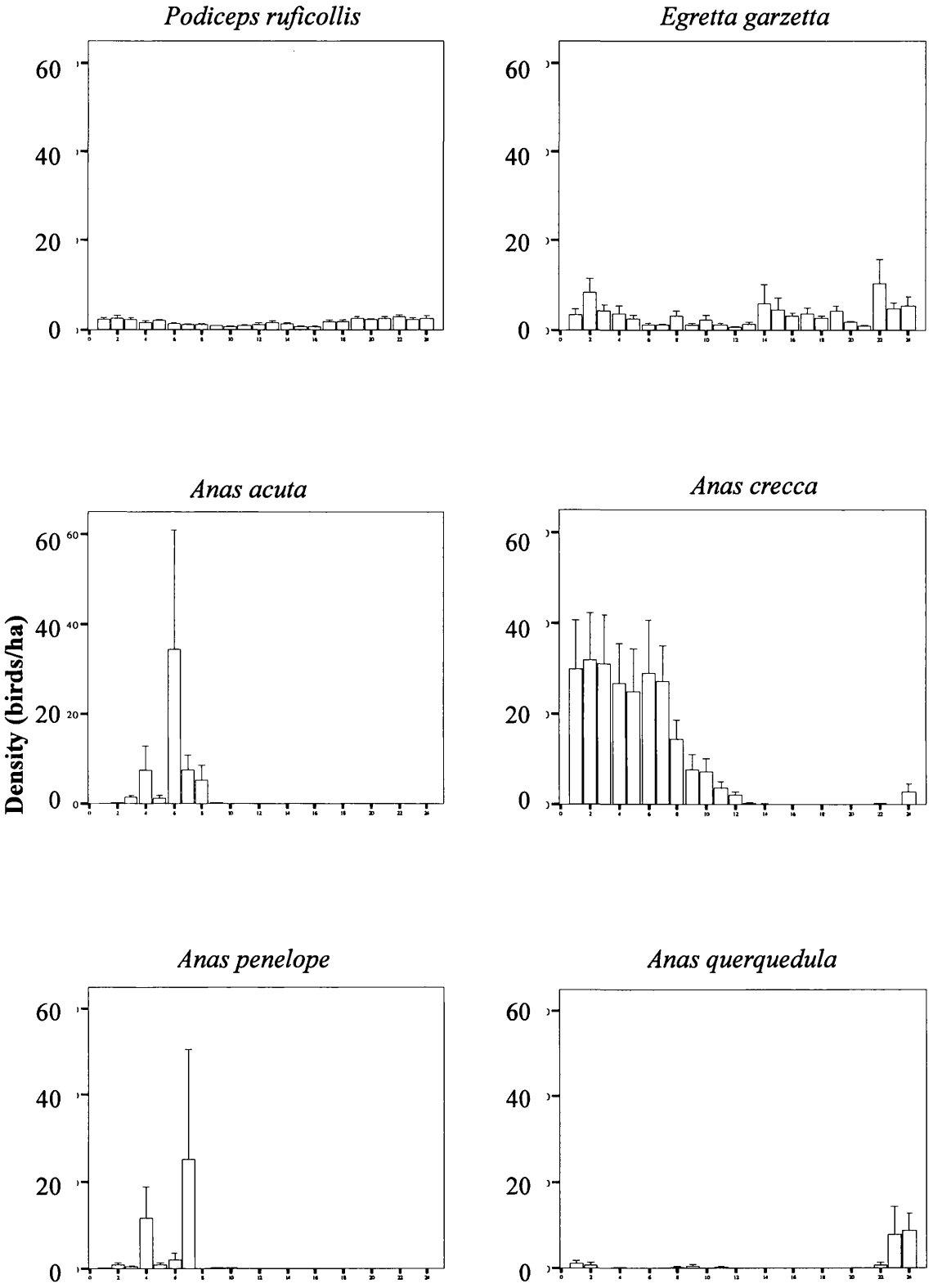


Figure 3.16. The mean abundance of *Podiceps ruficollis, Egretta garzetta, Anas acuta, Anas crecca, Anas penelope* and *Anas querquedula* per pond at a 15-day interval in the temporarily abandoned ponds. Error bars represent the standard error of the mean.

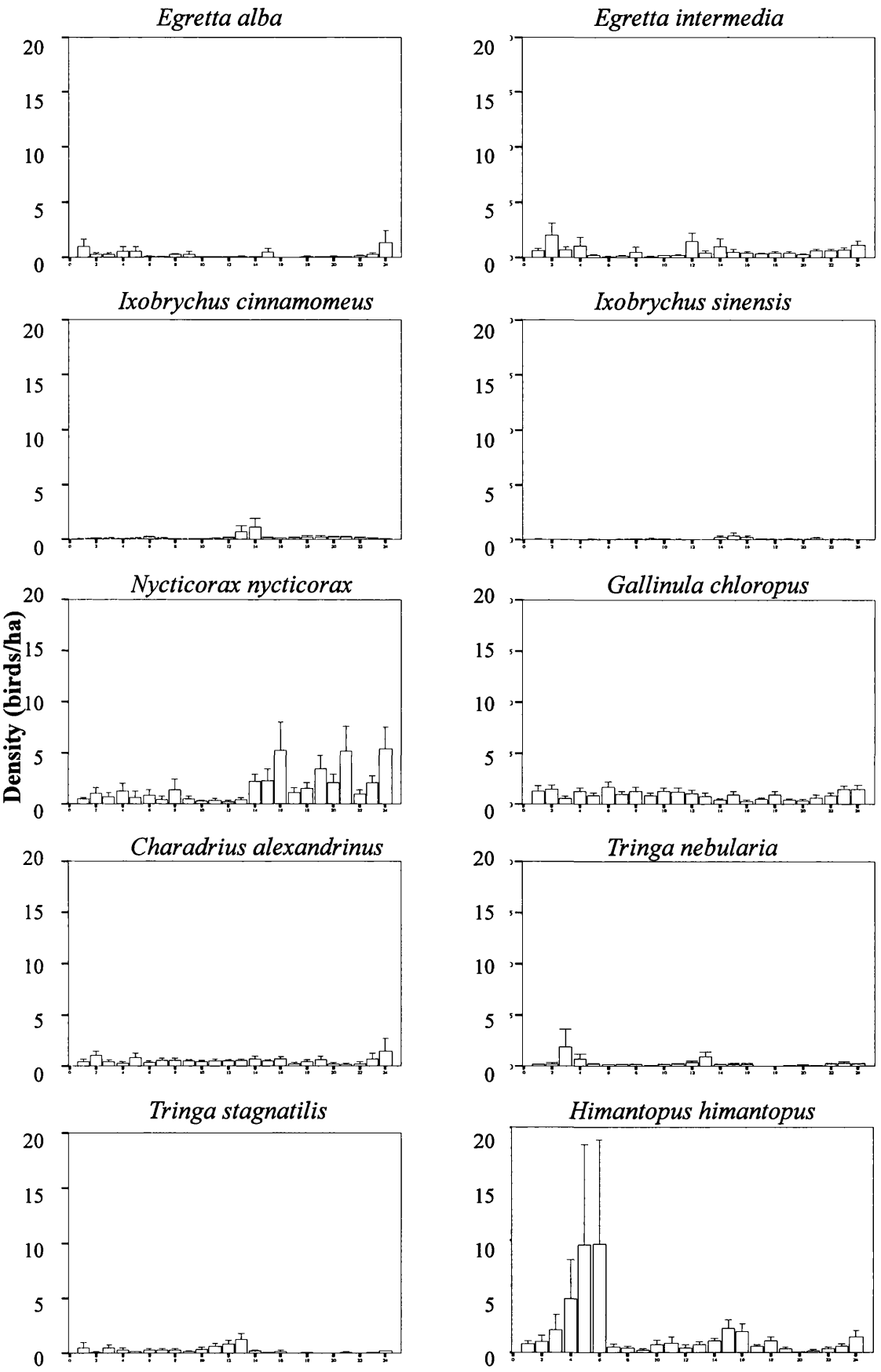


Figure 3.17. The mean abundance of *Egretta alba*, *Egretta intermedia*, *Ixobrychus cinnamomeus*, *Ixobrychus sinensis*, *Nycticorax nycticorax*, *Gallinula chloropus*, *Charadrius alexandrinus*, *Tringa nebularia*, *Tringa stagnatilis* and *Himantopus himantopus* per pond at a 15-day interval in the temporarily abandoned ponds. Error bars represent the standard error of the mean.

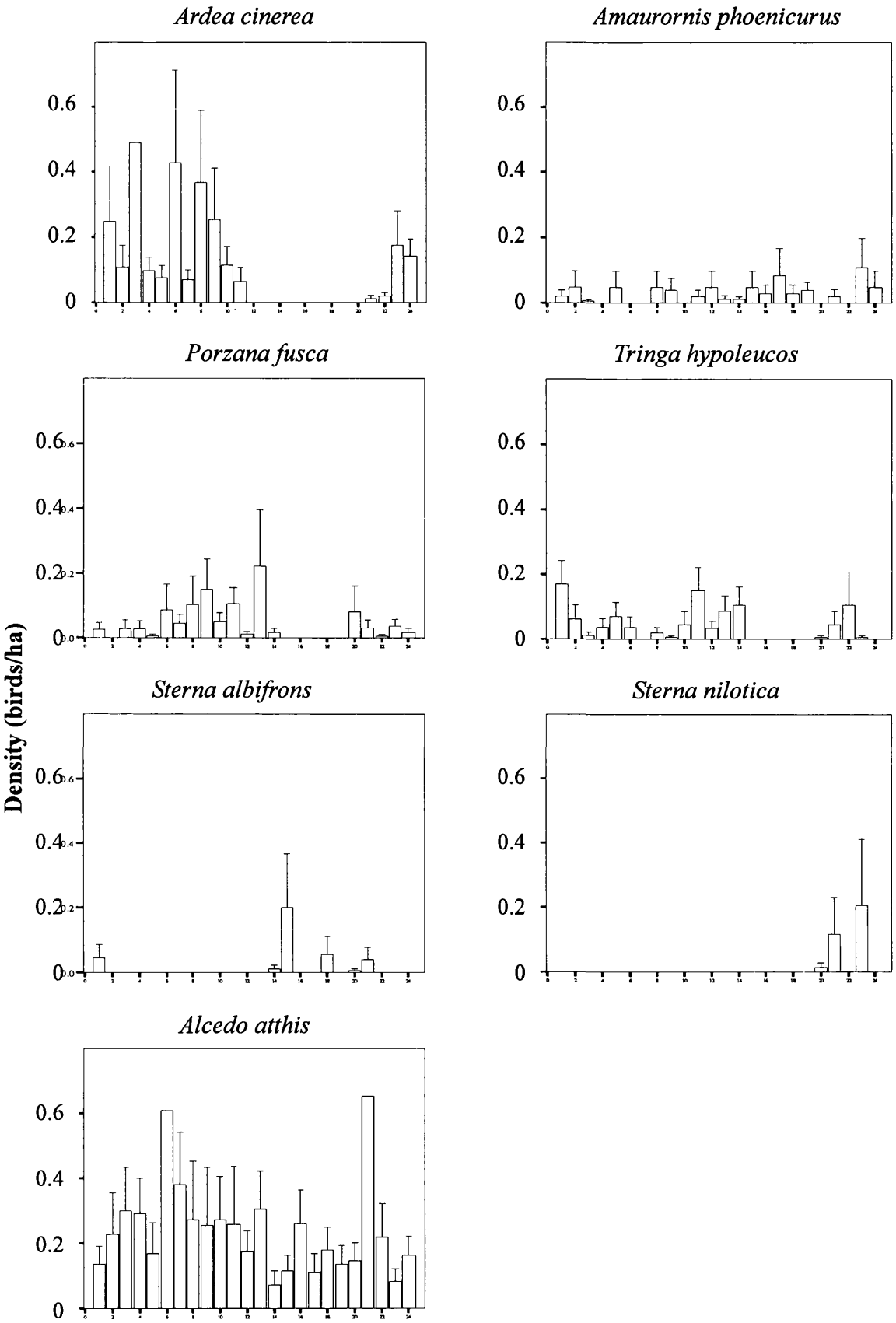


Figure 3.18. The mean abundance of *Ardea cinerea*, *Amaurornis phoenicurus*, *Porzana fusca*, *Tringa hypoleucos*, *Sterna albifrons*, *Sterna nilotica* and *Alcedo atthis* per pond at a 15-day interval in the temporarily abandoned ponds. Error bars represent the standard error of the mean.

The species that occurred on the saltpans principally consisted of egrets and waders, especially wader species. These species include the waders *Calidris alpina*, *Calidris ruficollis*, *Charadrius alexandrinus*, *Charadrius dubius*, *Calidris temminckii*, and the egrets *Egretta garzetta*, *Egretta intermedia*, *Egretta alba*. (Figures 3.19 and 3.20). Only two species, *Egretta garzetta* and *Charadrius alexandrinus*, could be considered to be resident on the saltpans (Figure 3.19). In general, there were fixed monthly numbers of newly-arrived species, one to three species, throughout the year in saltpans. In contrast, loss of species principally occurred during two periods of time, primarily during the northbound migratory season, from March to May, and secondly during the southbound migratory season, from September to November. Most common species were wintering species and were normally present from August or September to April or May. These species consisted of *Charadrius dubius*, *Pluvialis dominica*, *Calidris ruficollis*, *Tringa nebularia* and *Calidris temminckii* (Figures 3.19 and 3.20).

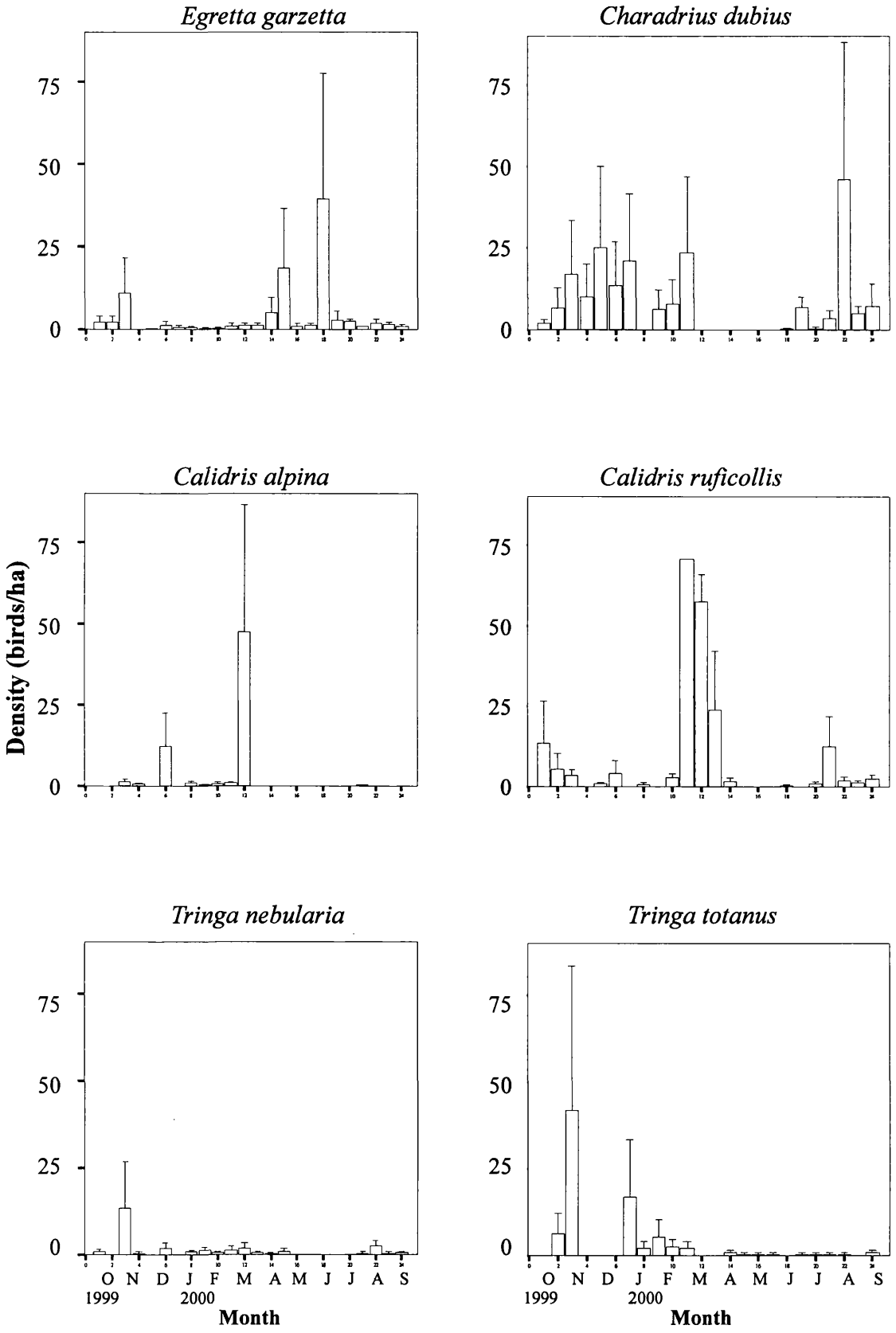


Figure 3.19. The mean abundance of *Egretta garzetta, Charadrius dubius, Calidris alpina, Calidris ruficollis, Tringa nebularia* and *Tringa totanus* per pond at a 15-day interval in saltpans. Error bars represent the standard error of the mean.

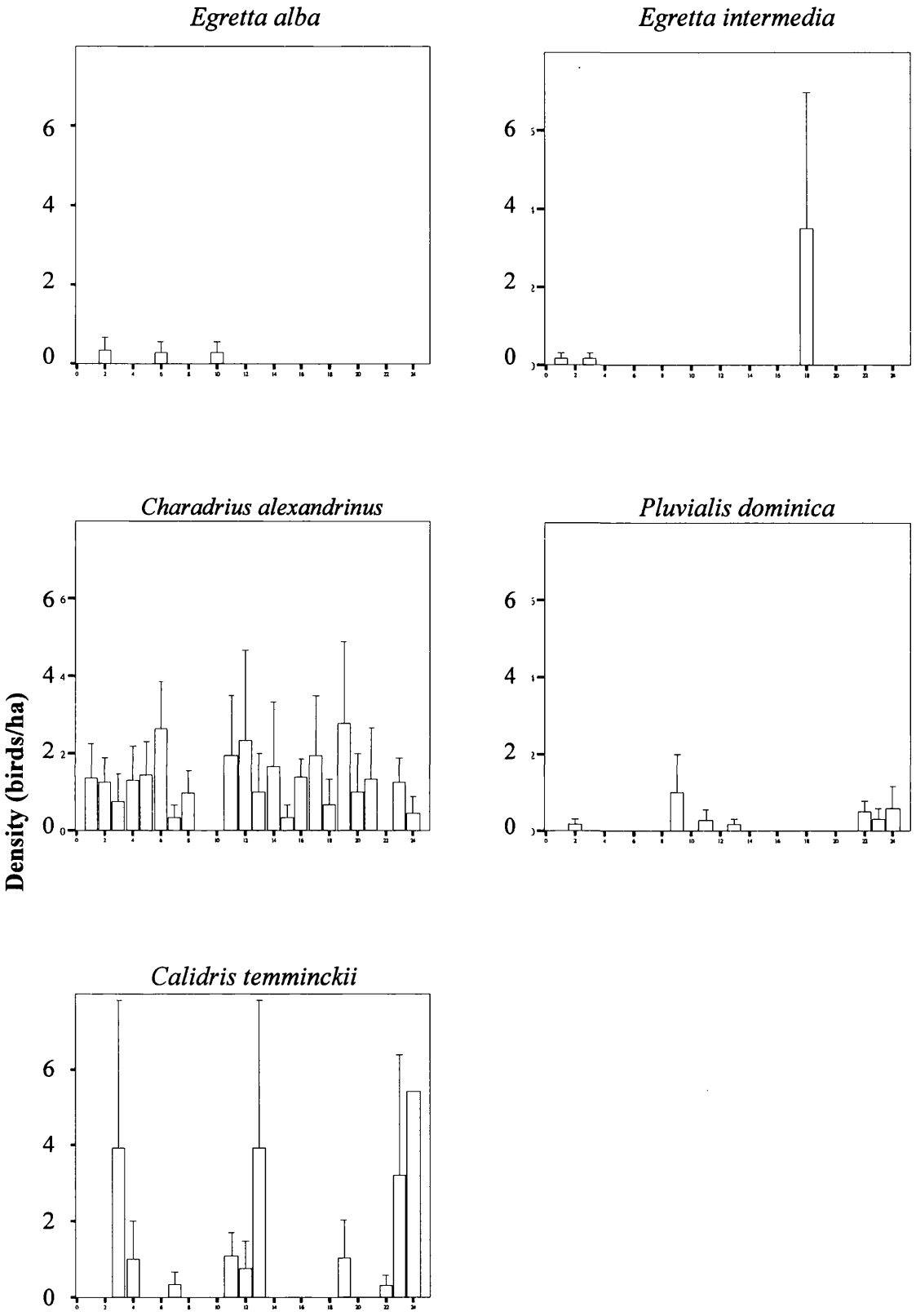


Figure 3.20. The mean abundance of *Egretta alba*, *Egretta intermedia*, *Charadrius alexandrinus*, *Pluvialis dominica*, and *Calidris temminckii* per pond at a 15-day interval in saltpans. Error bars represent the standard error of the mean.

Except for the duck species, the species composition in natural wetlands was similar to that in the temporarily abandoned ponds. Ten species are considered to be resident of natural wetlands. They include four wader species, *Charadrius alexandrinus*, *Pluvialis dominica*, *Calidris ruficollis* and *Tringa totanus*, three egret species, *Egretta garzetta*, *Egretta intermedia* and *Egretta alba*, and three other species, *Podiceps ruficollis*, *Gallinula chloropus* and *Alcedo atthis* (Figures 3.21 and 3.22).

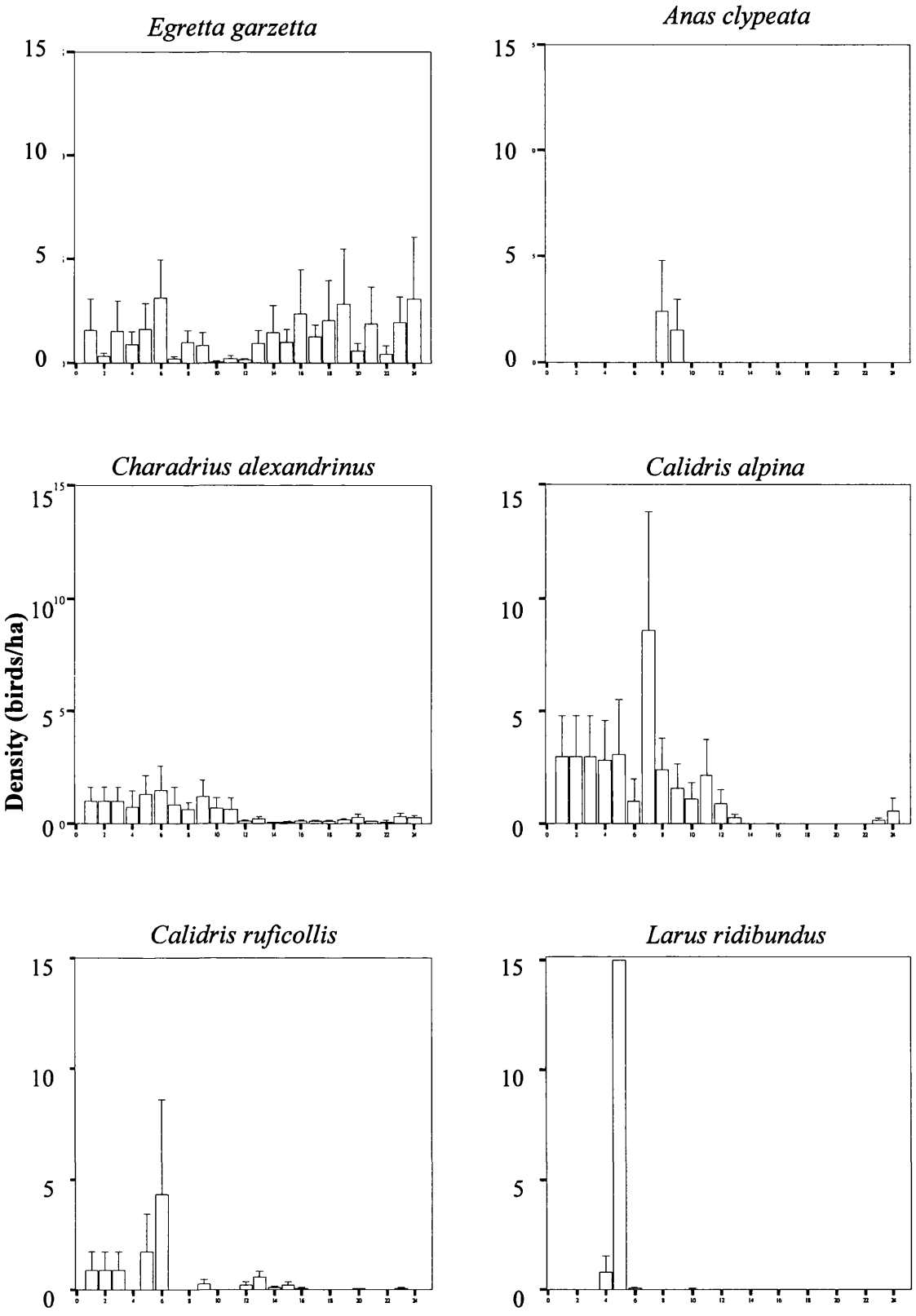


Figure 3.21. The mean abundance of *Egretta garzetta, Anas clypeata Charadrius alexandrinus, Calidris alpine, Calidris ruficollis* and *Larus ridibundus* per pond at a 15-day interval in natural wetlands. Error bars represent the standard error of the mean.

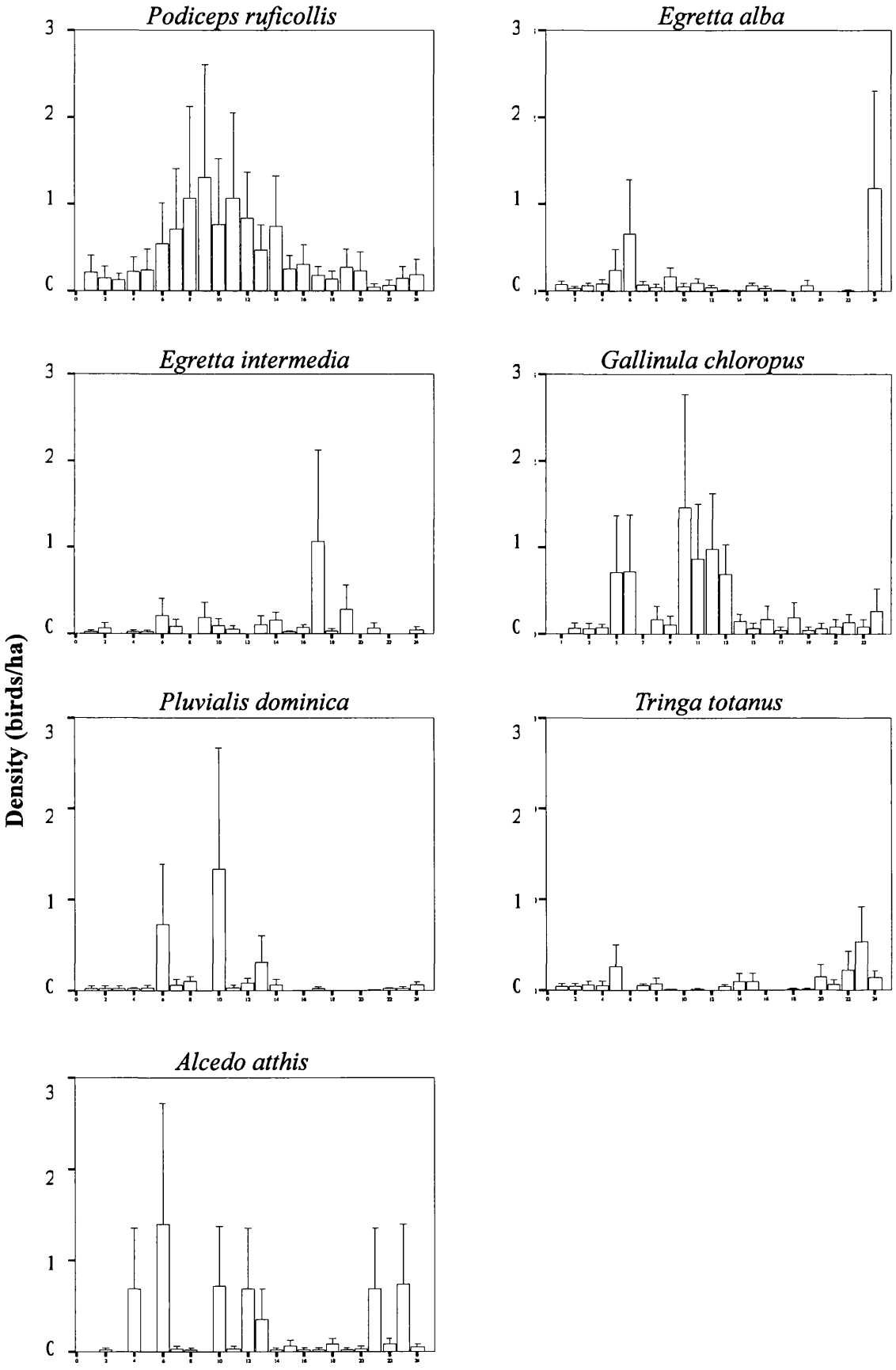


Figure 3.22. The mean abundance of *Podiceps ruficollis*, *Egretta alba*, *Egretta intermedia*, *Gallinula chloropus*, *Pluvialis dominica*, *Tringa totanus* and *Alcedo atthis* per pond at a 15-day interval in natural wetlands. Error bars represent the standard error of the mean.

Unlike the decrease in the species of waders in the temporarily abandoned ponds that started in March or April, the considerable decrease in the wader species in natural wetlands occurred in December when six waders species and two tern species were no longer present. These species include *Charadrius dubius, Pluvialis squatarola, Calidris acuminate, Limnodromus semipalmatus, Numenius arquata, Recurvirostra avosetta, Sterna caspia and Larus ridibundus* (Figure 3.23). From January to March, three duck species, including *Anas crecca*, *Anas poecilorhyncha* and *Anas clypeata,* appeared in the natural wetlands but they only occurred for one to three months (Figure 3.23).

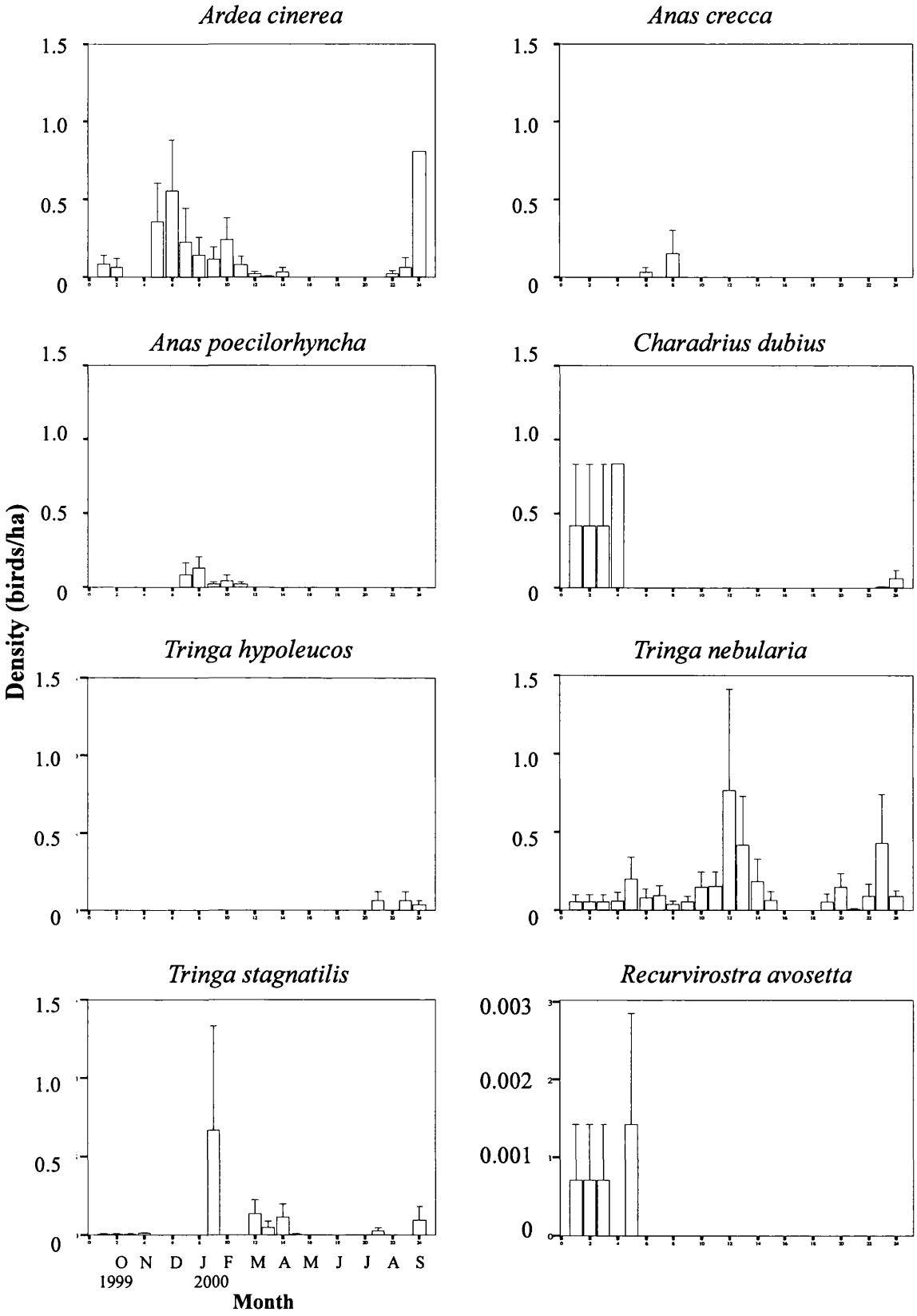


Figure 3.23. The mean abundance of *Ardea cinerea*, *Anas crecca*, *Anas poecilorhyncha*, *Charadrius dubius*, *Tringa hypoleucos*, *Tringa nebularia*, *Tringa stagnatilis* and *Recurvirostra avosetta* per pond at a 15-day interval in natural wetlands. Error bars represent the standard error of the mean.

3.4.1.3. Dominance in abundance

In order to know the dominance in abundance for individual species at a particular wetland type or age class category, the total number of birds recorded at that category for one particular species was divided by the total number of birds recorded for every species at that category. From this kind of calculation, *Calidris alpina* (18.6%, 24,471 birds) and *Anas crecca* (16%, 21,066 birds) were the most dominant species. They were only seasonally dominant from September to April. *Egretta garzetta* (9.3%, 12,201 birds) was the most common species for the next four months. However, of these three species, only *Egretta garzetta* shows significant variations in the 15-day-interval measurements of abundance (df=2,562, F=1.99, p=0.003**,). Its occurrence fluctuated to a considerable extent, although it remained relatively abundant throughout the year with peak values in October and November (Fig 3.12).

Apart from the resident species with significant seasonal variations in abundance, another eight resident species appeared at the aquaculture ponds. They include *Charadrius alexandrinus*, *Himantopus himantopus*, *Calidris ruficollis*, *Tringa totanus*, *Podiceps ruficollis*, *Egretta intermedia*, *Egretta alba* and *Alcedo atthis* (Figure 3.24). Of these species the first three species, *Charadrius alexandrinus*, *Himantopus himantopus*, *Calidris ruficollis*, could possibly include both resident and migrant individuals.

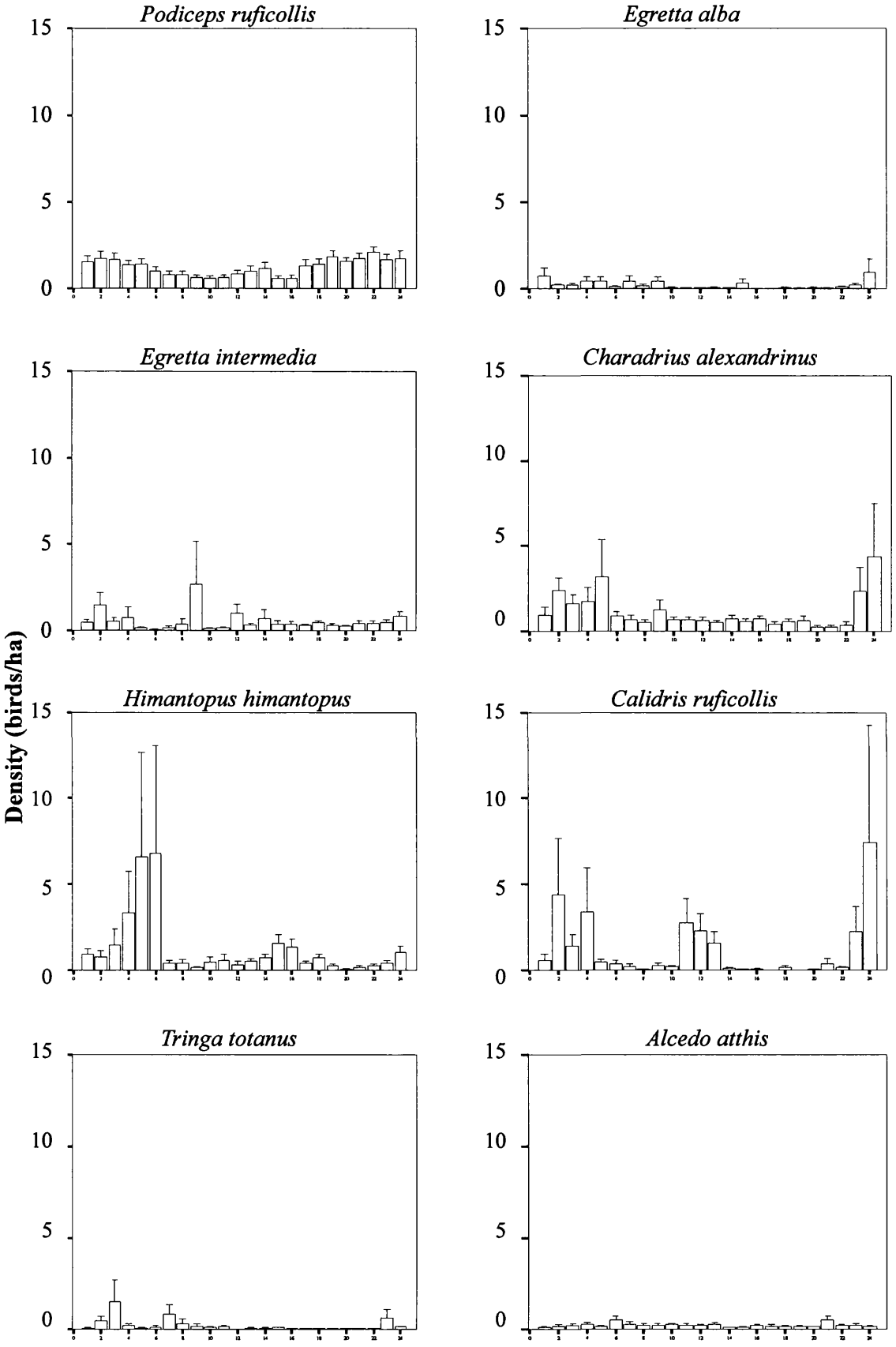


Figure 3.24. The mean abundance of *Podiceps ruficollis, Egretta alba, Egretta intermedia, Charadrius alexandrinus, Himantopus himantopus, Calidris ruficollis, Tringa totanus* and *Alcedo atthis* per pond at a 15-day interval in all sample ponds. Error bars represent the standard error of the mean.

3.4.1.3.1. Actively managed ponds

Three wader species, *Calidris alpina* (28.1%, 8,316 birds), *Calidris ruficollis* (27.7%, 8,193 birds) and *Charadrius alexandrinus* (18.1%, 5,364 birds), represented the majority of occurrence in the actively managed ponds and are particularly abundant from September to March or April, although *Charadrius alexandrinus* occurred all year round (Figure 3.14). However, only *Calidris alpina* exhibits significant variations in the 15-day-interval measurements of abundance ($p=0.02^*$, df=623). It shows a major peak during the southbound migratory season and a minor peak in March. The other two wader species also show similar fluctuation patterns, although their one-way ANOVAs do not show significant variations. From April to August, one of the most abundant resident species *Egretta garzetta* (8.7%, 2,577 birds) was the most abundant species in the actively managed ponds when most migrant species had departed for their breeding habitats (Figure 3.14).

3.4.1.3.2. Temporarily abandoned ponds

Among the 25 species with significant seasonal variations in the annual pattern of abundance, *Anas crecca* was the species with the most obvious fluctuation pattern. It was overwhelming abundant on the temporarily abandoned ponds although its abundance was seasonal (40%, 20,926 birds). From October to April, *Anas crecca* was often the most abundant species. *Egretta garzetta* (13.6%, 7,888 birds) became the most abundant species for the remainder of the year except in September, when *Egretta garzeta* was outnumbered by *Anas querquedula* (3.6%, 2,117 birds). These three abundant species all show significant variations in the 15-day-interval measurements of abundance. *Anas crecca* displays the temporal variation of a typical wintering species. It was frequently present from October to January and declined steadily thereafter. In contrast, *Anas querquedula* was a transient species, which showed a rapid numerical rise and fall within one or two months, with peak counts in September and October. *Egretta garzetta* shows a more complicated pattern that displays two indistinct peaks. The main peak was from September to November, and the minor one was from May to July (Figure 3.16).

Aside from these three aforementioned species, several species with significant variation pattern in the 15-day-interval occurrence are worthy of mention. Two duck species, *Anas penelope* (5.6%, 3,268 birds) and *Anas acuta* (7.3%,

4,230 birds), both only occurred from November to January with relatively high abundance (Figure 3.16). These two species, which show the pattern of transient species, had high abundance in the temporarily abandoned ponds and could be considered as their characteristic species. *Podiceps ruficollis* (4.9%, 2,878 birds) displays a smooth variation curve, which peaks in September and is smallest in February and March (Figure 3.16).

3.4.1.3.3.Saltpans

Two small-sized wader species, *Calidris ruficollis* (29.5%, 1,035 birds) and *Charadrius dubius* (17.9%, 630 birds) and an egret species, *Egretta garzetta* (13.2%, 462 birds), were the most abundant species in saltpans. *Calidris ruficollis* was the only abundant species that displays significant variations in the 15-day-interval measurements of abundance, and was present almost throughout the year, from August to May. It was most abundant in the early month of the northbound migratory season, from March to April and was also abundant during the southbound migratory season, between October and November (Figure 3.19).

3.4.1.3.4. Natural wetlands

Three wader species, *Calidris alpina* (37.3%, 15,138 birds), *Calidrius ruficollis* (16.0%, 6,508 birds) and *Charadrius alexandrinus* (13.6%, 5,530 birds), were the most abundant species in natural wetlands. *Calidris alpina* displays overwhelming abundance over other species. The most abundant egret species, *Egretta garzetta* (3.1%, 1,274 birds), which generally was one of the most abundant species in other wetland types, only shows relatively low abundance in natural wetlands. In summary, waders were the most abundant waterbirds in natural wetlands (Figure 3.21).

3.4.2.Chronosequences of avian attributes

One hundred and six temporarily abandoned ponds were used to determine the chronosequences of avian attributes, including the mean species richness and abundance per pond and the relative abundance of individual species. The selected sample ponds were classified into seven abandonment age classes, including 0-1 (N=144), 1-2 (N=312), 2-3 (N=168), 3-4 (N=168), 4-10 (N=168), 10-15 (N=696) and 15-20 (N=96) year age classes, to undertake the analyses of

chronosequence. The mean number of species per pond varied with abandonment time (one-way ANOVA, df=1,751, F=4.71, p=0.000**), but abundance did not (one-way ANOVA, df=1,751, F=0.66, p=0.679). This might indicate that the species richness of waterbird species increased with the abandonment time, but not the abundance of waterbirds. However, no obvious trend can be recognized in the chronosequences of the mean number of species per pond (Figure 3.25). There was no obvious trend in the chronosequence of abundance for most species, which show a high abundance at one or two age classes and remain constant for other age classes. However, one abundant species, *Bubulcus ibis,* shows different pattern, which displays a slow dome-shaped fluctuation pattern (Figure 3.26 and Table 3.4). *Podiceps rufficollis* and *Alcedo atthis* exhibit another pattern, which shows a decline trend in the first five younger age classes, then rose thereafter (Figure 3. 26 and Table 3.4).

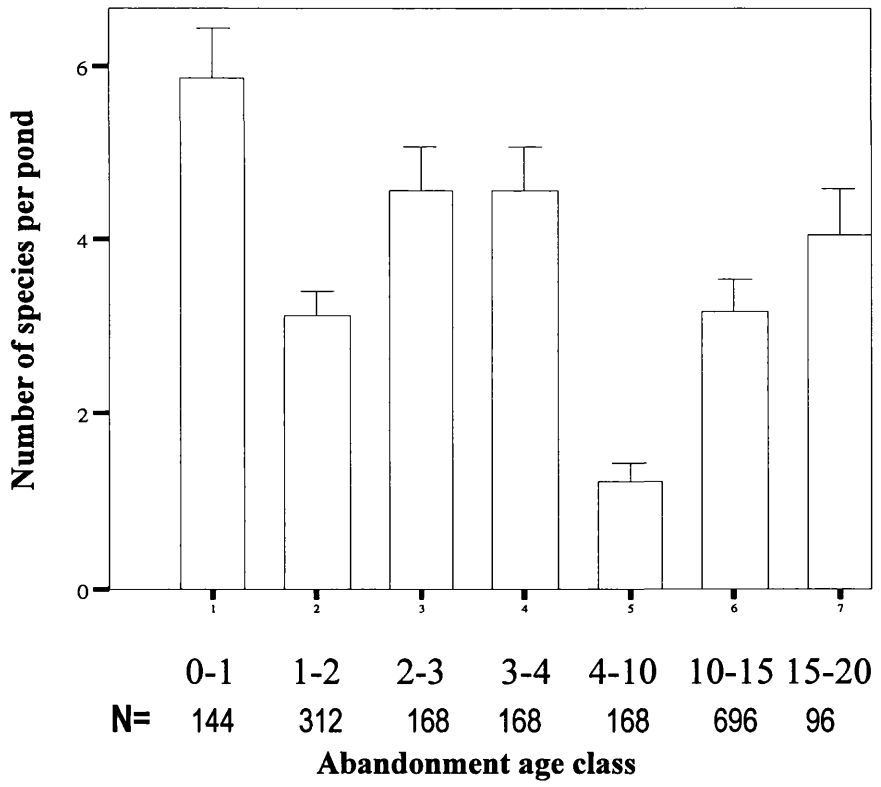


Figure 3.25. Chronosequence of the number of waterbird species per pond in the temporarily abandoned aquaculture ponds. Error bars represent the standard error of the mean.

Table 3.4. Summary of one-way ANOVAs and linear regression analyses of the abundance of several waterbird species versus abandonment time.

Species	Degrees of Freedom	F-value	Significance	Gradient coefficient	Intercept	Significance
Podiceps ruficollis	1,750	8.08	0.000**	0.03	1.367	0.045*
Bubulcus ibsi	1,751	3.83	0.001**	-0.02	0.317	0.001**
Alcedo atthis	1,751	11.06	0.000**	0.01	0.059	0.000**

P.S.: * means that p-value is no more than 5% and ** means that p-value is no more than 1%.

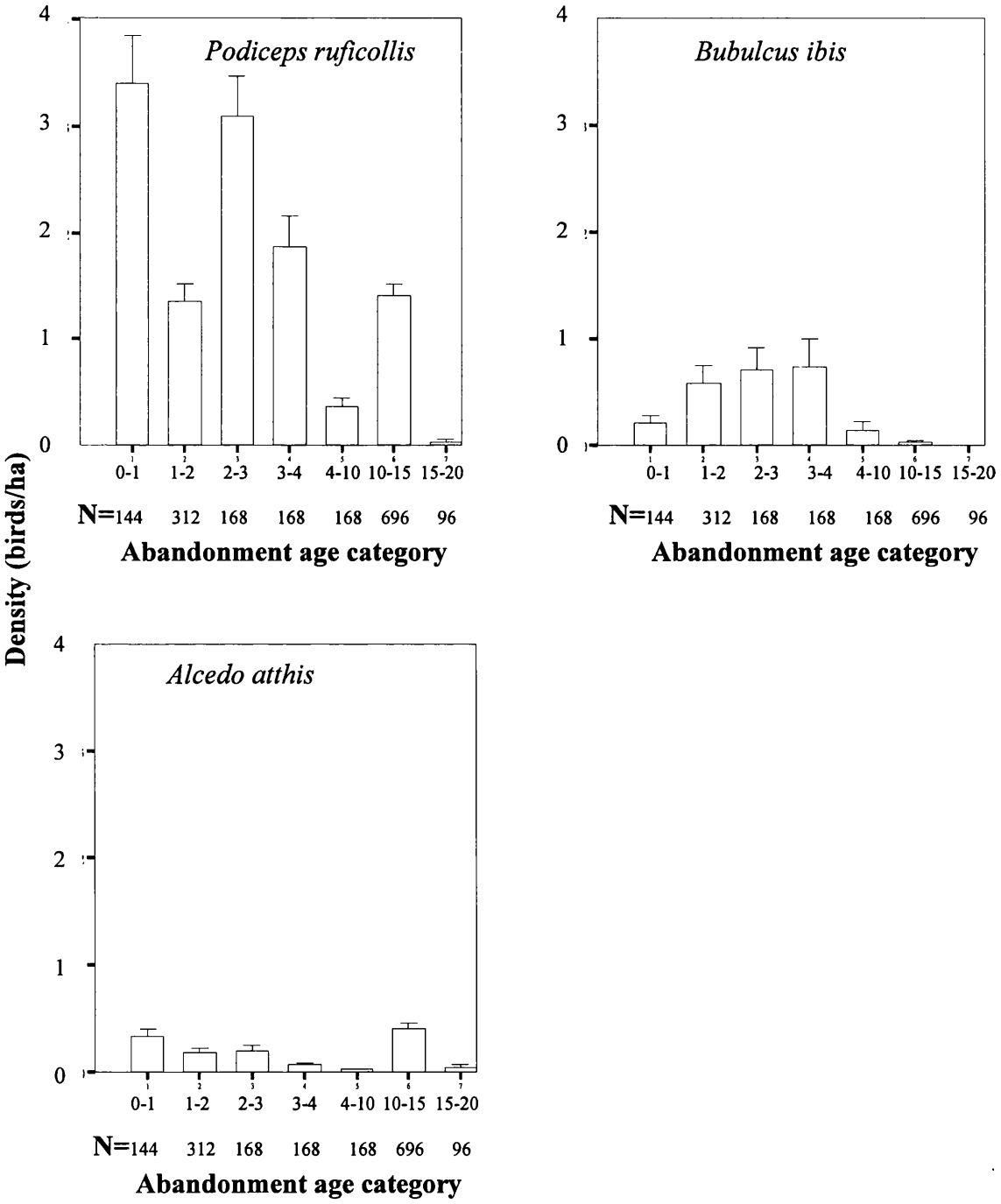


Figure 3.26. Chronosequence in the abundance of *Podiceps ruficollis*, *Bubulcus ibis* and *Alcedo atthis* per pond in the temporarily abandoned aquaculture ponds. Error bars represent the standard error of the mean.

3.4.2.1. Species composition

Along the abandonment time gradient, 25 out of 69 recorded waterbird species in the temporarily abandoned ponds show significant one-way ANOVAs in the abundance versus abandonment time. Among these 25 ANOVA significant species, 15 species shows significant variation in the independent samples t-test between younger ponds ($<$ 5 years old) and older ponds ($\geqq$ 5 years old), and the majority (12/15)of these 15 species peaked in the older ponds (Table 3.5). The 12 species which show significant variations for older ponds include mostly uncommon species. This relationship might indicate that older ponds are more attractive to uncommon species whose rare occurrence could be attributed to the specific habitat requirements only encountered in older aquacultural ponds.

Table 3.5. Summary of the mean abundance per age class for younger ponds (< 5 years old) and older ponds(≧ 5 years old), of 25 waterbird species which had a significant one-way ANOVA in the abundance versus abandonment time, and their independent T-tests between younger and older ponds.

Species	Mean		Degrees of Freedom	T-value	Significance
	Younger ponds	Older ponds			
Egretta garzetta	4.13(N=792)	4.81(N=960)	1,750	0.52	0.607
Charadrius alexandrinus	0.24(N=792)	1.04(N=960)	1,750	4.44	0.000**
Himantopus himantopus	2.41(N=792)	0.95(N=960)	1,750	-1.65	0.099
Podiceps ruficollis	1.40(N=792)	1.85(N=960)	1,749	2.34	0.019*
Nycticorax nycticorax	1.53(N=792)	1.17(N=960)	1,750	-1.01	0.313
Egretta intermedia	0.49(N=792)	1.12(N=960)	1,750	2.12	0.034*
Bubulcus ibsi	0.29(N=792)	0.08(N=960)	1,750	-3.44	0.001**
Gallinula chloropus	0.69(N=792)	0.48(N=960)	1,750	-2.56	0.011*
Ixobrychus cinnamomeus	0.05(N=792)	0.10(N=960)	1,750	2.56	0.010**
Ixobrychus sinensis	0.01(N=792)	0.03(N=960)	1,750	3.30	0.001**
Ardea cinerea	0.01(N=792)	0.33(N=960)	1,750	4.08	0.000**
Rostratula benghalensis	0.01(N=792)	0.01(N=960)	1,750	-0.75	0.452
Charadrius dubius	0.07(N=792)	0.31(N=960)	1,750	1.35	0.177
Pluvialis dominica	0.03(N=792)	0.27(N=960)	1,750	1.47	0.141
Calidris ruficollis	0.17(N=792)	0.45(N=960)	1,750	1.10	0.273
Tringa brevipes	0.00(N=792)	0.00(N=960)	1,750	1.58	0.115
Tringa hypoleucos	0.05(N=792)	0.02(N=960)	1,750	-2.43	0.015*
Alcedo atthis	0.07(N=792)	0.16(N=960)	1,750	4.63	0.000**
Porzana fusca	0.01(N=792)	0.03(N=960)	1,750	3.37	0.001**
Phalacrocora x carbo	0.00(N=792)	0.03(N=960)	1,750	3.05	0.002**
Ardea purpurea	0.00(N=792)	0.01(N=960)	1,750	3.20	0.001**
Circus aeruginosus	0.00(N=792)	0.01(N=960)	1,750	2.74	0.006**
Sterna leucoptera	0.02(N=792)	0.03(N=960)	1,750	0.21	0.831
Acrocephalus orientalis	0.00(N=792)	0.03(N=960)	1,750	3.33	0.001**
Limicola falcinellus	0.00(N=792)	0.00(N=960)	1,750	-1.48	0.140

P.S.: * means that p-value is no more than 5% and ** means that p-value is no more than 1%.

3.5. Discussion

There are a number of trends in avian attributes of active and abandoned ponds. The counts of most waterbird species show a single temporal peak in all sample ponds over time (Figures 3.10, 3.11 and 3.13). These trends could be caused by insufficient sampling or the coincidence between rare species and a particular age class category arising by chance rather than by any association with habitat preference. Accidentally falling into a pond age class is most likely to occur for the rare species. Long-term and periodic studies are recommended for collecting data for several abandoned ponds in order to elucidate trends in the habitat use of abandoned aquaculture ponds by waterbird species with abandonment time.

There is some evidence to support the proposition that actively managed ponds are a less used habitat for waterbirds than abandoned ponds. During the northbound migratory season, the loss of species in the actively managed ponds has been observed at other wetland types but without any corresponding increase in newly-arrived species (Table 3.3, Figures 3.3, 3.6 and 3.9). In addition, t tests show no increase in the number of waterbirds in the actively managed ponds during this migratory season. Such evidence suggests that the actively managed ponds offer a lower priority habitat for waterbirds (Independent samples t-test in the total number of waterbirds between up-to-three months before the northbound migratory season and this migratory season: **Active ponds**, $t_{257}=2.06$, $p=0.071$, **Temporarily abandoned ponds**, $t_{808}=2.71$, $p=0.007$**). The northbound migratory season is only for two months or so during which most waterbird species in the study area look to refuel quickly before their next migratory journey (Tsai, 1998; TCWBS, 1999; BSTP, 2000; Wang, 2000). In this short period are very likely to prioritise the wetland type in which abundant food resources can be exploited efficiently.

There is a clear differentiation in the habitat utilization of sample wetlands by duck species between wetland types. Ducks intensively used the abandoned aquaculture ponds and were present for the longest period among these wetland types (seven months) from October to April (Section 3.4.1.2.1). In comparison, they used actively managed ponds, natural wetlands and saltpans for five, three, zero months, respectively. In the actively managed ponds and temporarily abandoned ponds, ducks occurred from October but left actively managed ponds two months earlier. In natural wetlands, ducks even occurred as late as January. These relationships

suggest that there might be a habitat shift for ducks amongst these sample wetland types. When the ducks just arrived Taiwan in October from as far as Siberia or northern China, they almost only use aquaculture ponds, mainly temporarily abandoned ponds. From January, they start to explore natural wetlands as well. From March, they stop using actively managed ponds and then retreat from natural wetlands (April) and temporarily abandoned ponds (May) month by month (Figures 3.15, 3.16 and 3.25). More temporarily abandoned ponds are recommended to be included at a conservation site aiming to protect waterfowl. However, this inference should be treated with caution due to insufficient sample sizes in natural wetlands. Ducks display a similar seven-month presence a year in the study conducted by Birds Society in Taiwan Province (BSTP, 2000) in a mosaic of artificial and natural wetlands in western Taiwan. This might suggest that seven months could be the typical wintering stay for duck species in the study area. A shorter stay than seven months in a particular wetland type might imply the availability of a less diversified environment.

Variation of occurrence between the wetland types for individual egret species might be attributable to their distinct adaptation ability. Egret species are all carnivores and normally feed on a wide range of prey, and can be viewed as generalists in terms of their feeding habitats (Cramp & Simmons, 1977; del Hoyo *et al.*, 1992). Amongst the egret species in the sample wetlands, *Egretta garzetta* displayed a more general habitat requirement than other egret species, and was the most abundant egret species in the study area. It showed a high abundance throughout the year (Figure 3.12). This could result from their exceptional ability to adapt to a wide range of habitats and higher tolerance to human disturbance. During the routine drainage practice for harvesting in the actively managed ponds, *Egretta garzetta* stayed a relatively short distance, less than 20 metres in most instances, to people that were dealing with the drainage practice and continued consuming small fish that had been exposed when the water level was drawn down. In contrast, *Egretta alba,* a relatively shy egret species, is frightened away rather easily and takes longer time than *Egretta garzetta* to come back to the same pond. *Egretta alba* principally used natural wetlands but not artificial wetlands (Figure 3.14, 3.17, 3.20 and 3.22). Its overall abundance was much less than *Egretta garzetta.* In the study area, artificial wetlands such as aquaculture ponds and saltpans, were prevailing. The high ability to adapt to human to human-altered wetlands could result in the considerable abundance of *Egretta garzetta*

and its ecological success. In contrast, the fewer occurrences of *Egretta alba* could be attributed to its specific habitat requirements and smaller tolerance to human disturbance. This suggests that *Egretta alba* is a vulnerable species, and much more management effort is necessary to fulfill its habitat requirements than other common egret species such as *Egretta garzetta*.

Chapter 4

Guild classification, species composition and commonness of waterbird species

4.1. Introduction

Apart from the chronological changes in avian community and the physical features of temporarily abandoned wetlands, knowledge of species aggregations in waterbirds and their variations among wetland types and the abandonment age classes is necessary to clarify the intricate relationship between avian use and the features of aquaculture ponds. From the viewpoint of site managers, habitat requirements for every species are unlikely to be met simultaneously. The conflicts between these requirements will be particularly acute when numerous specific requirements of birds are considered. While trying to meet many of the specific needs of waterbirds at conservation sites, conflicting management practices might be encountered For instance, a depth of <5 cm and >30 cm is to be maintained at one pond to meet the individual habitat requirements of two guilds of waterbirds. Consequently, it is necessary to be pragmatic and only the habitat requirements of larger groups of species that share similar habitat requirements defined as guilds should be considered.

Furthermore, evaluation of habitat quality, subsequent management practices and the alteration of the habitats suitable to meet the habitat requirements of waterbirds will require considerable financial support. Taking account of all the requirements of waterbirds will therefore become even more difficult to achieve with an inadequate budget, by which, and compromises will need to be made by site managers.

In short, guild classification of waterbirds is crucial for a pragmatic approach to the management of aquaculture ponds of Taiwan and should be undertaken early on in the management planning process. This chapter deals principally with four avian attributes, namely guild classification of waterbirds, species composition, dominance in the number of waterbirds and their spatial distribution.

4.2. Methods

4.2.1. Sampling

Data from all sample ponds were used to conduct the overall guild classification and the calculation of spatial distribution of individual species. However, in order to eliminate bias caused by different sampling frequencies, only sample wetlands which had complete recordings for an entire year were used to determine guild classification, number and proportion of waterbirds among wetland types and age

classes. Avian variables such as the number of species, relative abundance and distribution of waterbirds, were measured for an entire year at a 15-day interval from October 1999 to September 2000.

4.2.2. Environmental and avian variables of sample wetlands

Information from environmental and avian attributes of aquaculture ponds contribute to guild classification of waterbirds.

Environmental attributes: These are the same as those discussed in section 2.2.2. (page 46)

Avian attributes: These include the number of species, species composition and the number of waterbirds for each species, all of which were measured at a 15-day interval for an entire year. Observation time and investigation methods are the same as 3.2.2. "Optimal time for observation" (page 95) and 3.2.3. "Investigation" (page 96) in Chapter 3.

Spatial distribution: The proportion of sample ponds with a particular species present is defined as spatial distribution of that species. This measurement for each species in each sample wetland was recorded at a 15-day interval. This information is used to understand the distribution pattern of waterbird species. Spatial distribution of individual species in this study is viewed as part of the range of distribution for that species.

4.3. Statistical analysis

CANOCO for Windows 4.0, a statistical software package that aims at dealing with ordination data, was employed to analyse the relationship between avian use and features of sample wetlands. Detrended correspondence analysis (DCA) with non-linear rescaling and detrending-by-segment axes was then used to identify the length of gradient in the avian data (Weckström & Korhola, 2001). Direct correspondence analysis methods, either redundancy analysis (RDA) or canonical correspondence analysis (CCA), were used to plot the species aggregation biplots. RDA was used to conduct the analysis if gradient length was less than 1.5 S.D. (standard deviation). In contrast, CCA was used if gradient length was more than 3 S.D. Either RDA or CCA produced satisfactory species-environmental biplots if the gradient length fell between 1.5 and 3.0 S.D (Ter Braak & Prentice, 1988). Several

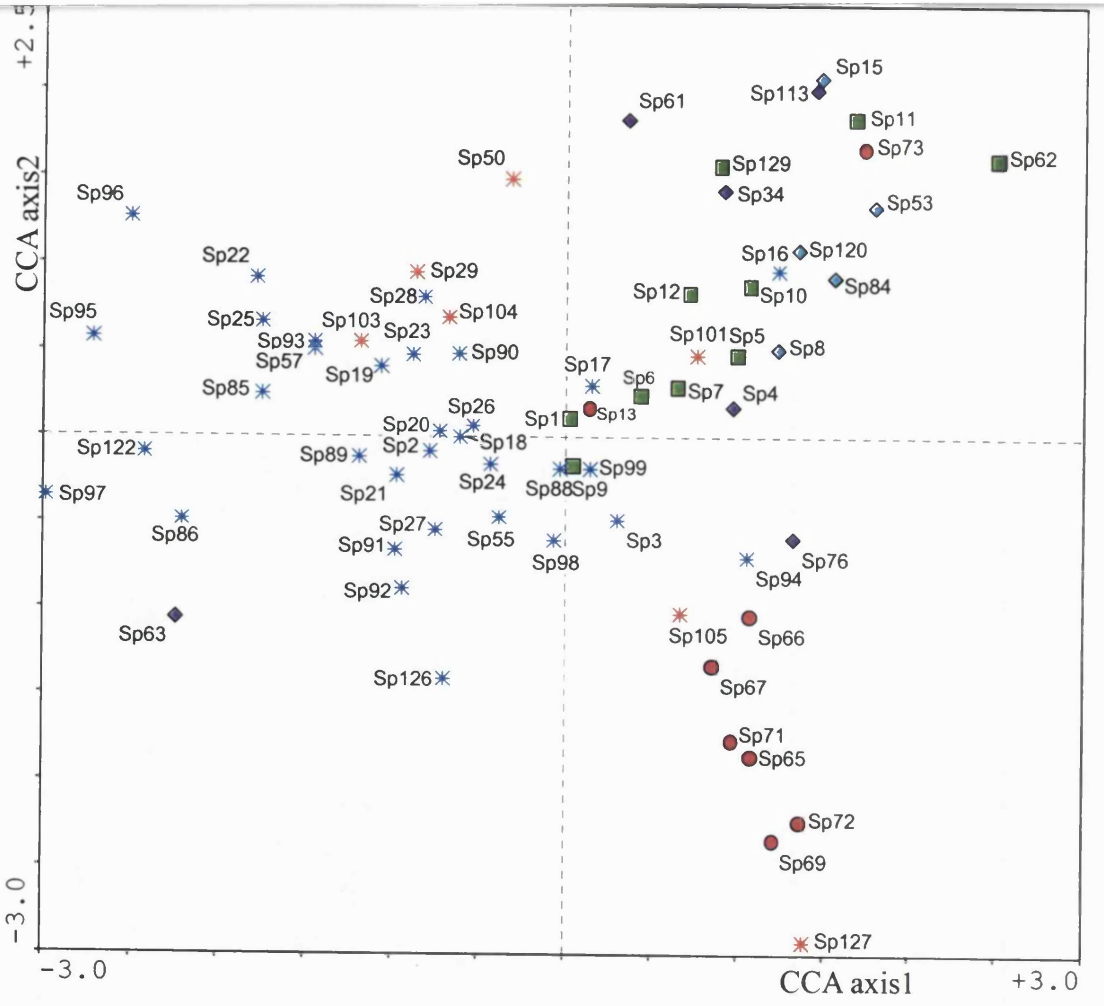
species aggregation plots with the scale of inter-species distance were produced using CanoDraw, which is the auxiliary software of CANOCO and was mainly designed for the production of result plots. Species were plotted using environmental and avian attributes of sample wetlands as factors. Species with similar habitat requirements will lie close together in the plot. According to the interpretation guidelines for CANOCO ordination, the species that lie near the origin of the plot do not have strong associations with any of investigated environmental attributes (Ter Braak & Prentice, 1988). This might suggest that these species did not have specific environmental requirements and therefore could adapt to a wide range of habitat niches. In contrast, species that occur far from the origin of the ordination have strong associations with the investigated environmental attributes, and suggest that they have more specific environmental requirements (Ter Braak & Prentice, 1988). This type of plot allows researchers to classify the overall species assemblage of waterbirds into several guilds, which are defined as group of species using a habitat in a similar way.

In order to understand the variations in species composition among wetland types, a 4×6 contingency table and a chi-square test were applied using four types of habitats and six categories of waterbird species. The 4x6 contingency table helps to indicate the categories of waterbirds with obvious differences from expectation by chance, while chi-square tests help to judge the statistically significant variations in the overall variations in the species composition among wetland types. The Shannon diversity index was employed to estimate the species diversity of all sample ponds (Melvin & Webb, 1998). The Shannon diversity index lays more weight on rare species (Odum, 1975; Krebs, 1989). Rare species are the major concerns for the site managers who are aiming to maintain a higher diversity in the biotic community at their managed sites. Furthermore, rare species are rather likely to be crucial in a changing ecosystem such as in aquaculture ponds. Their rarity could be caused by human activities, so these species require to be managed with extra effort. One-way ANOVA was used to assess the difference in the species diversity index among wetland types. In addition, student t test was employed to reveal the difference in the species diversity index between two individual wetland types.

4.4. Results

4.4.1 Guild classification of waterbirds

Avian and environmental measurements of 164 sample sites were collectively used to conduct the correspondence analyses using CANOCO software. Due to various sampling frequencies, each sample pond was given a different weighting according to its sampling frequency. As demonstrated by the species aggregation plot, three large aggregates of waterbird species can be identified: Duck, Egret-Rail and Wader-Tern (Figure 4.1). The duck group in particular shows an obviously different clustering pattern from the other two species groups. The three major groups of species are less distinct at the origin of the plot.



Waders:
sp2 *Charadrius alexandrinus* sp3 *Himantopus himantopus*
sp16 *Rostratula benghalensis* sp17 *Glareola maldivarum*
sp18 *Charadrius dubius* sp19 *Charadrius mongolus*
sp20 *Pluvialis dominica* sp21 *Calidris ruficollis*
sp22 *Calidris canutus* sp23 *Xenus cinereus*
sp24 *Tringa nebularia* sp25 *Tringa brevipes*
sp26 *Tringa totanus* sp27 *Phalaropus lobatus*
sp28 *Tringa hypoleucos* sp55 *Tringa stagnatilis*
sp57 *Arenaria interpres* sp85 *Charadrius leschenaultii*
sp86 *Pluvialis squatarola* sp88 *Calidris acuminata*
sp89 *Calidris alpina* sp90 *Calidris ferruginea*
sp91 *Calidris subminuta* sp92 *Calidris temminckii*
sp93 *Calidris tenuirostris* sp94 *Gallinago gallinago*
sp95 *Limosa lapponica* sp96 *Numenius arquata*
sp97 *Numenius phaeopus* sp98 *Tringa glareola*
sp99 *Tringa ochropus* sp122 *Limnodromus semipalmatus*
sp126 *Philomachus pugnax*

Gulls and Terns:
sp29 *Sterna albifrons* sp50 *Larus saundersi*
sp101 *Larus ridibundus* sp103 *Sterna hirundo*
sp104 *Sterna hybrida* sp105 *Sterna leucoptera*
sp127 *Sterna nilotica*

Egrets and Herons:
sp1 *Egretta garzetta* sp5 *Nycticorax nycticorax*
sp6 *Egretta intermedia* sp7 *Bubulcus ibis*
sp9 *Egretta alba* sp10 *Ixobrychus cinnamomeus*
sp11 *Ixobrychus sinensis* sp12 *Ardea cinerea*
sp62 *Ardea purpurea* sp129 *Butorides striatus*

Rails and Crakes:
sp8 *Gallinula chloropus* sp15 *Amaurornis phoenicurus*
sp53 *Porzana fusca* sp84 *Rallus striatus*
sp120 *Fulica atra*

Ducks:
sp13 *Anas poecilorhyncha* sp65 *Anas acuta*
sp66 *Anas clypeata* sp67 *Anas crecca*
sp69 *Anas Penelope* sp71 *Anas querquedula*
sp72 *Anas strepera* sp73 *Aythya fuligula*

Miscellaneous species:
sp4 *Podiceps ruficollis* sp34 *Alcedo atthis*
sp61 *Phalacrocorax carbo* sp63 *Platalea minor*
sp64 *Threskiornis aethiopicus* sp76 *Circus aeruginosus*
sp113 *Acrocephalus orientalis*

Figure 4.1. The aggregation biplot of water bird species based on a canonical correspondence analysis (CCA) using the avian and environmental data of all sample ponds. Different taxonomic groups of species of water birds are marked with different symbols.

Anas poecilorhyncha and especially *Aythya fuligula*, which were categorized into the Egret-Rail group, are particularly distant from the remaining Anatidae and were therefore not included in the Duck guild although they are taxonomically members of the Anatidae (Figure 4.1).

In the Egret-Rail guild, one minor group is more distant from the remaining species of this guild. Several species comprise the distinct minor group, including two egret species, *Ixobrychus sinensis* and *Ardea purpurea*; two rail species, *Amaurornis phoenicurus* and *Porzana fusca*; a duck species, *Aythya fuligula*; and two miscellaneous species, *Acrocephalus orientalis* and *Threskiornis aethiopicus* (neither waders, ducks, egrets, rails, terns or gulls). *Threskiornis aethiopicus* can be viewed as an outliner, which shows an obvious distance from the remaining species in the ordination plot and was not classified as a member of any of the three main guilds. The other minor group includes the majority of the Egret-Rail guild with seven egret species, three rail species and three miscellaneous species. In fact, most of the miscellaneous species are included in the Egret-Rail guild.

The Wader-Tern guild shows a more aggregated pattern than the other two guilds, although it contains 36 species, the largest number of species among the three guilds. These species includes 31 wader species, four tern or gull species and one miscellaneous species. Within the Wader-Tern guild, several species are relatively remote from the majority of species in this guild: *Limosa lapponica*, *Numenius arquata*, *Numenius phaeopus*, *Sterna caspia*, *Limnodromus semipalmatus*, *Pluvialis squatarola* and *Platalea minor*. With respect to terns and gulls, four species, *Larus saundersi*, *Sterna albifrons*, *Sterna hirundo* and *Sterna hybrida*, are closely associated with the remaining species of the Wader-Tern guild. Three tern or gull species are closely associated with two other guilds and should be considered as members of that guild (the Duck guild, *Sterna leucoptera* and *Sterna nilotica*; the Egret-Rail guild, *Larus ridibundus*) (Figure 4.1).

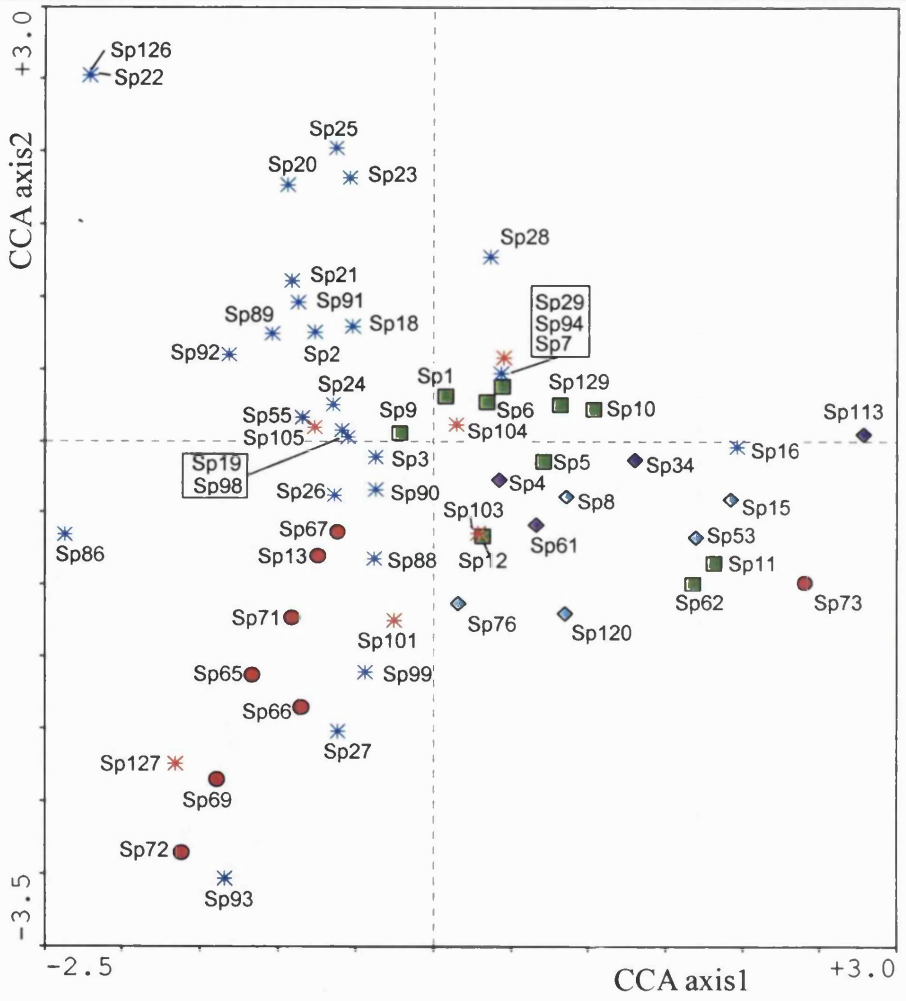
In short, the overall species assemblage of waterbirds can be classified into three guilds, Duck, Egret-Rail and Wader-Tern. The Egret-Rail guild is further divided into two sub-guilds. Nevertheless, the three main guilds of waterbirds are not distinctly separated at the origin of the species aggregation plot (Figure 4.1).

In addition to the above guild classification of waterbirds, analysis of the variations in the species aggregations among wetland categories such as wetland types and abandonment age classes, all help to compare the clustering pattern and relative importance of waterbird species among these wetland categories.

4.4.1.1. Variations among wetland types

Four wetland types: actively managed ponds, temporarily abandoned ponds, saltpans and natural wetlands, were separately analysed to reveal the species aggregation pattern of waterbirds in wetland types. However, no significant result was produced from the ordination analyses in saltpans or natural wetlands due to small sample sizes. Therefore, only actively managed ponds and temporarily abandoned ponds are discussed in this section.

From Figure 4.2, the clustering pattern of waterbirds in the temporarily abandoned ponds is similar to that observed in all sample ponds. As with the overall dataset three groups of waterbird species can be identified, Wader-Tern, Duck and Egret-Rail. In contrast, the species of waterbirds present in the actively managed ponds are mostly clustered at the origin of the plot, although several species, including most duck species and the miscellaneous species, are more dispersed (Figure 4.3). In comparison with wader species, egret species are relatively loosely clustered and overlapped slightly with wader species in the actively managed ponds. Duck species are distinctly separated from other species in the ordination and are widely dispersed in the actively managed ponds. *Anas poecilorhyncha* is the only duck species that was found amongst the main species assemblage (mostly wader species).



Waders:

sp2	*Charadrius alexandrinus*	sp3	*Himantopus himantopus*
sp16	*Rostratula benghalensis*	sp18	*Charadrius dubius*
sp19	*Charadrius mongolus*	sp20	*Pluvialis dominica*
sp21	*Calidris ruficollis*	sp23	*Xenus cinereus*
sp24	*Tringa nebularia*	sp25	*Tringa brevipes*
sp26	*Tringa totanus*	sp27	*Phalaropus lobatus*
sp28	*Tringa hypoleucos*	sp55	*Tringa stagnatilis*
sp86	*Pluvialis squatarola*	sp88	*Calidris acuminata*
sp89	*Calidris alpina*	sp90	*Calidris ferruginea*
sp91	*Calidris subminuta*	sp92	*Calidris temminckii*
sp93	*Calidris tenuirostris*	sp94	*Gallinago gallinago*
sp98	*Tringa glareola*	sp99	*Tringa ochropus*
sp126	*Philomachus pugnax*		

Gulls and Terns:

sp29	*Sterna albifrons*	sp101	*Larus ridibundus*
sp103	*Sterna hirundo*	sp104	*Sterna hybrida*
sp105	*Sterna leucoptera*	sp127	*Sterna nilotica*

Egrets and Herons:

sp1	*Egretta garzetta*	sp5	*Nycticorax nycticorax*
sp6	*Egretta intermedia*	sp7	*Bubulcus ibis*
sp9	*Egretta alba*	sp10	*Ixobrychus cinnamomeus*
sp11	*Ixobrychus sinensis*	sp12	*Ardea cinerea*
sp62	*Ardea purpurea*	sp129	*Butorides striatus*

Rails and Crakes:

sp8	*Gallinula chloropus*	sp15	*Amaurornis phoenicurus*
sp53	*Porzana fusca*	sp120	*Fulica atra*

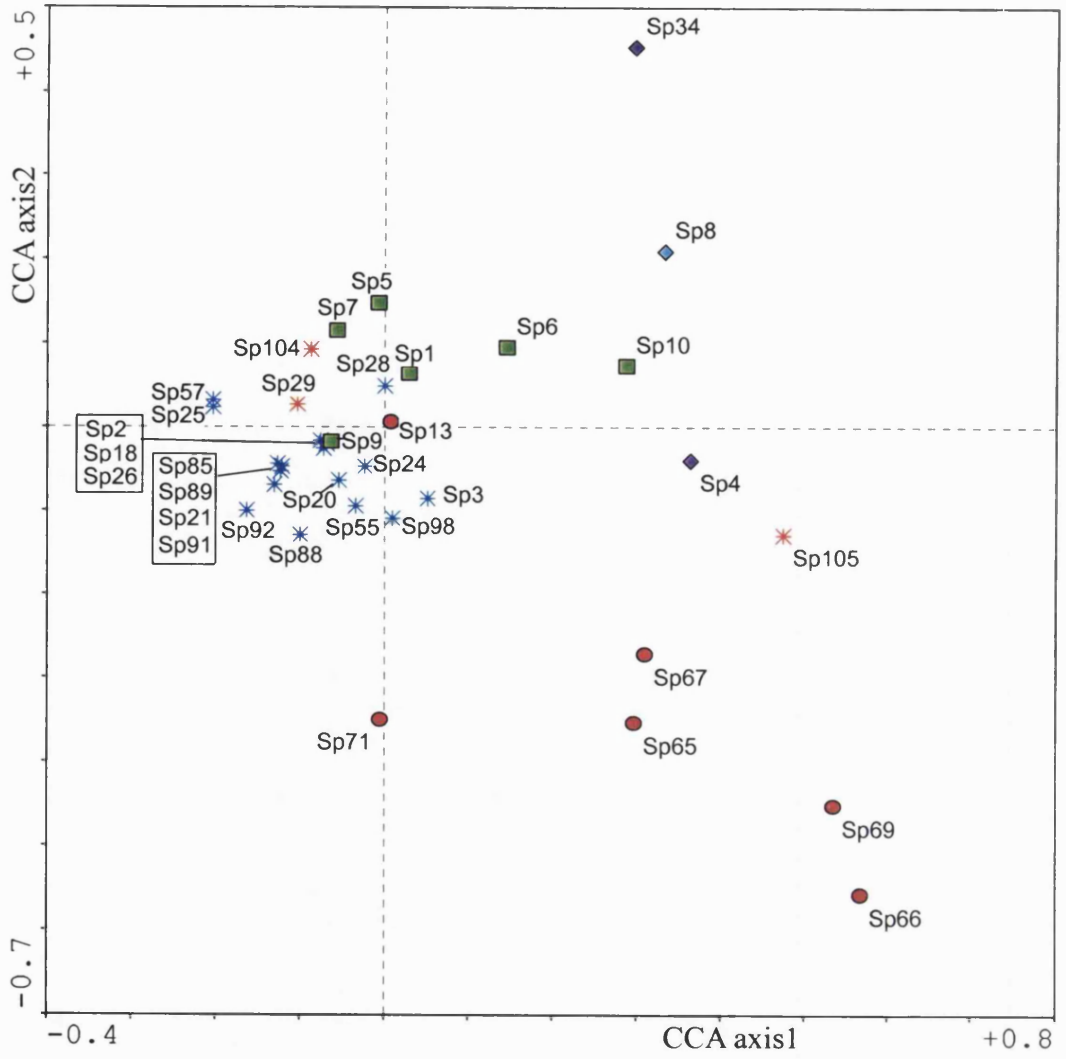
Ducks:

sp13	*Anas poecilorhyncha*	sp65	*Anas acuta*
sp66	*Anas clypeata*	sp67	*Anas crecca*
sp69	*Anas Penelope*	sp71	*Anas querquedula*
sp72	*Anas strepera*	sp73	*Aythya fuligula*

Miscellaneous species:

sp4	*Podiceps ruficollis*	sp34	*Alcedo atthis*
sp61	*Phalacrocorax carbo*	sp76	*Circus aeruginosus*
sp113	*Acrocephalus orientalis*		

Figure 4.2. The aggregation biplot of water bird species based on a canonical correspondence analysis (CCA) using the avian and environmental data of the temporarily abandoned aquaculture ponds. Different taxonomic groups of species of water birds are marked with different symbols.



Waders:
sp2 *Charadrius alexandrinus* sp3 *Himantopus himantopus*
sp18 *Charadrius dubius* sp19 *Charadrius mongolus*
sp20 *Pluvialis dominica* sp21 *Calidris ruficollis*
sp22 *Calidris canutus* sp23 *Xenus cinereus*
sp24 *Tringa nebularia* sp25 *Tringa brevipes*
sp26 *Tringa totanus* sp27 *Phalaropus lobatus*
sp28 *Tringa hypoleucos* sp55 *Tringa stagnatilis*
sp57 *Arenaria interpres* sp85 *Charadrius leschenaultii*
sp86 *Pluvialis squatarola* sp89 *Calidris alpina*
sp90 *Calidris ferruginea* sp93 *Calidris tenuirostris*
sp95 *Limosa lapponica* sp96 *Numenius arquata*
sp97 *Numenius phaeopus* sp98 *Tringa glareola*
sp99 *Tringa ochropus* sp122 *Limnodromus semipalmatus*

Gulls and Terns:
sp29 *Sterna albifrons* sp101 *Larus ridibundus*
sp103 *Sterna hirundo* sp104 *Sterna hybrida*
sp105 *Sterna leucoptera* sp127 *Sterna nilotica*

Egrets and Herons:
sp1 *Egretta garzetta* sp5 *Nycticorax nycticorax*
sp6 *Egretta intermedia* sp7 *Bubulcus ibis*
sp9 *Egretta alba* sp10 *Ixobrychus cinnamomeus*
sp11 *Ixobrychus sinensis* sp12 *Ardea cinerea*
sp62 *Ardea purpurea* sp129 *Butorides striatus*

Rails and Crakes:
sp8 *Gallinula chloropus* sp15 *Amaurornis phoenicurus*
sp53 *Porzana fusca* sp120 *Fulica atra*

Ducks:
sp13 *Anas poecilorhyncha* sp66 *Anas clypeata*
sp67 *Anas crecca* sp71 *Anas querquedula*

Miscellaneous species:
sp4 *Podiceps ruficollis* sp61 *Phalacrocorax carbo*
sp63 *Platalea minor* sp113 *Acrocephalus orientalis*

Figure 4.3. The aggregation biplot of water bird species based on a canonical correspondence analysis (CCA) using the avian and environmental data of the actively managed aquaculture ponds. Different taxonomic groups of species of water birds are marked with different symbols.

4.4.1.2. Clustering pattern of waterbirds among age classes

In order to have sufficient sample size for the correspondence analyses of the abandonment age classes, temporarily abandoned sample ponds were classified into three broader abandonment age classes, 0-3, 3-10, 10-20 year age classes. The length of the gradient in the 3-10, 10-20 year age classes was all smaller or slightly larger than 1.5 (gradient length: 0-3 year age class, 1.839; 3-10 year age class, 1.334; 10-20 year age class, 1.456); and therefore RDA was applied to the three age classes for demonstrating the species aggregation pattern of waterbirds. From Figures 4.4, 4.5 and 4.6, the three guilds of waterbirds at the three age classes do not display distinct separation. Members of the Wader-Tern guild are even mixed with two other guilds. Duck is the only guild, which still remained closely associated together among the age classes. This might either indicate that some members of the Wader-Tern and Egret-Rail do have similar habitat requirements to the other two guilds, or indicate that insufficient sample sizes have prevented a clear separation between guilds. Close association between members of the Duck guild might imply a high degree of similarity in the habitat use of sample wetlands within this guild.

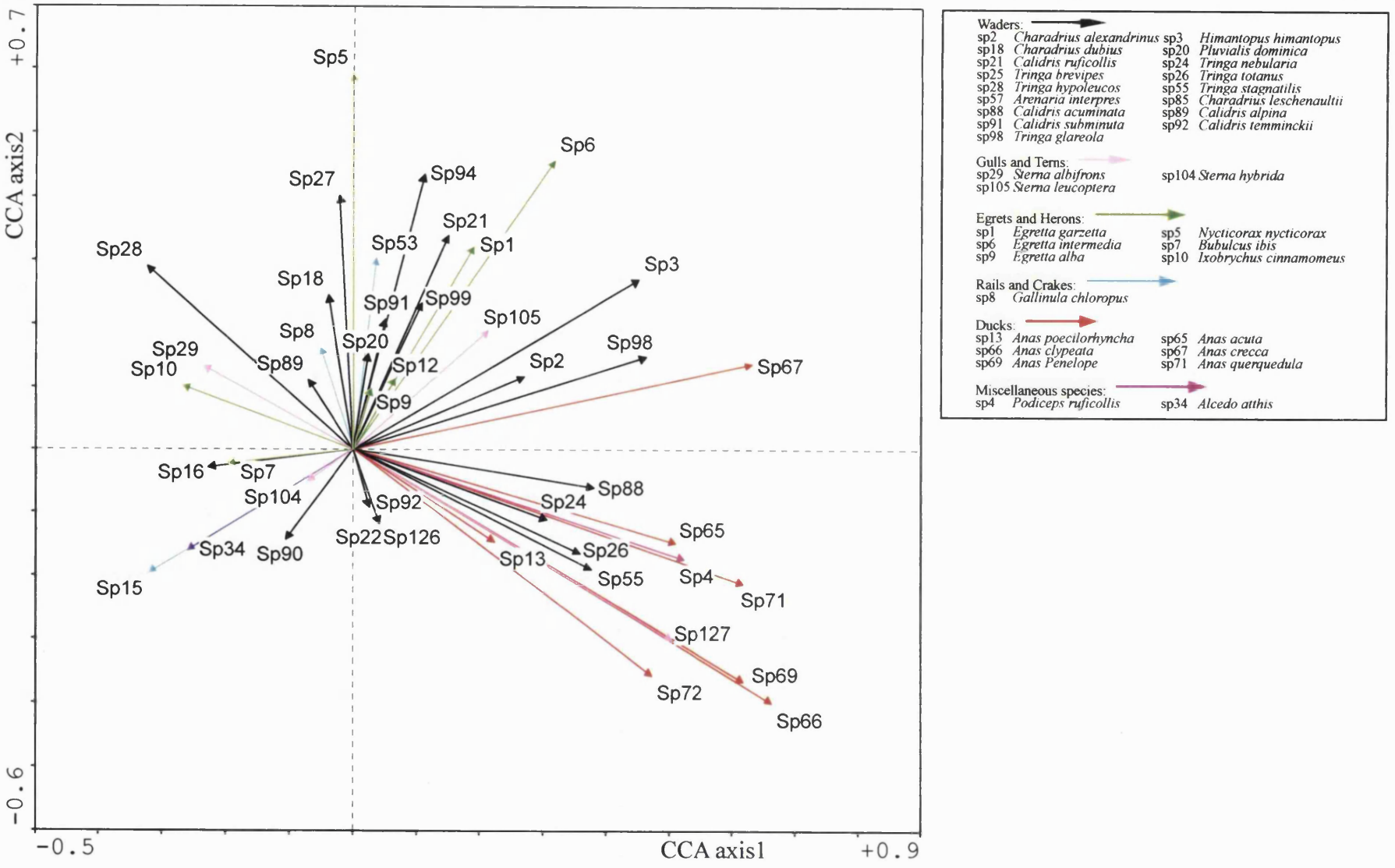


Figure 4.4. The aggregation biplot of water bird species based on a canonical correspondence analysis (CCA) using the avian and environmental data of the sample ponds in the 0-3 year age class. Different taxonomic groups of species of water birds are marked with different colours.

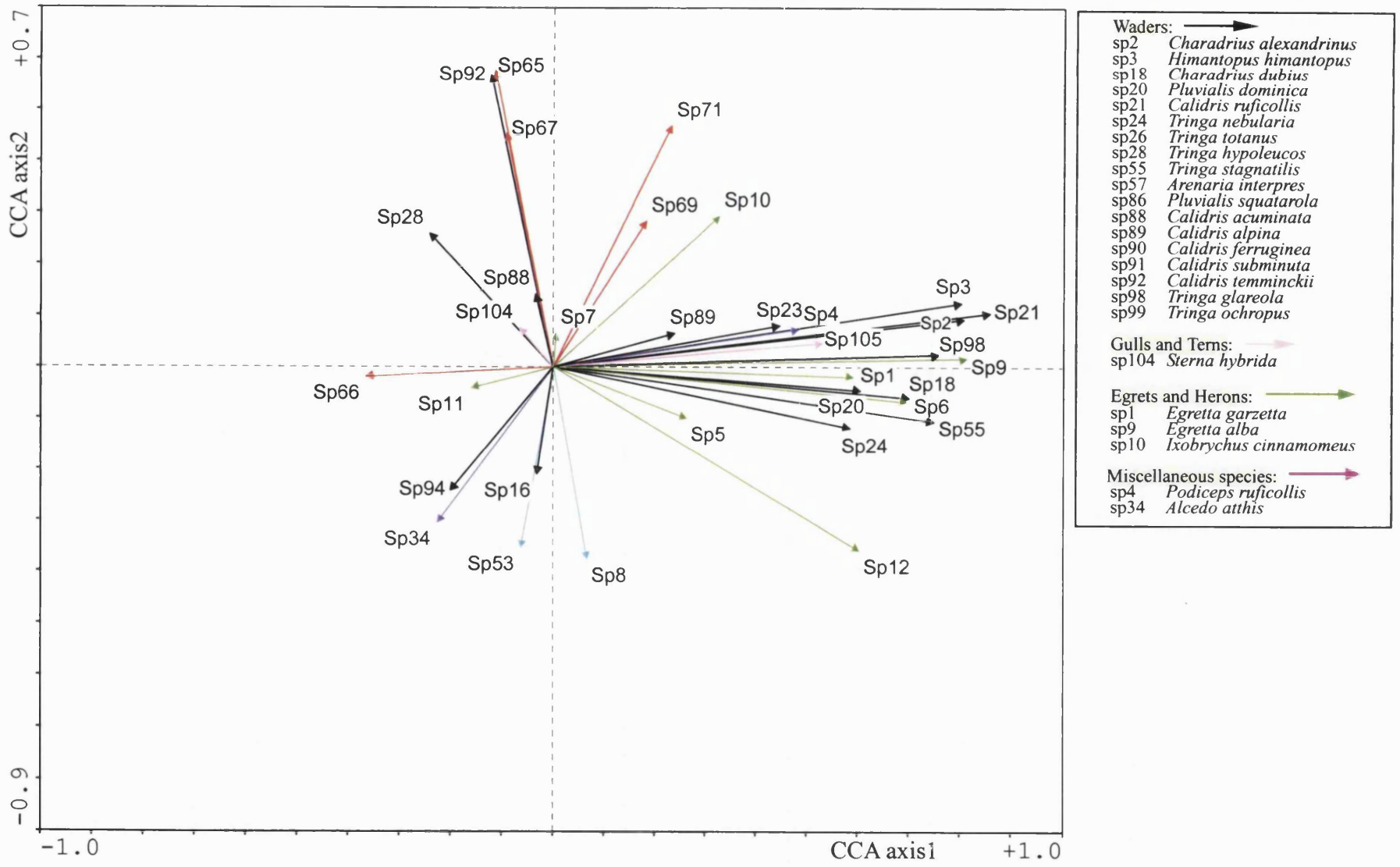
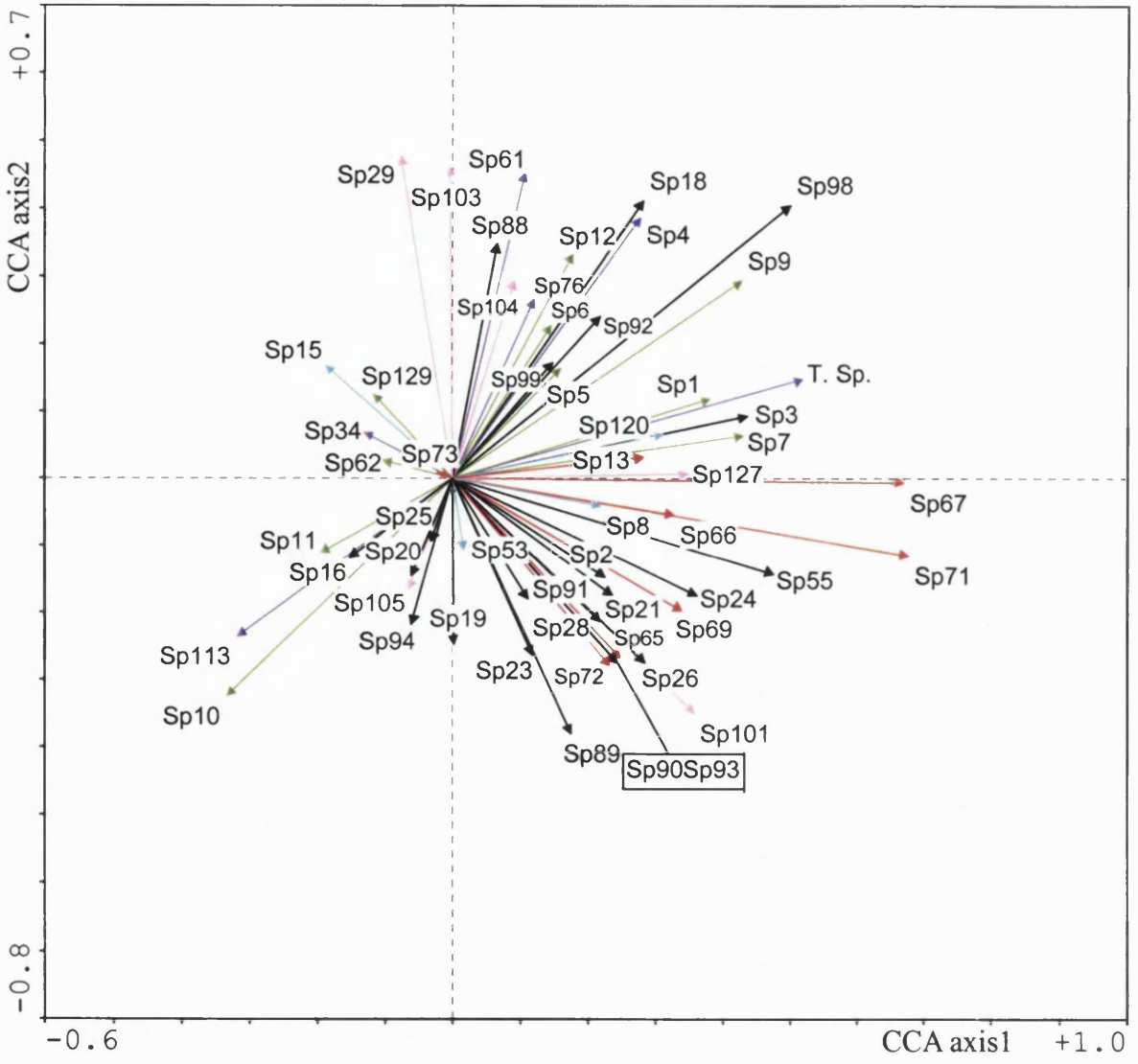


Figure 4.5. The aggregation biplot of water bird species based on a canonical correspondence analysis (CCA) using the avian and environmental data of the sample ponds in the 3-10 year age class. Different taxonomic groups of species of water birds are marked with different colours.



Waders:
- sp2 *Charadrius alexandrinus*
- sp3 *Himantopus himantopus*
- sp16 *Rostratula benghalensis*
- sp20 *Pluvialis dominica*
- sp21 *Calidris ruficollis*
- sp22 *Calidris canutus*
- sp24 *Tringa nebularia*
- sp26 *Tringa totanus*
- sp28 *Tringa hypoleucos*
- sp55 *Tringa stagnatilis*
- sp86 *Pluvialis squatarola*
- sp88 *Calidris acuminata*
- sp89 *Calidris alpina*
- sp92 *Calidris temminckii*
- sp98 *Tringa glareola*
- sp126 *Philomachus pugnax*

Egrets and Herons:
- sp1 *Egretta garzetta*
- sp5 *Nycticorax nycticorax*
- sp6 *Egretta intermedia*
- sp7 *Bubulcus ibis*
- sp9 *Egretta alba*
- sp10 *Ixobrychus cinnamomeus*
- sp12 *Ardea cinerea*

Rails and Crakes:
- sp8 *Gallinula chloropus*

Ducks:
- sp65 *Anas acuta*
- sp66 *Anas clypeata*
- sp67 *Anas crecca*
- sp69 *Anas Penelope*
- sp71 *Anas querquedula*

Miscellaneous species:
- sp4 *Podiceps ruficollis*
- sp34 *Alcedo atthis*

Figure 4.6. The aggregation biplot of water bird species based on a canonical correspondence analysis (CCA) using the avian and environmental data of the sample ponds in the 10-20 year age class. Different taxonomic groups of species of water birds are marked with different colours.

4.4.2. Species composition, dominance in abundance and spatial distribution

Ninety-one of the 129 bird species recorded in all sample ponds are waterbird species. Only these waterbird species are discussed in this dissertation (Appendix 2: complete avian fauna list). These consist of 34 wader species, nine tern and gull species, ten egret species, eight duck species, five rail species and nine miscellaneous species (the species with only one occurrence of one or two birds are excluded). The mean Shannon diversity index was 0.728. Five of the most abundant species comprise 64.56 % (N=83,923 birds) occurrence of birds. These species include three wader species, *Calidris alpina* (17.05%, N=22,166 birds), *Calidris ruficollis* (12.21%, N=20,982 birds) and *Charadrius alexandrinus* (8.89%, N=15,871 birds), a duck species, *Anas crecca* (16.14%, N=13,350 birds) and an egret species, *Egretta garzetta* (10.27%, N=11,554 birds). However, the most abundant species were not found in all sample ponds. *Egretta garzetta* (87.3%, N=145 ponds) and *Charadrius alexandrinus* (59.6%, N=99 ponds) were the only two species that were both rather abundant and widespread in the spatial distribution. Other abundant species were: *Calidris ruficollis* at 38.6%, N=64 ponds; *Anas crecca* at 30.1%, N=50 ponds and *Calidris alpina* at 29.5%, N=49 ponds in the number of sample ponds, respectively (Tables 4.1 and 4.2).

Table 4.1. Ten most abundant species from all sample ponds and four wetland types, showing their abundance and proportion with respect to all recorded number of birds by rank order.

Wetland type	Number of birds /proportion of all recorded number of birds (%), by rank order									
All sample wetlands										
Scientific name	*Calidris alpina*	*Calidris ruficollis*	*Charadrius alexandrinus*	*Anas acuta*	*Anas penelope*					
Scientific name	*Anas crecca*	*Egretta garzetta*	*Sterna hybrida*	*Podiceps ruficollis*	*Himantopus himantopus*					
Number of birds	22166	20982	15871	13350	11554	4456	4296	3732	3277	3238
Percentage occurrence	17.1	16.1	12.2	10.3	8.9	3.4	3.3	2.9	2.5	2.5
Actively managed ponds										
Scientific name	*Calidris alpina*	*Charadrius alexandrinus*	*Charadrius dubius*	*Calidris temminckii*	*Sterna hybrida*					
Scientific name	*Calidris ruficollis*	*Egretta garzetta*	*Tringa glareola*	*Tringa totanus*	*Tringa nebularia*					
Number of birds	8867	8778	5789	2828	1511	489	470	459	415	256
Percentage occurrence	28.1	27.8	18.4	9.0	4.8	1.6	1.5	1.5	1.3	0.8
Temporarily abandoned ponds										
Scientific name	*Anas crecca*	*Anas acuta*	*Podiceps ruficollis*	*Nycticorax nycticorax*	*Charadrius alexandrinus*					
Scientific name	*Egretta garzetta*	*Anas penelope*	*Himantopus himantopus*	*Anas querquedula*	*Egretta intermedia*					
Number of birds	20796	8712	4230	3268	3101	2953	2261	2117	1631	1538
Percentage occurrence	34.0	14.2	6.9	5.3	5.1	4.8	3.7	3.5	2.7	2.5
Saltpans										
Scientific name	*Calidris ruficollis*	*Egretta garzetta*	*Calidris alpina*	*Calidris temminckii*	*Phalaropus lobatus*					
Scientific name	*Charadrius dubius*	*Tringa totanus*	*Tringa stagnatilis*	*Charadrius alexandrinus*	*Tringa nebularia*					
Number of birds	1041	630	467	259	254	150	150	121	93	92
Percentage occurrence	29.0	17.5	13.0	7.2	7.1	4.2	4.2	3.4	2.6	2.6
Natural wetlands										
Scientific name	*Calidris alpina*	*Charadrius alexandrinus*	*Platalea minor*	*Tringa nebularia*	*Podiceps ruficollis*					
Scientific name	*Calidris ruficollis*	*Sterna hybrida*	*Egretta garzetta*	*Larus ridibundus*	*Calidris ferruginea*					
Number of birds	11733	5077	4013	3550	1993	1343	597.2	531	487	480
Percentage occurrence	34.9	15.1	11.9	10.6	5.9	4.0	1.8	1.6	1.4	1.4

Table 4.2. Ten most widely-distributed species from all sample ponds and four wetland types, showing the total number of sample ponds occupied and the proportion of sample ponds with these species present (spatial distribution) by rank order.

Wetland type	Total number and proportion of sample ponds with certain species present (by rank order)									
All sample ponds										
Scientific name	*Egretta garzetta*	*Egretta intermedia*	*Nycticorax nycticorax*	*Himantopus himantopus*	*Tringa glareola*					
Scientific name	*Charadrius alexandrinus*	*Podiceps ruficollis*	*Tringa nebularia*	*Gallinula chloropus*	*Tringa stagnatilis*					
No. of sample ponds occupied	145	99	93	88	86	84	83	83	79	78
Proportion of all sample ponds	87.3	59.6	56.0	53.0	51.8	50.6	50.0	50.0	47.6	47.0
Actively managed ponds										
Scientific name	*Egretta garzetta*	*Tringa hypoleucos*	*Tringa stagnatilis*	*Tringa glareola*	*Egretta intermedia*					
Scientific name	*Charadrius alexandrinus*	*Tringa nebularia*	*Calidris ruficollis*	*Himantopus himantopus*	*Sterna hybrida*					
No. of sample ponds occupied	48	39	35	26	24	23	23	20	19	19
Proportion of all sample ponds	90.6	73.6	66.0	49.1	45.3	43.4	43.4	37.7	35.8	35.8
Temporarily abandoned ponds										
Scientific name	*Egretta garzetta*	*Egretta intermedia*	*Nycticorax nycticorax*	*Alcedo atthis*	*Charadrius alexandrinus*					
Scientific name	*Podiceps ruficollis*	*Gallinula chloropus*	*Himantopus himantopus*	*Tringa glareola*	*Tringa nebularia*					
No. of sample ponds occupied	84	70	66	66	62	57	51	50	48	47
Proportion of all sample ponds	84.8	70.7	66.7	66.7	62.6	57.6	51.5	50.5	48.5	47.5
Saltpans										
Scientific name	*Charadrius alexandrinus*	*Pluvialis dominica*	*Tringa nebularia*	*Alcedo atthis*	*Calidris alpina*					
Scientific name	*Egretta garzetta*	*Calidris ruficollis*	*Tringa totanus*	*Tringa stagnatilis*	*Himantopus himantopus*					
No. of sample ponds occupied	5	4	4	4	4	4	4	4	4	3
Proportion of all sample ponds	100.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	60.0
Natural wetlands										
Scientific name	*Egretta garzetta*	*Egretta intermedia*	*Ardea cinerea*	*Tringa nebularia*	*Tringa stagnatilis*					
Scientific name	*Nycticorax nycticorax*	*Egretta alba*	*Pluvialis dominica*	*Alcedo atthis*	*Sterna hybrida*					
No. of sample ponds occupied	6	6	5	5	5	5	5	5	5	5
Proportion of all sample ponds	100.0	100.0	83.3	83.3	83.3	83.3	83.3	83.3	83.3	83.3

Some species were particularly widespread but rarely abundant. They include *Egretta intermedia* (56.0 %, N=93 ponds; 1.5%, N=1932 birds), *Podiceps ruficollis* (53.0 %, N=88 ponds; 2.9%, N=3803 birds), *Nycticorax nycticorax* (51.8 %, N=86 ponds; 1.9%, N=2509 birds), *Tringa nebularia* (50.6 %, N=84 ponds; 1.2%, N=1563 birds), *Himantopus himantopus* (50.0 %, N=83 ponds; 2.6%, N=3315 birds) and *Gallinula chloropus* (50.0 %, N=83 ponds; 1.0%, N=1232 birds). These were frequently found throughout the study area, but normally occurred either by themselves or in a small flock of birds (Tables 4.1 and 4.2).

4.4.2.1.Variations among wetland types

4.4.2.1.1. Species composition

The recorded waterbird species were grouped into six categories, namely waders, terns, egrets, rails, ducks and miscellaneous species; then the species number of each category by each wetland type were subjected to a Chi-square test to establish the variations in species composition among wetland types. Occasional rare occurrence of some species are not viewed as a sufficient evidence for the habitat use of sample wetlands by these species. Thus, the species with only one occurrence of a single or two birds are excluded from this section.

According to the 4×6 contingency table, wader species were the most abundant species in most wetland types, except in the temporarily abandoned ponds where duck species were most abundant (Table 4.1). In reality, duck and wader species are the principal categories of waterbirds which display strong differences between wetland types. More duck species than expected by chance occurred in the actively managed ponds and temporarily abandoned ponds, whilst fewer duck species occurred in the natural wetlands. In saltpans, no duck species occurred. In all sample wader species, considerably more species than expected by chance occurred in saltpans, whilst fewer species occurred in the temporarily abandoned ponds. However, the chi-square test on the variation of species composition among wetland types does not show a significant result (X^2=11.9, $X^2_{0.05, 15}$=25.0). The mean diversity indices for the four wetland types, actively managed ponds, temporarily abandoned ponds, saltpans and natural wetlands, are 0.684, 0.740, 0.673 and 0.949. According

to one-way ANOVA, no significant difference was found in the species diversity index among wetland types (p=0.083, df=156). Student t test was employed to reveal the difference in the species diversity index between two individual wetland types. According to this test, there was no significant difference in the species diversity index between two major sample wetland types, actively managed and temporarily abandoned ponds (p=0.194 df=145).

4.4.2.1.2. Dominance in abundance

In the wader-abundant habitats, *Calidris alpina* and *Calidris ruficollis* were undoubtedly the most abundant species, although they did not have the widest spatial distribution (Tables 4.1 and 4.2). *Charadrius alexandrinus* (18.4%, N=31,545 birds) accounts for a large proportion of waterbirds present in the actively managed ponds and *Charadrius dubius* (11.9%, N=33,624 birds) in the natural wetlands. In addition to these four abundant species, several less-abundant wader species occurred over a wide spatial distribution in a particular wetland type, *Tringa hypoleucos* (66.0 %, N=35 ponds), *Tringa nebularia* (49.1 %, N=26 ponds), *Tringa stagnatilis* (45.3 %, N=24 ponds) and *Tringa glareola* (43.4 %, N=23 ponds) in the actively managed ponds and *Pluvialis dominica* (80.0 %, N=4 ponds), *Tringa nebularia* (80.0 %, N=4 ponds), *Tringa totanus* (80.0 %, N=4 ponds) and *Tringa stagnatilis* (80.0 %, N=4 ponds) in saltpans (Table 4.2).

In the temporarily abandoned ponds, duck species, especially *Anas crecca* (34.0%, N=20,796 birds), were most abundant. In fact, *Egretta garzetta* (14.2%, N=8,712 birds) was the only non-Anatidae species abundant in the temporarily abandoned ponds. In the natural wetlands, in addition to the three most common species, *Calidris alpina* (34.9%, N=11,733 birds), *Calidris ruficollis* (15.1%, N=5,077 birds) and *Charadrius alexandrinus* (11.9%, N=4,013 birds), two non-wader species, *Sterna hybrida* (10.6%, N=3,550 birds) and *Platalea minor* (5.9%, N=1,993 birds) were also abundant (Table 4.1). *Platalea minor* is an internationally rare species. Its worldwide population might be approximately 1000, of which two thirds occur in southwestern Taiwan (WBSROC, 2002). The largest roosting site of this species is one of the six natural wetland sample sites in this study. This had led to a result

showing that this species was predominant in the natural wetlands.

4.4.2.1.3. Dominance in spatial distribution

With respect to spatial distribution, *Egretta garzetta* was consistently the commonest species in each wetland type except saltpans, where *Charadrius alexandrinus* was the commonest. Due to small sample sizes of saltpans and natural wetlands, interpretation of these two wetland types must be cautiously done. In other words, only the dominant ones in the spatial distribution was examined more comprehensively in the actively managed and temporarily abandoned ponds. In the actively managed ponds, in addition to *Egretta garzetta*, the most widely-distributed species were mostly waders. In contrast, temporarily abandoned ponds display a different set of abundant species. In addition to *Egretta garzetta*, most-widely-distributed species included two other egrets, *Egretta intermedia* and *Nycticorax nycticorax*, a grebe species, *Podiceps ruficollis* and a rail species, *Gallinula chloropus* (Table 4.2).

4.5. Discussion

Three guilds of waterbirds, namely the Egret-Rail, Wader-Tern and Duck, can be identified from the species aggregation ordination plot using the environmental and avian data of the collective sample ponds. However, these three guilds were closely associated at the origin of the ordination (Figure 4.1). This implies that the guild classification is not entirely clear. Habitat requirements of these three guilds might overlap each other to some extent. The most abundant species in each guild mostly occurred within this indistinct area near the ordination's origin. These species included *Egretta garzetta* and *Egretta intermedia* in the Egret-Rail guild, *Anas crecca* in the Duck guild and *Tringa glareola* and *Charadrius dubius* in the Wader-Tern guild. According to the interpretation guidelines for CANOCO ordination, the species that lie near the origin of the plot do not have strong associations with any of investigated environmental attributes (Ter Braak & Prentice, 1988). This might suggest that these abundant species did not have specific environmental requirements and therefore could adapt to a wide range of habitat niches. This might also account for their high abundance. In contrast, species that occur far from the origin of the ordination suggest that they have more specific environmental requirements (Ter Braak & Prentice, 1988). These species mostly included less abundant species such

as *Threskiornis aethiopicus* in the Egret-Rail guild, *Limosa lapponica* in the Wader-Tern guild and *Sterna nilotica* in the Duck guild. Their much more specific habitat requirements than other species could result in their low abundance, and thus the ideal habitats of these species should be particularly preserved to harbour these vulnerable species.

The actively managed aquaculture ponds showed a distinctive species composition from temporarily abandoned aquaculture ponds. Waders were the main component of the waterbird community in the actively managed ponds, whilst ducks were more dominant in the temporarily abandoned ponds (Table 4.1). The differences in the extent of anthropogenic disturbance and in the physical environment between these two wetland types could result in the variation in the species composition between these two wetland types. The constant presence of humans in the actively managed ponds could discourage shy species such as ducks from using these wetlands (personal communication with the local conservationists and managers of aquaculture ponds). Ducks are subjected to strong hunting pressure in the study area and are one of the game species in Taiwan. Additionally, the different physical environments such as the water levels and vegetations in these two wetland types, had attracted different sets of waterbirds. There is denser shore vegetation coverage in the temporarily abandoned ponds than in the actively managed ponds (section 2.4.1.3.1). Less dense shore vegetation in the actively managed ponds appears to be more attractive to waders (**the abundance of waders-shore vegetation coverage:** Pearson correlation: df=2,280, r=-0.089, p=0.000**; **the no. of wader species- shore vegetation coverage:** df=2,280, r=-0.408, p=0.000**; Figure 2.13). In all sample waterfowl, their diverse habitat requirements had been described by several authors (Cramp & Simmons, 1977; FWSDI, 1988; del Hoyo *et al.*, 1992). However, all the common waterfowl were small to medium-sized dabblers in the study area (Appendix 2). They appear to have similar habitat requirements and thus only occurred in a limited, less-disturbed wetland types such as the temporarily abandoned ponds. In contrast, many more wader species occurred in the study area (Appendix 2). Waders had diverse habitat requirements and thus can occupy a large range of wetland types (Cramp & Simmons, 1983; del Hoyo *et al.*, 1996). In this study, they occurred in most wetland types except in the temporarily abandoned ponds where less favourable microhabitats such as those with dense vegetation, were more likely to be found

(Tables 4.1, 4.2). It is recommended that particular wetland types are included at a conservation site for harbouring different groups of waterbirds. More abandoned ponds are necessary to protect ducks, while natural wetlands with an open space, active aquaculture ponds and saltpans are all appropriate habitats to attract a wide range of waders.

Duck species displayed the most distinct habitat utilization of sample wetlands amongst the three principal guilds of waterbirds. They occurred most abundantly in the temporarily abandoned ponds (one-way ANOVA: F=6.878, p=0.000**, df=3; expected abundance: 21723/31842=68.22%, observed abundance: 31393/31842=98.6%) and were even completely absent at saltpans (Table 4.1). Nystrom & Pehrsson (1988) had reported that ducks could not consume food items with a high salt content, and therefore they must selectively find less salty food items. In the natural wetlands, the abundance of ducks was smaller than that recorded in the actively managed or temporarily abandoned ponds (Table 4.1). This is unexpected since natural wetlands are viewed as a highly diversified wetland type, and expected to have abundant birds to visit. This might be partly due to the small sample sizes of natural wetlands and partly due to the bias in the selection of sample natural wetlands. The sampling of natural wetlands was restricted by a lack of suitable sites in the study area and consequently only tidal mudflats and tidal dykes, which are both not the preferred wetland types by the ducks, were sampled. More natural wetlands other than tidal mudflats and dykes are recommended to sample for elucidating the habitat selection of waterfowl.

Migrant activities had strong influences on the seasonal changes in the abundance of waterbirds in this study. Ducks and waders comprised the principal components of the waterbird community in the study area (Table 4.1). These two groups of waterbirds consisted principally of migrant species. This means that the overall abundance of waterbirds in the study area will fluctuate with the migrant activities of these species. Most predominant duck and wader species displayed an aggregated pattern in the spatial distribution (Tables 4.1 and 4.2). A predominant wader species, *Charadrius alexandrinus*, was an exception and was both abundant and widely-distributed at the same time (Tables 4.1 and 4.2). However, the abundance of this species fluctuated seasonally although it could be found throughout the year

(Figure 3.24). This species could include both the migrant and resident populations. The evidence of discriminating these two types of populations could be crucial in determining their habitat selection since the resident populations are more strongly associated with the habitat selection of this species rather than the migrant population. This evidence could be obtained from a detailed study using banding techniques.

Chapter 5

Environmental features in relation to the habitat use of aquaculture ponds by waterbirds

5.1. Introduction

The habitat selection of waterbirds at the abandoned aquaculture ponds is likely to be influenced by many factors. Principal factors might fall into two main categories, including biological factors such as competition (Jorde *et al.*, 1984; Bibbs *et al.*, 1987; Dubowy, 1988; Triplet *et al.*, 1999) and predation (Dekker & Ydenberg, 1987; Valone & Lima, 1987; Cresswell, 1996; Ydenberg et al., 2002) within avian community or other wildlife, and environmental factors such as water quality and vegetation cover of aquaculture ponds. Large-scale studies in all sample biological factors, mainly behaviour, are generally more difficult to conduct than the studies into the effects of environmental factors. The main reason for this is that the number of studied species will be strongly restricted by the ability to record the behaviour of several species simultaneously. Detailed well-designed behavioural observation and experiments may most likely reveal the complicated relationships between habitat selection and avian factors. However, intensive studies would inevitably need to be confined to small-scale ones that simultaneously consider a limited number of species and key factors. Consequently, behavioural research would be particularly difficult to perform if the whole set of species in a region were to be included in this study. Environmental features are much easier to record on a large scale and can be investigated regularly and frequently.

To sum up, the environmental approach is more appropriate for the study of habitat utilization for the whole avian community in an extensive region. From previous chapters, the annual changes and chronosequences of avian and environmental attributes have been elucidated. The grouping of species assemblages, the commonness of each species and their spatial distribution have been presented. Which environmental attributes have the strongest influence on the habitat utilization of abandoned aquaculture ponds by waterbirds? How do these environmental attributes influence their habitat utilization? What are the variations of their influences on the habitat utilization in each wetland type, for each abandonment age category, for each guild and each season? This chapter will try to answer these questions.

5.2. Methods

5.2.1.Sampling

The avian and most environmental variables were measured for a whole year at a 15-day interval from October 1999 to September 2000. The sampling of water chemistry were measured at each pond at a fifteen-day interval until May 2000. Thereafter sampling was taken monthly as water quality was found to be relatively constant.

5.2.2.Environmental and avian variables

Avian attributes: Sampling methodology is set out in section 4.2.2. in chapter 4 (page 139).

Environmental attributes: Sampling methodology is set out in section 2.2.2. in chapter 2 (page 46).

5.3. Statistical analysis

The data matrix in this study was created by combining two types of data for each sample pond. One is environmental data such as water chemistry, vegetation and water depth. The other is avian data such as the abundance of each species. The data matrix was subsequently used to conduct the ordination analyses of all sample ponds, in each wetland type and for each abandonment age category. In the last analysis, only intensively studied sites with year-round 15-day-interval recordings were used (10 intensively-studied sites :107 sample wetlands(actively managed ponds, N=26; temporarily abandoned ponds, N=73; saltpans, N= 3; natural wetlands, N=5)). These ordination analyses were performed using the computer programme CANOCO version 4.0 (Ter Braak & Smilauer, 1998).

The records of rare species are too few to justify analysis. Rare occurrence may unduly influence the correspondence analyses. In addition, the relations between the habitat use of wetlands by rare species and environmental features are hardly revealed by a general large-scale study like this one. Their relations can only be uncovered with more intensive and specific studies. To eliminate the bias from rare species, species with two or fewer occurrences in the total sample ponds were not included in the ordination analyses. Furthermore, the data for the remaining species were downweighted in reverse proportion to their abundance by the default formula in the

CANOCO in all ordination analyses to reduce the impact from the relatively rare species. Square-root transformation was applied to the abundance data whose measurements did not fit normal distribution. This helped stabilize their variance and diminish the statistical noise in the data with many zero values (Eilersten *et al.*, 1990). Many environmental variables had skewed distributions and were subjected to transformation either by log (x+1) or reciprocal (Weckström & Korhola, 2001). Additionally, every sample pond was subjected to a weighting process, in which every pond was given a weighting value in proportion to the sampling frequency (Table 5.1).

To summarize the pattern of variations in the measured environmental variables, the indirect correspondence analysis method, principal component analysis (PCA), was applied to environmental data. Detrended correspondence analysis (DCA) with non-linear rescaling and detrending-by-segment axes was then used to identify the length of gradient in the avian data (Weckström & Korhola, 2001). Direct correspondence analysis methods, either redundancy analysis (RDA) or canonical correspondence analysis (CCA), were used to plot the species-environment biplots revealing the relationship between the avian and the determined environmental data. RDA was used to conduct the analysis if gradient length is less than 1.5 S.D. (standard deviation). In contrast, CCA was used if gradient length is more than 3 S.D. Either RDA or CCA can produce satisfactory species-environment biplots if the gradient length fell between 1.5 and 3.0 S.D (Ter Braak & Prentice, 1988). Most of the gradient length from the total avian data or the data of a particular wetland type or age category fell between 1.5 and 3.0 S.D. CCA was applied to most instances except to the data from the 3-10 year age class, which had a gradient length of first canonical axis of only 1.389. As a result of these short gradient lengths, biplot scaling, not Hill's scaling (suitable for long gradient length) was applied in these correspondence analyses (Table 5.1).

Highly collinear variables, of which the variations can be explained by the linear combination of several other variables, are not worthy of interpretation in these ordination analyses (Ter Braak, 1986). The variables with high collinearity with the rest of variables will be also with high variance inflation factors (VIF), and will be

deleted if VIF is more than 10. After that, a set of statistical significant environmental variables was produced by CCA with forward selection and Monte Carlo permutation tests (300 permutations) (Table 5.1, Weckström & Korhola, 2001).

The interpreting power will be greatly reduced if the number of sites is relatively small compared to the number of environmental variables (Ter Braak & Prentice, 1988). Inevitably, some correspondence analyses were not conducted because insufficient sites occurred in a particular wetland type (saltpans or natural wetlands) or age category. Age classes were re-classified into several broader age categories to meet the basic requirement in the sample size for correspondence analysis.

After deleting manually the highly collinear and statistically insignificant environmental variables, CCA was conducted on the avian and environmental data of all sample ponds and on the data of every wetland type or abandonment age category. Species-environment biplots were created from these analyses. In these biplots, arrows represent environmental variables. The influence of a particular environmental variable on the habitat utilization of sample wetlands by waterbirds results in a greater correlation if the arrow of this attribute was longer. The species assemblage that aggregates around this arrow is positively correlated with this environmental variable. On the contrary, a species assemblage is negatively correlated with this variable if the arrow of a particular environmental variable points away from the symbols for a particular species assemblage. The shorter the arrow of a particular environmental variable the smaller its influence on the habitat utilization by the whole set of species. The species that lie far from the origin are often rare species, which means that either these species have particular habitat requirements or they are accidentally lying at the sites with extreme conditions due to their rare occurrence. In contrast, the species that fall near the origin are indifferent species that are not correlated with the ordination axes or have an optimal environment space near the origin (Ter Braak & Prentice, 1988).

Table 5.1. Summary of analytical procedure applied in this study for combining environmental data and avian data of sample wetlands to demonstrate their correlation.

Analytical procedure	Description
Elimination of rare species	Species with two or fewer occurrence in the total sample ponds were eliminated.
Downweighting by waterbirds' abundance	Abundance was downweighted in reverse proportion to waterbirds' abundance.
Data transformation	Square-root transformation was applied to the non-normal-distribution abundance data. Skewed-distribution environmental variables were transformed either by log (x+1) or reciprocal.
Weighting by sampling frequency	Sample wetlands were weighted in proportion to their sampling frequency.
Appling indirect correspondence analysis method	To summarize the pattern of variations in the measured environmental variables, the indirect correspondence analysis method, principal component analysis (PCA), were applied.
Identification of the length of gradient	Detrended correspondence analysis (DCA) with non-linear rescaling and detrending-by-segment axes was used to identify the length of gradient in the avian data.
Deletion of highly-collinear variables	The variables with high collinearity with the rest of variables will be also with high variance inflation factors (VIF), and will be deleted if VIF is more than 10.
Deletion of non-significant variables	A set of statistical significant environmental variables was produced by CCA with forward selection and Monte Carlo permutation tests (300 permutations).
Creation of environment-avian biplots	Environment-avian biplots were created by RDA or CCA. RDA was used if gradient length is less than 1.5 S.D. (standard deviation). In contrast, CCA was used if gradient length is more than 3 S.D. Either RDA or CCA was used if the gradient length fell between 1.5 and 3.0 S.D.

5.4. Results

5.4.1. Environmental features in relation to the habitat use of sample wetlands by waterbirds

Ter Braak (1994) interpreted the relationship between environmental variables that occurred in a correlation biplot of PCA. He reported that two variables that point in opposite directions from origin are negatively correlated. In contrast, two variables that point in the same direction or with an acute angle between them are

positively correlated. There is no correlation between two variables if the arrows of the two variables are perpendicular to each other. The longer the arrow of a particular variable is, the more associated the variable on the ordination axis is.

As shown in the Figure 5.1 PCA environment-site correlation biplot, vegetation-related variables and the proportion of surrounding ponds that are abandoned appear to play important roles in the overall variance of the physical environment in the sample ponds. The density of surrounding natural wetlands shows positive associations with both the first and second canonical axis while the density of surrounding aquaculture ponds as well as the distance to the nearest natural wetland and the sea shore, show negative associations. The proportion of surrounding ponds that are abandoned along with the vegetation-related variables, which behaved in a relatively similar way, associated positively with the first canonical axis and negatively with the second axis. In addition, pH, dissolved oxygen and the number of years since first abandonment behaved inversely with the area covered by open water, which shows a positive association with the second PCA axis. Water depth-related variables generally contributed slightly to the overall variance of environmental attributes in the sample wetlands. The eigenvalues of the first and second PCA axes were 0.58 and 0.19 respectively. Their cumulative percentage variance is 76.5% and quite effectively account for the variation in environmental variables.

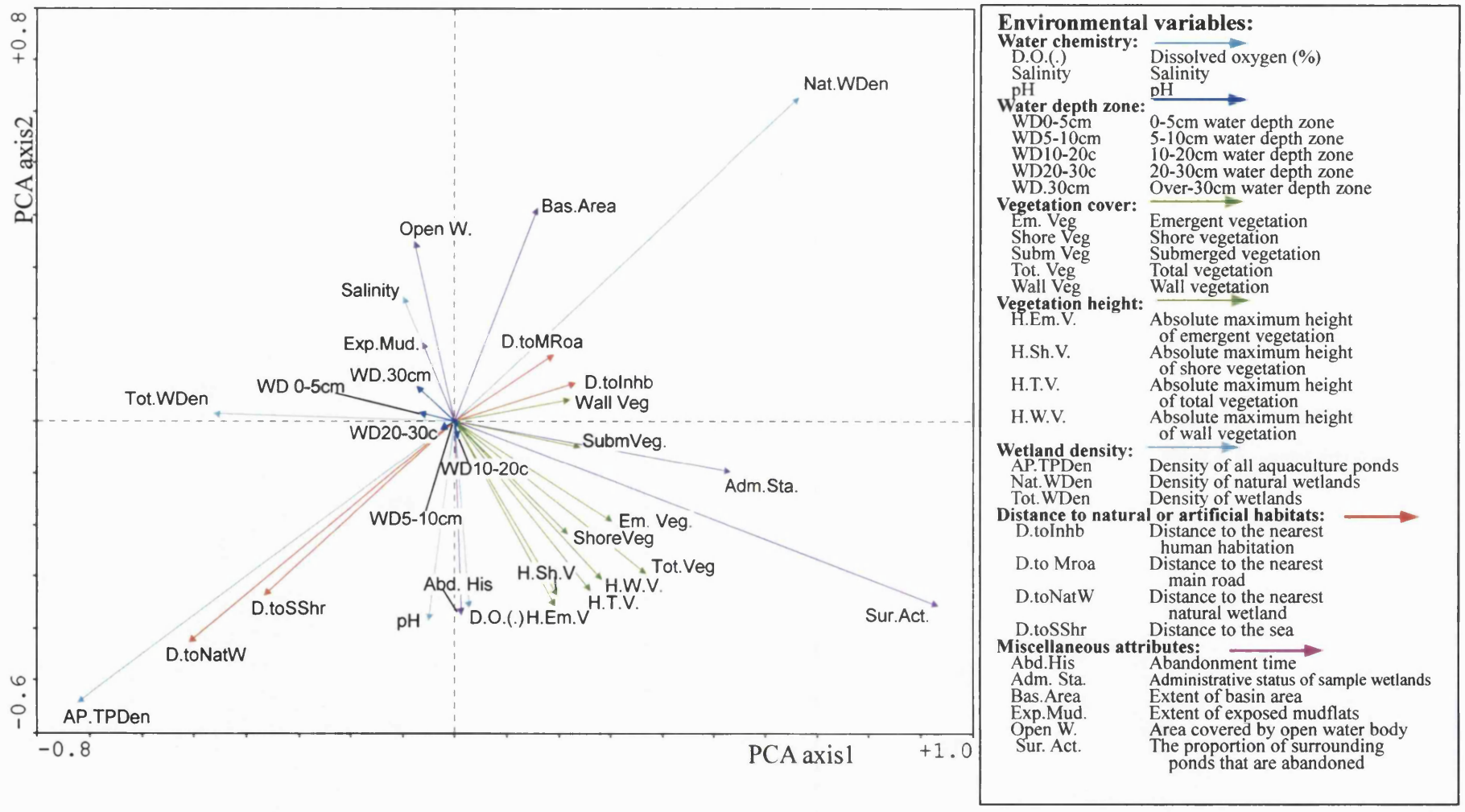


Figure 5.1. The principal component analysis (PCA) ordination plot based on the environmental data from all sample ponds, displaying the relationship between the physical variables of sample wetlands. Different types of environmental variables are marked with vectors of different colours.

First, four highly collinear variables with >10 VIF (the extent of the 5-10cm water depth zone and total vegetation, the density of surrounding natural wetlands and pH) were excluded. Second, the variables with no statistically significant variations were also deleted, namely the absolute maximum height of shore vegetation and cover of shore vegetation. Twenty four out of 30 environmental variables were left for the CCA of all sample ponds. These active variables had eigenvalues: 0.201 and 0.108, respectively, for the first and second CCA axes. They represent 20.9 % of the cumulative percentage variance of avian data. These active variables explain 82.0% of the variance of avian data. This indicates that these selected variables can adequately describe the variation of avian data (Table 5.2).

Table 5.2. Detrended correspondence analysis (DCA) of avian data and canonical correspondence analysis (CCA) of avian and environmental data from all sample ponds. Eigenvalues and cumulative percentage variance of the avian data represented by the first four axes are given.

	Eigenvalue		Variance explained (%)	
Axis	DCA	CCA	DCA	CCA
1	0.243	0.201	16.4	13.6
2	0.134	0.108	25.5	20.9
3	0.089	0.078	31.5	26.2
4	0.059	0.046	35.5	29.3

Two groups of environmental variables show strong associations with the first CCA axis. One group, which mainly consists of vegetation-related variables, associated positively with the first CCA axis. The other group, which consists of salinity, basin area, density of the total wetlands and the extent of the exposed mudflats and open water, associated negatively with the first CCA axis. In contrast, environmental variables display disproportional associations with the second CCA axis. Most environmental variables show negative associations with the second axis. The extent of the >30cm water depth zone and open water are the only two exceptions and show positive associations with the second CCA axis. Five environmental variables (salinity and basin area, the extent of the >30cm water

depth zone and the number of years since first abandonment as well as cover of submerged vegetation) show considerable influence on the habitat utilization of sample wetlands by three guilds: Wader-Tern, Egret-Rail and Duck. Nevertheless, other environmental variables also show minor influences. Vegetation-related attributes (cover of submerged vegetation excluded) generally show a rather similar influence, which shows negative associations, on the whole species assemblage. Two water depth zones, the 0-5cm and >30cm zones, display an inverse influence on the whole species assemblage. In addition, vegetation-related attributes (cover of submerged vegetation excluded) display equal positive influences on the Egret-Rail and Duck guilds (Figure 5.2).

Wader-Tern guild:

Salinity and basin area display strong positive correlations with the habitat use of sample wetlands by the Wader-Tern guild. Total wetland density might also exert some influence. In contrast, vegetation-related variables and the proportion of surrounding ponds that are abandoned both show negative correlations. The extent of the 0-5cm, >30cm water depth zones and exposed mudflats generally display no correlation (Figure 5.2).

Egret-Rail guild:

The most significant environmental variable on the habitat use of sample wetlands by the Egret-Rail guild was the extent of the deepest water depth zone (>30cm zone). Actually, most environmental variables show negative associations or slight associations. The extent of the >30cm water depth zone played a more important role in the outer subgroup of this guild, including mainly *Ixobrychus sinensis*, *Ardea purpurea*, *Amaurornis phoenicurus* and *Porzana fusca*, than the inner subgroup, including mainly *Egretta garzetta*, *Egretta intermedia*, *Bubulcus ibis*, *Podiceps ruficollis* and *Gallinula chloropus*. In contrast, the extent of the exposed mudflats and the shallower water depth zone (the 0-5cm water depth zone) show negative correlations with the habitat use of sample wetlands by the Egret-Rail guild. The overall density of wetlands and basin area both show negative correlations as well. By and large, cover of submerged vegetation and the number of years since first abandonment show no correlation (Figure 5.2).

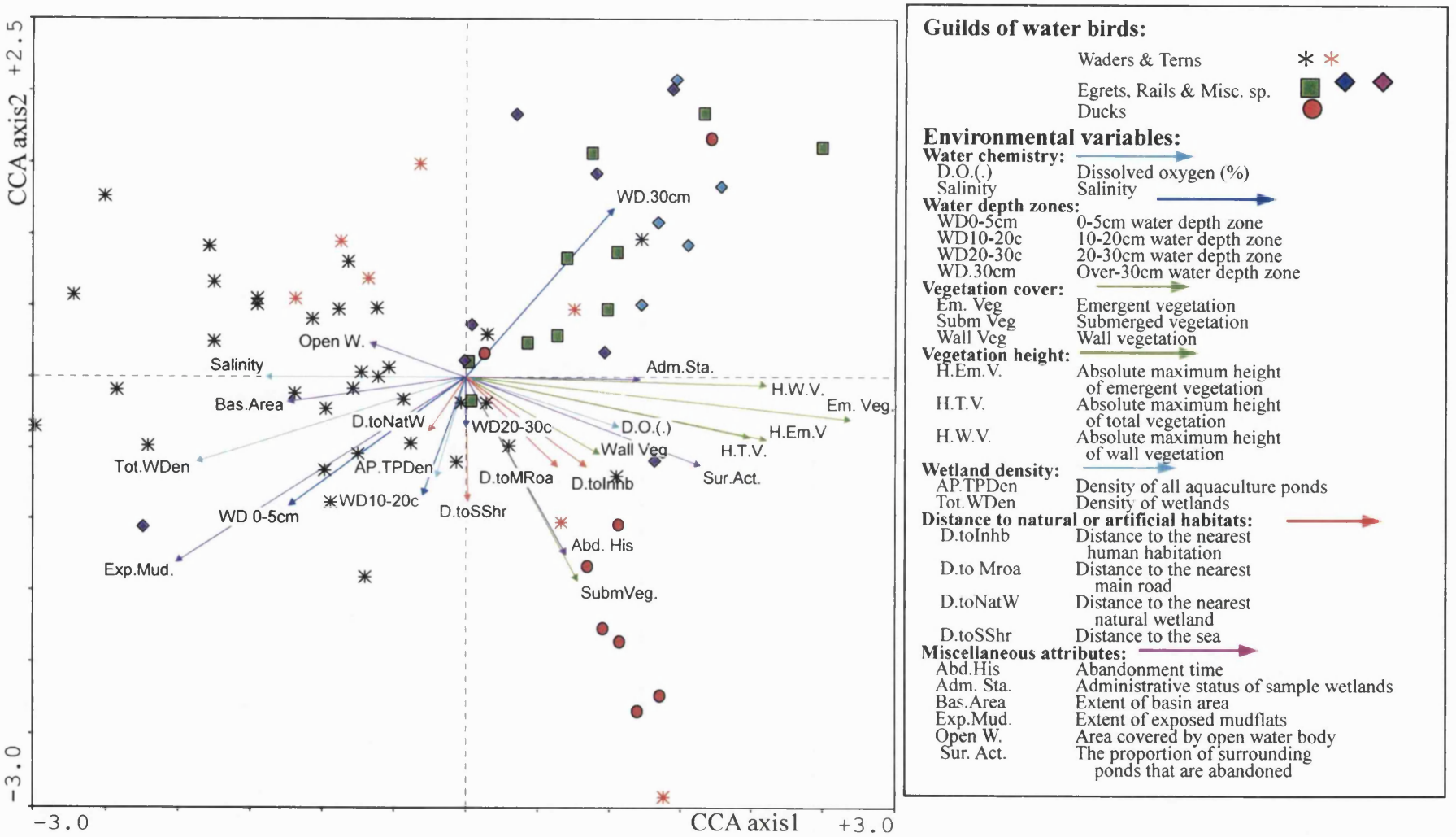


Figure 5.2. The canonical correspondence analysis (CCA) species-environment correlation biplot based on the avian and environmental data from all sample ponds, displaying the relationship between the guilds of water birds and the features of sample wetlands. Different subguilds of water birds and types of environmental features are marked with different symbols and vectors of different colours.

Duck guild:

Cover of submerged vegetation and the number of years since first abandonment both display positive correlations with the habitat use of sample wetlands by the Duck guild. Two distance-related variables, the distance to the nearest main road and human habitation, show positive associations with medium magnitude. *Anas poecilorhyncha* was the species that proved to be least related to the aforementioned variables amongst the species of the Duck guild. Generally, *Anas poecilorhyncha* shows no correlation at all with any recorded environmental variable. In contrast, the area covered by open water exhibits a negative correlation with minor magnitude. The extent of the >30cm and 0-5cm water depth zones and exposed mudflats display no correlation (Figure 5.2).

5.4.2. Variations among wetland types

According to Figure 5.3, the PCA environment-site biplot generally displays a separation between actively managed ponds and temporarily abandoned ponds. Vegetation-related variables, the proportion of surrounding ponds that are abandoned and administrative status of sample wetlands, all show a positive association with temporarily abandoned aquaculture ponds. In contrast, salinity, the overall density of wetlands and the extent of the exposed mudflats show strong positive links with actively managed ponds. The density of surrounding natural wetlands or aquaculture ponds and the distance to the nearest natural wetland and seashore exhibit no correlation.

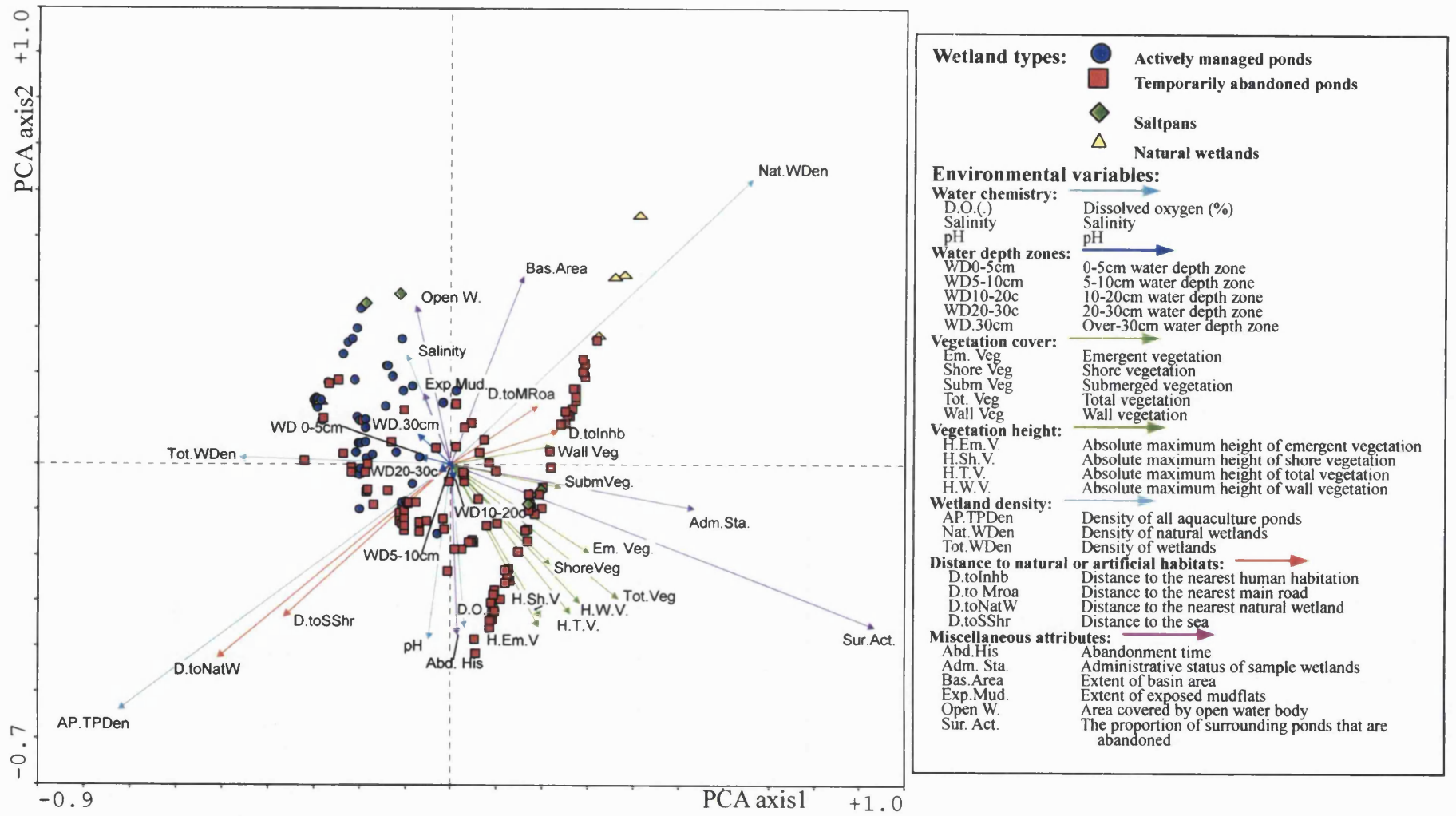


Figure 5.3. The principal component analysis (PCA) environment-site correlation biplot based on the environmental data from all sample ponds, displaying the relationship between the wetland types and features of sample wetlands. Ponds from different wetland types and types of environmental features are marked with different symbols and vectors of different colours.

The CCA environment-species-site triplot, which used 22 active environmental variables for CCA after deleting five highly correlated and two non-statistically-significant variables, displays almost identical associations between environmental variables and between wetland types as the PCA biplot (Figures 5.3 and 5.4). In addition, the associations between guilds and wetland types are clearly separated. The Duck guild is almost confined to temporarily abandoned aquaculture ponds. In contrast, the Wader-Tern guild used actively managed ponds, saltpans and natural wetlands. The Egret-Rail guild used both actively managed ponds and temporarily abandoned ponds at the same time, but primarily used temporarily abandoned ponds (Figure 5.4).

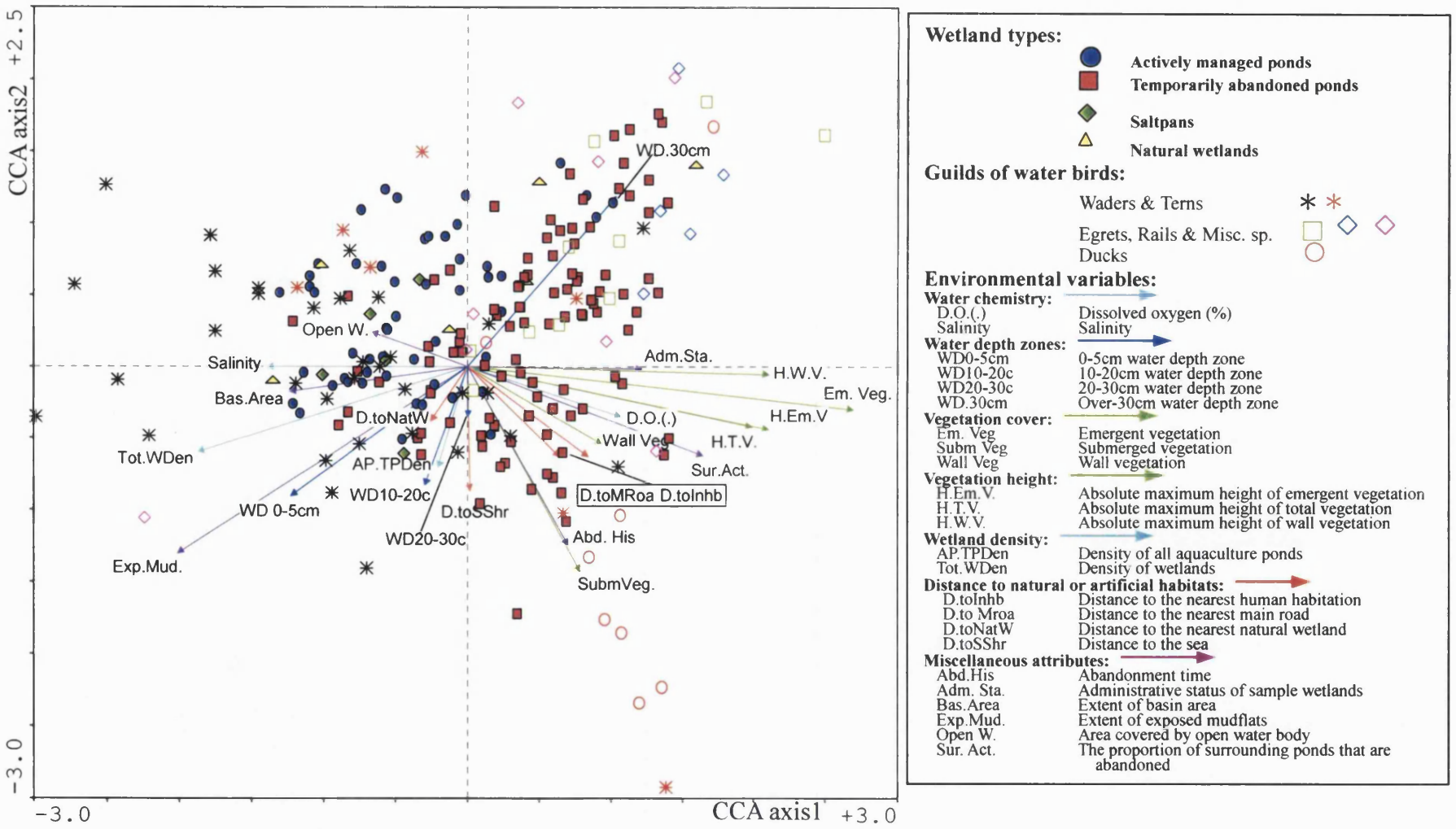


Figure 5.4. The canonical correspondence analysis (CCA) species-environment-site correlation triplot based on the avian and environmental data from all sample ponds, displaying the relationship between the guilds of water birds, wetland types and the features of sample wetlands. Ponds from different habitat types, subguilds of water bird and types of environmental features are marked with different symbols and vectors of different colours.

There were considerable variations in the correlation between environmental features and the habitat use of four wetland types by waterbirds. No individual guild consistently shows a strong association with particular environmental attributes between wetland types. An insufficient number of sample wetlands in two habitat categories, including natural wetlands and saltpans, limit interpretation of the ordination analyses. Consequently, ordination analyses of these two wetland types were not undertaken.

Actively managed ponds

The correlation amongst environmental variables occurring in the PCA correlation biplot of actively managed ponds is rather different from all sample ponds. Two main subgroups of environmental variables in the actively managed ponds are defined. One subgroup, which principally consists of vegetation-related variables, shows a positive association with the first PCA axis. The other subgroup, which consists of the remaining variables, shows a negative association with the first PCA axis. These two subgroups both show a positive association with the second PCA axis (Figure 5.5).

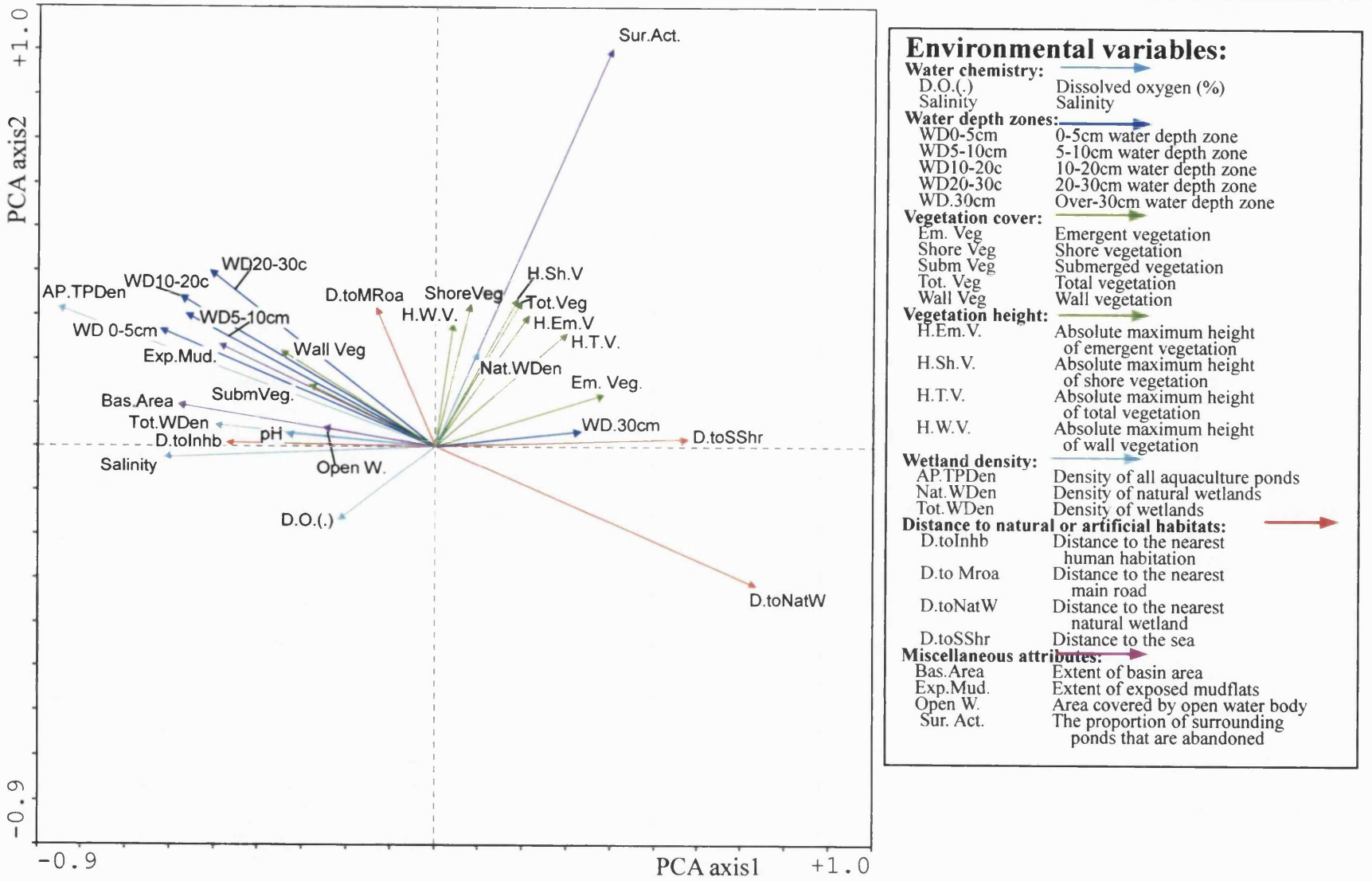


Figure 5.5. The principal component analysis (PCA) ordination plot based on the environmental data from the actively managed ponds, displaying the relationship between the physical variables of sample wetlands. Different types of environmental features are marked with vectors of different colours.

The eigenvalues of the first and second PCA axes are 0.39 and 0.27 respectively. Their cumulative percentage variance attained 66%, which indicates that the first two PCA axes can effectively explain the variation in these environmental variables. Through the variable deduction procedure, six highly collinear variables were excluded: basin area, pH, the extent of the 0-5 and 5-10cm water depth zones and cover of wall and total vegetation. Another five variables without statistical significant variations were also excluded from the following analysis: the absolute maximum height of total and shore vegetation, cover of shore and submerged vegetation and the extent of the 20-30cm water depth zone. In total, 17 out of 28 environmental variables were selected for CCA. These 17 active variables had eigenvalues, 0.175 and 0.108 for the first and second CCA axes and explain 20.8% of the cumulative percentage variance of avian data. In comparison with the cumulative percentage variance of avian data revealed by the first and second axes of DCA (25.1%), these selected variables explain 82.9% variance of avian data. This means these 17 active variables can successfully account for the variation of avian data (Table 5.3).

Table 5.3. Detrended correspondence analysis (DCA) of avian data and canonical correspondence analysis (CCA) of avian and environmental data from the actively managed ponds. Eigenvalues and cumulative percentage variance of the avian data represented by the first four axes are given.

	Eigenvalue		Variance explained (%)	
Axis	DCA	CCA	DCA	CCA
1	0.211	0.175	15.5	12.8
2	0.131	0.108	25.1	20.8
3	0.087	0.078	31.5	26.5
4	0.051	0.055	35.3	30.5

As seen in the CCA correlation biplot, environmental variables are roughly separated into two subgroups like the PCA biplot. One subgroup, which consists of vegetation-related variables and five other variables, all display a positive correlation with the first CCA axis. The other subgroup, which consists of the remaining variables, shows a negative association. In contrast, most environmental variables show negative associations with the second CCA axis (Figure 5.6).

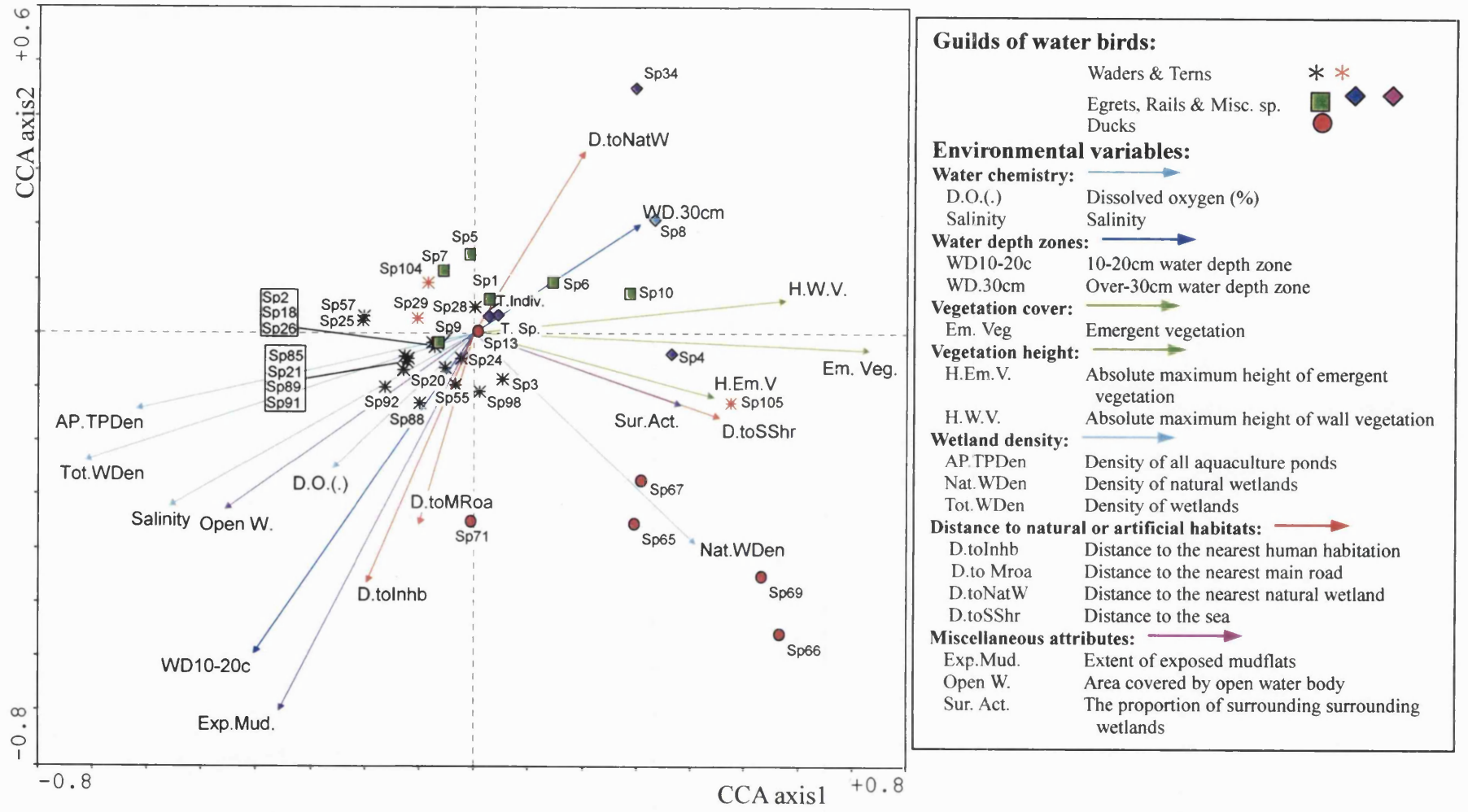


Figure 5.6. The canonical correspondence analysis (CCA) species-environment correlation biplot based on the avian and environmental data from the actively managed ponds, displaying the relationship between the guilds of water birds and the features of sample wetlands. Different subguilds of water birds and types of environmental features are marked with different symbols and vectors of different colours.

Duck is the only guild that shows strong correlations with the recorded environmental attributes in the actively managed ponds. The density of surrounding natural wetlands displays the strongest positive link in this guild. This might suggest that only actively managed ponds that are located in a mosaic habitat with high proportions of surrounding natural wetlands are more likely to have high occurrence of ducks. Apart from the density of surrounding natural wetlands, other environmental attributes either show minor associations or no association at all with duck species (Figure 5.6).

Egrets and rails are relatively sporadic in the CCA biplot. However, medium associations between environmental variables and this guild are recognized. The distance to the nearest natural wetlands and the extent of the >30cm water depth zone generally show positive correlations, whereas the extent of the exposed mudflats, the extent of the 10-20cm water depth zone and the distance to the nearest human habitation show negative correlations. The density of surrounding natural wetlands displays no correlation at all (Figure 5.6).

Wader species aggregate closely near the origin of the CCA correlation biplot. This implies no powerful recorded environmental attributes could adequately explain their habitat use (Figure 5.6).

Temporarily abandoned ponds

The associations of environmental variables in the temporarily abandoned ponds are similar to those in all sample wetlands, but the correlations between any one of the two main groups of environmental variables and the first or second PCA axis partly disagree. The PCA ordination biplot in the temporarily abandoned ponds is similar to that in all sample ponds if that in the temporarily abandoned ponds rotates 180 degrees by the origin. This indicates that the correlation between environmental variables and PCA axes in all sample ponds and temporarily abandoned ponds behaved approximately in the opposite way. Two groups of leading variables, namely 1) the distance to the nearest natural wetland and seashore and the density of surrounding aquaculture ponds, 2) the density of surrounding natural wetlands, salinity and the distance to the nearest main road and human habitation, behaved in a nearly opposite way. In addition, water depth-related attributes appear to play

more important roles in the temporarily abandoned ponds than all sample ponds (Figures 5.1 and 5.7).

The first and second PCA axes, which have eigenvalues, 0.60 and 0.18, respectively, collectively explain 77.6% of cumulative percentage variance of recorded environmental variables. This indicates that these two PCA axes can sufficiently explain the variance of these environmental variables of temporarily abandoned ponds. To delete the effect of unstable canonical coefficients coming from the highly collinear variables, five variables, the extent of the 0-5 and 5-10 water depth zones, total and wall vegetation and the density of surrounding aquaculture ponds, were excluded. Then, two variables without statistical significant variations were also deleted: dissolved oxygen and the absolute maximum height of shore vegetation. Only 22 of 29 variables were selected for the further CCA analysis. The eigenvalues of the first and second CCA axes, which used 22 active variables in the dataset, are 0.212 and 0.117, respectively and explain 28.55% of the cumulative percentage variance of avian data. These two CCA axes explain 89.2% variance of avian data when the cumulative percentage variance of avian data revealed by the first and second axes of DCA are compared. That means the first two CCA axes of the 22 selective variables effectively explain the variance of avian data (Table 5.4).

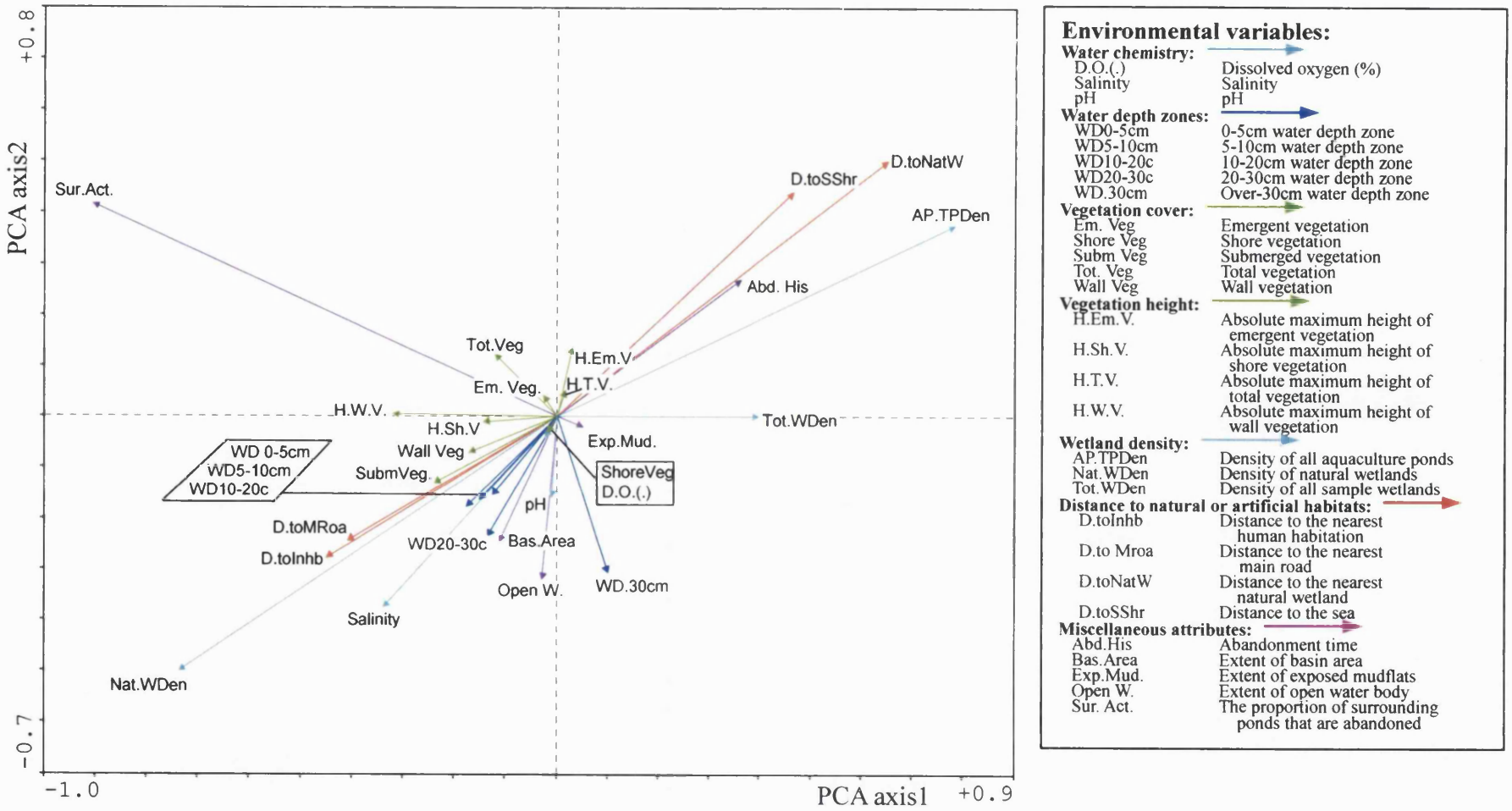


Figure 5.7. The principal component analysis (PCA) ordination plot based on the environmental data from the temporarily abandoned ponds, displaying the relationship between the physical variables of sample wetlands. Different types of environmental features are marked with vectors of different colours.

Table 5.4. Detrended correspondence analysis (DCA) of avian data and canonical correspondence analysis (CCA) of avian and environmental data from the temporarily abandoned ponds. Eigenvalues and cumulative percentage variance of the avian data represented by the first four axes are given.

	Eigenvalue		Variance explained (%)	
Axis	DCA	CCA	DCA	CCA
1	0.233	0.212	20.2	18.4
2	0.137	0.117	32.0	28.6
3	0.094	0.087	40.2	36.1
4	0.065	0.034	45.8	39.1

The extent of the >30cm water depth zone shows a strong positive correlation with the first CCA axis, whereas the extent of the exposed mudflats shows a negative correlation. In contrast, the distance to the nearest natural wetland displays an intermediate positive association with the second CCA axis, whereas the proportion of surrounding ponds that are abandoned and the density of surrounding natural wetlands display strong negative associations (Figure 5.8).

The relationship between the features and the habitat use of temporarily abandoned ponds by waterbirds is similar to that in all sample ponds. However, the most significant variables in relation to the habitat use of sample wetlands by a particular guild are different. The distance to the nearest human habitation and the proportion of surrounding ponds that are abandoned are the leading variables in the Duck guild while the overall density of wetlands and extent of the exposed mudflats are the most significant variables in the Wader-Tern guild. In the Egret-Tern guild, the extent of the >30cm water depth zone is still the most important variable as in all sample wetlands. In addition, vegetation-related variables also play important roles in this guild (Figure 5.8).

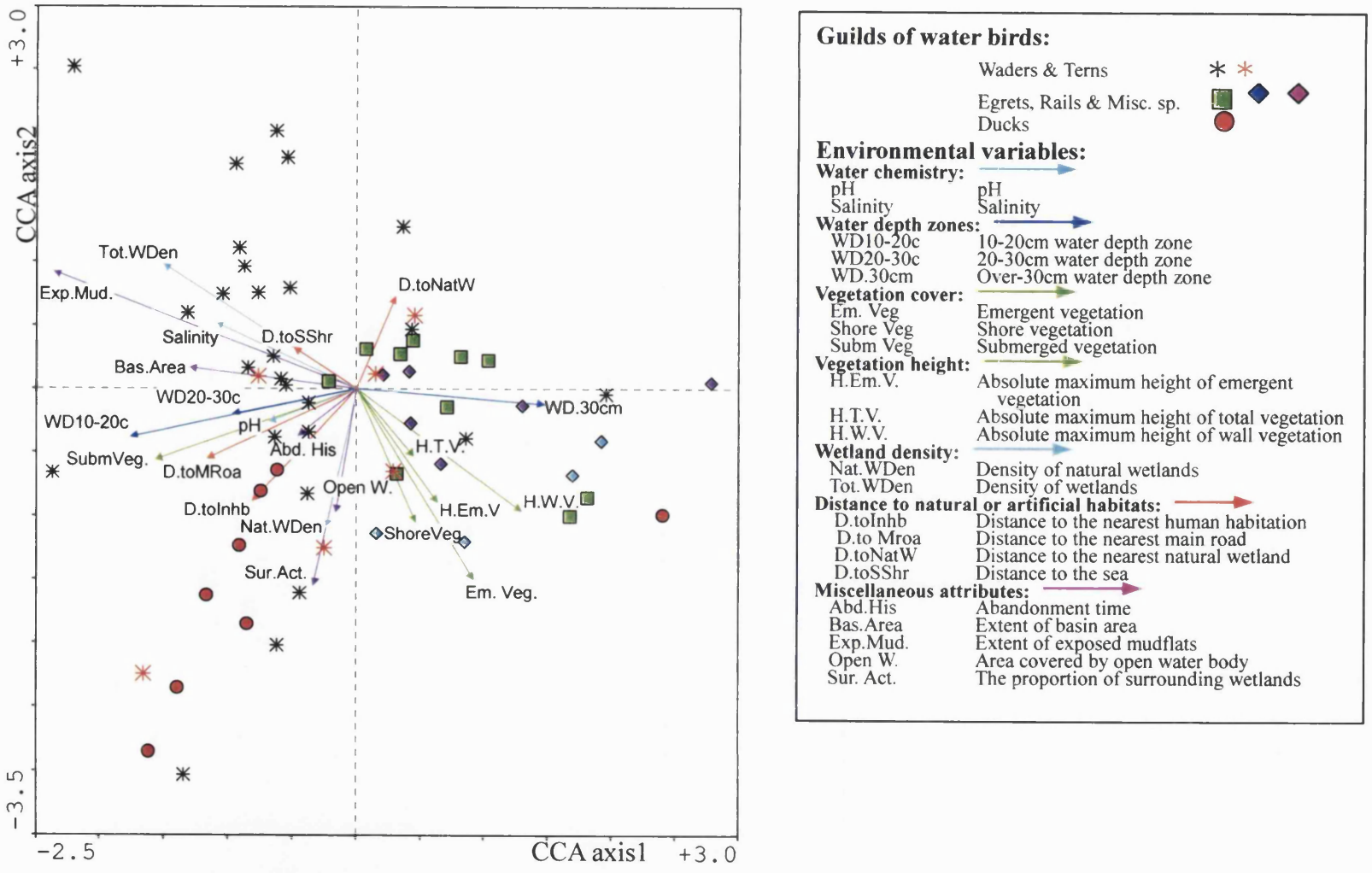


Figure 5.8. The canonical correspondence analysis (CCA) species-environment correlation biplot based on the avian and environmental data from the temporarily abandoned ponds, displaying the relationship between the guilds of water birds and the features of sample wetlands. Different subguilds of water birds and types of environmental features are marked with different symbols and vectors of different colours.

5.4.3. Variations among age classes

The sample ponds in each age class were marked identically in the PCA environment-site correlation biplot (Figure 5.9). Due to insufficient sample ponds in some abandonment time categories, only three age classes with uneven sample sizes were applied to this analysis. As seen in this plot, an unclear separation of the three age classes is identified. The youngest sample ponds, 0-3 year age class, appear to associate positively with the first and second PCA axes while the older ones, 10-20 year age class, associate negatively. The ponds in the 3-10 year age class occur between them. The ponds in the 0-3 year age class associated positively with four variables, the distance to the nearest natural wetland and seashores, the density of surrounding aquaculture ponds and the number of years since first abandonment. The ponds in the 10-20 year age class associated positively with the density of surrounding natural wetlands, the distance to the nearest main road and human habitation, salinity and most of the environmental variables of sample wetlands.

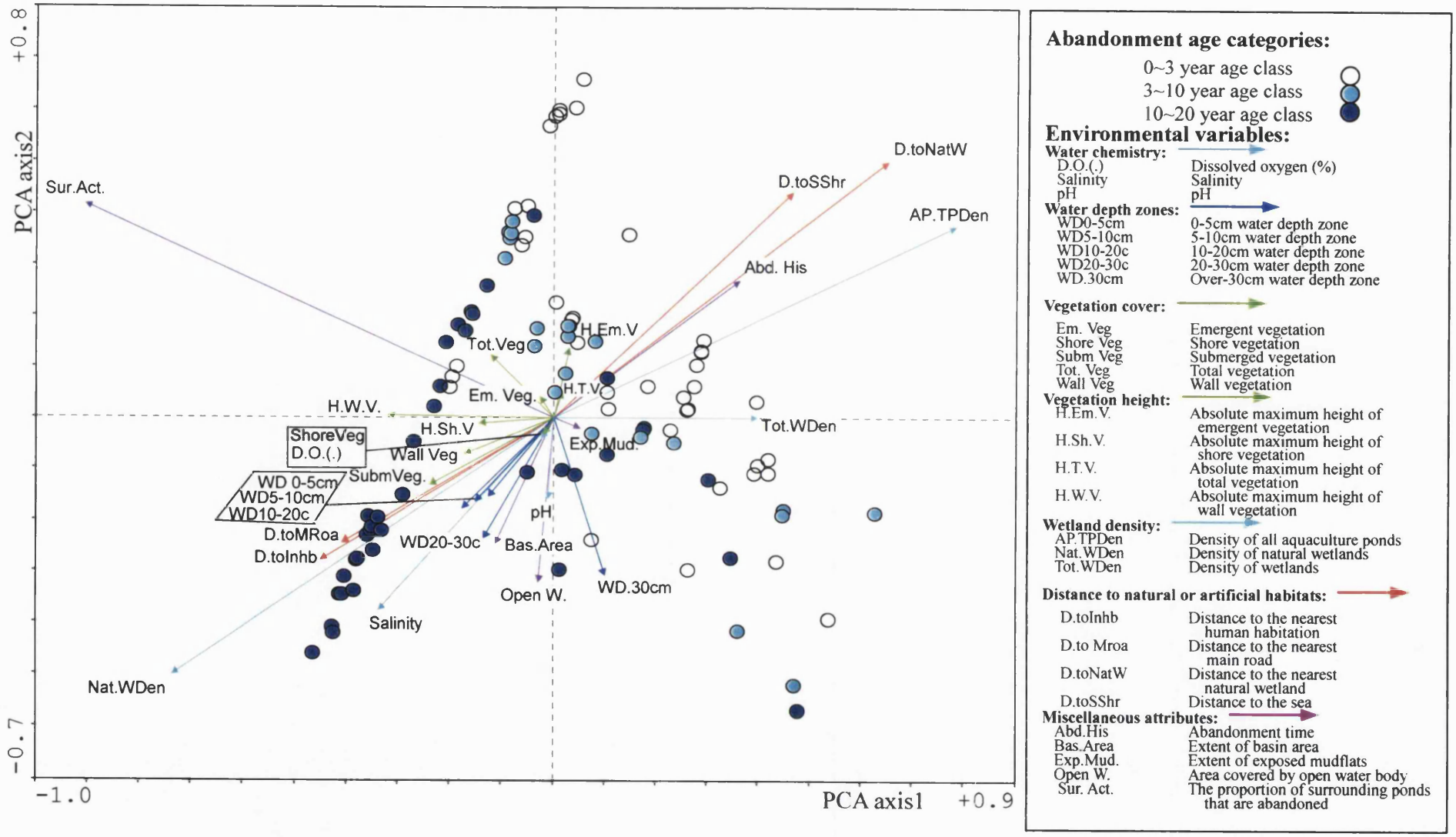


Figure 5.9. The principal component analysis (PCA) environment-site correlation biplot based on the environmental data from the temporarily abandoned ponds, displaying the relationship between the three abandonment age categories and the features of sample wetlands. Ponds from different age classes and types of environmental features are marked with different symbols and vectors of different colours.

Once five highly collinear variables and two variables without statistical significant variations had been excluded, the remaining 22 active variables were used to conduct CCA for the total temporarily abandoned ponds. According to Figure 5.10, the ponds in different abandonment age classes all intermingle together. In addition, no guild displays a link with the ponds in a particular age class. This may indicate that abandonment time is not the important variable for the habitat use of sample wetlands by waterbirds.

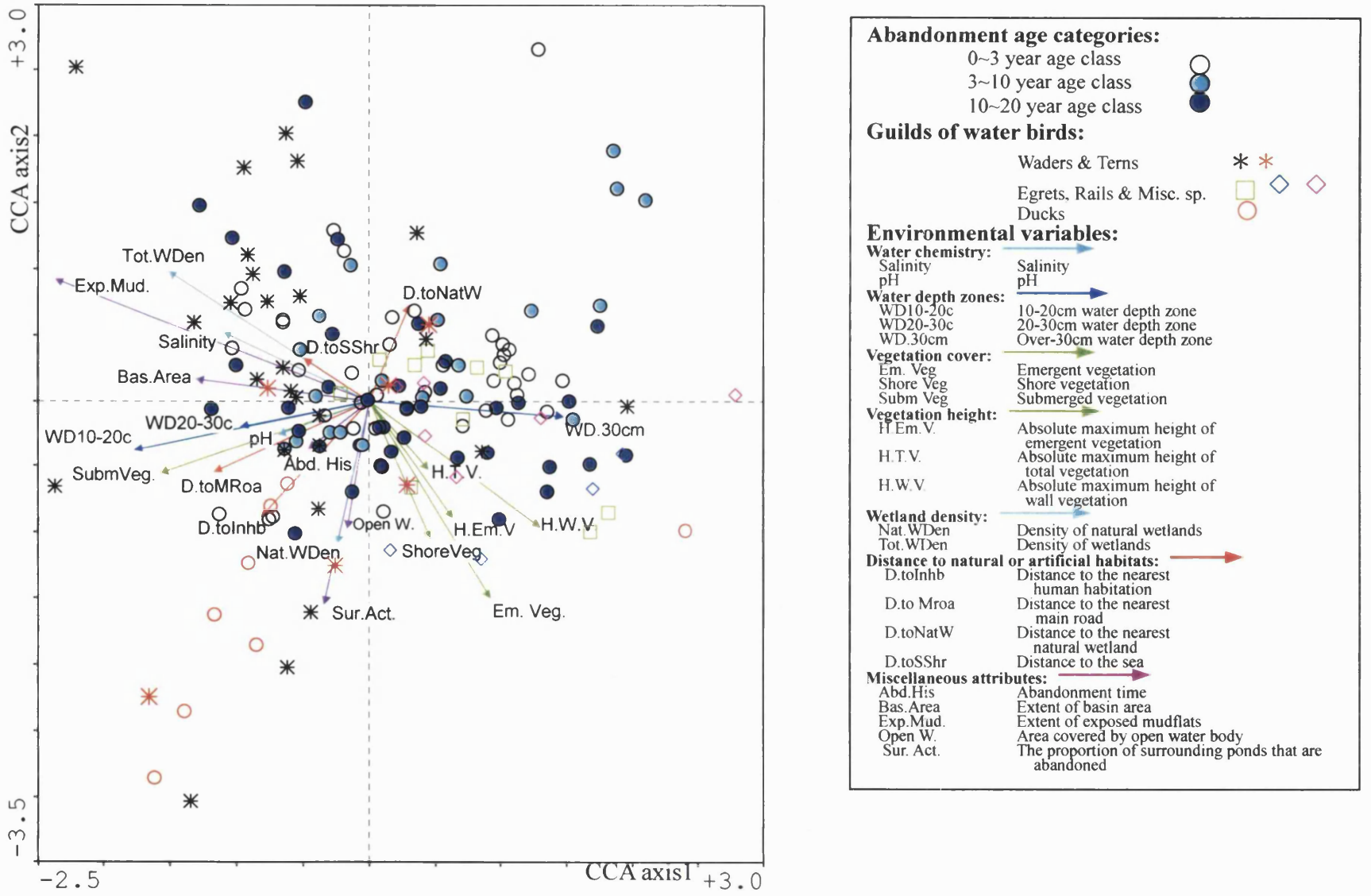
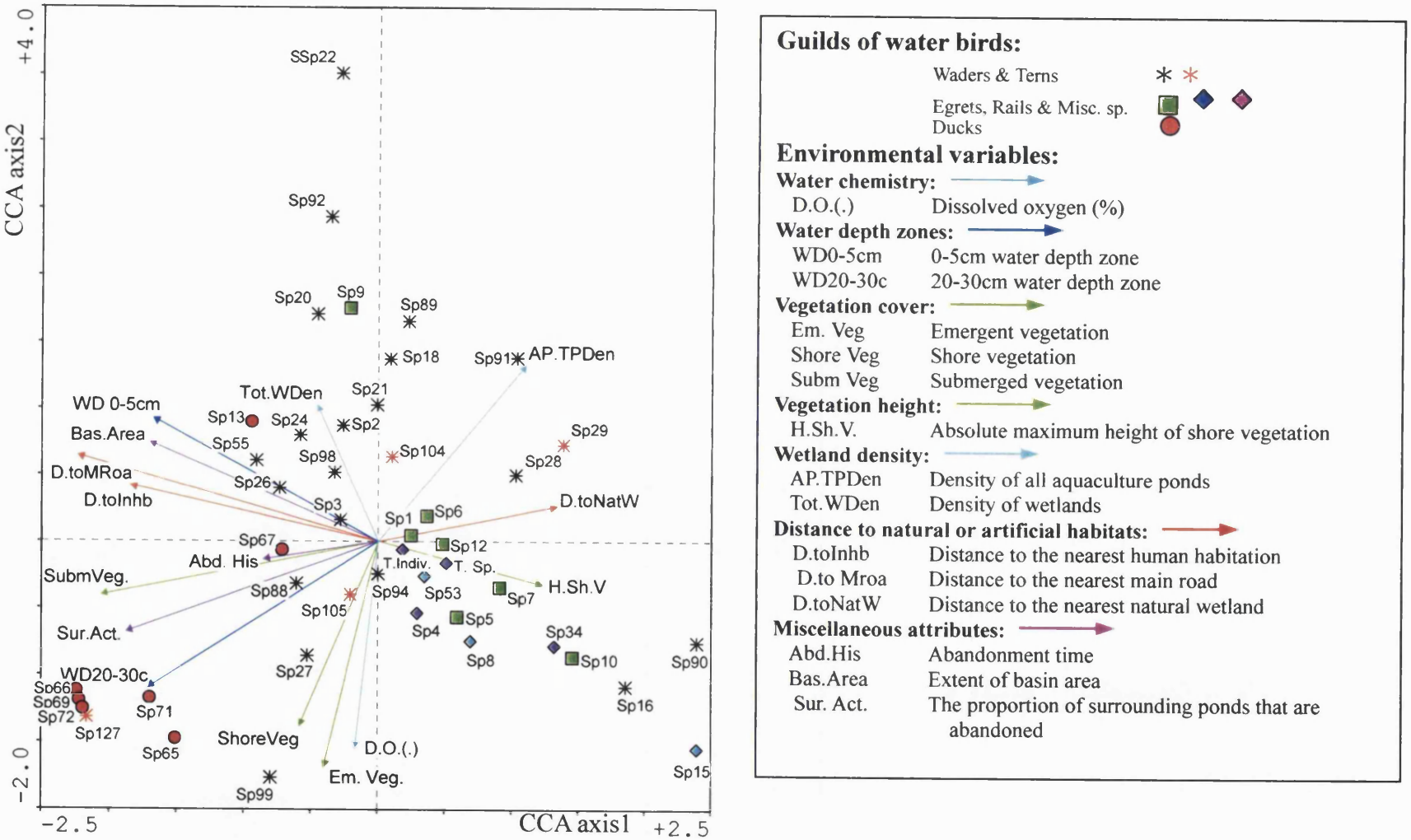


Figure 5.10. The canonical correspondence analysis (CCA) species-environment-site correlation triplot based on the avian and environmental data from the temporarily abandoned ponds, displaying the relationship between the guilds of water birds, the features of sample ponds and abandonment time. Ponds from different age classes, different subguilds of water birds and types of environmental features are marked with different symbols and vectors of different colours.

In order to elucidate the relationship between the features of temporarily abandoned ponds and the habitat use of temporarily abandoned ponds by waterbirds in the three broader abandonment age classes, the environment-species biplot for every age class had been undertaken. Amongst the three age categories, all three guilds display no consistent relationship between the features and the habitat utilization of sample wetlands. The total number of species and total abundance of waterbirds per pond both show no close link with any environmental variable of sample wetlands in the three age classes and remain rather close to the origins of the CCA ordination biplots (Figures 5.11, 5.12 and 5.13).

Wader-Tern guild: The overall density of wetlands is the only variable that affect the habitat use of sample wetlands by this guild through three age classes and played a leading role in the habitat use in the 0-3 year age class (Figures 5.11, 5.12 and 5.13). In the 3-10 year age class, salinity shows the strongest association with this guild, while the distance to the seashore is the most significant environmental variables in the 10-20 year age class (Figures 5.12 and 5.13). Generally, the species of the Wader-Tern guild in the 0-3 year age class are more widely distributed in the CCA ordination biplots than at either all sample ponds or the ponds in the two other age classes (Figures 5.2, 5.11, 5.12 and 5.13). These species display individual associations with particular environmental attributes and cannot be thought as a guild in this age class.



Guilds of water birds:

- Waders & Terns
- Egrets, Rails & Misc. sp.
- Ducks

Environmental variables:

Water chemistry:

D.O.(.)	Dissolved oxygen (%)

Water depth zones:

WD0-5cm	0-5cm water depth zone
WD20-30c	20-30cm water depth zone

Vegetation cover:

Em. Veg	Emergent vegetation
Shore Veg	Shore vegetation
Subm Veg	Submerged vegetation

Vegetation height:

H.Sh.V.	Absolute maximum height of shore vegetation

Wetland density:

AP.TPDen	Density of all aquaculture ponds
Tot.WDen	Density of wetlands

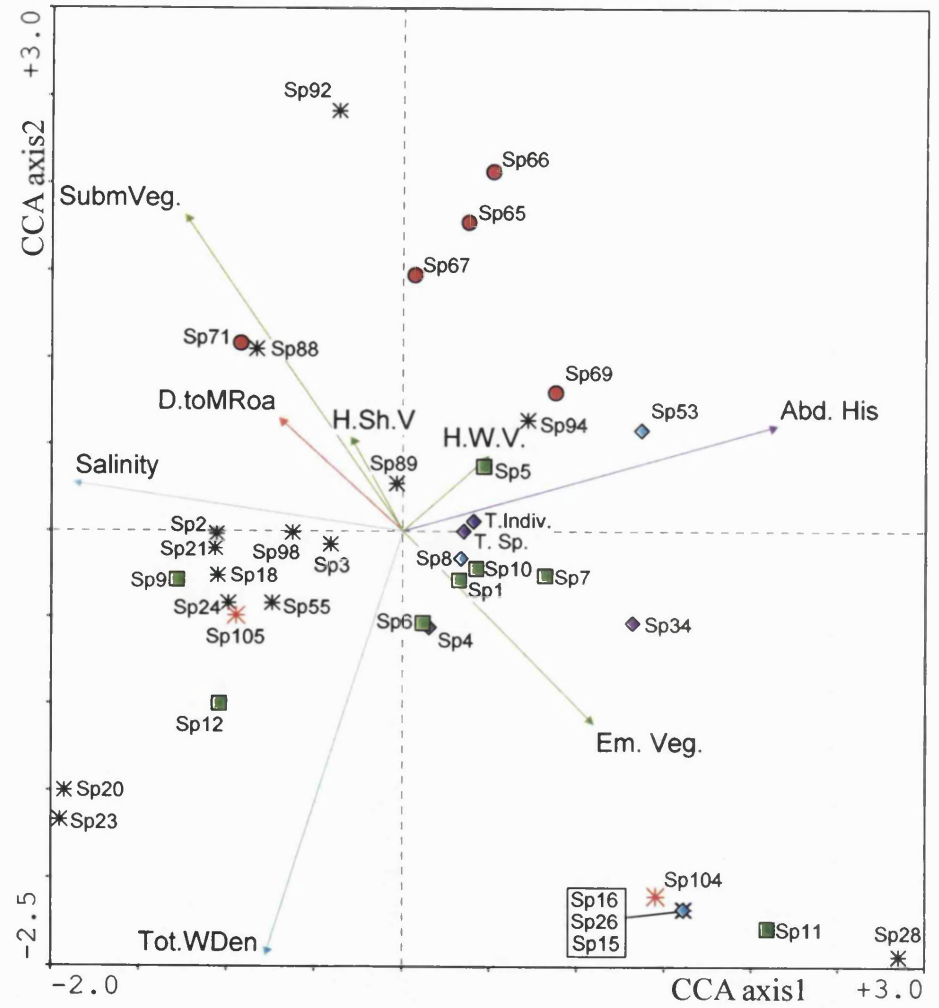
Distance to natural or artificial habitats:

D.toInhb	Distance to the nearest human habitation
D.to Mroa	Distance to the nearest main road
D.toNatW	Distance to the nearest natural wetland

Miscellaneous attributes:

Abd.His	Abandonment time
Bas.Area	Extent of basin area
Sur. Act.	The proportion of surrounding ponds that are abandoned

Figure 5.11. The canonical correspondence analysis (CCA) species-environment correlation biplot based on the avian and environmental data from the sample ponds in the 0-3 year age class, displaying the relationship between the guilds of water birds and the features of sample wetlands. Different subguilds of water birds and types of environmental features are marked with different symbols and vectors of different colours.



Guilds of water birds:

Waders & Terns

Egrets, Rails & Misc. sp.

Ducks

Environmental variables:

Water chemistry:

Salinity Salinity

Vegetation cover:

Em. Veg Emergent vegetation

Subm Veg Submerged vegetation

Vegetation height:

H.Sh.V. Absolute maximum height of shore vegetation

H.W.V. Absolute maximum height of wall vegetation

Wetland density:

Tot.WDen Density of wetlands

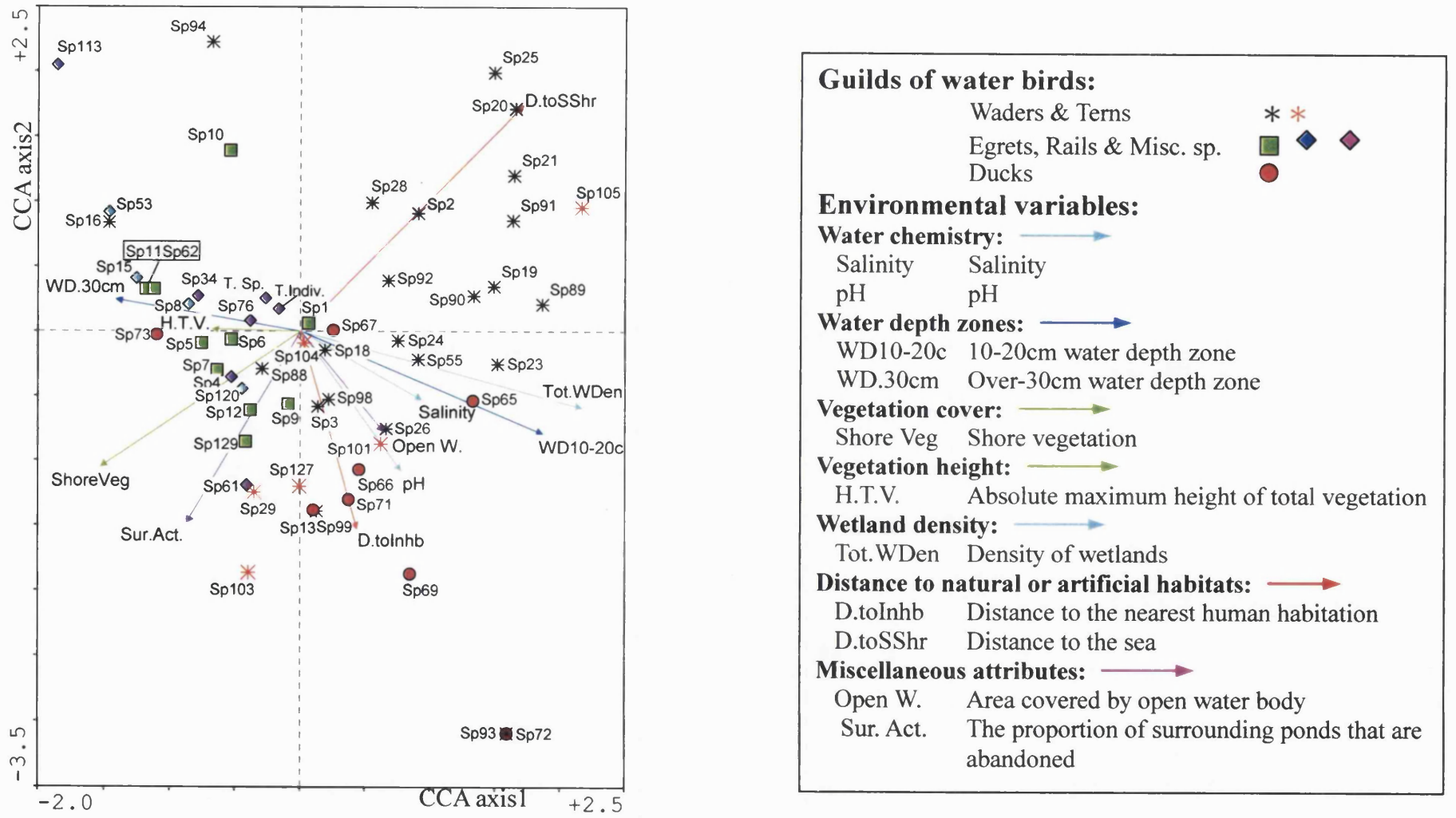
Distance to natural or artificial habitats:

D.to Mroa Distance to the nearest main road

Miscellaneous attributes:

Abd.His Abandonment time

Figure 5.12. The canonical correspondence analysis (CCA) species-environment correlation biplot based on the avian and environmental data from the sample ponds in the 3-10 year age class, displaying the relationship between the guilds of water birds and the features of sample wetlands. Different subguilds of water birds and types of environmental features are marked with different symbols and vectors of different colours.



Guilds of water birds:

Waders & Terns

Egrets, Rails & Misc. sp.

Ducks

Environmental variables:

Water chemistry:

Salinity — Salinity

pH — pH

Water depth zones:

WD10-20c — 10-20cm water depth zone

WD.30cm — Over-30cm water depth zone

Vegetation cover:

Shore Veg — Shore vegetation

Vegetation height:

H.T.V. — Absolute maximum height of total vegetation

Wetland density:

Tot.WDen — Density of wetlands

Distance to natural or artificial habitats:

D.toInhb — Distance to the nearest human habitation

D.toSShr — Distance to the sea

Miscellaneous attributes:

Open W. — Area covered by open water body

Sur. Act. — The proportion of surrounding ponds that are abandoned

Figure 5.13. The canonical correspondence analysis (CCA) species-environment correlation biplot based on the avian and environmental data from the sample ponds in the 10-20 year age class, displaying the relationship between the guilds of water birds and the features of sample wetlands. Different subguilds of water birds and types of environmental features are marked with different symbols and vectors of different colours.

Egret-Rail guild: In general, egret and rail species lie close together in the CCA species-environment biplots in the three age classes. However, diverse association with environmental variables occurred in the three age classes. There is no consistent leading environmental variable in the Egret-Rail guild within these three age classes. In the 0-3 year age class, the absolute maximum height of shore vegetation plays a leading role in the habitat use of sample wetlands by this guild (Figure 5.11). With respect to the 3-10 year age class, cover of emergent vegetation shows a positive association with this guild (Figure 5.12). In the 10-20 year age class, three environmental attributes, including the extent of the >30cm water depth zone and shore vegetation and the proportion of surrounding ponds that are abandoned, show equally positive associations with this guild. Multiple associations with environmental attributes in this guild may be caused by the fact that the members of this guild are more extensively distributed in this age class (Figure 5.13). The most abundant egret species, *Egretta garzetta*, shows no strong link with any environmental attribute in the three age classes and falls close to the biplots' origin (Figures 5.11, 5.12 and 5.13).

Duck guild: The members of the Duck guild have a medium-separated distribution in the CCA ordination biplots in the three age classes although there are a relatively small number of species in this guild. The associations with environmental attributes display a great deal of variations in the three age classes. In the 0-3 year age class, the extent of the 20-30cm water depth zone shows a strong positive correlation (Figure 5.11), while no obvious environmental attribute shows a strong positive association with this guild in the 3-10 year age class (Figure 5.12). The distance to the nearest human habitation shows a positive association with this guild in the 10-20 year age class (Figure 5.1). The most abundant duck species, *Anas creccea*, shows no strong link with any environmental attribute in the three age classes and falls close to the biplots' origins in two out of three age classes (Figures 5.11, 5.12 and 5.13)

5.4.4. Variations among localities

In order to elucidate the influence of locality on the habitat use of sample wetlands by waterbirds, several ordination analyses were conducted. In the PCA and CCA

environment-site biplots, all sample ponds in one sample area were marked identically. To conduct further comparisons between sites, the re-grouping of sample ponds is inevitable due to an insufficient number of sample ponds in a single site. Ten groups of sample ponds were regrouped into four broader sample areas. The ponds at three sample sites were excluded from the following ordination analyses due to a long distance to any other sample areas and an insufficient number of ponds in itself, to form a new broader sample area.

According to the PCA environment-site biplot, three out of four sample areas generally show an aggregated pattern (Figure 5.14). A similar situation occurs in the CCA environment-site biplot (Figure 5.15). This may imply that the influence of locality on the habitat use of sample wetlands by waterbirds did occur in some sample areas and may influence the interpretation of research results for the aggregated data.

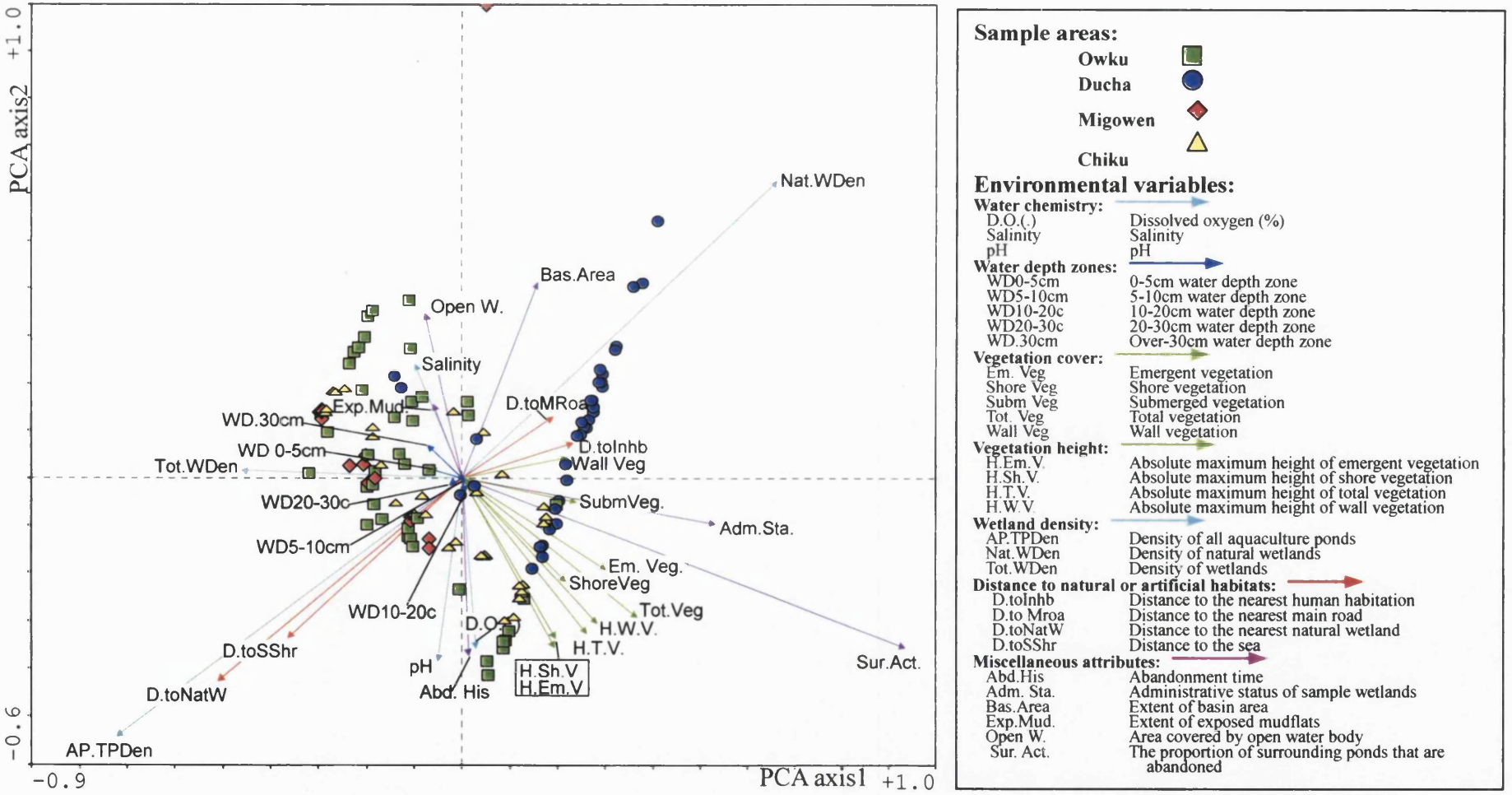


Figure 5.14. The principal component analysis (PCA) environment-site correlation biplot based on the environmental data from all sample ponds, displaying the relationship between the sample sites and the features of sample wetlands. Ponds from different localities and types of environmental features are marked with different symbols and vectors of different colours.

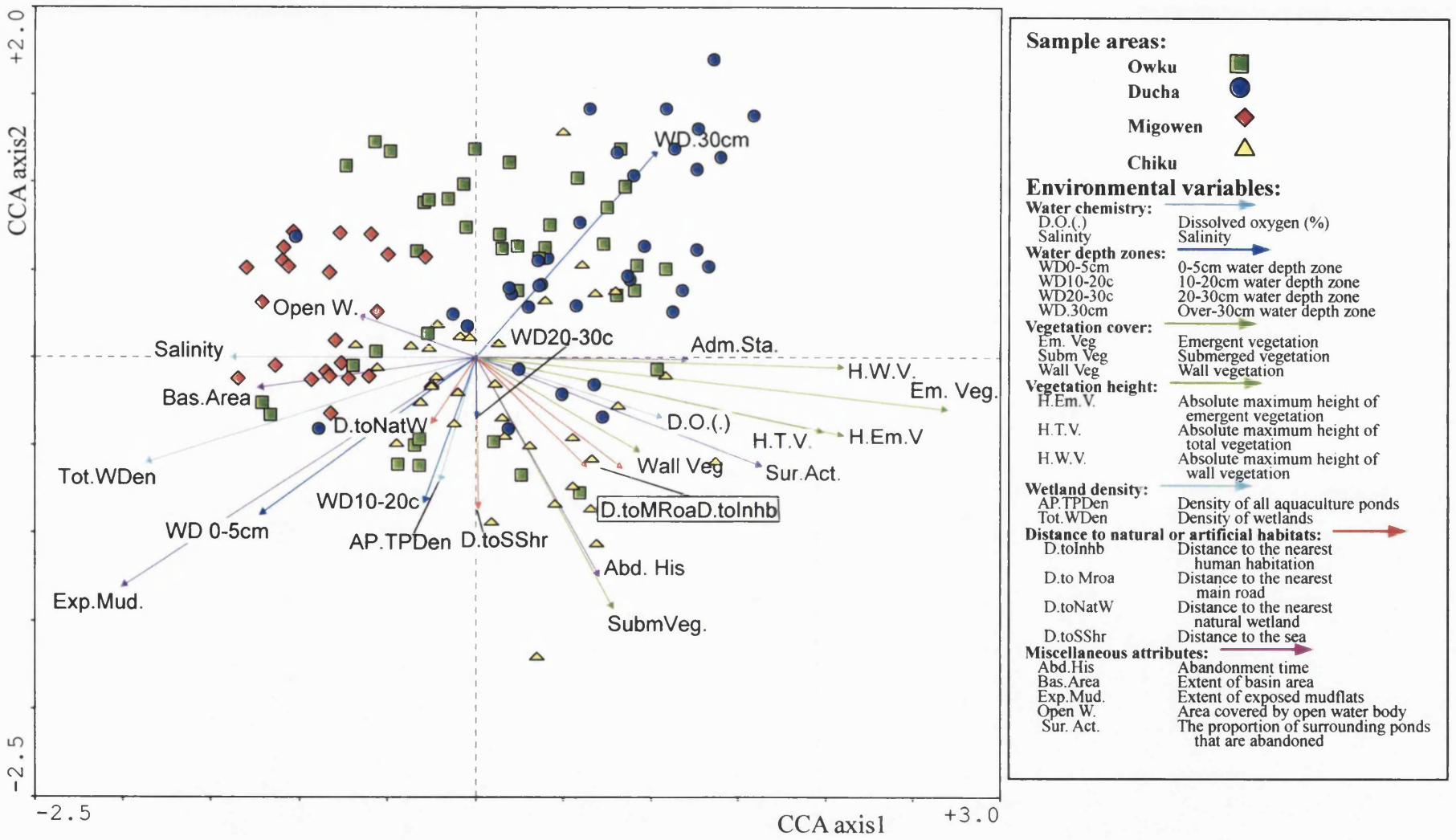


Figure 5.15. The canonical correspondence analysis (CCA) species-environment correlation biplot based on the avian and environmental data from all sample ponds, displaying the relationship between the avian fauna and the features of sample ponds at a particular site. Ponds from different localities and types of features are marked with different symbols and vectors of different colours.

There appears to be some association between sample areas and environmental features in every guild. The Wader-Tern guild had close links with the Migowen sample area and salinity. In contrast, the Egret-Rail guild displays positive correlations with the Owku and Ducha sample areas and the extent of the >30cm water depth zone. In the Duck guild, similar associations occurred between the Chiku sample area and two environmental variables: the number of years since first abandonment and cover of submerged vegetation (Figure 5.16).

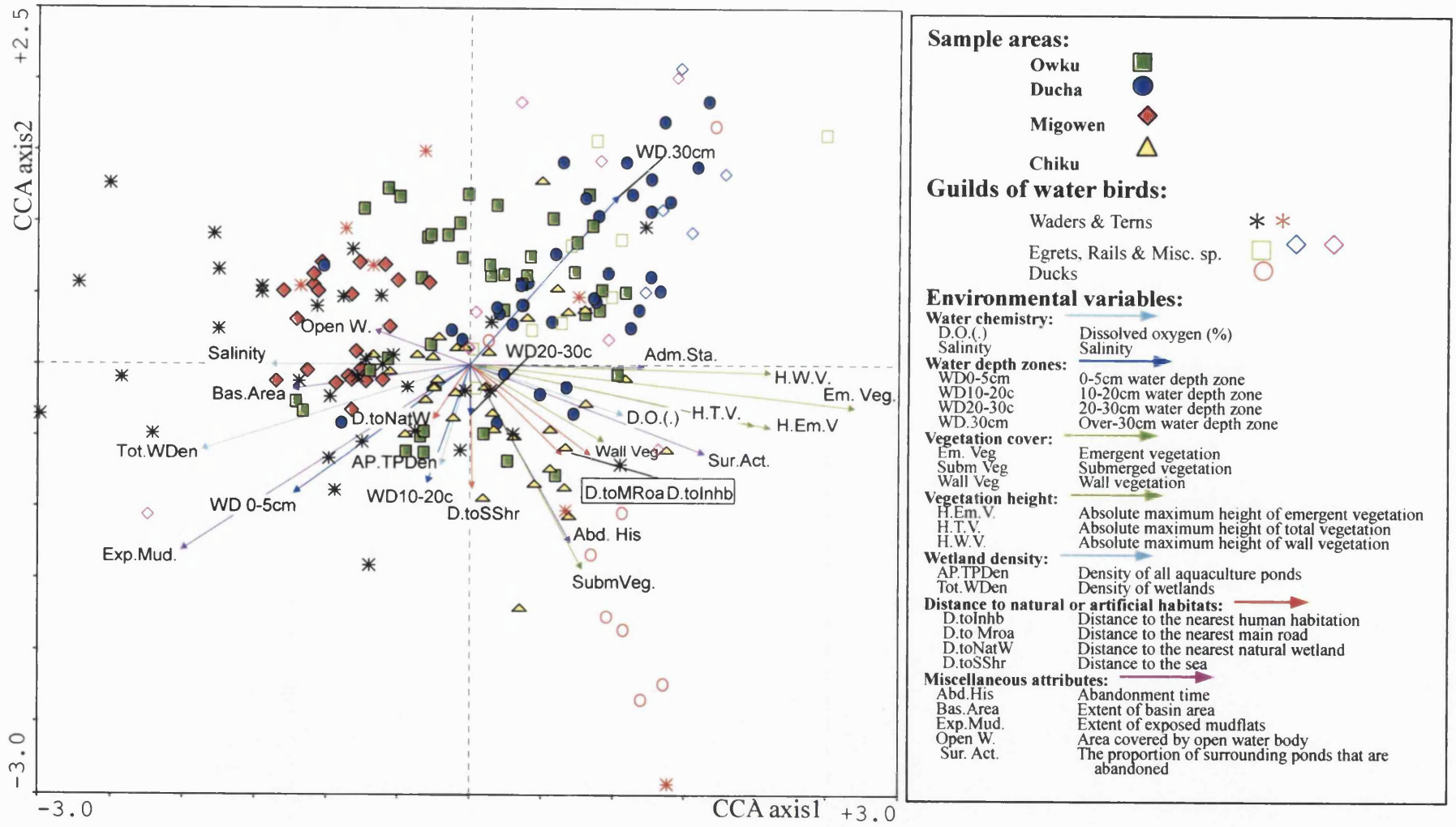


Figure 5.16. The canonical correspondence analysis (CCA) species-environment-site correlation triplot based on the avian and environmental data from all sample ponds, displaying the relationship between the guilds of water birds and the features and localities of sample wetlands. Ponds from different localities, subguilds of water birds and types of environmental features are marked with different symbols and vectors of different colours.

5.4.5. Summary

In Table 5.5, the correlations between guilds of waterbirds and principal associated environmental parameters of wetlands in all sample wetlands, two wetland types or three abandonment age categories are presented. In summary, salinity and basin area, the number of years since first abandonment and cover of submerged vegetation, and the extent of the >30cm water depth zone, respectively, display strong positive associations with the habitat use of sample wetlands by the Wader-Tern, Duck and Egret-Rail guilds. In contrast, vegetation-related variables and the proportion of surrounding ponds that are abandoned, the extent of the 0-5cm water depth zone, and the area covered by open water, respectively, exhibit negative associations with those of the Wader-Tern, Egret-Rail and Duck guilds. There were considerable variations in the correlation between environmental features and the habitat use of sample wetlands by waterbirds in two wetland types. No guild shows fixed and positive correlations with any particular environmental attribute in the sampled wetland types. Regarding three abandonment age categories, no guild shows a positive association with any fixed environmental attribute of sample wetlands. The influence of locality on the habitat utilization of sample wetlands by waterbirds might occur due to the local differentiation in the physical or vegetative characteristics of wetlands.

Table 5.5. The correlations between guilds of water birds and the principally associated physical parameters of wetlands in all sample wetlands, two wetland types and three abandonment age categories.

Correlation / Guild	Wader-Tern	Egret-Rail	Duck
All sample wetlands			
Positive association	Salinity Basin area	Extent of the over-30cm water depth zone	Cover of submerged vegetation Abandonment time
Negative association	Vegetation-related variables The proportion of surrounding ponds that are abandoned	Extent of exposed mudflats and the 5-10cm water depth zone	Area covered by open water
No association	Extent of the 5-10cm and over-30cm water depth zones and exposed mudflats	Cover of submerged vegetation Abandonment time	Extent of the over-30cm and 0-5cm water depth zones and exposed mudflats
Wetland types			
Actively managed ponds			
Positive association	___	Distance to the nearest natural wetlands Extent of the over-30cm water depth zone	Density of natural wetlands
Negative association	___	Extent of exposed mudflats and the 10-20cm water depth zone Distance to the nearest human habitation	___
No association	All investigated environmental attributes	Density of natural wetlands	Other environmental attributes
Temporarily abandoned ponds			
Positive association	Density of wetlands Extent of exposed mudflats	Extent of the over-30cm water depth zone	Distance to the nearest human habitation The proportion of surrounding ponds that are abandoned
Negative association	Vegetation-related variables	Basin area Extent of exposed mudflats	Distance to the nearest natural wetlands
No association	Distance to the nearest natural wetlands	Distance to the nearest natural wetlands Area covered by open water Density of natural wetlands The proportion of surrounding ponds that are abandoned	Vegetation-related variables Density of wetlands
Abandonment age categories			
0-3 year age class			
Positive association	Density of wetlands	Absolute maximum height of shore vegetation	Extent of the 20-30cm water depth zone
Negative association	Absolute maximum height of shore vegetation	Density of wetlands	Density of all aquaculture ponds
No association	Density of all aquaculture ponds	Density of all aquaculture ponds Extent of 20-30cm water depth zone	Density of wetlands
3-10 year age class			
Positive association	Salinity	Cover of emergent vegetation	___
Negative association	Abandonment time	Cover of submerged vegetation	Density of wetlands
No association	Cover of submerged and emergent vegetation	Absolute maximum height of wall vegetation	Salinity
10-20 year age class			
Positive association	Distance to the sea	Extent of the over-30cm water depth zone and cover of shore vegetation The proportion of surrounding ponds that are abandoned	Distance to the nearest human habitation
Negative association	Cover of shore vegetation	Distance to the sea Density of wetlands	___
No association	PH Area covered by open water	Distance to the nearest human habitation	Cover of shore vegetation

5.5. Discussion

According to the species-environment ordination of the actively managed and temporarily abandoned aquaculture ponds, the density of natural wetlands in surrounding areas might play an important role in the habitat selection of sample wetlands by waterfowl (Figures 5.6 and 5.8). Aquaculture ponds with high density of surrounding natural wetlands appear to have high occurrence of ducks, and vice versa. This might suggest that only the aquaculture ponds located in a mosaic habitat with high proportions of surrounding natural wetlands are more likely to have high occurrence of ducks. In other words, the aquaculture ponds which are located amid natural wetlands could have a better conservation value to waterfowl, and should be placed at a high priority to include within a waterfowl conservation site.

Human disturbance in wetlands such as hunting, water-based recreational activities, were reported to have strong interference to the habitat utilization of wetlands by waterfowl by many authors (Tuite *et al.*, 1983; Tuite *et al.*, 1984; Bell & Austin, 1985; Erwin, 1989; Mayhew & Houston, 1989; Dehorther & Tamisier, 1996). The extent of interference can vary by the affected species of waterfowl (Tuite *et al.*, 1984). For instance, the occurrence of waterfowl in the disturbed area can be four times higher than those in unaffected control area (Dehorther & Tamisier, 1996) and the flush distance of the sensitive species, Goldeneye (*Bucephala clangula*), can be up to 700m (Hume, 1976). In this study, several disturbance-related wetland characteristics show strong associations with the habitat use of sample wetlands by the Duck guild, namely abandonment time, the proportion of surrounding ponds that are abandoned, the mean height of the dominant species of wall vegetation and the distance to human habitation or main roads (Figures 5.2, 5.6, 5.8, 5.11, 5.12, 5.13 and Table 5.5). Being associated with so much disturbance strongly suggests that the habitat selection of waterfowl could be primarily influenced by anthropogenic disturbance in the study area. However, this result is different form that of Leschisin *et al.* (1992). They reported that the distance to the next large impoundment played a more important role in the occurrence of ducks than the distance to the nearest main road or human habitation. In other words, human disturbance could play only a minor role in the habitat selection of waterfowl in Leschisin's study, which was conducted in northern Minnesota, USA.

Human population density might cause the differences in conclusion between Leschisin's and this study. Human population density is much smaller in northern Minnesota than in southwestern Taiwan (northern Minnesota : southwestern Taiwan= 21.848 people/ km^2: 638.84 people/km^2= 1 : 29.2). Consequently, human disturbance in the vicinity of Leschisin's area were relatively slight and other environmental factors could then play a more decisive role in the habitat selection of waterfowl.

Aside from the individual habitat requirements of the three principal waterbird guilds, there are considerable variations in the habitat utilization of wetlands among wetland types by the three guilds (one-way ANOVA: Wader-Tern, F=67.107, p=0.000**, df=3; Duck, F=6.878, p=0.000**, df=3; Egret-Rail, F=66.249, p=0.000**, df=3). Separate guilds of waterbirds showed a strong association with different wetland types (Figure 5.4). This indicates that different guilds of waterbirds need different wetland types or a combination of several wetland types in different proportions. With respect to the Duck guild, a large proportion of undisturbed temporarily abandoned ponds would be ideal. The Egret-Rail guild needs actively managed ponds and temporarily abandoned ponds at the same time; the latter in particular should be in a high proportion for the guild to thrive. In all sample the Wader-Tern guild, a mosaic of natural wetlands, saltpans and actively managed ponds with frequent aquacultural practices would be ideal. Actively managed ponds are probably the most important wetland type for this guild, and an area of at least 50% would be needed in a conservation wetland complex.

Locality appears to have some extent of influence on the habitat selection of waterbirds. As shown in the figure 5.16, the ponds of one particular site generally lay close one another, and associated with one particular guild of waterbirds. In other words, the ponds at one particular sample site might share a common physical or vegetative characteristics, and were more intensively used by one particular guild of waetrbirds. The Duck guild associated with the Chiku site, the Egret-Rail guild had some associations with the Ducha site, the Wader-Tern guild associated with the Migowen site, while the Owku site appears to associate with the Egret-Rail and Wader-Tern guild at the same time. It suggests that locality could have some

influence on the habitat selection of waterbirds. It is suggested that separate analyses of study sites are conducted. However, in most instances, insufficient sample sizes had made this kind of comparisons impossible to undertake in the present study. More detailed analyses with larger sample sizes and observations are called for to bridge this gap.

Chapter 6

Manipulation experiment: water level control

6.1. Introduction

In earlier chapters, attempts have been made to evaluate the strength of relationships between waterbirds and several environmental parameters of existing wetlands that may affect their distribution and numbers. However, in order to elucidate the most decisive factors affecting ecology needs to be undertaken, manipulation experiments were undertaken to reveal empirical relationships between waterbirds and environmental variables.

Several reasons contribute to the selection of the water level as the variable for manipulation. First, many researchers have already underlined the strong influence of the water level on the habitat selection of waterbirds (Adair *et al.*, 1996; Weber & Haig, 1996; Safran *et al.*, 1997; Svingen & Anderson, 1998). Second, in the observations of aquacultural practice, it is apparent that the drainage of aquaculture ponds at the end of a fish culture season displays dramatic changes in the extent of habitat use by waterbirds. Chu (1995) reported similar observations in the commercial fishponds in Hong Kong. Third, when during the research in the study area the water level dropped in the sample wetlands, a dramatic increase in the numbers of birds was recorded several times. These studies all show that the water level may be an especially important factor in the habitat selection of waterbirds. Furthermore, water level control is the most practicable and potentially revealing type of manipulation experiment of all possible manipulation experiments to elucidate the habitat selection of waterbirds.

Aims: This experiment aims to reveal the chronological changes of species richness, abundance and composition, microhabitat use and the most frequent feeding depth, of waterbirds before and after manipulation of the water level. In addition, the variations between individual species are also compared. The findings will contribute knowledge about the particular habitat requirements of waterbird species.

6.2. Study sites

Three pairs of ponds with similar habitat configuration, including vegetation, basin area, the height of embankments, the number of years since abandonment and water depth, were selected for the conduct of the manipulation experiment. One pond in

each pair was treated as a reference pond with no alteration being made to the water level, and the other pond was used in the manipulation experiment. Due to the shortage of suitable reference ponds, pair 1 and pair 2 experimental ponds shared a reference pond. The three pairs of ponds were all under intensive routine investigation in the main study and are all brackish and situated in the southeast of the study area (Figures 6.1, 6.2 and 6.3). All ponds had been abandoned for about 13 years (Table 6.1).

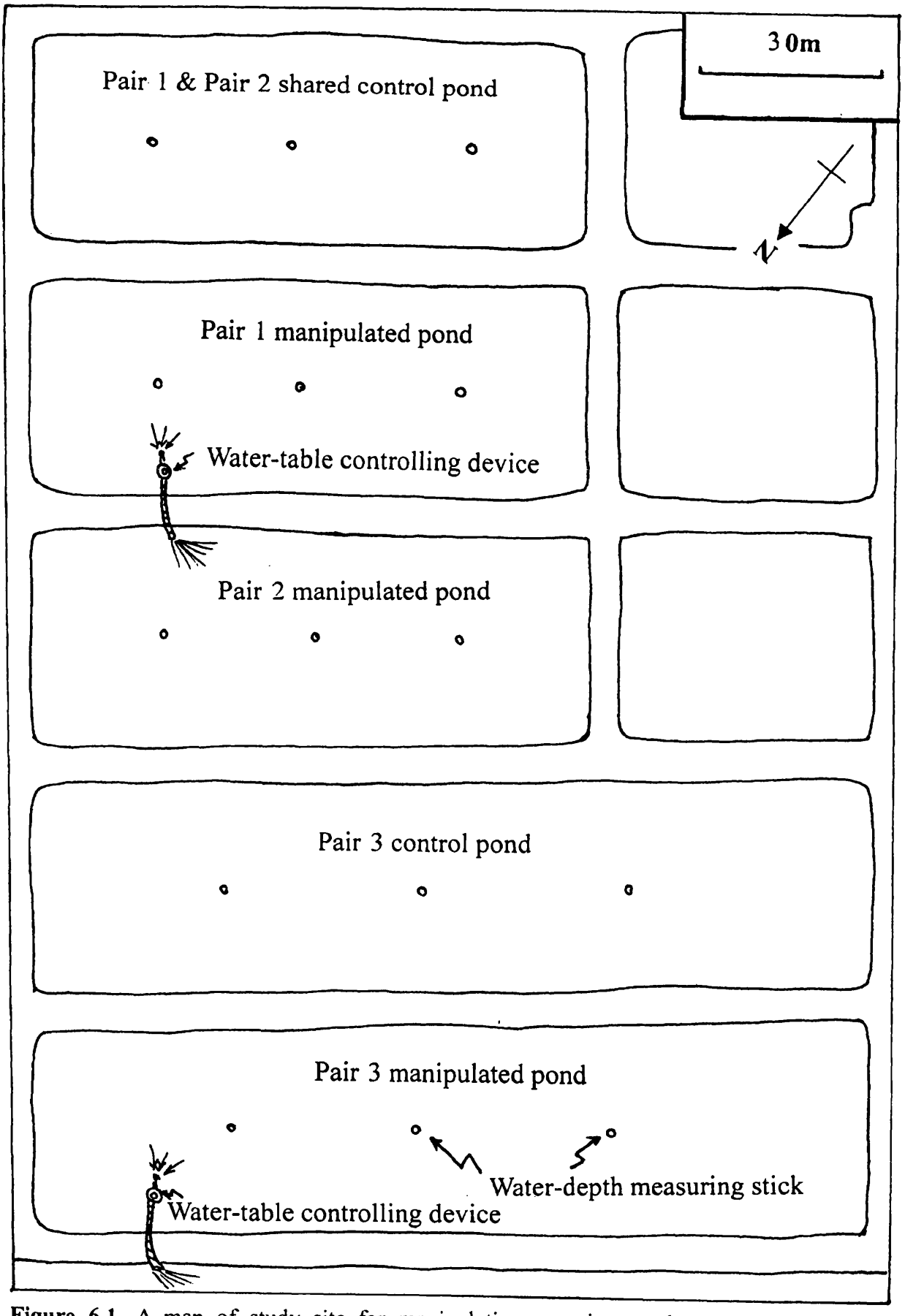


Figure 6.1. A map of study site for manipulation experiment, showing three pairs of experimental ponds. Water-table manipulating devices and water-depth measuring sticks are indicated.

Figure 6.2. Before water level manipulation (1) pair 1 manipulated pond (2) pair 2 manipulated pond (3) pair 3 manipulated pond (4) pair 1 and pair 2 shared reference pond (5) pair 3 reference pond (6) exposed macrophytes when water level being lowered to 30 cm depth.

(1) pair 1 manipulated pond

(2) pair 3 manipulated pond

Figure 6.3. After water level manipulation (1) pair 1 manipulated pond (2) pair 2 manipulated pond.

Table 6.1. Summary of wetland characteristics of the study ponds for the water level manipulation experiment.

Wetland characteristics	Pair 1 manipulated pond	Pair 2 manipulated pond	Pair 3 manipulated pond	Pair 1 and pair 2 shared reference pond	Pair 3 reference pond
Basin area(ha)	0.6	0.6	0.9	0.6	0.9
Abandonment time(yrs)	13	13	13	13	13
Freshwater or brackish	Brackish	Brackish	Brackish	Brackish	Brackish
Water depth before manipulation (cm)	60	45	70	70	70
Embankment's height(cm)	300	300	300	300	300
Dominant species of shore vegetation	*Phragmites communis*	*Phragmites communis*	*Paspalum vaginatum*	*Phragmites communis*	*Paspalum vaginatum*
Dominant species of wall vegetation	*Bidens pilosa*	*Bidens pilosa*	*Paspalum vaginatum*	*Bidens pilosa*	*Paspalum vaginatum*
Dominant species of emergent vegetation	*Paspalum vaginatum*	*Paspalum vaginatum*	*Paspalum vaginatum*	*Paspalum vaginatum*	*Paspalum vaginatum*
Dominant species of submerged vegetation	*Egeria densa*	*Egeria densa*	*Paspalum vaginatum*	*Egeria densa*	*Paspalum vaginatum*
Cover of shore vegetation (%)	100	100	100	100	100
Cover of wall vegetation (%)	100	100	100	100	100
Cover of emergent vegetation (%)	35	35	10	35	10
Cover of submerged vegetation (%)	100	100	80	100	80
Height of shore vegetation (m)	0.55	0.55	0.45	0.55	0.45
Height of wall vegetation (m)	0.65	0.65	1.65	0.65	1.65
Height of emergent vegetation (m)	0.55	0.55	0.35	0.55	0.35
Human involvement	Release of fry	Release of fry	Vegetation was completely covered by surface soil	Release of fry	Vegetation was completely covered by surface soil
Distance to the nearest natural wetland(m)	1500	1500	1600	1500	1600
Distance to the nearest main road(m)	860	840	820	880	800
Distance to the nearest human habitation(m)	420	420	400	420	400
Distance to the sea(m)	3800	3800	3800	3800	3800

Pair 1 and pair 2 experimental ponds

The basin area of each pond in pair 1 and pair 2 is 0.6 ha at a depth of 45 to 70 cm before manipulation. The most recent human involvement was the release of fry by the manager of nearby aquaculture ponds one year before the start of this manipulation experiment. Seashore paspalum *Paspalum vaginatum* was the dominant emergent vegetation, and Common water weed *Egeria densa* dominated the submerged vegetation. In terms of shore vegetation and wall vegetation, Common reed *Phragmites communis* and Hairy beggarticks *Bidens pilosa* shared the largest proportions of vegetation cover, respectively. Coverage of shore, wall and submerged vegetation all almost attained 100 per cent, while the height of wall and shore vegetation reached 65 cm and 55 cm, respectively. Coverage of emergent vegetation was approximately 35%, while its height was 55 cm on average. The nearest natural wetland, main road, human habitation and seashore are 1500m, 230m, 420m and 3800m away, respectively (Table 6.1).

Pair 3 experimental ponds

The basin area of pair 3 ponds is 0.9ha., and is slightly larger than pair 1 and pair 2, at the depth was 70 cm before manipulation. Any vegetation which had previously bordered these ponds had been entirely covered by soil from the rebuilding process of embankments and bed that took place ten months before the manipulation experiment. However, vegetation grew especially rapidly after the refurbishment of these ponds. *Paspalum vaginatum* dominated the emergent, wall and shore vegetation types. Both the wall and shore vegetation types had a coverage of 100%. In contrast, coverage of submerged and emergent vegetation was 80% and 10% respectively, while the mean height of the wall, shore and emergent vegetation was 165 cm, 45 cm and 35 cm, respectively. The nearest natural wetland, main road, human habitation and seashore are 1600m, 40m, 400m and 3800m away, respectively (Table 6.1).

6.3. Methods

The water level was manipulated using water pumps. The maximum drainage capacity is 0.9 m^3 per minute which can reduce (or increase for pair 2 pond) water depth by 0.9 cm per hour for pair 1 manipulated pond and by 0.6 cm per hour for pair 3 ponds. Water pumps were installed at the deepest part of the water body in pair 1

manipulated pond, with a pipe attached to the water pump to drain water into pair 2 manipulated pond (Figure 6.4). In pair 3 ponds, the water pump was installed at the deepest part of the water body of the manipulated pond, with a pipe leading to an adjacent ditch (Figure 6.5). In each manipulated pond, three sharpened bamboo poles, with marks evenly spaced at a five cm interval, were placed in the centre of the ponds equidistant from one another (Figure 6.6). This facilitates the estimation of water depths of the ponds with the help of binoculars without the need to wade into the water body. The water level was planned to drop by five cm each day for six days from 35 cm down to five cm depth, the latter being the lowest water depth that can be attained with the experimental apparatus. However, despite the fact that the water pump was operating 24 hours a day, the water level did not decrease on schedule and remained unchanged for eight days and even increased to a depth of 15 cm on one occasion in pair 1 manipulated pond. After this prolonged 10 cm depth period, the depth was dropped again and it reached a minimum of five cm. A five cm depth level was maintained till the end of the manipulation experiment.

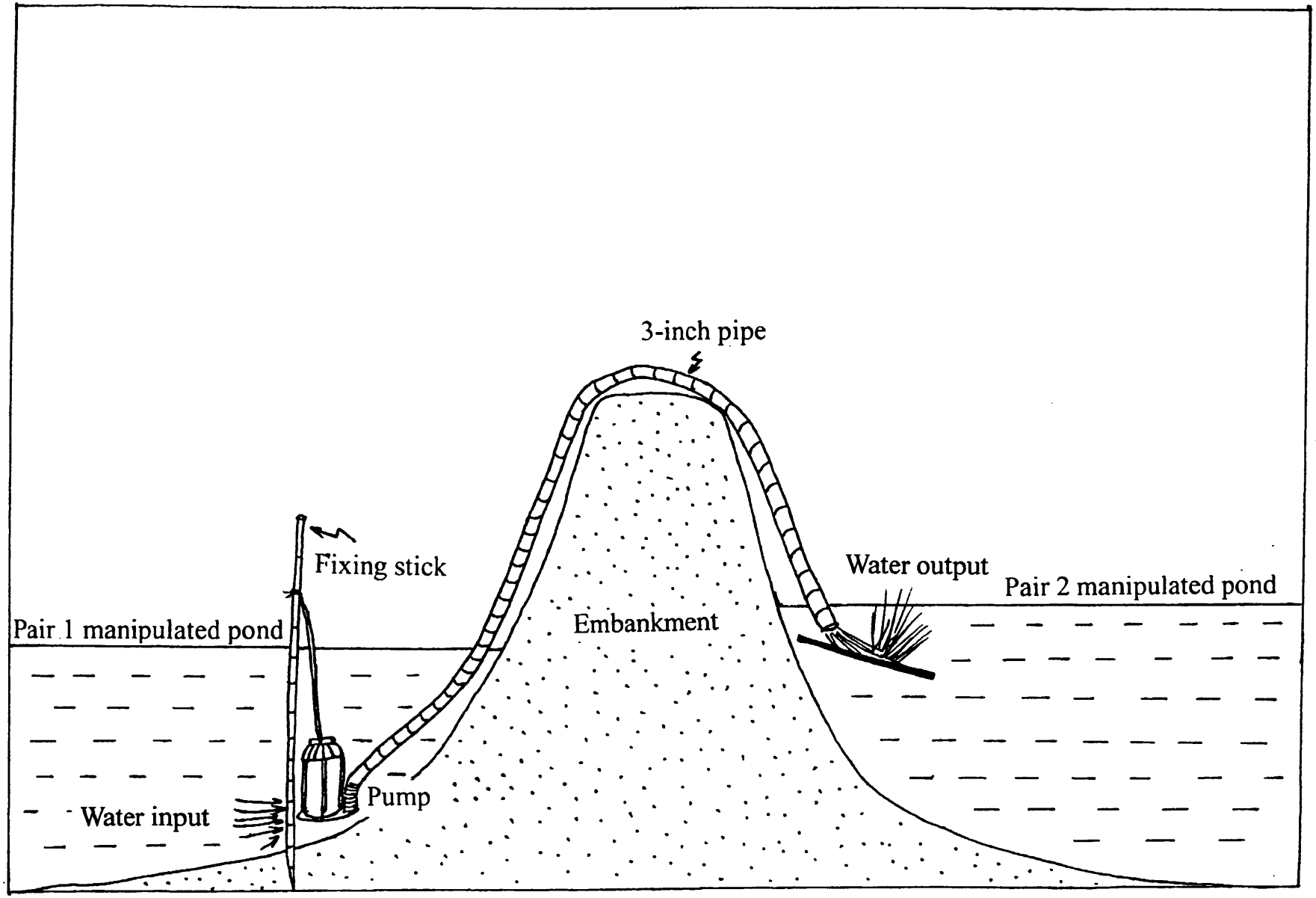


Figure 6.4. A cross-section of the installation of the water-table manipulating device across the shared embankment of Pair 1 and Pair 2 manipulated ponds. Water was drained from Pair 1 pond into Pair 2 pond.

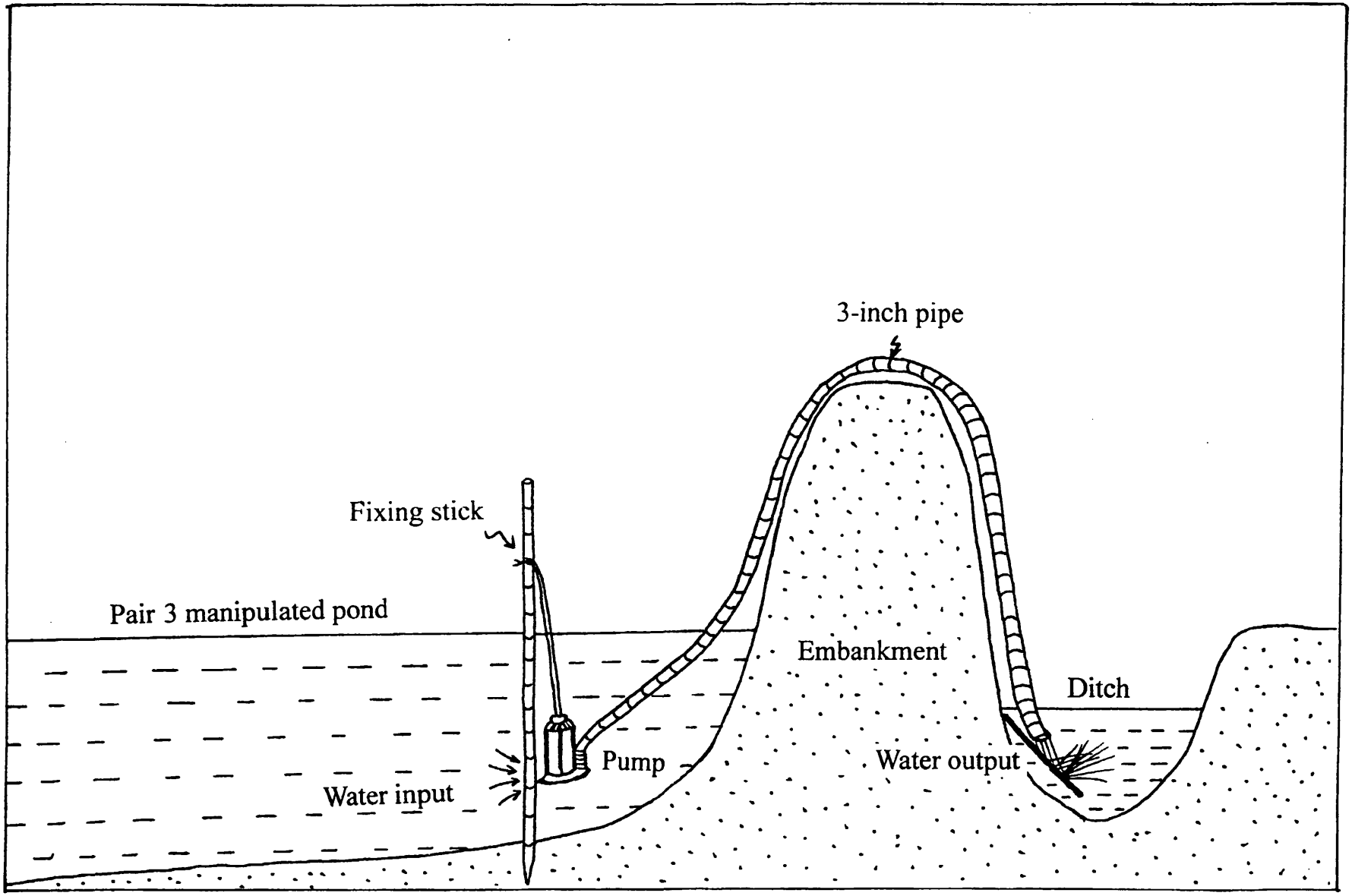


Figure 6.5. A cross-section of the installation of the water-table manipulating device, which drained water from Pair 3 manipulated pond into an adjacent ditch.

(1) Water pump and attached pipe

(2) Pipe

(3) Depth measuring pole

Figure 6.6. Installation of the water pump and measuring pole. (1) Water pump and attached pipe were fastened on the fixing stick (2) Strong water current from pipe were spread by a upside-down tin bathtub to reduce the damage to the embankment of manipulated ponds (3) three depth measuring poles were placed in the centre of the pond equidistant from each other.

Species richness, abundance and composition as well as microhabitat use and feeding depth of the waterbirds were recorded every day starting two days before manipulation for pair 1 and pair 2 ponds and four days before manipulation for pair 3 ponds. Observations continued until one day after the shallowest water depth was attained (5 cm for both pair 1 and pair 3 manipulated ponds). All observations were made in the early morning, no later than half an hour after sunrise. Due to the shyness of ducks and the high possibility that disturbance might make them unwilling to return to the study ponds, daily observations were conducted with extreme care and minimum disturbance. In addition, the researcher managed to almost totally avoid entering the ponds so as to minimize the bias caused by the presence of observers.

6.4. Statistical analysis

Histograms for the total number of species and the total number of birds at each pair of manipulated ponds and for the total number of birds for each waterbird species were first produced to give an indication of their changes along the gradient of water depth. Knowledge of this trend will help determine the most frequent feeding depth for each species. Next, in order to understand the correlation between water depth and the three parameters regarding waterbirds, namely species richness, abundance and microhabitat utilization, one-way analysis of variance (ANOVA) was conducted to determine the significance in the variations with water depth. Linear regression was then applied to variables such as species richness and abundance if they show significant variations in the ANOVA.

6.5. Results

Daily observations were made from 17th October 2000 for pair 1 and pair 2 ponds and 19th October 2000 for pair 3 ponds to 31st October 2000 (28th October 2000 excluded). Twenty-five waterbird species and 5,071 birds were recorded.

6.5.1. Species richness

The species richness at the pair 3 manipulated pond displays a strong negative association with the height of the water level. The total number of species started to increase at a depth of 35 cm and reached a peak value at a depth of 10 cm or less (Figure 6.7). Pair 1 manipulated pond shows an increase in the total number of

species starting at a depth of 10 cm, but shows a much greater variation in amplitude than pair 3 pond when the water level was lowered to 10 cm or less. The greatest number of species was recorded when the depth was lowered to 10 cm or less for six days (Figure 6.8). In contrast, the total number of species in pair 2 manipulated pond started to decrease even before the water level increased and remained low for the period of high water depth (at around 90 cm depth), but returned to its original value when the water level had been maintained at its highest level for 12 days (Figure 6.9).

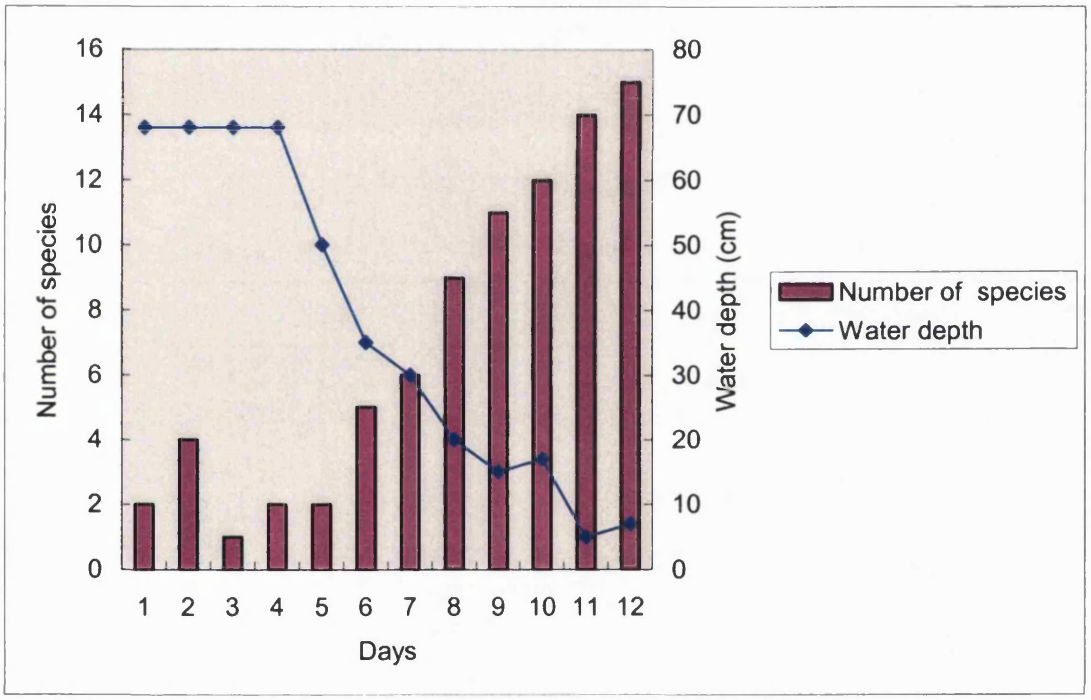


Figure 6.7. The chronological changes in the corresponding number of waterbird species to the manipulation of water level in Pair 3 manipulated pond.

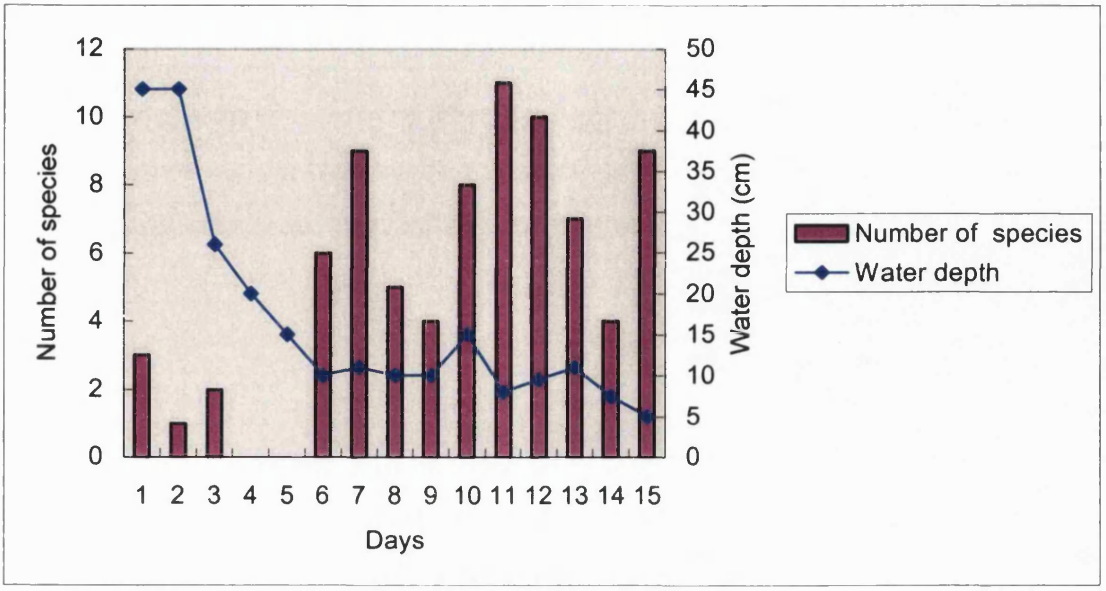


Figure 6.8. The chronological changes in the corresponding number of waterbird species to the manipulation of water level in Pair 1 manipulated pond.

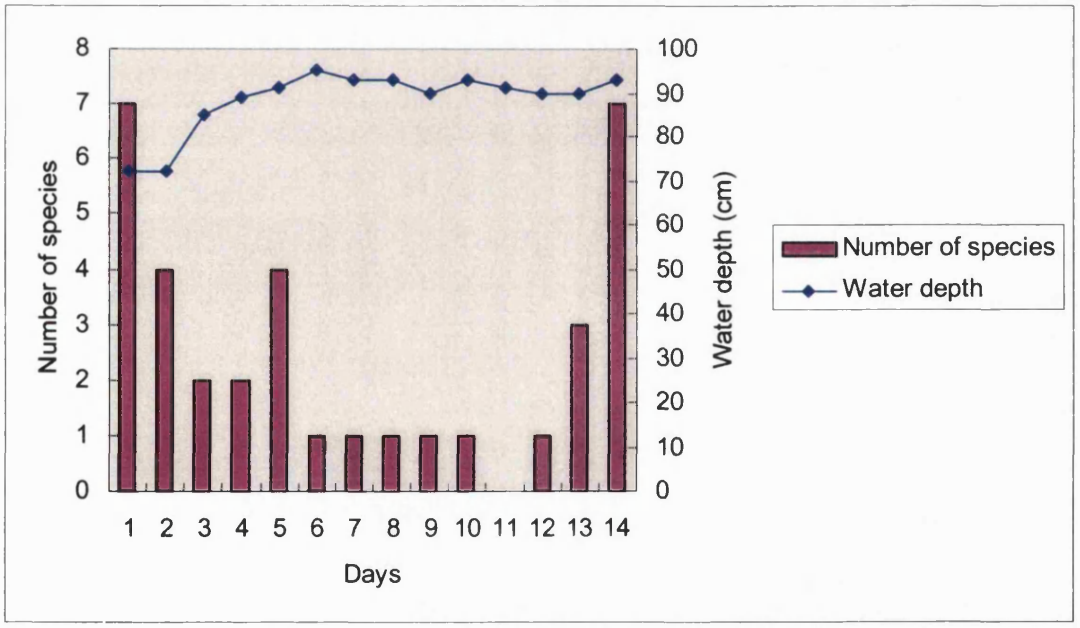


Figure 6.9. The chronological changes in the corresponding number of waterbird species to the manipulation of water level in Pair 2 manipulated pond.

One-way ANOVA and linear regression analysis of the variables with water depth are conducted on each of the three manipulated ponds individually. Two of the three ponds show significant variations in species richness (pair 1: df=14, F=6.27, p=0.026*; pair 2: df=13, F=4.70, p=0.051; pair 3: df=11, F=67.69, p=0.000**) and all show an increasing trend in the number of bird species when the water depth was

dropped. The gradient coefficients of the two significant regression equations are rather similar (pair 1: –0.164, pair 3:–0.186) although the intercepts vary greatly (pair 1:7.98, Figure 6.10; pair 3:13.9, Figure 6.11).

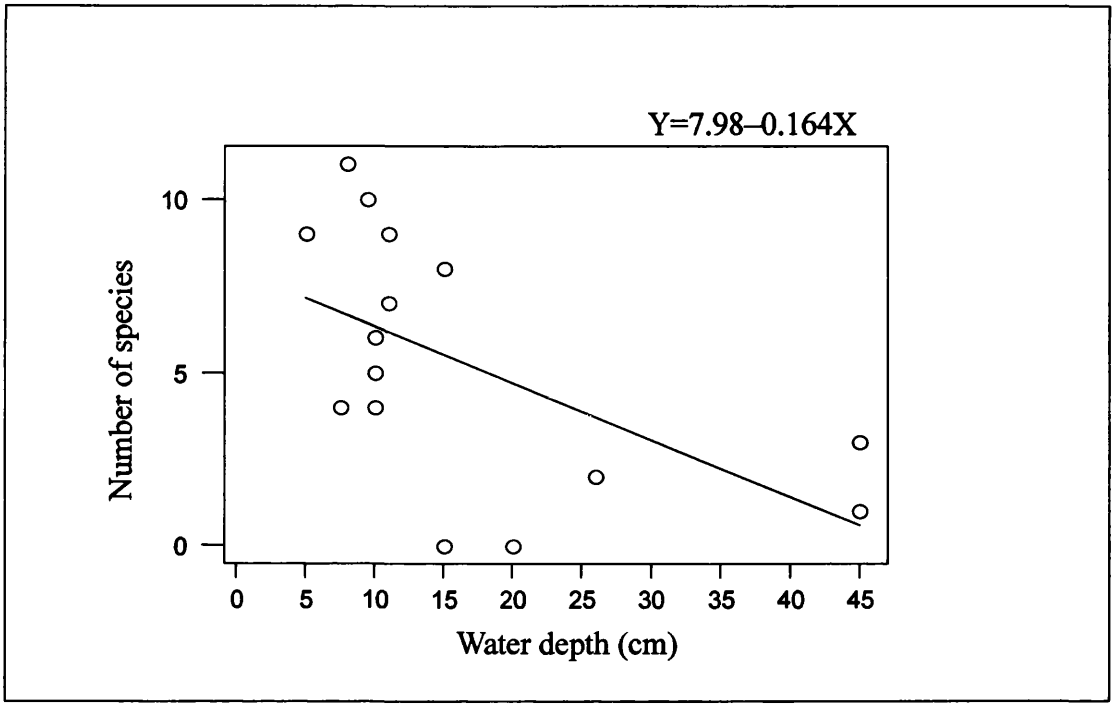


Figure 6.10. Trend of the number of waterbird species versus water depth in Pair 1 manipulated pond. Regression line is given (df=14, F=6.27, p=0.026*).

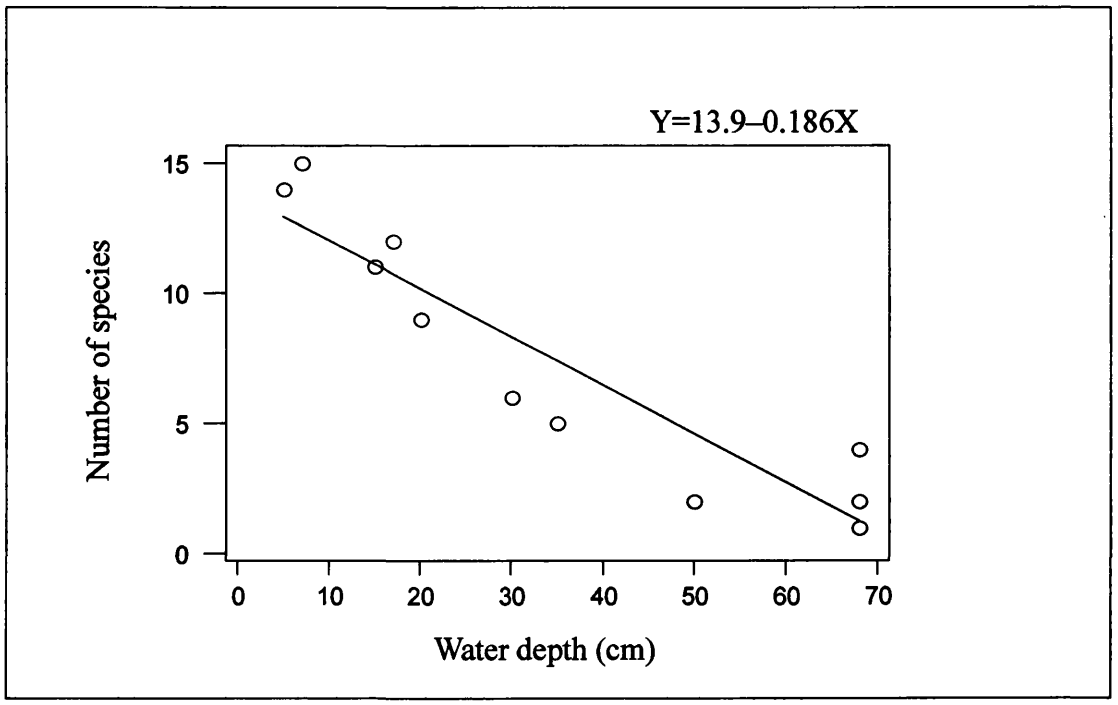


Figure 6.11. Trend of the number of waterbird species versus water depth in Pair 3 manipulated pond. Regression line is given (df=11, F=67.69, p=0.000**).

6.5.2. Abundance

The total number of birds display similar response to the manipulation of the water level than to the total number of species. In pair 1 and pair 3 manipulated ponds, once the water level was lowered to less than 10 cm and less than 15 cm respectively, the total number of birds increased abruptly and reached peak values after the lowest water level had been maintained for eight and three days, respectively (Figures 6.12 and 6.13). In contrast, the total number of waterbirds in pair 2 manipulated pond decreased abruptly once the water level increased, although it increased considerably after a high water level was maintained for 12 days (Figure 6.14).

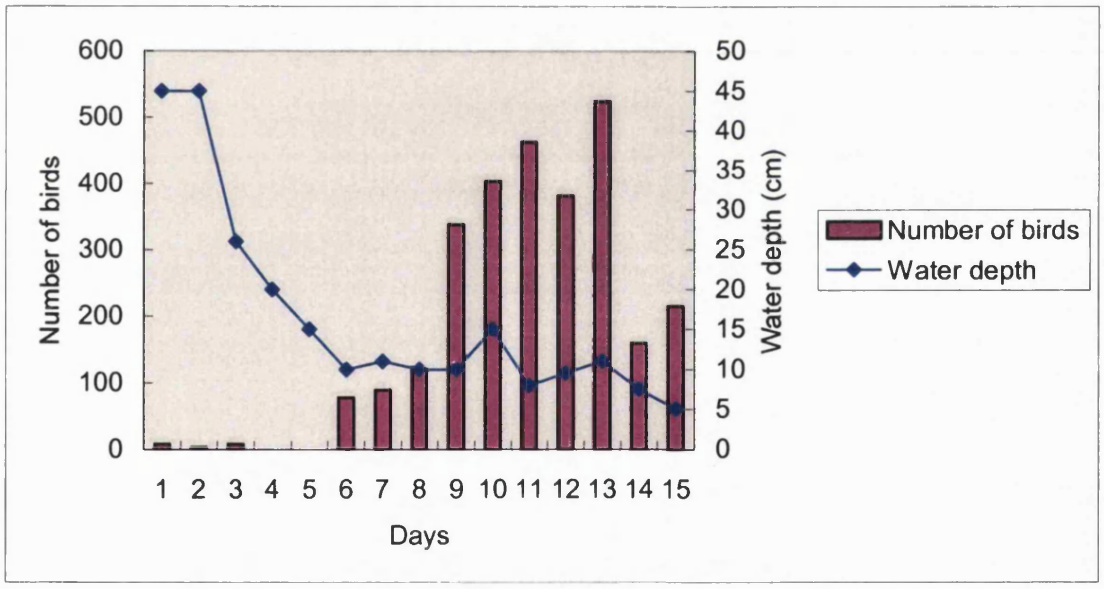


Figure 6.12. The chronological changes in the corresponding number of birds to the manipulation of water level in Pair 1 manipulated pond.

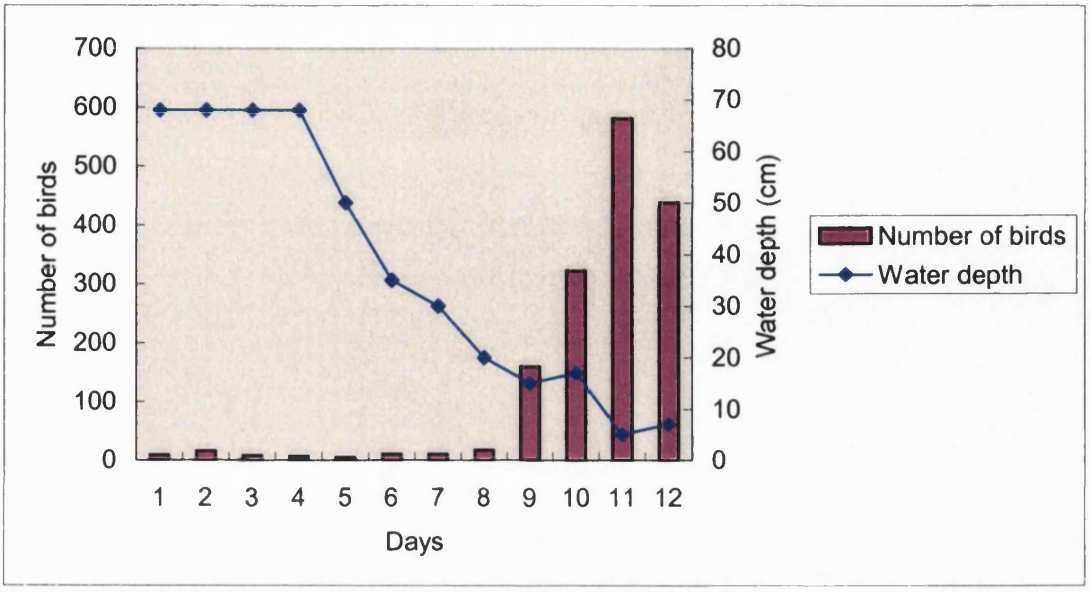


Figure 6.13. The chronological changes in the corresponding number of birds to the manipulation of water level in Pair 3 manipulated pond.

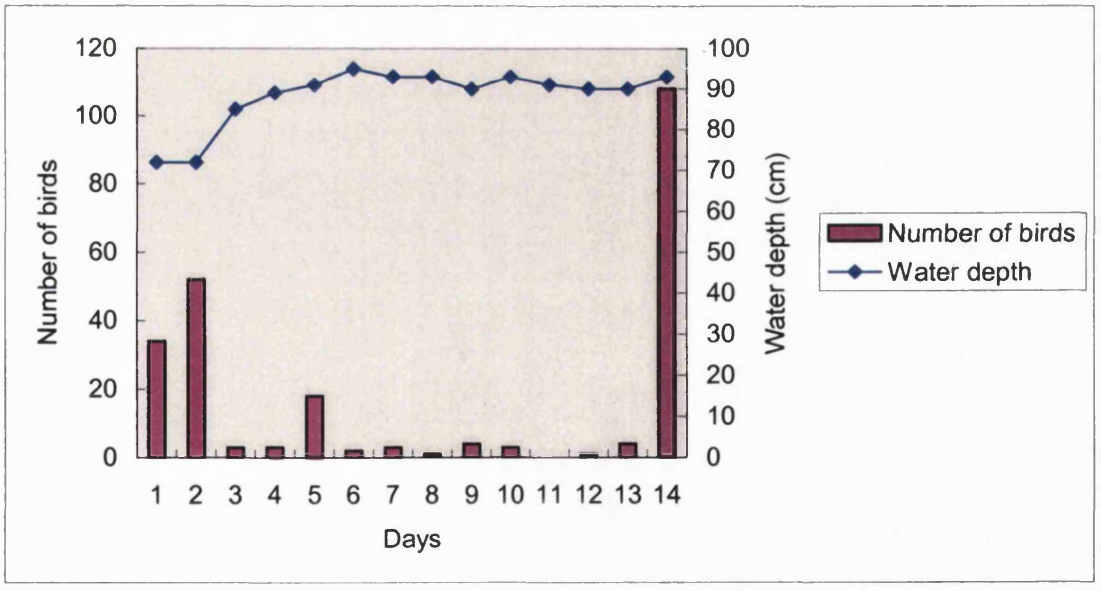


Figure 6.14. The chronological changes in the corresponding number of birds to the manipulation of water level in Pair 2 manipulated pond.

There were significant variations in the total number of birds for pair 1 and pair 3 manipulated ponds when a one-way ANOVA was conducted (pair 1: df=14, F-value= 5.06, p=0.042*; pair 2: df=13, F-value=4.70, p=0.051; pair 3: df=11, F-value=11.74, p=0.006**). In addition, the regression equations for the total

number of birds versus water depth display relatively similar values for both the gradient and the intercept for the two manipulated ponds (gradient: –7.82, –5.83; intercept: 315, 351; pair 1 and pair 3, respectively; Figures 6.15 and 6.16).

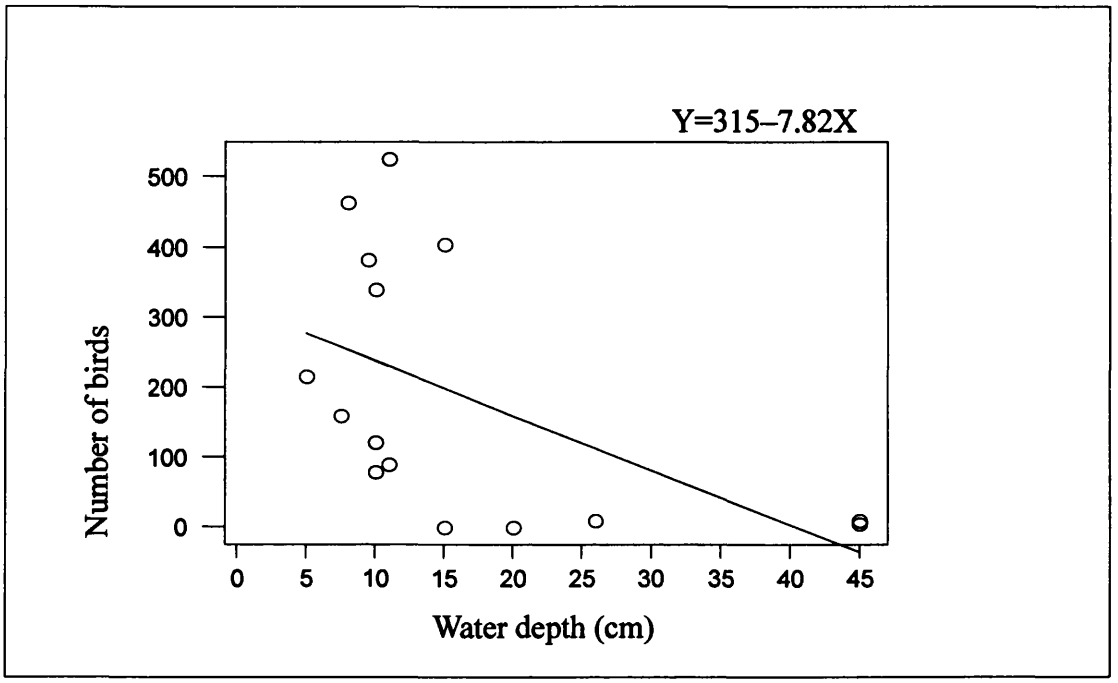


Figure 6.15. Trend of the number of birds versus water depth in Pair 1 manipulated pond. Regression line is given (df=14, F-value= 5.06, p=0.042*).

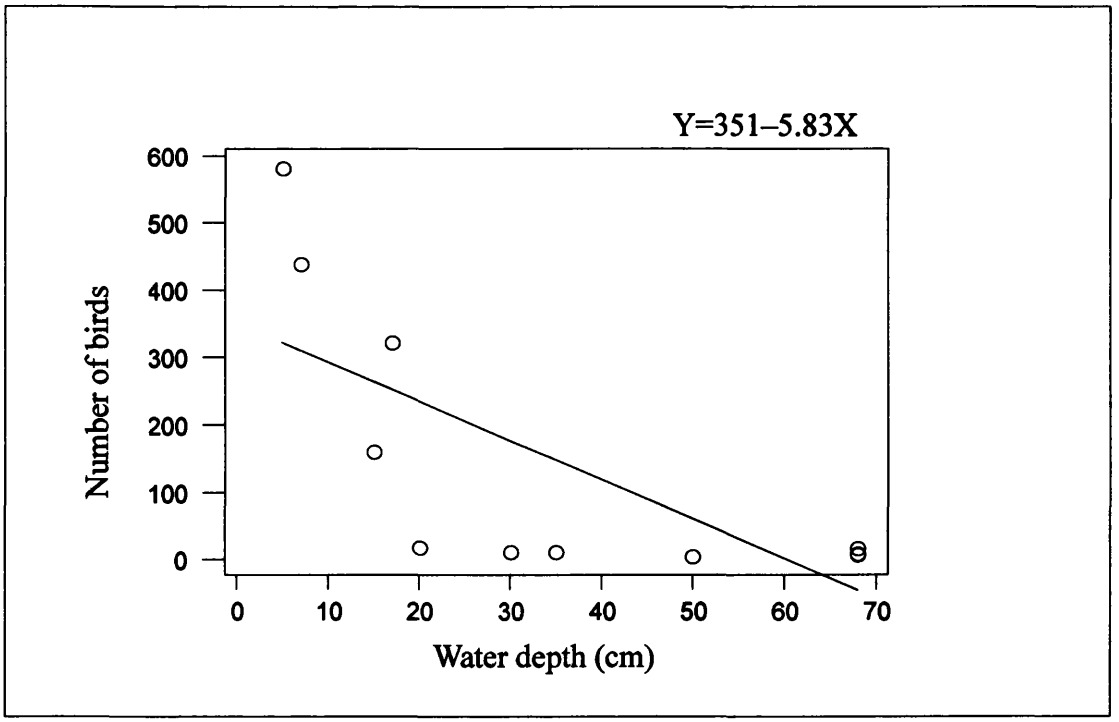


Figure 6.16. Trend of the number of birds versus water depth in Pair 3 manipulated pond. Regression line is given (df=11, F-value=11.74, p=0.006**).

In terms of the numbers of *Anas crecca* accounts for the greatest occurrence at each

pair of experimental ponds (pair 1, pair 2 and pair 3 ponds: 75.1%, N=2890; 54.1%, N=333; 55.1%, N=1690).

Pair 1 experimental ponds

According to the histograms for the total number of birds for every species, six species exhibit an obvious increasing trend with decreasing water depth. The following species show a peak in numbers on different days from the time the water level was maintained at its lowest (5-10 cm): *Himantopus himantopus* (the fifth day, Figure 6.17), *Anas crecca* (the eighth day, Figure 6.18), *Tringa nebularia* (the sixth day, Figure 6.19), *Tringa glareola* (the seventh day, Figure 6.20), *Tringa stagnatilis* (the fifth day, Figure 6.21) and *Egretta alba* (the sixth day, Figure 6.22). *Egretta garzetta* occurred in rather large numbers on only the fourth day since the lowest water level was maintained (Figure 6.23). In the one-way ANOVA only *Podiceps ruficollis* displays a significant variation in numbers between different depths (df=14, F-value=8.15, p= 0.014*). Due to only a positive abundance observation along the water depth gradient, regression is not conducted for this species.

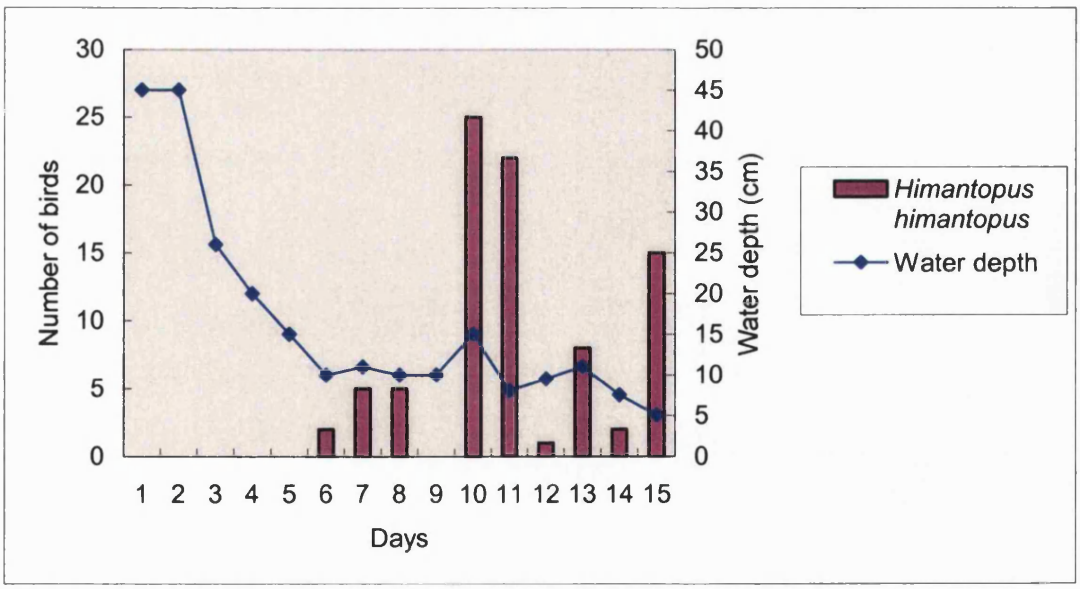


Figure 6.17. The chronological changes in the corresponding occurrence of *Himantopus himantopus* to the manipulation of water level in Pair 1 manipulated pond.

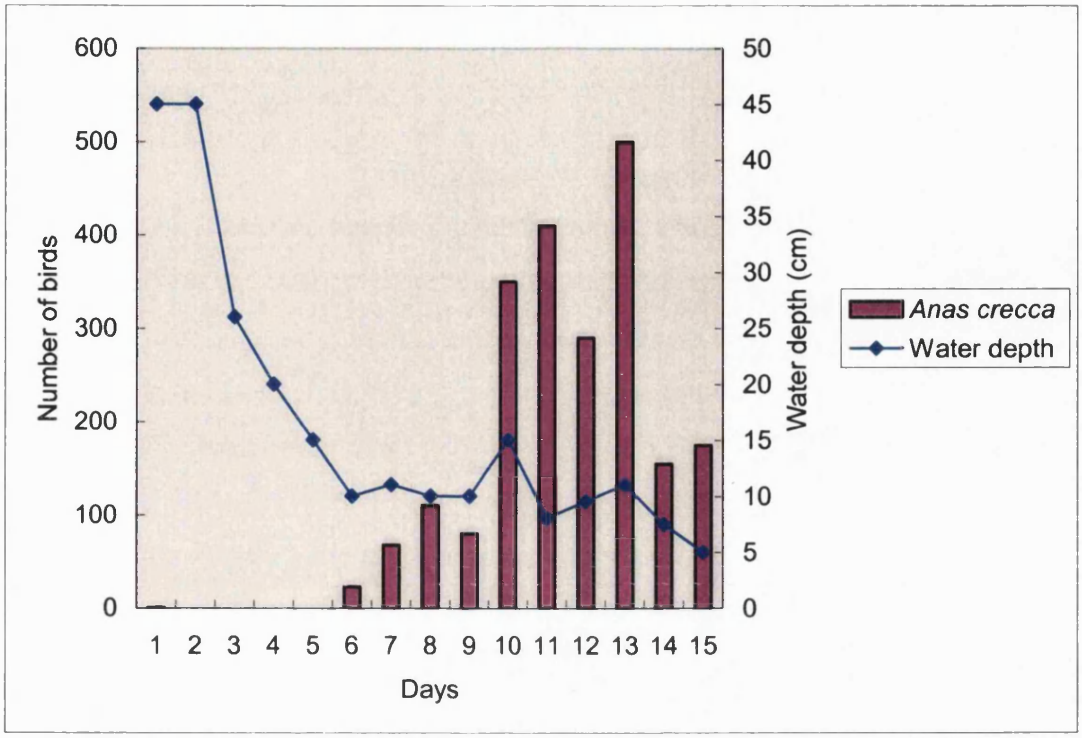


Figure 6.18. The chronological changes in the corresponding occurrence of *Anas crecca* to the manipulation of water level in Pair 1 manipulated pond.

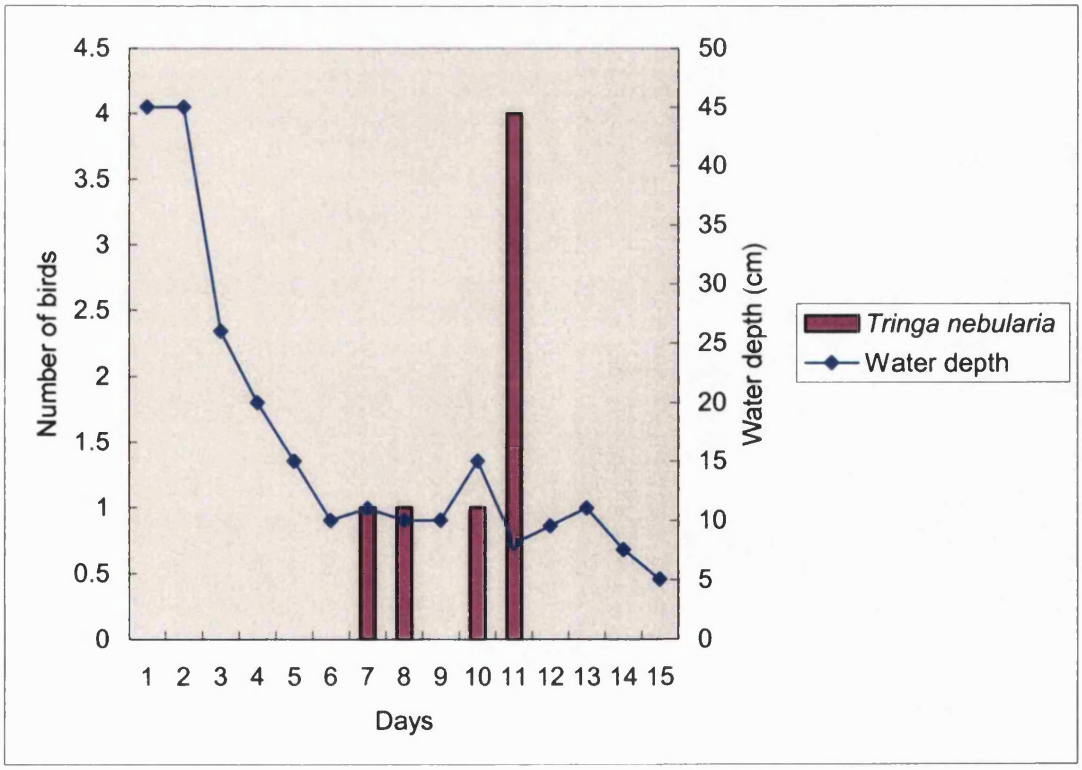


Figure 6.19. The chronological changes in the corresponding occurrence of *Tringa nebularia* to the manipulation of water level in Pair 1 manipulated pond.

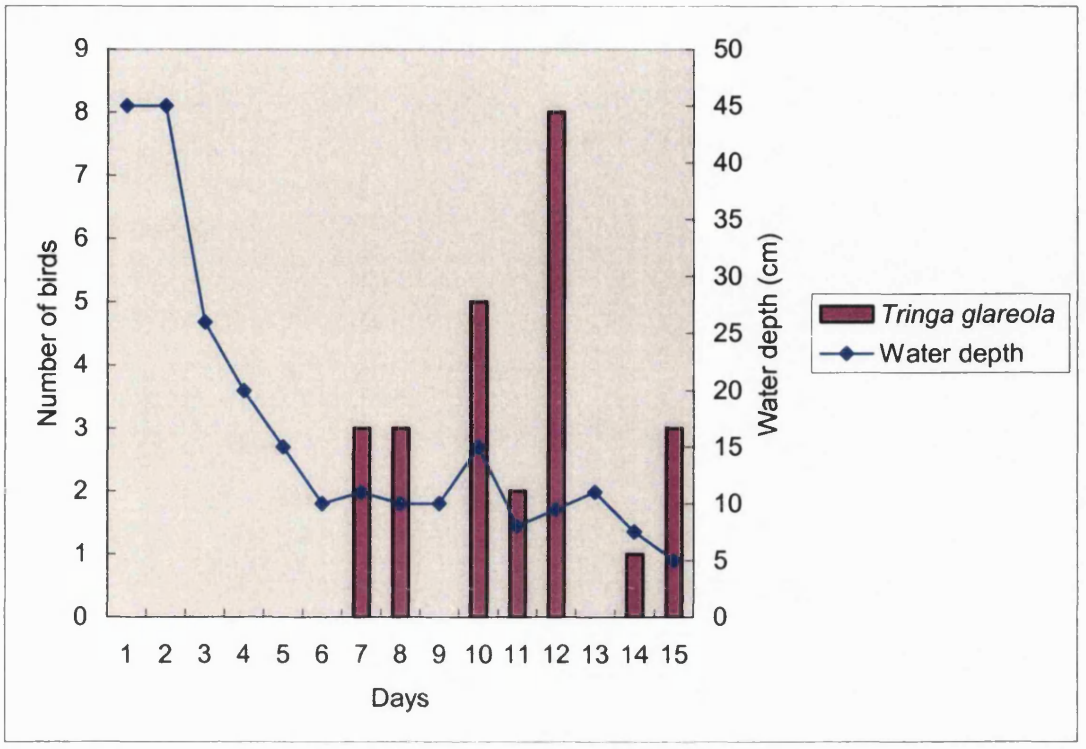


Figure 6.20. The chronological changes in the corresponding occurrence of *Tringa glareola* to the manipulation of water level in Pair 1 manipulated pond.

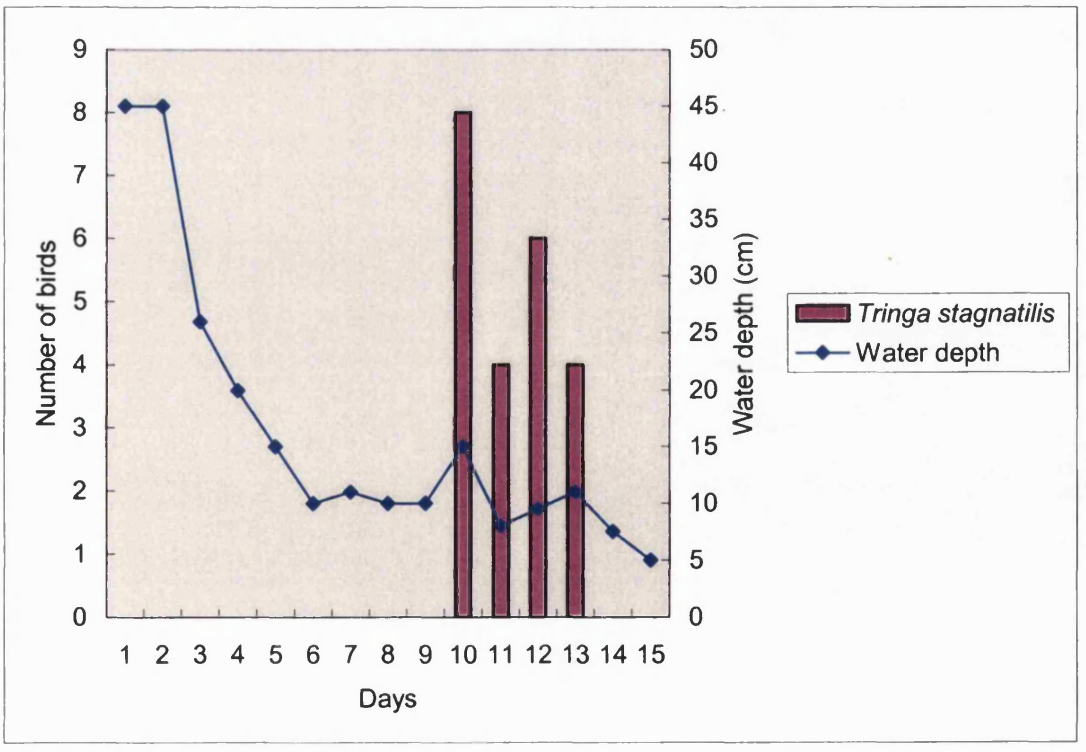


Figure 6.21. The chronological changes in the corresponding occurrence of *Tringa stagnatilis* to the manipulation of water level in Pair 1 manipulated pond.

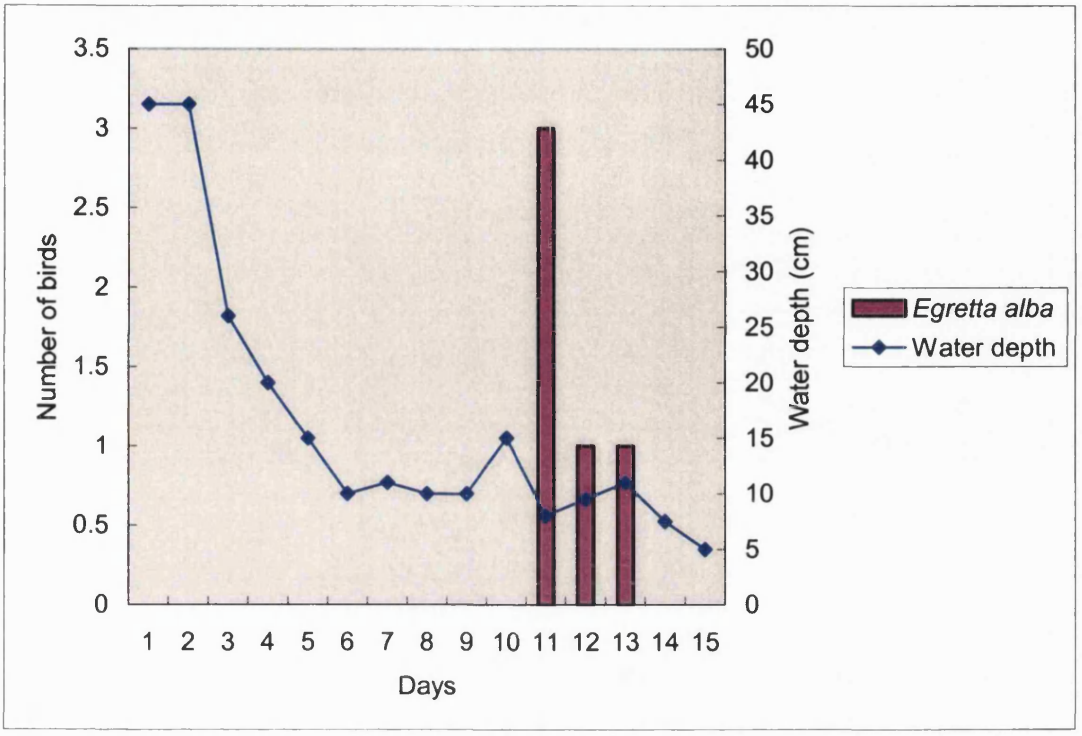


Figure 6.22. The chronological changes in the corresponding occurrence of *Egretta alba* to the manipulation of water level in Pair 1 manipulated pond.

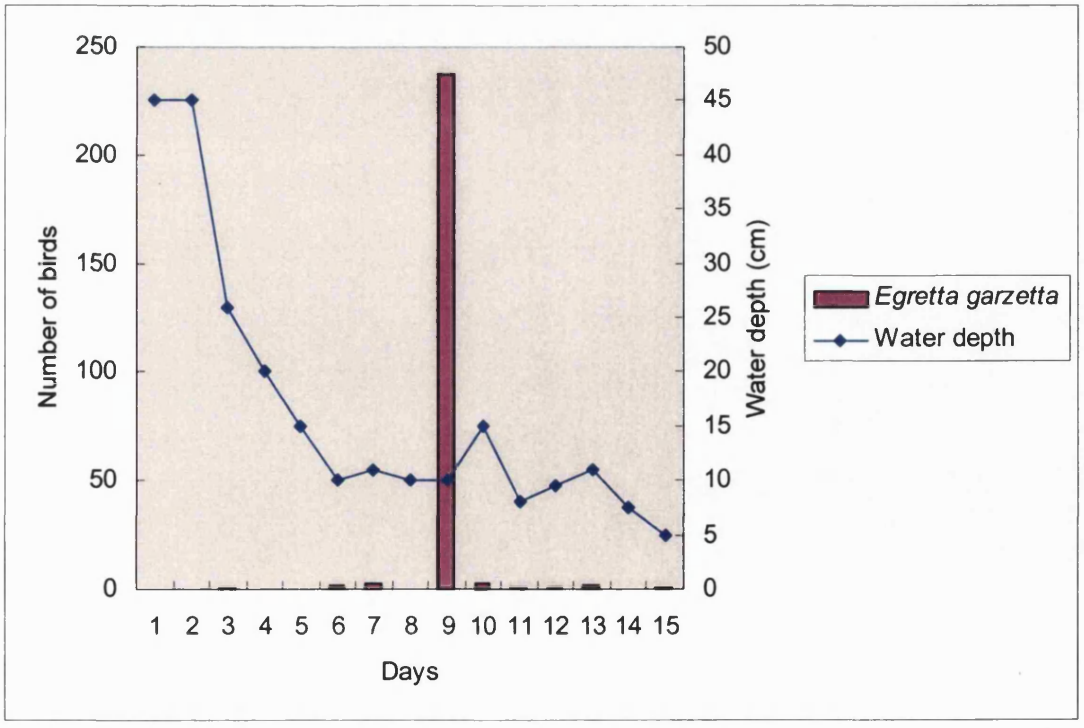


Figure 6.23. The chronological changes in the corresponding occurrence of *Egretta garzetta* to the manipulation of water level in Pair 1 manipulated pond.

Pair 2 experimental ponds

Two other species, *Charadrius dubius* and *Tringa glareola*, display significant variations in the one-way ANOVA in terms of their abundance at different water depths (*Charadrius dubius*: df=13, F-value=100.00, p= 0.000**; *Tringa glareola*: df=13, F-value=8.75, p=0.012*). The gradients and the intercept of the regression equation of *Tringa glareola* are –0.0440 and 4.25 (Figure 6.24). Due to only one positive abundance observation along the water depth gradient, regression was not conducted for *Charadrius dubius*.

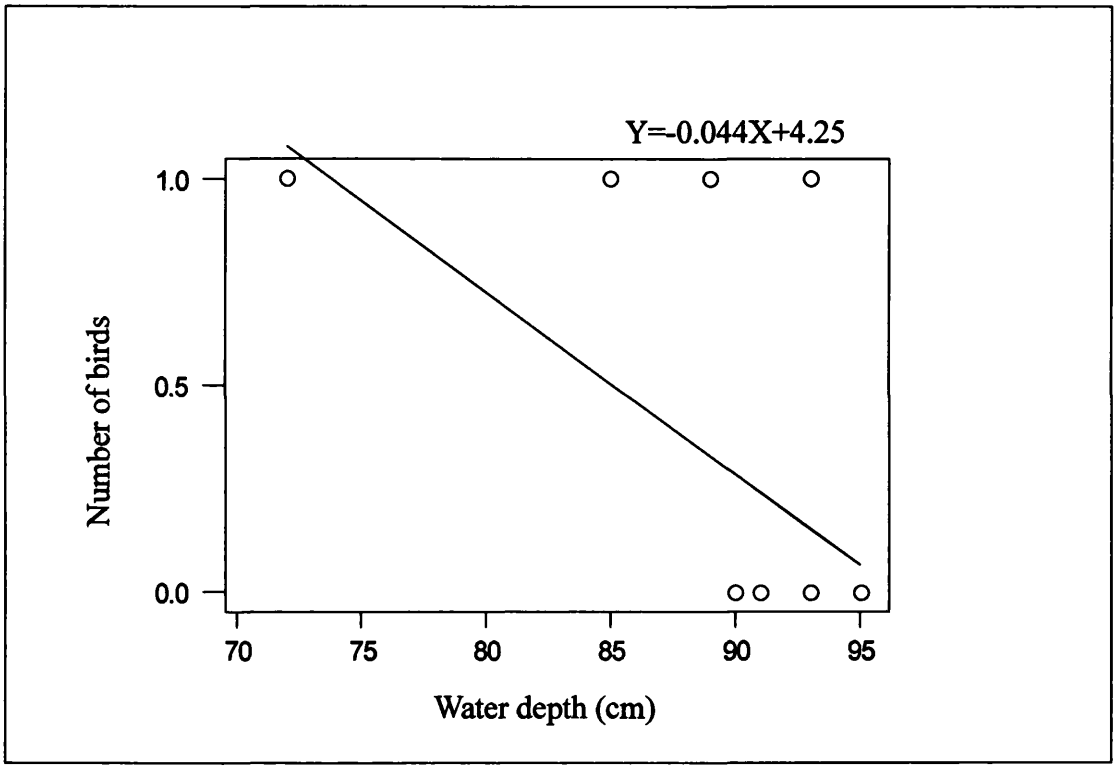


Figure 6.24. Trend of the occurrence of *Tringa glareola* versus water depth in Pair 2 manipulated pond. Regression line is given (df=13, F-value=8.75, p=0.012*).

Pair 3 experimental ponds

Twelve species exhibit an obvious increasing trend in the total number of birds with decreasing water depths in pair 3 manipulated pond and most of these species have their peak values on the first or second day after the lowest water depth (5-7 cm) was attained. These species include *Anas crecca* (Figure 6.25), *Tringa stagnatilis* (Figure 6.26), *Egretta garzetta* (Figure 6.27), *Egretta intermedia* (Figure 6.28), *Calidris ruficollis* (Figure 6.29), *Charadrius dubius* (Figure 6.30), *Tringa glareola*

(Figure 6.31), *Charadrius alexandrinus* (Figure 6.32), *Tringa totanus* (Figure 6.33), *Himantopus himantopus* (Figure 6.34), *Tringa nebularia* (Figure 6.35) and *Egretta alba* (Figure 6.36). Two large-sized waterbirds, *Egretta intermedia* and *Egretta alba,* are the only two species that show an increasing trend in the total number of birds with decreasing water depth, with a peak value at a depth of 17 cm. The fact that these species have longer legs than most waterbird species could explain their higher abundance in the deeper waters.

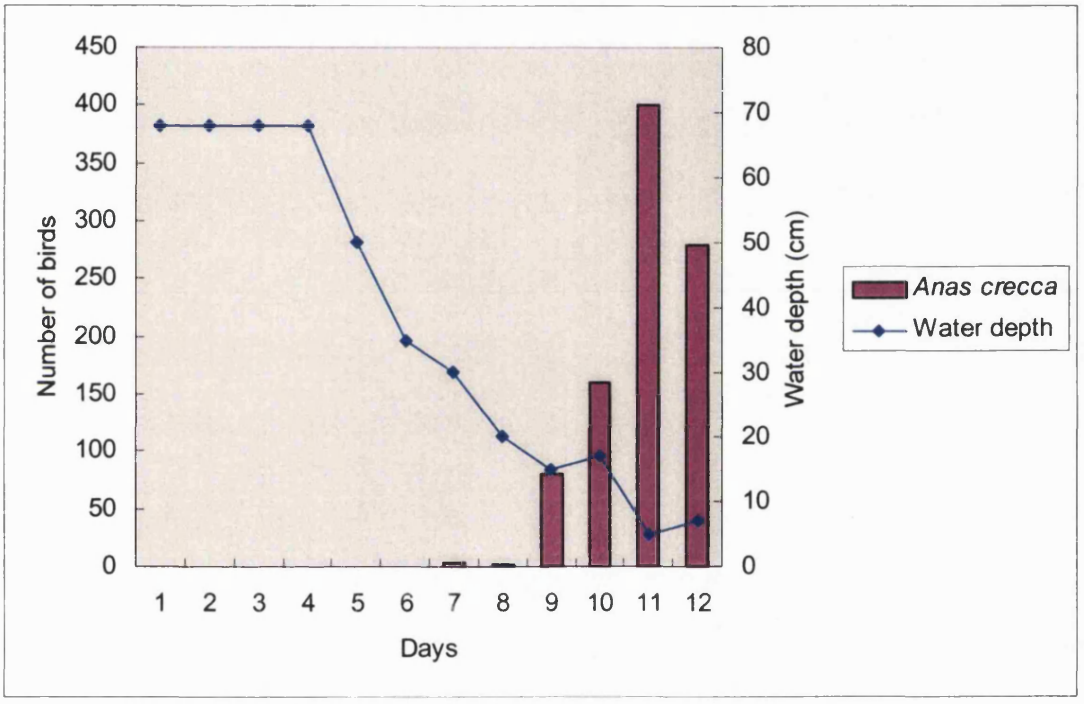


Figure 6.25. The chronological changes in the corresponding occurrence of *Anas crecca* to the manipulation of water level in Pair 3 manipulated pond.

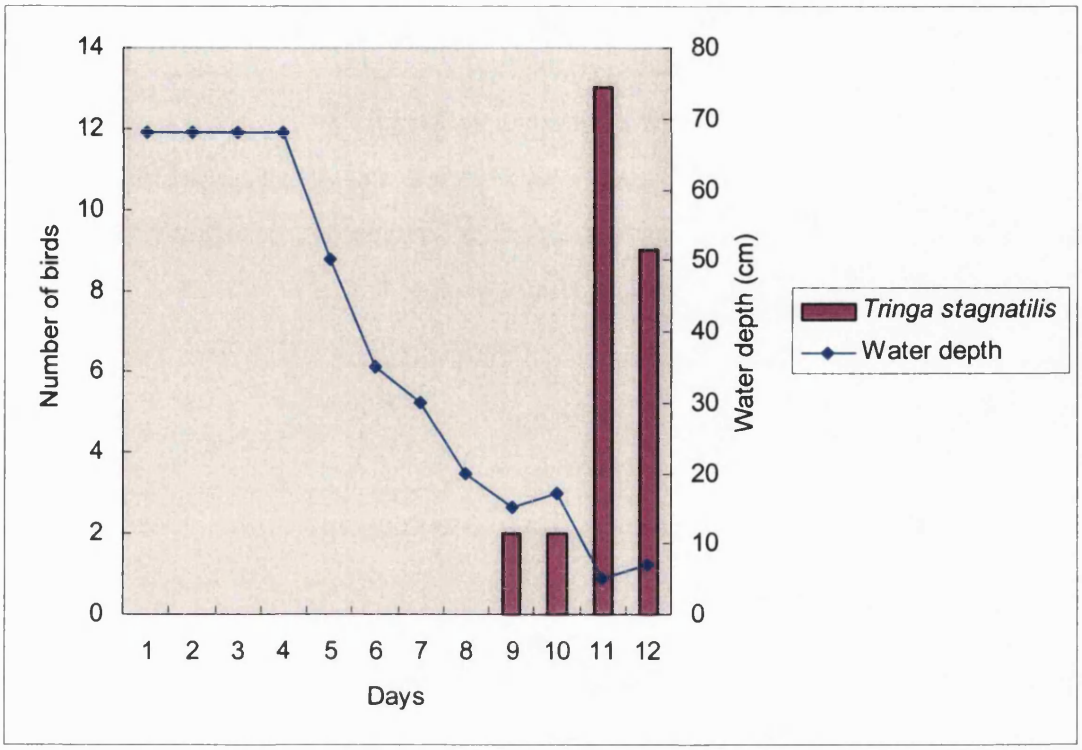


Figure 6.26. The chronological changes in the corresponding occurrence of *Tringa stagnatilis* to the manipulation of water level in Pair 3 manipulated pond.

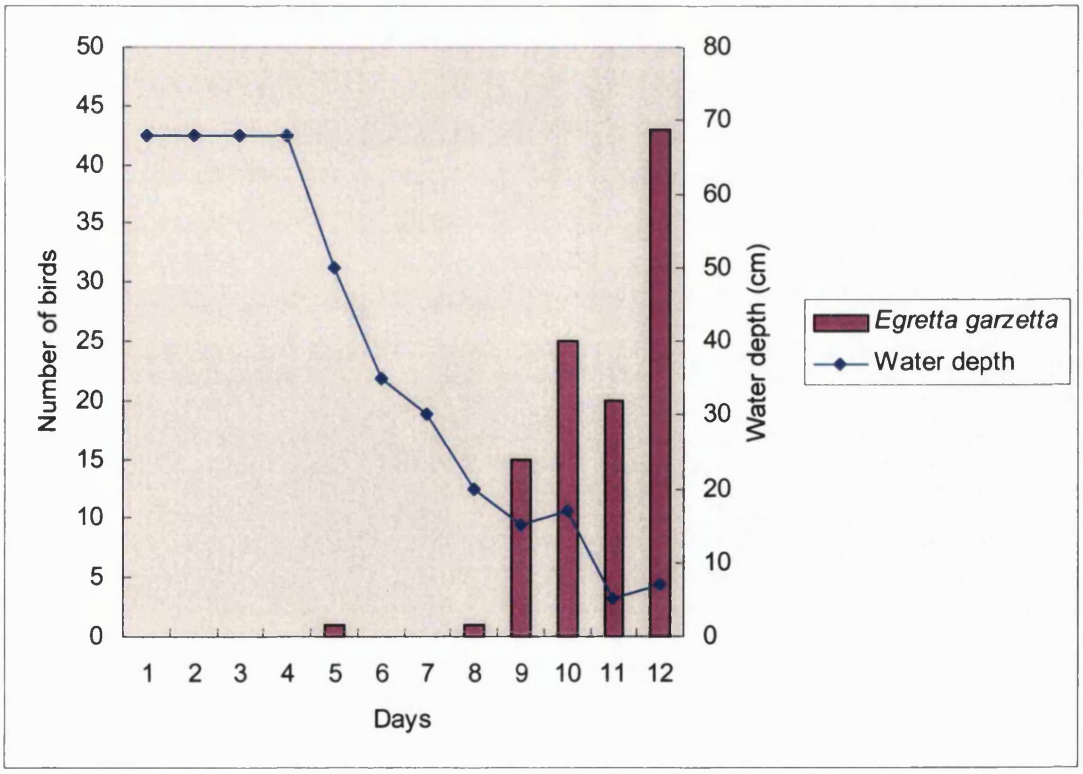


Figure 6.27. The chronological changes in the corresponding occurrence of *Egretta garzetta* to the manipulation of water level in Pair 3 manipulated pond.

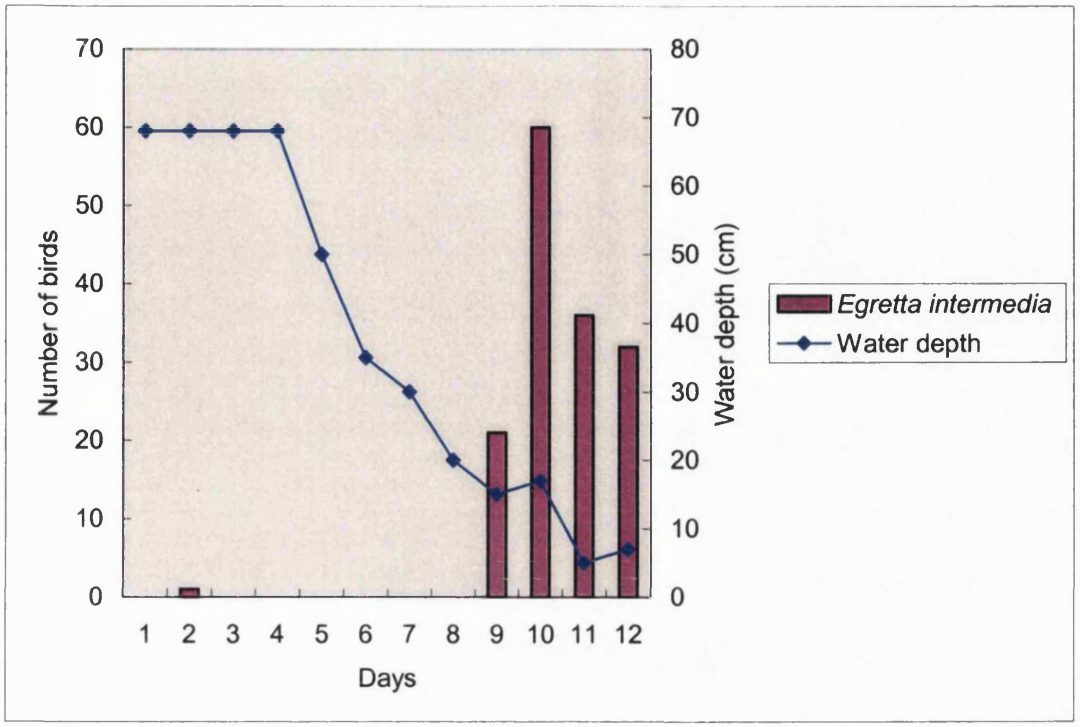


Figure 6.28. The chronological changes in the corresponding occurrence of *Egretta intermedia* to the manipulation of water level in Pair 3 manipulated pond.

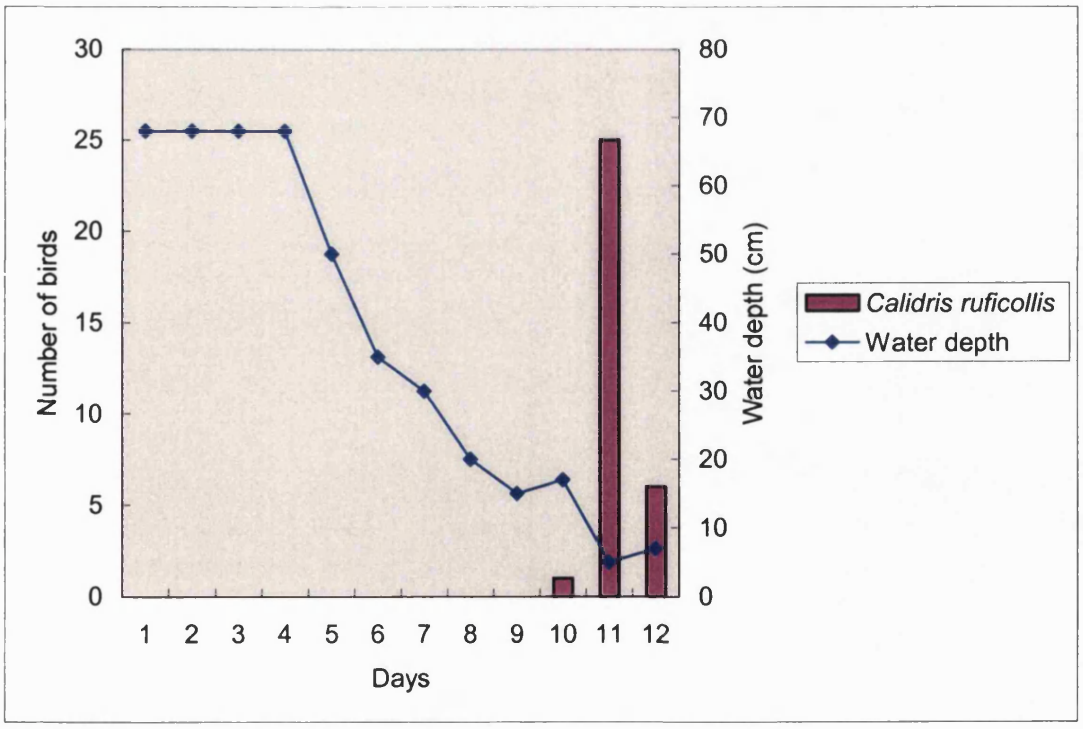


Figure 6.29. The chronological changes in the corresponding occurrence of *Calidris ruficollis* to the manipulation of water level in Pair 3 manipulated pond.

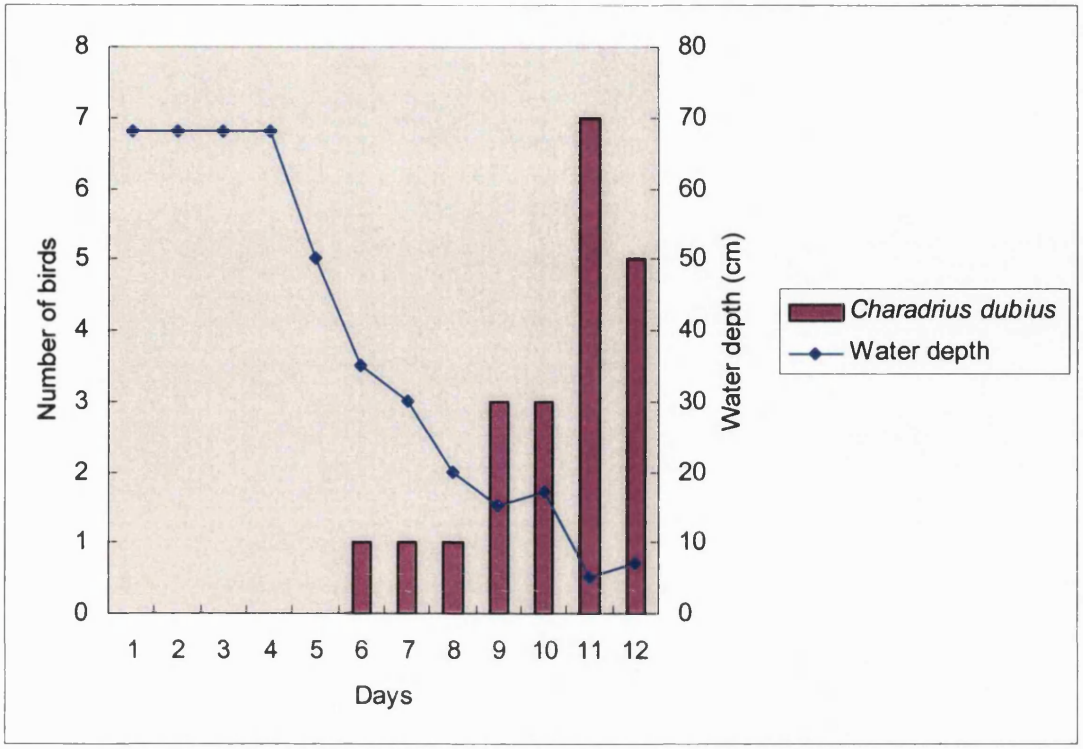


Figure 6.30. The chronological changes in the corresponding occurrence of *Charadrius dubius* to the manipulation of water level in Pair 3 manipulated pond.

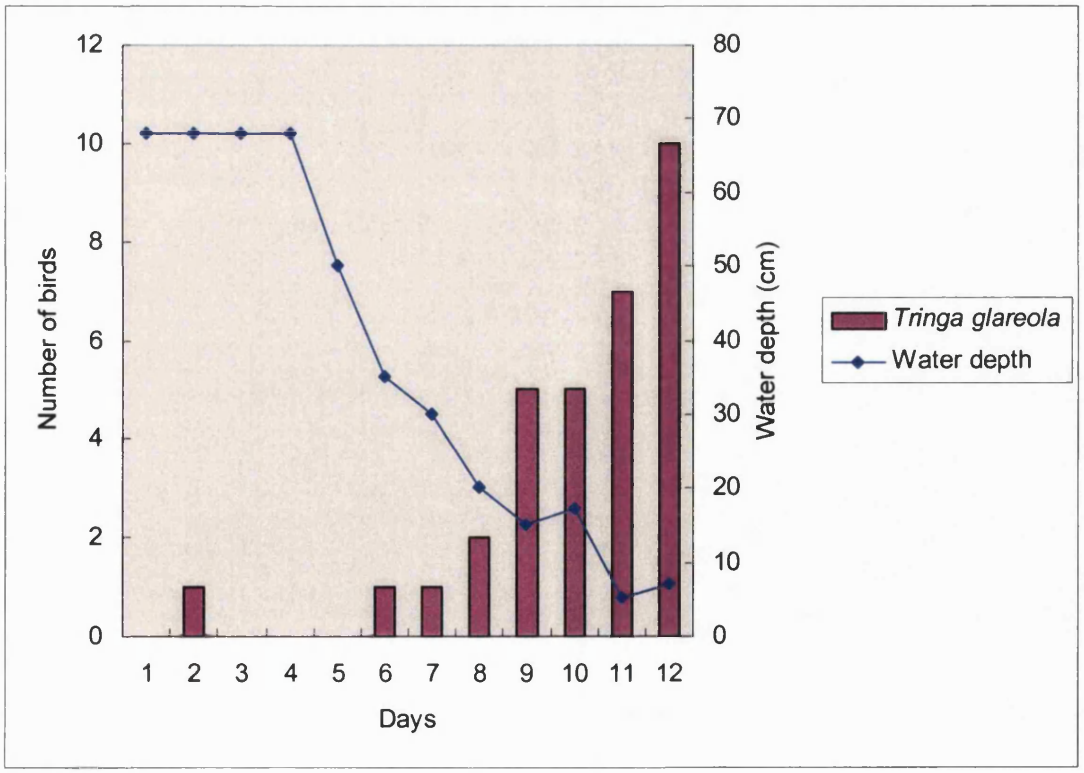


Figure 6.31. The chronological changes in the corresponding occurrence of *Tringa glareola* to the manipulation of water level in Pair 3 manipulated pond.

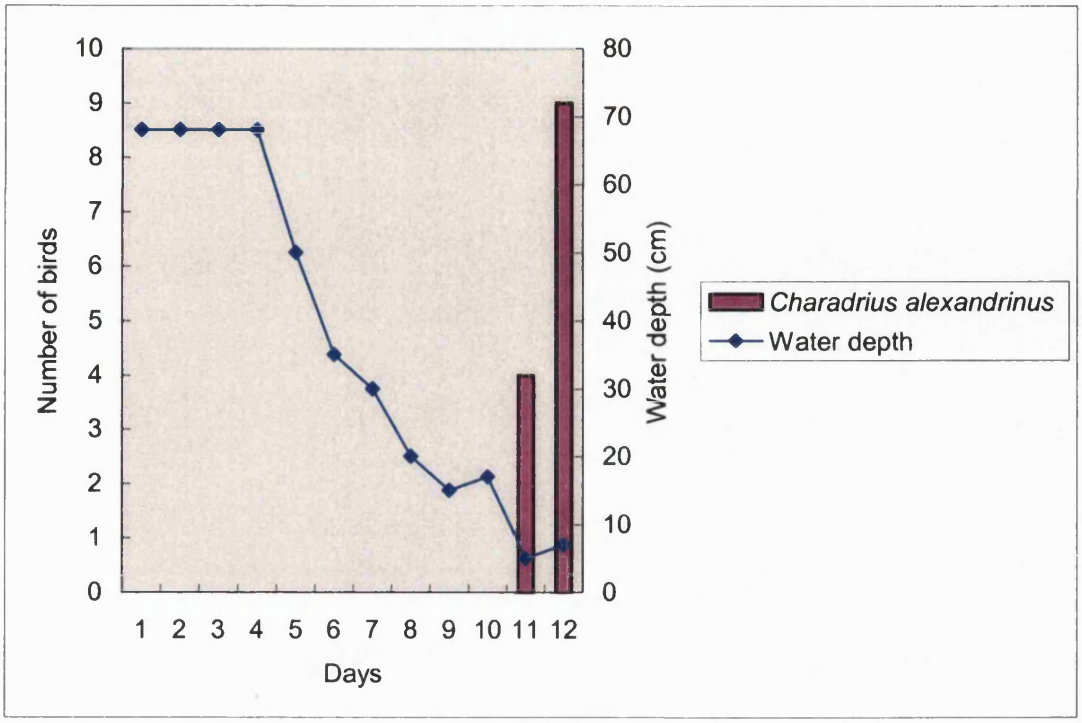


Figure 6.32. The chronological changes in the corresponding occurrence of *Charadrius alexandrinus* to the manipulation of water level in Pair 3 manipulated pond.

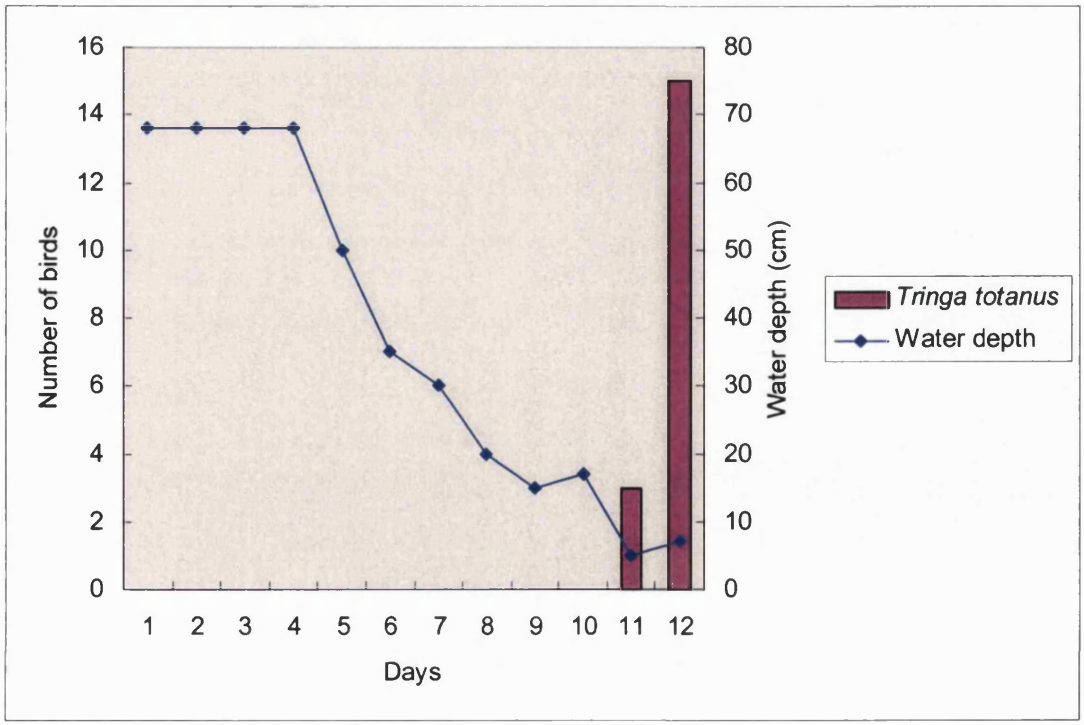


Figure 6.33. The chronological changes in the corresponding occurrence of *Tringa totanus* to the manipulation of water level in Pair 3 manipulated pond.

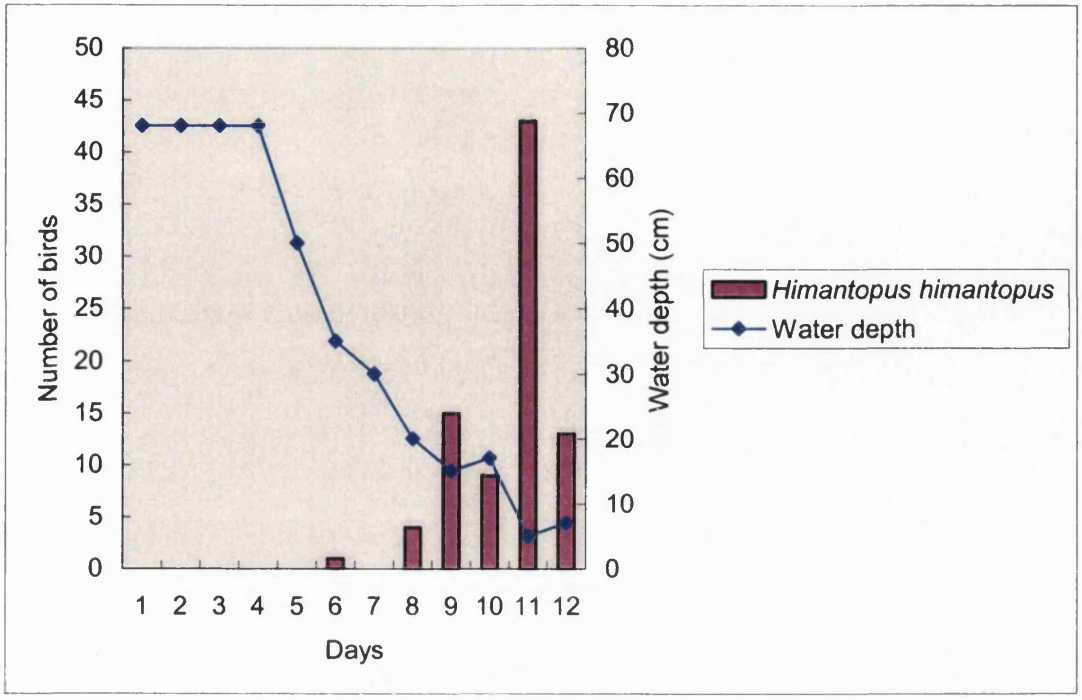


Figure 6.34. The chronological changes in the corresponding occurrence of *Himantopus himantopus* to the manipulation of water level in Pair 3 manipulated pond.

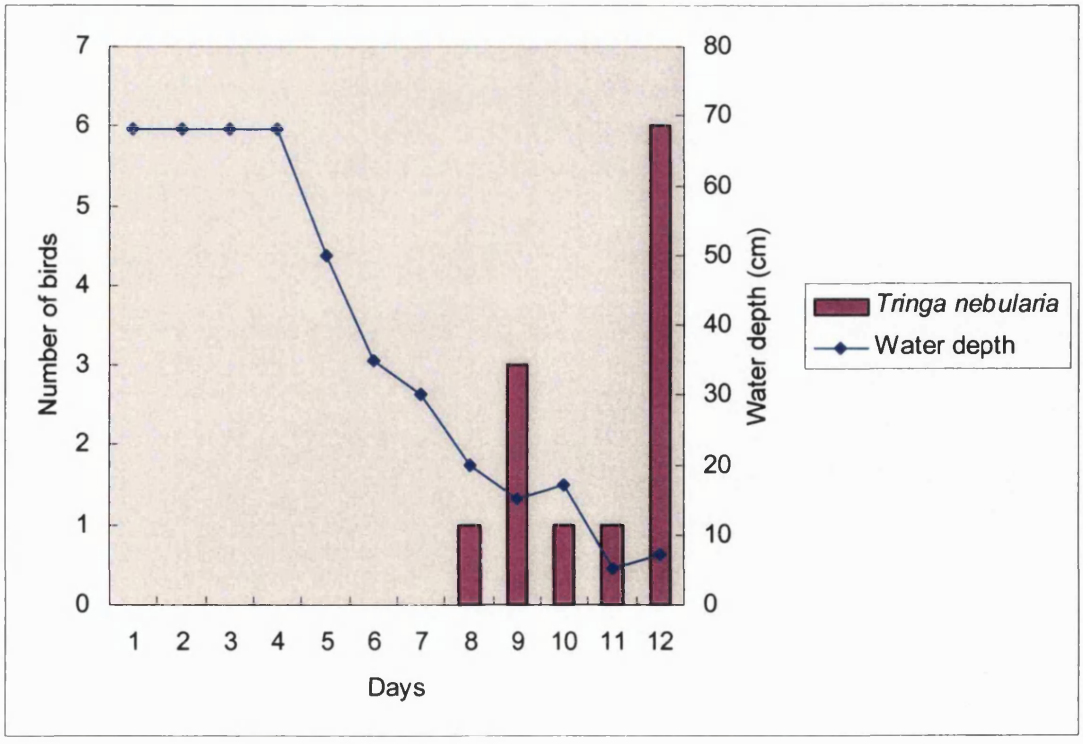


Figure 6.35. The chronological changes in the corresponding occurrence of *Tringa nebularia* to the manipulation of water level in Pair 3 manipulated pond.

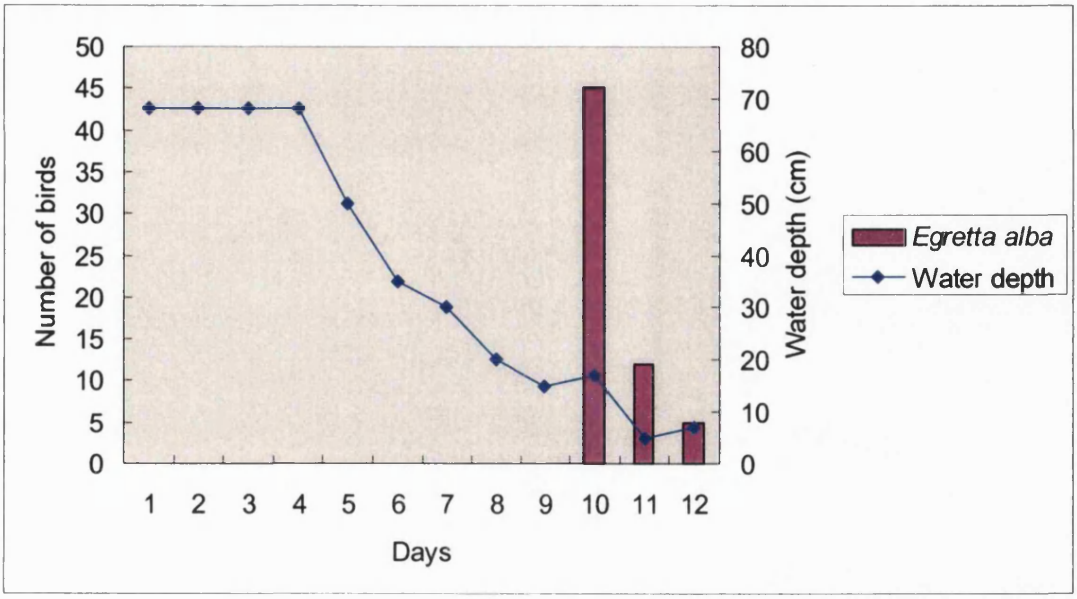


Figure 6.36. The chronological changes in the corresponding occurrence of *Egretta alba* to the manipulation of water level in Pair 3 manipulated pond.

Unlike the species in pair 1 manipulated pond, almost half of the species in pair 3 manipulated pond (including every abundant species in the pair 3 manipulated pond) display significant variations in the one-way ANOVA of abundance with decreasing water depth. All the species significantly increased in abundance with decreasing water depth including *Egretta garzetta*, *Himantopus himantopus*, *Egretta intermedia*, *Charadrius dubius*, *Tringa nebularia*, *Tringa stagnatilis*, *Platalea minor*, *Anas crecca* and *Tringa glareola* (Table 6.2). *Anas crecca* shows the largest gradient coefficient (gradient: –15.6, intercept: 398; Figure 6.37), followed by *Egretta intermedia* (gradient: –1.43, intercept: 47.3; Figure 6.38), *Egretta garzetta* (gradient: –1.34, intercept: 38.4; Figure 6.39) and *Himantopus himantopus* (gradient: –1.33, intercept: 34.8; Figure 6.40). These four species were the most sensitive to fluctuations in the water level.

Table 6.2. Summary of one-way ANOVAs of the waterbird species which show significant differences in their abundance versus water depth in pair 3 manipulated pond from 19th to 31st October 2000.

Species	Degrees of Freedom	F-value	Significance
Egretta garzetta	11	10.45	0.009**
Himantopus himantopus	11	8.55	0.015*
Egretta intermedia	11	8.41	0.016*
Charadrius dubius	11	22.76	0.000**
Tringa nebularia	11	6.73	0.027*
Tringa stagnatilis	11	7.45	0.021*
Platalea minor	11	5.02	0.049*
Anas crecca	11	10.11	0.010**
Tringa glareola	11	20.95	0.000**

P.S.: * means that p-value is no more than 5% and ** means that p-value is no more than 1%.

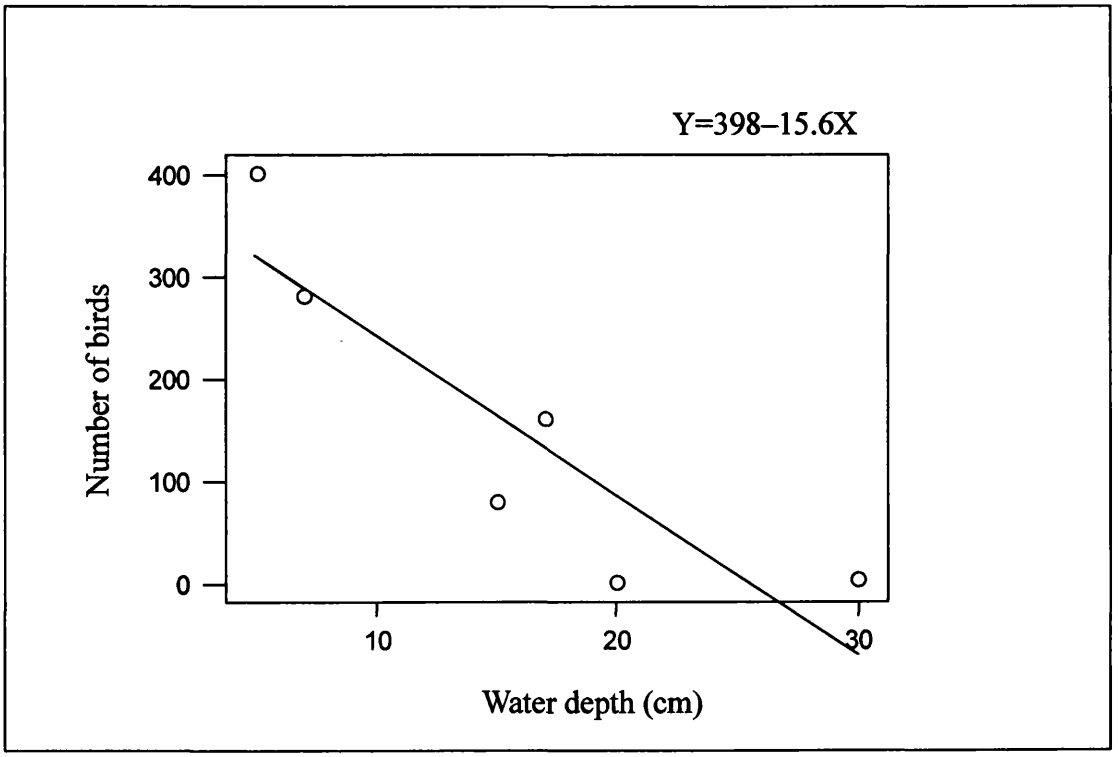


Figure 6.37. Trend of the occurrence of *Anas crecca* versus water depth in Pair 3 manipulated pond. Regression line is given (df=11, F-value=10.11, p=0.010**).

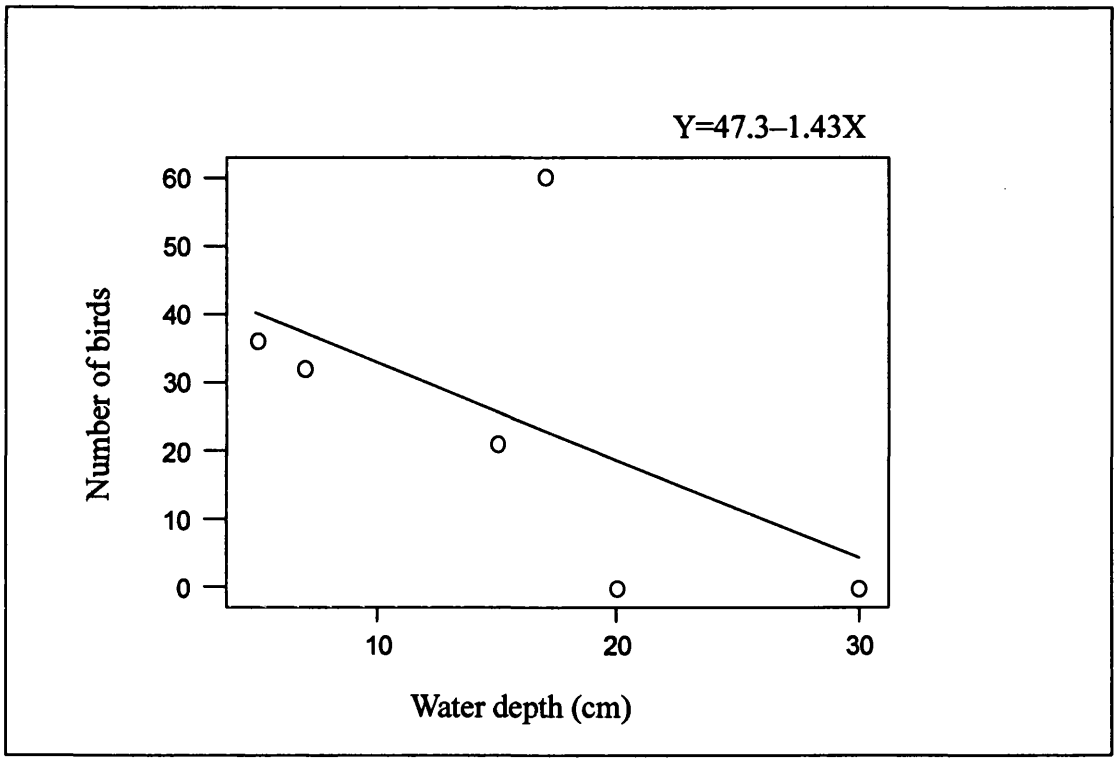


Figure 6.38. Trend of the occurrence of *Egretta intermedia* versus water depth in Pair 3 manipulated pond. Regression line is given (df=11, F-value=8.41, p=0.016*).

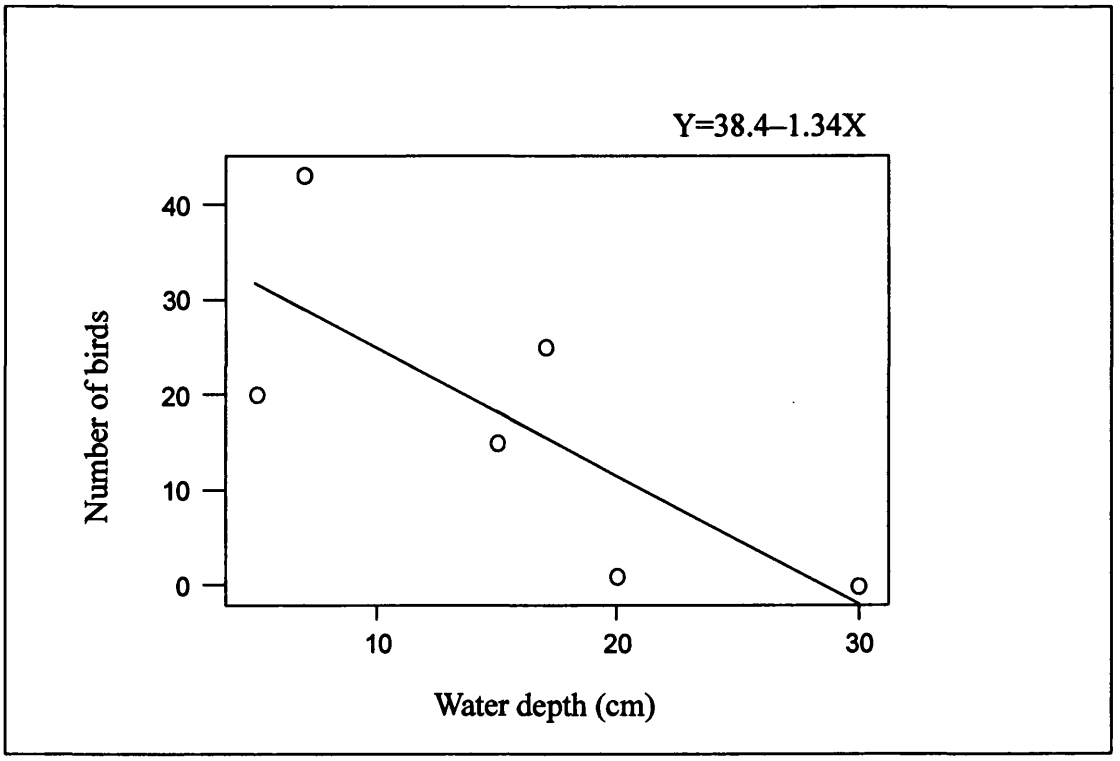


Figure 6.39. Trend of the occurrence of *Egretta garzetta* versus water depth in Pair 3 manipulated pond. Regression line is given (df=11, F-value=10.45, p=0.009**).

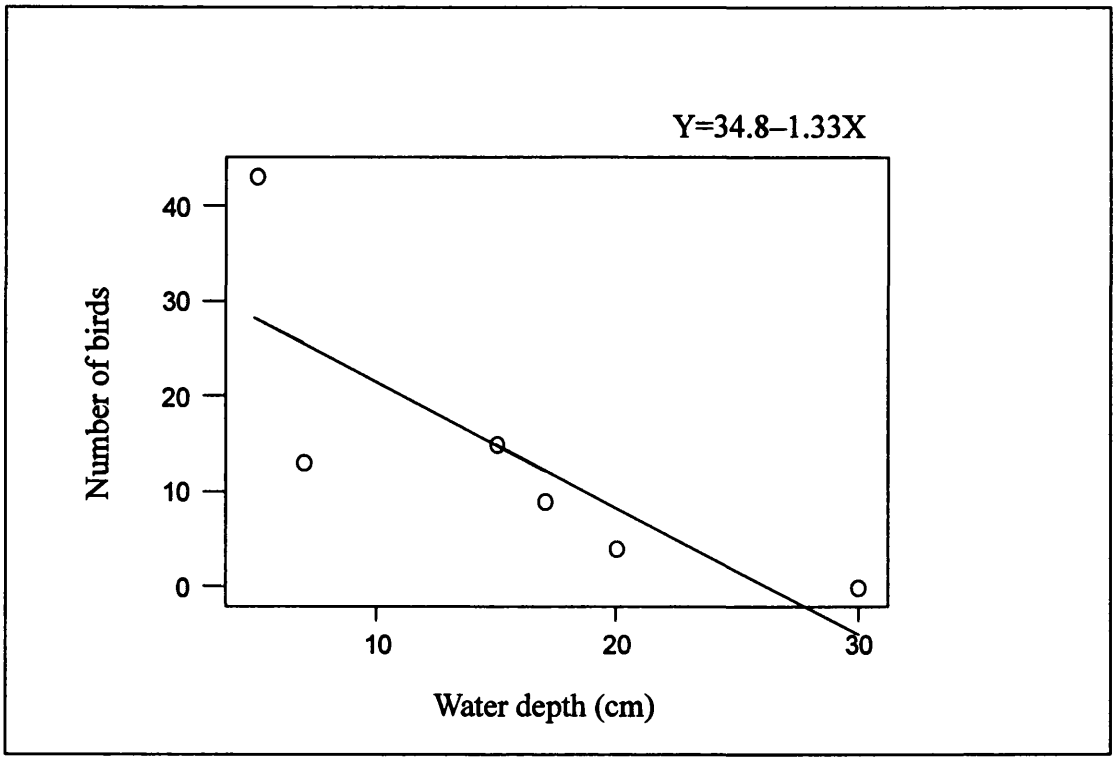


Figure 6.40. Trend of the occurrence of *Himantopus himantopus* versus water depth in Pair 3 manipulated pond. Regression line is given (df=11, F-value=8.55, p=0.015*).

6.5.3. Species composition

In total, eleven wader species, seven egret species, two duck species, a rail species and four miscellaneous species occurred at the three pairs of experimental ponds. Amongst these species, *Anas crecca* was the most abundant and accounts for 69.4% of all species counts.

Pair 1 experimental ponds

Nineteen species and 2,890 birds were recorded in pair 1 ponds. These species consisted of seven wader species such as *Himantopus himantopus* (2.9%) and *Tringa glareola* (0.9%), six egret species such as *Egretta garzetta* (8.8%) and *Nycticorax nycticorax* (6.9%), two duck species, *Anas crecca* (75.1%) and *Anas querquedula* (0.8%), a rail species, *Gallinula chloropus* (1.4%) and three miscellaneous species (complete species list in Appendix 3).

Species composition did not change much until the water level was dropped to a depth of 10 cm. *Anas crecca*, *Himantopus himantopus*, the total number of species

and the total number of birds responded rapidly without any time lag. Nevertheless, from the time that the lowest water level was maintained, peak values in numbers occurred at the fifth day for *Himantopus himantopus*, the sixth day for the total number of species and the eighth day for *Anas crecca* and the total number of birds (Figures 6.8, 6.12, 6.17 and 6.18). *Tringa nebularia* and *Tringa glareola* responded with a one-day time lag (Figures 6.19 and 6.20). Due to some unknown reasons, water depth did not decrease on schedule, and a depth of 10 cm was maintained for eight days. This unexpected situation provides a good opportunity to observe the responses of species with a diverse time lag. Three species, *Egretta garzetta*, *Tringa stagnatilis* and *Egretta alba*, consecutively joined the foraging species assembly starting from three to five days after the 10 cm depth had first been attained (Figures 6.21, 6.22 and 6.23). Eventually, water depth dropped again and reached a minimum of five cm. The total number of birds for any species does not appear to be influenced by a further decrease in water depth, displaying no further increase in numbers. This means that the peak occurrence of the species, the total number of birds and the total number of species all occurred at a depth of 10 cm or less. *Tringa stagnatilis* and *Himantopus himantopus* are the only exceptions and display peak occurrence at a depth of 15 cm (Figures 6.17 and 6.21).

Most species only occurred in the manipulated ponds for a short time period, namely one, two, three, four and five days for *Egretta garzetta*, *Himantopus himantopus*, *Egretta alba*, *Tringa stagnatilis* and *Tringa nebularia*, respectively (Figures 6.17, 6.19, 6.21, 6.22 and 6.23). *Tringa glareola* and *Anas crecca* were present for a much longer time period, namely nine and twelve days, respectively (Figures 6.18 and 6.20). The total number of species and the total number of birds also exhibit a long time period, but with different fluctuation patterns. The total number of species displays two peaks, whereas the total number of birds shows only one smooth peak (Figures 6.8 and 6.12).

Pair 2 experimental ponds

Ten species and 333 birds were recorded in pair 2 ponds. These species consisted of three egret species, *Egretta garzetta* (2.4%), *Nycticorax nycticorax* (15.9%) and *Bubulcus ibis* (0.9%), three wader species, *Tringa glareola* (2.1%), *Himantopus himantopus* (0.9%) and *Charadrius dubius* (0.6%), two duck species, *Anas crecca*

(54.1%) and *Anas querquedula* (2.4%), a rail species, *Gallinula chloropus* (8.7%) and a grebe species, *Podiceps ruficollis* (12.0%). (complete species list in Appendix 3). Unlike the species that occurred in pair 1 ponds, the species of pair 2 ponds do not show any recognizable trend. Only the total number of birds and the total number of species show a decreasing trend with no time lag after the water level was increased. However, a dramatic and unexpected increase in the total number of birds occurred twelve days after the start of the manipulation of the water level (Figures 6.9 and 6.14).

Pair 3 experimental ponds

Twenty species and 1,690 birds were recorded in pair 3 ponds. More than half of these species are waders such as *Himantopus himantopus* (5.0%), *Calidris ruficollis* (1.9%) and *Tringa glareola* (1.9%). In addition, five egret species, including *Egretta intermedia* (10.7%) and *Egretta garzetta* (6.9%), a duck species, *Anas crecca* (55.1%), a rail species, *Gallinula chloropus* (1.7%) and two miscellaneous species, were also recorded (complete species list in Appendix 3.).

When the water level was lowered, there was a strong corresponding increase for all common species, which explain 82.6% (N=1586) of the total number of birds at the pair 3 manipulated pond. The majority of these species started to arrive when the water depth was dropped to 15 cm. These species include *Anas crecca*, *Tringa stagnatilis*, *Egretta garzetta*, *Egretta intermedia* and *Calidris ruficollis* (Figures 6.25, 6.26, 6.27, 6.28 and 6.29). However, some species joined the foraging species assembly but with a different response to varying water depth. *Charadrius dubius*, *Tringa glareola* and the total number of species, started to be present at a depth as deep as 35 cm, while *Charadrius alexandrinus* and *Tringa totanus* did not display an increase in numbers until the water level was dropped to only 5 cm depth (Figures 6.7, 6.30, 6.31, 6.32 and 6.33). Nevertheless, a peak abundance of these species and peak value in the total number of birds occurred at a common depth of 5 cm, although they display considerable heterogeneity in water depth at which they joined the foraging species assembly (Figure 6.13). *Egretta intermedia* is the only exception, showing a peak abundance at a depth of 17 cm (Figure 6.28).

Most of the above species appear to display an incomplete surge in abundance at the

time at which the manipulation experiment terminated (Figures 6.25, 6.26, 6.27, 6.28, 6.29, 6.30, 6.31, 6.32, 6.33, 6.34, 6.35 and 6.41). This situation causes difficulties in estimating the time the species were present. From a limited amount of data provided by this pair of ponds, it is apparent that a time period of at least 6-7 days is usual. *Charadrius dubius* and *Tringa glareola* occurred for the longest duration (10 to 11 days after manipulation begun) (Figures 6.30 and 6.31). In contrast, *Himantopus himantopus*, *Egretta alba* and *Calidris ruficollis*, show an ephemeral reaction to the change in the water level, displaying a dramatic increase in abundance for a day and then returning to a relatively low abundance the very next day (Figures 6.29, 6.34 and 6.36).

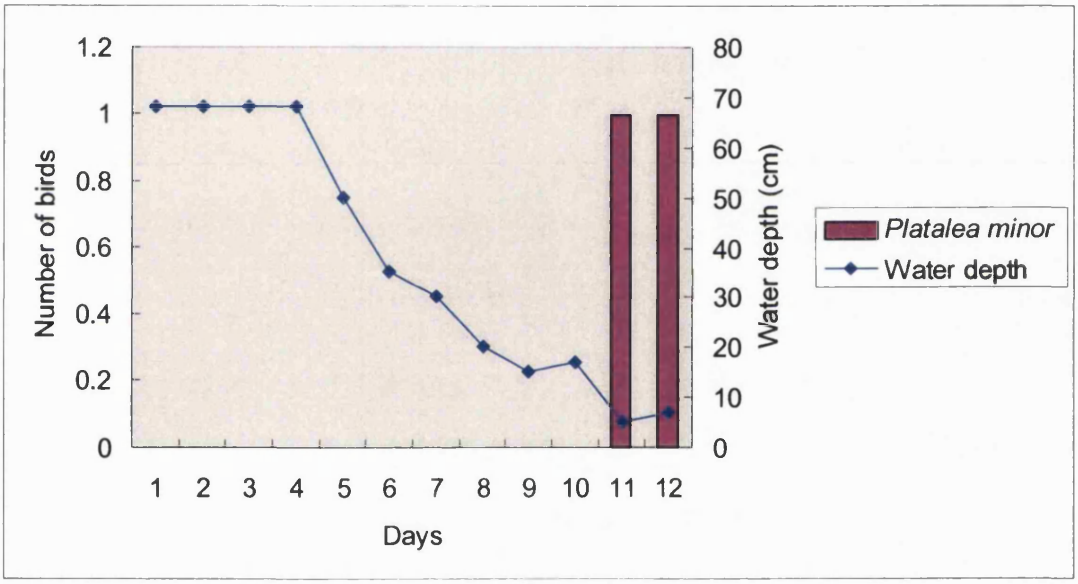


Figure 6.41. The chronological changes in the corresponding occurrence of *Platalea minor* to the manipulation of water level in Pair 3 manipulated pond.

6.5.4. Microhabitat utilization of sample wetlands by waterbirds

The microhabitats of the manipulated ponds are classified into seven independent zones: Central Water Body (CWB); strip Encircling the boundary of Central submerged Vegetation (in a radius approximately a metre wide encircling the central submerged vegetation and being from 50 cm inside to 50 cm beyond the boundary of central submerged vegetation, ECV); Peripheral Water Body (strip two metres in width along the shore, PWB); Shore Vegetation (SV); Shore Exposed Mudflat (SEM); Embankment Herbaceous Vegetation (EHV); and Embankment Shrub Vegetation (ESV) (Figure 6.42).

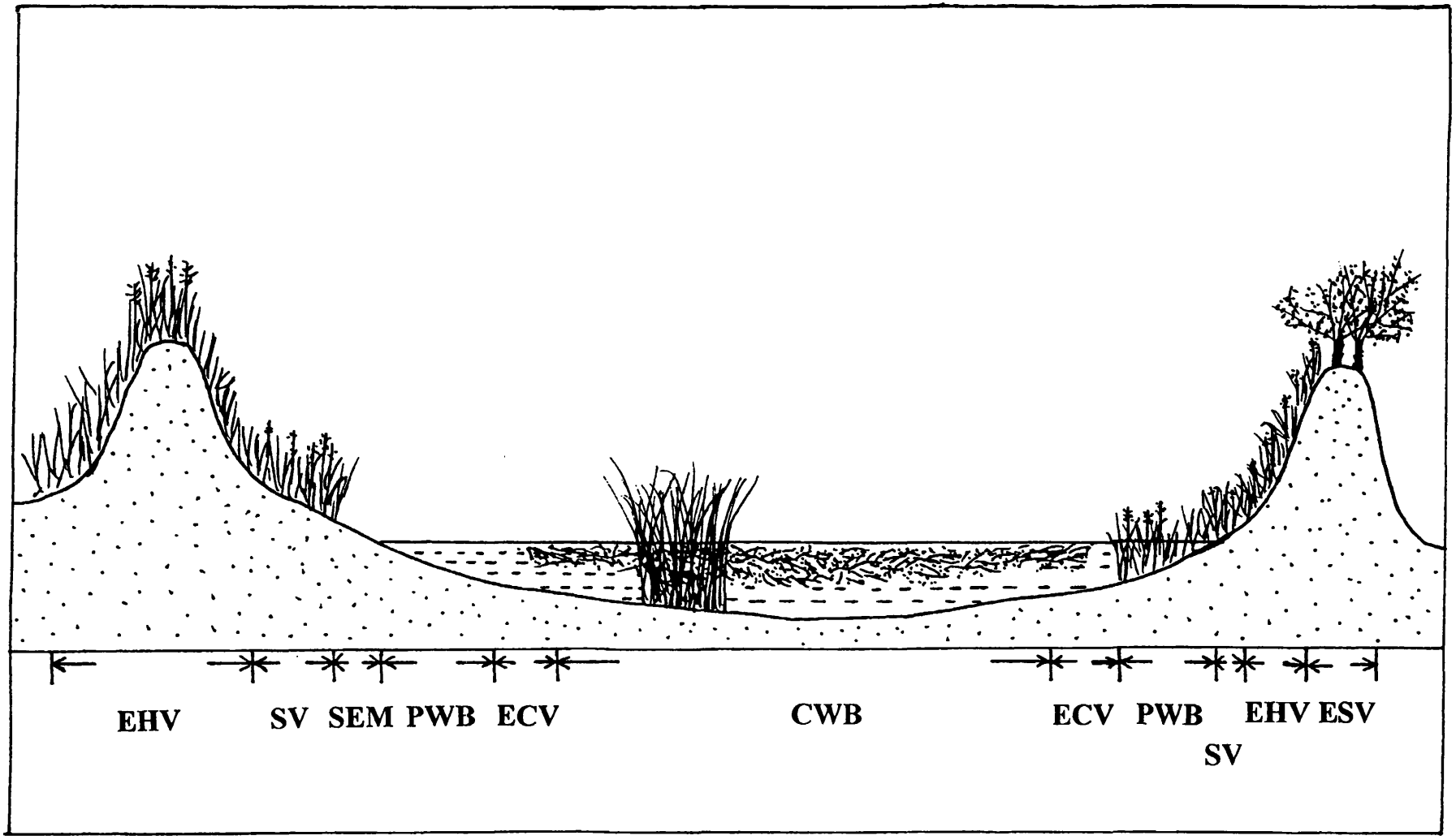


Figure 6.42. A cross-section of microhabitat zonation typical of the experimental ponds; Central Water Body (CWB), strip Encircling the boundary of Central submerged Vegetation (strip approximate one metre in width encircling the central submerged vegetation and being from 50cm inside to 50cm beyond the boundary of central submerged vegetation, ECV), Peripheral Water Body (strip two metres in width along the shore, PWB), Shore Vegetation (SV), Shore Exposed Mudflat (SEM), Embankment Herbaceous Vegetation (EHV) and Embankment Shrub Vegetation (ESV).

A one-way ANOVA was applied to determine the significance of the variations in the numbers of waterbirds within the microhabitat types. According to the ANOVA results, the seven microhabitats were used heterogeneously by the waterbirds. Two manipulated ponds with falling water level, pair 1 and pair 3 manipulated ponds, both show a significant variation in the numbers of waterbirds within seven microhabitats (pair 1 manipulated pond, df=475, F-value=5.00, p=0.000**; pair 3 manipulated pond, df=426, F-value=5.93, p=0.000**). However, the manipulated pond with rising water level has a different story and does not show a significant variation in the numbers of waterbirds within seven microhabitats (pair 2 manipulated pond, df=139, F-value=2.01, p=0.069). The ponds all show the greatest abundance of waterbirds in the CWB, as well as minor concentrated use in PWB.

Due to the small sample sizes, the data collected from the manipulated ponds in both pair 1 and pair 3 ponds, which had similar manipulation of their water levels, are combined for the one-way ANOVA analysing the abundance of individual species. The result from ANOVA reveals that all of the abundant species except *Egretta garzetta* show significant variations in microhabitat use in the ponds with falling water levels. Amongst the species that show significant variations, most display an intensive use of CWB, including *Himantopus himantopus* (df=90, F-value=10.32, p=0.000**), *Podiceps ruficollis* (df=48, F-value=23.94, p=0.000**), *Tringa nebularia* (df=55, F-value=4.28, p=0.002**), *Anas crecca* (df=76, F-value=5.40, p=0.000**) and *Tringa glareola* (intensive use of PWB, df=83, F-value=4.55, p=0.001**). However, some of the species that display significant variations show different patterns in microhabitat use. *Charadrius dubius* shows an intensive use of SEM (df=55, F-value=9.00, p=0.000**), whilst *Tringa stagnatilis* visited PWB more frequently (df=34, F-value=5.28, p=0.001**). Only a species, *Podiceps ruficollis*, shows a significant variation in microhabitat use in the manipulated ponds with rising water levels (df=69, F-value=9.91, p=0.000**). This species shows an intensive use of the two microhabitat types, CWB and PWB (Table 6.3).

Table 6.3. Summary of microhabitat use of sample wetlands by each waterbird species in the water-level manipulation experiment during this study. The major microhabitat type, which was used by one particular species, was marked in bold characters. The shifts between microhabitat uses were indicated by one-way (mono-shift) or two-way (multiple-shift) arrows. ESV stands for Embankment Shrub Vegetation, CWB for Central Water Body, PWB for Peripheral Water Body (strip two metres in width along the shore), and SEM for Shore Exposed Mudflat.

Species	Microhabitat types
Podiceps ruficollis	**CWB**, PWB
Nycticorax nycticorax	CWB ⟷ ESV
Anas crecca	PWB ⟷ **CWB**
Anas querquedula	CWB
Charadrius dubius	SEM
Calidris ruficollis	SEM
Tringa glareola	CWB or SEM ⟶ **PWB**
Tringa nebularia	CWB
Tringa stagnatilis	PWB
Himantopus himantopus	PWB ⟶ **CWB**

Many species display shifts in microhabitat use throughout the manipulation process. Only *Himantopus himantopus* and *Tringa glareola* are predictable in terms of their microhabitat selections. *Himantopus himantopus* changed from PWB to CWB, while *Tringa glareola* changed from either CWB or SEM to PWB. Other species show multiple shifts between microhabitats. *Anas crecca* shifted repeatedly between CWB and PWB, while *Nycticorax nycticorax* shifted between CWB and ESV. In contrast, several species, including *Podiceps ruficollis*, *Charadrius dubius*, *Calidris ruficollis*, *Tringa stagnatilis* and *Anas querquedula,* consistently utilized only a particular microhabitat type. *Podiceps ruficollis* and *Anas querquedula* used only CWB, *Tringa stagnatilis* used PWB, while *Charadrius dubius* and *Calidris ruficollis* only used SEM (Table 6.3).

In short, in the ponds with falling water levels, most species used the central water body, with *Tringa glareola* and *Tringa stagnatilis* using surrounding shallow water and *Charadrius dubius* and *Calidris ruficollis* abundant on the exposed mudflats. *Anas crecca* and *Nycticorax nycticorax* continuously shifted between CWB and PWB and between CWB and ESV, respectively. The microhabitat use by birds is similar in the pond with a rising water level, although fewer species occurred in this pond. There are no records for use of the shore exposed mudflat because this

microhabitat was absent from this pond (Table 6.3).

6.5.5. Feeding depth

The increasing trend in abundance with falling water depth for many individual species provides substantial supportive evidence for determining the most frequent feeding depth in which they might feed most efficiently. It is evident that there was a particular water depth at which a peak was attained in the total number of species and the total number of birds. These two findings are sufficient to determine the most frequent feeding depths for the species. However, a problem arises in that the beds of the experimental ponds are not perfectly flat. A pond generally has a range of water depths. An average is taken to get a mean water depth to represent the depth of this pond. For example, a depth of 10 cm for a pond indicates that the water is 10 cm depth. In this case, the total number of species and birds and the total number of birds of a particular species only provide limited information to determine the most frequent feeding depths of particular species. In order to obtain more accurate information regarding the most frequent feeding depth of individual species, direct observations of the absolute feeding depth, were made when waterbirds are feeding. However, the measurements of the absolute feeding depths are not obtained with ease, especially when hundreds of waterbirds simultaneously occupy a single small pond. An alternative measurement, anatomical feeding depth, was also taken in such circumstances. This measurement is estimated by observing the relative position of the water level to the legs of the feeding waterbirds such as 2 cm above the knee and 3 cm below the knee. These measurements are subsequently converted to an absolute feeding depth using the mean measurements of the tarsus of each species (Cramp & Simmons, 1977; Cramp & Simmons, 1980; Cramp & Simmons, 1983). This alternative measurement provides extra information regarding the particular needs of individual species when using a microhabitat. As absolute and anatomical feeding depth was recorded independently, except the depth of 0cm at which both measurements can share samples, the sample sizes of the two types of measurements did not necessarily match each other.

It can be seen from Figures 6.43 and 6.44 that the measurements of the absolute feeding depths and the anatomical feeding depths for the total waterbird species

assembly in the manipulated ponds show two distinctive distribution patterns. Except for the exposed mudflats (0 cm depth), which were over-recorded due to ease of recording, no intensively-used water depth can be identified for the absolute feeding depths (Figure 6.43). In contrast, the distribution of the measurements for the anatomical feeding depths shows an obvious pattern that displays a peak value at 2 cm below the knee (Figure 6.44). This may indicate that the anatomical restrictions in leg length of the waterbirds play a decisive role in their microhabitat use.

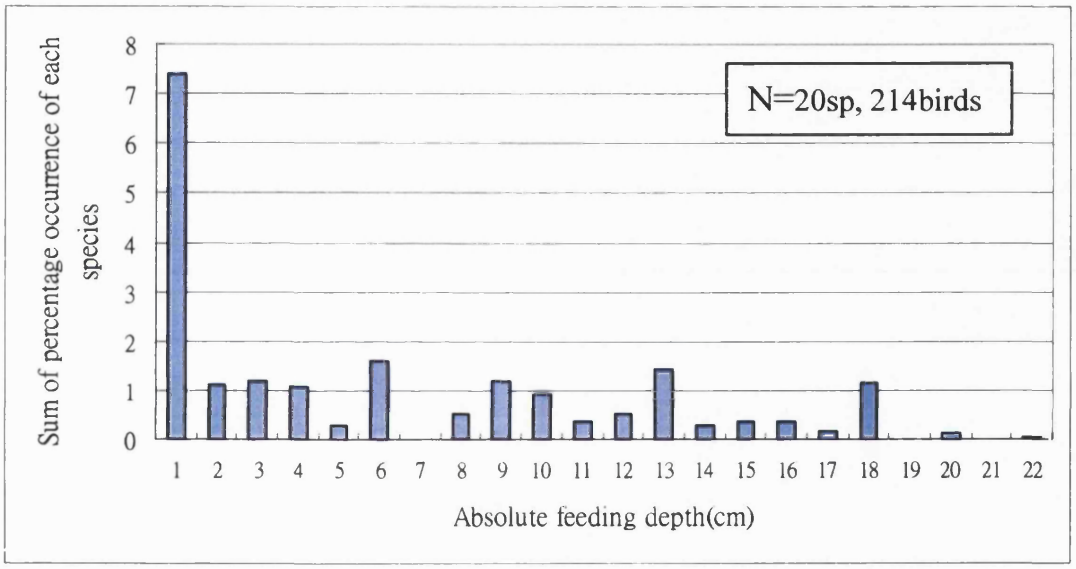


Figure 6.43. Utilization of water depth by waterbirds in the manipulated ponds according to the data for absolute feeding depth. Absolute feeding depth is defined as water depth where waterbirds are feeding.

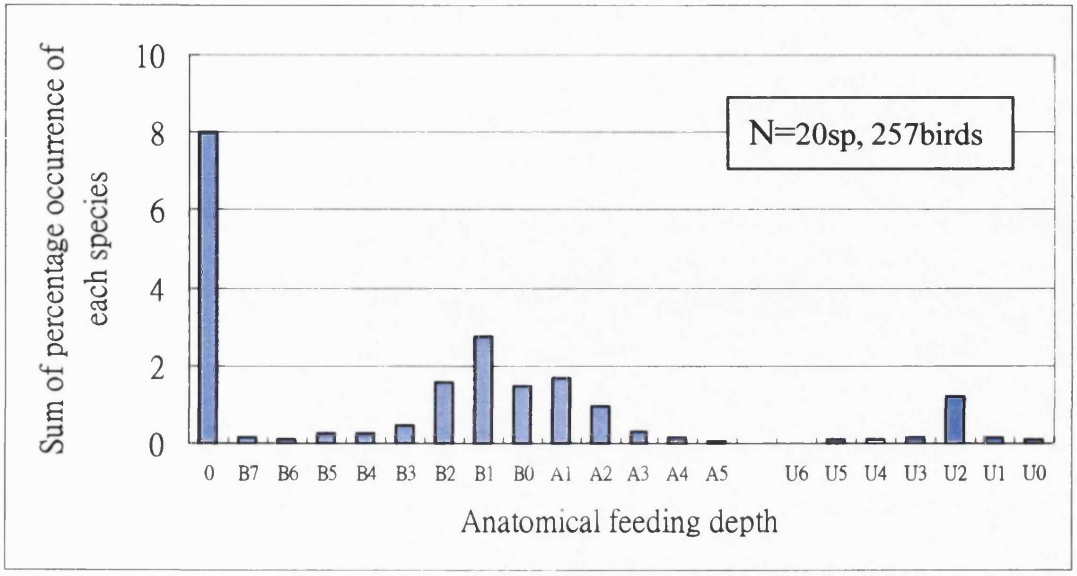


Figure 6.44. Utilization of water depth by waterbirds in the manipulated ponds according to the data for anatomical feeding depth. Anatomical feeding depth is defined as the relative position of water level to the legs of feeding waterbirds such as 7 cm beneath the knee (B7), 5 cm above the knee (A5) and 4 cm below the abdomen (U4). '0' indicates the ground level.

Individual species shows considerable variations between the absolute and anatomical feeding depths in the manipulated ponds. Amongst these species, *Himantopus himantopus*, *Egretta alba* and *Tringa glareola* all display a less diversified distribution pattern in the anatomical feeding depth than the absolute feeding depth. *Himantopus himantopus* mostly used microhabitats of a water depth ranging from 2 cm above or below the knee, although its feeding depth could vary considerably (Figure 6.45). One to seven centimetres below the knee were the most intensely-used feeding depths for *Egretta alba,* particularly at 5 cm below the knee (Figure 6.46). *Tringa glareola* has two most frequently used anatomical feeding depths, namely knee-height and ground level (Figure 6.47).

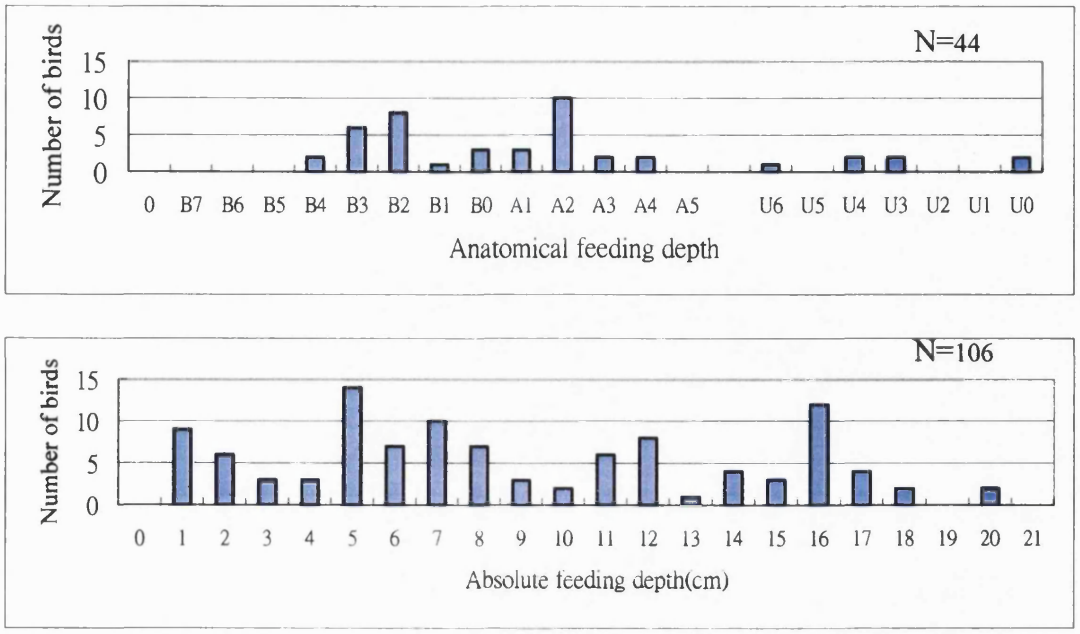


Figure 6.45. A comparison of the utilization of water depth by *Himantopus himantopus* in the manipulated ponds according to the data for absolute feeding depth and the data for anatomical feeding depth. Absolute feeding depth is defined as water depth where waterbirds are feeding; anatomical feeding depth is defined as the relative position of water level to the legs of feeding waterbirds such as 7 cm beneath the knee (B7), 5 cm above the knee (A5) and 4 cm below the abdomen (U4). '0' indicates the ground level. As absolute and anatomical feeding depths were recorded independently, the sample sizes of two types of measurements did not necessarily match each other.

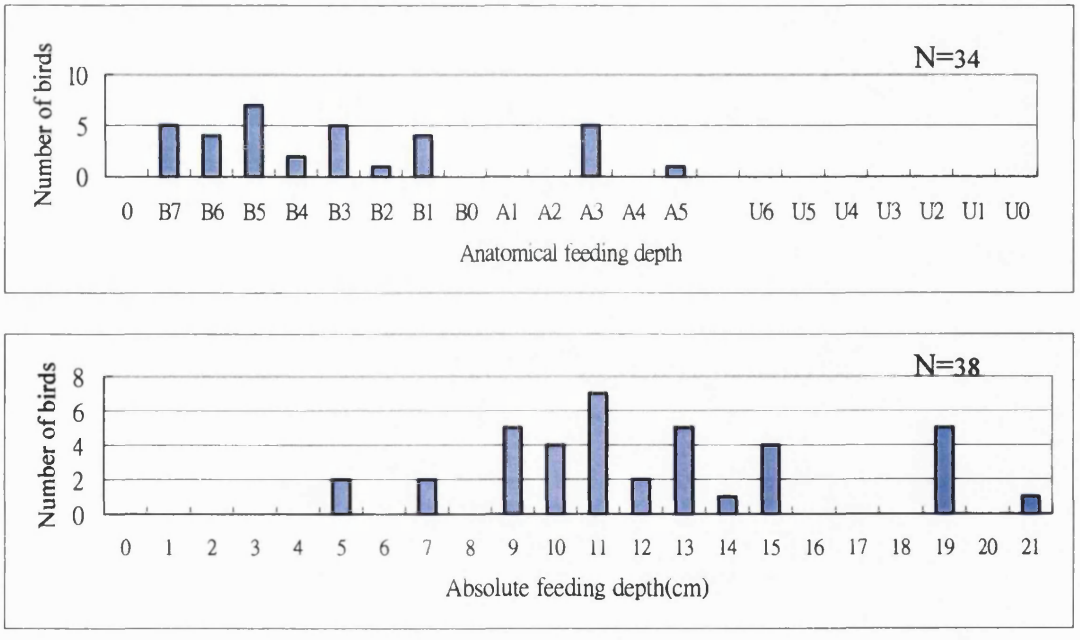


Figure 6.46. A comparison of the utilization of water depth by *Egretta alba* in the manipulated ponds according to the data of absolute feeding depth and the data for anatomical feeding depth. Absolute feeding depth is defined as water depth where waterbirds are feeding; anatomical feeding depth is defined as the relative position of water level to the legs of feeding waterbirds such as 7 cm beneath the knee (B7), 5 cm above the knee (A5) and 4 cm below the abdomen (U4). '0' indicates the ground level. As absolute and anatomical feeding depths were recorded independently, the sample sizes of two types of measurements did not necessarily match each other.

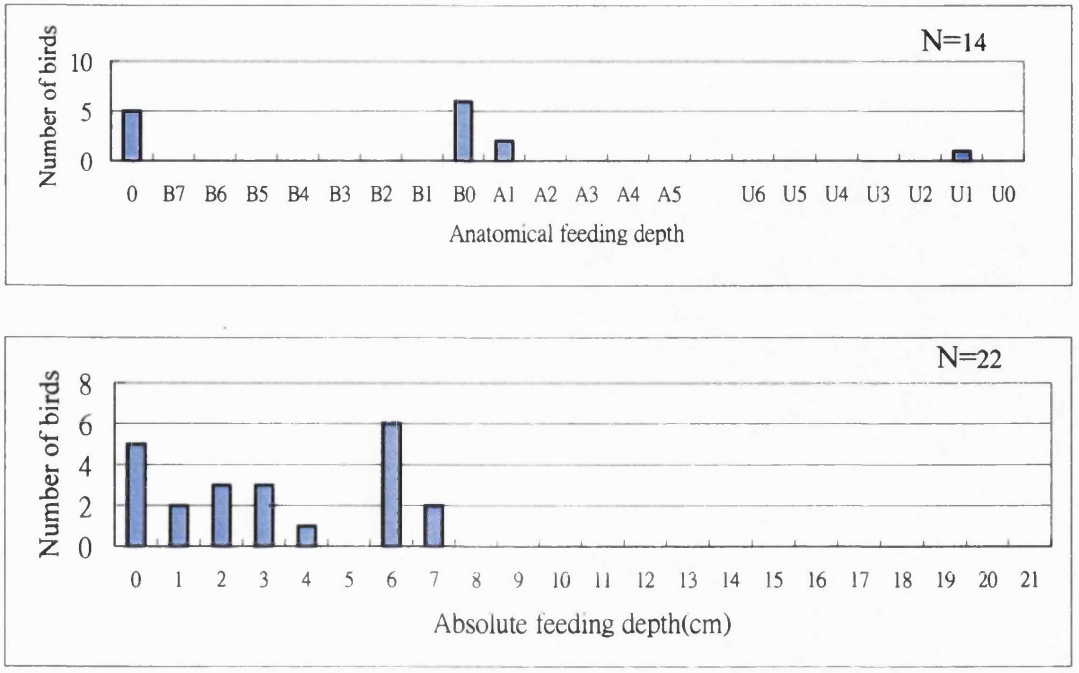


Figure 6.47. A comparison of the utilization of water depth by *Tringa glareola* in the manipulated ponds according to the data for absolute feeding depth and the data for anatomical feeding depth. Absolute feeding depth is defined as water depth where waterbirds are feeding; anatomical feeding depth is defined as the relative position of water level to the legs of feeding waterbirds such as 7 cm beneath the knee (B7), 5 cm above the knee (A5) and 4 cm below the abdomen (U4). '0' indicates the ground level. As absolute and anatomical feeding depths were recorded independently, the sample sizes of two types of measurements did not necessarily match each other.

Aside from the species which show obvious variations between the absolute and anatomical feeding depths, some waterbird species display a fixed and narrow feeding depth range. These species include *Charadrius alexandrinus* (0 cm), *Charadrius dubius* (0 cm), *Calidris ruficollis* (0 cm), *Anas crecca* (1 cm above the knee and 0 cm) and *Tringa totanus* (1 or 2 cm below the knee) (Figures 6.48, 6.49, 6.50, 6.51 and 6.52). However, many species do not show clear differences between these two types of feeding depths. This is probably due to the small sample sizes.

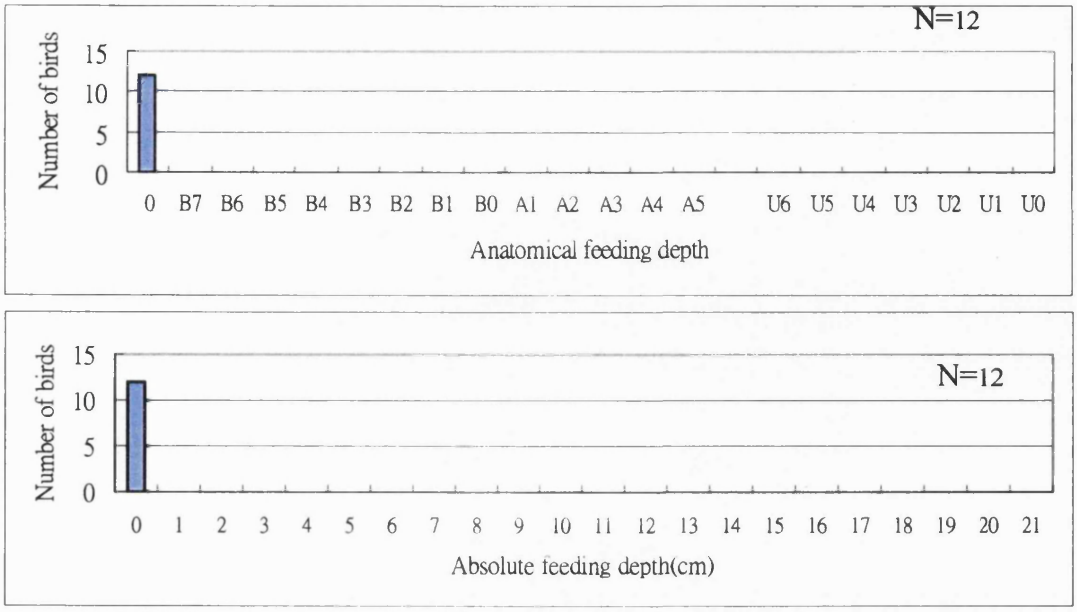


Figure 6.48. A comparison of the utilization of water depth by *Charadrius alexandrinus* in the manipulated ponds according to the data for absolute feeding depth and the data for anatomical feeding depth. Absolute feeding depth is defined as water depth where waterbirds are feeding; anatomical feeding depth is defined as the relative position of water level to the legs of feeding waterbirds such as 7 cm beneath the knee (B7), 5 cm above the knee (A5) and 4 cm below the abdomen (U4). '0' indicates the ground level. As absolute and anatomical feeding depths were recorded independently, the sample sizes of two types of measurements did not necessarily match each other.

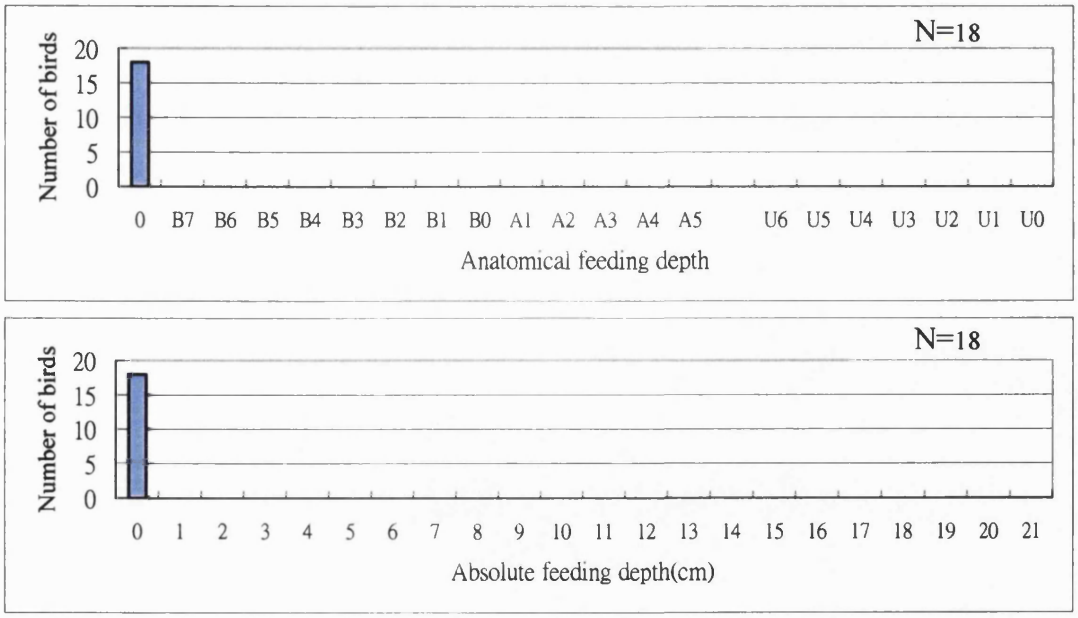


Figure 6.49. A comparison of the utilization of water depth by *Charadrius dubius* in the manipulated ponds according to the data for absolute feeding depth and the data for anatomical feeding depth. Absolute feeding depth is defined as water depth where waterbirds are feeding; anatomical feeding depth is defined as the relative position of water level to the legs of feeding waterbirds such as 7 cm beneath the knee (B7), 5 cm above the knee (A5) and 4 cm below the abdomen (U4). '0' indicates the ground level. As absolute and anatomical feeding depths were recorded independently, the sample sizes of two types of measurements did not necessarily match each other.

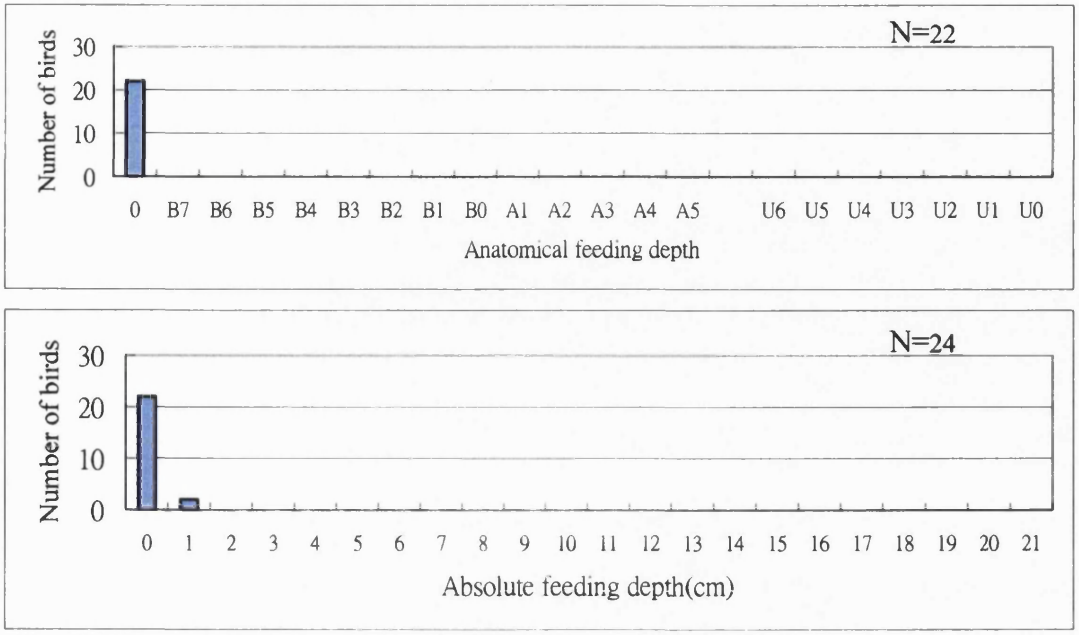


Figure 6.50. A comparison of the utilization of water depth by *Calidris ruficollis* in the manipulated ponds according to the data for absolute feeding depth and the data for anatomical feeding depth. Absolute feeding depth is defined as water depth where waterbirds are feeding; anatomical feeding depth is defined as the relative position of water level to the legs of feeding waterbirds such as 7 cm beneath the knee (B7), 5 cm above the knee (A5) and 4 cm below the abdomen (U4). '0' indicates the ground level. As absolute and anatomical feeding depths were recorded independently, the sample sizes of two types of measurements did not necessarily match each other.

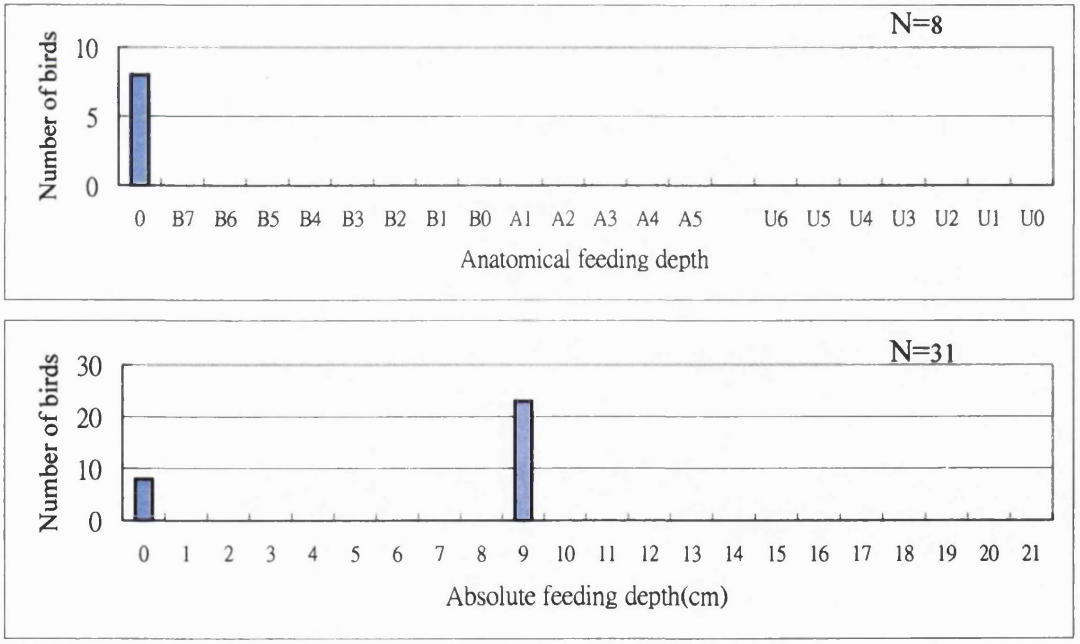


Figure 6.51. A comparison of the utilization of water depth by *Anas crecca* in the manipulated ponds according to the data for absolute feeding depth and the data for anatomical feeding depth. Absolute feeding depth is defined as water depth where waterbirds are feeding; anatomical feeding depth is defined as the relative position of water level to the legs of feeding waterbirds such as 7 cm beneath the knee (B7), 5 cm above the knee (A5) and 4 cm below the abdomen (U4). '0' indicates the ground level. As absolute and anatomical feeding depths were recorded independently, the sample sizes of two types of measurements did not necessarily match each other.

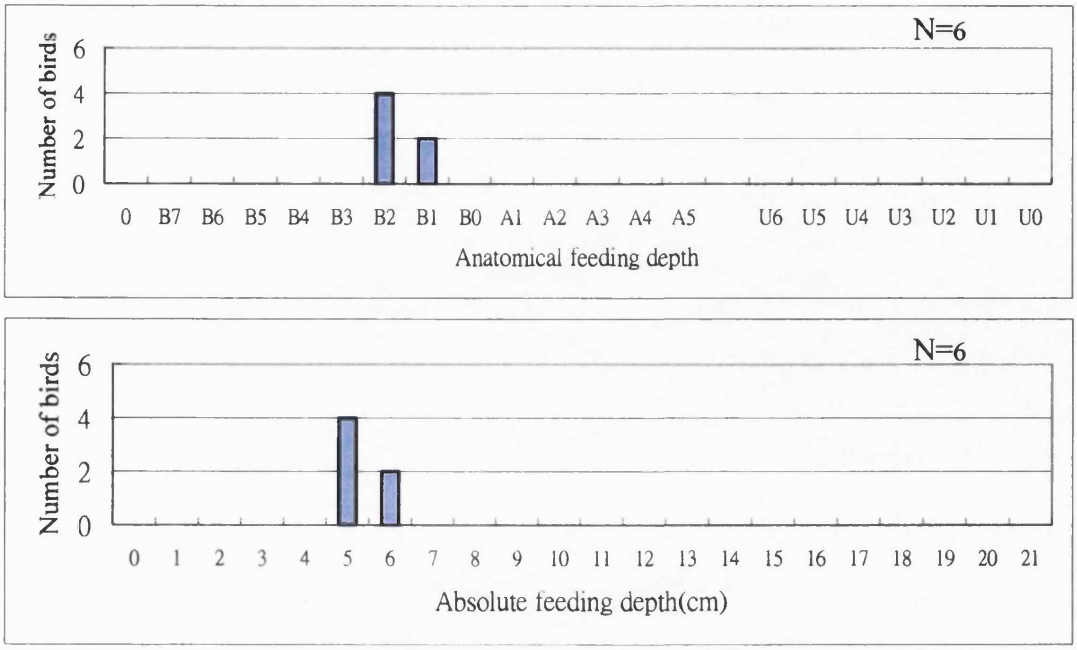


Figure 6.52. A comparison of the utilization of water depth by *Tringa totanus* in the manipulated ponds according to the data for absolute feeding depth and the data for anatomical feeding depth. Absolute feeding depth is defined as water depth where waterbirds are feeding; anatomical feeding depth is defined as the relative position of water level to the legs of feeding waterbirds such as 7 cm beneath the knee (B7), 5 cm above the knee (A5) and 4 cm below the abdomen (U4). '0' indicates the ground level. As absolute and anatomical feeding depths were recorded independently, the sample sizes of two types of measurements did not necessarily match each other.

6.6. Discussion

Several species responded differently to the manipulation of the two drawdown manipulation ponds. *Egretta garzetta* showed a one-day intensive utilization at the pair 1 manipulated pond, while it displayed an over-4-day utilization at the pair 3 manipulated pond (Figures 6.23 and 6.27). Fish is the primary prey of *Egretta garzetta*. Numerous *Egretta garzetta* (237 birds) were spotted on one single day at the pair 1 pond and could possibly result from an appropriate depth (less than 10 cm) for catching fish had been provided. This had consequently caused a rapid depletion of food resources. In contrast, only 26 birds per day on an average for the four peak days occurred at the pair 3 pond since a relatively greater depth was provided (16 cm) for the first two peak days. This might have created foraging difficulties so the species remained longer than at the pair 1 ponds. In addition, variation in the amount of food resources, and pond size between these two ponds could also result in the difference in the period of occurrence time for this species. *Himantopus himantopus* showed a

different variation. At the pair 1 pond, *Himantopus himantopus* started to visit from 10 cm depth when the water level was gradually dropped. In contrast, it started to visit pair 3 pond from 35 cm depth. However, in both cases, the peak occurrence occurred at a depth of 15 cm (Figures 6.17 and 6.34). *Anas crecca* also showed variation between these two drawdown manipulation ponds. At the pair 1 pond, *Anas crecca* started to use the pond when its water level had been dropped to 10 cm, whilst it started to visit pair 3 pond from 30 cm depth. However, its peak occurrence only occurred at a depth of approximately 10-15 cm in both ponds (Figures 6.18 and 6.25). The variations between these two manipulated ponds might indicate that at a depth of approximate 30-35 cm, both *Himantopus himantopus* and *Anas crecca* can barely use the manipulated ponds but the most frequent feeding depth should be approximate 10-15 cm. In summary, 10-15 cm appears to be a common depth to attract these three common waterbird species.

Poysa (1983) reported that dabblers used the central water body of wetlands with an average depth of 0.5-0.7m most intensively. The considerations pertaining to the risk of predation could result in this microhabitat selection. Staying in the central area of wetlands could greatly increase the respondse distance to predators, which normally approach from the peripheral area of wetlands. In the two manipulated ponds of this study, waterfowl, mainly *Anas crecca*, exploited not only the central water body but also the peripheral water body and shore exposed mudflats (one-way ANOVA for *Anas crecca*: df=76, F-value=5.40, p=0.000**). A great number of waterfowl came to visit the manipulated ponds, which are relatively small (0.6 and 0.8 ha), when the water level was drawn down and consequently not much central water body can be provided for waterfowl by the manipulated ponds. The peripheral water body and shore exposed mudflats were therefore used intensively. Large sized manipulated ponds (minimum 2 ha) are recommended for future studies to elucidate the microhabitat use of abandoned aquaculture ponds by waterfowl.

Several authors suggest alternating changes in the water level of wetlands (Rundle & Fredrickson, 1981; Breininger & Rebecca, 1990; O'Brien & Self, 1994; Rehfisch, 1994; Self, *et al.*, 1994; Vickery, *et al.*, 1997; Ashkenazi & Dimentman, 1998). Generally, this cycle includes an increase of water level in spring and summer for cumulating food resources (mostly invertebrates, young fish or aquatic plants) and a

decrease of water level in winter for increasing food accessibility to waterbirds. Rehfisch (1994) and Ashkenazi & Dimentman (1998) had both emphasized the importance of timing in manipulating the ups and downs of the water level. Only a well-designed water level control system could provide plentiful contributions to the conservation of waterbirds. Studies pertaining to the optimal cycling of the water level and the accurate timing of altering the water level should be a high priority for future studies.

Since the basins of the manipulated ponds were uneven, the microhabitats with a variety of water depths were provided by the manipulated ponds. The combination of several microhabitat types attracted several groups of species in the diverse microhabitat requirements and therefore no clear conclusion pertaining to the microhabitat selection of waterbirds can be drawn from this experiment. Future studies should be conducted in well-controlled ponds, in which the manipulated attributes should be more restrictedly controlled so that the interpretation of research results from these studies can be unambiguous and more convincing.

6.7. Conclusions

Water depth is likely to play an essential role in the habitat selection of temporarily abandoned aquaculture ponds by waterbirds. The significant variations which occurred in abundance, species richness and species composition of waterbirds in the manipulated ponds all support this hypothesis. Most species acted as opportunists and displayed one or even numerous microhabitat shifts. It is believed that a feeding depth of 10 to 15 cm is most frequently used by most waterbirds. *Anas crecca* appears to have benefited most from a decrease in water depth and responded with a rapid rise in number. Egret species such as *Egretta garzetta* and *E. intermedia*, as well as many wader species, also benefited from a drop in water level. However, anatomical restriction, namely leg length, rather than absolute depth seemed to limit the use made by waterbird species of temporarily abandoned ponds. A variety of water depths are necessary to encourage a rich and diverse species assembly in a conservation pond.

6.8. Future study

Small sample sizes have caused an insufficient amount of data for comparisons between guilds, species and wetland types and also explain a lack of significant variations in many statistical tests. As a result, descriptive instead of quantitative results are presented here. Long-term periodic and detailed studies are called for to provide more evidence to support the interpretation and inferences suggested by this study. Several types of studies are required. First, repeats of similar observations at other times of the year or at other principal wetland types such as saltpans and rice paddies, are necessary. These manipulation experiments should not only comprise the observations of water drawdown but also that of rising the level of water. Second, abundant accessible food resources could be a crucial factor to attract waterbirds to visit the manipulated wetland. Therefore, detailed studies in terms of the potential food organisms of waterbirds are also recommended. These observations might include several aspects, namely diversity of prey organisms, seasonal availability of prey species, food availability at different water depths, population dynamics of prey species, relative proportions of prey organisms consumed by waterbirds, the most frequent feeding depth for individual prey species. Then, based on knowledge obtained from the preceding feeding ecology-related studies, several wetland restoration schemes could be launched to outline the potential management measures for improving the habitat quality. These restoration schemes could consist of several aspects such as subsidization of food resources or nutrients, alteration in the cover or height of vegetation and subsequently the investigation of the response of waterbirds to the alterations of physical parameters of wetlands. Fourth, a large proportion of waterbirds such as duck species, are rather sensitive to the presence of people. It is worth considering the manipulation of surrounding vegetation of target wetlands and investigating its effects on waterbirds when the water level control is employed. Fifth, in a mosaic of artificial and natural wetlands and human-altered habitats, surrounding habitats of target wetlands could exert strong effects on waterbirds. In order to ascertain the effects from surrounding habitats on waterbirds, the distance to which the attracted birds fly need to be measured. Surrounding habitats are essential for the success of restored wetlands if most birds occurring in the manipulated wetland come from the nearby habitats. On the contrary, an isolated site can contribute considerably to the conservation of waterbirds

if most birds which are recorded in the manipulated wetland fly a long way to visit the site. Banding, radiotracking or other techniques are necessary to measure the travel distance of the visiting waterbirds.

Chapter 7

Discussion

In this chapter the findings of the field studies are brought together and are discussed under the following themes. First, the discussion explores possible synchronized relationships between avian variables and characteristic variables of the sample wetlands. In other words, synchronized fluctuations might imply a strong association between waterbird occurrence and wetland characteristics.

Second, since numerous waterbird species must be managed simultaneously at any conservation site, site managers who are in charge of more than several sites could only possibly manipulate their sites in accordance with the habitat requirements of several guilds of birds, but not of every individual species of bird. In order to provide site managers with practical recommendations to improve their management, the aggregation patterns and guild classification of waterbirds are discussed next. Third, and a crucial part of this study, is a discussion of the factors that relate to the habitat use of temporarily abandoned aquaculture ponds by waterbirds. Fourth, the findings of the manipulation experiment of the water level are discussed. Water depth is thought to a key factor determining the habitat selection of waterbirds. Long-term manipulation experiments are most likely to provide direct evidence to support a statistical relationship between the wetland characteristics and the habitat selection of waterbirds. Finally, potential future studies are outlined and discussed.

7.1. Annual changes in the characteristic attributes of temporarily abandoned aquaculture ponds and the population and species composition of waterbirds

7.1.1. The characteristic attributes of temporarily abandoned aquaculture ponds

Several authors have suggested that vegetation, which could provide waterbirds with food and shelter, has a strong influence on the habitat selection of waterbirds (Johnsgard, 1956; Murkin, *et al.*, 1982; Breininger & Rebecca, 1990; Halse *et al.*, 1993). Therefore, it is very likely that the chronological changes of vegetation could also play an important role in determining the population dynamics of waterbirds with time. According to Figure 2.9, the measurements of total vegetation cover at a 15-day interval remained relatively constant throughout the year in the temporarily abandoned aquaculture ponds (one-way ANOVA, $F=0.40$, $p=0.995$, $df=1660$). This result was against expectation. Different growth rates during the different seasons of the year may influence vegetation height and form,

but not vegetation cover. Plants can grow in all months of the year in Taiwan, and wherever a suitable habitat is formed, plants take advantage of it by rapidly colonizing the whole area. However, factors other than abandonment time may play a more important role in determining the annual changes of the combined vegetation cover. VanRees-Siewert and Dinsmore (1996) believed several factors might influence re-vegetation: the duration of drainage; past herbicide use; the cropping system; the effectiveness of drainage and isolation. Aside from these factors, the frequency and quantity of water inflows, salinity and pH might also play a crucial role in affecting the fluctuations of total vegetation cover after abandonment in this study. Hydrology and water quality, which can greatly limit vegetation growth, could be altered continuously after abandonment by the previous manager and the managers of adjacent ponds (personal communication), and therefore alter revegetation of the temporarily abandoned aquaculture ponds. However, the role of these factors requires further study.

Apart from vegetation cover, vegetation height could also play an important role in the habitat selection of waterbirds. Various vegetation heights could provide diverse niches for waterbirds, which can therefore result in higher species diversity (Rafe *et al.*, 1985). Consequently, the annual changes of vegetation height could influence the seasonal changes in the degree of habitat use of wetlands by waterbirds. Two groups of vegetation height-related measurements were recorded: absolute maximum height (A.H.) and mean height (M.H.) of the dominant vegetation. These two types of measurements responded differently to the annual vegetation changes. A.H. displayed an increasing trend ($p=0.00^{**}$, $df=2493$, Figure 2.15), while M.H. did not show a regular annual pattern. This indicates that only A.H. shows a predictable annual change, whereas M.H. does not. In other words, A.H. could be a better diagnostic vegetation-related parameter for assessing the degree of diversity in vegetation than M.H.

The extent of the exposed mudflats is another parameter which could strongly affect the habitat use of wetlands by waterbirds, particularly shorebirds (Breininger & Rebecca, 1990; Weber & Haig, 1996; Ashkenazi & Dimentman, 1998). Recent exposed mudflats, which normally support abundant invertebrates, could provide a feeding ground for waterbirds (Weber & Haig, 1996). In addition, a large extent of

the exposed mudflats could provide a secure area for waders, allowing them to be vigilant to their predators and other disturbance. The annual changes in the percentage extent of the exposed mudflats follows an obvious trend among different abandonment age classes (Figure 2.8). The ponds that had been abandoned the longest (minimum 15 years) contained mudflats even in the wettest months of the year. This observation contrasts with Hudson's study (1983). In his study, the percentage extent of bare shoreline showed a decreasing trend with increasing age of wetlands. His study ponds were all freshwater ponds and could reasonably be expected to support a greater vegetation cover, and consequently a smaller area of bare ground as wetlands become older. In contrast, all the sample ponds of the oldest abandonment category in this study were brackish. A high salt content in the water body could limit vegetation development or even entirely eradicate plants (Bell & Froend, 1990; Hart *et al.*, 1990). Consequently, this situation permitted a higher proportion of bare ground in the sample ponds which were subjected to gradual drying out after abandonment begun, and might suggest that older abandoned aquaculture ponds could play an important role in attracting waterbirds, waders in particular, which favour open areas.

7.1. 2. Annual changes in the population and species composition of waterbirds

Migrant species constituted a considerable proportion of the waterbirds recorded at the aquaculture ponds in this study (approximately 65%, some species are hard to classify as residents or migrants). Their strong seasonal occurrence might mask the actual trend in the selection of wetland habitat by waterbirds. The information regarding the seasonality of abundance, species richness and species composition can help us to understand the seasonality in the habitat use of sample wetlands by waterbirds.

The abundance and species richness of waterbirds are two of the most obvious parameters to describe the overall birds present in a wetland. There is a significant seasonality in the abundance and species richness of waterbirds with minor variation in the sample wetlands (Figures 3.1 and 3.2). The mean number of species per pond in the collective sample ponds showed two obvious peaks during the year, (with a major peak during the southbound migratory season and a minor peak during the northbound migratory season), whilst the mean abundance per pond only

showed a peak value during the southbound migratory season. During the southbound migratory season (from September to November), migrant birds, mainly from Siberia or Northern mainland China used the aquaculture ponds intensively for a winter or short stay to refuel. Consequently, this massive increase in species richness caused an increase in both species richness and the abundance of waterbirds in these artificial wetlands. During the northbound migratory season (from April to May) migrant birds produced an increase in species richness but not in abundance at these ponds. Similar research conducted around this study area showed that migrant birds produced an increase in both species richness and abundance during these two migratory seasons (Lin, 1994; TCWBS, 1999; BSTP, 2000; Wang, 2000). The variations in species composition between these two migratory seasons might contribute to the difference in the abundance of waterbirds. The principal members within the migrant waterbird group, the duck species, mostly occurred during the southbound migratory season (Figures 3.12 and 3.13). Their absence in the northbound migratory season possibly explains a lack of an obvious peak in the collective abundance of waterbirds during this season. This might imply that aquaculture ponds during the northbound migratory season are not as attractive to waterbirds as other wetland types. Another probable cause for the lower abundance of waterbirds at aquaculture ponds during the northbound migratory season is that there were more transient wetland habitats such as rainwater pools and dykes in the study area, during this time (April and May are the first months of the wet season). These extra wetland habitats could provide water, food resources and roosting sites for waterbirds and consequently dilute the density of waterbirds in each wetland, including aquaculture ponds. In other words, abandoned aquaculture ponds might be less used in the northbound migratory season due to other wetlands being available but not due to wetlands being less attractive to waterbirds.

However, not every species of waterbirds showed a strong seasonality in abundance. Resident species displayed a relatively constant abundance throughout the year. It can be seen from the annual pattern of species composition in the collective sample ponds that the migrant group of species was overwhelmingly abundant for seven to eight months (from September to April), whilst the resident group was most abundant for the rest of the year (from May to August, Figures 3.10, 3.11, 3.12 and

3.13). In addition, the resident group also displayed a maximum value in abundance when the migrant group was overwhelmingly dominant in abundance in the sample wetlands. This might imply that the resident species constantly used aquaculture ponds. When the migrant waterbirds arrived, they outnumbered the resident species and became the most abundant birds at aquaculture ponds, although at this time the resident species used the sample wetlands even more intensively than during other months. Another study (BSTP, 2000) had reported very similar population dynamics of residents and migrants during the year. This suggests that site managers could adjust their management practices for each of the two distinct groups of waterbirds, either resident or migrant species during the whole year.

Species composition in a wetland such as the species richness for each guild of waterbirds, could provide useful information for site managers about how the avian community uses the managed wetlands. As shown in Table 3.3, the new-arrival and absence of waterbird species in the collective sample ponds appear to have an obvious annual pattern which might contribute to two migratory seasons, namely southbound and northbound season. In general, this annual pattern was similar to the observations made in other studies that were conducted in Taiwan (Lin, 1994; Yen, 1994; Tsai, 1998; TCWBS, 1999; Zang, 1999; BSTP, 2000; Chou, 2000; Wang, 2000; Wong *et al.*, 1996). However, the major difference between the results of this study, which showed that ducks occurred from September to February, and Chou's study (2000) lies in the presence of duck species . As described by Chou, most common duck species (*Anas querquedula* excluded) started arriving at the wetlands from September and stayed uninterruptedly until April. Chou's study site was a national wildlife refuge, which was a long-abandoned, flooded arable field and existed in an almost natural state. The lengthier stay of these common duck species in that particular wildlife refuge might be attributed to a better protection status with less human disturbance and an abundant nearby food supply.

Much effort was made to find the potential synchronized fluctuations between the annual patterns of any avian and the physical attributes of the sample wetlands. However, no pair of avian-physical variables displayed a high degree of matching. This might suggest that numerous parameters, and also the abandonment time

contribute to the habitat selection of waterbirds. In this study, the influence of every parameter on the habitat selection of waterbirds was placed together for data analyses. Consequently, synchronized fluctuations between any pair of avian and physical attributes of the sample wetlands were not readily identified.

7.2. Aggregation pattern, guild classification, species composition and commonness of waterbird species

Three guilds of waterbirds, namely the Egret-Rail, Wader-Tern, Duck guilds, are clearly categorized using the physical attributes of sample wetlands in this study. This guild classification is similar to those proposed by both Breiniger & Rebecca (1990) and by Lin (1994) with only minor variations. Based on Lin's classification, waterbirds were grouped into three guilds: waders, ducks and rails. The Ardeidae species (egrets and herons) were separately allocated to duck, rail and a terrestrial guild. In this study, egrets and herons are generally allocated to one guild rather than several guilds. However, according to Figure 4.1, the members of the Egret-Rail guild appear to be less closely associated than the two other principal guilds, although the total number of species in this guild is the smallest. Cramp & Simmons (1983) described the members of the Ardeidae as a group of birds with diversified food habits and habitat requirements. Diverse habitat requirements could result in a loose grouping in the Ardeidae. In addition, the sample wetlands of Lin and Breiniger & Rebecca were both natural wetlands with higher habitat diversity, and were different from those in this study, which were mostly aquaculture ponds with a less diversified habitat. The differences in the habitat diversity of sample wetlands amongst these two and the present study might cause the differences in the habitat utilization of wetlands by waterbirds, and therefore result in a different classification of waterbirds. This might suggest that site managers could manage their sites by the composition of wetland types in their sites. In other words, diverse habitat could be created if the wetlands in their sites are mostly composed of aquaculture ponds. However, detailed study is necessary to understand the habitat use of wetlands by the Ardeidae such as the time budget, prey information and energy intake of the Ardeidae and the proportion of time of the day allocated to different wetland types. In Lin's study, *Egretta garzetta* was the species which was categorized into a terrestrial guild. The wetland types of the sample wetlands in this study almost always consisted of aquatic environments. Few terrestrial habitats occurred among the sample wetlands in this

study. Therefore, the difference in habitat utilization of sample wetlands by *Egretta garzetta* cannot be justified by the results obtained in this study. Amongst the aforementioned classification systems proposed by Lin and Breiniger & Rebecca and that in this study, waders are the only group of waterbirds that showed no variation in the classification of waterbirds and remains entirely independent from the other guilds. This might indicate that waders generally used aquaculture ponds in a unique way.

According to the guidelines for the interpretation of CANOCO ordination, the species with similar habitat requirements lie close in ordination, whilst the species with diverse habitat requirements lie far apart (Ter Braak & Smilauer, 1998). The same principle is applied to the relationship between guilds. This suggests that the aggregation pattern of species or guilds within a conservation site will influence the way these species or guilds are to be managed. The closely associated species and guilds should be provided with a specific habitat, whilst the less closely associated species and guilds should be provided with a broader range of habitat. In addition, the species that lie close to the origin of ordination are species with general habitat requirements, whilst the species that lie far from the origin are species with specific habitat requirements.

As seen in Figure 4.1, different guilds of waterbirds had different aggregation patterns. Egret species were less aggregated in the ordination despite the fact that the guild's species number is relatively small (N=9). Egret species could even be further separated into two sub-groups, generalist and specific sub-groups. The egret species therefore need a range of habitats to match their diverse habitat requirements in these two sub-groups if they are the target species at a particular conservation site. In comparison with the sparse distribution of egret species, members of the Wader-Tern guild were far more closely aggregated even though their total number of species was largest amongst the three main guilds of waterbirds. This indicates that the habitat requirements of wader species could be similar to each other. Furthermore, almost no duck, egret or rail species was closely associated with the Wader-Tern guild. This may indicate that the habitat requirements of waders are unique and are not shared with the species of the other two guilds. The two exceptional wader species, *Rostratula benghalensis* and *Gallinago gallinago*, lay close to the Egret-Rail and Duck guilds, respectively, favouring densely vegetated habitats as opposed to open

habitats (waders normally prefer open habitats). Waders occupy an extremely wide range of habitat niches from tropical forest to tundra (del Hoyo *et al.*, 1996). This indicates that waders should be a group of species which can make use of their habitat efficiently. However, in this study, waders appear to use sample wetlands, primarily aquaculture ponds, in a way that is distinct from those of the other two guilds. This might indicate that aquaculture ponds can only provide part of the habitat required by waders, and therefore waders only exploit sample wetlands in a restricted and relatively similar way. Duck species showed a medium degree of aggregation amongst the three main guilds of waterbirds. Two members of the Anatidae, *Anas poecilorhyncha* and *Aythya fuligula,* lay far from the Duck guild, and were viewed as members of the Egret-Rail guild. This could be caused by their distinct habitat requirement. *Aythya fuligula* is a diver, which appears to use deep ponds (over 60cm, del Hoyo *et al.*, 1992), while *Anas poecilorhyncha* preferred open areas, which is different from the preferred habitat for the most abundant duck species, *Anas crecca*, which prefer a pond with abundant fringe vegetation (del Hoyo *et al.*, 1992).

Regarding abundance and spatial distribution, migrant and resident waterbird species appear to follow different trends. The wader species, mostly migrant species such as *Calidris alpina* and *Calidris ruficollis,* were the most abundant species in all wetland types except in the temporarily abandoned ponds, where duck species such as *Anas crecca,* were most abundant (Table 4.1). Ducks and waders were only dominant in abundance but not in spatial distribution. In all sample spatial distribution, the egret species, mostly resident species such as *Egretta garzetta*, *Egretta intermedia* and *Nycticorax nycticorax* and some other resident species such as *Podiceps ruficollis* and *Gallinula chloropus,* were the most widely dispersed over most wetland types (Table 4.2). This might suggest that the sample wetlands were primarily used by migrant species, waders and ducks, but the birds were confined to a limited number of suitable ponds. On the other hand, most sample wetlands were widely used by resident species, egrets, rails and grebes, although their relative abundance was not highest among waterbird species. *Egretta garzetta* was the only exception, as it was dominant in both abundance and spatial distribution (Tables 4.1 and 4.2). Its ability to adapt to a wide spectrum of wetland types and its relatively high tolerance to the presence of humans might both contribute to its commonness. However, *Egretta garzetta*'s abundance was lower than the most abundant migrant species. The

migrant species were still the most abundant at every wetland type. In summary, migrants aggregated at a few wetlands, whilst residents were widespread but relatively few in number in the study area. This suggests that the loss of a pond suitable for migrants is far more deleterious to conservation of waterbirds than the loss of a pond suitable for residents.

7.3. Environmental variables determining the habitat use of aquaculture ponds by waterbirds

Numerous parameters might all contribute to the habitat selection of waterbirds in wetlands. The effort to manage conservation sites could be allocated efficiently and effectively if the parameters that primarily determine the habitat selection of waterbirds can be identified. According to Ter Braak & Prentice (1988), a species that lies closely to one particular environmental attribute in a species-environment biplot, implies a positive association between this species and the environmental attribute. The longer the arrow of a particular environmental variable the larger its influence on the habitat utilization by the whole set of species (Ter Braak & Prentice, 1988). As seen in Figure 5.2., the most important characteristic variables of wetlands pertaining to the habitat utilization of the Wader-Tern, Egret-Rail and Duck guilds were salinity and basin area; the extent of the >30 cm water depth zone; and the cover of submerged vegetation and abandonment time, respectively. In contrast, the habitat utilization of sample wetlands by the Wader-Tern guild could be negatively affected by the percentage cover of vegetation. These findings suggest that separate management plans are necessary to conserve these three guilds of waterbirds. Precipitation appears to have strong influences on most of the aforementioned variables. During the wet season from May to August, heavy rain, mainly from tropical storms known as typhoons, generate abundant rainfall and therefore cause an increase in the extent of the >30 cm water depth zone, which consequently favours the habitat use of sample wetlands by the Egret-Rail guild. In addition, the abundant precipitation benefits the growth of vegetation and results in an increase in the height and cover of vegetation. This promotes the habitat use of sample wetlands by the Duck guild, but discourages the Wader-Tern guild, which appears to prefer open areas (del Hoyo *et al.*, 1996).

In general, the Wader-Tern guild displayed a less specific correlation between its

habitat use and the environmental features of sample wetlands, amongst both individual wetland types, abandonment age classes and the collective sample wetlands (Table5.4). This might result from the extremely wide spectrum of habitat niches within this group of birds (del Hoyo *et al.*, 1996), and some wader species could shift between several food sources (Goss-Custard, 1970), and thus no particular environmental attributes showed a strong association with this guild. This finding could explain why the habitat utilization of wetlands by waders is not strongly associated with a particular characteristic variable of sample wetlands in this study. In addition, several authors reported a similar observation that waders were less confined to a particular wetland type during winter (most waders in the study area were wintering species) when food resources were most abundant (Withers & Chapman, 1993; del Hoyo *et al.*, 1996). Consequently, if the aim was to manage a wetland to protect the Wader-Tern guild, it would not be necessary to meet so many habitat requirements. Therefore, this guild is a better target group for conservation if the time and funds available for a wetland restoration scheme are limited.

The habitat selection of the Egret-Rail guild was positively associated with the extent of the >30cm water depth zone. In contrast, the extent of the shallower, the 5-10cm water depth zone, basin area and the extent of the exposed mudflats showed negative correlations (Figure 5.2 and Table 5.5). This suggests that the wetlands with deeper water bodies might attract more egrets and rails. Most egret species feed on small fish and shrimps (Cramp & Simmons, 1980; del Hoyo *et al.*, 1992). From the observations made in this study, they normally waded in the surrounding shallow water of a pond to catch their prey. When the depth of the whole water body drops below 30cm, most egret species, especially the most abundant species *Egretta garzetta,* can wade throughout the whole water body. The consumption of fish and shrimps then would be much easier and would therefore dramatically increase. This would consequently deplete food resources in the ponds within several days to a week. Such a situation was observed on several occasions in this study when restrictions such as a water depth too high to allow foraging, were removed. The ponds' managers in the study area installed nets to cover the surrounding shallow water bodies to prevent the forging of egret species, especially when the species under cultivation in their ponds were still rather small and vulnerable to the foraging of egrets (personal communication with the ponds' mangers in the study area). Several

authors reported similar observations, which showed that the presence of numerous shorebirds had caused a prey depletion (Goss-Custard, 1977[2]; Schneider and Harrington, 1981; Quammen, 1984). According to a study conducted by Yang (1997), a 10ha fish pond can be depleted in approximately one week. After the depletion of the food resources in a particular pond, only a few egret individuals will be found there. This means that the opportunity to record egret individuals is relatively low after food depletion in these shallower ponds. In contrast, due to the difficulty of catching fish and shrimps in a water body at a depth of over 30cm, egrets will repeatedly visit to try foraging even though their foraging success is comparatively low. In the long run, the opportunity to record egrets in a pond with a depth of over 30cm is higher than in shallower ponds. In summary, it is shallow water, not deep water, that attracts egrets and rails. This suggests that shallow habitats should be provided by conservation site managers to increase the abundance of egrets. Before the depletion of prey occurred, deep water (over 30cm) should be restored to permit the accumulation of prey abundance. The ponds at a conservation site can be separated into several independent feeding units, and their depths should be drawn down and elevated alternately (Rundle & Fredrickson, 1981; Kushlan, 1986; Breininger & Rebecca, 1990; Rehfisch, 1994; Self *et al.*, 1994; Ashkenazi & Dimentman, 1998). Future studies are required to discover the optimal timing for water drawdown and the duration of the subsequent prey accumulation phase.

Vegetation, which normally provides food as well as shelter for both adults and the broods of waterbirds, was reported as an environmental variable possibly associated with the habitat utilization of wetlands by the Duck guild (Johnsgard, 1956; Kadlec, 1962; Murkin *et al.*, 1982; Kaminski & Prince, 1984). According to Figures 5.2, 5.6, 5.8, 5.11, 5.12, 5.13 and Table 5.5, however, only submerged vegetation showed a positive association with the habitat selection of the Duck guild in this study. The ducks in the sample wetlands were mostly dabbling species and mainly fed on macrophytes in shallow water. In this case, submerged vegetation might mean food resources to these dabblers, and this suggests that food supply could be the most important role of vegetation in determining the habitat selection of the Duck guild in the study area. Management to permit the revegetation of macrophytes is recommended if ducks are the target group of species for conservation.

Other than vegetation, several studies have reported that water depth was an essential factor to determine the habitat utilization of wetlands by ducks (Phillips, 1991; Dehorther & Tamisier, 1996). Similar observations were obtained in this study, which showed that the extent of the 20-30cm water depth zone had a positive association with the habitat selection of this guild (Figure 5.11 and Table 5.5). Abundant macrophytes and high accessibility to this food resource in the 20-30cm water depth zone could result in the strong association between the habitat selection of waterfowl and this water depth zone in this study. Gopal (1995) described similar habitat requirements for these dabblers which showed that the optimal feeding depth for dabbling ducks was ten or fewer inches (maximum 25cm) and stated that food accessibility could be a key factor in the selection of wetlands by waterfowl. Gopal's conclusion is similar to that obtained in this study.

Apart from vegetation and water depth, human disturbance might also play a crucial role in determining the habitat selection of duck species. The ordination showed a strong positive association between the habitat use of wetlands by ducks and disturbance-related attributes, including abandonment time, the proportion of surrounding ponds that are abandoned, the mean height of the dominant species of wall vegetation and the distance to human habitation or main roads (Figures 5.2, 5.6, 5.8, 5.11, 5.12, 5.13 and Table 5.5). Longer abandonment time is normally associated with a lesser degree of human disturbance. The higher percentage in the proportion of surrounding ponds that are abandoned, means that more temporarily abandoned ponds occurred around a particular pond and therefore indicates fewer opportunities for human disturbance. The taller wall vegetation indicates that little surrounding disturbance occurred at these ponds. The farther from human habitation or main roads, the less likely it will be that a pond is subjected to human disturbance. In other words, human disturbance might be a decisive factor in the habitat use of sample wetlands by ducks. Similar statements which emphasize the considerable influence of human disturbance upon food accessibility to waterfowl have been reported (Mayhew & Houston, 1989; Mitchell, 1992; Gopal, 1995). This might suggest that a disturbance-free buffer zone or any management measures to keep disturbance away from waterfowl are necessary at a conservation site.

In summary, site managers should provide the following to attract waterfowl, a

wetland with only slight extent of disturbance of any kind and a large area of the 20-30cm water depth zone in which abundant submerged macrophytes thrive.

7.4. Water level manipulation experiment

Water level was reported as having considerable influences on the habitat selection of waterbirds by many authors (Kadlec, 1962; Rundle & Fredrickson, 1981; Breininger & Rebecca, 1990; Phillips, 1991; Mitchell, 1992; Furness & Greenwood, 1993; Green & Robins, 1993; O'Brien & Self, 1994; Rehfisch, 1994; Self *et al.*, 1994; Tyler, 1994; Boettcher & Haig, 1995; Dehorther & Tamisier, 1996; Weber & Haig, 1996; Safran *et al.*, 1997; Vickery *et al.*, 1997; Ashkenazi & Dimentman, 1998). According to the results of chapter 6, water depth was very likely to be one of the key environmental attributes to determine the habitat use of abandoned aquaculture ponds by waterbirds. However, the manipulation experiment in this study only proceeded for 15 days with three manipulated ponds. Detailed and well-controlled manipulation experiments should be conducted to obtain a solid conclusion in the future.

Most species benefited from a drop in the water level. Amongst these species, *Anas crecca* (gradient coefficient: –15.6 for pair 3 manipulated ponds, Figure 6.37) benefited most from the drawdown of water level. Egret species such as *Egretta garzetta* (gradient coefficient: –1.34 for pair 3 manipulated ponds, Figure 6.39) and *Egretta intermedia* (gradient coefficient: –1.43 for pair 3 manipulated ponds, Figure 6.38) as well as many shore bird species, also benefited. A drop in the water level might greatly increase the accessibility to food resources in the manipulated ponds and may consequently attract many waterbirds (Rehfisch, 1994; Safran *et al.*, 1997). However, this substantial increase in the occurrence of waterbirds might be a short-term phenomenon. The long-term drawdown of water level in a pond is very likely to cause the loss of macrophytes and other prey species for waterbirds. A recovery stage with deep-water flooding might be needed after a period of drawdown of water level. However, a long-term water drawdown could be applied whenever a densely-grown macrophyte community needs to be revitalized. The decaying marcrophytes can fertilize the ponds' beds, and contribute to a thriving invertebrate fauna which consequently can be used by waterbirds.

Water depth has diverse effects on the habitat selection of waterbird species of

different body sizes. Ten centimetres water depth is relatively shallow for large-sized species such as Great egret, but deep for a small-sized species such as Kentish Plover. Biological restriction could play an essential role in determining the optimal feeding depth of waterbirds. As seen in the results in section 6.5.5, anatomical feeding depth appears to have a greater influence on the habitat selection within sample wetlands by waterbirds than absolute feeding depth (Figures 6.43 and 6.44). Similar observation has been reported by Safran *et al.* (1997). They note that the responses of waterbird species to fluctuations in the water level could largely be attributed to their body size. Small waterbird species tend to be more sensitive to the fluctuations in the water level. This means that biological restrictions could play an important role in the habitat selection of waterbirds. In other words, there is possibly an optimal anatomical feeding depth, but not an optimal absolute feeding depth, for harbouring a group of waterbird species of a diverse body sizes. A pond designed to protect species of a range of body sizes will require a variety of depths to simultaneously match their needs. Alternatively, the water could be kept deep to breed potential food species, then drawn down to make food accessible. A series of ponds with staggered water drawdown could support a maximum of waterbirds.

Other than biological restrictions, the method of obtaining food could also influence a species' preferred feeding depth. *Charadrius alexandrinus*, *Charadrius dubius* and *Calidris ruficollis* mainly look for their prey in earth, sand or mud (Cramp & Simmons, 1983; del Hoyo *et al.*, 1996). Their preferred feeding areas should therefore be on bare mud or in rather shallow water. This inference corresponds to the observations made in this study regarding the preferred feeding depth of these species (*Charadrius alexandrinus*, Figure 6.48; *Charadrius dubius*, Figure 6.49; *Calidris ruficollis*, Figure 6.50). *Himantopus himantopus* principally uses vision to forage when wading (Cramp & Simmons, 1983; del Hoyo *et al.*, 1996) and in this study it showed the greatest abundance at a depth of 6-8cm at which it can easily wade and forage (Figure 6.45). *Tringa glareola* and *Tringa totanus* search for prey underwater using tactile methods (Cramp & Simmons, 1983; del Hoyo *et al.*, 1996). In this study, these species showed a preference for a 6-7cm depth or an anatomical feeding depth of 0-2cm below the knee (*Tringa glareola*, Figure 6.47; *Tringa totanus*, Figure 6.52). This finding conforms to their favourite method of obtaining food. Similar conclusions could be drawn for *Anas crecca*. *Anas crecca* preferred a depth

of 10cm (Figure 6.51) and generally dabbles at the bottom of a shallow pond to find its prey by touch (Cramp & Simmons, 1977; del Hoyo *et al.*, 1996). In short, the foraging techniques of waterbirds may have a strong influence on determining their optimal feeding depths. In order to fit the individually foraging requirements for each waterbird species, detailed studies pertaining to the relationship between the method of obtaining food and the optimal feeding depth for every individual waterbird species will be necessary.

Concluding remarks

Time-related factors appear to have relatively little influence on the chronological changes either in the physical attributes or in the habitat use of temporarily abandoned aquaculture ponds by waterbirds. Only the annual changes in the habitat use of temporarily abandoned aquaculture ponds by waterbirds showed a strong seasonality. Three guilds of waterbirds, namely the Egret-Rail, Wader-Tern and Duck guilds, can be separated by their habitat requirements. Water depth and vegetation-related attributes could be the most decisive factors that influence the habitat use of temporarily abandoned ponds by these three guilds of waterbirds.

7.5. Future studies

In the real world, managers need to consider a multiplicity of potentially interacting factors. The advantage of this research is that it attempts to consider simultaneously all major factors, rather than to concentrate on a single factor. The data obtained from this study could help to narrow down the potentially related environmental attributes of temporarily abandoned ponds related to habitat utilization by waterbirds. This study also simultaneously covered a variety of wetland types and compared the way in which waterbirds made use of them. There were, however, a number of limitations this study. The sample wetlands were spread throughout a great diversity of environments, so that no two wetlands were identical. This limits the grouping of and comparison between sample wetlands. Four recommendations for future studies are given to remedy the deficiency in the interpretation ability of the data in this study.

More proportionate samples in saltpan, natural wetland and other wetland types: Several wader species such as *Tringa glareola*, duck species such as *Anas poecilorhyncha* and egret species such as *Egretta garzetta*, also occurred in rice paddies,

which are numerous in the study area. The comparison of the habitat selection of waterbirds between wetland types would be more comprehensive if rice paddies were to be sampled. Future studies should also proportionately sample these artificial wetland types. These wetland types should at least include actively managed ponds, temporarily abandoned ponds, saltpans, natural wetlands and rice paddies, and should be sampled in a more or less similar proportion for each wetland type.

More studies on feeding ecology: Many authors suggested that food resources play an essential role in the habitat utilization of wetlands by waterbirds (Bengtson & Svensson, 1968; Goss-Custard, 1977[1]; O'Connor & Brown, 1977; Joyner, 1980; O'connor, 1981; Bailey & Titman, 1984; Hicklin & Smith, 1984; Pehrsson, 1984[2]; Vaneerden, 1984; Tome, 1988; Kelsey & Hassall, 1989; Wilson, 1990; Euliss & Jarvis, 1991; Goss-custard *et al.*, 1991; Phillips, 1991; Alerstam *et al.*, 1992; Hockey *et al.*, 1992; Colwell & Landrum, 1993; Sutherland & Anderson, 1993; Kalejta & Hockey, 1994; Michot & Chadwick, 1994; Rehfisch, 1994; del Hoyo *et al.*, 1996; Percival *et al.*, 1996; Safran *et al.*, 1997). The studies related to food resources are effective and useful in that they reveal direct supportive evidence to expand the understanding of the habitat use of wetlands by waterbirds. However, since considerable taxonomic knowledge is necessary to conduct this kind of study, relatively little effort had been allocated to record the information pertaining to feeding ecology of waterbirds in this study. These studies should include a detailed observation regarding the relationship between the population dynamics of waterbirds and their principal prey. In addition, day-energy expenditure for each waterbird species is suggested to be conducted as well. This kind of studies could help to determine the diverse energy use for each species, and take account of the effect coming from the various body sizes of waterbird species.

More studies in habitat restoration, manipulation of key factors and the influence of reclamation on the habitat use of aquaculture ponds by waterbirds: The 1990s were a time of turmoil in Taiwan aquaculture industry, and many aquaculture ponds were reclaimed for rice plantations, industry parks, recreation parks or other relatively intensive land uses. Many large-scale reclamation projects of wetlands in the coastal townships of Taiwan were proposed and several are likely to be undertaken in the near future (SIECLC, 1995). These diverse land uses resulted in varying degrees of

habitat degradation. Further studies are necessary to assess the degradation of aquaculture ponds by these reclamation projects if a mosaic of wetlands are to be integrated for the conservation of waterbirds. It is also necessary to determine the degree to which the ecological functions of aquaculture ponds, defined as the ability to provide shelter, food and roosting sites for waterbirds, are altered when a particular type of reclamation has been executed. This information will help to generate an understanding of which land use is acceptable within a proposed or existing waterbird sanctuary and what proportion of various land uses are adequate to provide sufficient ecological functions for waterbirds. Land with unacceptable types of reclamation should be restored to a better habitat quality such as that of natural wetlands. In order to increase the success rate of a habitat restoration scheme, the studies pertaining to the habitat restoration and manipulation of key factors, which were identified through the data analyses in chapter 5, should be encouraged.

Long-term and periodic studies for chronological changes in the physical attributes and habitat use of temporarily abandoned ponds by waterbirds: In this study, sample ponds with differing abandonment times were selected to determine the chronosequence of physical attributes and habitat use of temporarily abandoned ponds by waterbirds. Possibly, sample ponds are composed of several distinct types of wetlands, consequently no obvious trend was recognized. To reduce the influence of the individual differences in wetland characteristics between sample ponds on the chronosequence, continuous and periodic observations of three to five years are recommended. Since the same sample ponds will be used to determine the chronosequence throughout the long-term observations, the influences of the variations between sample ponds on their habitat use would be eliminated. These selected ponds should cover the entire spectrum of subtypes of temporarily abandoned aquaculture ponds.

Chapter 8

Monitoring guidelines for temporarily abandoned aquaculture ponds

8.1. Introduction

Monitoring is a crucial part of a management plan; it can help to assess the effectiveness of management activities and provide updated information regarding the environmental status of the wetlands under management (Brooks, 1990). This can therefore help to ensure the integrity of these sites and thus provide suitable wetlands for waterbirds and other biota (Goldsmith, 1993). Despite its importance, no standard monitoring procedure or methodology has been developed for wetlands, perhaps because there is often the marked influence of local variations on the monitoring activities. However, the methods for collecting baseline data are relatively similar for all wetland types. In general, the less time required for data collection, the better (Gopal, 1995).

According to Hellawell's strict definition, the replicated investigations of bird populations and their habitats do not necessarily qualify as monitoring. Monitoring schemes must have three components: clear objectives, precise procedures and a set of criteria to determine when to stop monitoring activities (Hellawell, 1991). In this chapter, these three crucial components for a model monitoring scheme are discussed. In addition, other parts of the monitoring scheme are also discussed, including conservation priorities, the recommended wetland characteristics for investigation, the species excluded from the proposed monitoring scheme, alternatives to the monitoring scheme, manpower, cost and administration issues (Goldsmith, 1991). The ideal pond conditions for the three principal waterbird guilds of temporarily abandoned ponds are also outlined.

8.2. Purpose

A monitoring scheme will be most effective and efficient if it has a clearly stated targets. This is particularly important in conservation due to often inadequate financial support from both governmental and private sectors. There are three principal targets in the monitoring schemes for temporarily abandoned ponds within protected areas. Firstly, the detection of natural or artificial deterioration such as a decline of waterbird population caused by global climate change, is a fundamental function of monitoring. Monitoring activities can provide updated information on the environmental state of protected wetlands so that site managers can rapidly

respond by removing the factors which caused the degradation or minimize the impacts on waterbirds by adjusting their management measures. In addition, as a result of international legislation, governmental obligations in Taiwan are aiming to maintain important waterbird populations although Taiwan is not a signatory of most international conservation agreements. These monitoring activities could help to update the population status of the international important waterbird species to conservation authorities. The second crucial target for a wetland monitoring scheme is the assessment and evaluation of the consequences and effects of management measures on the protected waterbirds and their habitats. This could be the most important goal of monitoring schemes. Eventually, temporarily abandoned ponds may be restored to as natural a state as possible. The management of abandoned ponds that are being restored may be constantly adjusted in response to the waterbirds' reactions to management activities (Holling, 1978). Thirdly, monitoring can also provide up-to-date information of selected waterbird species, mainly rare or flagship species, which can then be used to inform and educate the public (Simberloff, 1998). This third target is particularly important when an existing sanctuary would benefit from more support from the public. According to a report by MacKinnon *et al.* (1986), it is recommended that three characteristic attributes of waterbirds are recorded within a monitoring scheme: 1) trends in population numbers; 2) trends in reproductive success or productivity; 3) condition or quality of waterbird species. These records are likely to provide useful information on the short-term success of management such as an increase in the population of waterbirds, as well as the long-term success such as the birds' reproductive success.

8.3. Establishment of a baseline database

Before executing a monitoring scheme in target wetlands, a baseline database is required. This database can facilitate future comparisons and should be as broad as possible, including various categories of the physical attributes of wetlands. Most environmental variables display a strong seasonality and should be periodically sampled for at least three to five years to cover their complete cycle. However, the ideal situation where a sufficient baseline database was available before the commencement of a monitoring scheme will rarely occur in most monitoring schemes. Alternatively, the collection of baseline information, which could be conducted in the

surrounding habitats similar to the target wetlands, and the execution of the recommended monitoring scheme could occur at the same time. In all sample temporarily abandoned aquaculture ponds, this baseline information should include hydrology, water quality, flora and abundance of vegetation, fauna and abundance of invertebrates, vertebrate fauna, sediments, abandonment history, history before abandonment (cultivated species, pesticides and additives), wetland density, disturbance, population dynamics of waterbirds and other biota and other related information. This database should be enhanced by the accumulation of data from similar, surrounding habitats for at least 10 years.

8.4. Monitoring procedures

8.4.1. Selection of sample ponds

A monitoring scheme should survey several ponds, which are randomly selected from the ponds, within a conservation site. These sample ponds should cover the entire spectrum of wetland types with at least one repetition for each wetland type. Having multiple sample ponds can avoid bias due to an unusual pond of a particular wetland type on the database. When an unusual pond is accidentally sampled, the measurements of environmental variables in the two replicate sample ponds will show exceptional differences, in which case two replacement ponds should be selected. The data collected from these four sample ponds (two old ponds and two new ponds) will be compared in order to identify the typical pond of that particular wetland type. Other than the aforementioned sample ponds, two to three surrounding ponds outside a conservation site should additionally be sampled. These surrounding ponds, which can be viewed as reference wetlands, should be selected from the representative wetland types without repetition and can allow further comparisons to be made.

8.4.2. Wetland characteristics and priorities for monitoring

In general, the recommended parameters for monitoring wetlands are principally based on the ordination analyses in chapter 5 and the experimental results in chapter 6. They are similar for each of the waterbird guilds in the temporarily abandoned ponds. However, the monitoring priorities differ between guilds (Table 8.1). The physical parameters of wetlands for monitoring can be classified into two categories according to their importance: essential parameters and optional parameters. Essential

parameters should be monitored in detail and as frequently as manpower and funding permit. In contrast, optional parameters should only be investigated when further detailed information is required and when manpower and funding are abundant. These parameters are discussed separately for each of the three principal waterbird guilds.

Table 8.1. The parameters for monitoring and their recommended sampling frequencies, listed in order of priority and the three principal waterbird guilds occurred at the aquaculture ponds.

Parameters for monitoring /Guild	Egret-Rail	Sampling frequency	Duck	Sampling frequency	Wader-Tern	Sampling frequency
Essential parameters						
First priority	1.Community structure of waterbirds	**Biweekly**	1.Community structure of waterbirds	**Biweekly**	1.Community structure of waterbirds	**Biweekly**
	2.Abundance of each waterbird species	**Biweekly**	2.Abundance of each waterbird species	**Biweekly**	2.Abundance of each waterbird species	**Biweekly**
	3. Recruitment success of waterbirds	**Biweekly**	3. Recruitment success of waterbirds	**Biweekly**	3. Recruitment success of waterbirds	**Biweekly**
	4.Water level	**Weekly**	4.Disturbance-related parameters	**Whenever they occur**	4. Abundance of principal prey species for this guild	**Weekly**
	5. Abundance of principal prey species for this guild	**Weekly**	5.Cover of submerged vegetation	**Biweekly**	5.Salinity	**Biweekly**
	6.Extent of exposed mudflats	**Weekly**	6.Water level	**Weekly**	6.Water level	**Weekly**
	7.Aquaculture practices in surrounding wetlands	**Whenever they occur**			7.Cover and height of total vegetation	**Biweekly**
					8.Extent of exposed mudflats	**Weekly**
Second Priority	1.Cover and height of shore vegetation	**Biweekly**	1. Area covered by open water	**Weekly**	1.Other hydrology related attributes	**Weekly and whenever they need**
			2.Cover and height of shore vegetation	**Biweekly**	2.Cover and height of shore vegetation	**Biweekly**
Optional parameters	1.Cover of submerged vegetation	**Monthly**	1.Cover and height of emergent vegetation	**Weekly**	1.Sediment-related variables	**Monthly**
	2.Cover and height of emergent vegetation	**Weekly**				

The Egret-Rail guild

Essential parameters

First priority:

Community structure of waterbirds and the abundance of each waterbird species: There are two principal components in the community structure, species richness and species composition of the Egret-Rail guild. Firstly, biweekly investigations should be conducted for every selected pond. This investigation should be performed twice per day, in the early morning and late evening, but only the records with the higher species richness and the higher abundance of a particular species should be used. In all sample species composition, the morning and evening records are combined as a single record. The philosophy behind the investigation of these three parameters is to sample at the time with the highest species richness, the abundance of a particular species and the most diverse species composition. A biweekly investigation should be sufficient to sample most short-stay species, namely passage migrant species that normally stay at least two weeks. However, sampling frequency should be increased immediately after any management practice such as water level manipulation, and anthropogenic disturbance such as hunting, due to the rapid response of waterbirds to these changes (Gopal, 1995). These three variables can help site managers to identify any changes in the waterbird community structure and the population dynamics of the birds.

Recruitment success of waterbirds: Reproductive success may be viewed as a long-term use of habitats by wildlife and a measure of the success of habitat management.

Water level: Water level displays a strong association with the habitat selection of this guild (Table 5.5, Figure 5.2, 5.6, 5.8 and 5.13). Two to four water-level measurement rulers with calibration should be installed within each sample pond. Depth measurements should be recorded weekly. Generally, the drying-out of aquaculture ponds is predictable if no artificial or natural water input occurs, therefore weekly records should be sufficient to monitor this attribute (Figure 2.7).

The abundance of the principal prey species for this guild: Food resources frequently play a decisive role in the habitat selection of waterbirds (Wolff, 1969; Bryant, 1979; Drent & Daan, 1980; Evans & Dugan, 1984; Puttick, 1984). Despite its importance, the considerable work-load for data collection and considerable taxonomic skill for prey identification has discouraged research into the guild's food resources.

The extent of the exposed mudflats: The extent of the exposed mudflats displayed a negative association with the habitat selection of this guild (Table 5.5, Figures 5.2, 5.6 and 5.8). This means that the larger the extent of the exposed mudflats, the less attractive the wetland to the Egret-Rail guild. Due to the normally strong evaporation in southwestern Taiwan, weekly investigation is required to sufficiently monitor this parameter.

Aquacultural practices in surrounding wetlands: As discussed in chapter 6, the number of egrets, *Egreta garzetta* in particular, showed a dramatic increase with a drop in the water level (Figures 6.22, 6.23, 6.27, 6.28 and 6.36). Aquacultural practices have a strong influence on the habitat utilization of aquaculture ponds by this guild. The start and end date of practices should be noted. In addition, a descriptive record of aquacultural practices should be kept, including the area it affects, the degree of influence it has on the ponds and its intensity and frequency. Aquacultural practices in surrounding ponds frequently have a strong influence on the habitat use of the unaffected pond by this guild. The Egret-Rail guild appears to be able to exploit a large area and is very likely to be influenced by any activity including these aquacultural practices.

Second Priority:

Cover and height of shore vegetation: Cover and height of shore vegetation displays a positive association with the habitat use of aquaculture ponds by the Egret-Rail guild (Table 5.5, Figure 5.11 and 5.13). According to Figure 2.13, the 15-day-interval measurements of shore vegetation in this study displayed a steady trend throughout the year and can be monitored sufficiently at a

two-week interval.

Optional parameters

Cover of submerged vegetation: The cover of submerged vegetation displayed a negative association with the habitat use of aquaculture ponds by the Egret-Rail guild (Table 5.5 and Figure 5.12). Submerged vegetation might reduce the detectability of prey species and therefore discourage members of this guild from visiting wetlands with a high cover of submerged vegetation. Since it is necessary to wade into the water body of sample ponds to gain a precise estimate of this attribute, this can cause disturbance to waterbirds. Monthly estimations may therefore be more appropriate to monitor this parameter.

Cover and height of emergent vegetation: The cover of emergent vegetation displays a positive association with the habitat use of aquaculture ponds by the Egret-Rail guild (Table 5.5 and Figure 5.12). According to Figure 2.14, the 15-day-interval measurements of emergent vegetation in this study displayed a dynamic fluctuation throughout the year and therefore should be monitored at a shorter interval than two weeks. A one-week interval should be sufficient to sample this parameter.

The Duck guild

Essential parameters

First priority:

Community structure of waterbirds and the abundance of each waterbird species: This parameter should be monitored as for the Egret-Rail guild.

Recruitment success of waterbirds: This parameter should be monitored as for the Egret-Rail guild.

Disturbance-related parameters: Human disturbance could directly influence the habitat selection of waterfowl (Table 5.5, Figures 5.2, 5.6, 5.8 and 5.13). Furthermore, strong human disturbance could greatly influence the habitat utilization of aquaculture ponds by duck species.

Cover of submerged vegetation: The cover of submerged vegetation showed a positive association with the habitat use of aquaculture ponds by the Duck guild (Table 5.5 and Figure 5.2). Submerged vegetation could be the main food resource for this guild and should be sampled at an interval of two weeks or more. However the investigation of submerged vegetation could result in a serious disturbance to this guild and must be conducted with great caution. An elevated structure such as temporary towers or earth mound would greatly facilitate estimation of cover of submerged vegetation.

Water level: This parameter should be monitored as for the Egret-Rail guild.

Second Priority:

The area covered by open water: This parameter displayed a negative association with the habitat selection of the Duck guild (Table 5.5 and Figure 5.2). This means that a large area covered by open water might be less attractive to this guild. Due to the often strong evaporation in southwestern Taiwan, weekly investigation is required to sufficiently monitor this parameter.

Cover and height of shore vegetation: Shore vegetation could provide shelter for the resting birds of this guild when its cover is of moderate height. However, dense shore vegetation could reduce the detectability of predators and could decrease the attractiveness of aquaculture ponds to this guild. In southwestern Taiwan, natural predators of waterfowl are scarce. Wild dogs and people are possibly the main threats. According to Figure 2.13, the 15-day-interval measurements of shore vegetation in this study displayed a steady trend throughout the year and can therefore be sufficiently monitored at a two-week interval.

Optional parameters

Cover and height of emergent vegetation: This parameter should be monitored as for the Egret-Rail guild.

The Wader-Tern guild

Essential parameters

First priority:

Community structure of waterbirds and the abundance of each waterbird species: These parameters should be monitored as for the Egret-Rail guild.

Recruitment success of waterbirds: These parameters should be monitored as for the Egret-Rail guild.

The abundance of principal prey species for this guild: This parameter should be monitored as for the Egret-Rail guild. The prey species for this guild primarily include organisms like zooplankton, Polychaetes and Amphipods (Cramp & Simmons, 1983).

Salinity: Salinity displayed a positive association with the habitat use of aquaculture ponds by the Wader-Tern guild (Table 5.5, Figures 5.2 and 5.12). According to the 15-day-interval and monthly measurements of salinity in this study, illustrated in Figure 2.4, the 15-day-interval changes in this attribute were relatively stable when no extreme meteorological events such as typhoons or heavy rain, occurred. Biweekly sampling should be sufficient to monitor the temporal change of this parameter.

Water level: This parameter should be monitored as for the Egret-Rail guild.

Cover and height of total vegetation: Vegetation showed a negative association with the habitat use of aquaculture ponds by the Wader-Tern guild (Table 5.5, Figures 5.2 and 5.8). Waders and terns appeared to prefer open areas and were discouraged by dense vegetation. In other words, sparsely vegetated aquaculture ponds appear to attract more waders and terns. According to Figure 2.12, the 15-day-interval measurements showed that total vegetation cover in this study is rather constant throughout the year and can be sufficiently monitored at a two-week interval.

The extent of exposed the mudflats: According to Table 5.5 and Figure 5.8, the

extent of the exposed mudflats showed a positive association with the habitat use of aquaculture ponds by the Wader-Tern guild. Due to the often strong evaporation in southwestern Taiwan, weekly investigation is required to sufficiently monitor this parameter.

Second Priority:

Other Hydrology related attributes: Waders normally feed on invertebrates during the winter on coastal tidal mudflats. In artificial wetlands, water input, from tides in particular, can bring in these prey species and the nutrients they needed. Discharge of water, especially tidal water and some hydrological events such as flooding, could be an important factor in the habitat selection of waders (Gopal, 1995).

Cover and height of shore vegetation: This parameter showed a negative association with the presence of the Wader-Tern guild (Table 5.5, Figures 5.11 and 5.13). This might indicate that shore vegetation could reduce the detectability of predators by the waterbirds. This parameter should be monitored as for the Egret-Rail guild. According to Figure 2.13, the 15-day-interval measurements of shore vegetation in this study displayed a steady trend throughout the year and can be sufficiently monitored at a two-week interval.

Optional parameters

Sediment-related variables: The microenvironment of aquaculture ponds, especially their sediments, might have a strong influence on the abundance of invertebrates. Because data collection is labour intensive, monthly measurements should be an adequate frequency for monitoring.

8.4.3. Sampling methods

Community structure of waterbirds and the abundance of each waterbird species: This parameter should be sampled biweekly. Other sampling is the same as in section 4.2.2. in chapter 4 (page 139).

Recruitment success of waterbirds: The measures that should be recorded include the number of breeding pairs and nests in use, clutch size and the

number of young. A distribution map of nests is also recommended to permit detailed comparisons. These parameters should be recorded biweekly when the investigation of community structure and the abundance of waterbirds is conducted. During the breeding season the investigation frequency should be increased to a weekly basis. Recorders should be especially cautious to avoid any disturbance to the breeding waterbirds.

The abundance of the principal prey species for this guild: This parameter should be sampled on a weekly basis if manpower and funding are available. Weekly recordings are sufficient to sample the population dynamics of prey species, which are normally small fish or large invertebrates. During a season with the highest abundance, sampling frequency should be even twice a week.

Water level: This parameter should be sampled weekly. Other sampling methodology is the same as in section 2.2.2. in chapter 2 (page 46).

Other Hydrology related attributes: The volume and quality of input and output of water, and the duration and frequency of flooding might all contribute to the abundance and accessibility to food resources and therefore should be monitored periodically. The input and output of water should be monitored weekly whilst flooding events should be recorded whenever they occur.

The extent of the exposed mudflats: This parameter should be sampled weekly. Other sampling methodology is the same as in section 2.2.2. in chapter 2 (page 46).

The area covered by open water: This parameter should be sampled weekly. Other sampling methodology is the same as in section 2.2.2. in chapter 2 (page 46).

Cover and height of total and shore vegetation: This parameter should be sampled biweekly. Other sampling methodology is the same as in section 2.2.2. in chapter 2 (page 46).

Cover and height of emergent vegetation: This parameter should be sampled weekly. Other sampling methodology is the same as in section 2.2.2. in chapter 2 (page 46).

Cover and height of submerged vegetation: This parameter should be sampled

monthly. Other sampling methodology is the same as in section 2.2.2. in chapter 2 (page 46).

Aquacultural practices in surrounding wetlands: Any new aquacultural practices, especially water drawdown, should be recorded. However, regular baiting and other trivial practices are not necessary to be recorded.

Disturbance-related parameters: The duration of these parameters and the degree of influence on the habitat use of aquaculture ponds by this guild should be monitored whenever they occur. These disturbance might be brought about by the following causes: i) resource exploitation activities based on fish, shrimps or algae; ii) bird hunting; iii) water-based recreational activities such as fishing, flying light aircrafts or boating; iv) traffic on nearby roads or highways; v) ecotourism such as bird watching. The harvest of fish, shrimps or algae should be closely monitored in terms of frequency, total catch, size of individual fish, changes in the species caught and any variation from the exploitation contract or permission issued by site managers or local authorities (Gopal, 1995).

Salinity: This parameter should be sampled biweekly. Other sampling methodology is the same as in section 2.2.2. in chapter 2 (page 46).

Sediment-related variables: Redox potential, organic matter content and accumulation of phosphorus, pesticides, heavy metals and other toxic substances was recommended by Gopal (1995), and should be sampled monthly. One sample for each pond is suggested.

8.5. Alternatives to the monitoring scheme

In some instances, site managers might not be able to conduct the recommended monitoring scheme due to different conditions. Several alternatives are provided for particular situations. The alteration of the frequency and intensity of monitoring parameters from the original monitoring scheme should be applied when there are specific needs for particular circumstances.

Inadequate financial support: Most conservation sites have inadequate financial support. There is often a shortage of funding to purchase monitoring equipment and computers, as well as for hiring personnel to conduct a monitoring scheme.

Recommendations: A reduction in monitoring frequency, parameters investigated and the number of sample ponds is suggested. The degree of reduction could correspond to the shortfall of funds. The suggestion to reduce investigated parameters is based on the priority stated in the context of the recommended monitoring scheme. Monitoring equipment could perhaps be borrowed from local universities or research institutes.

A Lack of manpower: In Taiwan, most wildlife sanctuaries are owned and managed by conservation authorities with a variety of statutory obligations. The officials in charge of the management of these protected wetlands work mostly on a part-time basis. It is difficult for them to conduct monitoring activities in person.

Recommendations: Contracts to conduct the monitoring schemes can be made with the local conservation organizations, universities or research institutes. The investigated parameters can be assigned to several bodies according to their expertise. These bodies should be organized and coordinated under a monitoring team leader or monitoring board. The officials in charge of the conservation authorities should be involved in every principal stage of the monitoring scheme such as design, enforcement and analysis. However, not every parameter for investigation can be successfully assigned to one organization, or the required intensity or frequency of monitoring may not necessarily be attained by these helping organizations. The officials in charge should record parameters not covered by helping organizations and change the monitoring scheme to a lower frequency and intensity for these parameters. However, it is important that the investigation of any parameter should be recorded using a standard method and the same investigators.

A lack of time: Occasionally, a large-scale development scheme might be proposed in the area surrounding a conservation site. Generally, a certain amount of funding will be assigned to conduct an environmental impact assessment (EIA). In this instance, time could be the most limiting factor for the monitoring scheme.

Recommendations: An increase in the monitoring frequency, the number of sample ponds and parameters recorded is suggested, and the increase should occur in that order. The recommended parameters for all three waterbird guilds should be

investigated. In addition, water quality, including pH, dissolved oxygen and turbidity, could also be investigated. The sample ponds could include several ponds which are situated outside the conservation site but are similar to the principal wetland type of the conservation site.

Specific interests: Some species or parameters of wetlands should be monitored more intensively than miscellaneous species in several instances such as when: 1) a particular conservation site is designated to protect several flagship, rare or ecologically important species; 2) some supporters show a strong interest in certain species (and an intensive monitoring scheme is assigned to these species); 3) some species are reported as keystone species or species with high conservation importance in the literature; 4) some parameters of wetlands are believed to be more important than others by site managers; 5) there is a long history of ecological impacts at the conservation site such as habitat deterioration caused by heavy metal pollution.

Recommendations: Extra investigations of focal species are recommended such as research pertaining to their foraging and reproductive behaviour. In addition, the environmental attributes of aquaculture ponds which have strong associations with these species could be monitored more frequently than the proposed monitoring schemes or new monitoring could be started. Extra sample ponds could be selected to specifically investigate these focal species. The parameters damaged by ecological disasters should be intensively monitored such as the water quality after heavy metal pollution.

8.6. Species excluded from the recommended monitoring scheme

In the current recommended monitoring scheme, only a few parameters were selected for the monitoring of each waterbird guild. Some species might therefore be insufficiently monitored if investigators only use the recommended parameters. These include four types of species and are discussed as follows.

1. **Generalists**: According to the interpretation guidelines for the ordination plot, species that lie close to the origin of the ordination are generalists (Ter Braak, 1994). In other words, these species have no strong association with any of the investigated attributes. Insufficient consideration of these generalist

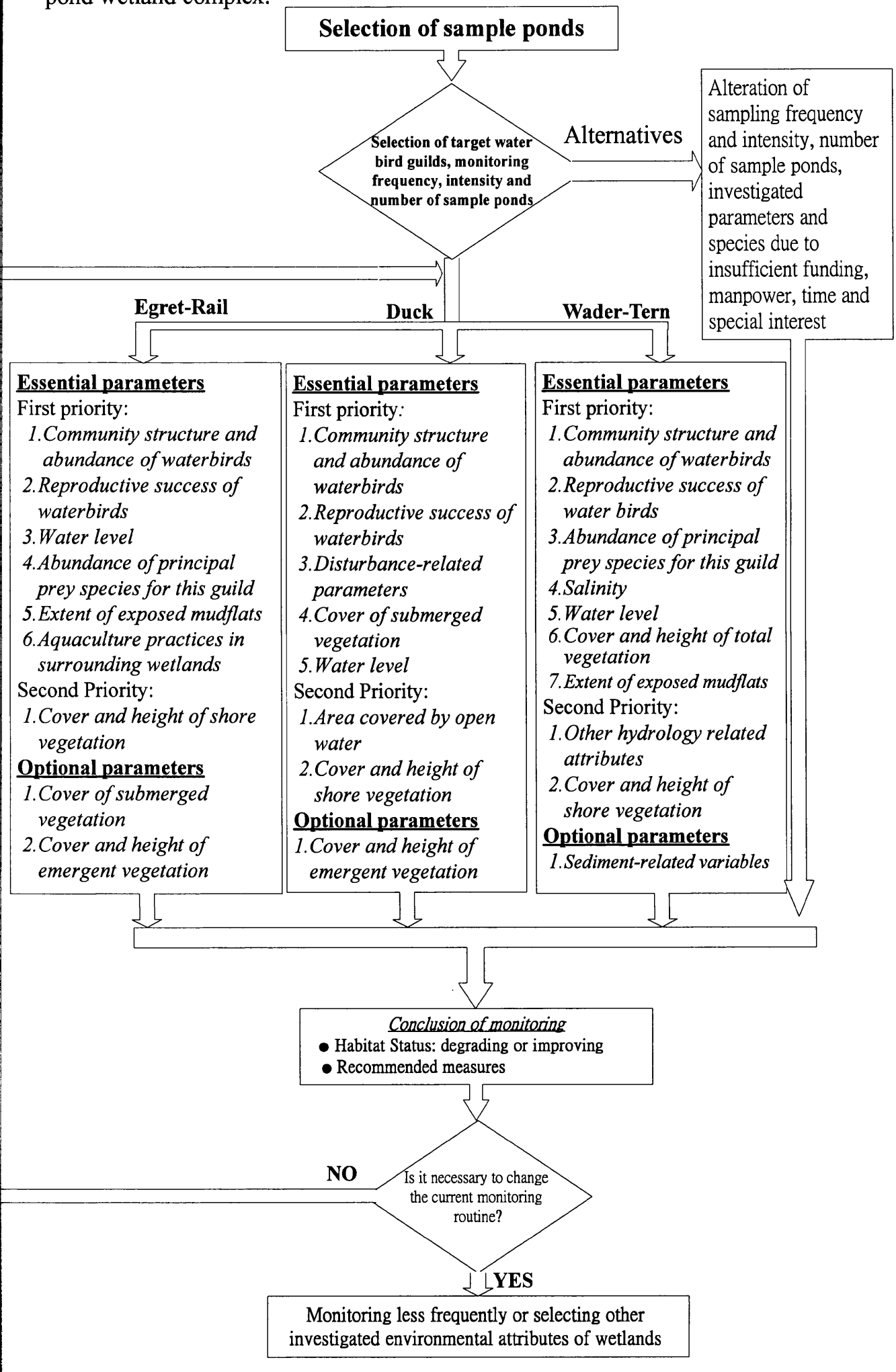
species may occur if the recommended monitoring scheme is conducted. These species include *Egretta garzetta, Anas poecilorhyncha, Egretta alba, Calidris acuminata* and *Tringa ochropus* (Figure 4.1)

2. **Species that lie between guilds**: *Larus saundersi, Phalacrocorax carbo* and *Philomachus pugnax* fall between the principal species assemblies of two guilds (Figure 4.1). Their habitat preferences might be in between these two guilds but not closely associated with either one. They could be inadequately monitored, particularly if only one of these two guilds is selected as a target group of protected species and only one set of recommended parameters is monitored.
3. **Outliers**: Some species such as *Threskiornis aethiopicus*, lie far from the origin of the ordination. These species lie far from any of the main species aggregations and cannot be classified as a member of any of these guilds and so were not considered in this recommended monitoring scheme.
4. **Rare species**: Species with very rare occurrence were excluded from further ordination analyses. Consequently, these species were not considered in this monitoring scheme. They include *Ixobrychus flavicollis, Pandion haliaetus* and *Halcyon pileata,* amongst others.

8.7. Conclusion of monitoring

A conclusion of monitoring report should be produced seasonally (every three months) and annually to report on the habitat status of wetlands (degrading, steady, or upgrading). Management measures to improve the habitat status should be recommended if habitat degradation has occurred (Table 8.2). In addition, a decision should be taken regarding whether a less-frequent monitoring scheme than the adopted one will be adequate.

Table 8.2. Outline of the monitoring procedures for the conservation of an aquaculture pond wetland complex.



8.8. Criteria for Stopping monitoring schemes

Monitoring can easily be conducted for its own sake. The results obtained in each monitoring event can differ from the previous ones. However, monitoring is a labour-intensive and costly activity and cannot be conducted indefinitely without inadequate financial support (Usher, 1991). It is therefore necessary to establish fulfillment criteria. Three targets for the monitoring of aquaculture pond conservation sites were given earlier in this chapter: 1) detection of natural or artificial deterioration in the conservation value of wetlands; 2) assessment and evaluation of the consequences and effects of management measures on the protected waterbirds and their habitats; and 3) updated information to inform and educate the public.

The fulfillment of the first target is unlikely to occur, as site managers must expect some habitat deterioration in the future. However, financial resources are unlikely to be unlimited. Monitoring activities must be terminated or conducted less frequently such as biannually, annually or biennially, than the current recommended monitoring schemes when no obvious habitat deterioration has occurred at the conservation sites. From less-frequent sampling, managers can still diagnose habitat quality from indirect evidence such as the abundance of waterbirds and their prey species, or from direct evidence such as unusual values in the measurements of the wetland characteristics. The abundance of waterbirds appears to be a simpler parameter for investigation and relates directly to the main concerns of site managers.

In all sample, the second target, monitoring activities should be terminated whenever no disturbance or new management measures, restoration activities or manipulation experiments occur at a site. Only when these aforementioned activities occur should monitoring schemes be re-launched.

In order to fulfill the third target, site managers must have a clear picture of the chronological changes in the population dynamics of waterbirds and the wetland characteristics. After five years of continuous monitoring, the pattern of chronological changes should be relatively clear. However, a ten-year monitoring scheme is recommended if the chronological changes of the aforementioned attributes vary considerably.

In summary, a less-frequent monitoring scheme than the recommended plan should be used whenever the three following observations are found at the conservation sites: 1) no perceptible habitat deterioration; 2) no disturbance, new management measures, restoration activities or manipulation experiments, and; 3) sufficient information to describe the patterns in the temporal changes of two groups of parameters, namely the population dynamics of waterbirds and the wetland characteristics.

8.9. Manpower, cost, expertise and administration

Manpower: The following estimation is based on a monitoring scheme for 5-6 sampling ponds with a basin area of less than 2 ha each.

Data collection:	Person- Day /month (p-d/ month)*
Community structure and population dynamics of waterbirds	2 p-d / month
Vegetation-related, hydrological and other environmental parameters of wetlands	1-2 p-d / month
Data entry:	1 p-d / month
Data analysis:	1 p-d / month
	5-6 p-d /month

N.P.: (p-d/ month)*= person per day per month

Cost: The cost of monitoring is calculated using the local standard of living in southwestern Taiwan and was transformed to sterling. The one-year monitoring cost is given. The purchase expenses for equipment which can be used for more than a year is given collectively and separately with other expenses.

		(Currency: Sterling)
for essential parameters:		
Wages	£40 ×(5-6 p-d /month×12 month)	2400-2880/year
Computer and printer		1000
Computer maintenance and consumptive materials		200/year
Salinity meter		300
Current velocity meter (for estimating discharge of input and output of water within a pond)		200
Binoculars		1200
Telescope		500
Tripod		50
Digital camera		200
Stationary		120/Year
Other expenses		200/Year
Subtotal (equipment excluded)		**2920-3400/Year**
Subtotal (equipment included)		**6170-6650/Year**
for essential and optional parameters		
Equipment for sampling invertebrate and piscine fauna		400
Equipment for monitoring sediment-related parameters (e.g. Redox meter)		4000
Extra wages for sample collection and classification	£40 ×(3 p-d /month×12 month)	1440/year
Other expenses		400/year
Total (equipment excluded)		**4760-5240/year**
Total (equipment included)		**12410-12890/year**

Expertise: Several types of knowledge and skills are required to conduct the recommended monitoring schemes for conservation sites with aquaculture ponds.

- ✧ Taxonomy of waterbirds (especially waders, ducks and egrets), common piscine fauna and invertebrate fauna, including Polychaetes, Amphipods and common plankton
- ✧ Skills for sampling and measuring water quality-related variables
- ✧ Skills for sampling fish, invertebrates and plankton
- ✧ Skills for counting waterbirds

Administration: Full time site managers should spare 5-9 person-day per month to conduct monitoring. Alternatively, skilled members of local bird societies could be hired (or asked to volunteer) to conduct the investigation of the community structure

and population dynamics of waterbirds. The same assistant investigator must be available for at least a year to avoid the bias created from individual variations in investigation skills. The investigation of the wetland characteristics and the task of entering data into a database could also be done by temporary staff. These monitoring activities should also be conducted by the same people throughout the project. Full-time site managers or administrative staff should get involved in the design of the monitoring schemes and the process of data collection and data entry, and should conduct data analyses themselves. This would help the site managing body to obtain updated information which would enable them to ensure a rapid response to any habitat change or disturbance.

8.10. Ideal ponds

As discussed in chapter 5, the three principal waterbird guilds of aquaculture ponds have considerably different habitat requirements (Table 5.5). In other words, separate considerations should be taken when different target guilds are selected for particular wetland restoration schemes. According to the results discussed in chapter 5 and 6, the ideal ponds for these three guilds are described separately.

The Egret-Rail guild

A mosaic of actively managed aquaculture ponds, temporarily abandoned aquaculture ponds and natural wetlands is the best habitat for egrets and rails. Actively managed ponds could provide plenty of food resources for a short period of time when they are drained for harvest of cultivated biota (e.g. fish, shrimp and algae), whilst temporarily abandoned ponds and natural wetlands could provide shelter for temporary resting and foraging. The wall vegetation of temporarily abandoned ponds, should be dense and with tall hedge plants for egrets to perch in. Ponds with a large area of less than 20cm water depth and with thriving and tall emergent vegetation are most attractive to egrets and rails.

The Duck guild

Three- to four-year-old, average (approximately 2 ha.) abandoned aquaculture ponds, or a wetland complex of four to ten small-sized (0.2 ~0.5 ha.) abandoned aquaculture ponds could be the ideal roosting wetlands for ducks. The wall vegetation of these

ponds should be dense and tall. At least 50% of shore should consist of exposed mudflats, while a minimum of 20% of the extent of the water body should be the 20-30cm depth zone with thriving algae. This should help to provide food resources for the ducks arriving after a long and exhausting migratory journey. These ponds should be surrounded by an over-500m-wide buffer zone free of people and other disturbance.

The Wader-Tern guild

A large (at least 6 ha.) temporarily abandoned aquaculture pond with constant water input from tidal water and a large extent of the exposed mudflats would be an ideal pond for shore birds and terns. This type of wetland could provide both a roosting habitat and an alternative foraging habitat for the birds. Sparsely distributed vegetation (including shore, wall and emergent vegetation) within these ponds is favoured by this guild. In addition, a large area of the less than 10cm water depth zone is an essential requirement to attract abundant waders. It is also important that the pond is located a short distance to the coast or estuary, which may be the guild's principal foraging habitat. Relatively large, actively managed ponds can provide abundant food for waders when these ponds are drained for harvest. These ponds could serve as temporary foraging habitats and could be depleted in a short period of time.

Chapter 9

Protocol for restoring temporarily abandoned aquaculture ponds for waterbirds

9.1. Introduction

As a consequence of a period of depression in the aquaculture industry in Taiwan, a large number of artificial ponds have been temporarily or permanently abandoned. If some of these ponds were brought under the management of conservation agencies, it could provide a rare opportunity to restore them to a more natural state and thereby compensate for the past loss in the natural wetlands in Taiwan. This excellent opportunity could be used most efficiently if a standard protocol based on the ecology and behaviour of waterbirds were made available to conservation site managers. This protocol should be derived from an investigation based on a large number of aquaculture ponds, which cover the entire spectrum of representative wetland types of aquaculture ponds. However, this standard protocol must take into account the specific habitat requirements of different groups of waterbirds and the state of abandoned ponds prior to their conservation management. Consequently, several types of management policies may be recommended by such a protocol.

9.2. Objectives

According to the most extensively cited definition, restoration means to return a disturbed habitat to a condition that, in both structure and function, is a close approximation of the ecosystem that existed before disturbance (NRC, 1992). Based on this definition, the objectives of restoration schemes with specific considerations associated with abandoned aquaculture ponds are given (Drysdale, 1994; Reive *et al.*, 1994; Ward *et al.*, 1997; Stephen & Darold, 2001).

1. *Diversity of waterbirds*: To restore species diversity and the abundance of waterbirds typical of natural wetland communities in southwestern Taiwan and the reproductive activities of these waterbirds to the state found prior to commercial management.
2. *Function and structure of wetlands*: To restore and maintain the ecological function and structure of natural wetlands such as water quality, vegetation and topographic features, in southwestern Taiwan, including coastal tidal mudflats, brackish lagoons and mangroves (Chang, 1995; Chen, 1998).
3. *Hydrology*: To restore hydrological characteristics of wetlands to their natural state, including natural fluctuations of the water level, drainage patterns, input and output of water and the wetlands' capacity to retain abundant water of appropriate quality

at critical times of the year.

4.*Ecological integrity*: To maximize the ecological integrity of the local wetland ecosystems by encouraging, supporting and co-operating in the restoration, management and connectivity with local conservation sites, remnant natural areas and other artificial wetlands (such as actively managed ponds, saltpans and rice paddies) close to the restored sites.

9.3. Procedure for restoration schemes

9.3.1. Assessment of the potential for habitat restoration

Assessment is the first and most essential step to ensure the success of habitat restoration. A detailed assessment could expose the potential for success of any proposed restoration scheme, and could also ensure the best use of limited funding and manpower for conservation. Many considerations for the selection of a favourable wetland for restoration have been suggested by several authors (Kusler & Kentula, 1990; Spellerberg, 1992; Stoneman & Brooks, 1997). From these considerations, several useful points can be chosen for the restoration scheme of aquaculture ponds (Table 9.1).

Table 9.1. Outline of restoring procedures for the conservation of an aquaculture pond wetland complex.

Assessment of the potential of selected wetlands for habitat restoration

1. **Geographic considerations:** locality, area, isolation, habitat diversity
2. **Biological considerations:** species richness, sbundance of water birds, number of indigenous water bird species, rarity of indigenous water birds, rarity of other water birds
3. **Environmental considerations:** hydrology, water quality, vegetation
4. **Other considerations:** naturalness, representativeness, abandonment history, ownership of land, natural and anthropogenic disturbances

Alteration of the characteristic attributes of target wetlands

1. *Hydrology*: The natural dynamics of water input and output should be restored.
2. *Water quality*: Any contaminants in the water body and sediment should be removed.
3. *Disturbances*: Protective measures such as buffer zones and barriers should be erected to reduce or eliminate any anthropogenic disturbance.
4. *Aquaculture and other wastes*: Rubbish, construction wastes, industrial wastes and unused aquacultural equipment and facilities should be removed or modified.

Selection of target guild

Egret-Rail	Duck	Wader-Tern
1. *Basin area*: A group of small ponds should be integrated by removing their embankments whereas large ponds should be subdivided to several medium- or small-sized independent units 2. *Vegetation*: Shore and emergent vegetation need to be planted if natural re-vegetation is too slow, while dense submerged vegetation should be thinned. 3. *Water table control*: Lowering the water table (<20cm) after prolonged flooding for every subunit	1. *Basin area*: Large ponds should remain undivided or subdivided to a group of medium- or small-sized ponds only if some other guilds are also to be protect.ed. A group of adjacent small ponds which are managed under one management body is an alternative choice. 2. *Infrastructure of target wetlands*: Low embankments required to be altered to high embankments. 3. *Vegetation*: Shore and emergent vegetation should be controlled at <70% and <50%, respectively, while submerged vegetation should be introduced if natural re-vegetation is too slow. 4. *Water table control*: A water body with a range of water depths is the optimal choice.	1. *Division of ponds and water table control*: Large ponds should be subdivided into several independent subunits. The water table for every subunit should then be lowered alternately after a prolonged flooding. 2. *Vegetation*: All types of vegetation should be thinned or removed to provide an open area for this guild. 3. *Hydrology*: The restoration of the natural dynamic pattern of water input and output is especially important for this guild.

Monitoring system:

1. *Mid-course survey*: To diagnose the effectiveness of restoration measures
2. *Periodic monitoring*: To assess the effectiveness of restoration schemes and to assure the appropriateness of restoration systems

Geographical considerations

1. *Locality*: Human disturbance could have the most serious potential impacts on the habitat utilization of aquaculture ponds by waterbirds, waterfowl in particular (Table 5.5). Ponds situated farther away from a main road or human habitation are better for waterbirds (Table 5.5, Figures 5.6, 5.8 and 5.13). Estuarine and coastal areas could be the principal feeding grounds for waterbirds. Ponds that are relatively close to the coast or estuary could be a better choice for restoration. In addition, being close to existing reserves would provide the opportunity of linking the local conservation sites into a larger conservation system, which would increase the conservation value of target restoration sites as well as other local conservation sites. These restoration sites could function as a buffer zone to the main conservation sites and thereby provide more contributions for conservation than isolated sites. There is a considerable area covered by wetlands in southwestern Taiwan (Chang[1], 1994; Chang[2], 1994). However, only a few natural reserves have been set aside in this region (Tsai & Chang, 1996). Most wetlands in this region are artificial and are exposed to a great deal of human disturbance due to fishery and agriculture practices. This disturbance has prevented the utilization of the wetlands by waterbirds. Protected wetlands could provide better habitats for waterbirds, with more resources such as food and shelter. A high priority should be placed on any site that can increase the connectivity of a local reserve network. A regional reserve network should be considered as a whole. Sites that are located within a gap between two reserves should be preferentially selected to increase the ecological function of the local reserve system to waterbirds, since these restored sites could provide a better connectivity in the local reserve networks.
2. *Area*: Sites with a basin area of 2~3 ha would be most preferred. From the interviews with the managers of aquaculture ponds, ponds of this size could be handled most effectively and efficiently.
3. *Isolation*: A mosaic of various wetland types in an area could operate as an integrated functional unit to attract waterbirds. A relatively large area of diverse wetlands at a site could provide a stronger attraction to waterbirds than a small area, even though waterbirds are a group of highly mobile organisms. This could result from a higher success rate in foraging, due to a shorter travel distance between feeding grounds or between feeding grounds and roosting habitats.

Apart from natural wetlands and temporarily abandoned ponds, a small proportion of active aquaculture ponds, which are the common wetland type in southwestern Taiwan, are also required. Active aquaculture ponds can provide seasonal food and shelter for waterbirds and are at present an essential wetland type in the wetland ecosystem of southwestern Taiwan (personal observations).

4. *Habitat diversity*: Habitats with a high diversity are more likely to provide numerous habitat niches for a range of waterbird species and are therefore more favourable for wetland restoration, which would normally aim for a high biodiversity. This parameter can be considered separately within and outside the target site. The degree of habitat diversity for waterbirds is more important within the site than outside.

Biological considerations

1. *Species richness*: One of the objectives of the recommended restoration scheme is to increase the biodiversity of waterbirds, biodiversity being comprised of two components, namely species richness and evenness of abundance. A relatively high species richness in a selected wetland indicates that less effort is required to achieve the objectives than in a wetland with a lower species richness.
2. *The abundance of waterbirds*: A relatively high abundance of waterbirds at a site normally indicates that the site is a good habitat for waterbirds and requires less restoration effort.
3. *The number of indigenous waterbird species*: Indigenous waterbirds are a higher priority for protection than widely-distributed species, and conservation management should act accordingly.
4. *Rarity of indigenous waterbirds*: Rare and indigenous waterbirds are more important than general species and should be placed in the highest priority category for protection.
5. *Rarity of other waterbirds*: Regional or international rarity is also one of the main concerns in wetland conservation.

Environmental considerations

1. *Hydrology*: It is one of the fundamental elements in restoration schemes for wetlands. Water input and output (e.g. tidal water) could be one of the most crucial parameters in determining vitality of wetlands and should be restored to as

natural a state as possible.

2. *Water quality*: The sites contaminated by heavy metals, toxic chemicals and other pollutants may take a longer period of time to be restored and cost a great deal to be cleared of contaminants. This kind of site is therefore a less preferred choice for restoration.
3. *Vegetation*: Sites with much terrestrial vegetation often indicate an insufficient supply of water. The cost of altering this vegetation could be rather expensive. In addition, a less-developed hydrological system could also hinder the restoration process.

Other considerations

1. *Naturalness*: Natural wetlands are the final state that restoration schemes aim to achieve. Ponds which have a state close to natural wetlands are therefore better for restoration. Establishing baseline information about natural wetlands is a procedure necessary for future comparison between natural wetlands and restored wetlands. This comparison permits researchers to determine how much the restoration schemes have progressed.
2. *Representativeness*: The species of wetland birds currently occurring in Taiwan are largely determined by the type of wetlands currently available to them. So restoring representative wetlands is more likely to protect more endemic species than restoring other less common wetland types. These representative wetland types are the minimum requirement for restoration. Restoration schemes should also cover locally rare wetland types if they are present, as they could possibly harbour some rare indigenous waterbird species and are worthy of restoration.
3. *Abandonment history*: Older ponds are generally more valuable for the conservation of waterbirds due to fewer recent anthropogenic disturbance. Use of pesticides in the target ponds should also be reconsidered. A protracted regime of pesticide use may hinder the re-colonization of phytoplankton and aquatic macrophytes.
4. *Ownership of land*: Only the full ownership of land can allow site managers and researchers to restore the target sites freely. However, full land ownership is not available in most cases. Restoration schemes under contract or under compensation terms could still achieve a certain level of conservation targets. This may be greatly affected by the attitude of landowners.

5.*Natural and anthropogenic disturbance*: Less disturbance is best. In order to assess the possible influence of various types of disturbance on the habitat use of wetlands by waterbirds, every potential disturbance should be examined carefully. Consultation with local pond owners or neighbouring pond mangers is also necessary.

Future potential threats also require consideration. Many development-related schemes that attempt to reclaim abandoned aquaculture ponds, particularly along the coast, have been proposed in the study area. Any proposed development-related schemes, which may include the target sites for restoration, should be examined carefully to gain an understanding of their potential influence of these schemes on the habitat use of target wetlands by waterbirds.

Several wetlands may be selected for restoration schemes at a conservation site by assessing their potential to be restored after comparing the aforementioned points. Ponds with the highest potential to be successfully restored should be selected for the restoration scheme.

9.3.2. Alteration of the characteristic attributes of target wetlands

After the preliminary assessment of wetland candidates, ponds with a high potential for success should be treated separately according to the category of wetland type and the guild of waterbirds that the particular restoration scheme will favour. These separate treatments, which are principally based on the results and discussion in chapter 5, 6 and 7, could help the particular habitat requirements of waterbirds to be met more precisely (Appendix 9.1).

Three characteristic attributes of wetlands are recommended to be altered to a state as close as natural wetlands no matter what type of ponds or what guild of waterbirds that a restoration scheme is selected to favour.

1. *Hydrology*: Hydrology could be a crucial parameter determining the success of restoration schemes (Lewis *et al.*, 1995). Several hydrological parameters should be restored, namely the water level, the flow system and water input and output. The natural dynamics of the water level as well as its input and output should first be restored. Next, the frequency and duration of flooding, the area which was

flooded, and the volume, frequency and duration of inflow and outflow should be restored to as natural a state as possible. Artificial waterways should be removed or modified if they obstruct the natural flow or change the speed of flow (Brooks, 1990; Williams *et al.*, 1997).

2. *Water quality*: Water quality determines what kind of aquatic biota can occur within a pond. It is crucial for the restoration process to restore water to a high quality. Any type of contaminants, including pesticides, heavy metals and other toxic substances, should be removed. These residues will greatly harm the water quality and will consequently influence the growth of the prey species for waterbirds. Although some contaminants could increase the growth rate of prey species, it is nevertheless recommended that the physical environment of the target wetland is restored to its original, natural state, thus the contaminants should be removed. These include pollutants in both the water body and in sediments. Pollutants may be continuously released from sediments into the water body and thereby harm the water quality. They should be removed if possible.

3. *Disturbance*: Abandoned aquaculture ponds are normally situated amidst a mosaic of actively managed artificial wetlands, including aquaculture ponds, rice paddies and arable. These surrounding lands with various land uses could cause a range of anthropogenic disturbance to waterbirds. Any type of anthropogenic disturbance should be eliminated or at least reduced to the extent that the restoration schemes will not be influenced significantly. This anthropogenic disturbance includes commercial disturbance: fishing and netting for a living; sport-related ones: fishing, hunting, boating, flying light aircrafts; tourism-related ones: birdwatching; development-related ones: traffic, construction of roads, buildings and other facilities. Adequate protective measures should be applied to keep human disturbance of all kinds at a minimum. These protective measures can be divided into barriers and buffer zones.

Barriers such as hedges, fences and trenches, could be the most direct and effective protection facilities. Barriers with a height of two metres and a width of one metre should be adequate. Local endemic plant species provide the best

material with which these barriers can be built due to their higher ecological function in the local wetland ecosystem. Concrete or wooden fences are not recommended due to their obtrusive appearance. Before any hedges are fully grown, temporary metal net or wire fences need to be installed and should be removed once the hedges are fully grown. In terms of trenches, a trench with a width of two metres and a depth of one metre should be sufficient to minimize the impact of most human disturbance.

Despite the effectiveness of barriers, their high installation cost has discouraged their widespread use. Buffer zones are an alternative protection measure and may be cheaper to apply. Site management agencies or conservation authorities could provide subsidies for the neighbouring landowners to limit any activity that could disturb the waterbirds, including harvesting activities. The recommended restriction of these anthropogenic activities may not completely halt the disturbance to waterbirds, but their frequency and intensity may be reduced. In order to reduce the extent of this disturbance, detailed discussion is required with local landowners, conservation authorities and site managers. Despite a high consensus that it is necessary to establish a buffer zone to effectively restore wetlands, little information pertaining to the construction of buffer zones is available. A relatively wide buffer area is likely to be more effective in eliminating disturbance. However, wider buffer zones normally entail greater subsidies for landlords. Thirty to 50 metres or wider buffer strips were recommended for a restored wetland by the Environment Agency (1996). A buffer zone with a width greater than 50m should provide a sufficient buffer space for waterbirds in the wetlands proposed for restoration.

Frequent natural disturbance, such as summer subtropical storms, known as typhoons, are impossible to prevent and should be viewed as parts of the natural process. However, they should be monitored and recorded (frequency and extent of damage) so that future damage, for example, to the infrastructure of ponds and the population of waterbirds, can be minimized in advance by management measures such as securing water sluices and providing temporary shelter to the broods and nests of rare and target species.

4. *Aquacultural and other wastes*: Abandoned aquaculture ponds are very likely to be viewed as junkyards by local people and therefore accumulate rubbish, construction and industrial waste. In addition, the unused aquacultural equipment and facilities such as pumps, tubes and buildings, could still remain in the target ponds. This waste should be removed when restoration schemes commence. However, aquacultural equipment and facilities could be modified for use in restoration schemes. For instance, construction waste might be used to repair embankments.

Aside from the aforementioned general parameters necessary for restoration, the specific parameters for each waterbird guild are discussed. Several parameters are likely to be rather similar between guilds. However, the aspects of these parameters that need to be altered are rather different. These parameters include vegetation, water level and basin area.

The Egret-Rail guild

According to the observations made in this study, large and open aquaculture ponds might not be the preferred wetlands for this guild and were principally used when the water level dropped down to 20cm or less, for example during the drainage of actively managed aquaculture ponds in the harvest season or in abandoned ponds during the dry season (discussion in section 7.3; Yang, 1997). Medium-sized ponds (approximately 2 ha) seem to be preferred by this guild. Small ponds (0.5 ha or smaller) could discourage use by species in this guild because of the higher risk of disturbance. Emergent and shore vegetation increases the attractiveness of target ponds to a considerable extent but submerged vegetation seems to decrease their attractiveness (Table 5.5, Figures 5.11, 5.12 and 5.13). Emergent and shore vegetation could provide roosting habitats for egrets and rails and could also harbour their prey species such as fish and invertebrates. In contrast, submerged vegetation could decrease the detectability of this prey and thus decrease the attractiveness of the pond to the guild. If necessary, additional shore and emergent vegetation should be planted but these vegetation types, especially emergent vegetation, should not be so dense that they cover the whole water body.

Recommendations for the Egret-Rail guild:

1.Basin area: Removal of embankments from a group of small ponds (maximum 0.6 ha) to combine them into a larger pond (1.5 to 2 ha) is necessary. In contrast, larger ponds (minimum 3 ha) should be subdivided into several medium- to small-sized independent units (0.6 ha to 1.5 ha) (Figure 9.1).

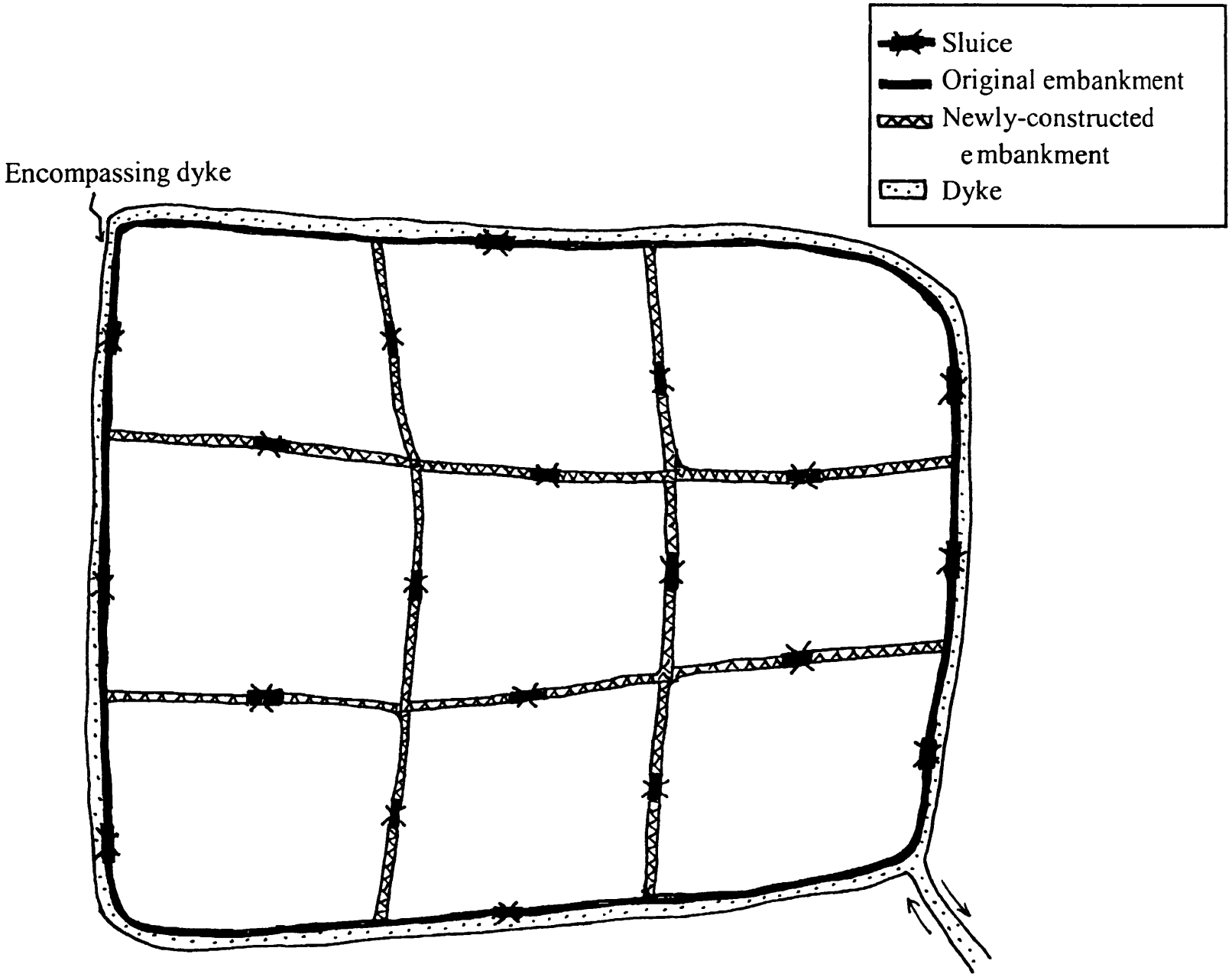


Figure 9.1. The subdivision of a large aquaculture pond for the habitat use of the Egret-Rail guild.

2. *Vegetation*: The shore and emergent vegetation should be planted to accelerate expansion if the natural process is relatively slow. However, the growth of some of these vegetation types may be limited by some factors. Management measures might be necessary to remove these limiting factors and thereby accelerate re-vegetation process. Shore and emergent vegetation could provide roosting and nesting habitats for egrets and rails (Table 5.5, Figures 5.11, 5.12 and 5.13). In contrast, thinning of submerged vegetation should be undertaken if this vegetation type is too dense for the use by this guild.
3. *Water level control*: Seasonal lowering of the water level is necessary to increase the accessibility to food resources to this guild. These measures must be followed by long-term flooding and a rise in the water level for the re-growth of prey species (Rundle & Fredrickson, 1981; Breininger & Rebecca, 1990; Rehfisch, 1994; Vickery *et al.*, 1997; Ashkenazi & Dimentman, 1998). It is suggested that the water level in every subunit is sequentially drawn down to 20 cm or less. Egrets are known to deplete food resources in a short period of time (Yang, 1997). Through these measures, a restored wetland complex could provide a constant food resource, thereby attracting egrets and rails.

The Duck guild

As stated in the results and discussion of sections 7.3. in Chapter 7, human disturbance could be the most crucial parameter affecting the habitat selection of duck species (Table 5.5, Figures 5.2, 5.8 and 5.13). Abandonment time, the distance to the nearest human habitation or main road and the proportion of surrounding wetlands that are abandoned all indicate that the wetlands with a lesser degree of human disturbance could attract more waterfowl. Large ponds normally provide more security for waterfowl that can respond to distant disturbance and so are their preferred type of wetlands. Apart from disturbance-related parameters, foraging considerations may be the second most important parameter that influences the ducks' habitat selection (Table 5.5, Figures 5.2, 5.8 and 5.13). Thriving vegetation within the aquaculture ponds such as shore, emergent and submerged vegetation types, is also important to this guild (Table 5.5 and Figure 5.2). These vegetation types could harbour food resources (mainly submerged vegetation) and provide shelter (shore and emergent vegetation) for waterfowl (Cross, 1988). Regarding water depth of restored ponds, 20-30cm is believed to be the ideal depth

at which waterfowl could obtain ready access to food resources (Table 5.5 and Figure 5.11).

Recommendations for the Duck guild:

1. *Basin area*: Large ponds should remain undivided. This will provide the waterfowl with a larger buffer zone when responding to occasional disturbance. However, target wetlands are sometimes designed not only for waterfowl, but also for other guilds. As an alternative, large ponds can be subdivided into a group of medium- to small-sized subunits. In this study, a high abundance of waterfowl was frequently observed in a wetland complex of several adjacent small-sized abandoned ponds, for example at site CK (Appendix 1.1). These small ponds should be viewed as a functional unit and managed under a single conservation authority. A large ratio of embankment to basin area within this group of wetlands would provide abundant roosting habitats for waterfowl. Dense wall vegetation would be required to ensure the value for waterfowl, as it can provide a more secure environment for the birds.
2. *Infrastructure of target wetlands*: Low embankments should be built up to at least 2m. A high embankment will decrease the risk of disturbance from outside the ponds.
3. *Vegetation*: Submerged vegetation could be the most essential vegetation type for waterfowl (Table 5.5 and Figure 5.2). It can provide a food resource necessary for herbivorous waterfowl. The introduction of aquatic macrophytes is recommended if the presence of submerged vegetation is receding. Shelter-providing, shore and emergent vegetation are also required and could be planted to increase the amount of sheltered habitats available to waterfowl (Cross, 1988). The cover of shore and emergent vegetation types should not exceed 70% and 50%, respectively. Very dense shore and emergent vegetation could both decrease the foraging function of wetlands and increase the risk of predation on waterfowl, due to their reduced awareness of the predators.
4. *Water level control*: Not every part of the water body in a pond should be manipulated to the ideal depth (20-30cm). A variety of depth zones need to exist in a pond. A small proportion (approximately 10 % of the water body) should consist of a relatively deep water (over 50cm) to conserve the core of aquatic plants and ensure their regrowth after intensive consumption by migratory birds.

A large area (over 40%) of the 20-30cm water depth zone is recommended to supply an abundant food resource for waterfowl (Table 5.5 and Figure 5.11).

The Wader-Tern guild

Large ponds (5 ha or larger) are ideal for waders and terns (Table 5.5 and Figure 5.2). Large and open ponds with a low embankment can provide a perfect roosting site for flocking migratory waders and terns and a considerable buffer space to escape from any disturbance. However, the largest sampled aquaculture pond in this study was only 8.6 ha, so no conclusion can be drawn for ponds with a basin area of more than 8.6 ha. Open space is also important. This means that low vegetation cover is ideal for the Wader-Tern guild, no matter whether it is shore or emergent vegetation (Table 5.5, Figures 5.2, 5.8, 5.11 and 5.13). Twenty centimeters or less is the ideal depth for the foraging of this guild. In addition, the restoration of the ponds' natural hydrology, especially water input and output, is crucial to promote prey species for shorebirds and terns (Rundle & Fredrickson, 1981; Breininger & Rebecca, 1990; Rehfisch, 1994; Vickery *et al.*, 1997; Ashkenazi & Dimentman, 1998).

Recommendations for the Wader-Tern guild:

1. *Division of ponds and water level control*: Large ponds are preferred by this guild (Table 5.5 and Figure 5.2). However, to avoid the rapid depletion of food resources by aggregation of migratory waders, large ponds can be subdivided into several independent subunits (minimum 1 ha) with low embankments (maximum 80cm). Generally, the water level of these subunits should remain over 60cm depth and be alternately lowered (10-20cm for large waders or 5-10cm for medium to small waders) to provide food resources for waders by increasing accessibility to prey one subunit at a time (Rundle & Fredrickson, 1981; Breininger & Rebecca, 1990; Rehfisch, 1994; Vickery *et al.*, 1997; Ashkenazi & Dimentman, 1998). When subdividing the target ponds, the subunits should not all be the same size. Approximately 40% of each basin, in the centre of the pond, should remain undivided. The water level in this large, central compartment must be maintained a 5cm or less depth to satisfy the roosting needs of waders and terns (Figure 9.2). The restored pond should be encircled by a dyke system

which connects the pond to tidal or other water resources. Every subunit should have at least one sluice to connect it with the central roosting compartment, adjacent compartments and the encompassing dyke.

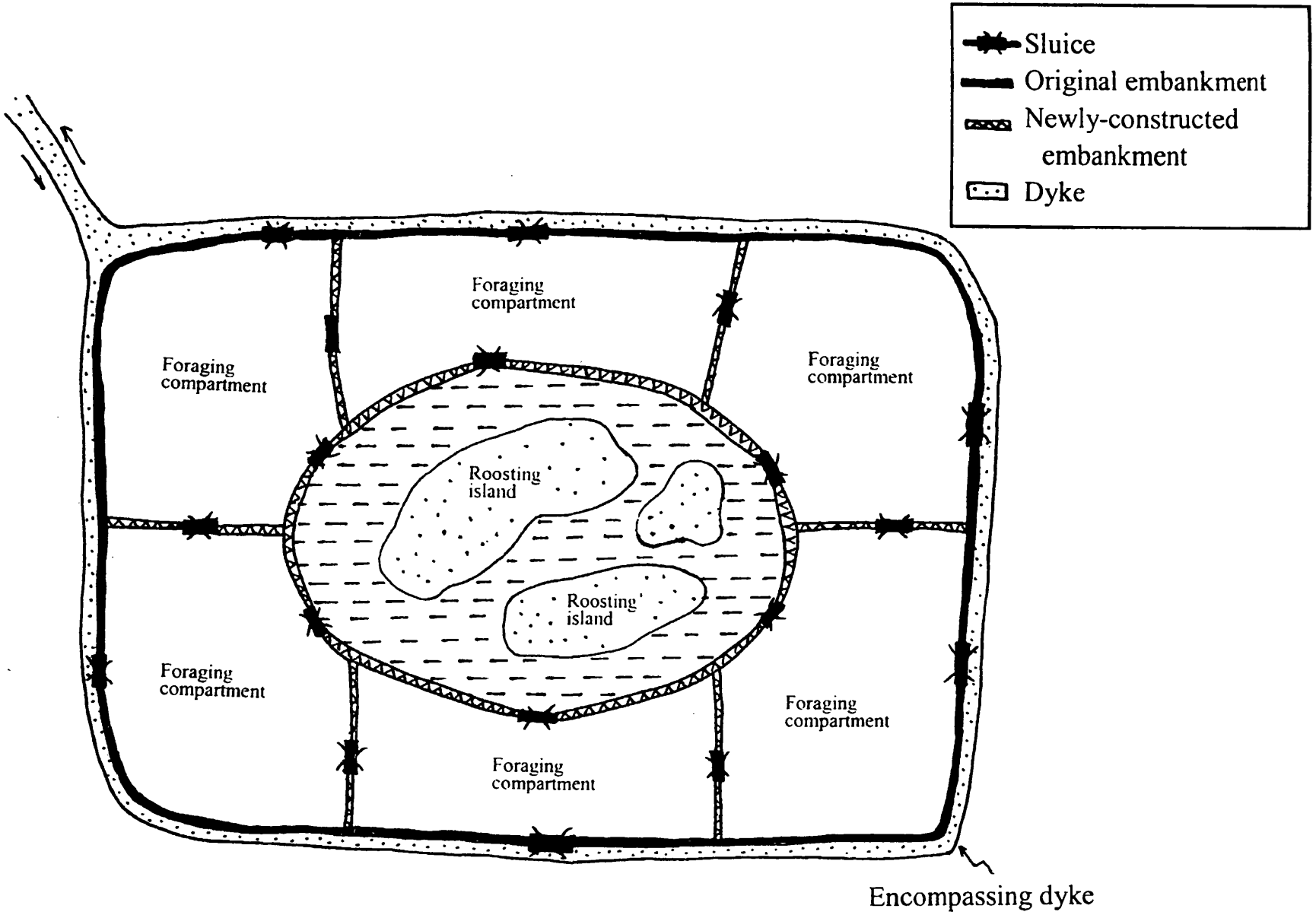


Figure 9.2. The subdivision of a large aquaculture pond for the habitat use of the Wader-Tern guild.

Due to the flocking habit of most waders and terns, small ponds could provide rather limited opportunities for this guild. A group of small adjacent ponds under a single conservation authority might play an important role in the habitat use of wetlands by the Wader-Tern guild. Each individual pond should be treated as an independent functional unit. In other words, it should be possible to manipulate the water level and the input and output of water independently. The whole group of ponds can be designed as shown in the plan in Figure 9.3 if sufficient ponds are available. The reconstruction works should also involve the removal of embankments to form the large, central roosting compartment, and the construction of dyke and sluice systems. The embankments of these small, peripheral, food-providing compartments need not necessarily be altered to the size of the ideal foraging pond for this guild unless these compartments are too small (0.4 ha or smaller) to function properly. Water depth should be manipulated as described for the large ponds in the previous paragraph.

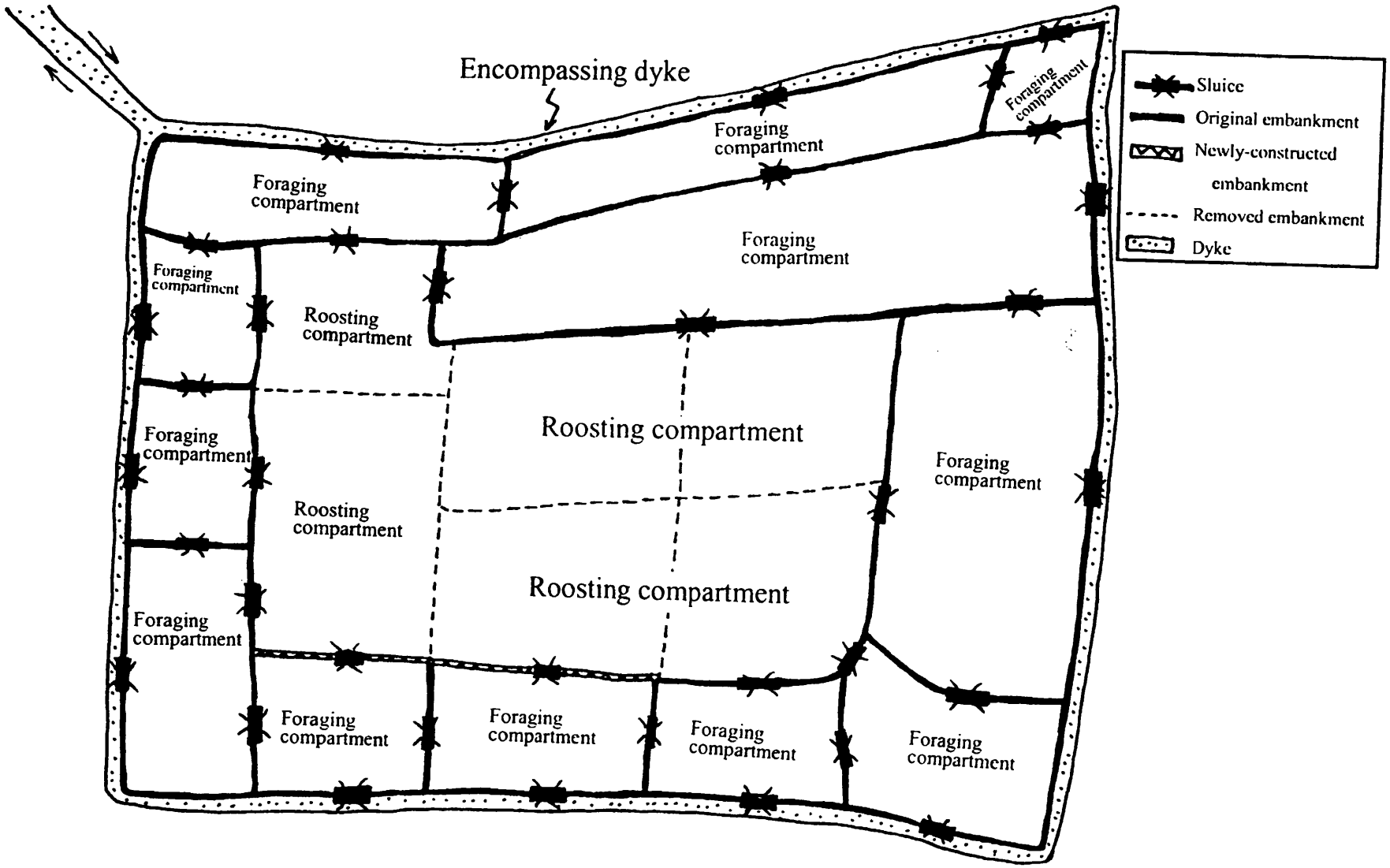


Figure 9.3. The integration of small adjacent aquaculture ponds for the habitat use of the Wader-Tern guild.

2. *Vegetation*: Dense vegetation inside the pond should be thinned or removed to maintain openness (Table 5.5, Figures 5.2, 5.8, 5.11 and 5.13). Cover of any vegetation type, including wall, emergent, and shore vegetation, should be maintained under 20, 10 and 20%, respectively.
3. *Hydrology*: For this guild, restoring the natural dynamics of water input and output (e.g. tidal water) is more important than for other guilds, due to the particular importance of frequent flooding to encourage their prey species (Rundle & Fredrickson, 1981; Breininger & Rebecca, 1990; Rehfisch, 1994; Vickery *et al.*, 1997; Ashkenazi & Dimentman, 1998). It is also important to develop a dyke system to reconnect the restored ponds with the tidal water (either by building a connection with tidal dykes or directly with the sea) or other water sources.

9.3.3. Monitoring to assess the effectiveness of restoration schemes

A mid-course survey of the target wetlands can form a part of adaptive management. In other words, this survey could be used to identify any inappropriate work pertaining to the restoration scheme. Recommended measures should then be made to improve the restoration activities. The mid-course survey should include biological parameters such as species richness and population dynamics of waterbird species and physical parameters of target wetlands such as vegetation, hydrology and water quality (Appendix 9.1). In addition, periodic monitoring should be carried out to assess the effectiveness of restoration schemes and to assure the appropriateness of restoration systems. This periodic monitoring scheme should be conducted as described in chapter 8.

9.4. Risk and probability of success of restoration schemes

The risk and probability of success of any restoration scheme is difficult to ascertain due to many associated attributes. However, this information could be useful when the recommended restoration scheme is seeking funds from conservation authorities or non-governmental organizations (NGOs). Several parameters could play important roles in determining the risk and probability of success of the recommended restoration schemes, for instance the closeness of the restored parameters to the expected state, the attitude of landowners from surrounding areas, the history of the selected wetlands, the locality, basin area and topographic characteristics of the

wetlands, the current impact of any disturbance, the regional trend in the population dynamics of waterbirds, and the status of the local economic and political environment. All these parameters should be considered collectively to determine their influence upon the risk and probability of success of the restoration schemes.

9.5. Restrictions of restoration schemes

The recommended restoration scheme intends to restore aquaculture ponds to a natural state. However, many factors could possibly limit the outcome, which the restoration scheme can achieve.

1. *Influences of surrounding environment:* Abandoned aquaculture ponds are typically situated in a mosaic of actively managed ponds, abandoned aquaculture ponds, natural wetlands, rice paddies and other wetlands. These surrounding wetlands, actively managed wetlands in particular, remove the direct connection between the restored wetland and the sea or any other natural water source. This results in a lower possibility to restore the natural hydrological dynamics of the wetland. In addition, the pollution from surrounding artificial wetlands can easily influence the water quality of restored ponds and make the control of water quality more difficult to implement.
2. *Insufficient scale of restoration:* Restoration may only be possible on a small scale due to limited funding. However, small restored wetlands can barely provide limited resources for waterbirds.
3. *Insufficient manpower:* Not many protected wetlands in Taiwan have adequate manpower to conduct routine management works. Many conservation sites need to share part-time managers. It is even less likely to find full-time managers in most sites (personal communication with conservation officers in the local and central government of Taiwan). Without full-time managers, many restoration schemes, including manipulation of the water level and the restoration of hydrology, could be difficult to achieve due to a lack of assistance to control the power supply to pumps and water flow.
4. *Numerous unpredictable parameters:* Many wetland characteristics could influence the habitat utilization of wetlands by waterbirds. Only a few of these attributes may have a clear relationship with the habitat selection of waterbirds. Most attributes did not display any clear correlations. In a restoration scheme, only a

few selected parameters with a clear association with the habitat selection of waterbirds can be altered to restore the environment of target wetlands. The outcome of restoration schemes could differ from expectation due to the considerable influence of other unmanaged parameters on the habitat selection of waterbirds.

5. *Unpredictability in the behaviour of waterbirds:* Waterbirds are a group of highly mobile organisms. They can explore a large area in a short period of time and could ignore the restored wetlands even when they become an ideal habitat. This could occur if better habitats are available somewhere else or due to chance.
6. *Difficulties in controlling the cover of vegetation:* Vegetation cover is difficult to manipulate in a subtropical area where the growth rate of vegetation is rapid. Vegetation removal often needs to be replicated on a regular basis. However, the ideal state of cover of particular vegetation types may not be achieved even with repeated management.
7. *Difficulties in eliminating human disturbance:* Some of the human disturbance such as traffic, road construction and flying light aircrafts, may never be completely eliminated, even when the most powerful protective measures are employed. This disturbance could greatly reduce the habitat utilization of target restored wetlands by waterbirds.

9.6. Cost, manpower and administration

Cost and manpower: The manpower and cost necessary for restoration has been estimated separately according to several groups of parameters, including hydrology, water quality, the water level, the infrastructure of ponds, vegetation, waste and human disturbance, and is based on the estimation for the alteration of a 2-ha pond. The calculation of the required manpower and cost for each guild should be summed in accordance with the parameters, which are necessary for that guild. The cost of restoration is calculated using the local standard of living in southwestern Taiwan and was converted to pounds sterling.

According to personal interviews with the officials in the fishery department of the local government and managers of aquaculture ponds, two typical types of aquaculture ponds can be identified in the study area (Figure 1.5). One type of

aquaculture pond has a basin area of 2 ha or more. This type of pond normally has a low embankment (maximum 1 m) and is primarily used for the short-term growth of fish fry. Residues of nutrients and pesticides in this type of pond are relatively low. The other type of pond has a smaller basin area of 2 ha or less. This type of pond generally has a high embankment (minimum 1m, generally 3 m) and is principally used for harvesting mature fish. The expenditures required altering the characteristic parameters of these two types of ponds differ and are assessed separately (Figures 9.2a and 9.2b).

Table 9.2a. Expenditure for restoring a 2-ha low-bank temporarily abandoned ponds in the study area.

(Currency: Sterling)

A. ***Hydrology***	
1. Construction and repair of sluices	200/sluice × 8 sluices=**1600**
2. Repair of embankments:	
Hiring a bulldozer with operator	150/day × 0.5 day=**75**
3. Leveling the bed of ponds	
Hiring a bulldozer with operator	150/day × 1 day=**150**
4. Clearing dykes:	
Hiring a crane with operator	200/day × 1 day=**200**
Hiring trucks with operators (for the collection and dumping of earth)	30/truck × 5 trucks=**150**
5. Manipulation of the natural dynamics of water input and output	
Installation of power system:	
Wire & switch boxes	**80**
Temporary workers:	40/p-d* × 1 p-d=**40**
Pumps	300/pump×2 pumps =**600**
Electricity bill	**240/Year**
Current velocity meter (for estimating inflow and outflow of water within a pond)	200/meter × 1 meter=**200**
Subtotal:	**3335 (including one-year electricity bill)**
B. ***Water quality***	
1. Drainage:	
Hiring pumps	20/pump-day ×4 pump-day=**80**
Electricity bill	**10**
2. Removal of sediments:	
Hiring a bulldozer with operator	150/day × 10 days=**1500**
Hiring trucks with operators (for the collection and dumping of sediments)	40/truck × 200 trucks=**8000**
3. Refilling pond with water:	
Hiring pumps	20/pump-day ×4 pump-day=**80**
Electricity bill	**10**
Subtotal:	**9680**

C. ***Water level***

1. Installation of measuring poles for water depth
   Measuring poles 4/pole × 4 poles=**16**
   Temporary workers: 40/p-d × 0.5 p-d=**20**
2. Construction of sluices 400/sluice × 8 sluices=**3200**
3. Manipulation of the water level:
   Pumps 400/pump × 2 pumps=**800**
   Electricity bill
   240/Year
   Subtotal: **4276(including one-year electricity bill)**

D. ***Infrastructure of ponds***

1. Set-up of embankments:
   a. Earth bank:
      Construction of sluices 400/sluice × 8 sluices=**3200**
      Hiring a bulldozer with operator (to set up embankments) 150/day × 1 day=**150**
      Hiring a bulldozer with operator (for leveling bed of pond) 150/day × 1 day=**150**
   b. Concrete or brick bank: not recommended
   Subtotal: **3500**

2. Removal of embankments:
   a. Earth bank:
      Hiring a bulldozer with operator (for removal of embankments) 150/day × 1 day=**150**
      Hiring trucks with operators (for collection and dumping of embankment waste) 30/truck × 30 trucks=**900**
      Hiring a bulldozer with operator (for leveling bed of pond) 150/day × 1 day=**150**
   b. Concrete or brick bank:
      Hiring a bulldozer with operator (for removal of embankments) 150/day × 1 day=**150**
      Hiring trucks with operators (for collection and dumping of embankment waste) 40/truck × 30 trucks=**1200**
      Hiring a bulldozer with operator (for leveling bed of pond) 150/day × 1 day=**150**
      Subtotal: **2700**

E. ***Vegetation***

1. Re-vegetation of ponds:
   a. Shore vegetation:
      1st re-vegetation:
      Temporary workers:(follow-up 6-month care of young plants included) 40/p-d × 18 p-d=**720**
      Young plants 1 × 3 plants/m× 600 m (perimeter of the water body) =**1800**
      2nd re-vegetation:
      Temporary workers:(follow-up one-year care of young plants included)

40/p-d × 20

p-d=**800**

Young plants 1 × 1 plants/m× 600 m (perimeter of the water body) =**600**

3rd re-vegetation:

Temporary workers: 40/p-d × 2

p-d=**80**

Young plants 1 × 100 plants=**100**

Subtotal: **4100**

b. Emergent vegetation:

1st re-vegetation:

Temporary workers: 40/p-d × 40 p-d=**1600**

Young plants 1 ×(20 plants/100 ㎡)× 20000 ㎡(basin area) =**4000**

2nd re-vegetation:

Temporary workers: 40/p-d × 16 p-d=**640**

Young plants 1 ×(20 plants/500 ㎡)× 20000 ㎡ (basin area) =**800**

3rd re-vegetation:

Temporary workers: 40/p-d × 4 p-d=**160**

Young plants 1 ×(20 plants/2500 ㎡)× 20000 ㎡ (basin area) = **160**

Subtotal: **7360**

c. Submerged vegetation:

1st re-vegetation:

Temporary workers: 40/p-d × 20 p-d=**800**

Young plants 1 ×(10 plants/100 ㎡)× 20000 ㎡ (basin area) =**2000**

2nd re-vegetation:

Temporary workers: 40/p-d × 8 p-d=**320**

Young plants 1 ×(10 plants/500 ㎡)× 20000 ㎡ (basin area) =**400**

3rd re-vegetation:

Temporary workers: 40/p-d × 2 p-d=**80**

Young plants 1 ×(10 plants/2500 ㎡)× 20000 ㎡ (basin area) =**80**

Subtotal: **3680**

2. Removal or thinning of vegetation:

a. Wall vegetation

Hiring a bulldozer with operator 150/day × 0.5 day× 2 times=**150**

Subtotal: **150**

b. Shore vegetation:

Hiring a mini bulldozer with operator 100/day × 1 day × 3 times=**300**

Subtotal: **300**

c. Emergent vegetation:

Temporary workers: 40/p-d ×5 p-d × 2 times =**400**

Disk mowers 100/mower × 2mowers=**200**

Subtotal: **600**

d. Submerged vegetation:

Temporary workers: 40/p-d ×10 p-d × 2 times =**800**

Subtotal: **800**

F. ***Waste***: expenses depend on the amount of waste in the pond

1. Clearance of waste:

Hiring a bulldozer with operator 150/day × 1 day=**150**

Hiring trucks with operators (for the collection and dumping of waste)
40/truck × 10 trucks=**400**

2. Removal of sediments:
   Hiring a bulldozer with operator 150/day × 10 days=**1500**
   Hiring trucks with operators (for the collection and dumping of sediments)
   40/truck × 200 trucks=**8000**
3. Leveling of pond's bed:
   Hiring a bulldozer with operator 150/day × 1 day=**150**
   Subtotal: **10200**

G. ***Human disturbance:***

1. Buffer zones:
   Subsidies: 500/ha.-year × 1 ha.=**500/year**
   Subtotal: **500/year**
2. Hedges:
   Temporary workers (for plantation of trees) 40/p-d ×20 p-d =**800**
   Temporary workers (for care of trees) 40/p-d ×12 p-d/year × 5 years =**2400**
   Young trees
   1st plantation: 4 /plant× 3 plants/m× 300m (half the perimeter of pond) =**3600**
   2nd plantation: 4 /plant×180 plants=**720**
   Installation of temporary barrier
   Metal net fences 0.5/m× 300 m (half the perimeter of pond) =**150**
   Wooden poles 0.5/pole × pole/5 m× 300 m (half the perimeter of pond) =**30**
   Temporary workers 40/p-d ×1 p-d =**40**
   Subtotal: **7740**
3. Trenches:
   Hiring a crane with operator 200/day × 2 days=**400**
   Hiring trucks with operators (for the collection and dumping of earth)
   30/truck × 20 trucks=**600**
   Subtotal: **1000**

N.B.: p-d*=person per day

Table 9.2b. Expenditure for restoring a 2-ha high-bank temporarily abandoned ponds in the study area.

(Currency: Sterling)

A. ***Hydrology***

1. Construction and repair of sluices 200/sluice × 8 sluices=**1600**
2. Repair of embankments:
   Hiring a bulldozer with operator 150/day × 0.5 day=**75**
3. Leveling the bed of ponds
   Hiring a bulldozer with operator 150/day × 1 day=**150**
4. Clearing dykes:
   Hiring a crane with operator 200/day × 1 day=**200**
   Hiring trucks with operators (for the collection and dumping of earth)
   30/truck × 5 trucks=**150**
5. Manipulation of the natural dynamics of water input and output
   Installation of power system:

Wire & switch boxes **80**
Temporary workers: 40/p-d* × 1 p-d=**40**
Pumps 300/pump×2 pumps =**600**
Electricity bill **240/Year**
Current velocity meter (for estimating inflow and outflow of water within a pond) 200/meter × 1 meter=**200**
Subtotal: **3335 (including one-year electricity bill)**

B. ***Water quality***

4. Drainage:
   Hiring pumps 20/pump-day ×4 pump-day=**80**
   Electricity bill **10**
5. Removal of sediments:
   Hiring a bulldozer with operator 150/day × 10 days=**1500**
   Hiring trucks with operators (for the collection and dumping of sediments) 40/truck × 200 trucks=**8000**
6. Refilling pond with water:
   Hiring pumps 20/pump-day ×4 pump-day=**80**
   Electricity bill **10**
   Subtotal: **9680**

C. ***Water level***

4. Installation of measuring poles for water depth
   Measuring poles 4/pole × 4 poles=**16**
   Temporary workers: 40/p-d × 0.5 p-d=**20**
5. Construction of sluices 400/sluice × 8 sluices=**3200**
6. Manipulation of the water level:
   Pumps 400/pump × 2 pumps=**800**
   Electricity bill **240/Year**
   Subtotal: **4276(including one-year electricity bill)**

D. ***Infrastructure of ponds***

1. <u>Set-up of embankments</u>:
   c. Earth bank:
      Construction of sluices 400/sluice × 8 sluices=**3200**
      Hiring a bulldozer with operator (to set up embankments) 150/day × 2 days=**300**
      Hiring a bulldozer with operator (for leveling bed of pond) 150/day × 1 day=**150**
   d. Concrete or brick bank: not recommended
   Subtotal: **3650**

2. <u>Removal of embankments</u>:
   a. Earth bank:
      Hiring a bulldozer with operator (for removal of embankments) 150/day × 4 day=**600**
      Hiring trucks with operators (for collection and dumping of embankment waste) 30/truck × 120 trucks=**3600**
      Hiring a bulldozer with operator (for leveling bed of pond)

150/day × 1 day=**150**

b.Concrete or brick bank:

Hiring a bulldozer with operator (for removal of embankments)

150/day × 4 day=**600**

Hiring trucks with operators (for collection and dumping of embankment waste)

40/truck × 120 trucks=**4800**

Hiring a bulldozer with operator (for leveling bed of pond)

150/day × 1 day=**150**

Subtotal: **9900**

E. ***Vegetation***

1. Re-vegetation of ponds:

d. Shore vegetation:

1st re-vegetation:

Temporary workers:(follow-up 6-month care of young plants included)

40/p-d × 18 p-d=**720**

Young plants 1 × 3 plants/m× 600 m (perimeter of the water body) =**1800**

2nd re-vegetation:

Temporary workers:(follow-up one-year care of young plants included)

40/p-d × 20 p-d=**800**

Young plants 1 × 1 plants/m× 600 m (perimeter of the water body) =**600**

3rd re-vegetation:

Temporary workers: 40/p-d × 2 p-d=**80**

Young plants 1 × 100 plants=**100**

Subtotal: **4100**

e. Emergent vegetation:

1st re-vegetation:

Temporary workers: 40/p-d × 40 p-d=**1600**

Young plants 1 ×(20 plants/100 ㎡)× 20000 ㎡(basin area) =**4000**

2nd re-vegetation:

Temporary workers: 40/p-d × 16 p-d=**640**

Young plants 1 ×(20 plants/500 ㎡)× 20000 ㎡ (basin area) =**800**

3rd re-vegetation:

Temporary workers: 40/p-d × 4 p-d=**160**

Young plants 1 ×(20 plants/2500 ㎡)× 20000 ㎡ (basin area) = **160**

Subtotal: **7360**

f. Submerged vegetation:

1st re-vegetation:

Temporary workers: 40/p-d × 20 p-d=**800**

Young plants 1 ×(10 plants/100 ㎡)× 20000 ㎡ (basin area) =**2000**

2nd re-vegetation:

Temporary workers: 40/p-d × 8 p-d=**320**

Young plants 1 ×(10 plants/500 ㎡)× 20000 ㎡ (basin area) =**400**

3rd re-vegetation:

Temporary workers: 40/p-d × 2 p-d=**80**

Young plants 1 ×(10 plants/2500 ㎡)× 20000 ㎡ (basin area) =**80**

Subtotal: **3680**

2. Removal or thinning of vegetation:

e. Wall vegetation
Hiring a bulldozer with operator 150/day × 0.5 day× 2 times=**150**
Subtotal: **150**

f. Shore vegetation:
Hiring a mini bulldozer with operator 100/day × 1 day × 3 times=**300**
Subtotal: **300**

g. Emergent vegetation:
Temporary workers: 40/p-d ×5 p-d × 2 times =**400**
Disk mowers 100/mower × 2mowers=**200**
Subtotal: **600**

h. Submerged vegetation:
Temporary workers: 40/p-d ×10 p-d × 2 times =**800**
Subtotal: **800**

F. ***Waste***: expenses depend on the amount of waste in the pond

4. Clearance of waste:
Hiring a bulldozer with operator 150/day × 1 day=**150**
Hiring trucks with operators (for the collection and dumping of waste)
40/truck × 10 trucks=**400**

5. Removal of sediments:
Hiring a bulldozer with operator 150/day × 10 days=**1500**
Hiring trucks with operators (for the collection and dumping of sediments)
40/truck × 200 trucks=**8000**

6. Leveling of pond's bed:
Hiring a bulldozer with operator 150/day × 1 day=**150**
Subtotal: **10200**

G. ***Human disturbance:***

4. Buffer zones:
Subsidies: 500/ha.-year × 1 ha.=**500/year**
Subtotal: **500/year**

5. Hedges:
Temporary workers (for plantation of trees) 40/p-d ×20 p-d =**800**
Temporary workers (for care of trees) 40/p-d ×12 p-d/year × 5 years =**2400**
Young trees
1st plantation: 4 /plant× 3 plants/m× 300 m (half the perimeter of pond) =**3600**
2nd plantation: 4 /plant×180 plants=**720**
Installation of temporary barrier
Metal net fences 0.5/m× 300 m (half the perimeter of pond) =**150**
Wooden poles 0.5/pole × pole/5m× 300 m (half the perimeter of pond) =**30**
Temporary workers 40/p-d ×1 p-d =**40**
Subtotal: **7740**

6. Trenches:
Hiring a crane with operator 200/day × 2 days=**400**
Hiring trucks with operators (for the collection and dumping of earth)
30/truck × 20 trucks=**600**
Subtotal: **1000**

N.B.: p-d*=person per day

Administration: Full-time site managers could assist with several small but important restoration tasks. Some of these tasks require frequent pump or sluice attendance to maintain the water level or to restore the hydrological balance, respectively. This restoration work would require the constant, daily presence of researchers, but only for small tasks each day. It would therefore not be worthwhile for them to visit the restored site every day. Full-time site managers could also assist in surveying the growth status of shore vegetation and hedges. Site managers could also initiate remedial work if maintenance works are shown to be inadequate. This could greatly increase the survival of these plants. In addition, it would be necessary to determine the positions in the restored pond to install pumps, sluices, switch boxes and plugs for power supply, which requires the supervision of full-time site managers. Full-time site managers could help in reducing potential conflicts in the management of the restoration pond and other parts of the conservation site.

9.7. Conclusion

Restoration schemes must deal with many unpredictable factors, including natural and anthropogenic disturbance, the behaviour of animals and plants and pollution (Erwin, 1990). These factors could all result in failure of the restoration schemes, no matter how well-designed the schemes were. A detailed preliminary assessment of the selected site for the potential of restoration would greatly reduce the rate of failure. Separate considerations for each category of parameters and the mid-course survey for diagnosing the restoration procedure could also reduce failure rates. Due to similar commercial practices in these abandoned aquaculture ponds, they have relatively homogenous features such as infrastructure, vegetation and hydrology. This provides a greater opportunity to apply a standard protocol for restoration of these artificial wetlands.

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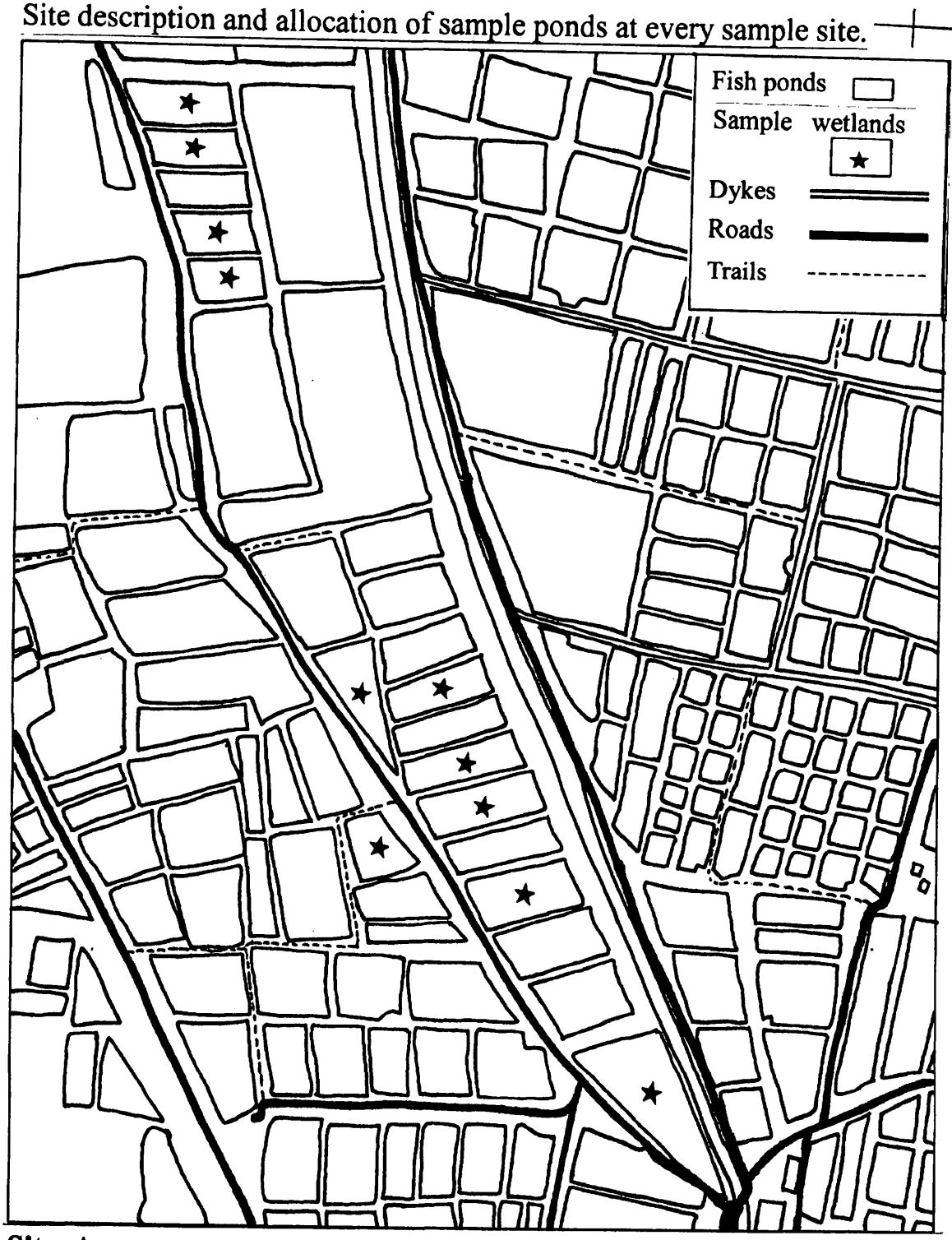
Appendices

Appendix 1.

Site description and allocation of sample ponds at every sample site.



Site: A

Number of ponds sampled:

Managed ponds: 5 Abandoned ponds: 7 Saltpans: 0 Natural wetlands: 0

Range of the basin area for each sample pond at site A: 0.6~4.4 hectares

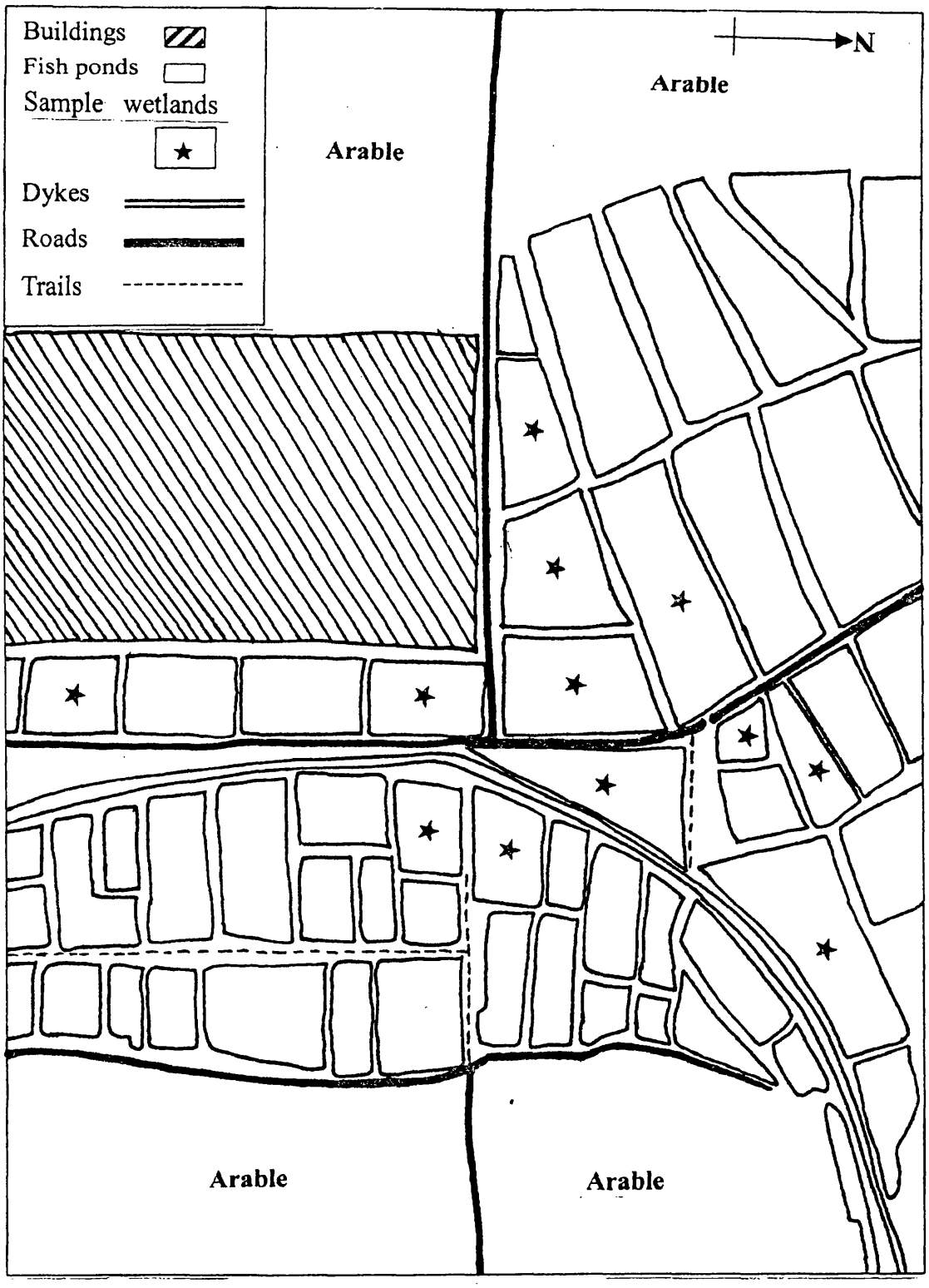
Abandonment time (abandoned ponds only): 2.5~20 years

Salinity: 4.6~30.7 ppt

Mean distance from the centre of site A, which is defined as the geometric centre of all sample ponds at site A, to seashore: 4900 metres

Mean distance from the centre of site A to the nearest main road: 66 metres

Total wetland density within a one-km radius from the centre of site A: 87%



Site: C

Number of ponds sampled:

Managed ponds: 2 Abandoned ponds: 10 Saltpans: 0 Natural wetlands: 0

Range of the basin area for each sample pond at site C: 0.2~2.0 hectares

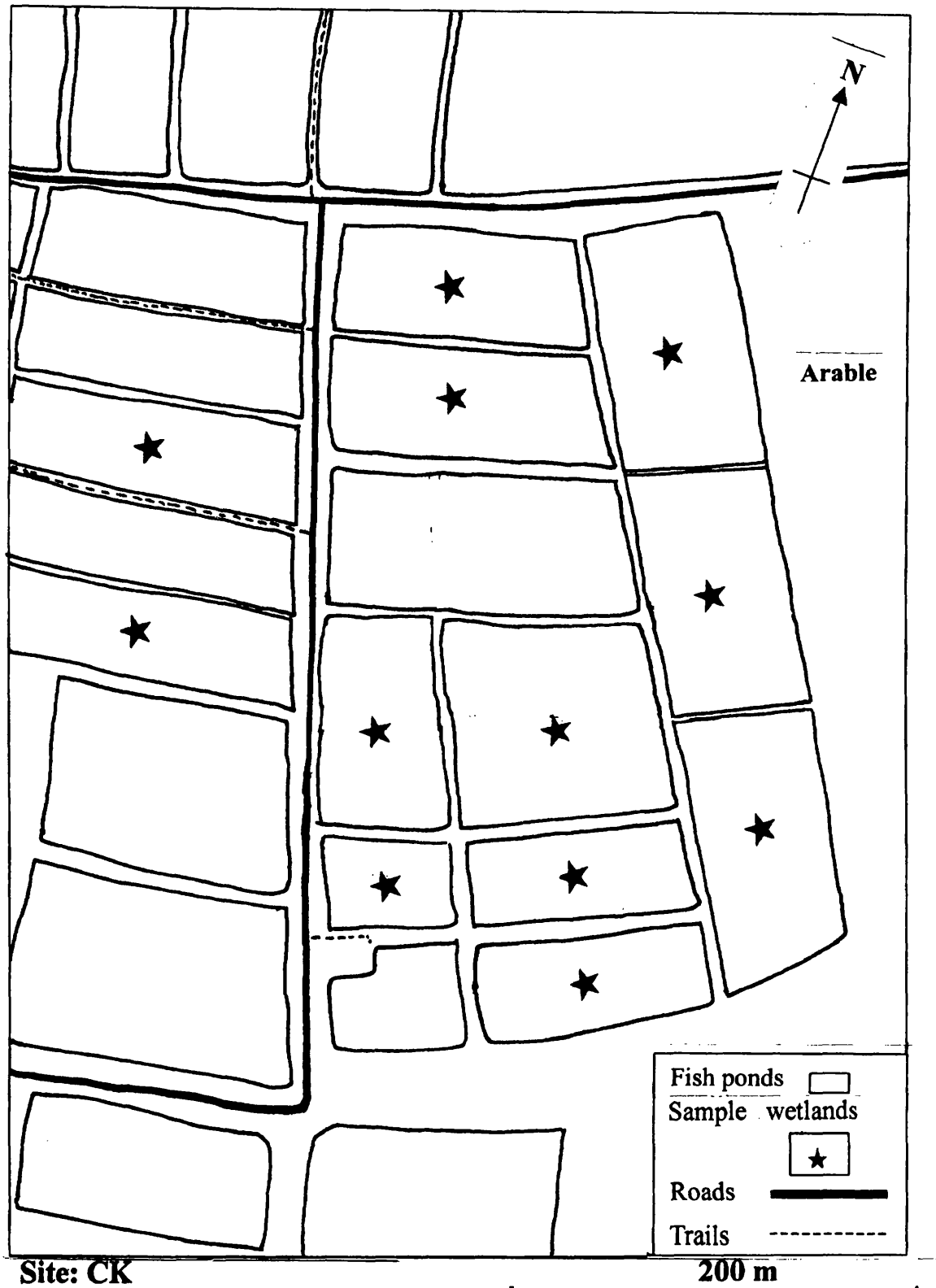
Abandonment time (abandoned ponds only): 11.5 years

Salinity: 0.45~26.2 ppt

Mean distance from the centre of siteC, which is defined as the geometric centre of all sample ponds at site A, to seashore: 725 metres

Mean distance from the centre of site C to the nearest main road: 119 metres

Total wetland density within a one-km radius from the centre of site C: 62%



Site: CK

Number of ponds sampled:

Managed ponds: 2 Abandoned ponds: 10 Saltpans: 0 Natural wetlands: 0

Range of the basin area for each sample pond at site CK: 0.3 ~0.9 hectares

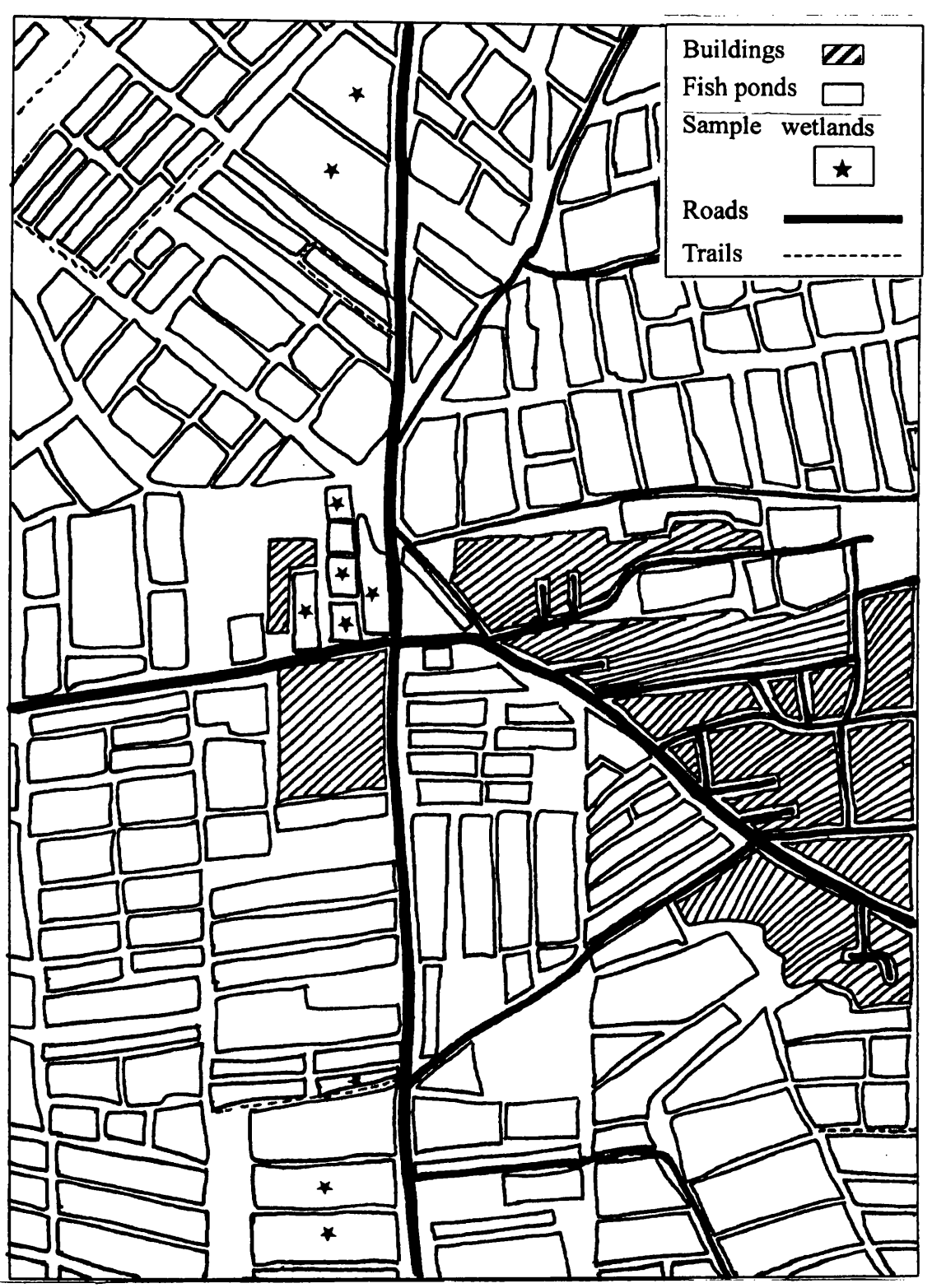
Abandonment time (abandoned ponds only): 3~8 years

Salinity: 4.3 ~24.7 ppt

Mean distance from the centre of site CK, which is defined as the geometric centre of all sample ponds at site CK, to seashore: 3800 metres

Mean distance from the centre of site CK to the nearest main road: 179 metres

Total wetland density within a one-km radius from the centre of site CK: 75%



Site: DC (Ducha)

Number of ponds sampled:

Managed ponds: 2 Abandoned ponds: 8 Saltpans: 1 Natural wetlands: 0

Range of the basin area for each sample pond at site DC: 0.1~1.4 hectares

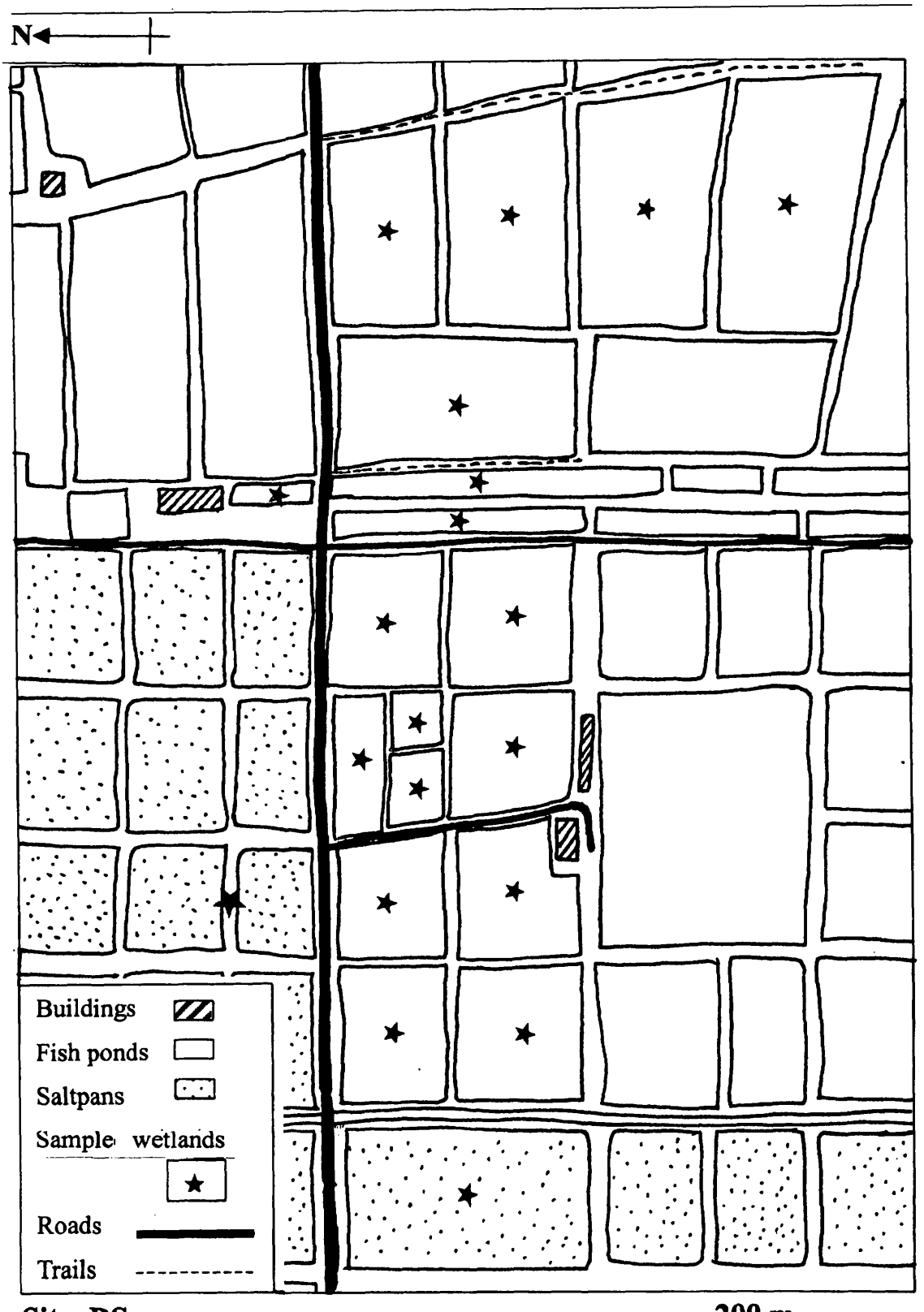
Abandonment time (abandoned ponds only): 1.2~5 years

Salinity (saltpans excluded): 1.0~44.5 ppt

Mean distance from the centre of site DC, which is defined as the geometric centre of all sample ponds at site DC, to seashore: 5360 metres

Mean distance from the centre of site DC to the nearest main road: 58 metres

Total wetland density within a one-km radius from the centre of site DC: 84%



Site: DS

Number of ponds sampled:

Managed ponds: 12 Abandoned ponds: 6 Saltpans: 0 Natural wetlands: 0

Range of the basin area for each sample pond at site DS: 0.1~1.4 hectares

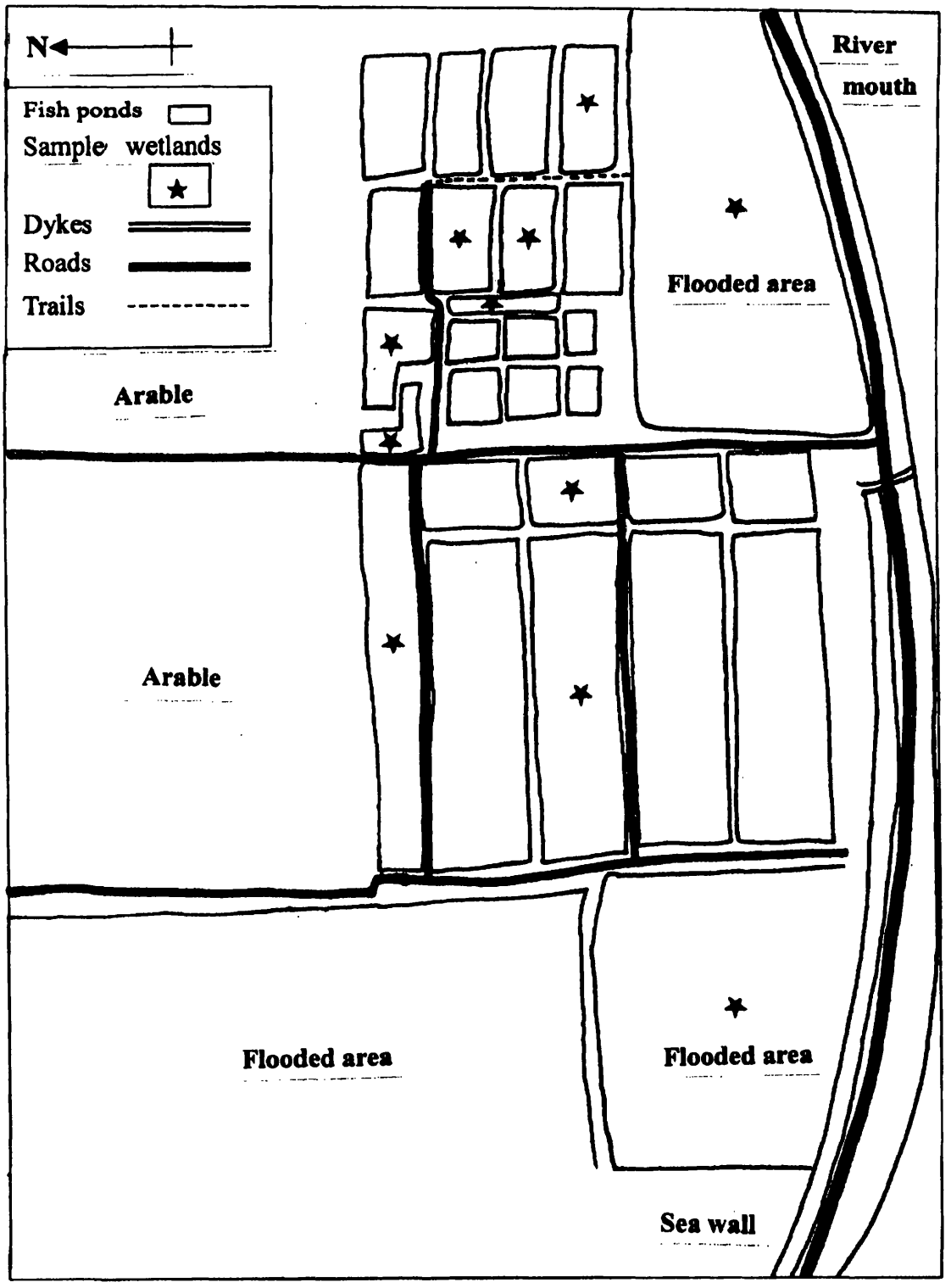
Abandonment time (abandoned ponds only): 1~2 years

Salinity: 3.2~52.6 ppt

Mean distance from the centre of site DS, which is defined as the geometric centre of all sample ponds at site DS, to seashore: 4680 metres

Mean distance from the centre of site DS to the nearest main road: 89 metres

Total wetland density within a one-km radius from the centre of site DS: 99%



Site: G

Number of ponds sampled:
Managed ponds: 0 Abandoned ponds: 10 Saltpans: 0 Natural wetlands: 3

Range of the basin area for each sample pond at site G: 0.1~60 (2.8 if natural wetlands are excluded) hectares

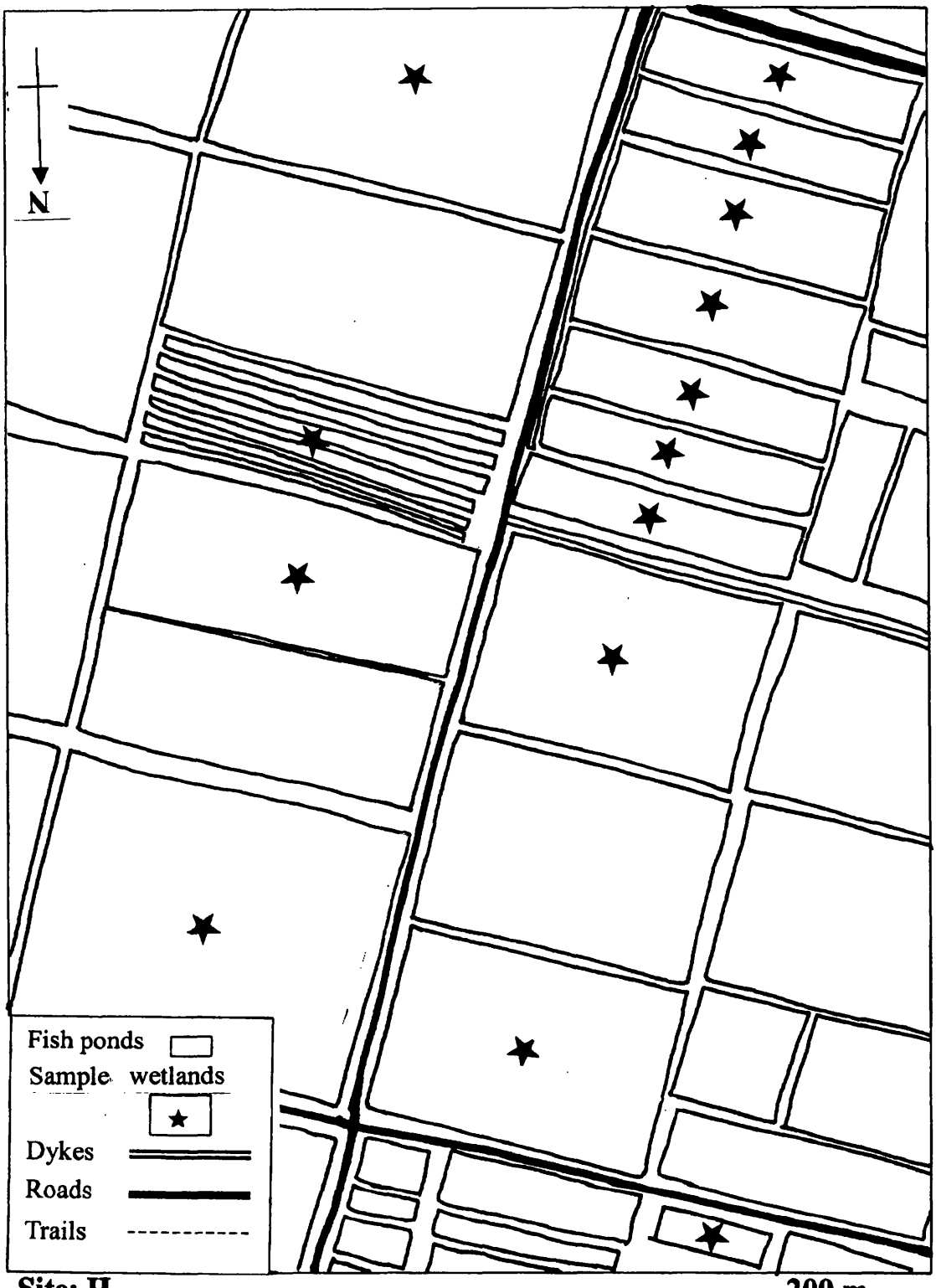
Abandonment time (abandoned ponds only): 11.5 years

Salinity: 6.3~27.8 ppt

Mean distance from the centre of site G, which is defined as the geometric centre of all sample ponds at site G, to seashore: 370 metres

Mean distance from the centre of site G to the nearest main road: 171 metres

Total wetland density within a one-km radius from the centre of site G: 70%



Site: H

Number of ponds sampled:
Managed ponds: 15 Abandoned ponds: 4 Saltpans: 0 Natural wetlands: 1

Range of the basin area for each sample pond at site H: 0.3~140 (8.3 if natural wetland is excluded) hectares

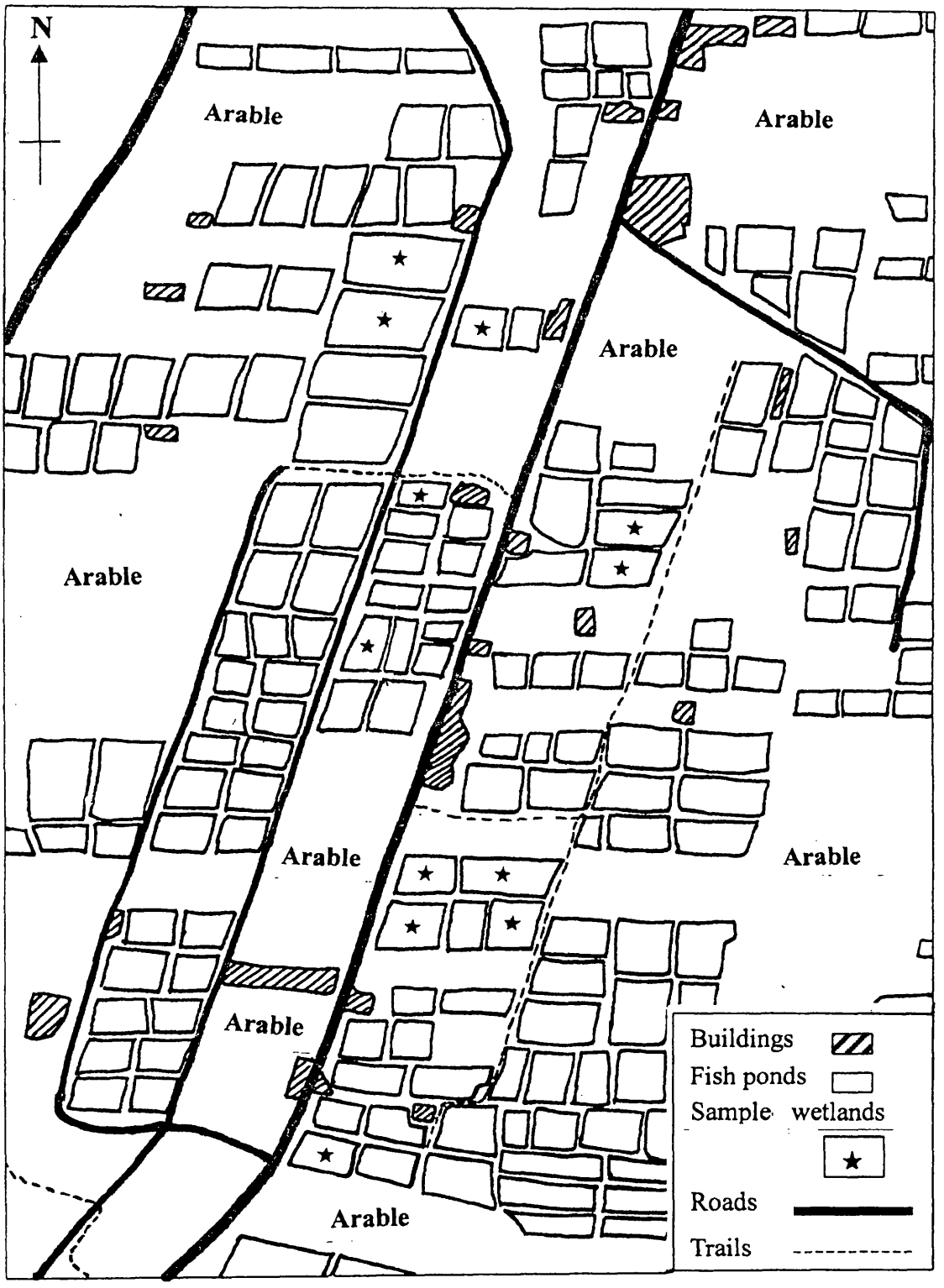
Abandonment time (abandoned ponds only): 2~12.5 years

Salinity: 29.0~50.5 ppt

Mean distance from the centre of site H, which is defined as the geometric centre of all sample ponds at site H, to seashore: 1520 metres

Mean distance from the centre of site H to the nearest main road: 241 metres

Total wetland density within a one-km radius from the centre of site H: 100%



Site: M

Number of ponds sampled:

Managed ponds: 2 Abandoned ponds: 9 Saltpans: 0 Natural wetlands: 0

Range of the basin area for each sample pond at site M: 0.1~0.4 hectares

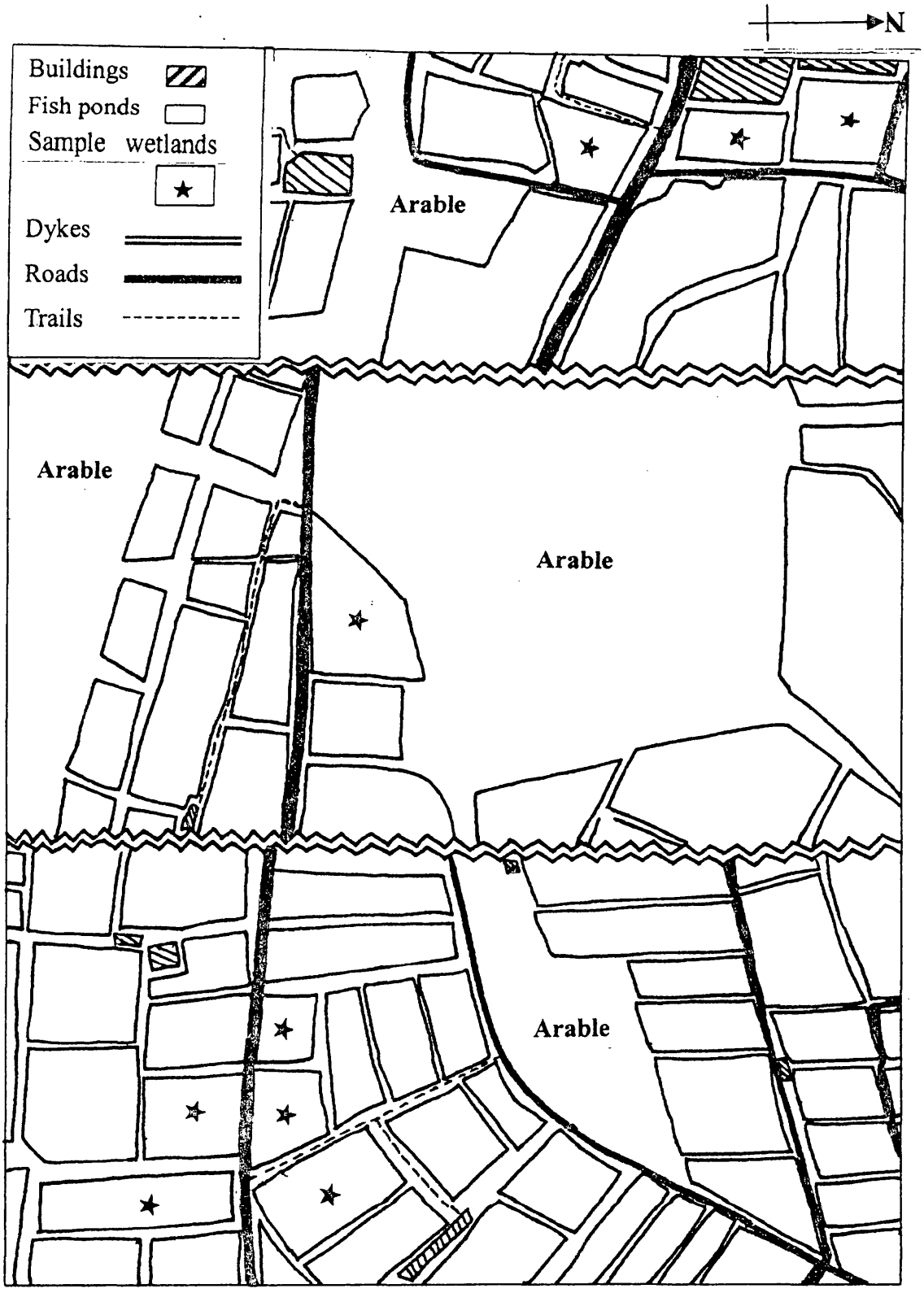
Abandonment time (abandoned ponds only): 1.5~8 years

Salinity: 0.4~0.9 ppt

Mean distance from the centre of site M, which is defined as the geometric centre of all sample ponds at site M, to seashore: 4500 metres

Mean distance from the centre of site M to the nearest main road: 75 metres

Total wetland density within a one-km radius from the centre of site M: 39%



Site: MV **200 m**

Number of ponds sampled:
Managed ponds: 5 Abandoned ponds: 5 Saltpans: 1 Natural wetlands: 0

Range of the basin area for each sample pond at site MV: 0.3~1.4 hectares

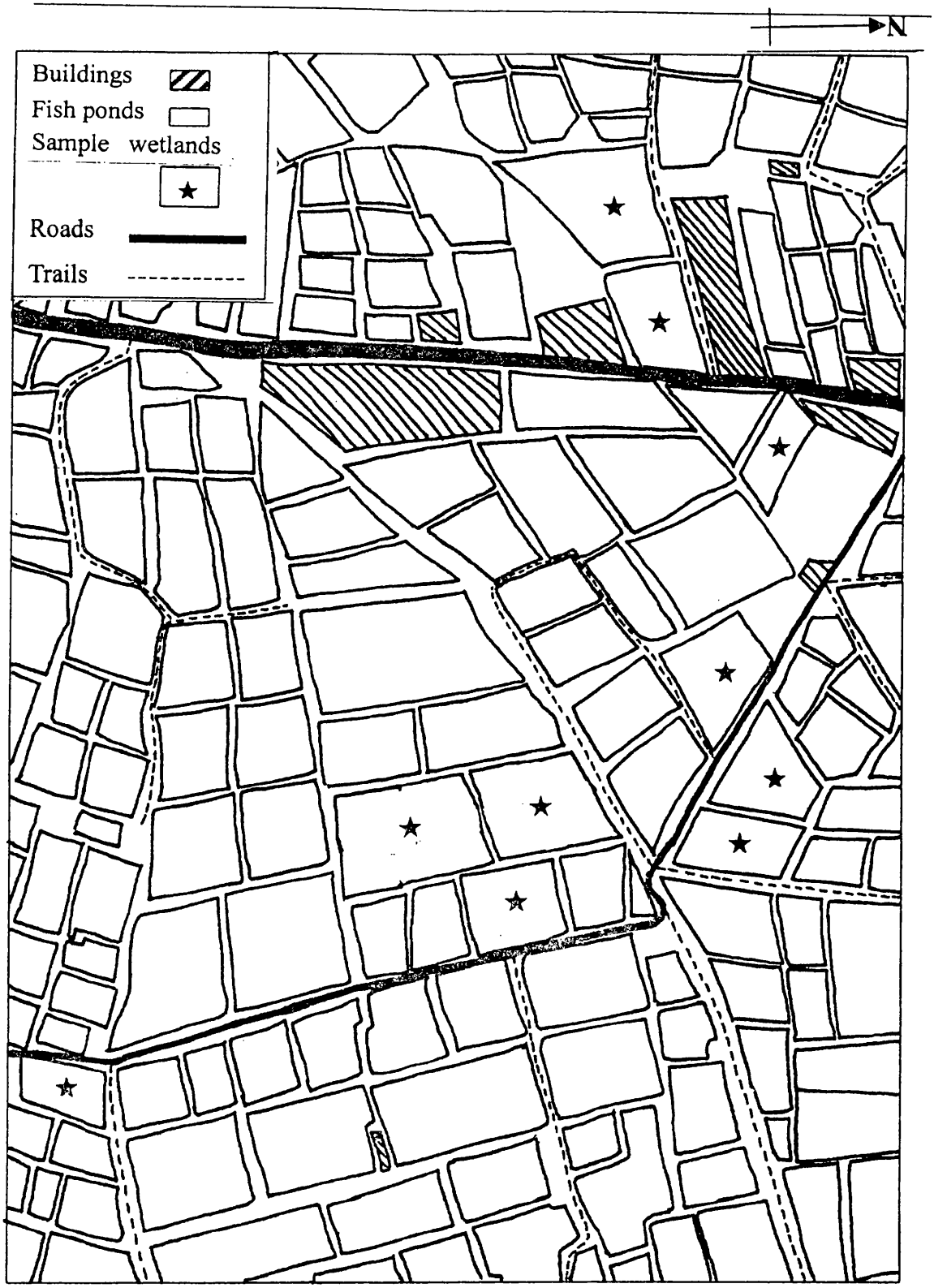
Abandonment time (abandoned ponds only): 1~2years

Salinity (saltpans excluded): 1.4~18.5 ppt

Mean distance from the centre of site MV, which is defined as the geometric centre of all sample ponds at site MV, to seashore: 3800 metres

Mean distance from the centre of site MV to the nearest main road: 49 metres

Total wetland density within a one-km radius from the centre of siteMV: 70%



Site: P (Pudia)

Number of ponds sampled:

Managed ponds:2 Abandoned ponds: 8 Saltpans: 2 Natural wetlands: 0

Range of the basin area for each sample pond at site P: 0.3~2.3 hectares

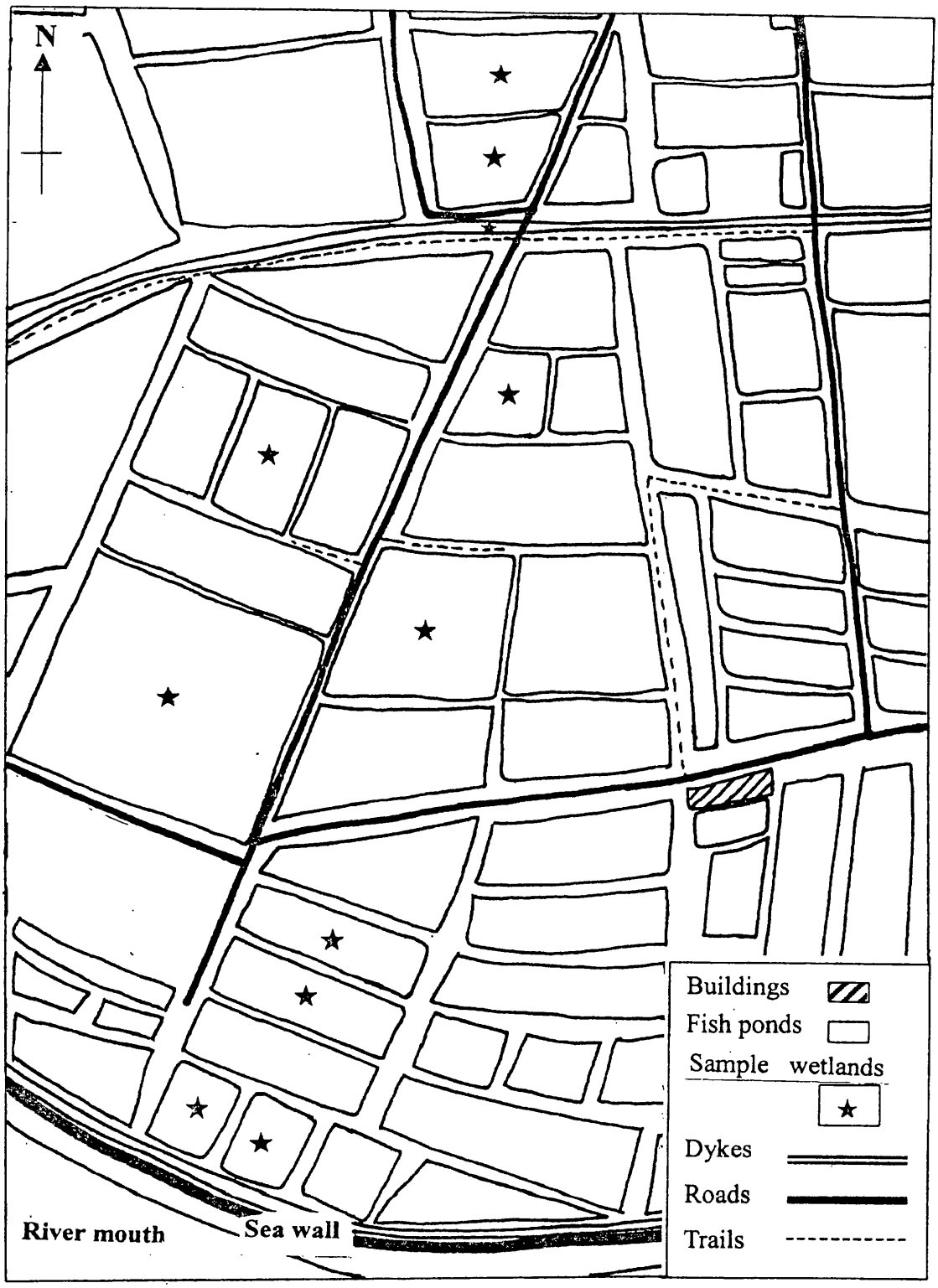
Abandonment time (abandoned ponds only): 1~3.2 years

Salinity (saltpans excluded): 0.2~10.7 ppt

Mean distance from the centre of site P, which is defined as the geometric centre of all sample ponds at site P, to seashore: 1690 metres

Mean distance from the centre of site P to the nearest main road: 63 metres

Total wetland density within a one-km radius from the centre of site P: 93%



Site: S **200 m**

Number of ponds sampled:

Managed ponds:6 Abandoned ponds: 4 Saltpans: 0 Natural wetlands: 1

Range of the basin area for each sample pond at site S: 0.3~9 hectares

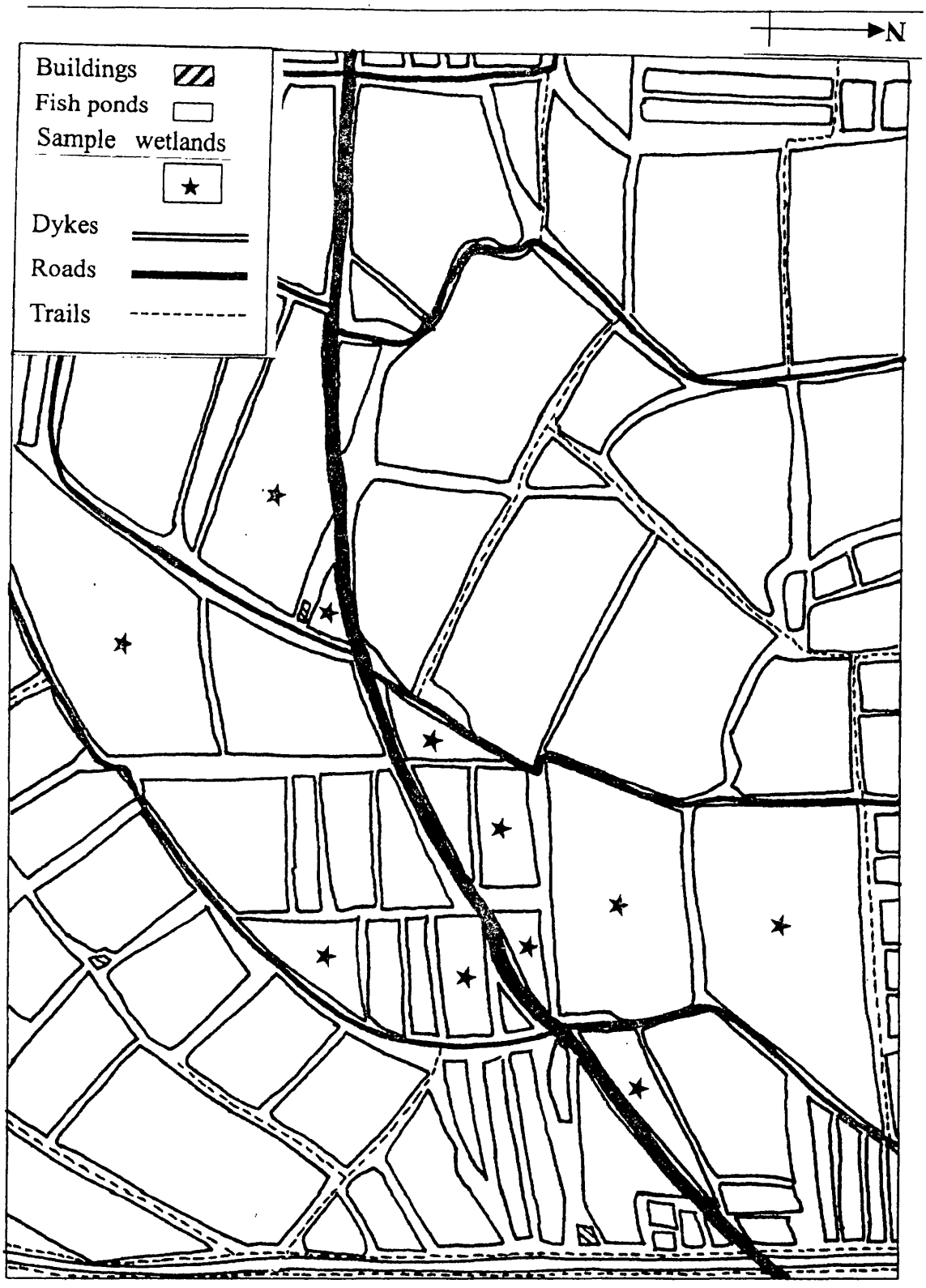
Abandonment time (abandoned ponds only): 0.5~15 years

Salinity: 11.1~39.7 ppt

Mean distance from the centre of site S, which is defined as the geometric centre of all sample ponds at site S, to seashore: 2950 metres

Mean distance from the centre of site S to the nearest main road: 325 metres

Total wetland density within a one-km radius from the centre of site S: 91%



Site: T (Tuchen)

Number of ponds sampled:

Managed ponds:3 Abandoned ponds: 8 Saltpans: 0 Natural wetlands: 0

Range of the basin area for each sample pond at site T: 0.2~5.5 hectares

Abandonment time (abandoned ponds only): 1.5~8.5 years

Salinity: 7.4~38.8 ppt

Mean distance from the centre of site T, which is defined as the geometric centre of all sample ponds at site T, to seashore: 635 metres

Mean distance from the centre of site T to the nearest main road: 94 metres

Total wetland density within a one-km radius from the centre of site T: 94%

Appendix 2. Avian fauna recorded during the study period in the study area.

Order Podicipediformes

Family Podicipedidae

Podiceps ruficollis Little Grebe

Order Pelecaniformes

Family Phalacrocoracidae

Phalacrocorax carbo Great Cormorant

Order Ciconiiformes

Family Ardeidae

Ardea cinerea Grey Heron

Ardea purpurea Purple Heron

Bubulcus ibis Cattle Egret

Butorides striatus Striated Heron

Egretta alba Great Egret

Egretta garzetta Little Egret

Egretta intermedia Intermediate Egret

Ixobrychus cinnamomeus Cinnamon Bittern

Ixobrychus flavicollis Black Bittern

Ixobrychus sinensis Chinese Little Bittern

Nycticorax nycticorax Black-crowned Night Heron

Family Threskiornithidae

Platalea minor Black-faced Spoonbill

Threskiornis aethiopicus Sacred Ibis

Order Anseriformes

Family Anatidae

Anas acuta Pintail

Anas clypeata Northern Shoveler

Anas crecca Green-winged Teal

Anas falcata Falcated Teal

Anas penelope Eurasian Wigeon

Anas platyrhynchos Mallard

Anas poecilorhyncha Spot-billed Duck

Anas querquedula Garganey

Anas strepera Gadwall

Aythya ferina Common Pochard

Aythya fuligula Greater Scaup

Tadorna tadorna Common Shelduck

Appendix 2. (Cont') Avian fauna recorded during the study period in the study area.

Order Falconiformes

Family Accipitridae

Accipiter soloensis Chinese Sparrowhawk

Circus aeruginosus Marsh Harrier

Circus cyaneus Hen Harrier

Pandion haliaetus Osprey

Family Falconidae

Falco tinnunculus Common Kestrel

Order Galliformes

Family Phasianidae

Excalfactoria chinensis Indian Blue Quail

Order Gruiformes

Family Turnicidae

Turnix suscitator Bustard Quail

Family Rallidae

Amaurornis phoenicurus White-breasted Water Hen

Fulica atra Coot

Gallinula chloropus Moorhen

Porzana fusca Ruddy-breasted Crake

Rallina eurizonoides Banded Crake

Rallina fasciata Red-legged Crake

Rallus aquaticus Water Rail

Rallus striatus Blue-breasted Banded Rail

Order charadriformes

Family Rostratulidae

Rostratula benghalensis Painted Snipe

Family Charadriidae

Charadrius alexandrinus Kentish Plover

Charadrius dubius Little Ringed Plover

Charadrius leschenaultii Greater Sand Plover

Charadrius mongolus Mongolian Plover

Pluvialis dominica American Golden Plover

Pluvialis squatarola Black-bellied Plover

Vanellus vanellus Lapwing

Family Scolopacidae

Arenaria interpres Ruddy Turnstone

Appendix 2. (Cont') Avian fauna recorded during the study period in the study area.

Calidris acuminata Sharp-tailed Sandpiper
Calidris alpina Dunlin
Calidris canutus Red Knot
Calidris ferruginea Curlew Sandpiper
Calidris ruficollis Rufous-necked Stint
Calidris subminuta Long-toed Stint
Calidris temminckii Temminck's Stint
Calidris tenuirostris Great Knot
Eurynorhynchus pygmeus Spoon-billed Sandpiper
Gallinago gallinago Common Snipe
Gallinago stenura Pintail Snipe
Limicola falcinellus Broad-billed Sandpiper
Limnodromus semipalmatus Asian Dowitcher
Limosa lapponica Bar-tailed Godwit
Limosa limosa Black-tailed Godwit
Numenius arquata Eurasian Curlew
Numenius minutus Little Curlew
Numenius phaeopus Whimbrel
Philomachus pugnax Ruff
Tringa brevipes Gray-tailed Tattler
Tringa glareola Wood Sandpiper
Tringa hypoleucos Common Sandpiper
Tringa nebularia Greenshank
Tringa ochropus Green Sandpiper
Tringa stagnatilis Marsh Sandpiper
Tringa totanus Redshank
Xenus cinereus Terek Sandpiper

Family Recurvirostridae

Himantopus himantopus Black-winged Stilt
Recurvirostra avosetta Avocet

Family Phalaropodidae

Phalaropus lobatus Northern Phalarope

Family Glareolidae

Glareola maldivarum Large Indian Pratincole

Family Laridae

Larus crassirostris Black-tailed Gull
Lanus ridibundus Black-headed Gull

Appendix 2. (Cont') Avian fauna recorded during the study period in the study area.

Larus saundersi Saunders' Gull
Sterna albifrons Little Tern
Sterna caspia Caspian Tern
Sterna dougallii Roseate Tern
Sterna hirundo Common Tern
Sterna hybrida Whiskered Tern
Sterna leucoptera White-winged Black Tern
Sterna nilotica Gull-billed Tern

Order Columbiformes

Family Columbidae

Streptopelia chinensis Spotted Dove
Streptopelia tranquebarica Red Turtle Dove
Columba livia Rock Dove

Order Cuculiformes

Family Cuculidae

Centropus bengalensis Lesser Coucal

Order Coraciformes

Family Alcedinidae

Alcedo atthis Common Kingfisher
Halcyon pileata Black-capped Kingfisher

Order Apodiformes

Family Apodidae

Apus affinis House Swift

Order Passeriformes

Family Alaudidae

Alauda gulgula Oriental Skylark

Family Hirundinidae

Hirundo daurica Red-rumped Swallow
Hirundo rustica Barn Swallow
Hirundo tahitica Pacific Swallow
Riparia paludicola brown-throated Sand Martin

Family Motacillidae

Anthus cervinus Red-throated Pipit
Motacilla alba White Wagtail
Motacilla cinerea Gray Wagtail
Motacilla flava Yellow Wagtail

Appendix 2. (Cont') Avian fauna recorded during the study period in the study area.

Family Pycnonotidae

Pycnonotus sinensis Chinese Bulbul

Family Laniidae

Lanius cristatus Brown Shrike

Lanius schach Black-headed Shrike

Family Muscicapidae

Acrocephalus orientalis Oriental Great Reed Warbler

Cettia diphone Bush Warbler

Cettia fortipes Strong-footed Bush Warbler

Cisticola juncidis Fan-tailed Warbler

Monticola solitarius Blue Rock Thrush

Phoenicurus auroreus Daurian Redstart

Prinia flaviventris Yellow-bellied Prinia

Prinia polychroa Brown Hill Warbler

Prinia subflava Tawny-flanked Prinia

Saxicola torquata Stonechat

Family Zosteropidae

Zosterops japonica Japanese White-eye

Family Emberizudae

Emberiza spodocephala Black-faced Bunting

Family Ploceidae

Lonchura punctulata Nutmeg Mannikin

Passer montanus Tree Sparrow

Family Sturnidae

Acridotheres cristatellus Crested Myna

Family Dicruridae

Dicrurus macrocercus Black Drongo

Family Corvidae

Dendrocitta formosae Himalayan Tree Pie

Pica pica Magpie

Appendix 3. Avian fauna of the three pairs of experimental ponds.

	Pair 1	Pair 2	Pair 3
Order Podicipediformes			
Family Podicipedidae			
Podiceps ruficollis Little Grebe	V	V	V
Order Ciconiiformes			
Family Ardeidae			
Ardea cinerea Grey Heron	V		
Bubulcus ibis Cattle Egret	V	V	
Egretta alba Great Egret	V		V
Egretta garzetta Little Egret	V	V	V
Egretta intermedia Intermediate Egret	V		V
Ixobrychus cinnamomeus Cinnamon Bittern			V
Nycticorax nycticorax Black-crowned Night Heron	V	V	V
Family Threskiornithidae			
Platalea minor Black-faced Spoonbill			V
Order Anseriformes			
Family Anatidae			
Anas crecca Green-winged Teal	V	V	V
Anas querquedula Garganey	V	V	
Order Gruiformes			
Family Rallidae			
Gallinula chloropus Moorhen	V	V	V
Order charadriformes			
Family Charadriidae			
Charadrius alexandrinus Kentish Plover			V
Charadrius dubius Little Ringed Plover	V	V	V
Family Scolopacidae			
Calidris alpina Dunlin			V
Calidris ruficollis Rufous-necked Stint			V
Gallinago gallinago Common Snipe	V		V
Tringa glareola Wood Sandpiper	V	V	V
Tringa nebularia Greenshank	V		V
Trinaga ochropus Green Sandpiper			V
Tringa stagnatilis Marsh Sandpiper	V		V
Tringa totanus Redshank	V		V
Family Recurvirostridae			
Himantopus himantopus Black-winged Stilt	V	V	V
Order Coraciformes			
Family Alcedinidae			
Alcedo atthis Common Kingfisher	V		
Order Passeriformes			
Family Muscicapidae			
Acrocephalus orientalis Oriental Great Reed Warbler	V		