Modelling Information Acquisition and its Impact on Social Structure

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Abstract

Numerous social structures exist in the animal kingdom, all of which fill a niche in which the organisms find themselves. The various levels of aggregation and hierarchy within the majority of these social structures can be explained by selective pressures such as predation avoidance, resource exploitation and mating opportunity. The necessity and affordance of acquiring social and ecological information has been proposed as another possible factor in the evolution of certain colonial structures, such as those of ravens and ospreys. We explore the conditions under which the use of socially acquired information benefits individuals within a colony using an agent-based model. The agents are simple finite-state automata following a forage-and-return behaviour in which they can also breed and die. The model allows agents to socially acquire information by determining whether foragers have been successful. The agents can then decide whether to follow other agents or forage on their own. Increased competition at foraging sites is the cost for following but environments in which resources are patchily distributed and/or ephemeral in time provide a challenge to individual foragers. The preference for the use socially over personally acquired information, in the model, is a heritable trait and allowed to vary across generations. We demonstrate that more sociality in groups evolves in challenging environments. Although the model is an abstract representation of colonial species, it can provide a platform for understanding the behaviour of real animals.

Introduction

Several types of social structure are exhibited in the animal kingdom; from solitary individuals through to eusocial groups and even 'colonial organisms' such as the Portuguese man o' war. Group living imparts a cost on the individuals through increased competition for resources, increased likelihood of detection by predators and increased spread of parasites and pathogens [15]. However, there are obvious benefits such as better predator detection, increased mating opportunity, reduced thermo-regulation and increased information acquisition opportunity [10, 6].

One standard conception of information is anything that reduces uncertainty [4]. However, when concerned with behavioural and evolutionary ecology it is also important that it be useful [3]. Information can be acquired personally, by exploring and interacting with one's environment. One can also gain information through observation of conspecifics and, in some cases, heterospecifics [8]. This socially acquired information can be through purposeful signals such as the waggle dance of honey bees [13] or through 'inadvertent social information' [3]. Social cues are a discrete form of inadvertent social information such as vultures dropping their legs indicating hey have spotted a carcass to feed on [5]. These cues can create cascades of information spread, drawing in individuals from vast distances, but, due to the limited detail of the information, can lead to sub-optimal behaviour [7]. More graded public

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information can lead to more intelligent decision making such as that by ospreys determining foraging strategy based on the types of fish with which other ospreys return to the roost [9]. The affordance of being able to socially acquire information greatly reduces the cost to individuals of acquisition but for those individuals that excel at personally acquiring information, the cost of information parasitism may be greater than the benefit.

The purpose of information acquisition is to inform the decision making process. Whether it be information regarding which females are in oestrus guiding mating decisions or information about resource locations directing foraging paths, the informed individual has an advantage over uninformed conspecifics. When modelling movement decisions in simple organisms, random walk models have dominated the literature [2]. However, many examples of exist of informed route making in species such as gibbons [1] and spider monkeys [16]. When an individual is also a member of a group, there is the necessity to integrate personal and socially acquired information. For groups that remain together, some species follow high social status individuals, others show voting behaviours [12]. Other groups don't remain together, forming dynamic social structures such as fission-fusion in which subgroups split off to forage and return to the larger group at after a period of time. Studies such as that by Kerth et al. [11] suggest that fission-fusion species show a hierarchy of reliance on information:

negative personal > socially acquired > positive personal

One hypothesis proposed to explain aggregation into colonies is the information centre hypothesis, in which the pressure to gather information, particularly regarding sparse resources, is the main aggregation pressure [17]. Here we explore how variations in the environment affect the information acquisition strategy of colonial individuals.

Experiments

We use agent-based modelling (ABM), in which individuals follow a simple set of rules which can produce complex macro-level patterns. ABM has been used in a variety of fields including behavioural ecology, for example to model baboon group decision making [14]. In our model individuals are able to gather information about resources within the environment through searching. They can also choose to follow other agents that are leaving the roost to feed at known resource locations. The state diagram for the agent behaviours is shown in figure 1. Each agent has a level of preference for using one behaviour over the other and this preference is passed on to their offspring. There are costs associated with each strategy, whether it be the possibility of not finding food when searching or increased competition for food when following.

We simulated groups of agents in environments in which resources are more or less patchily distributed and/or more or less ephemeral. The total amount of food within the environment is the same regardless of patchiness, so if there are fewer resource patches, each one will hold more food. Figure 2 shows that, when resources are more difficult to find by searching alone, there are a greater range of conditions where groups of agents can only survive when they can socially acquire information. Further, the population sizes achievable are related to the level of social information acquisition as well as the ease of finding resources. The usefulness of information regarding resources is increased in patchy environments as one is less likely to find resources by searching and there is more likely to be food left at a patch even if one follows another agent to it.

In order to explore how a preference for socially acquired information would evolve, we ran the simulation over a range of patchiness levels and allowed the inherited information acquisition preference to vary by a random normally-distributed amount. As such, there will be a spread of information acquisition strategies within a group. Those individuals with an information acquisition preference most suited to the environment will have a fitness advantage over other agents and will produce fitter offspring. We observe the change in information preference over 500 generations, from a starting preference of 0.5 i.e equally likely to choose personal or social information acquisition. In very patchy environments, with fewer than 20 resource patches, populations were unable to survive for 500 generations. Figure 3 shows that the number of resources within the environment, and therefore the probability of finding resources through searching, is positively correlated to the preference that agents have for following as opposed to searching alone. Even in environments in which there are many locations to feed from, and therefore

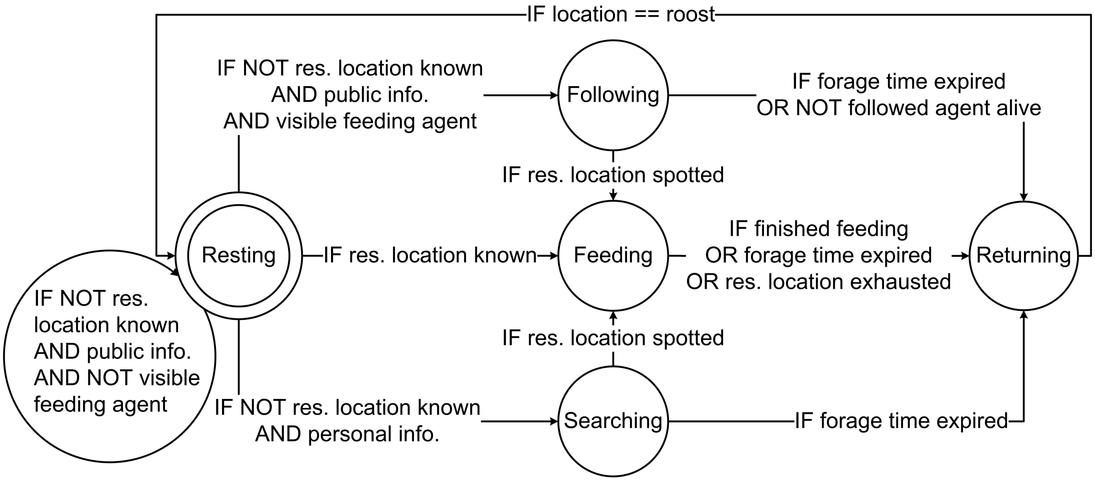

Figure 1: A state machine describing the behaviour of each agent. When an agent decides to socially acquire information (or use "public information") they leave the roost following another agent, if there is one to follow. If the agent decides to use "personal information" they leave the roost and perform a search. If they know about a resource location, they head directly for it. Individuals die if their energy falls to 0 or their age reaches a threshold. Agents also produce offspring when at the roost, if their energy level is over a given threshold.

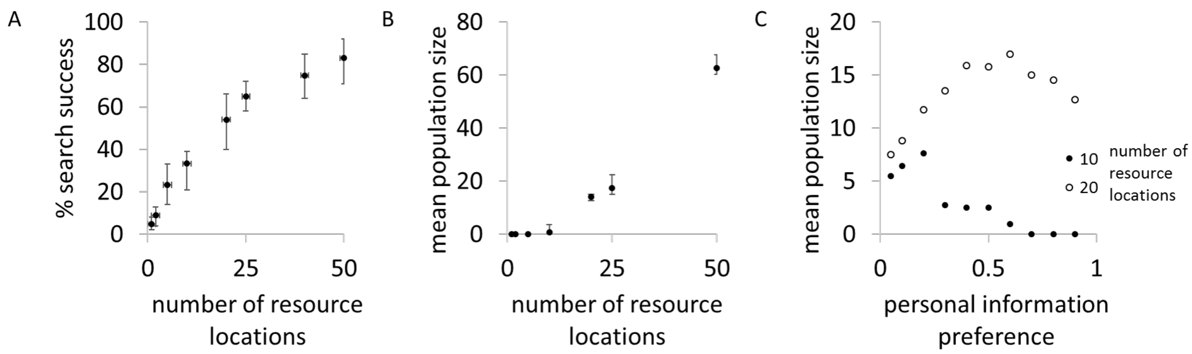

Figure 2: A) When an agent leaves the roost to search for food, the likelihood of successfully finding a patch corresponds to the number of resource patches in the environment. B) After 50 generations, when the number of resource locations is low, groups of agents that don't have the ability to socially acquire information aren't able to survive. C) However, if the agents are allowed to socially acquire information, rather than rely just on their own personal information, groups are able to survive. (The bars show the range, of the last 5 generations, for each replicate and the black circles show the mean of the replicates.)

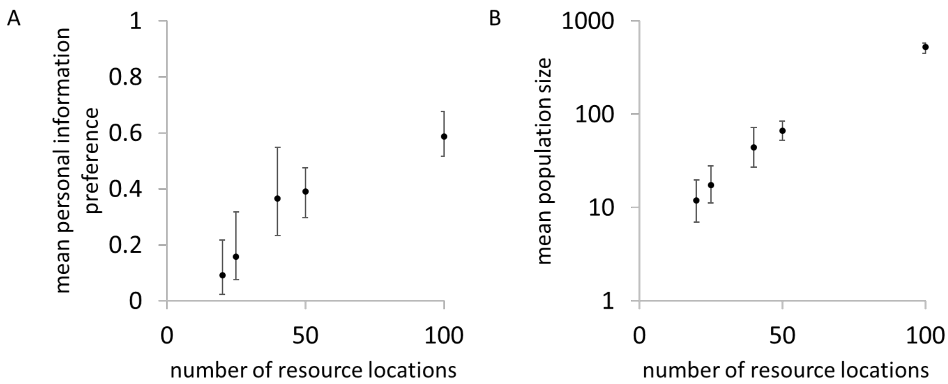

Figure 3: Over 500 generations the preference for socially acquired information over personal information is allowed to adapt. A) When resources are very patchily distributed, individuals that take greater advantage of socially acquired information have a fitness advantage leading to a change in the population's information preference. B) The size of the population that an environment is able to sustain, even after 500 generations of adaptation, follows an exponential trend with the number of resources within it. (The bars show the range, of the last 10 generations, across 8 replicates and the black circles show the mean of the replicates.)

limited food at each resource patch, there is no drive towards preferring personal information acquisition. This is likely due to the fact that, in such environments, even if an agent follows another and the resource patch becomes exhausted there is likely to be another patch close by at which the agent can feed. We do see that the number of agents that the environment is capable of maintaining is also correlated to the resource patchiness.

Further, we looked at how ephemerality of resources affects the information acquisition strategies of agents. We varied how long each resource patch existed in the environment before disappearing. When a resource disappeared or was exhausted a new patch was created. Again, we ran the simulation for 500 generations and recorded the preferences of each agent for socially or personally acquiring information. The results can be seen in figure 4. Ephemerality of resources leads to a clear preference for socially acquiring information over foraging alone. Interestingly, it also leads to higher sustainable population levels. This may be due to depleted resource patches being replaced by those with greater quantities of food. If a large number of agents follow to a single patch, the newly created patch will be able to feed many more than the depleted one. However, when the number of resource locations is very low (25 patches and below), a long resource lifetime is required for a population to have a chance of survival. Unexpectedly, even when the resource lifetime is at its lowest, and all information is redundant as agents don't have time to return to resources before they disappear, agents still have a clear preference for following as opposed to searching alone.

Conclusion

Pressures and costs to aggregating in to groups vary depending on context. The information centre hypothesis proposed that aggregation in to social groups is driven by the affordance of sharing information regarding sparse resources. We built an agent based model in which individuals could have a weighted preference for foraging alone by randomly searching for resources or following knowledgeable individuals. Simulations showed that, when resources were sparsely distributed, groups that had a preference for social information acquisition were able to survive where non-sharing groups were not. By allowing the information acquisition preference to vary across generations, we showed that socially acquiring information in patchy environments provides a fitness advantage which leads to a "more social" group. Finally, we demonstrated that ephemerality has an impact on preference for socially acquiring information, though surprisingly also enables larger groups to survive.

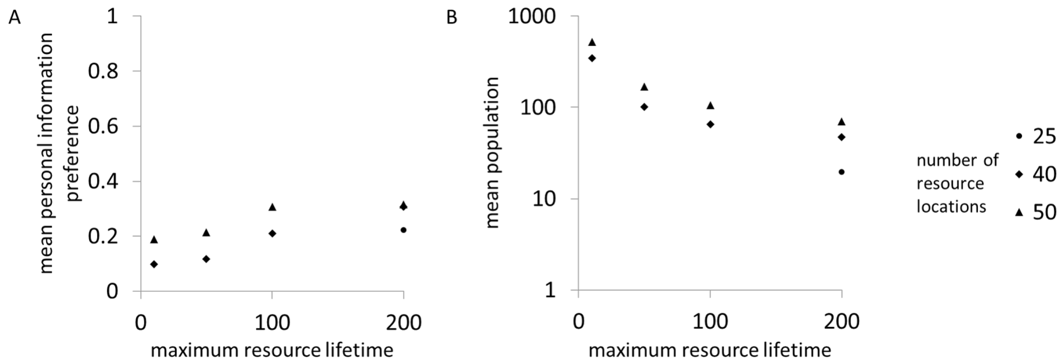

Figure 4: A) In environments with the most patchy *and* ephemeral resources, the agents favour following other agents over foraging on their own. B) Very ephemeral resources can sustain larger populations than longer lived resources. However, with the number of resource locations as low as 25, a population can only be sustained when there is a long resource lifetime. (The data points show the means of the last 10 generations of 8 replicates.)

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