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The evolution of donators in a common-pool resource problem

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Abstract Issues regarding foraging in groups have been addressed and researched in a range of domains. Questions arise regarding the benefits to the group as a whole and the cost placed upon individual group members. In this paper, we model the foraging problem as a common resource pool problem and evolve populations in a range of scenarios. In these simulations, agents (group members) forage for food, may contribute to a common pool resource and may benefit from this group resource. We present and discuss results illustrating the scenarios under which agents evolve to behave for the common good of the group and its effect on the survival and the fitness of the population.

Keywords Evolutionary computation · Cooperation · Foraging · Common pool resource problems · Artificial life

1 Introduction

The importance of group behaviours has been addressed in a range of domains including, among others, biology, anthropology, ecology and artificial life. Most species exhibit some form of group behaviour. The advantages and benefits of group membership include, among others, increased anti-predator vigilance (Treherne and Foster 1980), conservation of energy (Andrews and Belknap 1986), dilution of risk (Turner and Pitcher 1986) and foraging benefits (Creel 1997, Schmitt and Strand 1982, Wilkinson 1984). There are also potential costs

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associated with group membership; examples include potential theft of individual resources (klepoparasitism) (Broom and Ruxton 2003) and interference in foraging (Ruxton 1993).

Several of the oft-cited examples of group behaviour represent social dilemma problems where the optimal behaviour for the group differs from behaviours that are best for the individual. Free-rider problems abound whereby individuals may reap the benefit of group membership while avoiding the costs. The task of foraging and hunting represents one such free-rider problem. In many cases, foraging as a group confers an advantage to the members in the group. However, there is a temptation to reap the rewards while attempting to avoid the costs.

There are many examples of group behaviour whereby members choose not to free ride and instead choose the behaviour that is collectively rational (Wilkinson 1984).

Several of these examples can be modelled as a common resource pool problem, where participants may contribute to a common pool and may also utilise this pool when required.

In this paper, we evolve populations of agents participating in foraging tasks (in different environments). In this simulator, agents may contribute to a given pool which may be used by all members.

The paper is structured as follows. The following section briefly discusses some related work. Section 3 discusses our model and experimental setup. The subsequent sections presents results, discussions and conclusions.

2 Related work

2.1 Foraging and groups

The majority of work undertaken in the study of foraging in groups has involved empirical studies of species and their behaviours. There have been several studies on particular examples of cooperative group behaviour adopted in foraging. These have involved: individuals working together to attack and kill a prey that individually would have been impossible to kill (Creel and Creel 1995); sharing information regarding the location of prey or food (Valone 1989); and sharing obtained food with other members (Wilkinson 1984). An oft-cited example of food sharing by contributing to a common pool is that of the Aché tribe (Gurven 2004) whereby hunters donate all their gains to a common pool and exclude themselves from sharing in their own hunted prey.

2.2 Social dilemmas and common pool resource problems

Problems inherent in group foraging can be viewed as social dilemmas and free-rider problems. In these problems, all group members benefit from whatever utility or gain is earned by the group. However those that do not contribute to the common pool effectively gain the most by not expending energy in contributing. A well-known example is the *Tragedy of the Commons* (Hardin 1968). In this dilemma, land (the commons) is freely available for farmers to use for grazing cattle. For any individual farmer, it is advantageous to use this resource rather than their own land. However, if all farmers adopt the same reasoning, the commons will be over-used and soon will be of no use to any of the participants, resulting in an outcome that is sub-optimal for all farmers.

This is has been modelled in many ways including the N-player prisoner's dilemma and as common pool resource problems. In previous work, researchers have investigated means which induce the optimal outcome for the group. Previous approaches include spatial constraints (Lindgren and Nordahl 1994, Hauert 2006, Dieckmann et al. 2000), tagging mechanisms (Riolo 1997) and trust and reputation systems (Ramchurn et al. 2004).

3 Model

The model consists of a population of agents that inhabit an environment where they must forage for food to survive. Each agent is born with a certain amount of energy that is expended during its life. The agent has a number of foraging opportunities, each of which cost the agent one unit of life energy. If the agent successfully finds food, its life energy is augmented. The likelihood of an agent successfully finding food is controlled by a simple probability. This is a global probability, meaning that all agents have the same probability of finding food.

Each agent also has an opportunity to donate foraged food to a common pool. The amount of food that an agent will donate to the pool is determined by its genetic makeup. Each agent has a chromosome of 20 bits which corresponds to the amount of food that agent will donate to the pool at the end of all foraging turns.

Once all agents have foraged for the given number of foraging turns, the pool is redistributed across the population. However, the pool is also allowed to grow during this time, meaning that the amount distributed at the end of each generation is larger than the amount that was placed in the pool. This is done to ensure that there is sufficient incentive for an agent to donate to the common pool. An agent's fitness is directly linked to its life energy and therefore, to the amount of food it has been able to forage, plus the slice of the pool it receives. Mating opportunities are proportional to fitness, but if an agent's life force reaches 0 the agent is considered to have died and is not capable of reproducing. It is therefore possible for an entire population to become extinct.

The division of the common pool can be implemented in a number of ways. In these experiments, we analyse the effects of two methods. The first, the equal distribution method, divides the pool equally between those agents that are still alive at the end of a generation. The second, the proportional distribution method, divides the pool proportionally—in other words, an agent receives a portion of the pool proportional to the amount of food it contributed.

The two distribution types equate to a population sharing its resources among the whole population (benefiting free-riders) in the case of equal distribution, and a population where resources are only given to those that contributed to the resource pool. Thus the model can be seen as examining the effects of sharing on populations.

In addition, we wish to examine the effect of altering the foraging success of the population. We implement this by running a number of separate experiments varying the foraging success probability from 0.2 to 0.8. Each set of results is averaged from 20 independent runs. The experiments are allowed to run for 500 generations. Each use a population of 250 agents. Each generation of agents is allowed 10 foraging turns and the reward for a successful foraging is 3 units of life energy. Finally, the common pool grows to three times its size at each generation.

4 Experiments

The experiments examine the effects of different forage success probability values on two populations: one distributing the common pool equally and the other distributing it propor-

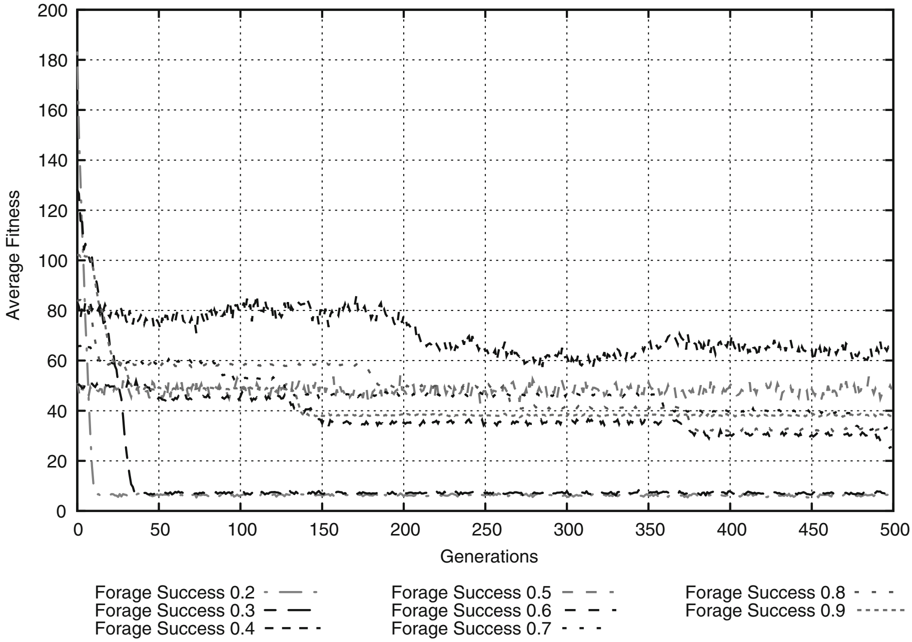

Fig. 1 Average fitness in equal distribution population

tionally. In the first set of experiment each population is initialised such that each individual has a random number of 1s in its genome. This means that the vast majority of individuals in these populations will donate something to the pool. A second experiment shows the effect of initializing the first generation with exactly zero donators.

4.1 Equal distribution

The first set of results illustrated in Fig. 1 shows the fitness of each population over time. As one would expect, the populations with the lowest probability of foraging success have the lowest fitness. However, the populations with the highest probability of success do not have the highest fitness. Instead, it is population with a success probability of 0.4.

The second figure illustrates the size of each population over time (Fig. 2). The largest populations are those with the highest foraging probability, although even populations with lowest success probabilities are capable of maintaining up to 80% of the original population. Therefore, the situation for the populations with higher success probabilities is that they have large populations, but only mediocre fitness. In contrast, the population with the highest fitness (success probability 0.4) has a relatively small population.

The mediocre fitness results obtained for the high success probability populations is likely to be caused by the fact that the high foraging success does not provide a sufficient incentive for individuals to donate to the pool, as they are likely to have foraged enough food. As a result, the pool size will be lower meaning that individuals will receive less, resulting in lower fitness in contrast to the other populations.

The third set of results is the average percentage donators in the population, illustrated in Fig. 3. The populations with the fewest donators are those with the lowest probabilities of

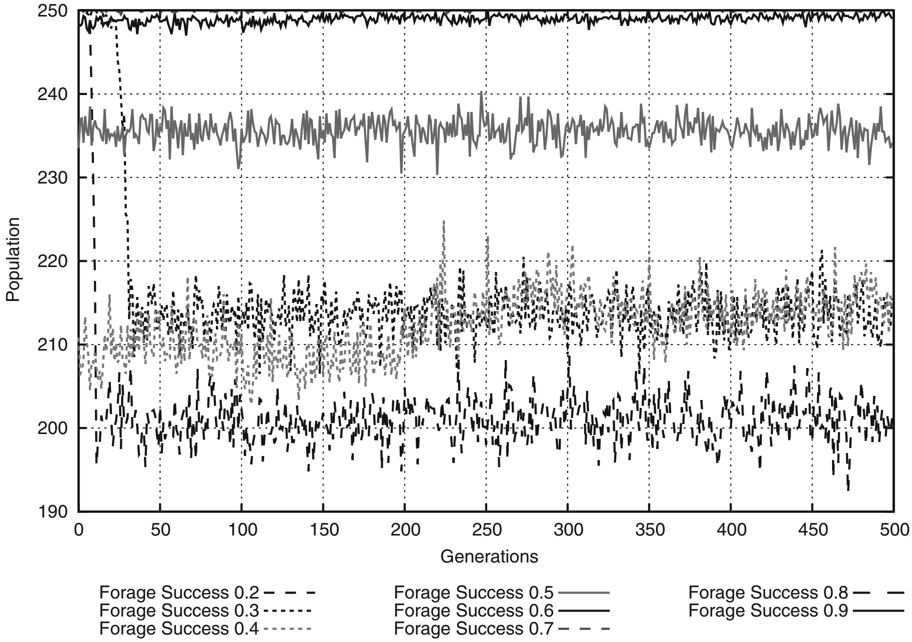

Fig. 2 Average population size in equal distribution population

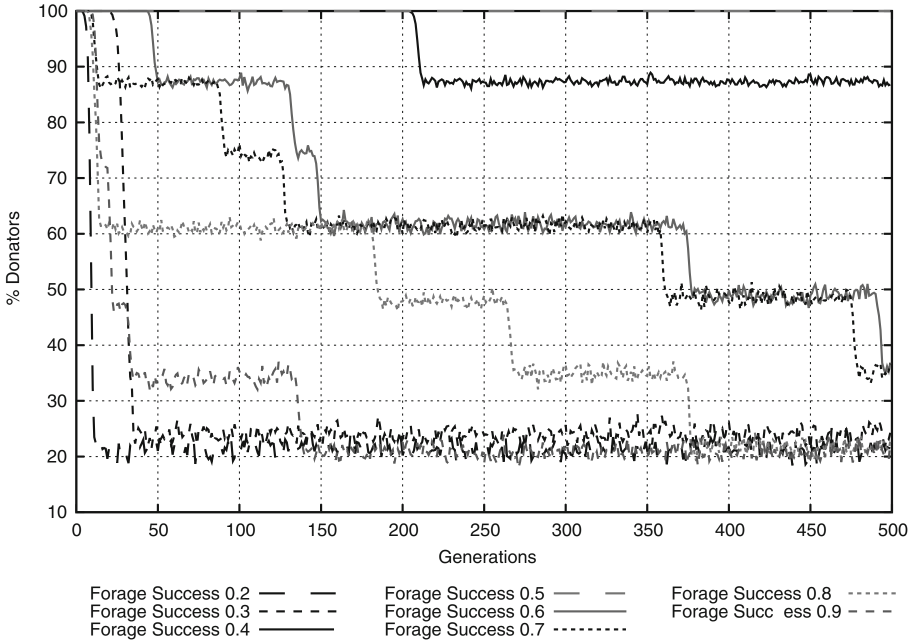

Fig. 3 Average percentage donators in equal distribution population

foraging success (0.2–0.3). Again, this is understandable as they are not capable of finding food often, they are unlikely to donate food to the common pool.

Populations with high foraging success (0.7–0.9) begin with many donators but then decline over the course of the experiment. Clearly, the benefit received from the common pool does not justify the expense of donating food and these populations begin to lose donators.

The populations with the highest number of donators are those that are exposed to foraging success approaching the median (0.4–0.5) and in fact, the highest of all is the population with foraging success of 0.5. Clearly, for these populations it is advantageous to donate to the pool because the likelihood of unsuccessful foraging is precarious enough for the common pool to be useful. Equally, the likelihood of consistently finding food is low enough to allow the common pool to be useful to successful foragers.

The final set of results shows the average amount donated by each population and are illustrated in Fig. 4. Once again, the same patterns emerge, with the populations with the lowest probabilities of success donating the least, followed by the populations with the highest probabilities of success. The most generous population in terms of donations is the population with foraging success of 0.4.

To summarize, populations with high probabilities of foraging success tend to be large, but with only mediocre fitness. While they initially contain a high number of donators, this decreases dramatically over time and in any case, the donations given to the common pool tend to be small. Populations with low probabilities of foraging success tend to be relatively small, with low fitness and contain few donators which donate very little to the common pool.

The most interesting results are those from populations with foraging success probabilities that are around 0.4–0.5. These have smaller, more fit populations that contain relatively

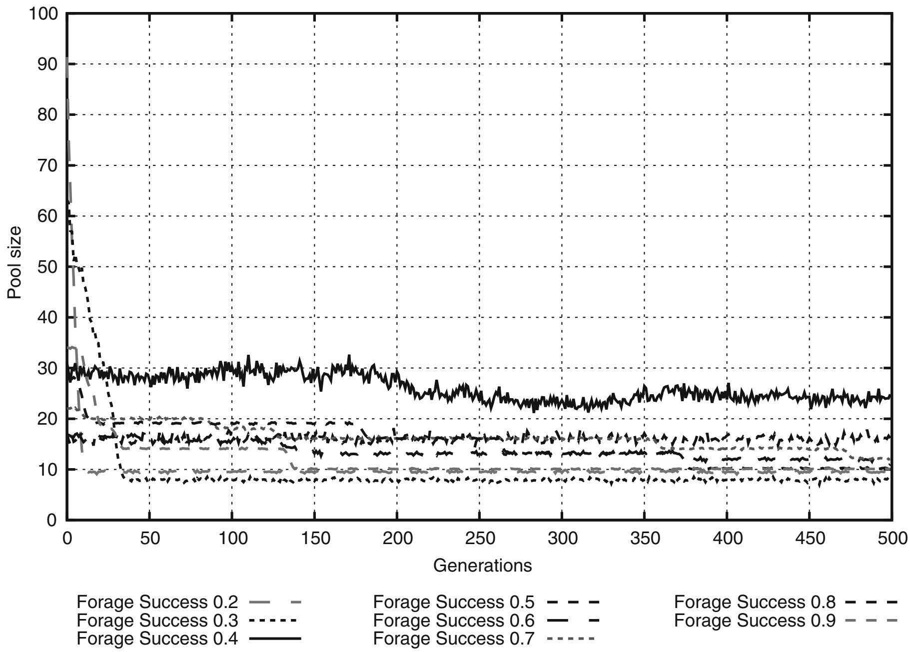

Fig. 4 Average amount donated in equal distribution population

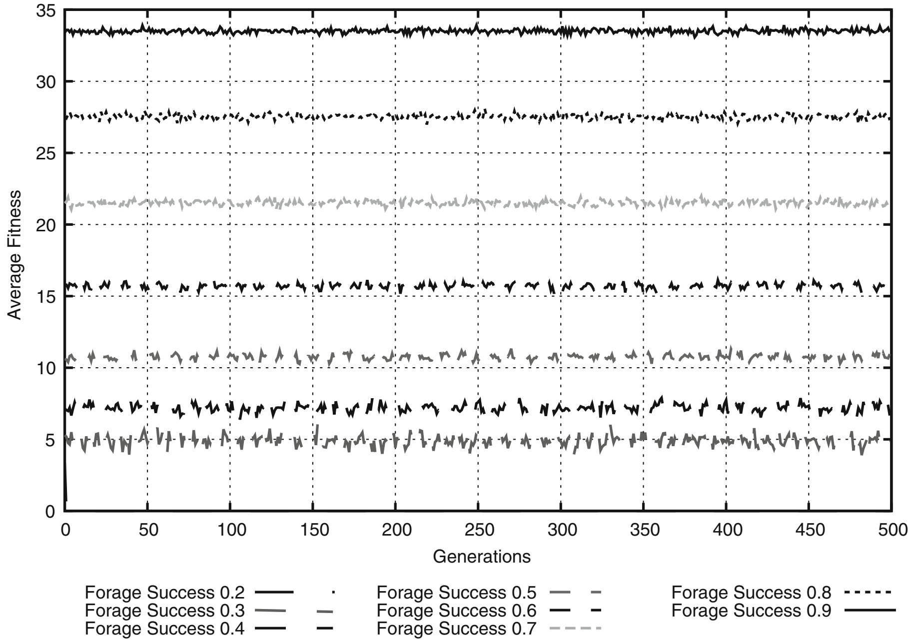

Fig. 5 Average fitness in proportional distribution population

many donators which donate generously to the common pool. Thus, while these populations may not be able to sustain as many individuals as those with more foraging success, it would seem that the individuals are fitter on average (clearly as a result of the redistribution of the common pool).

4.2 Proportional distribution

The following set of results examine the effect of distributing the common resource pool among individuals in proportion to the donation an individual has made. Thus, individuals that do not contribute to the pool do not receive a share of the pool.

The first set of results, illustrated in Fig. 5, shows the fitness of each population over time. In contrast to the experiments where the common pool is distributed equally across the population, the fitness of each population is highly dependent on the forage success of each population. The most successful population from the point of view of fitness is the one with a forage success of 0.9. This is followed by the populations with 0.8, 0.7 and so on. Thus, it can be said that the common pool does not seem to have a large effect on the fitness of the population, as the populations stratify according to forage success, just as one would expect if no distribution were employed.

The second set of results, examining population size, are illustrated in Fig. 6. The largest populations are those with highest forage success (0.6–0.9). Even the population with only 0.5 forage success is capable of sustaining a relatively large population. The worst performing population is that with forage success of 0.2, which becomes extinct almost immediately. There is also a considerable difference between the population with forage success of 0.3 and that with 0.4.

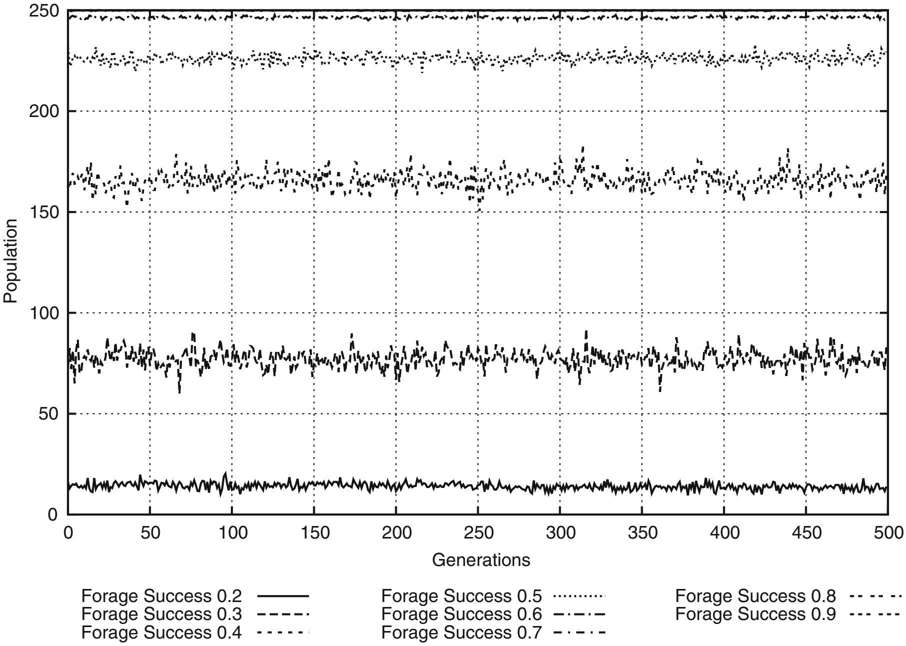

Fig. 6 Average population size in proportional distribution population

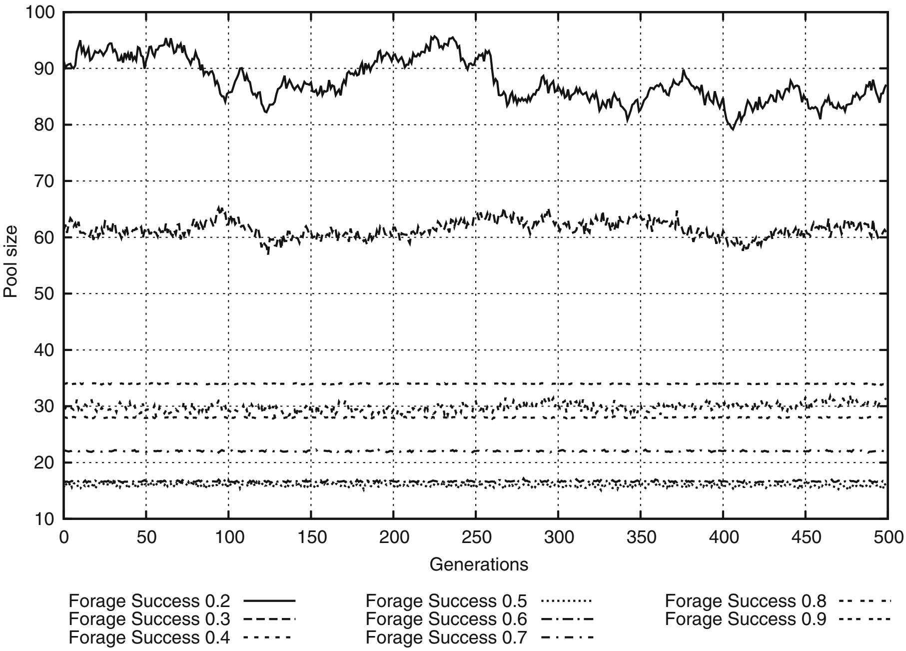

Fig. 7 Average amount donated in proportional distribution population

To understand these results, they must be examined in conjunction with the amount of resources each population is contributing to the common pool. This is illustrated in Fig. 7. The first interesting aspect of these results is that the population with forage success of 0.3 donates the largest amount of resources to the common pool by a large margin. In contrast, the population with forage success of 0.2 is tied with the population with forage success of 0.6 with the lowest contributions.

The difference between the 0.2 and 0.3 populations is striking. Clearly, the risk of a population becoming extinct is high with a forage success of 0.2 and is only slightly better with a forage success of 0.3. The population with forage success of 0.3 is capable of foraging slightly more food on average than that of the population with 0.2 forage success. However, if population invests heavily in the common resource pool, it will be able to counter some of the effects of unsuccessful foraging.

The remaining populations are clustered quite closely at a moderate level of donation. Thus the most successful populations are those with high foraging success. These tend to donate only moderately to the common resource pool. The most interesting population is that with forage success of 0.3, which is capable of staving off extinction only through heavy investment into the common resource pool. The graph for the percentage donators in each population is not shown because in each case, the percentage was 100%. In other words, in each population every individual contributes something to the pool.

4.3 Initializing with no donators

In the previous experiments, the first generation is initialised such that each agent contains a randomized chromosome. This means that in nearly every instance, each individual is likely to contribute something to the pool (since the probability of an agent containing at least a single one in its chromosome is much higher than that of an agent containing only zeros). As a result, populations begin each experiment with nearly every individual donating something to the common pool.

This second set of experiments examines the effect of initializing the first generation to contain exactly no donators. This was done by initializing the population such that each individual's genome contained all zeros. This is the only experiment parameter that was changed with respect to the previous set of experiments. The following sub-sections present results obtained from the equal distribution and proportional distribution populations.

In this set of experiments the focus is on the number of donators present in the populations rather than fitness or population size. This is because the purpose of the experiment is to examine whether these values will rise to match the levels observed in the previous experiments.

4.3.1 Equal distribution

Figure 8 shows the number of donators in the equal distribution populations. The number of donators begins at zero and quickly climbs to stabilise at between 20% and 25% across each population. Clearly, the proportion of donators across the population is not greatly affected by the quality of the environment. If we compare this result to that obtained in the previous set of experiments, it becomes clear that the results illustrated in Fig. 3 show a gradual convergence by each population to donator proportions of around 20–25%.

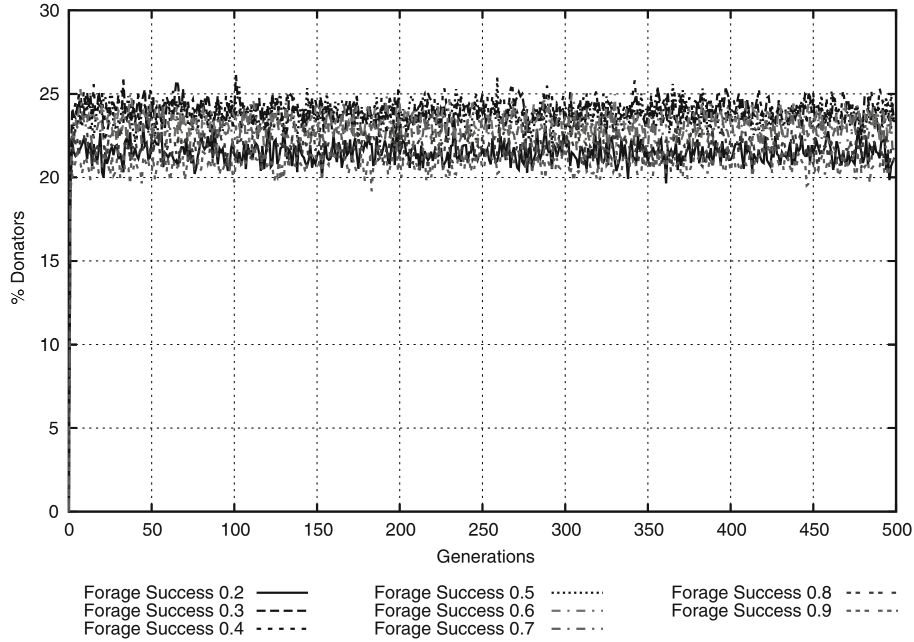

Fig. 8 Average amount donated in equal distribution population, starting with zero donators

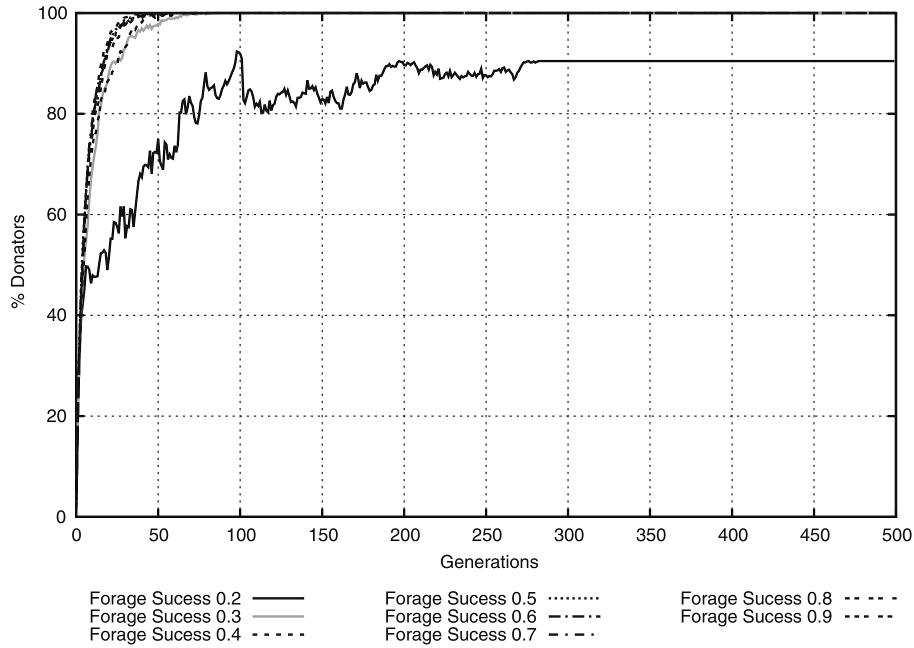

Fig. 9 Average amount donated in proportional distribution population, starting with zero donators

4.3.2 Proportional distribution

The results obtained for the proportional distribution populations are illustrated in Fig. 9. Each population begins with no donators, but the number of donators quickly rises as the experiment progresses. In the previous experiments, the number of donators in these populations was almost uniformly 100%.

This experiment shows that the majority of the populations do indeed evolve such that everyone in the population donates something to the common pool. The sole exception is the population inhabiting the most difficult environment (0.2 foraging success). This is most likely explained by the fact that evolving generous individuals in such an environment can be dangerous as individuals may donate all their food to the common pool and die out in the process. Thus, the environment is not capable of sustaining 100% donation.

5 Discussion/conclusion

The two experiments examine the difference between populations where a common resource pool is distributed equally, and one where the pool is distributed in proportion to the amount each individual donated. There are a number of striking differences between the two populations. Firstly, the only extinction occurs in the population employing proportional distribution. Not only do no extinctions occur in the equal distribution populations, but the size of the smallest population is around 200 individuals, only 20% smaller than the maximum.

In populations employing equal distribution, most populations converge towards small donations given by a relatively small number of individuals. By contrast, the populations employing proportional distribution, every individual tends to donate larger amounts.

Finally, the fitness of the two populations is very different. The average fitness of each population is considerably smaller in populations using proportional distribution than in those that share the pool equally. Furthermore, the fitness levels associated with the population employing proportional distribution are stratified according to forage success. Thus it is likely that the population as a whole gains little, if anything, from the distribution of the common resource pool.

As a model of group foraging, our model explores outcomes in a range of scenarios. Real world examples are far more complex than the abstract view adopted in our work and the types of foraging are influenced by a number of factors not considered in our model e.g. status of the individual in the society, the presence of relations between members. Future work will involve further investigation of foraging societies. In particular, we wish to extend the model further to explain reported phenomena in the existing empirical studies.

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