What advantages and disadvantages arise when decisions have to be made in groups? How might the study of collective animal behaviour help our society?

Decision-making is an integral part of animal behaviour which has direct effects on an individual's fitness across a wide range of important life-history processes, such as direction of migration, mate choice and which food resource to exploit *(Dill LM, 1986)*. These decisions are made in the context of biological uncertainty, whereby to increase the design accuracy of their decisions, animals must react correctly to certain environmental cues that may covary with aspects of biological significance and will ultimately affect their fitness. It has been suggested that in groups, the addition of social cues may further reduce the uncertainty surrounding said decisions *(Kao AB & Couzin ID, 2014)* as well as promoting fitness in other ways within the context of decision making. This type of group decision making can be observed in the animal kingdom across a number of different taxa, although in general it appears to follow the same mechanism whereby local rules adopted by individuals can propagate and influence the decision making of a group on a larger-scale to give the impression of 'self-organisation' *(Davies NB, Krebs JR & West SA, 2012)*. This essay will assess examples of advantages that are brought about by group decision making as well as some disadvantages that might not exist if an individual were to have made the decision solely by itself. It will then briefly evaluate how humans can study such collective animal behaviour and learn from it to help our own way of living.

## Advantages

Group decision-making can essentially split into two processes that will lead to a group undergoing the same collective decision: leadership and voting. Leadership group decision-making occurs when a small proportion of the group will have information that allows them to make a decision, whereas the rest of the group is naïve. However, without any complex communication, the small group of individuals that can make the decision are able to influence the rest of the group to a significant degree such that the entire group undergo the same choice *(Davies NB, Krebs JR & West SA, 2012)*. It has been suggested that this proportion can be as few as 5% in a group of 200 individuals in the case of deciding which direction to move in *(Couzin ID et al, 2005)*. The advantageousness of this process is fairly obvious in the sense that uninformed individuals following those with information will be increase their fitness relative to if they were to ignore them, for example, if it were towards a food source *(Rands SA et al, 2003)*. The second type of group-decision behaviour is 'voting', whereby a group reaches a consensus or quorum of what decision to make, which is dependent on the number of individuals within the group that 'vote' for that option *(Davies NB, Krebs JR & West SA, 2012)*. However, the classification into these two processes is somewhat arbitrary and it can be difficult to assign every incidence of group decision-making to one or the other.

For example, in wild olive baboons (*Papio anubis*), it is clear that group decision-making benefits the population, but it is less clear as to how consensus is achieved following the conflicts of interests. The group decision at hand takes form as a series of different decisions made by different subsets of the troop that is shared across differing individuals over time. Within a troop of up to 100 individuals, this strategy drives their collective movement and foraging for a range of different food resources. This group behaviour has been assessed by Strandburg-Peshkin et al by tracking the individual movements of individuals within a group with custom designed GPS collars that recorded their location every second. The relative movements of pairs within the group were then analysed as such to give more insight to the group decision-making: an individual that moves away from another is the "initiator", which was either followed (a "pull") or not followed and thus returned to the other (an "anchor"). The data supported the hypothesis that decisions were indeed, on average, made by the group as a whole and there was no disproportionate decision-making by any dominant individual. It was also shown that baboons were most likely to follow when there were many initiators with high agreement, but conversely when the agreement is low more concurrent initiators decreased the likelihood of a baboon following. On top of this, it was found that when individuals had to decide between two subgroups of initiators, followers were more likely to move towards the larger subgroup, with the tendency growing stronger consistently as the numeric difference also did *(Strandburg-Peshkin A et al, 2015)*. These observations are all significant when coupled with field-based theories that state that a dominant individual, if motivated, does have the capability of shaping movement patterns *(King AJ et al, 2008)*. The fact that such an individual within this species *could* dictate the troops movement, but chooses not to, carries with it strong implications that the group decision-making confers additive fitness.

This in part feeds into perhaps one of the most prominent theoretical and empirical ideas of the advantages of group-decision making which is the concept of the 'wisdom of crowds'. This concept is based on the idea that a group of individuals will pool their imperfect estimations which, due to their increased number, will lead to increased overall decision accuracy *(King AJ & Cowlishaw G, 2007)*. An example can be used to illustrate this regarding the orientation of navigating birds, whereby many readings from multiple inaccurate compasses will yield a single much more accurate compass because individual orientation error is suppressed by the rest of the group's cohesion. With this in mind, a simple model can be drawn where it is assumed that in the flock of birds there are no innate differences in orientation accuracy among individuals and they contribute equally to the mean direction. This model would state that the expected flock accuracy is a function of flock size (i.e. smaller flocks are more likely to miss there target) and would be underpinned by flock cohesion alone *(Simons AM, 2004)*.

A more complex example that demonstrates large group decision-making is that of the choice of nesting site by swarms of up to 10,000 honeybees. This does not manifest itself in quite as simple a way as the previously discussed bird flock example, but exhibits more complex interactions that take place within the group to increase fitness. The process involves several hundred bees working cooperatively to find multiple tree cavities and then selecting the best option. It has been hypothesised that this decision-making is achieved through the swarm sensing a quorum, whereby scout bees 'vote' for a site by spending time at it and then interacts with the other scouts such that the proportion at better sites rise. This will increase until a threshold or quorum is reached, and at this point the bees still at sites, will initiate the swarm to move to this site *(Seeley TD, Visscher PK & Passino KM, 2006)*.

This collective decision-making behaviour has many implications of being advantageous relative to other strategies. Firstly, the process is diffused fairly evenly among all of the scout bees, which leads to more diversity in knowledge in the sense that each of the hundreds of bees acts as an autonomous agent with the potential to provide unique information regarding new nest location. This can be observed in their behaviour when the scouts search independently, managing to cover a huge area due to the allocation of the task, and then bring back knowledge and communicate the quality as well as location of the potential nest site in their 'waggle dances'. This decentralised organisation is key in helping ensure the broad set of options and could not happen without the group as a whole. As well as this, the quorum-sensing process combines the independent opinions of the scouts regarding different sites in a way that balances the speed and accuracy of the decision-making. The quorum is high enough such that sufficient bees must have assessed the site before it is ultimately chosen among the diversity of other sites that were visited *(Seeley TD, Visscher PK & Passino KM, 2006)*. It is clear that this behaviour and process of decision-making on a huge scale of individuals is advantageous for the population at hand.

However, recent research into the topic of group decision-making has supported the hypothesis that decision accuracy in complex environments is most likely to be maximised by small group sizes across a number of contexts. Kao and Couzin constructed a model based on collective decision-making that included complex environments whereby it was assumed that in a decision bout, each member of the group observes the cue(s) present in the environment and uses a strategy to convert the observation into a discrete 'vote' for one of the options. The votes are then aggregated and the group will make a consensus decision for the majority preference. From this, it was calculated the probability that a group would choose the correct option in a certain environment and for a given group size and voting strategy *(Kao AB & Couzin ID, 2014)*.

Their research lead to overwhelming support of the concept that collective intelligence depends highly on the animal's voting strategy and the properties of their environment. Notably, when the regime is such that the group decision is predominantly dictated by a cue that has a high observational correlation, which may be realistic across many ecosystems, it highlights the potential of highly correlated information to undermine the 'wisdom of the crowds' hypothesis. In such environments it was found that the optimal group size that maximises decision accuracy was actually fairly small. It is the noise that is inherent in these surprisingly small groups that results in enhanced performance by letting individuals escape the constraints of highly correlated information while still preserving some advantages of pooling collective information *(Kao AB & Couzin ID, 2014)*.

A mixture of theoretical models and observations of groups in the field supports the hypothesis that the collective decision-making strategy can be advantageous for animal populations to varying degrees.

Disadvantages

When decisions are made in groups perhaps the most obvious disadvantage is that incorrect decisions, which lead to accidentally decreasing fitness, will influence a higher proportion of a population compared to if it were performed at an individual level. For those not involved in the decision-making process, such as 'followers' in the example of leadership based group decision-making, if the decision leads to a decrease in fitness then this might potentially be worse than if it were to make the decision individually.

Another potential reason that group decision-making might result in an action that is unfavourable is in the case of some compromise decisions. For example, it has been seen that in wild olive baboons that when two initiators lead in separate directions, but at an angle less than 90º to each other, the group will compromise by following them at an angle that falls between the two original directions *(Strandburg-Peshkin A et al, 2015)*. This may be disadvantageous, because it could potentially be that both of the original directions would have provided better foraging routes, but the group decision resulted in a different direction altogether that might be less beneficial in terms of food availability and quality.

A final reason that this strategy might be disadvantageous is with regards to the time spent in consensus or quorum-sensing group decision-making. For example, the competitive nature of the mechanism by which honeybees 'vote' for the best nest site by spending time at it may take a long time *(Seeley TD, Visscher PK & Passino KM, 2006)* despite the fact that, on an individual level, the best nest site may be found very quickly.

The disadvantages that have been discussed are fairly negligible given that they are essentially unavoidable when coupled with the benefits that group-decision making provides. For example, in the honeybee example, whilst it may take a while for the best nest site to be chosen despite the fact it might be found by an individual immediately, it is necessary for the 'voting' behaviour to take place in order to maintain the strategy by which a wide diversity of different sites are considered. Therefore, while there may be some disadvantages of group decision-making, it seems that behaviours that have specifically evolved in different species through natural selection are tuned in such a way that the advantages outweigh any problems that might arise.

<u>How might the study of collective animal behaviour help our society?</u>

In studying group decision-making in different species we may be able to gain insights in how to improve different elements of human design and processes. This formal use of biology as a design tool is known as biomimicry *(Benyus JM, 1997)* and has been a recently expanding area of research, especially with regard to social insects. It is the decision-making without any centralised control which is of particular interest as this is something that is not often achieved in any human systems but may be useful to implement. For example, group prey retrieval occurs in the ant *Aphaenogaster cockerelli* without centralised control and this has potential to be used in robots to perform tasks such as waste disposal. Researchers are currently investigating the communication pathways that occur with the hope to translate them into algorithms that can be used in robots *(Holbrook CT et al, 2010)*.

A group of researchers have formally discussed how biomimicry of social insects might be used in our society, discussing how human organisations could benefit from embracing certain inspired solutions and designs. However, it was important that they put emphasis on the fact that the innovation should not just be perceived to be better due to its ‘natural’ origin, but still assessed on its effectiveness as a solution to the specific human problem at hand *(Holbrook CT et al, 2010)*.

## Conclusion

Group decision-making is evident across various marine and terrestrial taxa in the animal kingdom. In the clades in which it has evolved, the behaviours that make up the process are under selection thus leading to an optimised strategy whereby the populations make decisions to increase their own fitness, thus conferring advantageousness. Despite this, there will still reside some specific scenarios whereby a group decision might lead to a decrease in fitness. But in general, where it is found across the animal kingdom seems to be advantageous with respect to the clade that is using the behavioural strategy. Group decision-making is something that, as humans, we have not embraced as a fully conceivable strategy in our own lives, and thus we should look to how it could be used in novel ways to increase the efficiency in an array of human systems.

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