# Consensus Decisions

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## Introduction

Animals routinely face decisions that are crucial to their survival and fitness: they have to decide when and where to rest or forage, which individual to mate with, where to live, when to reproduce, and so on. Social animals have to make many such decisions not as individuals acting alone but collectively, as a group. A large proportion of collective decisions even require that all the members of a group reach a consensus. Consider a group of carnivores deciding where to move after a resting period, a shoal of fish deciding when to leave a foraging patch, or a colony of ants choosing a new nest site: unless all the members decide on the same action, some will be left behind and will be deprived of the advantages of group living, at least for the time being.

In animals, a consensus decision is defined as a decision in which members of a cohesive group choose, collectively, a single action from a set of mutually exclusive options, and that choice is binding in some way for all the members. In this context, consensus does not imply that all the group members necessarily share the same interest, or even like the decision outcome, but only that all members comply with the collective decision outcome to maintain group cohesion. Nor does the fact that the decision is collective mean that all the group members necessarily have the same influence on the decision outcome (see more on this below). Typical examples of consensus decisions are choosing between different movement destinations, nest sites, migration routes, or cooperative strategies, or the timing of group activities (e.g., foraging or resting).

## Aggregation Rules

When animals make decisions, they typically have a choice between two or more options. In order to make decisions collectively (and achieve a group consensus), the preferred choices of individual group members have to be aggregated in such a manner that the group 'agrees' on one option. That is, an aggregation rule is required. Formally, an aggregation rule is defined as a function that assigns to each combination of individual inputs (e.g., choices or 'votes') a resulting collective output (e.g., a decision outcome). The classic example of an aggregation rule is majority voting between two options, under which the group selects the option that receives more votes than the other. However, a dictatorial decision rule, under which the group always adopts the choice of a single preordained individual, the 'dictator,' is also an aggregation rule. Humans often use aggregation rules that are based on majority voting, but in which only the choices of particular group members count (e.g., children are usually not allowed to vote in national elections).

In animals, empirical aggregation rules range from dictatorial ones to majority voting. For example, Andrew King and co-authors reported that in wild chacma baboons (*Papio ursinus*), the dominant male chooses the group's foraging patch, even if the choice is against the foraging interests of the majority of other group members. On the other hand, in wild red deer (*Cervus elaphus*), the majority of deer determine a herd's departure time from their resting site. Gerald Kerth and colleagues reported that in Bechstein's bats (*Myotis bechsteinii*), it can also be the majority of bats that decide when to change roosting sites. However, in most observed cases in non-human animals, the decision is made by several particular group members, not by all the members. This is very well documented by Thomas Seeley and colleagues' detailed work on honeybee swarms: new nest sites are chosen only by a few hundred informed scouts within the swarm. A group's aggregation rule is important, since it greatly influences the costs and benefits of the group's decision outcome to individual members and to the group as a whole (see also below).

## Communication: Global and Local

While the implementation of complex aggregation rules in humans is obvious and familiar to all of us (e.g., national elections, parliamentary decisions), it is more difficult to see how animals could implement aggregation rules and thereby make decisions collectively. At first sight, their lack of a sophisticated language and their limited cognitive abilities seem to prohibit the necessary negotiations and voting that underlie many complex aggregation rules. How, then, can animals decide collectively in meaningful ways?

To address this question, it is helpful to distinguish between two types of animal groups: small groups and large groups. These groups should not be distinguished by the actual number of group members, but by the manner in which members can communicate with each other.

Small groups are defined as groups in which all the members can, at least in principle, communicate with all the others. In such groups, global communication is a possibility. Typical examples are groups of carnivores, primates, or some ungulate and bird species. In contrast, large groups are defined as groups in which global communication is no longer possible. Instead, group members can, at most, communicate with their neighbors (local communication). Typical examples are swarms of insects, large shoals of fish, large flocks of birds, or large herds of ungulates.

In small groups with global communication, group decisions could, at least in principle, be reached by general negotiations among all the members and explicit voting, or by central orders or coercion. Voting has been reported in several mammal and bird species, and dictatorial or coerced decisions in others. Empirical examples of voting behaviors include the use of specific body postures, ritualized movements, and specific vocalizations. In order to implement majority voting, animals do not need to be able to count explicitly but do need to assess relative numerousness (e.g., are more group members standing or sitting?). A recent review by David Sumpter and Stephen Pratt indicates that quorum responses, whereby an individual's probability of exhibiting a behavior is a sharply nonlinear function of the number of others already performing this behavior, could also be a plausible mechanism. In simpler terms, we speak of quorum responses when individuals are much more likely to perform a behavior if they find a threshold number of other individuals (the quorum) already performing this behavior than if they do not.

In large groups with only local communication, individuals are assumed to follow their own local behavioral rules, based on local information and local communication but resulting in a global group behavior that is not centrally orchestrated but self-organized. A good example of such self-organization is given by the movements of large flocks of starlings (*Sturnus vulgaris*), studied in great detail by Michelle Ballerini, Irene Giardina, Charlotte Hemelrijk, and their colleagues. Each flock member continuously tries to avoid collision with direct neighbors or obstacles but, at the same time, continuously tries to maintain cohesion with its neighbors. The overall result is the fascinatingly synchronized and well-coordinated flock movement that we observe in nature.

At first glance, self-organization seems to prohibit decisions made either by general negotiation and voting or by central orders or coercion. However, theoretical models suggest that aggregation rules in self-organizing groups can arise as intrinsic consequences of local behaviors of group members. They can range from majority rules (if all the group members adopt the same local behaviors, as illustrated by the work of Iain Couzin and colleagues in 2005) to aggregation rules in which only certain members influence the decision outcome (by adopting more independent local behaviors than do other members). Empirical observations by Jens Krause and colleagues on roach (*Rutilus rutilus*) and by Herbert Prins on African buffalo (*Bufallo bufallo*) support the model predictions. Quorum responses also play an important role in large groups and have been described in honeybees (*Apis mellifera*) by Thomas Seeley and colleagues, in cockroaches (*Blattella germanica*) by Jean-Louis Deneubourg and colleagues, and in ants (*Leptothorax albipennis*) by Nigel Franks, Stephen Pratt, and colleagues. As in small groups, quorum responses are plausible mechanisms for decision aggregation.

## Main Factors Influencing Consensus Decisions

The two most important factors influencing consensus decisions in social animals are (1) information and (2) interests. We address these in turn. Additionally, several side constraints can also play important roles, most notably time constraints. For more details on side constraints, we recommend the Further Reading section.

### Information

In order to make advantageous decisions, decision makers require environmental information (e.g., about the quality of a foraging patch, the presence of predators, the best traveling routes, etc.). However, individuals typically have only incomplete and noisy information about the state of the environment. Groups of animals making decisions have the potential advantage, relative to solitary decision makers, that the private information of all their members taken together is likely to be more complete and more accurate than that of a single animal. This is because some group members might know about good foraging patches, some about good traveling routes, some about predators, and so on. Additionally, any false private information that one member might hold could be corrected by more accurate private information from others. Hans Wallraff suggested already in the 1970s that homing or migrating flocks of birds show better orientation than individuals would do on their own, and recent empirical work by Dora Biro lends further support to this notion. Stephen Reebs and Andrew Ward have made similar observations in fishes, and David Lusseau in bottlenose dolphins (*Tursiops* sp.).

In order to use the private information of all group members in a sensible way, the information has to be aggregated. The way in which the information is aggregated across group members can greatly influence the decision pay-offs or accuracy. For example, suppose a group has to make a choice between two options. Each member has some independent private information about which option is better, and that information is correct with probability $p$ (where $0.5 < p < 1$). Condorcet's classic jury theorem shows that in this case, it is more likely that majority voting will yield a correct group decision outcome than does a dictatorial aggregation rule. And the accuracy of the majority decision will increase with the number of group members. However, if group members differ in the probabilities that their information is correct, or if different potential decision errors would result in different costs, other aggregation rules distinct from majority voting can result in more effective pooling of the available information.

### Interests

The pay-offs of a decision outcome for a group of individuals obviously depend on whether the outcome is consistent with the members' interests. Group members can share the same interests during a decision. For example, when a swarm of honeybees is deciding on a new nest site, it is advantageous to all bees to choose the best site. There can be differences in information between bee scouts about which site is best, but there are no conflicts of interest: the nest site that offers the best survival and reproduction prospects for the swarm is the best nest site for all the bees. However, in many groups, members differ in sex, age, size, genetic relatedness, and physiological status and consequently have different requirements. This means that decision outcomes that are good for some members might be bad for others. For example, in many ungulates, females with young are more vulnerable to predation, and therefore prefer safer but lower quality foraging sites, than do males. Kathrin Ruckstuhl and Peter Neuhaus reported that conflicts of interest during collective ungulate movement decisions not seldom are so large that groups fail to reach consensus and split.

If there are conflicts of interest within a group, the way in which different individuals' preferences are aggregated can make a great difference to the group's overall pay-offs, and also to the individual pay-offs received by each group member. Often, aggregation rules that assign decision weight to a greater number of group members yield higher overall group pay-offs, and therefore, in human decision making are often considered as desirable and fair. However, since pay-offs are not necessarily higher for each individual group member and might even be lower for some members, the question of whether such fair and inclusive aggregation rules are likely to evolve in animals is complex. Work by Sean Rands, Iva Dostalkova and Marek Spinka and colleagues suggests that for pairs of individuals, aggregation rules that take the preferences of both partners into account are likely to evolve. However, in larger groups the evolution of aggregation rules can be very complex, and fair and inclusive aggregation rules are not always guaranteed, but at least some skew in the influence of individual group members is often likely to evolve (see Further Reading).

## Concluding Comments

The study of consensus decisions in animals is still relatively young, with the exception of studies of social insects. However, the topic has recently started to attract wider attention, and the literature is now expanding rapidly. The only review to date is still: Conradt L and Roper TJ (2005) Consensus decision making in animals. *Trends in Ecology and Evolution* 20: 449–456 (doi:10.1016/j.tree.2005.05.008). However, a themed issue (Group decision making in humans and animals) has just been published in Philosophical Transactions of the Royal Society London B, 364 (2009, eds L. Conradt & C. List; doi:10.1098/rstb.2008.0256). This issue consists of 11 contributions by natural and social scientists, and aims to introduce long-standing social science concepts on group decision making into the newly-emerging, relevant fields within the natural sciences.

Some classical theoretical papers are those by Iain Couzin et al. (2005) Effective leadership and decision-making in animal groups on the move. *Nature* 433: 513–516 (doi:10.1038/nature03236); and Conradt and Roper (2003) Group decision-making in animals. *Nature* 421: 155–158 (doi:10.1038/nature01294). A short note introducing Condorcet's jury theorem into this field is List (2004) Democracy in animals groups: a political science perspective. *Trends in Ecology and Evolution* 19: 168–169 (doi:10.1016/j.tree.2004.02.004). As a brief starting selection of mainly empirical papers, we recommend the publications in the Further Reading.

*See also:* Collective Intelligence; Decision-Making: Foraging; Group Living; Group Movement; Nest Site Choice in Social Insects; Rational Choice Behavior: Definitions and Evidence; Social Information Use.

## Further Reading

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