

ECOLOGY

Seabirds—Individuals in Colonies

Henri Weimerskirch

In a large seabird colony, hundreds of thousands of individual birds rear their young (see the figure). Such colonies require abundant food resources within the foraging range of individuals. But what happens when two or more colonies occur in close vicinity? On page 68 of this issue, Wakefield *et al.* (1) provide strong evidence that seabirds in neighboring colonies do not directly compete for food but rather segregate to search for food in different areas. They propose modeling hypotheses on how such separation might have evolved over time.

In extremely rich marine ecosystems—such as off the coasts of Peru, where nutrient-rich water upwelling from the deep ocean allows the development of immense quantities of anchovies—millions of guano-producing seabirds breed in spectacular colonies (see the figure). Fifty years ago, Ashmole argued that if food is limited, competition between individuals from the same species occurs, and resources are likely to become depleted around the colony, forcing individuals to forage farther (2). Foraging range is restricted to a maximum range set by the movement abilities of parents and the need of offspring to be fed frequently, and each colony has therefore been assumed to have its own foraging zone in the neighborhood (3). But when two colonies are located nearby, maximum ranges overlap, causing competition between individuals of the two colonies unless some form of segregation between colonies exists.

Development of satellite telemetry in the early 1990s allowed seabirds to be tracked from their colonies, allowing these hypotheses to be tested. Several studies have provided evidence that colony size and foraging range are influenced by food availability and that overlap between foraging zones of colonies may be limited. Wakefield *et al.* now report the foraging movements of gannets tracked simultaneously from 12 colonies around the United Kingdom. They show that overlap between birds from the different colonies is surprisingly limited, especially between nearby colonies, where one would expect the highest overlap, and that larger colonies use longer foraging ranges. Using a model simulating the movements of gannets, they can



Divide and conquer. When food is abundant, seabird colonies can concentrate hundreds of thousands of individuals on a single island, such as here off the coast of Peru, where guano-producing boobies, cormorants, and pelicans pack. Wakefield *et al.* show that if such colonies are located near each other, they do not compete for food but rather segregate such that birds from each colony search for food in different locations.

only reproduce the segregation at sea between colonies if they introduce rules imposing density-dependence and neighborhood effect. Thus, by mixing two long-standing hypotheses—the Ashmole and Neighborhood models—their model can reproduce compellingly how segregation occurs.

If individuals from two neighboring colonies do not overlap at sea, this means that they do not forage randomly in all directions but fly in particular directions from the colonies. How did such segregation arise over time? Wakefield *et al.* tackle this question by modeling individual movements. They show that to obtain segregation between colonies, individuals must remember previous foraging trips and use information from other birds of the same species.

Seabirds forage from colonies in zones of high food abundance, where food availability is predictable at large scale over time. However, the exact locations of prey aggregation are generally less predictable, and to locate them, predators use specific foraging strategies (4). Given that seabirds are

Seabirds from nearby colonies forage in different locations rather than directly competing for food.

long-lived, they probably use their memory not only to return to a successful prey patch from one trip to the next but also to identify larger-scale features from one season to the next and probably over their lifetime. Because prey location may change at small scale from one foraging trip to the next, having the most recent information on prey location could be important for a rapid provisioning. Colonial animals may also use information on food location from other birds of the same species, with colonies acting as an information center (5). Such information transfer has long been known for social insects such as bees but has been controversial for colonial vertebrates because of a lack of empirical evidence due to the difficulty of studying social interactions, particularly in the case of marine animals (6). Yet, information transfer between foragers may be the key process that allows active segregation between two neighboring colonies.

Although Wakefield *et al.* show through modeling that such information transfer may help to explain the evolution of segregation

over time, it is still necessary to understand how individuals convey information on food location (7). They may do so passively, with birds first dispersing homogeneously and then joining other birds of the same species that have located a food patch (8). Alternatively, they may convey the information actively, similar to the way in which bees transfer information on food location in the hive by their dance (5). No study has so far been able to demonstrate this latter hypothesis, but some recent studies have suggested that the information may be passed not in the colony but through aggregations away from the colony that signal the direction of food resources (9).

To date, studies on seabird foraging have mostly remained descriptive, focusing on the patterns of distribution and their rela-

tion with the environment. Wakefield *et al.* go beyond this to not only show clear segregation patterns, but also examine the underlying processes through modeling. The next step will be to use empirical or experimental research to explore how these behaviors may have evolved through culture and social behaviors. These investigations will be facilitated by further technological developments that allow us to determine not only an animal's location but also its precise behavior, activity, energy expenditure, and prey capture. Studying interactions between individuals in the colony and at sea is also technically feasible but requires large numbers of individuals to be tracked (10). These future data on animal foraging and social interactions will open new perspectives in our understanding and ability to make more

robust predictions on many aspects, such as colony dynamics and the future impact of climate change or of fisheries (11).

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PHYSICS

Spectroscopy Beyond the Single-Particle Limit

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Scientists can now routinely detect and study single molecules and nanoparticles (1). However, direct observation of chemical processes and/or atomic motions in real time remains a challenge, primarily because ultrafast (subpicosecond) time resolution is needed. Optical techniques have recently been developed to study the dynamics of individual molecules or nanoparticles where two laser beams (a pump and a probe) are focused onto a single nano-object under a microscope (2, 3). The spatial resolution of these measurements is limited by the diffraction of light, so that the movements of the individual atoms can only be inferred. On page 56 of this issue, Clark *et al.* (4) present a study of the lattice motions of individual gold nanoparticles recorded using ultrafast coherent x-ray pulses as a probe. These measurements yield three-dimensional images of the atomic displacements in the particles as a function of time, with a spatial resolution that is orders of magnitude better than what can be achieved with optical microscopes.

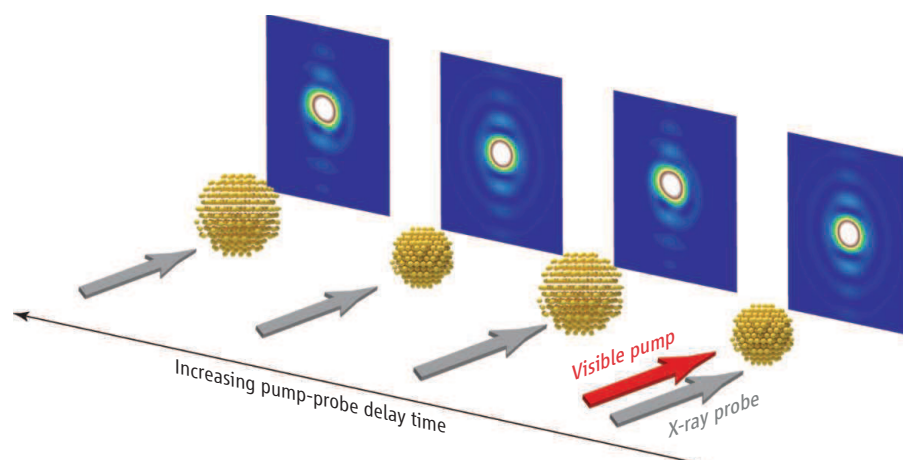
The usual way of studying single molecules or particles, by selecting isolated objects with a high-magnification micro-

scope, is not currently possible for x-ray sources. To overcome this limitation, Clark *et al.* used a fundamentally different approach to single-particle spectroscopy. Particles with different orientations have spatially separated Bragg diffraction patterns at the image plane of the detector (5). By analyzing the position and phase of the diffraction patterns, the authors could reconstruct the time-dependent lattice distortions of selected particles. These data experimentally determine the form of the

Ultrafast x-ray diffraction studies reveal the lattice vibrations of single gold nanoparticles.

vibrational normal modes that are excited by the pump laser in the experiments, as well as their frequencies (see the figure).

This type of information is not accessible in conventional optical transient absorption measurements, where the assignment of the observed modes (that is, a picture of what the vibrational motion looks like) relies on comparing the measured oscillation periods to continuum mechanics calculations (6, 7). For particles with simple shapes (spheres and wires), these calculations can



Particularly revealing. Time-resolved x-ray measurements by Clark *et al.* reveal the lattice motions of single nanoparticles with subnanometer spatial resolution.

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