year for which pesticide use data are available and a year in which nearly 40% of soybean acres were planted with Roundup Ready varieties (in 1999, more than 40 million acres were planted with Roundup Ready soybeans in the United States). The data show a 16% increase in pounds of herbicides used and a 12% increase in total acreage. This modest increase in herbicide use is not what one would expect on the basis of Benbrook's findings.

Although the total amount of herbicides used with soybeans has changed little with the introduction of Roundup Ready varieties, the data show a substantial reduction in the number of applications made to soybean acreage. From 1995 to 1998, the total number of applications decreased by 8%, even with the increase in total acreage. This demonstrates growers using fewer active ingredients and making fewer trips over the field, which translates into ease of management.

The primary reason growers have adopted Roundup Ready weed control programs is the simplicity of a weed control program that relies on one herbicide to control a broad spectrum of weeds without crop injury or crop rotation restrictions. Before the introduction of Roundup Ready soybean varieties, growers would choose between many herbicides, often applying three or more active ingredients, some of which would cause damage to the growing soybean plants, or cause harm to corn crops that commonly follow soybeans. As for economic benefits, the introduction of Roundup Ready varieties has provided an overall savings in herbicide costs for both adopters and nonadopters of the technology. Competition in the soybean herbicide market resulted in the manufacturers of other products dropping their prices, in some cases by 40%. This resulted in an estimated $278 million cost savings for soybean growers, or 28% of total herbicide expenditures.

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Benefits of Membership

Explaining the multitudinous forms of social aggregation across animal taxa is a major challenge in evolutionary biology. In their Viewpoint "Complexity, pattern, and evolutionary trade-offs in animal aggregation" in the "Complex Systems" special issue (2 April 1999, p. 99), Julia K. Parrish and Leah Edelstein-Keshet contribute to an emerging new framework that considers the evolution of animal aggregations as by-products or "emergent properties" of other natural processes. For instance, J. R. Pawlik (*1*) explained the huge aggregations of marine invertebrates that form some of the world's largest living aggregations (for example, coral reefs) as the by-product of settlement based on attraction between individuals of a species. Relying on conspecific cues for habitat selection is likely to naturally lead animals to aggregate, as illustrated by colonial and noncolonial bird species (*2, 3*). Mate choice is another set of processes that have long been understood to explain another kind of aggregation, that of display territories in promiscuous species [for example, leks (*4*)] and more recently breeding territories of monogamous species (*5, 6*). Accordingly, we have proposed that colonial breeding may be the by-product of the two interacting processes of breeding habitat selection and mate choice (*2, 3*).

The new framework for understanding the evolution of animal aggregations has important implications that require emphasis. For example, individual animals do not necessarily benefit from aggregation, suggesting that attempts to identify benefits of aggregation may be a fruitless approach because aggregation is, at least in the first step, not a target of selection. Instead, it would be more fruitful to identify the mechanisms that generate aggregation. We agree with Parrish and Edelstein-Keshet that it is difficult to argue that all animal aggregations have a functional purpose and stress that aggregations may form without the operation of any Darwinian natural selection. However, in the case of assemblages of living units, as an emergent property of other behaviors, aggregation may become the object of selection. An example is the case of the origin of metazoa, which has involved spatial patterns of kinship in the ancestral cell organisms (*7, 8*). The individual that emerged from such aggregates of single-cell organisms then became the object of selection, and evolutionary ecologists now, 800 million years later, consider it as the unit of selection. Nevertheless, it would not be correct to consider that such aggregations first evolved because of all the properties that are now linked to the individual metazoa. This example illustrates the difficulty of distinguishing between the ultimate causes of a trait and its emergent properties.

Finally, the new framework implies that aggregated distributions may be the natural state of most animals (*2, 3*). If so, we should contemplate the constraints that prevent solitary species from aggregating rather than exclusively searching for the reasons that cause social animals to aggregate. In studying the evolution of colonial breeding, such a reformulation has led to unexpected results (*9*), and we anticipate that more counterintuitive findings will emerge when the new thinking about animal aggregation is applied.

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References

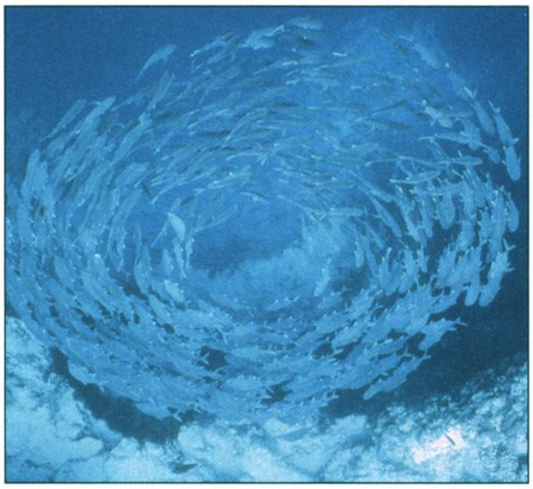
1. J. R. Pawlik, *Nature* **370**, 511 (1994).
2. E. Danchin and R. H. Wagner, *Trends Ecol. Evol.* **12**, 342 (1997)
3. R. H. Wagner, I. Danchin, T. Boulinier, F. Helfenstein, *Behav. Ecol.*, in press.
4. J. Hoglund and R. V. Alatalo, *Leks* (Princeton Univ. Press, Princeton, NJ, 1995).
5. R. H. Wagner, *J. Theor. Biol.* **163**, 333. (1993).
6. H. Hoi and M. Hoi-Leitner, *Behav. Ecol.* **8**, 113 (1997).
7. J. M. Smith and E. Szathmary, *The Major Transitions in Evolution* (Freeman, San Francisco, 1995).
8. R. E. Michod, *Am. Nat.* **149**, 607 (1997).
9. C. Rolland, E. Danchin, M. de Fraipont, *Am. Nat.* **151**, 514 (1998).

Response

We would not characterize animal aggregations as "emergent properties," or by-products, of other natural forces, as Danchin and Wagner describe. Rather, we submit that *aspects* of persistent aggregations, such as edges, uniform density profiles, and shape, are the emergent properties. And although we support the supposition that evolution may explain why animals aggregate, we do not believe that it can necessarily describe how they do it.

The emerging view that complexity and evolution are alternate, antagonistic theories describing patterns in nature (*1*) is simplistic and obfuscational. It is obvious from the inanimate world that self-organization is a prevalent schema (*2–4*). To assume that life is not governed, at least in part, by the same constraints is difficult to imagine (*5*). At the same time, we recognize evolution at the level of the individual by means of natural selection as the major structural framework shaping life, from cell structure to ecosystems. Can these theories be linked using animal aggregation as a model?

The process of animal aggregation is a continuum, from territorial individuals that gather briefly to mate, through vast single-species aggregations, to the more socially gregarious groupings in which individuals may be related to each other and/or come into frequent contact with other known group members. Our Viewpoint article, and this reply, concentrate on the middle of this spectrum—large, persistent groups where individuals (i) are not related, do not know each other, and may be unlikely to interact repeatedly in the sense of reciprocal altruism; (ii) have no sense of the whole; and (iii) can move throughout the physical group including freedom to come and go (that is, membership is fluid).



Schooling pattern as an emergent property may indirectly be an object of natural selection.

Consider open-water schooling fish [of which there are several hundred species worldwide (*6*)]. Could the classic responses to predators, such as vacuoles, fountains, and flash expansions, be only the result of natural selection? It is unlikely, given the number of unrelated species displaying them. Biophysical constraints, such as the interaction between sensory systems and the fluid medium, will dictate some arrangements of individuals over others. This is self-organization. At the same time, these maneuvers undoubtedly aid the "average" group member, and perhaps all group members, to the extent that defecting loners are immediate targets. An integrated explanation of these repeated patterns is that self-organizational constraints produced a range of response pathways that themselves became the indirect object of selection, leaving the subset we see today, which fulfills the constraints of both theories.

Complexity theorists have suggested that ecosystems are complex adaptive systems with the following properties: (i) diversity and individuality of components; (ii) localized, nonlinear interactions among components; (iii) hierarchical structure as a result of those interactions; (iv) flow of energy, resources, or information as a result of the structure; and (v) component replication or enhancement by means of an autonomous process (such as natural selection) (*7, 8*). Animal aggregations such as fish schools, ungulate herds, and bird flocks are also complex adaptive systems. Members are, in fact, selfish individuals that interact at the local neighbor-to-neighbor level without knowledge of the whole. These interactions result in the structures we recognize as schools, herds, and flocks that display impressive, coordinated responses that may be enhanced (for example, flash expansion of fish schools) or damped (for example, absorption of a smaller group into a larger one). Information is transferred, passively and actively (*9*), through these "sensory integration systems" (*10*). Fluid membership is not unlike market forces that select for efficient individuals, at the expense of inefficient ones. This is the struggle for individuality within the emergent constraints of conformity. Heterogeneity is maintained because of the rewards of winning the resource competition, however veiled, within the group. In essence, complexity sets the environmental theater while evolution directs the behavioral ecology play.

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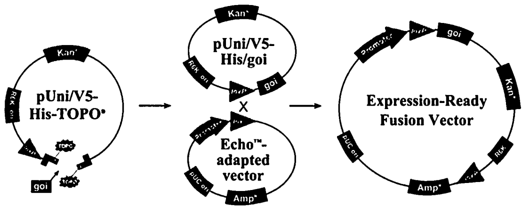

References

1. R. Lewin, *New Sci.*, 28 (14 December 1996).
2. G. Nicolis and I. Prigogine, *Exploring Complexity* (Freeman. New York, 1993).
3. A. B. Cambel, *Applied Chaos Theory: A Paradigm for Complexity* (Academic Press, New York, 1993).
4. P. Bak, *How Nature Works* (Springer-Verlag, New York, 1996).
5. S. Kauffman, *At Home in the Universe* (Oxford Univ. Press, New York, 1995).
6. G. S. Helfman, B. B. Collette, D. E. Facey, *The Diversity of Fishes* (Blackwell, Malden, MA, 1997).
7. J. Holland, *Hidden Order: How Adaptation Builds Complexity* (Addison-Wesley, Reading, MA, 1995).
8. S. Levin, *Fragile Dominion* (Perseus Books, Reading, MA, 1999).
9. T. J. Pitcher and J. K. Parrish, in *Behavior of Teleost Fishes*, T. H. Pitcher, Ed. (Chapman & Hall, London, 1993), pp. 363–439.
10. C. R. Schilt and K. S. Norris, in *Animal Groups in Three Dimensions*, J. K. Parrish and W. M. Hamner, Eds. (Cambridge Univ. Press, New York, 1997), pp. 225–244.

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CORRECTIONS AND CLARIFICATIONS

At the end of the legend for Figure 2 in the report "A short Fe-Fe distance in peroxodiferric ferritin: Control of Fe substrate versus cofactor decay?" by J. Hwang *et al.* (7 Jan., p. 122), the penultimate term should have read "+$O_2$$^{25\ \mathrm{ms}}$."

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In the NetWatch section of the January 7 issue (p. 7), there were errors in two items. The item "Current retrospectives" should not have implied that sugar granule–sized semiconductors developed in 1967 (not 1968, as stated in the item) were the "first" semiconductors. And in the item "Power trip," the URL was truncated: it should have read ippex.pppl.gov/ippex/

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The image of Edvard Munch's woodcut *Evening* that accompanied Leon Eisenberg's review of *Night Falls Fast: Understanding Suicide* bt Kay Redfield Jamison (*Science*'s Compass, 24 Dec., p. 2455) was incorrectly printed. Because of a reversal of color plates during the printing process, the red in the woodcut was replaced by green. A correct color representation appears at right.

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In the Perspective "Charon's first detailed spectra hold many surprises" by Eliot Young (*Science*'s Compass, 7 Jan., p. 53), the distance of 19,636 km between Pluto and its satellite Charon is one and a half times Earth's diameter, not circumference. And the measurements 2370 km and 1252 km are the diameters (not the radii) of Pluto and Charon, respectively.

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In the News Focus article "Unearthing monuments of the Yarmukians" by Michael Balter (7 Jan., p. 35), the size of the foundation of a monumental stone building was misstated. It is 800 square meters, not 3200 square meters.