

Why Gobies Are Like Hobbits

Stephen R. Palumbi and Robert R. Warner

As Bilbo Baggins famously warned, travel is an uncertain business: “You step into the Road, and ... there is no knowing where you might be swept off to” (1). For the better part of a century, marine biologists have assumed the roads of ocean currents are

just as uncertain, and that the drifting eggs and larvae and rafting propagules of many marine species end up

far from their homes, on distant shores. Now, on page 107 of this issue, Taylor and Hellberg (2) help to overturn this notion. They provide further evidence that at least some marine species whose larvae have the potential to disperse over long distances, instead show a remarkable fondness for home.

During the past 2 years, evidence for this new way of thinking has come from two very different sources: advanced genetic monitoring of widely scattered populations, as demonstrated by Taylor and Hellberg in their new work; and elemental analysis of the chemical signatures contained in larval structures (3).

By comparing the genes of individuals collected from different places, genetic analysis can help to underscore the way in which marine populations move around. Because every adult or larva or egg that moves carries with it the genes it inherited from its parents, genetic variation can serve as a natural tag. Moreover, population genetic theory shows that even a small amount of migration between populations can wipe out most genetic differences. So, when differences emerge from marine genetic data, the implications are strong that very little population exchange has taken place.

Just such a conclusion emerges from the Taylor and Hellberg study (2). They show that there are remarkably strong patterns of genetic structure in the mitochondrial genes of a small Caribbean reef goby fish (see the figure). Such patterns demonstrate not only that distant islands harbor genetically distinct populations, but also that there are sharp

genetic breaks between island groups that live relatively close together. These breaks coincide with well-established color-pattern differences among goby fish—for example, the white and blue forms in the Caribbean waters around Puerto Rico are genetically distinct populations even though they reside within 23 km of each other (see the figure).



In living color. The white (top) and blue (middle) forms of the cleaner goby fish, *Elacatinus (Gobiosoma) evelynae*. In the Caribbean waters around Puerto Rico, the white and blue forms of the goby live within 23 km of each other, yet remain genetically separate. Even though their pelagic larvae could be dispersed over large distances by ocean currents, the larvae prefer to remain close to home. (Bottom) A cleaner goby (also called a sharknose goby) cleans the parasites from a red hind (*Epinephelus guttatus*).

The gobies studied by Taylor and Hellberg have high dispersal potential—their larvae remain adrift in ocean currents for about 3 weeks, a period long enough for drifting buoys to travel hundreds of kilometers (2). Two types of explanations are possible for sharp genetic distinctions in the face of such dispersal potential. First, there might be strong selection against the wrong genotypes. These gobies are cleaners—that is, they make their living picking the parasites off larger fish, often the same fish that any rational goby would consider a dangerous predator. Yet the large fish hold their appetites at bay while the tiny gobies dart about them, picking their skin clean of parasites. The variable color

patterns—electric blue in the western Caribbean, lemon yellow in the Northern Bahamas, and stark white in the eastern Caribbean—might be local signals to predators that these gobies are the valet service rather than the entrée. If this is true, then the wrong color pattern of an “immigrant” goby may not be recognized, and so would be strongly selected against.

But within two of the three color areas, goby populations remain remarkably distinct from island to island, so this explanation cannot suffice. The other possibility is that the

goby larvae manage somehow to avoid dispersing on ocean currents—that is, they have a hidden level of drift control not predicted by most larval biologists. Gobies may be particularly adept at this because their larvae are often found nearer to shore than are the larvae of other reef fishes. But this genetic pattern is by no means restricted to gobies. In fact, gobies join an increasing number of island species that have fine-scale genetic structures and low dispersal. Mantis shrimp in Indonesia show genetic differences similar in spatial scale and genetic depth to the gobies studied

by Taylor and Hellberg (4). Fish within closed Polynesian lagoons are genetically different from those outside the lagoons (5). And crabs, fish, oysters, and mussels, a veritable genetic paella, show gene-frequency differences across biogeographic boundaries between the Gulf of Mexico and the west Atlantic (6), or between the Mediterranean and the east Atlantic (7).

These genetic results are paralleled by new information gleaned from the chemical signature of fish otoliths (calcareous components of the inner ear) or mollusk statoliths (calcareous components in the balance organs). These hard structures of calcium carbonate grow like tiny pearls within the animal, depositing a layer for each day of life—including the days spent as pelagic larvae. As larvae pass through different trace-metal environments, the hard parts act as a sort of flight recorder that can be read after the larvae settle in their final location. The information thus gleaned differs in significant ways from that obtained through genetic analysis. It reflects an individual's history since birth, including the pelagic pathway taken as a larva, and potentially provides much more fine-scale spatial data. But the results are similar to those obtained by genetic analysis. For example, populations of fish on tropical

S. R. Palumbi is in the Department of Biological Sciences, Stanford University, Pacific Grove, CA 93950, USA. E-mail: spalumbi@stanford.edu R. R. Warner is in the Department of Ecology, Evolution, and Marine Biology, University of California, Santa Barbara, CA 93106, USA E-mail: warner@lifesci.ucsb.edu

islands are capable of seeding themselves despite having larvae that survive for weeks with the potential for long-distance dispersal (3). Whelk populations along the California coast also appear to be colonized by locally produced larvae (8).

These emerging empirical data obtained using two very different approaches are telling us the same thing: that in some times and places, marine larvae are capable of maintaining close links to home despite their proximity to the ocean highways of the sea. Of course, many other marine species seem to disperse broadly, and the examples cataloged here are

uncharacteristic in that they are almost all from island populations (9). Yet these examples of fine-scale patterns in genetic or chemical signatures tell us that the conventional wisdom of marine biology—that the ocean road is a long one for larvae—may prove to be a coarse generalization (10). It turns out that most hobbits do not take the long road either—Bilbo was an exception—and in the end gobies and hobbits like to stay at home.

References and Notes

1. J. R. R. Tolkien, *The Lord of the Rings: The Fellowship of the Ring* (Houghton Mifflin, Boston, 1994), p. 72.
2. M. S. Taylor, M. E. Hellberg, *Science* **299**, 107 (2003).

3. S. E. Swearer *et al.*, *Bull. Mar. Sci.* **70**, 251 (2002).
4. P. H. Barber, S. R. Palumbi, M. V. Erdmann, M. K. Moosa, *Nature* **406**, 692 (2000).
5. S. Planes, P. Romans, R. Lecomte-Finiger, *Coral Reefs* **17**, 9 (1998).
6. J. C. Avise, *Phylogeography* (Harvard Univ. Press, Cambridge, MA, 2000).
7. H. Quessada, C. Zapata, G. Alvarez, *Mar. Ecol. Progr. Ser.* **116**, 99 (1995).
8. D. Zacherl, thesis, University of California, Santa Barbara (2002).
9. C. Mora, P. F. Sale, *Trends Ecol. Evol.* **17**, 422 (2002).
10. The extent of marine larval dispersal will be one of the subjects of a symposium at the upcoming AAAS meeting in Denver, CO: "Opening the Black Box: Understanding Ecosystem Dynamics in the Coastal Ocean" (B. Menge, R. Warner, and J. Lubchenco, co-organizers).

PERSPECTIVES: CHEMISTRY

Diamondoid Hydrocarbons— Delving into Nature's Bounty

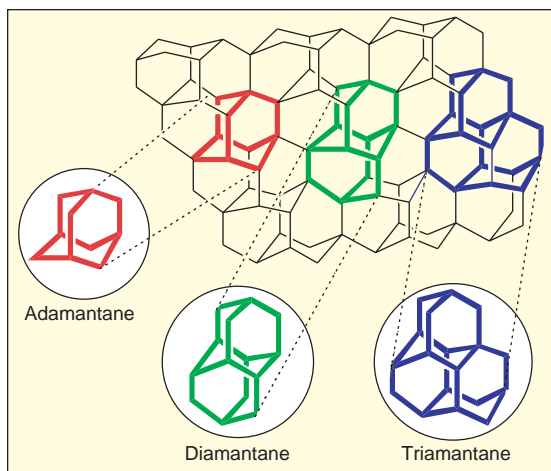
Alan P. Marchand

The molecular lattice of diamond, first elucidated in 1913 (1), consists of repeating units of 10 carbon atoms forming a tetracyclic cage system. Shortly thereafter it was recognized that a series of saturated hydrocarbons can be superimposed on this diamond lattice. The simplest of these "diamondoids," with the common name adamantane (from $\alpha\delta\alpha\mu\alpha\zeta$, the Greek word for diamond), is a tricyclic $C_{10}H_{16}$ isomer. The series of saturated hydrocarbons can then be regarded as higher "adamantologs" of adamantane (see the figure).

Adamantane and the larger diamondoids long remained hypothetical molecules. They could neither be isolated from a natural repository, nor made through rational organic synthesis. As a result, interest in these molecules and their chemistry remained dormant until 1957, when Schleyer reported that *endo*-trimethylenenorbornane (which can be prepared readily) rearranges to adamantane when refluxed overnight with aluminum bromide or aluminum chloride (2).

This Lewis acid-catalyzed thermodynamic rearrangement of hydrocarbons afforded a method to prepare adamantane simply and inexpensively. It led to renewed interest in the synthesis and chemistry of adamantane and related diamondoid molecules with the chemical formula $C_{(4n+6)}H_{(4n+12)}$, where $n = 0, 1, 2, 3, \dots$

The next diamondoid molecule to become a focus of attention was diamantane



Diamond in miniature. The structures of adamantane (left), diamantane (center), and triamantane (right) are segments of the diamond lattice.

tane ($C_{14}H_{20}$) (see the figure). This compound—unknown in the literature at the time—was chosen as the official emblem of a 1963 IUPAC conference. In response to the implied challenge, Schleyer again used his "rearrangement synthesis" approach successfully to prepare diamantane (3). The third member of the diamondoid series, $C_{18}H_{24}$, nicknamed triamantane, was isolated and characterized shortly thereafter (4).

As higher diamondoids were sought, however, it rapidly became apparent that the rearrangement synthesis approach has severe limitations. Whereas each of the first three members of the series (adamantane, diamantane, and triamantane) exists as a single isomer, higher members of the series can exist in more than one isomeric

form. Thus, there are 3 $C_{22}H_{28}$ tetramantanes, 6 isomeric $C_{26}H_{32}$ pentamantanes, and as many as 17 possible $C_{30}H_{36}$ hexamantane isomers.

As the number of isomers increases, differences between their relative thermodynamic stabilities decrease, and the complexity of the potential-energy surface connecting these isomers increases. Thus, it becomes increasingly difficult to promote a smooth thermodynamic rearrangement to obtain a single isomer. As the limitations of rearrangement synthesis became clear, interest in diamondoid hydrocarbons waned once again.

In a report by Dahl *et al.* (5) on page 96, they present results that may reawaken interest in this important class of compounds. There are compelling reasons to do so. Substituents can be introduced easily at bridgehead positions of diamondoids (6, 7). Such functionalized diamondoid molecules have important pharmaceutical applications. Perhaps the most widely known is 1-aminoadamantane

(also known as amantadine or Symmetrel), which is used extensively as an antidyskinetic to treat parkinsonism and related extrapyramidal syndromes and as a chemical antiviral agent to treat Type A influenza in humans (6). Polyalkyladamantanes have been studied as high-energy-density materials, particularly as components of jet fuel blends (8–10). There is also renewed interest in nanotechnological applications of diamondoid molecules, particularly in the area of microelectronics (11).

Dahl *et al.* (5) have isolated and characterized several previously unknown higher diamondoid hydrocarbons from crude oil. In addition, they have developed improved methods for isolating higher diamondoids that hold considerable promise for the

The author is in the Department of Chemistry, University of North Texas, Denton, TX 76203, USA. E-mail: marchand@unt.edu