Foreign Invaders

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In this issue of *Science*, Carlton and Geller (*1*) report the global dispersal of alien plankton by inadvertent transport in the ballast water of ships. Their analysis demonstrates, among other things, that the modern giant bulk cargo ship is an ideal medium for the transfer of one harbor's biota to another. These ships carry enormous quantities of sea or harbor water as ballast and can unload this water in a few hours after arrival in port. The temperature and salinity conditions of the ballast water and the water of the destination can sometimes be nearly the same, so in some circumstances there is no environmental shock for the new arrivals. What the shock may be for the host biota only becomes apparent later.

All sorts of organisms have been introduced from the harbors of one continent to the harbors of another. Several striking examples are from the west coast of the United States. The Pacific coasts of Washington, Oregon, and California have remarkably few estuarine regions. All of them are in geologically younger regions than the estuaries of the Atlantic and Gulf coasts, and in California these regions are subject to great variations in salinity. In 1862, a great flood (so large that it may not be duplicated for another 1000 years) turned San Francisco Bay fresh for a week, drowned the legislature out of Sacramento, and forced the estuarine mixing region out to sea beyond the Golden Gate. This probably altered the ecosystem of the bay. Then, in 1867 the completion of the transcontinental railroad made it possible to transport live oysters from the eastern seaboard to San Francisco Bay. As a result, a dozen or so organisms that lived on or among the clusters of oysters found new homes in the bay, although we were unable to naturalize the oyster itself. Because of these events in the 19th century and the lack of studies of any consequence before 1912, we have no clear idea of what the natural fauna of San Francisco Bay was like before European settlement. Indeed, as of 1979, there were at least 255 foreign invertebrates in San Francisco Bay (*2*).

A new invader to the bay was first observed in Suisun Bay, the upper arm of San Francisco Bay, in 1985. This is an Asian clam, *Potamocorbula amurensis*, an organism that can thrive in salinities ranging from almost freshwater to at least 33 parts per thousand. It may have arrived from China in ballast water as veliger larvae. As this clam thrives on both diatoms and crustacean larvae and has attained a density of more than 10,000 per square meter, it is capable of seriously interrupting the basic food chain of San Francisco Bay (*3*). Panic buttons have been pushed and research projects set in motion. Now, another invader may be coming to the rescue. This newcomer is inordinately fond of clams and mussels and is known in its native European waters to "control distribution of mussels, sea urchins, and dog-whelks" (*4*). This is the European green crab *Carcinus maenas* (see figure), a small (less than 3 inches broad) but voracious and belligerent crab that can even bite people.

The crabs that eat the clams. *Carcinus maenas* from San Francisco Bay. [Photo by Carolyn Kott, courtesy of California Academy of Sciences]

It is a veteran traveler (it has reached Australian and South African waters) and is related to our eastern blue crab. *Carcinus maenas* was first noticed in the southern part of San Francisco Bay in 1990, and in a very short time has spread throughout most of the bay. Indeed, the green crab has a frighteningly efficient reproductive capacity. Like all brachyuran crabs, the female has a special pouch-like arrangement for holding viable sperm for a year and may spawn fertile egg masses several times from a single mating. It is no wonder that it has managed to populate most of the bay in 2 or 3 years. The latest news is that it is moving upstream toward freshwater. According to Dusty Chivers of the California Academy of Sciences, when presented with *Potamocorbula*, the green crab will eat them "like pistachio nuts" (*5*). If this crab eats up all the clams, what will happen next?

Freshwaters are not immune to foreign invasion, although it may take the invaders a bit longer to get here. The zebra mussel, *Dreissena polymorpha*, a native of the Caspian Sea, appeared in the Great Lakes in the summer of 1988. It may have traveled by ballast water—possibly from the low-salinity Baltic Sea or from England, where it has been naturalized since 1824 and is a favorite food of the Tufted Duck (*5*). By 1990 the numbers of this small mussel had increased enormously in Lake Erie, where it clings together in masses by means of its byssus threads, clogs water intake pipes, and sinks buoys by adhering to them. It is impeding commerce by costing industries millions of dollars simply to clean it out of their intake pipes. It can resist exposure for several days and attaches itself to pleasure boats. Because of this it can be transported overland and is already invading the Appalachians. There is no way to stop it from crossing the Continental Divide. It is feared that it may obliterate the unique freshwater mussels of Appalachian streams (*6,7*).

As if their experience with rabbits and cactus was not enough, Australians deliberately introduced the tropical American toad *Bufo marinus* to the sugar cane plantations of their northern states to eat up the native beetles that were ruining the crops. Unfortunately the toads are nocturnal feeders and the beetles are abroad by day, while the toads sleep under rocks, boards, and burrows. By night the toads flourish, reproduce phenomenally well, and eat up everything they can find. The cane growers were warned by Walter W. Froggart [sic!], president of the New South Wales Naturalist Society, that the introduction was not a good idea and that the toads would eat the native ground fauna. He was immediately denounced as an ignorant, meddlesome crank. He was also dead right. Released on the subcontinental mass of Australia, *Bufo marinus* thrived, multiplied, and ate everything but the cane beetles. And now the toads are called cane toads in Australia and nobody knows what to do about them. The sugar cane growers use benzene hexachloride, and the beetles are held at bay (*8*).

All things considered, man, whether by intent or inadvertence, is the principal agent responsible for introducing organisms of all sorts to North America and elsewhere. The colonists brought Kentucky bluegrass from England, and the Spaniards brought the for-

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age plants of California that have replaced the native bunch grasses. Captain Cook on his second expedition in 1773 introduced pigs to New Zealand (where they are still called "Captain Cookers") (9). Recently a predacious terrestrial planarian from New Zealand has appeared in Scotland; this planarian may cause problems because its preferred diet is earthworms (10). Is this New Zealand's revenge? New Zealand itself has had its share of introduced species. Somebody planted those Port Orford cedars at the Christchurch airport. Those Monterey cypresses that adorn the town square of Punta Arenas around the statue of Magellan must have also had some help. Earnest bird lovers, wanting to feel at home in the New World, brought us English sparrows and starlings, and we have returned the compliment with the gray squirrel and raccoon. Some of these introductions are pleasant reminders of faraway places, but many are detrimental to their new ecosystems. It is to be hoped that all our bays and estuaries will not become so much alike in their flora and fauna that there is no interest in traveling to see strange and interesting things (like little blue soldier crabs in Australia). But we must also hope that the bureaucrats do not spin a web of regulations more entangling than the ornithologist's mist nets and thereby defeat their own good intentions.

References and Notes

1. J. T. Carlton and J. B. Geller, *Science* **261**, 78 (1993).
2. J. T. Carlton, thesis, University of California, Davis (1979).
3. J. T. Carlton *et al.*, *Mar. Ecol. Prog. Ser.* **66**, 81 (1990).
4. W. C. M. Klein Breteler, in *Ecology of the Wadden Sea*, W. J. Wolff, Ed. (Balkema, Rotterdam, 1981), vol. 1, pp. 119–121.
5. J. Kear, *Man and Wildfowl* (Poyser, London, 1990).
6. W. Stolzenburg, *Nature Conservancy* **42**, 16 (1992).
7. The problems that have been caused by the *Dreissena* invasion stirred the National Oceanic and Atmospheric Administration into arranging a workshop from 20 to 22 April 1993, in Seattle to discuss nonindigenous estuarine and marine organisms. There were 60 participants, including visitors from Belgium, Finland, Tasmania, and the Australian mainland. In addition to the scientists, there were also speakers from industry, aquaria, and aquaculture, as well as administrators. The workshop did not ask for recommendations or pass resolutions, but did agree that the magnitude of the distribution of exotic organisms in coastal waters had been greatly underestimated. Nonindigenous estuarine and marine organisms are causing ecological change in coastal waters, and it may be only a matter of time before something as bad as the zebra mussel arrives in our estuaries. More careful and thorough analyses of the taxonomic status of introduced organisms are needed. The tone of the meeting was that additional regulation will not help much, but that all industries should become more aware of this problem of transferring organisms from one part of the world to another.
8. S. Lewis, *Cane Toads, An Unnatural History* (Dolphin Doubleday, New York, 1989).
9. J. Druett, *Exotic Intruders: The Introduction of Plants and Animals into New Zealand* (Heinemann, Auckland, 1983).
10. D. MacKenzie, *New Scientist* **131**, 31 (1991).

Molecular Muscle

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It is almost 40 years since the sliding filament model of muscle contraction (in which muscle filaments move past one another) was proposed independently by A. F. Huxley and R. Niedergerke (1) and by H. E. Huxley and J. Hanson (2). There followed 20 years of progress in structural, mechanical, and biochemical studies—the synthesis of which led to the idea that the thick and thin filaments slide past one another by means of rotating crossbridges (3). Thin filaments consist mainly of the globular protein actin, and thick filaments mainly of myosin, a long protein with a prominent "head." This model has been considered to be basically correct, with perhaps only a few details to be filled in, and certainly suitable for entry into standard textbooks. Now in this issue of *Science*, Rayment and co-workers take our understanding of muscle contraction to a new level of sophistication by reporting the three-dimensional structure of the myosin head at 2.8 Å and then using this structure and other existing data to propose a model of the actomyosin complex that begins to explain the molecular movements that underlie muscle contraction.

Striated muscle. Magnification, x23,800. [Photograph by D. W. Fawcett/Visuals Unlimited]

The essence of the sliding filament model is that the myosin head binds to the actin filament in one orientation, rotates to a second orientation, possibly a 45° change, and then detaches. The cycle is driven in one direction by coupling these transitions to the steps of adenosine triphosphate (ATP) hydrolysis. The rotation need not involve the whole head but requires only a part, which could be accomplished by a bending of the protein structure. In either case, part of the free energy of ATP hydrolysis is stored mechanically as a "stretched spring" in the head or, alternatively, in the connection of the head to the myosin filaments.

In the 20-year effort to fill in these details we have learned a great deal about muscle contraction and cell motility, but we have been unable to satisfactorily determine how actin and myosin actually interact. What has been lacking is the three-dimensional structures of the proteins. In 1990, the structure of the actin monomer was obtained, and a model was proposed for the packing of monomers in the actin filament (4, 5). Now that Rayment *et al.* have described the three-dimensional structure of the myosin head at 2.8 Å resolution (6), they have also been able to propose a model of the actomyosin complex in which the conformational changes during contraction can be discussed in terms of the molecular structure (7).

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We have waited a long time for this structure of myosin and the model of actomyosin. Now that we have these, what can we expect to learn? First, we should now be able to synthesize the information that has been accumulated on actin and myosin. Indeed, a test of the correctness of the structure is its consistency with this extensive evidence. The new results pass this test easily. Affinity labeling, crosslinking, energy transfer, and image reconstruction of the actomyosin complex had provided a low-resolution model in which the substrate and actin binding sites and the relative positions of some side chains had been determined (8, 9). There is surpris-