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The Exotic Species Threat to California's Coastal Resources

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Abstract

The potential scale and impact of biological invasions in coastal waters is demonstrated by invasions in the San Francisco Bay/Delta Estuary. Biodiversity, ecosystem processes and human activities have already been substantially affected, while new organisms continue to be introduced into the ecosystem. Protecting coastal biodiversity, and preventing new impacts on the human use of coastal resources, will require regulation of the various mechanisms by which exotic marine and freshwater organisms are transported across oceans and continents to California. The broad scope of the problem is known, as are some of the steps needed to reduce the rate of transport and invasion. The most critical vector now operating is undoubtedly the transport of organisms in ships' ballast water. To reduce the flood of invasions into California's coastal waters, there is an urgent need for the adoption and implementation of clear legal requirements for the high-seas exchange of ballast water.

Introduction

In 1852 Commodore John Sloat arrived on the Pacific coast with orders to find a site for a naval base that was "safe from attack by wind, wave, enemies, *and marine worms*" (Lott, 1954). The worm that worried the U. S. Navy was the Pacific shipworm *Bankia setacea*—which is not, taxonomically-speaking, a worm, but rather a clam with a skinny, worm-like body and small shells modified for boring into wood. Shipworms were infamous for infesting, weakening and frequently destroying the hulls of ships and boats and the pilings that supported shore-side structures. Commodore Sloat eventually chose a site in the northern part of San Francisco Bay, where the waters were too fresh for the Pacific shipworm to survive. Thus the Mare Island Naval Shipyard was founded and operated for many decades free from attack by any of its feared enemies.

But then in 1913 an Atlantic shipworm, which had probably travelled from its native waters in the hull of a ship, was discovered in a piling at the shipyard (Hill 1927; Neily 1927). The Atlantic shipworm could tolerate fresher water than its Pacific cousin, and reproduced and spread so vigorously that it soon began to chew its way through the entire maritime infrastructure of northern San Francisco Bay. Over a two-year period, an average of one major wharf, pier or ferry slip collapsed into the water every two weeks, including the Union Oil Company railroad dock at Oleum, which took several loaded freight cars into the Bay along with it, the Benicia Municipal Wharf and Customs House, three grain warehouses, one highway and two railroad bridges and twelve ferry terminals. Mare Island lost several docks, the causeway and an 8,000-foot-long dike. The present value of the damage to these structures is estimated at several billion dollars, not including collateral damage (such as the freight cars), lost business, damage from the shipworm in

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other parts of the Bay, subsequent damage, and subsequent costs of treating structures to be resistant to the shipworm (Hill 1927; Neily 1927; Lemmon and Wichels 1977; Cohen, 1996).

Biological Invasions

Exotic organisms (also known as nonindigenous, introduced or alien organisms) not only endanger maritime activities, but may also constitute the largest single threat to the biological diversity of the world's coastal regions. In California, exotic organisms have invaded many coastal habitats, including beaches and dune areas, marshes, mudflats and open waters, in fresh, brackish and salt-water environments.

These invasions have been most intensively studied in the San Francisco Bay/Delta Estuary, which now hosts over 200 exotic species including plants, protists and invertebrate and vertebrate animals. More significant than the sheer number of exotic species is their dominance in many habitats, accounting for 40% to 100% of the common species at many sites. The organisms living on the muddy bottom of the Bay and on the sides of the docks are mostly exotic, most of the Delta's fish are native to the eastern United States, and the zooplankton in the northern part of the Estuary now consist primarily of several species of Asian copepod and Asian mysid shrimp. Moreover, the rate of invasion has been increasing, probably due in large part to the development of new or more active or more diverse mechanisms for transporting organisms across and between oceans, related to the rapid modern expansion of international trade and travel (Cohen and Carlton 1995).

Exotic species are not confined to the San Francisco Estuary, but are commonly reported in Los Angeles, San Diego and many smaller harbors and embayments in California, and in coastal regions around the world. Once established in one bay, organisms may readily invade another along the coast: the European green crab, first reported in 1989-90 from San Francisco Bay, had spread to Bodega Bay by 1993, Elkhorn Slough in Monterey Bay by 1994, Humboldt Bay by 1995, and Coos Bay, Oregon by 1997 (Cohen *et al.* 1995; Grosholtz and Ruiz 1995; Miller 1996; N. Richmond, pers. comm. 1997). Exotic species may also deploy out of the bays to invade the open coast. A predatory New Zealand sea slug that was collected in San Francisco Bay in 1992 and is now found from San Diego to Bodega Harbor, has become the most commonly collected sea slug in southern California's coastal waters (Gosliner 1995; D. Cadien, pers. comm. 1996).

Types of Impacts

In recent decades, negative impacts from accidentally-introduced exotic marine and freshwater organisms have attracted increasing attention in many parts of the world.

- The Atlantic comb jelly *Mnemiopsis leidyi*, introduced into the Black and Azov Seas by the early 1980s, became phenomenally abundant and ate up the zooplankton, contributing to the destruction of the region's anchovy and sprat fisheries and of the fishing fleets (from six countries) that depended on them (Travis 1993).
- European zebra mussels, appearing in the Great Lakes in the late 1980s, have become a massive nuisance, causing billions of dollars of damage by closing beaches that became fouled with sharp-edged mussel shells and rotting mussel flesh; agglomerating in enormous numbers on navigational buoys, and sinking them; and blocking the water intake systems of cities, factories and power plants. In a few year's time, zebra mussels spread across much of North America, from Canada to New Orleans and from the Hudson River to Oklahoma (Nalepa and Schloesser 1993)
- Toxic red tides thought by many to be caused by introduced dinoflagellates have appeared in many parts of the world (Hallegraeff et al. 1989; Hallegraeff and Bolch 1991; G. Lembeye, pers. comm. 1996). The toxins accumulate in clams or mussels, sickening and occasionally killing the people that eat them. In New Zealand, a recent red tide outbreak was so severe that people walking along the shore became ill (O'Hara 1993).
- In 1991 during the South American cholera epidemic, the cholera-causing bacterium *Vibrio cholerae* was discovered in oysters and fish in Mobile Bay, Alabama. The U. S. Food and

Drug Administration subsequently sampled ships arriving from South America and found *Vibrio cholerae* in one third of them (*Federal* 1991). It was even possible that cholera initially reached South America via ballast water (Ditchfield 1993).

Table 1 lists some categories of effects resulting from the introduction of marine, estuarine and aquatic organisms. Ecological effects can alternately be sorted into two broad classes based on our assessment of their impacts. On the one hand, each introduction produces specific changes which may be judged to be positive, negative or neutral, depending on the system, the observer and the cultural context. On the other hand, every introduction of an exotic species into a region has a negative impact on the region's native diversity, and diminishes to some degree the distinctive faunal characteristics and ecological relationships that have developed or evolved there.

Table 1. Types of Effects from Exotic Species in Coastal Waters

Effects on Ecosystems	Effects on Human Activities
species-species interactions • predation • competition • hybridization • introduction of new parasites and diseases	*simple effects* • fouling of boats and marine structures • boring of wooden boats and structures • fouling of waterways and water systems • new fisheries • changes in populations that support existing fisheries • new human parasites or diseases
ecosystem effects • habitat alteration • changes in productivity • changes in trophic pathways • changes in nutrient or contaminant cycling • ecosystem instability	*systemic effects* • disruption of services • management uncertainty and failure
diversity impacts • reduction of populations and loss of native species • loss of genetic diversity • increase in local species number • loss of geographic diversity	
indirect effects • pollution from herbicides, pesticides and anti-fouling compounds • introduction of biocontrol organisms	*indirect effects* • costs of maintaining facilities and services against fouling and other damages • costs of monitoring, intercepting and controlling exotic species

In a similar manner, economic effects and other effects on human activities may be sorted into a few broad classes. Again specific changes may be judged positive, negative or neutral, depending on the situation, but there are two general aspects of such change that are usually or invariably negative. First, human activities as they interface with natural resources are typically dependent on the stability of those resources—for example, when we invest in a fishing fleet and fish processing facilities we do so anticipating that the fishery will remain viable, at an adequate level of production, for some years. The introduction of exotic organisms brings change, and if the effect on existing resources is substantial there will be a cost in adapting to it, irrespective of whether the change in the long run is economically harmful or useful. From an economic perspective, other things being equal, we'd prefer to not have our ecosystems change on us. Second, many types of economically-important activities, such as the construction of dams and water diversions, the dredging of waterways for navigation, the creation or expansion of port facilities, and the development and maintenance of commercial fisheries, are increasingly subject to regulations that require a demonstration that the proposed activity will not unduly harm native populations of organisms or endangered species. To make a convincing demonstration requires some basic understanding of the affected ecosystem and some ability to predict its future response, and these requirements become harder to meet if the ecosystem is continually being altered by the addition of new species.

This latter problem has been noted by the managers of California water systems whose diversions affect the size and timing of outflows from the Sacramento-San Joaquin River Delta into San Francisco Bay. Concern for many years has focussed on the level of productivity of the phytoplankton—the microscopic floating plants that are important contributors to the pelagic food web—in the northern part of the Estuary. Productivity was believed to be dependent on the size of the outflows, and years of effort were spent on scientific data collection and analysis in order to illuminate the nature of that dependence (Arthur and Ball 1978; Nichols 1985). Then, just about the time that relationship began to be reasonably understood, an Asian clam was introduced into the ecosystem and became so abundant, and was so effective at feeding on phytoplankton, that the dynamics of phytoplankton productivity were immediately and dramatically altered. Almost overnight it was as if a new ecosystem had appeared, and all that had been learned about predicting and managing the response of ecosystem productivity to flows was, in essence, lost (Nichols *et al.* 1990; Cohen 1990).

Finally, while exotic species that have been intentionally introduced to aquatic and marine ecosystems to support or enhance human activities have sometimes served their intended function, sometimes failed to do so, and sometime produced harmful results, only rarely has an accidentally introduced organism produced a positive economic result. The impacts of accidental introductions are more commonly negative, and occasionally disastrous. Thus, while there may be cause for lively debate about proposed intentional introductions, there should be no question about the value of reducing or eliminating accidental introductions.

Ballast water

Major pathways responsible for the introduction of exotic organisms into California waters include the transport of organisms in ships' ballast water, the introduction of organisms via aquaculture activities, and the release or escape of organisms imported in the aquarium and live food trades. Ballast water is by far the most important mechanism in terms of the number and variety of organisms transported and released.

Ballast water is water that ships pump into empty cargo holds or into dedicated ballast tanks at the start of a voyage in order to achieve proper trim and buoyancy, and later discharge on arrival at a new port prior to taking on cargo. The amount of water involved can be as much as tens of millions of gallons per ship. Water was first used for ballast as early as the 1880s when iron hulls and steam-driven pumps came into use, but the amount of ballast water transported around the world has been rapidly increasing in recent decades with the expansion of international trade.

Numerous studies have found that ballast water can carry an enormous number and variety of aquatic organisms (Carlton 1985; Carlton and Geller 1993), and in most parts of the world, including the entire California coast, these are freely discharged into coastal waters without regulation. Ballast water is credited with transporting the zebra mussel to North America, the comb jelly *Mnemiopsis* to the Black Sea, toxic red tides to many parts of the world, and the bacterium that causes cholera to coastal waters of the southeastern United States. Roughly 50 exotic organisms are thought to have been introduced into the San Francisco Estuary via ballast water in recent decades (Cohen and Carlton 1995).

In the long run it might be possible to stop the introduction of exotic organisms in ballast water by means of some technological fix—a treatment process to kill ballast water organisms that can be installed on-board ship—but such a fix will take at least several decades to develop and to install in the world's merchant shipping fleet. In the meantime, however, we could substantially and immediately reduce ballast water invasions by requiring ships to exchange their ballast water at sea, replacing the coastal water (and associated coastal organisms) in their ballast tanks with mid-ocean water (and organisms). Because of differing conditions in the coastal and mid-ocean environments, coastal organisms discharged into the middle of the ocean are unlikely to survive or compete effectively, and mid-ocean organisms discharged into coastal waters are also unlikely to survive and compete.

Federal regulations requiring such high-seas ballast water exchange have been in effect for several years for ships entering the Great Lakes from overseas ports. The shipping industry has apparently complied with these requirements without ill effect and at insignificant cost. However, despite last year's passage of much-ballyhooed federal legislation that purported to deal with aquatic invasions, these regulations have not been extended to the rest of the country. Thus untold numbers of living marine and freshwater organisms from other parts of the world, comprising probably thousands of different species, continue to be dumped into California waters every year, unrestricted by any law or regulation.

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