Invasions Status and Policy on the U. S. West Coast

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Abstract: Over the past 20 years, a rapidly accumulating body of knowledge has demonstrated that invasions by non-native organisms threaten the aquatic flora and fauna in the world's coastal regions and the human activities and economies that depend on them. Intensive research in the San Francisco Bay/Delta Estuary has revealed striking alterations in biodiversity and ecosystem functioning, and provided evidence that the rate of invasion is increasing. This increase appears linked to the expansion and globalization of commerce, and the wider and faster movement of goods and people around the world. The consequences are not limited to the oceans. On land as in the sea, exotic predators and competitors alter ecosystems, while parasites or diseases of crops, livestock, native animals or plants, or human beings, may arrive with devastating effect on populations that lack genetic or acquired immunities. Although methods exist to reduce the frequency of invasions by exotic organisms, we have thus far done little to apply them. Failures at the international and national level to effectively control a major transport vector of exotic species, the transoceanic relocation of aquatic organisms via ships' ballast water, have led to increasing state and local efforts to regulate ballast water discharges.

Key words: invasion, exotic species, nonindigenous species, ballast water, San Francisco Bay

Introduction

The marine waters of the globe are sometimes regarded as constituting a single, interconnected ecosystem–the world ocean. However, biogeographers have long recognized that the organisms inhabiting temperate zone coastal waters are distributed in distinct bioregions, separated by continents, by zones of tropical water, and by reaches of deep ocean inimical to the survival of coastal life. Each of these regions, developing in relative isolation from the others, has evolved its own unique assemblage of native endemic organisms.

These assemblages, and potentially the species that comprise them, are increasingly threatened by exotic organisms transported in association with human commerce and travel. Over the past decade and a half, several spectacular invasions–European mussels (*Dreissena polymorpha*) clogging Midwestern water pipes, a tropical seaweed (*Caulerpa taxifolia*) "astroturfing" the Mediterranean, Atlantic comb jellies (*Mnemiopsis leidyi*) vacuuming the zooplankton from the Black Sea–have persuaded limnologists and oceanographers that something is seriously amiss. Known vectors transporting invasive species into aquatic habitats are expanding in scale, new vectors are being created, and bays, estuaries and freshwater ecosystems are progressively becoming invaded by exotic organisms.

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An Invaded Estuary

Recent studies in the San Francisco Bay/Delta Estuary provide a glimpse of just how bad things can get. We have now documented over 230 exotic plants, protists, and animals that have become established within the Estuary, with over 160 of these found in the salt- and brackish-water portion of the estuary (Cohen and Carlton 1995, 1998). We have identified another 100-200 species as cryptogenic–meaning that we do not know whether they are native or exotic (Carlton 1996). Perhaps even more impressive than the sheer number of exotic species is the frequency with which they visually and numerically dominate habitats in the Estuary. Exotic species account for 40 to 100% of the common organisms in several biotic communities at various sites, whether calculated as a percentage of the number of species present, a percentage of the number of individuals, or a percentage of biomass.

For example, the organisms clinging to the sides of the docks and burrowing in the sediment on the bottom of the Bay are nearly all exotic, primarily from North Atlantic or Asian coasts. Common crabs in the Bay are from Europe, the eastern United States, and China; common mussels derive from the Atlantic, the Mediterranean, and the southern hemisphere; the most common clams come from the Atlantic and from Asia; and the most common snails are from the Atlantic (Cohen and Carlton 1995). Most of the fish in the Delta are native to the eastern United States (Moyle 1976). The crustacean zooplankton are increasingly dominated by Asian species (Orsi 1995), while several exotic jellyfish have arrived from the Black Sea (Mills and Sommer 1995). These introductions have dramatically reduced some native populations, altered habitat structure and energy flows, and caused direct economic damage amounting to billions of dollars (Cohen and Carlton 1995; Cohen 1996).

One recent invasion demonstrates the potential for exotic species to damage ecosystems in myriad ways. In October 1986, three small, nondescript clams of a type never before seen on the Pacific coast of North America were collected in San Francisco Bay by a community college biology class. By the summer of 1987, nine months later, this clam had become the most abundant clam in the northern part of the Bay, averaging over 2000 clams per m^2. The clam (an Asian species, *Potamocorbula amurensis*) also turns out to be a highly efficient filter feeder, ingesting bacteria and small zooplankton as well as phytoplankton. At the densities in which it occurs in the Bay, virtually the entire water column may pass through the filtering apparatus of these clams between once and twice a day. Since its arrival the clam has eliminated annual phytoplankton blooms that had previously characterized the ecosystem, disrupted food webs, reduced the populations of existing zooplankton species, and possibly increased the vulnerability of the ecosystem to invasions by exotic zooplankton, many of which have since occurred (Carlton *et al.* 1990; Nichols *et al.* 1990; Alpine and Cloern 1992; Werner and Hollibaugh 1993; Kimmerer *et al.* 1994; Orsi 1995). Changes at higher trophic levels, though less clear, may also have resulted. The clam may also be acting as an accumulator of contaminants, possibly concentrating selenium in the diets of bottom-feeding fish and birds at levels that might be high enough to cause reproductive defects (Thompson 1997).

Exotic species are present not only in San Francisco Bay, but are common as well in other harbors and bays in California and along the Pacific Coast. For example, recent compilations indicate about 50 exotic species known to be established in Puget Sound (Cohen *et al.* 1998), about 25 exotic species in Morro Bay in central California, and about 80 exotic species in the bays and harbors of southern California. Once established in one bay, exotic organisms may quickly spread to another through either natural or anthropogenic transport. For example, the European green crab *Carcinus maenas*, first observed in San Francisco Bay in 1989-90, had spread to Bodega Bay by 1993, to Elkhorn Slough in Monterey Bay by 1994, to Humboldt Bay by 1995, to Coos Bay in southern Oregon by 1997, and to Willapa Bay and Grays Harbor in Washington and Morro Bay in California by 1998, and to southern Vancouver Island in British Columbia by 1999 (Cohen *et al.* 1995; Grosholtz and Ruiz 1995; Miller 1996; N. Richmond, B. Dumbauld, E. Grosholtz, G. Jamieson, pers. comm.). Exotic species initially established in bays may also move out of them to invade the open coast. A predatory New Zealand sea slug, *Philine auriformis*, that was collected in San Francisco Bay in 1992, appears subsequently to have spread north to Bodega Bay and south to near San Diego, becoming the most commonly collected sea slug along the southern California coast (Gosliner 1995; D. Cadien, pers. comm. 1996–although the presence of one or more additional exotic sea slugs in the same genus may confound this picture [M. Chow, T. Gosliner, M. Behrens, pers. comm.]).

On Land As in the Sea

Biologic invasions in California are by no means limited to aquatic environments. Some 1,023 species[2] of exotic plants, at least 18 species of exotic

[2] This includes both terrestrial and aquatic plants. The number is from the most recent manual of California flora (Hickman 1993), and includes both "naturalized" and "waif" species. An estimate based on the prior manual (Munz 1968) had been criticized for including plants that are not fully established and capable of persisting without human interference, such as narrow garden escapes, taxa that are only sparingly established, and agricultural weeds that are maintained though summer irrigation, and a more conservative estimate was calculated that excluded these (Howell 1972 and Raven 1988, cited in Rejmanek *et al.* 1991). Reducing the estimate of 1023 species by the same proportion yields a more conservative estimate of 686 introduced and established plants in California.

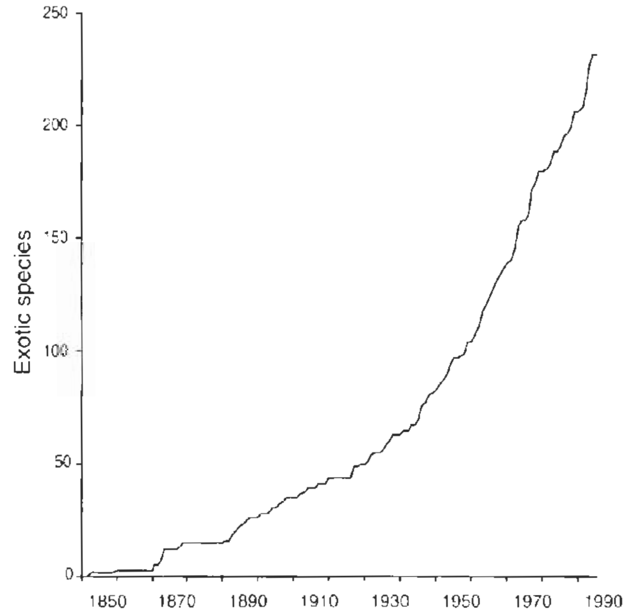

Figure 1. Increasing rate of invasions. Cumulative number of exotic species established in the San Francisco Bay/Delta Estuary. Adapted from Cohen and Carlton 1998.

land snails and slugs, 24 species of exotic birds, 22 species of exotic mammals, and an unknown but certainly large number of exotic insects and other terrestrial arthropods have been reported as established in California (Hanna 1966; Hickman 1993; Laudenslayer *et al.* 1991 as updated by R. Jurek, pers. comm.). The data for plants have been interpreted as indicating a decline in the rate of invasion since the 1950s (that is, a decline in the rate at which new plants become established in California; many previously established plants continued to expand their range and abundance) (Rejmanek *et al.* 1991).

The data from aquatic habitats, however, reveal a substantial acceleration in invasions (Figure 1). Roughly half of all invasions documented for the San Francisco Estuary occurred in the last 35 years. Overall, the rate of invasion increased from an average of one every 55 weeks between 1851 and 1960, to one every 14 weeks from 1961 to 1995 (Cohen and Carlton 1998). In the decade from 1986 to 1995, for example, 43 exotic species were newly collected in the Estuary, with at least 33 of these apparently becoming established (Cohen 1997). Similarly, a study of the Great Lakes also found the rate of invasion to be increasing, though not as steeply, from one every 64 weeks between 1840 and 1959, to one every 39 weeks from 1960 to 1990 (Mills *et al.* 1993).

Pathways and Policies

Within aquatic and especially marine ecosystems, important pathways for the introduction of exotic species include transport with transoceanic shipping (in ballast tanks and other components of ships' seawater systems, and as fouling on hulls, anchor chains, etc.) and transport via aquaculture activities (including both the intentional or accidental release of fish, shellfish or other cultured species in areas where they may become established, and the accidental transport and introduction of accompanying organisms, including predators, parasites, or diseases of fish and shellfish). Both of these areas of activity are expected to increase substantially over the coming decades.

The transport of exotic organisms in ships' ballast water has received a good deal of attention in recent years. Various data suggest that the relative importance of this pathway has been increasing in recent decades, so that currently it is probably responsible for the transport and introduction of more aquatic species than any other mechanism. For example, it appears that none of the exotic organisms established in San Francisco Bay that were reported on the Pacific coast of North American prior to 1920 were initially introduced via ballast water; however, ballast water was the initial introduction pathway for between 6 and 62% of the species that were first reported in the 1950s, and for 53–88% of the species first reported in the 1990s (Figure 2).

One method that could reduce the introduction and establishment of exotic organisms via ballast water discharges is the exchange of ballast water at sea. If done properly, the ballast water later discharged in or near bays or harbors should contain primarily oceanic organisms, which are thought to be unlikely to survive or become established in coastal waters. For reasons related to vessel architecture, sea conditions, and ship safety, some ships cannot exchange ballast water at sea under some conditions, and even when exchange is conducted, the completeness of exchange will vary. Thus, at-sea ballast water exchange is at best a partial solution, though still worthwhile where better alternatives are not available.

For several years, U. S. federal regulations have required the at-sea exchange of ballast water for

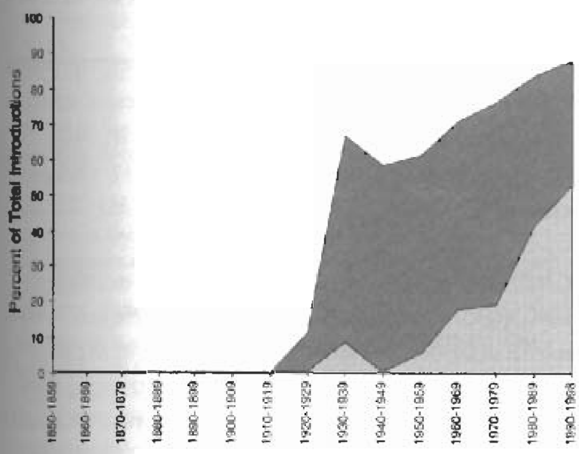

Figure 2. Ballast water introductions as a percentage of total introductions. Based on the date of the first records on the Pacific coast of North America for exotic organisms in the San Francisco Bay data set. Lower line indicates probable ballast water introductions: organisms for which no other mechanism but ballast water seems likely as the pathway for initial introduction. Upper line indicates possible ballast water introductions: includes organisms for which other mechanisms as well as ballast water appear likely. Based on data updated from Cohen and Carlton 1995).

ships entering the Great Lakes and upper Hudson River from overseas ports; in 1996 similar requirements were placed on oil tankers transporting Alaskan oil overseas and returning in ballast. However, despite mounting evidence of the extent of marine invasions and of ballast water introductions in other parts of the country, the 1996 National Invasive Species Act (NISA) failed to extend these requirements to the rest of the country. The NISA did mandate a process that could provide for the eventual promulgation of regulations by the Secretary of Transportation, but this process has been greatly delayed (Table 1).

Responding to the display of federal inaction under NISA, several efforts have been initiated outside of Washington, DC to regulate the discharge of exotic species into the nation's coastal waters, either through state laws or through other federal laws (Figure 3). Most of these intiatives would use water pollution laws to regulate the release of exotic organisms in ballast water–as a waste discharge of a biological pollutant–and there appears to be a developing consensus around this approach as an effective mechanism for managing the problem. This

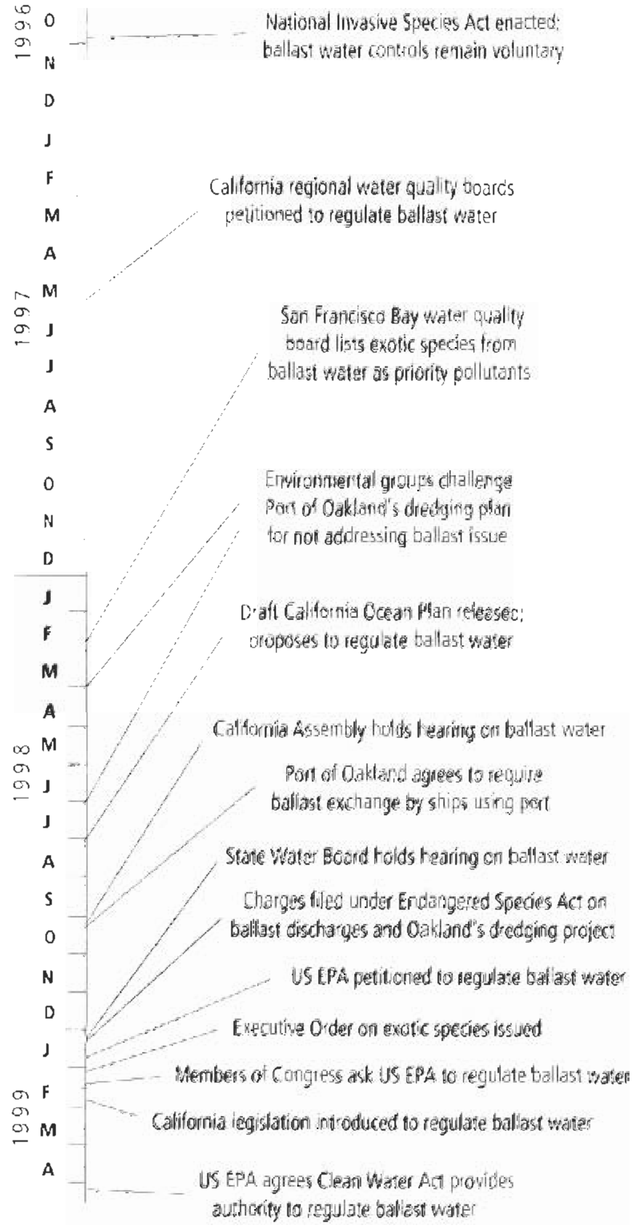

Figure 3. Policy initiatives regarding ballast water management in the United States since the enactment of the National Invasive Species Act.

approach is likely to lead beyond requiring ballast water exchange, and require the treatment of ballast water discharges to remove or kill the exotic organisms in them, much as other wastewater discharges are treated to prevent the introduction of pollutants into the nation's waters.

Table 1. Delay in implementation of actions directed by the National Invasive Species Act (NISA) regarding the consideration and promulgation of mandatory regulations for ballast water exchange.

Action Directed	Action Taken
April 16, 1996: NISA enacted into law Oct. 16, 1997: Secretary of Transportation to issue voluntary guidelines.	Draft guidelines were published in the Federal Register on April 10, 1998, and final guidelines were published as an Interim Rule on May 17, 1999 (over 18 months behind schedule).
April 16, 1998: Aquatic Nuisance Species Task Force to submit criteria for assessing compliance with and effectiveness of guidelines.	In April 1999 the Task Force appointed a committee to develop recommendations for criteria, which were to be submitted in initial form to the Task Force and made available for public review by Nov. 11, 1999, with final recommendations submitted to the Task Force in May 2000. The Task Force would then develop and submit criteria to the Secretary of Transportation. However, as of May 31, 2000, the committee had not yet submitted draft criteria or made them available for public review. (The schedule set by the Task Force when appointing the committee was thus over 2 years behind NISA's schedule; and the work has now fallen at least six months further behind.)
April 16, 2000: Secretary of Transportation to submit report to Congress on guideline compliance and effectiveness.	Because of delays to date, the report will likely be delayed until at least November 2001 (a minimum of over 18 months behind schedule).
Oct. 16, 2000: Secretary of Transportation to assess guideline compliance and effectiveness and, if criteria are not met, promulgate mandatory regulations.	Because of delays to date, the Secretary's consideration of mandatory regulations will likely be delayed until at least May 2002 (a minimum of over 18 months behind schedule).

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