Ships' Ballast Water and the Introduction of Exotic Organisms into the San Francisco Estuary

Current Status of the Problem and Options for Management

by

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Summary

Ships' ballast water is probably the most important mechanism transporting exotic marine and freshwater organisms around the world today. Although it is illegal to release exotic organisms into California waters,[1] ships arriving at ports in both the Bay and Delta regions of the San Francisco Estuary routinely discharge large quantities of ballast water, thereby releasing over the course of a year probably thousands of different species of exotic marine and freshwater organisms.[2]

In recent years ballast water discharges have introduced the Asian clam, the New Zealand sea slug,[3] two or three species of Black Sea jellyfish, over a dozen species of Asian zooplankton, possibly the Chinese mitten crab, and scores of other exotic organisms that have become established within the San Francisco Estuary.[4] The rate of ballast water invasions has risen sharply in recent decades,[5] and unless preventive measures are taken, the rate may accelerate further if the amount of foreign ballast water arriving in the Estuary rises with projected port expansions and further globalization of trade. As in the past, some of the exotic species that first arrive in the Estuary will then spread to other sites along the Pacific Coast, and some organisms that first arrive in other parts of the Pacific Coast will eventually spread into the Estuary.[6]

Ballast water discharges are responsible for a substantial portion of the more than 200 exotic species that have become established in the San Francisco Estuary, which together have dramatically altered the ecosystem's flora and fauna. Exotics now account for more than 90 percent of the species, individuals or biomass in several habitats.[7] Some individual ballast water invaders, such as the Asian clam (*Potamocorbula amurensis*), have by themselves substantially altered the ecosystem. Soon after its arrival around 1986, the Asian clam had become the most abundant clam throughout much of the Estuary. It is a highly-efficient filter feeder, ingesting bacteria and small zooplankton as well as phytoplankton.[8] It severely depleted phytoplankton populations in the northern part of the Estuary, reducing or altering the food available to some of the organisms higher in the food chain. It may also have reduced native zooplankton populations and made the ecosystem more vulnerable to invasion by Asian species of zooplankton.[9] In addition, *Potamocorbula* accumulates selenium in its tissues, thereby making this contaminant available to the fish and birds that feed on *Potamocorbula* at concentrations that seem likely to impair reproduction.[10]

Ballast water invasions in other parts of the world have caused substantial harm to economic activities. The European zebra mussel has become a major problem in the Great Lakes region by clogging water systems for cities, factories and power plants, by fouling boat hulls and by accumulating in immense numbers on recreational beaches.[11] A voracious Atlantic comb jelly virtually eliminated the crustacean zooplankton from the Black Sea, contributing to the decline of the region's fisheries.[12] A Japanese sea star has devastated shellfisheries in Tasmania.[13]

Ballast water discharges also pose suignificant risks to human health. In some parts of the world there have been new or increasingly frequent outbreaks of toxic red tides caused by microscopic organisms called dinoflagellates. These dinoflagellates produce neurotoxins that accumulate in shellfish, causing illness and sometimes death in the people that eat them.[14] Recent studies have shown that in some of these regions toxic dinoflagellates were introduced in the sediments transported with ballast water.[15] *Pfiesteria piscicida*, another neurotoxin-producing dinoflagellate that could be transported with ballast, has caused large fish kills on the east coast of the United States and memory loss and learning problems in some people exposed to contaminated waters.[16] Cholera can also be transported with ballast water. An epidemic strain of cholera from South America was apparently discharged with ballast water into waters on the Gulf Coast of the United States, where it was discovered in fish and shellfish;[17] and it may have been ballast water that originally transported the strain from Asia to South America, triggering an epidemic in 1991 that resulted in one million reported cases and over 10,000 deaths.[18] Meanwhile, Canadian studies

conducted in the winter of 1997 on ships arriving mainly from Europe found that ballast water discharges commonly violated water quality standards, with 50 percent of the ships carrying ballast water contaminated with fecal coliforms. Ships arriving in the summer, or from Asian ports, would be likely to have substantially higher rates of contamination.[19]

There are several steps that could be taken to reduce the threat of ballast water invasions without reducing the flow of trade. An immediately available option is to require ships carrying ballast water from overseas ports that want to use the Estuary's port facilities to exchange their ballast water in the open ocean[20] before arrival, and to adopt other ballast management practices. Several regions of the world have already adopted regulations of this sort. A second mechanism would be to off-load ballast water that would otherwise be discharged into the Estuary and either store it for later use by departing ships in need of ballast, or treat it to kill the organisms it contains—as wastewater is routinely treated. This step does not require any substantial development of novel technology and could be implemented relatively quickly; some ports already require the off-loading of some ballast water, including the off-loading and treatment of ballast water carried in the cargo holds of oil tankers. This approach would probably provide better protection against invasions than would open-ocean exchanges, and would eliminate any concerns about ship safety. Finally, it may be possible to develop effective on-board treatment technologies, such as filtration, heating, treatment with chemicals or with ultraviolet or microwave radiation, or other means. However, the development and deployment of such methods (which are likely to involve substantial retrofitting or reconstruction of ships) may take decades, and some observers doubt that treatment requiring the maintenance or operation of sophisticated equipment would be effectively implemented on much of the world's commercial fleet.

The following actions are recommended to help reduce the introduction of exotic species via ships' ballast water (described more fully in the report's final section):

- ***Sample and assess arriving ballast water.***
- ***Collect and analyze data on shipping activity and ballast discharges.***
- ***Encourage ships to utilize appropriate ballast management measures.***
- ***Prohibit the dumping of ballast sediments.***
- ***Require ships to conduct open-ocean exchange of ballast water, or an equally effective alternative treatment, subject to safety considerations.***
- ***Encourage ships to assess the safety of exchange methods, to use the safest approach if there is uncertainty, and to make any needed retrofits.***
- ***Support research into on-shore treatment, including approaches tailored to the Bay/Delta region.***
- ***Monitor and participate in the assessment of voluntary federal ballast water guidelines.***
- ***Assess the power of existing laws to prohibit or reduce the discharge of exotic species in ballast water, and use them.***
- ***If existing law is not adequate for this task, pass laws that are.***

What is Ballast Water?

A ship carrying little or no cargo rides high in the water. This may make the ship vulnerable to being knocked over by high waves and winds, increase the potential for "slamming" the bow or stern when riding over large waves, or raise the propellor so that it is insufficiently covered by water. So, at the start of a voyage a ship may take on a large quantity of water—of whatever water the ship is floating in, fresh water if in a river port, or salt water if in the sea—in order to lower the ship to a safer and more efficient position in the water. At the end of the voyage the ship will then discharge this ballast water into a new port or coastal region (perhaps thousands of miles from its source) before loading cargo. Ballast water is also loaded or discharged for other purposes, including adjusting the ship's trim, improving maneuverability, increasing propulsion efficiency, reducing hull stress, raising the ship to pass over shallow areas (reducing draft), and lowering it to get under bridges or cranes (reducing air draft).

Ballast water enters a ship through intakes located below the water line. These intakes are typically covered with grates or strainer plates with openings of about half an inch or larger, although corrosion can further enlarge these openings and the plates sometimes fall off.[21] The function of the strainer plates is to prevent damage to the ship's pumps from objects that might otherwise be drawn in, although when present and in good condition they would incidentally serve to prevent the introduction of large organisms into ballast tanks. Depending on the level of the tank relative to the water surface, water may be taken on or discharged either by pumping or by gravitational flow. Ballast water is generally carried in several different compartments on board ship, often in tanks set aside for that purpose (called "segregated" or "dedicated" ballast tanks), although bulk carriers and tankers may carry ballast water in their cargo holds ("unsegregated" tanks). Some individual ships can carry tens of millions of gallons of ballast water (Tables 1 and 2).

Table 1. Segregated Ballast Water Capacity of Some Ships

Examples of ships of various types with relatively large ballast capacities; some may be too large to call at Bay Area ports due to draft limitations.

Capacity (gallons per ship)	Ship Name	Ship Type
21,491,000	Front Driver	ore/bulk/oil carrier
17,903,000	Leon	coal carrier
15,245,000	Landsort	tanker
14,870,000	Iron Whyalla	bulk carrier
14,265,000	Knock Allan	tanker
11,823,000	Western Bridge	bulk carrier
10,759,000	Yeoman Burn	bulk carrier
9,439,000	Olympic Serenity	tanker
6,503,000	Dixie Monarch	woodchip carrier
4,430,000	Hannover	container ship
4,264,000	Helice	liquefied petroleum gas carrier
4,755,000	Arbat	products tanker
2,662,000	Annapurna	gas tanker
1,976,000	Conger	chemical tanker
1,163,000	Krasnogard	roll-on/roll-off cargo carrier

Sources: Rigby & Hallegraeff 1994; Carlton *et al.* 1995, at p. 54; Wonham *et al.* 1996.

Table 2. Average Ballast Water Capacity of Ships

Average ballast water capacity (in gallons per ship) of ships arriving at United States and San Francisco Estuary ports from foreign ports.

Ship Type	U. S. Average	Estuary Average
Bulk Carriers	5,060,000	2,350,000
Container Ships	2,800,000	—
Tankers	3,575,000	3,100,000
All 3 Ship Types	3,200,000	2,520,000

Source: Carlton *et al*. 1995, page 77 and Appendix D.

Ships are said to be "in ballast" when they carry ballast and no cargo, and "in cargo" when they carry some cargo. Ships in cargo may also carry considerable quantities of ballast water (Table 3). When ships have pumped out all the ballast water that they can, they may be described as having "no ballast on board" ("NOBOB" in some reports). However a substantial amount of water, perhaps tens or even hundreds of thousands of gallons, often containing a high concentration of sediment, may remain in ballast tanks after the pumps have lost suction. This is known as unpumpable ballast or dead water (Table 3), and while the amount involved may seem insignificant to a mariner concerned with ship operations, it may be quite substantial to a biologist concerned with the potential for transporting organisms. Further operations may subsequently mix and then discharge this unpumpable water with other water.[22] As a result of unpumpable ballast, most large vessels carry some ballast water virtually all the time.[23]

In addition, sediment may accumulate in ballast tanks or ballasted cargo holds.[24] This sediment may include mud and small debris pumped in with the ballast water, rust and interior coatings that flake off the inside walls of the tank, and residue from previously carried cargo. Sediment is typically removed from ballast tanks every 3-5 years when a ship is in drydock, and from ballasted cargo holds on every voyage at the cargo-loading port. Sediment from cargo holds, which may amount to 500 gallons per ship,[25] is typically shovelled or hosed out and dumped into port or coastal waters, or sometimes retained and disposed of on land or at sea.[26]

Table 3. Average Ballast Water Carried by Ships

Average amount of ballast water (in gallons per ship) in ships arriving at United States and San Francisco Estuary ports from foreign ports.

Ship Type	U. S. Average	Estuary Average
	— Ships in Ballast —	
Bulk Carriers	3,800,000	1,670,000
Container Ships	not applicable [1]	not applicable [1]
Tankers	3,170,000	2,370,000
All 3 Ship Types	2,720,000	1,840,000
	— Ships in Cargo —	
Bulk Carriers	–	1,670,000
Container Ships	1,380,000	1,380,000
Tankers	–	640,000
All 3 Ship Types	–	1,380,000
	— All Ships —	
Bulk Carriers	3,000,000	1,670,000 [2]
Container Ships	1,380,000	1,380,000 [2]
Tankers	900,000	1,000,000 [2]
All 3 Ship Types	1,580,000	1,410,000 [2]
	— Unpumpable Ballast —	
Bulk Carriers	18,000	–
Container Ships	38,000	–
Tankers	22,700	–
All 3 Ship Types	24,500	–

Source: Carlton *et al*. 1995, page 77 and Appendices D & E.

1 Container ships rarely sail without cargo, and thus do not normally arrive "in ballast."

2 The quantities of ballast water discharged by these types of ships entering the Estuary, calculated from data in US Coast Guard 1996, are:

Bulk Carriers	1,730,000 gallons
Container Ships	1,270,000 gallons
Tankers	2,760,000 gallons
All 3 Ship Types	1,520,000 gallons

The substantial difference in tanker data from the two studies is primarily due to Carlton *et al*. including data only for the relatively small tankers that call at the Port of San Francisco, and excluding the large tankers that call at the Estuary's oil refinery terminals.

Organisms Carried in Ballast Water

It has long been recognized that marine and freshwater organisms can be transported in the water carried by ships. As early as 1897 biologists had shown that marine plankton (organisms that drift within the water column, most of which are microscopic or nearly microscopic) can pass through pumps into a ship's seawater system and survive. In 1908 it was reported that an Asian diatom had been introduced to the North Sea in ballast water,[27] and the invasion of northern Europe by the Chinese mitten crab was believed to result from a pre-1912 ballast water introduction.[28] Not until the 1970s, however, did scientists begin directly sampling the organisms in ballast water. Numerous studies have since shown that ballast tanks typically contain many species of animals, plants, protozoans, bacteria and viruses, sometimes in considerable abundance (Tables 4-6). However, the organisms in the ballast water of ships arriving in the San Francisco Estuary have never been sampled.

Small planktonic organisms may be readily pumped into and out of ballast tanks. Plankton can be characterized as holoplankton, meroplankton or tychoplankton. *Holoplankton* spend their entire lives drifting in the water column, and include various bacteria, protozoans, unicellular plants (phytoplankton), and small animals (zooplankton). The latter primarily consist of copepods, mysid shrimp, arrow worms and comb jellies in salt water, and copepods, water fleas and rotifers in fresh water. *Meroplankton* spend only part of their live cycle drifting in the plankton, and include the larvae or eggs of various worms, clams, snails, crabs, starfish, sea squirts, fish and other organisms. *Tychoplankton* are organisms that normally live on the bottom but have been temporarily suspended in the water column. Certain other organisms that in a strict sense are not planktonic may be associated with planktonic hosts, such as certain viruses and parasitic nematodes and flatworms. In addition, some organisms that are non-planktonic may be carried into ballast tanks attached to or clinging to bits of wood or other floating debris, and small fish or shrimp may swim in through ballast intake ports.

Table 4. Investigations of Ballast Tank Biota

Includes both reported observations and systematic studies. Numbers of species given are minimum numbers based on conservative counts from reported data, and may differ from the original authors' counts. The numbered studies refer to data reported in Table 5.

	Study Site and Period	Sampling Regime and Results
1	Australia 1973	Plankton sampled in 1 ship from Japan included polychaetes, copepods, amphipods, ostracods and chaetognaths (Medcof 1975).
2	Australia 1976-78	Plankton and fish in 23 woodchip carriers from 13 Japanese ports included 61 species; most common were copepods, molluscs, larvaceans and barnacles. Sediments from 9 woodchip carriers from 7 Japanese ports yielded 32 crustaceans and polychaetes (Williams *et al*. 1988).
3	Montreal and St. Lawrence River 1980	Plankton samples from 46 ships that had ballasted outside the northwest Atlantic included 132 phytoplankton, 7 protist and 35 invertebrate species (Bio-Environmental Services 1981).
4	North Atlantic 1981	Plankton sampled from a variety of ships and routes included 3 protist, 24 invertebrate and 1 fish species (Carlton *et al*. 1982).
	Australia 1981	Identified 4 fish and reported mysids in ballast water of a domestic bulk carrier (Middleton 1982).
5	Coos Bay, OR 1986-91	Plankton samples from 159 woodchip carriers from 25 Japanese ports included 402 species in 24 animal, plant and protist phyla, with the most common being copepods, diatoms, polychaetes, barnacles, molluscs and flatworms (Carlton & Geller 1993; Pierce *et al*. 1997).

Table 4 Continued. Investigations of Ballast Tank Biota

Study Site and Period		Sampling Regime and Results
6	Australia 1987-93	Sediment from ballasted cargo holds in 12 Japanese woodchip carriers arriving in Tasmania in 1987-88 yielded 56 phytoplankton species, including abundant diatoms in 4 ships and dinoflagellates cysts in 7 ships (Hallegraeff *et al.* 1990). Sediments from 31 out of 83 mainly Japanese woodchip, wheat and ore carriers arriving in Australia in 1987-89 (including the 12 already mentioned) contained dinoflagellate cysts, with toxic species in 4 ships (Hallegraeff & Bolch 1991). 343 ships were sampled by 1990, with sampling continuing through at least 1993 (Hallegraeff & Bolch 1992).
7	Great Lakes and upper St. Lawrence River 1990-91	Plankton samples from 86 ships included 110 species of zooplankton in 11 phyla, mainly copepods, cladocerans and rotifers; and 100 species of bacteria, phytoplankton and protists, mainly diatoms and dinoflagellates including 21 bloom-forming, red tide and/or toxic species (Locke *et al.* 1991, 1993; Subba Rao *et al.* 1994).
	Japan 1991	Ballast water and sediments sampled in ships at 17 Japanese ports by the Japanese Assoc. for the Prevention of Marine Accidents. Results not published (noted in Kelly 1992).
8	Washington state 1991	Samples from 6 Japanese woodchip carriers arriving at Tacoma and Port Angeles in 1991 yielded 21 species of phytoplankton and protists from incubated sediments; and at least 8 orders of organisms in ballast water from 3 ships (Kelly 1992, 1993).
	Gulf of Mexico 1991-92	Ballast water samples in 5 of 19 ships yielded *Vibrio cholerae,* which genetic analysis found to be identical to the strain responsible for the 1991 South American cholera epidemic and found in oysters in Mobile Bay, Alabama (McCarthy & Khambaty 1994).
	Germany 1992-95	Plankton sampled in 189 ships, along with organisms in sediment, fouling organisms on tank walls, and larger crabs and fish where possible, included over 350 species, mainly unicellular algae, copepods, other crustaceans and molluscs (Gollasch *et al.*, in press).
9	Chesapeake Bay 1993-94	Plankton net, whole and bottom water samples in 70 ships from foreign ports yielded 275 plant, protist & animal species; and 4 species in sediment from 5 ships (Smith *et al.* 1996).
10	Hong Kong 1994-95	Plankton samples from 5 ships from both sides of the North Pacific included 82 species of invertebrates and protists, with copepods being the most common (Chu *et al.* 1997).
11	Scotland 1994-95	Plankton sampled from 32 ships and sediment from 24 ships yielded dinoflagellates, diatoms and other organisms. This study is ongoing (Macdonald, in press).
12	Baltimore, MD 1995	Plankton samples from 1 coal carrier from Israel yielded 23 species of dinoflagellates and invertebrates, numerically dominated by copepods, bivalves, polychaetes and gastropods (Wonham *et al.* 1996).
	New Zealand 1995-97	Plankton and bottom water samples from tanks with foreign ballast water in 50 container ships, bulk carriers and break bulk carriers arriving at Lyttelton and Nelson yielded live phytoplankton in 80% of tanks, dominated by diatoms, heterotrophic flagellates and dinoflagellates, and live invertebrates in 83% of tanks with arthropods, molluscs and annelids occurring most frequently (Hay *et al.* 1997).
13	Valdez, AK 1996	Plankton from 16 domestic and 1 foreign oil tanker included 68 taxa (Ruiz & Hines 1997).
	Israel 1996	Cultured ballast water and sediment samples from 17 ships yielded at least 198 heterotrophs (reported as flagellate, pseudopodial and cilate forms), plus diatoms, cnidarians, turbellarians, nematodes, rotifers, gastrotrichs, polychaetes and copepods (Galil & Hülsmann 1997).
	various sites	Studies are under way or being undertaken in Chesapeake Bay, Long Island Sound, the Port of Morehead City in North Carolina, the Port of Long Beach in California, the Port of Honolulu in Hawaii, the Gulf of St. Lawrence, British Columbia, Sweden and Wales (Gauthier & Steel 1996; Walton & Crowder, 1998; Eldredge 1998; J Carlton, pers. comm.).

Table 5. Organisms Collected in Ballast Tanks

Number of distinct taxa (=minimum number of species, conservatively counted) of living organisms reported in ballast tanks. In some cases the numbers listed are my counts based on the species data reported in the cited works, and may differ from the original authors' counts. In most cases the actual number of species in the ballast tanks were probably much higher than the reported numbers. The level of taxonomic effort applied to different organism groups varies greatly, making comparions between groups and between studies difficult.

Study[1]	1	2a	2b	3	4	5	6a	6b	7	8	9	10	11	12	13
Number of Ships	1	23	9	46	n.a.	159	12	100	86	6	70	5	32	1	16
Type of Sample[2]	P	P	S	P	P	P	S	S	P	S, P	P	P	S, P	P	P
Vascular Plants	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
Bacteria	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–
Cyanophytes	–	–	–	15	–	–	–	–	1	–	1	–	–	–	1
Chlorophytes	–	–	–	26	–	2	–	–	1	2	1	–	2	–	–
Rhodophytes	–	–	–	2	–	2	–	–	–	–	1	–	–	–	–
Phaeophytes	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–
Chrysophytes	–	–	–	1	–	–	–	–	1	–	–	–	–	–	–
Xanthophytes	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–
Cryptophytes	–	–	–	5	–	–	–	–	–	–	–	–	–	–	–
Diatoms	–	–	–	57	–	128	42	15	61	16	17	13	25	–	3
Dinoflagellates	–	–	–	20	–	4	14	51	30	3	25	5	32	6	2
Flagellates	–	–	–	3	–	–	–	–	2	2	–	–	–	–	–
Foraminifers	–	–	–	–	–	3	–	–	–	–	1	3	1	–	1
Radiolarians	–	–	–	–	–	2	–	–	–	–	2	2	–	–	–
Ciliates	–	–	–	7	3	37	–	–	3	–	53	3	2	–	1
Cnidarians	–	1	–	–	–	25	–	–	1	–	7	4	–	–	1
Ctenophores	–	–	–	–	–	–	–	–	–	–	4	–	–	–	1
Platyhelminthes	–	1	–	–	1	33	–	–	1	–	3	2	–	1	1
Nemerteans	–	–	–	–	–	1	–	–	–	–	1	–	–	–	1
Nematodes	–	–	–	1	1	1	–	–	1	–	3	2	1	–	–
Rotifers	–	–	–	3	1	1	–	–	10	–	5	–	–	–	–
Gastrotrichs	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
Annelids	1	1	4	2	2	43	–	–	10	1	26	4	–	1	10
Sipunculids	–	–	–	–	–	1	–	–	–	–	1	–	–	–	–
Molluscs	–	–	–	2	1	19	–	–	2	2	8	3	–	2	3
Arthropods	4	54	28	27	17	73	–	–	81	3	97	39	–	13	34
Tardigrades	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–
Bryozoans	–	–	–	–	–	3	–	–	1	–	1	–	–	–	1
Echinoderms	–	–	–	–	–	6	–	–	1	–	4	–	–	–	2
Phoronids	–	–	–	–	–	1	–	–	–	–	1	–	–	–	1
Chaetognaths	1	1	–	2	–	3	–	–	1	–	9	1	–	–	1
Hemichordates	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
Urochordates	–	1	–	–	–	6	–	–	–	–	2	1	–	–	1
Cephalochordates	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Fish	–	2	–	–	1	2	–	–	–	1	6	–	–	–	1
TOTAL	6	61	32	176	28	398	56	66	210	30	279	82	63	23	67

1 Studies are those reported in: (1) Medcof 1975; (2a,b) Williams *et al.* 1988; (3) Bio-Environmental Services 1981; (4) Carlton *et al.* 1982; (5) Carlton & Geller 1993, Pierce *et al.* 1997; (6a) Hallegraeff *et al.* 1990; (6b) Hallegraeff & Bolch 1992; (7) Locke *et al.* 1991, 1993, Subba Rao *et al.* 1994; (8) Kelly 1992, 1993; (9) Smith *et al.* 1996; (10) Chu *et al.* 1997; (11) Macdonald, in press; (12) Wonham *et al.* 1996; (13) Ruiz & Hines 1997. See Table 4 for information on these studies.

2 Sample types are: P=plankton (mainly by plankton net, sometimes including whole water samples, and sometimes including sampling of larger fauna with nets at surface or in near-empty cargo holds); S=sediment.

Table 6. Densities of Organisms Collected in Ballast Tanks

These studies reflect ballast water of various ages, and in some cases may reflect mixtures of older and freshly-loaded ballast water. Generally, in a given ballast tank, the density of organisms declines with time (see Table 7).

Study	Mesh Size of Collecting Device	Range, Maximum or Mean Density of Organisms (individuals per 1,000 gallons)			
Bio-Environmental Services 1981	80 μm	diatoms	max = 270,000	annelids	max = 650
		dinoflagellates	max = 1,600	molluscs	max = 4,600
		other algae	max = 860,000	cladocerans	max = 3,000,000
		ciliates	max = 6,600	copepods	max = 260,000
		rotifers	max = 670,000	barnacles	max = 3,100
		nematodes	max = 14,000		
Carlton *et al*. 1982	153 μm	polychaetes	max = 80	copepods	max = 18,000
		molluscs	max = 40	barnacles	max = 1,200
Wang 1990	80 μm	crustaceans	range = 300 to 3,500		
Hallegraeff & Bolch 1992	20 μm	in tank-bottom sediments:			
		dinoflagellate cysts		max = 85 billion	
		toxic dinoflagellate cysts		max = 57 billion	
Carlton & Geller 1993	80 μm	polychaetes	>750	copepods	>5,700
		molluscs	>750	barnacles	>750
Locke *et al*. 1993	41 μm	total living and dead individuals of:			
		zooplankton	range = 80 to >260,000		
		a rotifer	max = 200,000		
		a water flea	max = 130,000		
		copepods	max = 80,000		
Subba Rao *et al*. 1994	sedimented whole-water samples	for individual species of:			
		diatoms	max = 11 billion	ciliates	max = 39 million
		dinoflagellates	max = 14 million	copepods	max = 1.5 million
		flagellates	max = 60 billion		
		bacteria & autotrophic plankton			max = 10 trillion
Smith *et al*. 1996	80 μm	organisms except bacteria & viruses		range = 0 to 68,000	
		in non-exchanged tanks		mean = 3,400	
		in exchanged tanks		mean = 160	
Wonham *et al*. 1996	80 μm		on a 17 day voyage:	at start	at end
		in cargo hold	zooplankton	≈30,000	≈300
			phytoplankton	≈7,000	≈40
		in deck tanks	zooplankton	≈10,000	≈0.4
			phytoplanton	≈4,000	0
Chu *et al*. 1997	80 μm	copepods	max = about 4,000		
Ruiz & Hines 1997	80 μm	all organisms	range = 5,700 to 62,000	mean = 26,000	
		diatoms	range = 0 to 5,500	mean = 3,600	
		dinoflagellates	range = 0 to 1,200	mean = 240	
		annelids	range = 2 to 4,700	mean = 1,200	
		molluscs	range = 5 to 18,000	mean = 2,600	
		copepods	range = 70 to 38,000	mean = 14,000	
		barnacles	range = 50 to 16,000	mean = 2,700	

Many planktonic organisms can survive relatively long voyages drifting in the ballast water carried in ships, to be discharged into coastal waters at the end of the voyage. Other organisms may settle out within a ballast tank as juveniles or adults, living in sediments accumulated on the bottom of the tank or attaching to the sides or bottoms of tanks or to the insides of pipes or other components of the ballast system. Some planktonic organisms produce cysts or spores or other resting stages, which may be tolerant of extreme environmental conditions and capable of remaining dormant for weeks or months. Notable among these are some toxic species of dinoflagellates, whose viable cysts have been found in ballast sediments in enormous numbers.[29] These resting stages may release planktonic forms back into the ship's ballast water prior to discharge, or may themselves be introduced into the environment with discharged sediments.

Table 7. Decline of Biota with Age of Ballast Water

Carlton *et al.* 1982	A series of studies conducted on research and commercial ships found the following: *Study KB2*–No apparent decline in zooplankton density or diversity after 15 and 18 days with little change in ballast water temperature. *Study KB3*–Zooplankton density dropped 100-fold and diversity dropped from 7 to 1 species in 13 days with a large (19°C) increase in ballast water temperature. *Study KB-IS*–Zooplankton density remained stable over 7 days of relatively constant temperature, then dropped about 40-fold over 14 days when temperature rose and fell through an estimated 6-8°C. Diversity dropped from 11 to 3 species over the 21 day period. *Study TA-I*–Net zooplankton density dropped about 60-fold over 64 days, diversity dropped from 12 to 1 species over 95 days. Rotifers were present at the start of the voyage but gone by day 31; microflagellates and ciliates were present through day 64 but gone by day 95. Ballast water temperature varied over 22°C during the 95 days. *Study TA-II*–Zooplankton density dropped about 20-fold and diversity dropped from 8 to 5 species over 30 days. Ballast water temperature varied over a 14°C range. *Study TA-III*–Zooplankton density dropped about 20-fold and diversity dropped from 4 to 2 species over 31 days. Ballast water temperature varied over a 15°C range. *Study MRI*–Zooplankton demsity dropped 100-fold and diversity dropped from 12 to 2 species over 12 days. A period of elevated temperature and low dissolved oxygen occurred.
Williams *et al.* 1988	In ships arriving in Australia from Japan, the number of species declined with age of ballast water; the trend suggested few if any species would survive 24 days.
Wonham *et al.* 1996	On a coal carrier in ballast from Israel to Baltimore, plankton density dropped about 100-fold in 16 days in a ballasted cargo hold (4.5 million gallons). In smaller deck tanks (0.5 million gallons), zooplankton density dropped >10,000-fold in 15 days, phytoplankton dropped 1,000-fold in 4 days. In 16 days the number of species dropped from 38 to 23 in the cargo hold, and from 36 to 3 in the deck tanks, while temperature, salinity and dissolved oxygen remained nearly constant.
Smith *et al.* 1996	In ships arriving in Chesapeake Bay, there were higher densities of organisms in ballast water less than 14 days old than in water 14-24 days old, but this could be due to differences in water sources. The oldest ballast water containing an organism (one copepod) was 41 days old.
Gollasch *et al.*, in press	On a container ship bound from Singapore to Bremerhaven, the density of planktonic diatoms and dinoflagellates dropped >90% in 9 days, and zooplankton density dropped 90% in 4 days. Diatom species dropped from 30 to 4 in 23 days, dinoflagellates from 13 to 0 in 14 days, and zooplankton from 24 to 4 in 23 days. While bound from Colombo to Bremerhaven, zooplankton in one tank dropped from 16 to 4 species in 14 days, but one surviving species increased greatly in abundance.
Chu *et al.* 1997	In ships arriving in Hong Kong, the number of species declined with the age of ballast water, but about 5-10 species were present in one-year-old ballast water.
Hay *et al.* 1997	No "free-swimming" phytoplankton were found in ballast water more than one month old.
Ruiz & Hines 1997	In ships arriving in Prince William Sound from the U. S. west coast, the density of annelids and molluscs but not of total organisms was lower in ships with older ballast water. Sampling of 4-6 day old ballast water showed no overall decline in abundance over 48 hours.

The density of organisms reported from ballast water and ballast sediments varies greatly (Table 6). Several studies have reported dramatic declines in the number and diversity of organisms over the duration of a voyage (Table 7). Although in some studies these declines occurred in conjunction with substantial changes in temperature or reductions in dissolved oxygen,[30] in other cases declines occurred even when environmental variables remained stable at non-stressful levels.[31] In such cases the declines may be due to depletion of food resources, since there is no light in ballast tanks that would allow phytoplankton to photosynthesize. A few live organisms have been collected from ballast water or ballast sediments after periods of up to a year (Table 8). Such long-term survival might be due in part to the presence of resting stages (spores, cysts or diapause eggs) of diatoms, dinoflagellates, protozoans and copepods,[32] or to the long-term persistence of protozoan and invertebrate communities in ballast tank sediments.[33]

Table 8.
Longest Records of Persistence of Organisms in Ballast Water or Sediments

months:	1 2 6 12	Reference
Diatoms	--	Chu *et al*. 1997
Dinoflagellates	--------------------------	Hallegraeff *et al*. 1990
Protozoans	--	Chu *et al*. 1997
Microflagellates	---------	Carlton *et al*. 1982
Ciliates	---------	Carlton *et al*. 1982
Flatworms (Turbellaria)	----	Carlton *et al*. 1982
Nematodes	---------	Carlton *et al*. 1982
Polychaete larvae	----	Carlton *et al*. 1982
Bivalve larvae	----	Carlton *et al*. 1982
Barnacle larvae	----	Carlton *et al*. 1982
Cladocerans	----	Carlton *et al*. 1982
Copepods (Calanoida)	--	Chu *et al*. 1997
Copepods (Cyclopoida)	--	Chu *et al*. 1997
Copepods (Harpacticoida)	--	Chu *et al*. 1997
Mites (Hydracarina)	----	Carlton *et al*. 1982

Even with large declines, substantial numbers and considerable diversity of living organisms may remain in ballast tanks after voyages of 10-20 days. It appears that densities on the order of 0.1-1 relatively large (>80 μm, or >0.003 inch) planktonic organisms per gallon, and greater densities of smaller organisms, may frequently be present in ballast water at the conclusion of a transoceanic voyage. Given the large capacity of ship's ballast water pumps,[34] a single deballasting ship may thus discharge into the environment millions of exotic phytoplankton and invertebrate zooplankton per hour, and larger numbers of protists, bacteria and viruses.

Organisms Introduced by Ballast Water

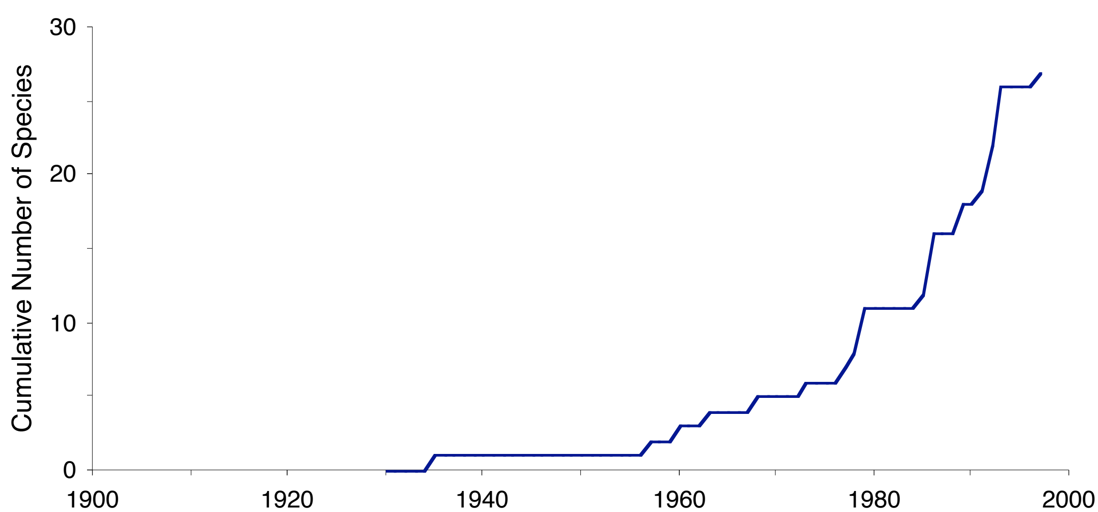
Recent studies have identified over 230 exotic species that have become established in the San Francisco Estuary. At least another 125 organisms in the Estuary are considered to be "cryptogenic," meaning that we do not have enough evidence to determine whether they are native or exotic. Exotic species dominate many of the Estuary's biotic communities, including infaunal and epifaunal soft-bottom benthos (organisms living in or on bottom sediments), fouling communities, brackish-water zooplankton and freshwater fish. In these communities exotic organisms may account for 40% to 100% of the common species, up to 97% of the total number of organisms, and up to 99% of the biomass (the weight of living organisms).[35]

Perhaps even more striking than the number of exotic species and their dominance, is the rapidly increasing rate at which they are arriving and becoming established. Roughly half of the exotic species identified in the Estuary were first recorded here within the last 35 years. Overall, the rate of invasions has increased from an average of at least one new species established every 55 weeks from 1851 to 1960, to at least one new species every 14 weeks from 1961 to 1995. Considered together, the large number of exotic species, their dominance in many habitats, and the rapid and accelerating rate of invasion suggest that the San Francisco Estuary may be the most invaded estuary in the world.[36]

These exotic organisms arrived on the Pacific Coast and in the Estuary through a variety of mechanisms. Historically, the most important of these involved organisms attached to the hulls of ships, organisms transported with oysters planted in the Bay, and fish imported for stocking, primarily in the Delta or tributary waters. For the last several decades, however, these mechanisms have either not been operating or have been of declining importance, while increasing numbers of organisms have been introduced with ballast water.[37] Although a few species may have been introduced by ballast water during the first half of the 20th century (Appendix A), clear evidence of the expanding role of ballast water began to appear in the 1960s (Figure 1). The pace of recent

Figure 1. Ballast Water Invasions in the San Francisco Estuary

Exotic species established in the San Francisco Estuary, for which there is clear evidence of introduction to the Pacific Coast via ballast water. Tallied by the date of the first Pacific Coast record (Appendix A-1).



ballast invasions is indicated by 15 species of small Asian crustaceans (eight copepods, a cumacean, an isopod, three mysid shrimp and two amphipods) that have been discovered in the Estuary since 1970; and by two Asian clams, two Japanese gobies, and a carnivorous sea slug from New Zealand that have been discovered since the 1980s.

Figure 1 shows the cumulative increase in the Estuary of organisms clearly introduced through ballast water. Ballast water discharges are responsible for introducing between 27 and 87 exotic species that are now established in the Estuary, or 12 to 37 percent of the total number of established exotics (Appendix A). However, this percentage appears to be increasing: of the exotic species that were first reported in the Estuary in 1986-1995, it appears that 47 to 77 percent arrived in ballast water.[38]

Within the San Francisco Estuary, exotic species introduced in ballast water have come to dominate many areas. One spectacular recent invasion was that of the Asian clam *Potamocorbula amurensis*. This nondescript little clam was first found in San Francisco Bay in 1986, when a biology class from Diablo Valley College collected three of them. Within a year *Potamocorbula* had become the most abundant clam in the northern part of the Estuary, averaging 200 clams per square foot. At these densities it proved capable of filtering virtually the entire water column between once and twice a day, and in the process eliminating phytoplankton blooms, consuming native zooplankton and disrupting food webs. It may also be concentrating and directing the metal selenium into the diets of bottom-feeding fish and birds, which are accumulating levels of selenium that are known to cause reproductive defects.[39] In the 1980s, selenium poisoning caused an epidemic of reproductive deformities in birds at Kesterson National Wildlife Refuge in the Central Valley, which led to closure of the Refuge.

Elsewhere in the world, ballast water has been responsible for a several recent, harmful invasions, some of which have caused alarming damage to ecosystems and economies:

- The Atlantic comb jelly *Mnemiopsis leidyi*, a small, floating organism similar to a jellyfish, was introduced into the Black and Azov Seas by the early 1980s. It became phenomenally abundant and by consuming much of the seas' crustacean zooplankton contributed to the decline of the region's fisheries, affecting fishing fleets in six nations.[40]

- European zebra mussels, *Dreissena polymorpha*, were discovered in the Great Lakes in the late 1980s. The mussels have caused expensive problems, blocking the pipes that deliver water to cities and factories and cooling water to nuclear- and fossil fuel-fired power plants; attaching in enormous numbers to ship and boat hulls, marine structures and navigational buoys; and covering beaches with sharp-edged mussel shells and rotting mussel flesh. The average cost of damages from this invasion has been estimated at $360,000/year for affected cities and industries and $825,000/year for nuclear power plants, with maximum reported costs through 1995 of $600,000 for one shipping company, $1.5 million for a single factory, $3.7 million for a water treatment facility, and $6 million for a power plant. The estimated total costs over ten years are $3.1 billion for the power industry and $5 billion overall.[41] Zebra mussels disrupt existing food webs (consuming phytoplankton and essentially removing this food resource from other organisms), alter physical conditions (increasing light levels and thereby promoting nuisance blooms of algae) and threaten biodiversity (fouling or competing with native organisms including clams and crayfish).[42] The zebra mussel has now spread across much of North America, from Canada to New Orleans and from the Hudson River to Oklahoma.[43]

- Toxic dinoflagellates have been introduced in ballast sediments to some and perhaps several countries around the Pacific Ocean. These microscopic organisms can become phenomenally abundant, producing discolorations of the sea known as red tides. Red tides may kill fish or invertebrates by clogging their gills, and some produce human neurotoxins that accumulate in clams or mussels, sickening and sometimes killing the people that eat them. In recent decades there have been increasing reports of red tides around the world, which seem to be occurring more frequently and in parts of the world where they were previously unknown. At least some of these resulted from dinoflagellates introduced with ballast water or ballast tank sediments, including outbreaks in Australia and Tasmania, and possibly also in New Zealand and Chile.[44]

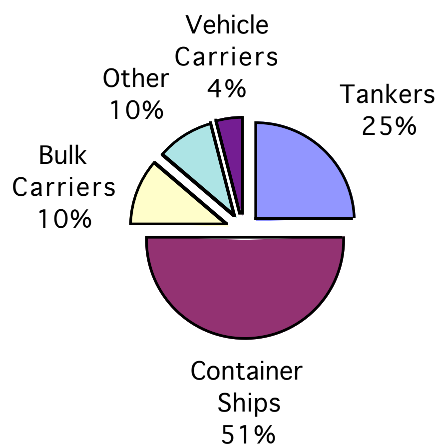
Ballast water discharges may pose an even more serious public health threat. During the 1991 South American cholera epidemic the bacterium that causes cholera (*Vibrio cholerae*) was discovered in oysters and fish in Mobile Bay, Alabama. The U. S. Food and Drug Administration then sampled the ballast water of 19 ships arriving in Gulf of Mexico ports from Latin America and found the South American epidemic strain of cholera in 5 of them.[45] The epidemic strain may even have originally been transported from Asia to South America in ballast water.[46]

Ballast Water Discharged into the Estuary

There is little direct information available on the quantities, sources, seasonal patterns or time trends of ballast water discharged into the San Francisco Estuary. Information on ballast water carried and discharged may be developed from ship surveys or estimated from data on ship capacity or cargo volume. Both methods are employed here.

About half the commercial ships that arrive in the Estuary are container ships, a quarter are tankers, and a tenth are bulk carriers (Fig. 2). Three-quarters of the ships arrive from ports on the North American west coast, and most of the remainder from elsewhere on the Pacific Rim (Fig. 3).

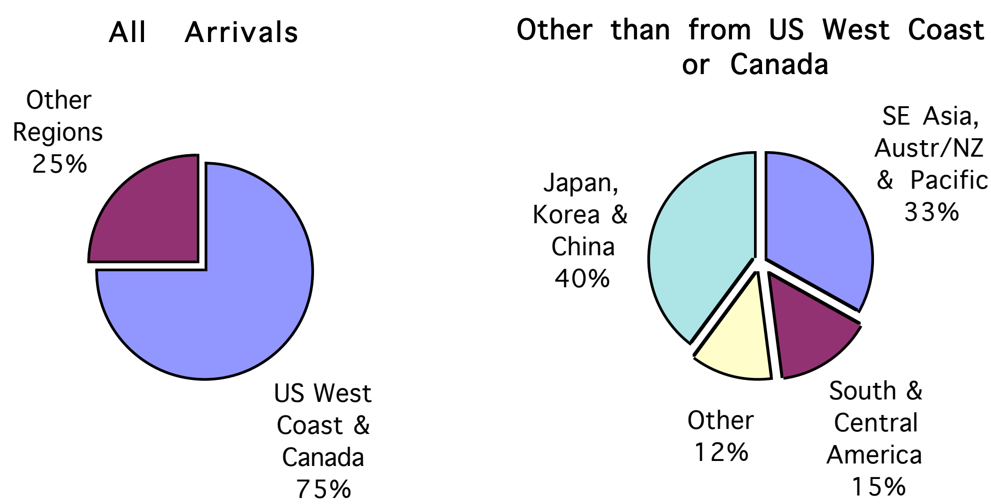
Figure 2.
Arrivals in the San Francisco Estuary by Type of Ship



Data for 1996 (Marine Exchange 1997)

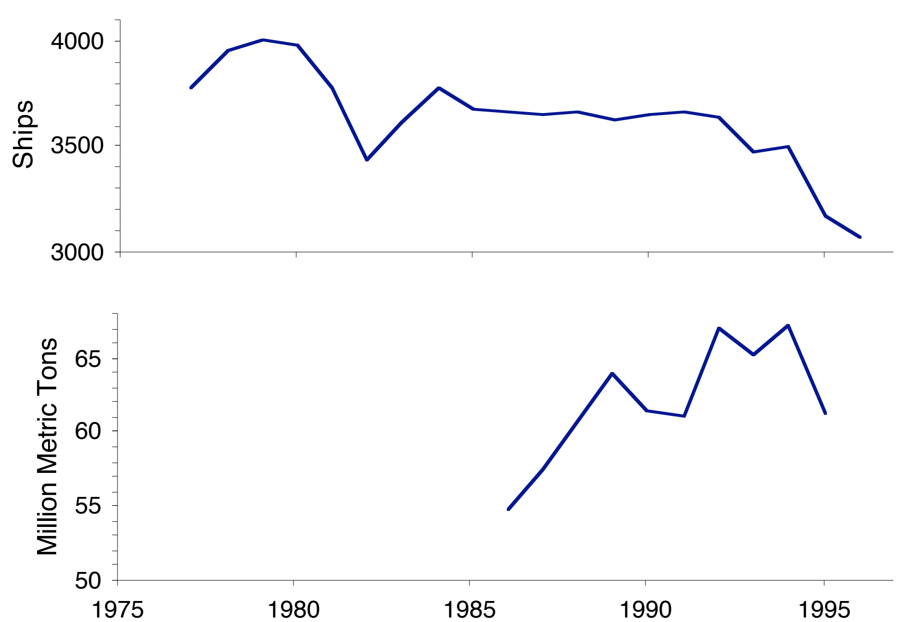
While the number of ships arriving in the Estuary has been gradually declining, the sizes of the ships and the amount of cargo they handle have been increasing (Fig. 4). For example, the 1996 update of the Bay Area Seaport Plan reported that the number of vessel calling at Bay Area ports fell from 2,597 to 2,299 ships between 1988 and 1993, while the quantity of cargo handled rose from 18 to 20 million metric tons (20 to 22 million short tons).[47] The shipping and cargo study conducted for the Seaport Plan projects substantial further increases.[48] The total tonnage of cargo exported is projected to grow from less than 6 million metric tons in 1980 to over 36 million metric tons in 2020 (Fig. 5), primarily due to increases in containerized cargo (growing from 2.5 to 22.4 million metric tons, and accounting for 64% of the total increase) and petroleum products (growing from 0.7 to 8.8 million metric tons, accounting for 26% of the increase). Imports are projected to increase from 7 to almost 25 million metric tons between 1980 and 2020, with containerized cargo (growing from 1.3 to 7.5 million metric tons) and petroleum products (growing from 4 to 12 million metric tons) again being the main contributors, together accounting for nearly 80% of the total increase.

Figure 3. Arrivals in the San Francisco Estuary by Last Port of Call



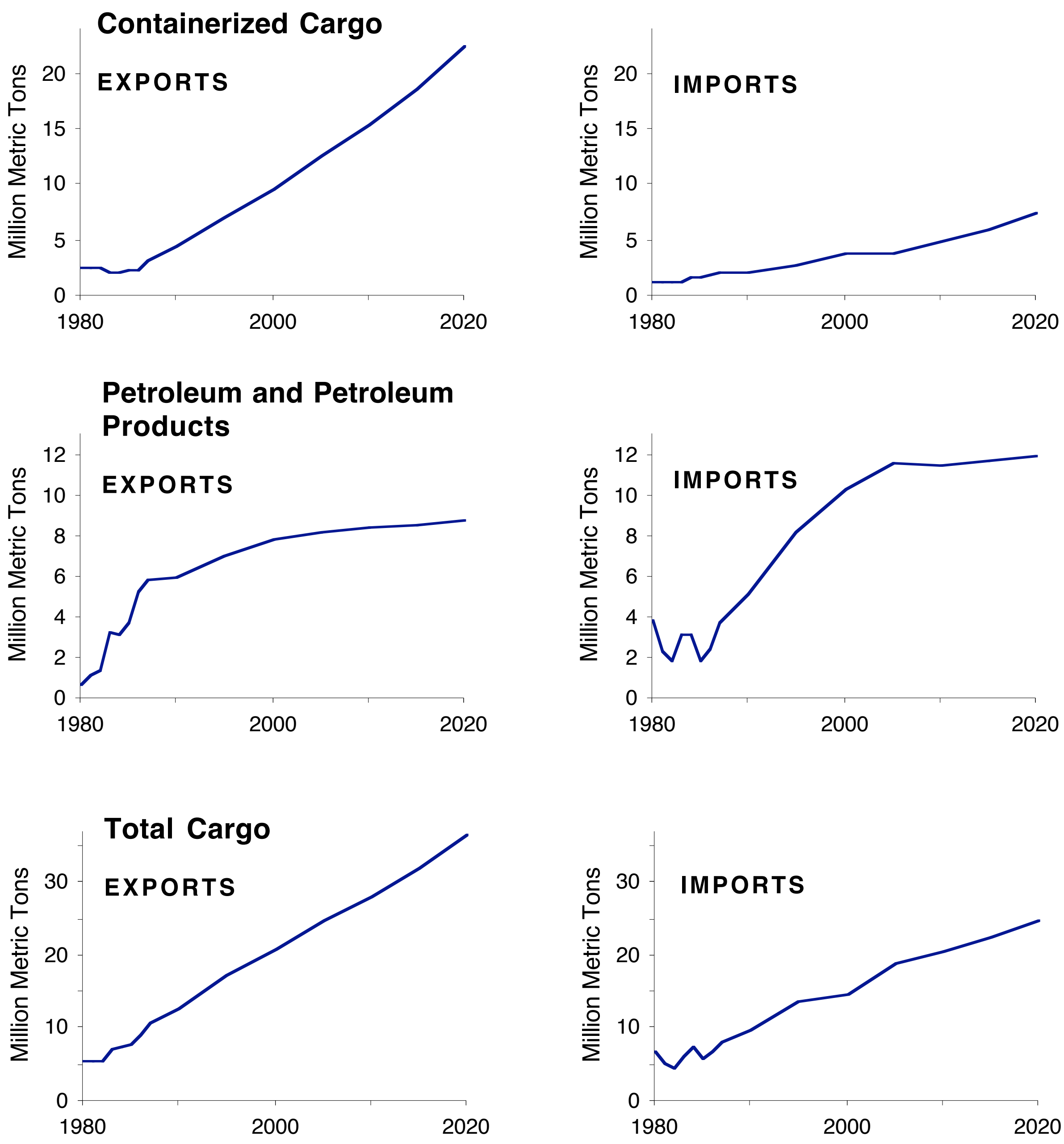
Data for 1996 (Marine Exchange 1997)

Figure 4.
Trend of Ship Arrivals and Cargo Tonnage at San Francisco Estuary Ports



Ship data from Marine Exchange 1997. Cargo data from US Army Corps 1996.

Figure 5.
Export and Import of Cargo Tonnage through San Francisco Bay Area Ports



Based on data from Manalytics 1988. 1980-87 is actual cargo tonnage; figures to 2020 are projections.

In recent years researchers have begun surveying ships to determine the amount of ballast water carried or discharged. Two studies provide survey data for ships entering the San Francisco

Estuary. The first study,[49] conducted for the U. S. Coast Guard and the U. S. Department of Transportation, estimated the quantity of ballast water carried by certain types of ships arriving in selected U. S. ports from foreign ports. The second study, conducted by the Coast Guard, asked ships that arrived in the Estuary in July 1986 about the amount of ballast water they were discharging.[50] I used each of these sources of information to estimate the total quantity of ballast water carried or discharged into the Estuary (Appendix B, Estimates 1-9).

Ballast water quantities carried or discharged can be estimated in a variety of other ways:

- **Estimates based on gross registered tonnage.** Gross tonnage is a measure of the volume of enclosed space on board a ship. For various ship types, ballast capacity has been estimated as averaging 33-84% of gross tonnage; ballast carried as 28-57% for ships in ballast and 3-16% for ships in cargo; and ballast discharged as 26-54% for ships in ballast and 7-15% for ships in cargo.[51] Regression equations have been developed relating gross tonnage to ballast capacity.[52]
- **Estimates based on net registered tonnage.** Net tonnage is a measure of the volume of enclosed space on board a ship excluding crew and passenger quarters, galley, wheelhouse, machinery and fuel spaces, etc. The quantity of ballast water entering a port has been estimated as equal to the net tonnage of ships entering in ballast (i. e. ships carrying only ballast and no cargo).[53] These estimates have been described as maximum figures; however, the exclusion of ships in cargo—which also carry ballast—could produce an underestimate at some ports.
- **Estimates based on deadweight tonnage.** Deadweight tonnage is a measure of the carrying capacity of a ship. It is equal to the difference between the vessel's weight at light displacement and at full or loaded displacement, and thus includes the weight of cargo, ballast, crew and passengers and their effects, gear and furnishings, fuel, potable water, provisions, etc. For different ship types, ballast capacity has been estimated as averaging 32-47% of deadweight tonnage; ballast carried as 32-36% for ships in ballast and 5-28% for ships in cargo; and ballast discharged as 1-20%.[54] One authority stated that ballast carried is normally about 25% of deadweight tonnage, but may be 20% for short trips and good weather, 30% for heavy weather, and up to 40% in severe conditions.[55] Others have estimated ballast carried by bulk carriers at typically 30-40% of deadweight tonnage, and 40-50% in heavy weather.[56] Ballast water discharged has been estimated as 40% of the deadweight tonnage of entering ships.[57] Estimates of ballast water entering a port calculated as 30% of the deadweight tonnage of ships entering in ballast have been considered a minimum estimate, since that amount of ballast is stated to be the minimum needed for stability on unladen bulk carriers.[58] Regression equations relating deadweight tonnage to ballast capacity have also been developed.[59]
- **Estimates based on ballast capacity.** The normal amount of ballast carried has been estimated as 6-89% of ballast capacity, and the amount discharged as 3-46% of ballast capacity, over a range of ship types and conditions.[60]
- **Estimates based on tonnage of export cargo.** Ballast-to-load ratios—the ratio of ballast water discharged for the purpose of maintaining proper draft to the net tonnage of cargo loaded—have been estimated at 0.18 for refrigerated cargo ships of 4,000-11,000 deadweight tons, 0.15-0.25 for container ships, 0.35-0.40 for bulk carriers of up to 60,000 deadweight tons, and 0.45-0.55 for larger bulk carriers.[61]

In addition to estimates based on survey data, I used cargo tonnage data from three different sources combined with ballast-to-load ratios to estimate the quantity of ballast water discharged into the Estuary (Appendix B, Estimates 10-12). Overall, these various estimates indicate that about 0.5-1 billion gallons of foreign ballast water[62] and perhaps 2-4 billion gallons of total ballast water are discharged into the Estuary each year. These are rough figures, and should be taken as provisional estimates until better data are developed.

While ballast water originating from overseas should probably poses the greatest risk for the introduction of exotic species, ballast water from ports on the west coast of North America that host exotic organisms which are not established in the Estuary could also be the source of species introductions. Shorter travel times from west coast than overseas ports may result in relatively larger numbers of viable individuals arriving, increasing the likelihood of establishment. However, given the much larger number of exotic species established in the San Francisco Estuary than in other port areas along the coast,[63] intracoastal ballast water transfers probably represent a greater risk to that other ports areas than to the Estuary.

I used projections of the tonnage of cargo imported and exported through the year 2020 to estimate future changes in the volume of ballast water discharges.[64] Exports are projected to increase from around 17 million metric tons in 1995 to 37 million metric tons in 2020; aggregate net exports to increase from about 4 to 12 million metric tons; and net exports disaggregated by major cargo categories from 6 to 17 million metric tons. Cargo tonnage will be increasingly dominated by containerized cargo, which is projected to grow from 41% of export tonnage in 1995 to 61% in 2020. Overall, the projections suggest a 2-fold to 3-fold increase in exports and net exports, and about a 2-fold increase in the volume of ballast water discharges over this period.[65] In contrast the U. S. Army Corps of Engineers and the Port of Oakland estimate that the amount of ballast water discharged by ships arriving at the Port of Oakland will decrease by 45% between 1996 and 2010, based on an expectation that future container ships will discharge less ballast water.[66]

Reducing Ballast Water Introductions

Proposals for reducing or eliminating the introduction of harmful organisms in ballast water generally fall into four main categories:

- management of where, when or how ballast water is loaded or discharged;
- the exchange of ballast water at sea;
- the on-board treatment of ballast water; or
- the on-shore treatment of ballast water.[67]

These approaches are discussed below. Either because of intrinsic limitations or operational constraints, no approach is likely to be 100% effective. Combinations of approaches, or different approaches in different areas or in different parts of the industry, may ultimately be adopted. For all approaches, certain issues must be considered: the safety of the ship and crew, the approach's effectiveness in destroying potential invading organisms, its environmental impacts, its practicality, its compatibility with ships' operations, and the cost of implementing it.[68]

Managing the Loading or Discharging of Ballast Water

Several management actions have been suggested that are primarily aimed at either reducing the amount of ballast water loaded or discharged in coastal areas, reducing the number of organisms or of harmful organisms taken in during loading, or avoiding the discharge of ballast water in sensitive or vulnerable areas (Table 9). Such measures could potentially contribute to the effectiveness of a ballast management program when combined with ballast water exchange or ballast water treatment, but are unlikely by themselves to resolve the problem of introductions in ballast water. For example, there are limits to how much the coastal loading and discharging of ballast water can be reduced. Although sea conditions can be less severe in coastal waters than in the open ocean, proper stability, draft and trim are nevertheless necessary and are achieved in part by loading or discharging ballast water.

Table 9. Measures that have been Suggested for Managing Ballast Water at Loading or Discharging

<u>At Ballasting Port</u>

- Arrive at ballasting port with the maximum allowable ballast. Load minimum allowable ballast at port consistent with ship safety. Load any additional ballast needed in water of sufficient depth to minimize the intake of sediment and bottom organisms.
- Do not ballast where water is likely to contain unwanted organisms, such as near sewage discharges or dredging operations; in areas with known incidence of transportable disease; in waters with algal blooms, especially toxic dinoflagellate blooms, or dense plankton populations; in water with high sediment loads; or in shallow water.
- Post warnings of toxic dinoflagellate blooms when they occur so ships may avoid loading ballast.
- Do not ballast at night, when many benthic, epibenthic and planktonic organisms migrate toward the surface.
- In shallow water use ballast intakes located high on the ship's hull to avoid entraining bottom sediments or organisms living near the bottom.
- Use contrary ballasting: ballast in fresh water when expecting to deballast in salt water, and ballast in salt water when expecting to deballast in fresh water.

<u>At Deballasting Port</u>

- Arrive at deballasting port with the minimum allowable ballast.
- Do not discharge near mariculture areas or marine protected areas.
- Dispose of ballast tank sediments on land.

SOURCES: IMO 1991; Bolch & Hallegraeff 1994; Carlton *et al.* 1995; Weathers & Reeves 1996; Marine Board 1996; Gauthier & Steel 1996; Hay *et al.* 1997; Reeves 1998.

Theoretically, careful control of where, when or how the ballast is loaded could reduce, though not eliminate, the loading of organisms. In practice most ships will not be free to exercise this level of control, since the place and timing of ballast loading will to a large degree be constrained by the ship's itinerary, schedule and operational needs.

Similarly, with sufficient investment in biological monitoring programs and the development of an international notification system, it would theoretically be possible for ships to avoid ballasting in the midst of concentrations of identified harmful organisms, such as toxic dinoflagellates. However, constraints imposed by the ship's itinerary, schedule or operational needs may make it difficult or impossible to avoid ballasting among such concentrations, even when they have been identified.

One variant on the "avoid ballasting harmful organisms" approach is to test a ship's ballast water, and to require ballast water exchange or treatment only if harmful organisms are found.[69] Although this approach has obvious appeal, implementing it may be difficult, and its usefulness limited. The problems of rapidly and adequately sampling and assessing the organisms in a ship's ballast tanks are substantial. More fundamentally, while some of the organisms that may be transported in ballast water can be identified as clearly harmful, for most organisms we simple do not know—and perhaps can never know—whether or not they will be harmful when introduced into a novel environment.[70]

Finally, avoiding discharging into or near sensitive sites may be of limited value, since exotic species, once established at one site, may spread to other sites along the coast. For example, the European green crab, first collected on the Pacific Coast in San Francisco Bay in 1989 or 1990, has since spread northward to Gray's Harbor in Washington, a distance of about 800 miles; and the New Zealand sea slug, first collected on the Pacific Coast in San Francisco Bay in 1992, has spread south at least as far as San Diego, a distance of over 500 miles.[71]

Ballast Water Exchange

Ballast water exchange is most often proposed for ships arriving from overseas ports. Such ships would exchange their ballast water over deep ocean water, referred to here as an open-ocean exchange (also called a mid-ocean, high seas, at sea or deep water exchange[72]). In most cases where criteria have been specified, an open-ocean exchange should be made at least 200 miles offshore, or in waters that are at least 2,000 meters deep, or both (Table 10). There have been some suggestions that vessels engaged in coastwise traffic should conduct ballast water exchanges some lesser distance offshore (such as 25 miles).

The primary purpose of an open-ocean exchange is to remove the coastal water containing coastal organisms, and load only open-ocean water in the ballast tanks. On arriving at its destination, the ship would then release into coastal waters only open-ocean organisms. Such organisms are not expected to survive, or at least not to thrive, in the coastal zone or to compete effectively with organisms adapted to coastal conditions.[73]

Table 10. Distance and Depth Requirements for Ballast Water Exchange

See Appendix C for descriptions and references for laws, regulations and other authorities.

Implementing Body: Law, Regulation or other Authority	Requirements for Exchange
IMO: Guidelines (1991)	In water at least 2,000 meters deep.
US: NANPCA (1990) and NISA (1996)	Outside the US 200-nautical-mile Exclusive Economic Zone (EEZ).
US: Regulations implementing NANPCA (1993)	Outside the US and Canadian 200-mile EEZ and in water at least 2,000 meters deep.
US: Proposed amended regulations for NANPCA and NISA[1]	Outside the US and Canadian 200-mile EEZ and in water at least 500 meters deep.
US: Final Rule re exporting Trans-Alaska Pipeline oil (1996)	In water at least 2,000 meters deep.
US: US Navy procedures (1994)	At least 12 miles from shore.
Canada: Voluntary Guidelines (1989)	In water at least 2,000 meters deep; backup zone specified in water over 340 meters deep.
Israel: Notice to Mariners (1994)	Beyond the continental shelf or freshwater current effect.
Chile: Regulations (1995)	At least 12 miles from shore.

1 Federal Register 1998 at p. 17784.

Ballast water exchange may be done in two basic ways. In the most straightforward approach, an empty-and-refill exchange, a ballast tank is pumped empty (or as empty as possible; see the discussion of unpumpable ballast above) and then refilled.[74] An alternate approach is to pump water in through one portal and allow it to flow out through another, called a flow-through exchange.[75]

An empty-and-refill exchange could potentially make a ship unstable or prone to slamming (by discharging too much ballast for the sea conditions), cause insufficient propellor immersion, or impose unacceptable stresses on the hull (by changing the buoyancy in one section of the vessel relative to another). Stability problems are in general likelier for small ships, and unacceptable stresses are likelier for large ships.[76] A figure that appeared early in the ballast exchange literature and has been repeatedly cited is that empty-and-refill exchange is unsafe for vessels over 40,000 deadweight tons.[77] One modelling study based on three ships of 37,700 to 110,000 tons displacement[78] found that empty-and-refill exchange conducted at sea would produce no instability problems and place no unacceptable stresses on these ships until the seas reached significant wave heights of somewhere between 10 and 20 feet.[79] One modelling study on a bulk carrier of 150,000 deadweight tons uncovered no problems with stability, bending moment or shear forces if exchange is conducted in an appropriate sequence, while two modelling studies and records of displacement during an exchange indicated unsafe stresses for four bulk carriers of 70,000 to 188,000 deadweight tons[80] (Table 11).

Table 11.
Safety Assesssments of Open-Ocean, Empty-and-Refill Ballast Exchange

	Length x Breadth (feet)	Displacement Tonnage (metric tons)	Deadweight Tonnage (metric tons)	Ballast Capacity (gallons)	Study Results
Bulk carrier	595 x 75	37,700		4,210,000	Modelling found no stability problems. Bending moments and shear forces safe in seas with 10-foot significant wave heights. May occasionally exceed design values in seas with 20-foot significant wave heights.[1]
Container ship	677 x 95	40,000		1,400,000	
Tanker	884 x 106	110,000		9,920,000	
Bulk carrier	930 x 155		141,500	14,870,000	Modelling found instances of propellor emergence, unsafe bending moment and shear force.[2]
Bulk carrier	853 x 141		150,000	17,820,000	Modelling found no problems with stability or hull girder loads.[3]
Bulk carrier	740 x 105	79,000	70,000		Modelling found all stability criteria met; found instances of propellor emergence, increased risk of forward slamming, unsafe bending moment or shear force.[4]
Bulk carrier	950 x 140	189,000	165,000		
Bulk carrier			188,200		Displacement gauges showed stress variations judged to be undesirable.[5]

1 Woodward *et al*. 1994; see discussion in text and endnotes.
2 Rigby & Hallegraeff 1994.
3 AQIS 1993b at pp. 46-48, 150-163.
4 Prior 1995, cited in Weathers & Reeves 1996; Gauthier & Steel 1996 at p. 13.
5 Rigby *et al*. 1993.

Such problems do not occur with flow-through exchange. Because the ballast tanks are never emptied, stability is not compromised and hull stresses are never significantly altered. However, flow-through exchange is difficult in many ballast tanks because there is usually only one pipe for both filling and draining the tank. In some ships, flow-through exchange has been conducted by pumping water in through a single pipe at the bottom of the tank and overflowing water onto the decks through hatch covers or air ventilators at the top of the tank.[81] In general, conducting a flow-through exchange through one pipe is inefficient, and in some cases may be unsafe. Retrofitting ballast tanks with a second pipe and other changes that have been suggested (Table 12) could make flow-through exchange both safe and more efficient, even for the largest vessels.[82] However, more water does have to be pumped than in an empty-and-refill exchange, typically requiring about 3 full tank volumes to be flowed through in order to achieve a comparable exchange (Table 13).

Open-ocean ballast exchange can be conducted while the ship is moving en route, although in some cases a ship may need to reduce speed.[83] Under normal conditions crew members of commercial vessels are busiest when entering and leaving port, and would therefore be available to conduct ballast water exchanges while at sea, so that in most cases the hiring of additional crew would not be necessary. The main cost of ballast exchange is the cost of the fuel needed to run the pumps to move the water in or out of the tanks.[84]

Table 12. Measures that have been Suggested for Improving the Effectiveness or Safety of Open-Ocean Ballast Exchange

Retrofitting

- In tanks which cannot be exchanged by empty-and-refill method because of hull stress and which have single pipes, install a second pipe to allow flow-through exchange.
- Install or modify hatches and interconnections between tanks, or enlarge ventilator pipes, to allow more effective flow-through exchange.
- Extend pipes or modify pumps to improve flow and suction and reduce unpumpable ballast.
- Install higher capacity pumps to reduce the time required for exchange.
- Install small piping to flush areas trapping water and sediments within tanks; where possible provide gaps between supports and hull to improve flushing.

Operational: While Conducting Exchange on the Open Ocean

- Load ballast through intakes located low on the ship to avoid entraining organisms living at or near the water surface.
- If freshwater ballast is loaded and a full exchange cannot be conducted, conduct partial exchange so salt water may act as a (partially-effective) biocide.
- Flush sea water through ballast pumps after each tank has been drained, before using pumps to load new ballast.
- Conduct partial ballast-and-deballast exchange (also called rinse-and-spit) in tanks considered empty but containing unpumpable ballast (also called residual ballast or deadwater).

Other Measures

- Regularly inspect and clean ballast tanks, suction wells and other parts of the seawater system to remove organisms and accumulations of sediment.
- Include written procedures in the ships' operational manual for ballast water exchange and sediment removal.
- Require log-keeping for all ballast uptakes and discharges, and sediment management procedures.
- Take and analyze ballast water and sediment samples to test survival of organisms and pathogens in order to monitor compliance and effectiveness of exchange; sample sediment in suction wells, chain lockers, etc.

SOURCES: IMO 1991; Pollutech 1992; AQIS 1993b; Bolch & Hallegraeff 1994; Carlton *et al*. 1995; Weathers & Reeves 1996; Kabler 1996; Marine Board 1996; Reeves 1998.

Table 13. Evidence Regarding the Effectiveness of Ballast Water Exchange

Observations Regarding Ships Claiming to have Conducted an Open-Ocean Exchange
6 ships contained no copepods endemic to the source region, which were found in at least 5 of 6 ships not conducting an exchange (Williams *et al*. 1988).
14 of 32 ships retained significant amounts of sediment and dinoflagellate cysts (Hallegraeff & Bolch 1992; Rigby *et al*. 1993).
14-33% of ships originating from fresh or brackish ports retained freshwater-tolerant zooplankton (Locke *et al*. 1993).
Several ships retained coastal organisms from the source region (Carlton *et al*. 1995 at p. 159).
Ships had 5% of the number of organisms and half the number of species relative to ships that did not exchange. On one ship, an exchanged ballast tank had 0.1% of the number of coastal worm (spionid worm) larvae, 1% of the number of organisms, and 19% of the number of species relative to an unexchanged cargo hold (Smith *et al*. 1996).
Observations from Experimental Exchanges
Empty-and-refill 96-100% efficient exchange of water in 3 deck tanks, based on mean salinity; some coastal zooplankton remained at <1 organism/m^3 (Wonham *et al*. 1996).
Flow-through In combined double-bottom and topside tanks, with the ship in port (static conditions), eliminated 75% of dead plankton by replacing 3 tank volumes; with the ship at sea, eliminated 70% of dead plankton by replacing 1 tank volume; 88% of water (estimated with dye) by replacing 2 tank volumes; and 95% of dead plankton and 96% of water by replacing 3 tank volumes (Rigby & Hallegraeff 1994).
Flow-through On one ship, replacing 1 tank volume in each of 2 wing tanks changed salinity from 10 to 25 ppt indicating ≈60% exchange of water, and eliminated 80-100% of 5 coastal zooplankton groups relative to 2 unexchanged wingtanks. A similar test on another ship but replacing 3 tank volumes changed salinity from 32 to 35 ppt indicating ≈70-100% exchange of water, and eliminated 93-99.7% of 8 coastal zooplankton groups (one additional group, perhaps including some oceanic species, was reduced by 70%) (Ruiz & Hines 1997).

On-Board Treatment

On-board treatment could occur in-line as the ballast water is being loaded or discharged; *in situ* in the ballast tanks while the ship is underway; or by recirculating water out of the ballast tanks, through a treatment unit, and back into the tanks while the ship is underway. In general, in-line treatment during loading or discharge requires a larger treatment plant, with greater space and power requirements, to handle higher flow rates.[85] The treatment would also need to be conducted during the busiest parts of the voyage. On the other hand, in-line treatment ensures that all the water is treated, and that it is treated only once, while treatment while underway may require repeated treatments of some of the same water as ballast tanks are topped up or are partially emptied and then refilled. Any system to be used on-board ship must be designed to operate reliably in that sometimes difficult environment, and complex systems requiring sophisticated operation or substantial maintenance may not be practical for a significant portion of the world's commercial fleet.[86]

Similar classes of treatment methods could theoretically be used either on-board or on-shore. However, most of the scoping studies and experiments to date have been directed toward on-board application, and have primarily looked at the use of chemical biocides (including extreme alterations of salinity and pH), filtration and heat treatment. Other methods that have been proposed include ultraviolet (UV) radiation, ultrasound, microwaves, electric pulse and pulse plasma, magnetic treatment, mechanical agitation, and deoxygenation.[87]

Use of Biocides. Biocides that may potentially be used to disinfect ballast water include oxidizing biocides such as chlorine, ozone and hydrogen peroxide, and nonoxidizing biocides such as various metal ions, glutaraldehyde and organic acids. In laboratory tests, 24-hour exposure to copper sulphate (at up to 200 ppm), an algicide[88] (up to 10,000 ppm) and varying levels of pH (2-10) and salinity (15-100 ppt) were ineffective in killing dinoflagellate cysts (chosen as the target organism because of their potential harm to shellfisheries and human health, and their resistance to chemical treatment relative to motile organisms[89]), while chlorine (tested at 10-2,000 ppm of free chlorine) and hydrogen peroxide (tested at 100-60,000 ppm) were effective only at high concentrations that would make them prohibitively expensive.[90] These chemicals may be infeasible for other reasons as well, including lack of adequate storage space on ships, reduced effectiveness in water with sediment or organic material, corrosiveness, and concerns about discharging chlorinated water into the environment.[91] Prior filtration to remove cysts and sediment would make these approaches more feasible. Some biocides (chlorine, copper and silver ions) can be electrolytically generated from seawater, but expensive equipment and a substantial supply of power is needed.[92] Current research efforts are investigating the possible use of glutaraldehyde or organic acids to treat the relatively small amounts of unpumpable ballast remaining in ballast tanks on NOBOB ("no ballast on board") ships, but these chemicals are too expensive for general treatment of ballast water.[93]

Filtration. Various types of screens, strainers or membrane filtration systems have been considered for on-board use in several studies.[94] In general there are tradeoffs between efficiency, size, complexity and cost: systems that remove very small organisms at an adequate flow rate tend to be large,[95] and shrinking the system tends to make it complex and costly. The size ranges of organisms that may need to be treated include invertebrate eggs at 20-100 microns, algal spores and cysts at 5-25 microns, fungi at 1-100 microns, protozoa at 1-80 microns, bacteria at 0.1-100 microns and viruses at 0.01-1 micron.[96] Filters also need to be cleaned periodically, producing backwash material that may need to be stored and ultimately disposed of;[97] However, an in-line filter system operating at loading should be able to discharge backwash materials back into the source waters. Because of the difficulties involved in filtering to a fine enough scale to remove all organisms of concern, filtration is often proposed as a first step to be followed by additional treatment, such as UV disinfection.[98] One feasibility assessment considered the use of filters in the 15-150 micron range, and a project on the Great Lakes is currently testing filters in the 25-250 micron range.[99]

Heat Treatment. Laboratory tests have shown that heating water to 40-45° C (104-113° F) for 30-90 seconds will kill many species of dinoflagellate cysts.[100] Field trials are underway on an Australian bulk carrier and a Japanese ore carrier to determine the temperature levels that can be reached using the waste heat from ships' engines.[101] Calculations for one bulk carrier indicate that to sufficiently heat its 12 million gallons of ballast water would require 45-90 megawatts of power in addition to the 20 megawatts available as waste heat, or 2-4 times the power generated by the ship's main engine.[102] In addition to issues of cost and space, concerns include thermal stresses to the vessel and thermal pollution from discharging heated ballast water.[103]

UV Radiation. While UV kills bacteria and other micro-organisms, it may not be effective for larger organisms, cysts and spores, algae and fungi, and its effectiveness is reduced in water containing suspended matter. For that reason, UV is generally considered to be practical only after some form of filtration.[104]

Other Treatments. To the extent that they have been studied, other treatment approaches have not shown great promise. For example, high intensity ultrasound can potentially kill organisms through cavitation or pressure waves, but the results may be frequency dependent with no single frequency effective for a wide range of organisms, it may require substantial exposure time to be effective, and it is likely to require more energy than UV.[105] Microwaves appear to be prohibitively expensive and of questionable effectiveness.[106] Electric pulse and pulse plasma technologies are at the experimental or exploratory levels, their ability to kill the range of organisms present in ballast water has not been demonstrated, and the costs of development are likely to be high and development times long.[107] While magnetic treatment or mechanical agitation can kill some organisms, their effectiveness regarding the range of ballast water organisms is unknown.[108] Deoxygenation can be achieved by adding chemicals such as sodium metabisulfate with cobalt chloride catalyst, but this approach would be ineffective or of limited effect on anaerobic bacteria and the encysted life stages of various organisms, its effectiveness with regard to other organisms may be compromised by difficulties in achieving an airtight sealed ballast tank and surface reoxygenation of the ballst water, corrosive compounds and hazardous gases would be generated, and there are likely to be environmental concerns regarding the discharge of anoxic and possibly sulfur-rich water.[109]

On-Shore Treatment

Several concepts have been proposed for on-shore treatment or management of ballast water (Table 14). Water could be treated in on-shore facilities either before or after it is used for ballast on a ship, and it may be treated either in facilities dedicated to ballast water treatment, or possibly in existing facilities designed for the treatment (including disinfection) of water or wastewater. Water could also be stored and recycled for use as ballast by other ships.

Table 14. General On-Shore Treatment Approaches

<u>Pre-treatment</u>
• Load water from city water systems.
• Load water from ballast water pretreatment facility.
<u>Post-treatment</u>
• Discharge ballast water to city sewage system or existing wastewater treatment facility.
• Discharge ballast water to ballast water treatment facility.
<u>Recycling</u>
• Transfer ballast water to a ship in need of ballast.
• Discharge ballast water to and load ballast water from a ballast water holding facility.

There has been less study of on-shore treatment of ballast water than of on-board treatment and ballast exchange, however feasibility studies conducted for the Canadian and Australian governments estimated costs for on-shore treatment approaches that compared favorably with other treatments.[110] On-shore treatment would appear to provide several advantages and a few disadvantages relative to on-board treatment and open-ocean exchange (Table 15). On-shore treatment would avoid ship and crew safety issues that arise with empty-and-refill exchanges, or with the on-board use of toxic materials.[111] Well-established and relatively cheap methods of initial treatment such as sedimentation (possibly augmented by coagulation, flocculation or solids-contact clarifiers), flotation or media filtration may be employed on-shore, but would be difficult or impossible to employ with the limited space and lack of a steady free surface pertaining on-board ship.[112] Sedimentation or media filtration may be capable of removing many resistant life stages (such as cysts and spores) as well as organic and inorganic suspended sediment, making subsequent treatment (by UV or biocides, for example) cheaper and more efficient. Given the evidence of rapid mortality of mobile forms within enclosed ballast tanks (see Table 7), settling and/or media filtration followed by simply holding the water in tanks for a few weeks or months might prove to be a cheap, efficient and environmentally safe method of treating ballast water. At the very least, this rapid mortality over time should augment the effectiveness of on-shore treatment.

Table 15. On-Shore Treatment vs. On-Board Treatment

Potential advantages of on-shore treatment

- Eliminates concerns about crew safety or wear or stress on the ship (i. e. concerns over storage and use of toxic chemicals, corrosion or thermal stresses that arise with various on-board treatments).
- Fewer space and power constraints (space is limited on-board, especially in engine rooms which may be the best sites for treatment facilities; power is also limited, and installing more may be impractical).
- Treatment managed by water treatment professionals rather than ship's crew. Maintenance of equipment and operation of treatment process likely to be more consistent and reliable than in the more variable and sometimes difficult conditions on-board.
- Deposited and suspended sediments and organic material (which interfere with many treatment methods) may be removed by gravitational settlement or media filtration, which are impractical on board due to space constraints and mixing of the water from ship movements.
- Resting stages (cysts, spores, etc.), which are the forms most resistant to treatment, may similarly be removed.
- Mortality of organisms due to additional holding time (this may be possible to manipulate as a partial or full treatment).
- Economies of scale in constructing and operating relatively few on-shore treatment plants versus plants on board each ship.
- In some cases it may be possible to make some use of existing treatment facilities/personnel.
- Only need to treat the water actually discharged (versus all potential discharge).
- Easier monitoring and regulation of the treatment process and effluent quality.

Potential disadvantages of on-shore treatment

- Cost of retrofitting ships to off-load ballast water (although this may be less than the cost of retrofitting ships to accomodate some types of on-board treatment[1]) and retrofitting ports to receive it.
- High cost of land for treatment plant in some areas (although a floating "treatment ship" may offer an alternative at reasonable cost[2]).
- Possible delays to ship during off-loading of ballast water.
- No treatment of ballast water discharged prior to ships' entry into port (such as when a ship must lessen its draft before crossing a shallow bar or entering a shallow port).

1 Pollutech 1992; Reeves 1998.
2 AQIS 1993a.

With regard to the costs of the treatment plant component, for any particular treatment method, due to economies of scale it should be cheaper to build, maintain and operate relatively fewer and larger on-shore plants than a much larger number of on-board plants, to provide the same total treatment capacity.[113] Further, the opportunity to construct buffer storage on-shore should substantially reduce the treatment capacity needed in an on-shore approach, and fewer space, power and operational constraints should allow the choice of the cheapest treatment method from a wider array of available options. Finally, it may be possible to work in co-ordination with or make some use of existing wastewater treatment facilities and personnel to further reduce costs.[114]

Laws and Regulations

Various laws, regulations, guidelines, administrative orders and other directives issued by international, national and sub-national governing bodies have attempted to address the problem of exotic organisms carried in ships' ballast water, with most of these directives arising since 1989 (described in Appendix C, and summarized here). They have included both voluntary guidelines and mandatory requirements. As noted above, most have focussed either on the management of where, when or how ballast water is loaded or discharged, or on open-ocean exchange of ballast water, with on-board and on-shore treatment approaches often noted as acceptable alternatives.

Ballast water discharges were recognized as an international concern in 1973, when the United Nations Conference on Marine Pollution requested the World Health Organization to investigate the potential spread of epidemic disease in ballast water.[115] As early as 1976 the Tasmania State Government in Australia reportedly required the open-ocean exchange of ballast water for inbound ships,[116] and in 1982, concerned about the potential for introducing toxic dinoflagellates into local mussel farms, the Candian Coast Guard prohibited the discharge of unexchanged ballast water in the vicinity of the Iles-de-la Madelaine in the Gulf of St. Lawrence.[117] Between 1989 and 1993 Canada, Australia, New Zealand and the United Nations' International Maritime Organization (IMO) adopted guidelines on ballast water management. These were in large part spurred by concerns over toxic dinoflagellates, based on studies that had demonstrated their introduction in Australia.[118] Although these guidelines were primarily advisory and voluntary in nature, under their authority Australia and New Zealand apparently prohibited the discharge of some ballast water into their coastal waters. In 1998 New Zealand adopted mandatory regulations requiring ocean exchange or treatment of foreign ballast water.[119] Israel issued regulations requiring open-ocean exchange of foreign ballast water in 1994, and Chile, Japan and several other countries and ports have reportedly adopted various ballast water regulations, although it is not clear in all cases that they are consistently implemented or enforced.[120] Laws or port regulations prohibit the dumping of ballast tank sediment in various regions, including the ports of London, Los Angeles, the Canadian Great Lakes and St. Lawrence River, Melbourne in Australia, New Zealand and Japan.[121]

In the United States concern over ballast water introductions developed with the discovery of zebra mussels in the Great Lakes in 1986, apparently introduced via ballast water.[122] In November 1990 the Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA) was signed into law. NANPCA set voluntary guidelines, which became mandatory requirements in 1993, for ballast water management by ships arriving from overseas ports and entering the Great Lakes. This law essentially requires ships to exchange their ballast water in the open ocean before discharging it into the Great Lakes, although alternative treatments that are as effective are allowed.[123] Further support for this regulatory approach resulted from the discovery in 1991 that a strain of epidemic cholera was being carried in ballast water from South America to the U. S. Gulf Coast, where it was found in oysters and fish.[124] In 1994 the mandatory ballast water regulations were amended to include ships entering the upper Hudson River.

In October 1996 the National Invasive Species Act (NISA) became law. NISA retained mandatory regulations for the Great Lakes and Hudson River, and added similar voluntary guidelines for the rest of the country. However unlike NANPCA, in which the voluntary guidelines for the Great Lakes had automatically become mandatory within two years of enactment, under NISA the voluntary guidelines that apply to the rest of the country will remain voluntary unless the Secretary of Commerce determines that they are ineffective or not being complied with, following a mandated review process.[125] NISA requires the initial review to be completed within four years of enactment, but at the current time, 23 months after enactment, the process is apparently already about a year behind schedule.[126] Once the review is completed and if the Secretary determines that compliance or effectiveness are inadequate, regulations are to be promulgated "promptly"—but no schedule or deadline is given.

Meanwhile, between 1990 and 1993 several state legislatures on the Pacific Coast considered resolutions on ballast water. California, Washington and Alaska's resolutions found that introductions of exotic organisms in ballast water threatened aquatic resources and asked the U. S. Coast Guard to prohibit "the dumping of ballast water originating in foreign ports in any west coast river, estuary, bay or coastal area."[127] Hawaii's resolution called for the creation of a task force to investigate the problem and recommend solutions.[128] California and Alaska adopted their resolutions in 1990 and 1992.

In 1992 California passed a law adopting the IMO guidelines as the policy of the state, and after Jan. 1, 1994 requiring all operators of vessels carrying ballast water and entering a California port to complete a form describing their ballast water management, so that compliance with the guidelines could be monitored.[129] However, this reporting requirement was never implemented. A 1997 amendment of the law instead directed that information on ballast water be obtained from the U. S. Coast Guard, which under NISA is expected to start distributing and collecting such information. The State of Washington considered two bills related to ballast water management, but passed neither. The first, introduced in 1992, would have required ships to exchange their ballast water on the open ocean prior to entering the state's waters. The second, introduced in 1993, was similar to California's 1992 bill.[130] In 1998 Washington passed a bill which sets up a task force to identify the pathways of introduction for zebra mussels and green crabs—which would presumably include consideration of ballast water as a pathway—and make recommendations for monitoring, control and further legislation.[131]

In 1996 and 1997, national or local actions required the open-ocean exchange of ballast water for ships arriving from overseas at three port regions on the West Coast. In April and May, 1996 a Presidential Memorandum and a Final Rule required that oil tankers exporting Trans-Alaska Pipeline oil overseas conduct ballast water exchanges on their return voyages.[132] In November 1996 the Humboldt Bay Harbor, Recreation and Conservation District, and in March 1997 the Port of Vancouver, British Columbia, each required overseas ships using their ports to conduct open-ocean exchange.[133] The Port of Vancouver is the largest bulk freight port on the West Coast, and both the total amount of ballast water discharged into the port, and the ballast water carried and discharged per ship, is much greater than in the San Francisco Estuary. Within the Estuary, the Port of Oakland is considering adopting regulations requiring open-ocean exchange.[134]

In addition to these legislative and administrative actions specifically intended to address ballast water introductions, other laws, regulations or agreements at the state, national or international level might conceivably be applied to promote more effective management of ballast water. In general these address one of five regulatory areas:

- the importing, transporting or release of live organisms;
- the protection of aquatic environments or of particular species or types of species (such as endangered species, or fish and game species, or commercially harvested or cultured species) that may be found in aquatic environments;
- the protection of water quality and the prevention of pollution;
- the prevention of environmental impacts in general; or
- the protection of human health.

Some examples of these are discussed in Appendix D, and summarized here.

Various international conventions may obligate the signatory nations to take steps to prevent or manage the introduction of exotic species in ballast water. For example, the United Nations Convention on the Law of the Sea directs states to "take all measures necessary to prevent, reduce and control...the intentional or accidental introduction of species, alien or new, to any particular part of the marine environment, which may cause significant or harmful changes thereto."[135] It has been argued that this phrase imposes a due diligence standard on the signatories, including a duty to identify the pathways transporting exotic specie and "close them off,"[136] and that failure to take such measures may make them liable for any damages caused by such introductions.[137]

Provisions of the federal Clean Water Act related to the protection of water quality may potentially apply to the introduction of exotic organisms in ballast water releases, as a waste discharge of a biological pollutant. For example, the San Francisco Bay Regional Water Quality Control Board (RWQCB) recently listed exotic species discharged in ballast water as a priority pollutant causing impairment of the waters of San Francisco Bay, under Section 303(d) of the Act. This listing automatically triggers a process for the setting and implementation of effluent limitations needed to eliminate the water quality impairment.[138]

State water quality laws may similarly apply to ballast water discharges. For example, the San Francisco BayKeeper and DeltaKeeper petitioned the San Francisco Bay and Central Valley RWQCBs, seeking regulation of ballast water discharges under California's Porter-Cologne Water Quality Control Act.[139] Specifically, the petitions argue that the ballast water discharged by ships constitutes a "waste" as defined by Porter-Cologne, and that the RWQCBs are therefore authorized by the Act to set waste discharge requirements for ballast water. They recommend that these requirements provide the basis for waste discharge permits to be issued to marine ports and terminals, regulating the conditions under which the waste (ballast water) may be discharged by the vessels using these facilities. The petitions also argue that state regulation of ballast water discharges is not preempted by federal law and does not violate the Commerce Clause.[140]

Another federal law which may apply to ballast water introductions is the Lacey Act, which prohibits the importation of certain injurious species, including some that may be found in ballast water.[141] Two sets of California regulations similarly make it unlawful to import, transport, possess or release into the wild various listed animals, unless specifically authorized to do so, including some that may be found in ballast water.[142]

The Endangered Species Act could restrict or prohibit the introduction of exotic organisms that are likely to jeopardize a listed species.[143] Delta smelt and winter run chinook are listed species that are dependent on healthy water quality and appropriate habitat conditions in the Estuary. The introduction of exotic species could affect these listed species by diverting or reducing energy flows through the food web (which could affect zooplankton or insects that are prey to the listed fish), altering habitat conditions, altering the bioavailability of toxic contaminants, competing or hybridizing with listed species, or introducing parasites or diseases. Under the Act federal agencies might be prevented from authorizing, funding or carrying out actions that would jeopardize a listed species (possibly including such actions as permitting, financing or constructing projects that would increase or alter the pattern of discharge of ballast water containing exotic species); nonfederal entities might be barred from such projects by the prohibition against "taking" a listed species; and recovery plans might include measures that constrain the discharge of ballast water containing exotic species or require its treatment.

The National Environmental Policy Act (NEPA) may require the assessment of potential mitigations for ballast water discharges by any project, such as a port expansion project, that alters the pattern of transport and discharge of ballast water.[144] NEPA requires the disclosure of environment impacts stemming from projects involving federal actions. For "projects significantly affecting the quality of the human environment" an Environmental Impact Statement (EIS) must be prepared. The EIS must discuss the environmental impacts of the project; identify any adverse, avoidable environmental effects; discuss alternatives to the proposed project; and discuss any appropriate mitigation measures not already included in the project. The lead agency must also make certain findings in a record of decision that, among other things, states "whether all practicable means to avoid or minimize environmental harm from the alternative selected have been adopted, and if not, why not."[145]

Most projects involving the creation, expansion or alteration of marine terminals or ports will involve some federal action in granting necessary permits or providing funding or other assistance, and thus trigger some level of environmental review under NEPA, often a full EIS. Where such projects entail or enable an expansion in the volume of shipping or an alteration in the pattern of shipping (relative to the "no project" alternative), there may be significant environmental impacts in the form of an increased risk of introducing exotic organisms in ballast water or sediments from overseas ports, or of introducing exotic organisms in ballast water or sediments from other ports along the coast where those organisms had been previously established. Thus NEPA would require for such projects a discussion of these impacts, identification of unavoidable impacts, consideration of project alternatives that might avoid these impacts, discussion of mitigation measures (such as requiring ships to exchange or treat their ballast water, or constructing on-shore facilities to treat ballast water), and if such mitigations were not adopted, an explanation of why they were not.

In additional to federal law, the corresponding state environmental review laws, the so-called "baby NEPAs," may also apply to such projects, and may entail other requirements in addition to those of NEPA. The California Environmental Quality Act (CEQA),[146] for example, has requirements for disclosure of impacts and discussion of mitigations in an Environmental Impact Report (EIR) that generally parallel those of NEPA, but also requires public agencies to "deny approval of a project with significant adverse effects when feasible alternatives or feasible mitigation measures can substantially lessen such effects."[147] Thus California law may require the mitigation of significant ballast water impacts, where feasible, when such impacts stem from the creation, expansion or alteration of a marine port or terminal. The Center for Marine Conservation and seven other nonprofit organizations,[148] have raised this concept in comments arguing that the EIS/EIR for the proposed channel deepening project of the Port of Oakland is inadequate under state and federal law because it fails to identify, discuss and adopt mitigations for the ballast water impacts of the project.[149]

Several other California laws or regulations may bear on the importing and release of exotic organisms in ballast water, such as the following:

- "No live aquatic plant or animal may be imported into this state without the prior written approval of the Department [of Fish and Game]" (Fish and Game Code §2271(a)).
- "It is unlawful to deposit in, permit to pass into, or place where it can pass into the waters of this state ... any substance or material deleterious to fish, plant life or bird life" (Fish and Game Code §5650).
- "It is unlawful to place, plant, or cause to be placed or planted, in any of the waters of this state, and fresh or salt water animal, or any aquatic plant, whether taken without or within the State, without first submitting it for inspection to, and securing the written permission of, the Department [of Fish and Game]" (Fish and Game Code §6400).
- "No person shall release in to the wild without written permission of the [Fish and Game] Commission any wild animal [note: defined to include fish, crayfish and gastropods] ... which ... is not native to California" (California Code of Regulations §671.6).
- "The biological productivity and the quality of coastal waters, streams, wetlands, estuaries and lakes ... shall be maintained ... through, among other means, minimizing adverse effects of waste water discharges" (Public Resources Code §30231).
- "All port-related developments shall be ... designed ... so as to ... minimize substantial adverse environmental impacts" (Public Resources Code §30708).
- "The Department [of Food and Agriculture] shall prevent the introduction and spread of injurious insect or animal pests, plant diseases, and noxious weeds" (Food and Agriculture Code §403).

- "It is unlawful for any person to willfully import into, or ship or transport within, the state any live ... pest ... unless the shipment ... is authorized prior to shipment" (Food and Agriculture Code §6305).
- "Wastewater discharges shall be treated to protect present and future beneficial uses, and, where feasible, to restore past beneficial uses of the receiving waters. Highest priority shall be given to improving or eliminating discharges that adversely affect any of the following: (1) Wetlands, estuaries, and other biologically sensitive sites; (2) Areas important for water contact sports; (3) Areas that produce shellfish for human consumption; (4) Ocean areas subject to massive waste discharge" (Water Code §13142.5(a)).
- "Independent baseline studies of the existing marine system should be conducted in the area that could be affected by a new or expanded industrial facility using seawater in advance of the carrying out of the development" (Water Code §13142.5(d)).
- "The state board shall formulate and adopt a ... California Ocean Plan [which shall] guarantee that the current standards are adequate and are not allowing degradation to indigenous marine species or posing a threat to human health ... the state board shall develop [and] adopt ... bioassay protocols and complementary chemical testing methods and shall require their use in the monitoring of complex effluent ocean discharges ... "complex effluent" means an effluent in which all chemical constituents are not known or monitored" (Water Code §13170.2).

The application of some laws or regulations may hinge on whether the release or discharge of an exotic organism is considered to be "accidental" rather than "deliberate" or "intentional." Given the extensive documentation of living marine and freshwater organisms occurring in ships' ballast water, and the extent to which the shipping industry and the general public have been apprised of the role of ballast water in introducing exotic species, it is questionable whether the routine discharge of exotic organisms in ballast water could be considered accidental any more than the routine discharge of pollutants by a factory could be considered accidental.

Finally, if existing statutes are inadequate to effectively manage ballast water, it is apparently within the authority of the states or of appropriate local or regional governments and agencies to adopt the necessary laws or ordinances. The regulation of ballast discharges by state or local government is nothing new. In *Two Years Before the Mast*, Richard Henry Dana described regulations in California in the 1830s prohibiting the discharge of solid ballast (stones, mud or soil carried as ballast by ships before the advent of steam-powered pumps and steel hulls made water ballast far more convenient) into harbor waters.[150] Similar laws remain on the books in Oregon, Washington and Alaska.[151] Rhode Island also prohibits the discharge of contaminated ballast water, while Alaska prohibits the discharge of ballast water carried in the cargo tanks of oil tankers.[152] In examining this Alaska statute, the courts have ruled that the state authority to regulate ballast water discharges is not preempted by federal law.[153]

Conclusions and Recommendations

- The loading and discharging of ballast water is an essential component of the operation of cargo ships. Ballast water is loaded and discharged for a variety of reasons, and carried in various configurations of tanks and holds.

- Scientific studies over the past 15 years have demonstrated that a wide variety of marine and freshwater organisms, may survive transoceanic and interoceanic transport in ballast tanks to be released in ballast discharges in viable condition. Sediments, sometimes in substantial volumes, may accumulate on the bottom of ballast tanks, and a variety of organisms may live within these sediments; under some conditions these may also be discharged with ballast water, or they may release larvae or eggs that may be discharged. Some organisms may form resting stages within ballast tanks—cysts, spores or other forms—which may remain viable for extended periods. These may also eventually be discharged with ballast water, or may produce motile forms that are discharged.

- The concentrations of organisms in ballast water varies greatly. Several studies report dramatic declines in the number and diversity of organisms in ballast tanks during the course of voyages. This may be due to adverse environmental conditions, including the depletion of food resources. A few types of organisms have been collected alive from ballast tanks after periods of up to a year, but these may result from the presence of resting stages or the persistence of organisms within sediments. Despite declines, organisms are sometimes abundant in ballast tanks at the conclusion of transoceanic voyages, such that a single ship may discharge many millions of individual organisms.

- Although researchers have sampled and studied the organisms arriving in ballast water at many ports around the world, the ballast water arriving in the San Francisco Estuary has never been sampled. Information on the organisms discharged with this ballast water is needed to assess the urgency of implementing ballast water management, to characterize the nature and intensity of this stressor on the Estuary's ecosystem, and to provide baseline data against which to measure the effectiveness of future control efforts.

⇒ ***The ballast water arriving in the Estuary should be sampled and analyzed to characterize the diversity and abundance of exotic organisms it carries, its water quality parameters, the degree to which it is contaminated by sewage or other pollutants, and any potential public health risks.***

- A large number (>230) of exotic species have become established within the Estuary; exotic species dominate several habitats; and the rate of invasion within the Estuary has been increasing. The transport and release of organisms through ballast water discharges is a major mechanism responsible for introducing exotic species. Both the absolute and relative importance of this mechanism of introduction in the Estuary have been growing.

- Exotic aquatic species may threaten ecological integrity, economic activity and public health in the regions to which they are introduced, both in the San Francisco Estuary and in other parts of the world. Threats to economic activities include the fouling of water supply systems and the destruction of fisheries. Threats to public health include the potential for introducing toxic dinoflagellates, cholera and other pathogenic organisms, and the discharge of sewage-contaminated ballast water.

- We know little about the quantities, sources, seasonal patterns or time trends of ballast water discharged into the Estuary. This information is needed to characterize the nature and intensity of this stressor on the Estuary's ecosystem, and to provide baseline data against which to measure the rate of compliance with and effectiveness of future control efforts.

⇒ ***Data on recent shipping activity in the Estuary should be compiled and analyzed. Data should also be collected from ships using the Estuary's ports on the sources of their ballast water, the volume of their discharges and their ballast water management activities. Projections of future ballast water imports and discharges should also be developed.***

- Current estimates, based on limited data and best considered as very rough estimates, indicate that about 0.5-1 billion gallons of foreign ballast water and about 2-4 billion gallons of total ballast water are discharged into the Estuary each year. The likely sources of this ballast water may be indicated by the pattern of ship arrivals: three-quarters of the ships arrive from U. S. west coast and Canadian ports; of the remaining quarter, 40% arrive from Japan, Korea or China, 33% arrive from Southeast Asia, Australia, New Zealand or Pacific ports, and 15% arrive from Central or South America.

- Approaches to reducing the introduction of exotic organisms in ballast water fall into four broad categories: management of ballast water loading and discharge; exchanging ballast water at sea; treating ballast water on-board ship; or treating ballast water on shore. Some of the measures suggested for managing the loading and discharge of ballast water may usefully augment other approaches to reducing ballast water introductions, but most are unlikely to substantially reduce introductions on their own.

⇒ ***Ships should be encouraged to utilize those management approaches that will reduce the loading of organisms in ballast water, especially the loading of known harmful organisms.***

- One especially useful measure would be the removal and disposal of ballast tank sediments on land or in the open ocean rather than in coastal waters. Many ports and regions of the world prohibit the dumping of ballast sediments in port areas or coastal waters.

⇒ ***Ships using the Estuary's ports should be prohibited from dumping ballast sediments within the Estuary or within 200 miles of shore.***

- Ballast water exchange on the open ocean (generally defined as more than 200 nautical miles from shore and/or in water of at least 2000 meters depth) has been adopted as the primary defense against species introductions via ballast water. Properly conducted exchanges by either the empty-and-refill or the flow-through method are capable of eliminating 95% of the water and organisms in the original ballast water. Open-ocean exchange is conducted while the ship is underway and is relatively cheap, the main cost in most cases being the cost of fuel to run the pumps. Several ports or regions of the world now require some form of open-ocean exchange of ballast water (or an alternative treatment if as effective) by ships seeking to discharge ballast water.

⇒ ***Ships using the Estuary's ports and seeking to discharge ballast water should be required at a minimum to conduct open-ocean exchange of ballast water (or an equally effective alternative treatment), subject to the qualifications contained in federal and international regulations and guidelines that exempt ships from open-ocean exchange requirements if conditions would risk compromising the ship's safety.***

- The evidence regarding the safety of empty-and-refill exchange for various types and sizes of vessels is as yet unclear. In general, stability problems would be expected more often for smaller vessels and problems with unacceptable stresses more often for larger vessels. Testing and experience to date have uncovered no stability problems from open-ocean exchange, but have found some potential stress problems, especially with larger ships. This suggests that empty-and-refill exchange is probably safe for most small ships, and possibly not safe for some large ships.

- Flow-through exchange can be conducted without causing stability or stress problems, even in large ships. However, it is an awkward procedure for some ballast tank configurations, and it requires pumping about three times as much water as does an empty-and-refill exchange. Various retrofits have been suggested that would enhance the effectiveness, convenience or safety of conducting flow-through exchange, including the installation of a second pipe in ballast tanks.

⇒ ***Ships should be encouraged to assess the safety issues related to conducting an empty-and-refill exchange; to use the flow-through method if there is any uncertainty about the safety of conducting an empty-and-refill exchange; and to make any retrofits needed to facilitate flow-through exchanges.***

- Feasibility studies of most on-board treatment approaches indicate that they are likely to be prohibitively expensive, and in some cases entail other issues such as questionable effectiveness, excessive space or power requirements, corrosion problems, safety hazards or environmental impacts. Nevertheless, several approaches have been or are the subject of laboratory or pilot tests.

- On-shore treatment appears to offer several potential advantages over on-board treatment, including economies of scale, fewer space and power constraints, generally easier operating conditions, a greater choice of feasible treatment methods, some possibility of using existing treatment facilities and personnel, operation and maintenance by water treatment professionals rather than by ships' crew, and cheaper and more reliable monitoring and regulation. The major drawbacks appear to be that any water discharged prior to arrival in port would not be treated, and the possibility of delays to ships while off-loading ballast water. Despite their apparent promise, on-shore treatment approaches have received little study.

⇒ ***Research into promising on-shore treatment approaches should be supported. On-shore treatment opportunities tailored to the shipping patterns and available facilities in the Bay/Delta region should be explored.***

- The National Invasive Species Act of 1996 directed that national voluntary guidelines be promulgated for ballast water management, based on the mandatory regulations adopted for ships entering the Great Lakes or upper Hudson River, which require open-ocean exchange of ballast water or an alternative, equally-effective treatment. The Act further directed that the compliance with and effectiveness of the voluntary guidelines would be assessed within 4 years of the Act's enactment; and that if compliance or effectiveness were found to be inadequate, the guidelines would promptly be made mandatory, either on a national or a regional basis. This assessment, however, is already about a year behind schedule.

⇒ ***Bay/Delta region interests should monitor and participate in the assessment of the voluntary guidelines, to keep this process from falling further behind schedule, to ensure that appropriate measures and standards are used to assess compliance and effectiveness, and to encourage the adoption of mandatory requirements for ships entering the Estuary (similar to those in force in the Great Lakes/Hudson River) if compliance with or effectiveness of the voluntary guidelines are found to be inadequate, or if implementation and assessment of the guidelines falls further behind schedule.***

- Several mechanisms may be available under existing state or federal law to regulate ballast water discharges or to require that the impacts of such discharges be mitigated, including mechanisms that may be available under state water quality, fish and game, or food and agriculture laws, or under state or federal laws pertaining to the assessment and mitigation of environmental impacts.

⇒ ***Bay/Delta region interests, including relevant state resource agencies and regulatory bodies, should assess the mechanisms that are available under various existing laws to regulate and manage the discharge of exotic species in ballast water. State agencies should use the authorities available to them to reduce or prohibit the discharge of exotic species in ballast water.***

- The language of the Commerce clause, court decisions, and an attorney general opinion all indicate that states have the right to regulate ballast water discharges.

⇒ ***If existing laws prove to be inadequate, then Bay/Delta area residents and legislators should seek passage of such state laws as would be needed to effectively reduce or prohibit the discharge of exotic species in ballast water.***

Notes

1 For example, California Fish and Game Code §2271(a) prohibits the importing of live aquatic plants or animals without a written permit, and §6400 makes it "unlawful to place, plant, or cause to be placed or planted, in any of the waters of this state, any fresh or salt water animal, or any aquatic plant" without a written permit. The regulations provide for penalties of up to $5,000 and one year in jail for each violation. Other relevant laws are discussed in the section on "Laws and Regulations."

2 This was estimated from the following information. Over 700 ships arrived in the San Francisco Estuary from a broad range of overseas ports in 1996 (Marine Exchange 1997). A study in Coos Bay reported at least 367 species present in the ballast water of 159 ships (Carlton & Geller 1993). The ballast water all derived from a single source region. The study did not sample ballast sediments. Samples were collected with an 80 μm mesh plankton net, which would have failed to collect many small protist, bacterial and viral species, and bacteria and viruses were not examined or reported on by the study. Even among the organisms sampled, as noted by the authors, it is likely that the number of species present in certain taxonomic groups was grossly underestimated by these figures. For example, where the original study reported two species of tintinnids (a type of ciliated protozoan) in the ballast water, subsequent detailed morphological analysis of the samples from 56 of the ships that had been noted as containing tintinnids identified 33 tintinnid species from 15 genera (Pierce et al. 1997). Molecular genetic analysis might reveal yet more species of tintinnids.

3 Although this recently introduced sea slug in San Francisco Bay was identified as *Philine auriformis* from New Zealand by Gosliner 1995, W. Rudman has argued on the internet that it is not that species. As these arguments are as yet unpublished, this report will continue to refer to the sea slug as *P. auriformis*.

4 Cohen & Carlton 1995a.

5 Cohen & Carlton 1995a.

6 Cohen & Carlton 1995a.

7 For example, see Nichols & Thompson 1985; Nichols & Pamatmat 1988; Herbold & Moyle 1989; Cohen & Carlton 1995a, 1998.

8 Zooplankton and phytoplankton are, respectively, animals and plants that drift within the water column. Collectively they are called plankton. Most planktonic organisms are small to microscopic.

9 Carlton *et al.* 1990; Nichols *et al.* 1990; Alpine & Cloern 1992; Kimmerer *et al.*, 1994; Orsi 1995.

10 Luoma & Linville 1997; Thompson 1997.

11 OTA 1993; O'Neill 1996. Many of the largest water systems in California appear vulnerable to invasion by the zebra mussel, and the resulting costs could be substantial (Cohen & Weinstein 1998).

12 Shushkina & Musayeva 1990; Travis 1993; Harbison & Volovik 1994.

13 Seastar Ecology Group 1996; Furlani 1996.

14 Culotta 1992.

15 Hallegraeff *et al.* 1989; Hallegraeff & Bolch 1991, 1992.

16 Culotta 1992; Mlot 1997.

17 Federal Register 1991, 1998; McCarthy *et al.* 1992; McCarthy & Khambaty 1994.

18 Epstein *et al.* 1993; Ditchfield 1993; Tauxe 1995.

19 Whitby 1998. See also Federal Register 1998 at p. 17784 regarding a 1995 Canadian study. Bio-Environmental Services 1981 at p. iv reported "one ballast tank sample contained raw

sewage, indicating that a potential health hazard exists if this material is deballasted within the vicinity of populated areas." The same study (at p. 49) suggests that parasitic nematodes or other human parasites could be introduced in ballast water.

20 This has typically been defined as exchange occurring outside the 200-mile Exclusive Economic Zone, in waters at least 2,000 meters deep, or both. See Table 10.

21 Carlton 1985; AQIS 1993a at p. 20; AQIS 1993b at p. 25; Carlton *et al*. 1995; Marine Board 1996.

22 Kabler 1996; Weathers & Reeves 1996; Reeves 1998.

23 Carlton *et al*. 1995; Marine Board 1996. Locke *et al*. 1991 reported an average of 42,000 gallons of unpumpable ballast on seven foreign vessels entering the St. Lawrence Seaway.

24 Accumulated sediment may range from negligible to quite substantial amounts. Pollutech 1992, Appendix A at p. 21 records a foot-thick layer of mud in the ballast tanks of one ship.

25 Kelly 1993.

26 Williams *et al*. 1988; Hallegraeff *et al*. 1990; AQIS 1993a at p. 21; Kelly 1993; Marine Board 1996.

27 Carlton 1985.

28 Cohen & Carlton 1997.

29 Hallegraeff *et al*. 1990; Hallegraeff & Bolch 1991, 1992.

30 Carlton *et al*. 1992.

31 Wonham *et al*. 1996.

32 Carlton 1985; Williams *et al*. 1988; Hallegraeff *et al*. 1990; Hallegraeff & Bolch, 1992; Galil & Hülsmann 1997.

33 Smith *et al*. 1996.

34 Typical ships' pumping capacities are 0.3-0.5 million gal/hr for general cargo and container ships, 1.3-2.6 million gal/hr for bulk freighters and ore carriers, and 1.3-5 million gal/hr for tankers (Marine Board 1996 at p. 37).

35 Cohen & Carlton 1995a, 1998.

36 Cohen & Carlton 1998.

37 Cohen & Carlton 1995a.

38 Based on the species listed in Cohen 1997.

39 Carlton *et al*. 1990; Nichols *et al*. 1990; Werner & Hollibaugh 1993; Kimmerer *et al*. 1994; Alpine & Cloern 1992; Luoma & Linville 1997; Thompson 1997. For a personal description of the extent of this invasion, see Cohen & Carlton 1995b.

40 Shushkina & Musayeva 1990; Travis 1993; Harbison & Volovik 1994.

41 For reports and estimates of zebra mussel-related costs see: NANPCA 1990; OTA 1993, p. 68; LePage 1993; Glassner-Shwayder 1996; O'Neill 1997.

42 Hushak 1995.

43 O'Neill 1997.

44 *Alexandrium catenella*, *A. minutum* in Australia and *Gymnodinium catenatum* in Tasmania (Hallegraeff *et al*. 1988; Hallegraeff & Bolch 1991, 1992; Hallegraeff 1993); *G. breve* in New Zealand (Smith *et al*. 1993); *A catenella* in Chile (G. Lembeye, pers. comm.).

45 Federal Register 1991, 1998; McCarthy *et al*. 1992; McCarthy & Khambaty 1994.

46 Epstein *et al*. 1993; Ditchfield 1993.

47 Seaport Plan 1996, at p. 13. One metric ton (also called a "tonne") is equal to 1.102 short tons (the standard ton in use in the United States, equal to 2,000 pounds). Because the metric ton is

the unit most commonly used in shipping data and is not much different from a short ton, the shipping data in this report will henceforth be reported in metric tons and not converted.

The quantities cited in the text from the Bay Area Seaport Plan are less than those depicted in Fig. 4 because the Seaport Plan only includes data for the ports of San Francisco, Oakland, Richmond, Benicia and Redwood City and the Encinal Terminal, while Fig. 4 includes data for the ports of Sacramento and Stockton and the oil refinery and other industrial terminals in the Estuary.

48 Manalytics 1988, Tables 11 and 15.

49 Carlton *et al*. 1995.

50 US Coast Guard 1986.

51 Based on ships arriving in Great Lakes and St. Lawrence River ports from foreign ports in 1991 (Reid & Carlton 1997).

52 Carlton *et al*. 1995 at p. 11; Reid & Carlton 1997.

53 Hutchings *et al*. 1986, reporting estimates of ballast water entering Australia by Williams *et al*. 1982.

54 Based on ships arriving in U. S. ports from foreign ports in 1992 (Carlton *et al*. 1995 at pp. 76, 83).

55 These figures may refer to bulk carriers. This report also notes that ice-strengthened vessels operating in ice may carry up to 80% of deadweight tonnage in ballast water (Pollutech 1992 at Appendix A, p. 8).

56 AQIS 1993a at p. 15-16; AQIS 1993b at p. 16. Locke *et al*. 1993 report that modern ships on transoceanic voyages may carry 25-35% of their deadweight tonnage as ballast water.

57 Estimate by MacDonald Wagner Pty. Ltd. for ships from Japan entering Queensland, Australia, probably consisting mainly of large bulk carriers, reported in Hutchings *et al*. 1986. Hay *et al*. 1997 at p. 11 and Hayden (in press) report an estimate made by Hayden of ballast discharged to New Zealand ports, based on average ballast capacity per deadweight ton by ship type, adjusted by ratios of ballast discharged to ballast carried derived from information on ballast reporting forms.

58 Hutchings *et al*. 1986, reporting estimates for ballast water entering Australia.

59 Carlton *et al*. 1995 at p. 11.

60 Based on ships arriving in U. S. and Canadian ports from foreign ports in 1991 and 1992 (Carlton *et al*. 1995; Reid & Carlton 1997).

61 Hay *et al*. 1997. Elston 1997 at p. 41 reported an estimate based on a ratio of 0.48 for coal carriers at the Port of Vancouver.

62 Note that from a biological perspective, the concern is not whether the ballast water is from foreign (outside the United States) sources but whether it is from sources outside the bioregion (outside the Northeastern Pacific Coastal Bioregion, generally defined by marine biogeographers as extending from the west coast of Baja California to southern Alaska [Ekman 1953; Briggs 1974; Moyle & Cech 1996]). Unfortunately, the available shipping, cargo and ballast water data are categorized by nationality (i. e. from foreign or domestic ports), rather than by bioregion. It appears reasonable, however, to use data on quantities originating from foreign ports as rough approximations for quantities from outside the bioregion, at least until better data have been compiled, by the following logic. Data on ships, cargo or ballast water arriving in the Estuary from foreign ports include quantities from Canada (presumably mainly from western Canada) and Mexico, with most of the former and possibly some of the latter thus originating from within the bioregion; while domestic data include quantities from Atlantic and Gulf coast ports, from Hawaii, and from U. S. possessions, which are outside the bioregion. Out of 3,075 total ship arrivals in the Estuary in 1996, 147 (less than 5% of the total) were from Canada or Mexico and 174 (less than 6% of the total) were from

the U. S. Atlantic or Gulf coast, Hawaii or U. S. possessions (Marine Exchange 1997). Thus adjusting "foreign and domestic" data to become "outside and inside the bioregion" data would not change the numbers dramatically.

63 Carlton 1979; Cohen & Carlton 1998.

64 Projections are from Manalytics 1988.

65 Appendix B, Table B-4, comparison of Estimates 10 and 13.

66 US Army Corps/Port of Oakland 1998 at Appendix X, p. X-8 (in Vol. V). These estimates have been questioned in one comment letter (Letter of June 29, 1998 to Robert McIntyre, Review Manager, Policy Review Branch, HQ U. S. Army Corps of Engineers, Alexandria VA; from Warner Chabot, Director, Pacific Region, Center for Marine Conservation, and seven other organizations).

67 Some studies consider a category of "port treatment" where ballast water is transferred from cargo ships to a treatment plant on a specially-designed vessel floating in the port (e. g. AQIS 1993a). Here, this approach is considered a variant of on-shore treatment, and not dealt with further.

68 Marine Board 1996 at p. 47.

69 Marine Board 1996 at p. 91.

70 Australia's and New Zealand's regulatory efforts have been substantially oriented toward preventing the introduction of specific organisms or types of organisms that have been the focus of concern: for Australia, toxic dinoflagellates, primarily from northwestern Pacific ports; for New Zealand, the North Pacific Seastar *Asterias amurensis* from Tasmania. For regulatory programs focussed on one or a few specific organisms, approaches based on rapid biological assays of ballast water may be feasible.

71 B. Dumbauld, pers. comm. ; D. Cadien, pers. comm.

72 See Carlton *et al*. 1995 at p. 154 for a discussion of these terms.

73 Similarly, coastal organisms are not expected to do well in the middle of the ocean. Coastal waters are characterized by higher turbidity, lower UV, and more variable and generally lower salinities. These conditions are thought to make transplants from either environment into the other likely to fail (Locke *et al*. 1993; Carlton *et al*. 1995 at p. 153; Reeves 1998). Higher levels of nutrients in coastal waters, different availability of food resources, and different intensities of competition and predation may also play a role (Rigby & Hallegraeff 1994; Carlton *et al*. 1995; Reeves 1998). For many coastal meroplankton—organisms with planktonic larvae that must settle on the bottom for the adult phase of their lives—and for coastal tychoplankton—benthic organisms temporarily lifted into the water column—open ocean regions where the bottom is more than 2,000 meters down would provide singularly inhospitable environments.

Two other reasons sometimes cited for open-ocean exchange are based on phenomena that may augment the effectiveness of the exchange process, but are not the primary objectives of the process. First, higher salinity ocean water may act as a biocide, killing organisms adapted to freshwater or to lower salinity coastal water (Locke *et al*. 1991; Pollutech 1992, Appendix B at p. 12; Weathers & Reeves 1996; Rigby & Taylor, in press; however some freshwater organisms have been found to survive open-ocean exchange—Locke *et al*. 1991, 1993; Carlton *et al*. 1995, at pp. 159-162; Reeves 1998); and second, on transequatorial voyages, the influx of warmer tropical water may kill off temperate species, and the tropical species loaded would be unlikely to survive or thrive when discharged to temperate coasts (Hay *et al*. 1997 at p. 7). It has also been suggested that exchange will result in fewer organisms being released because lower concentrations or diversity of organisms occur in the open ocean than in coastal waters (e. g. Pollutech 1992, Appendix B at p. 8; Welch 1996), but this is not necessarily true (Carlton *et al*. 1995 at p. 155).

[74] This has also been called deballast-and-reballast exchange, reballasting, sequential release and replacement, sequential exchange, pumpdown exchange and complete exchange.

[75] Also called flow-through dilution, flushing, continuous flushing, flush-through exchange, continuous exchange, dilution exchange and overflow exchange.

[76] Hay *et al*. at p. 8.

[77] Rigby *et al*. 1993; Bolch & Hallegraeff 1994; Carlton *et al*. 1995 at p. 164; Reeves 1998. It is not clear from these sources what this figure is based on. Pollutech 1992, Appendix B at p. 23 gives the limit for safe exchange as ships of up to 30,000 tonnes cargo, without providing reference or basis.

[78] Displacement tonnage is somewhat greater than deadweight tonnage.

[79] No problems were indicated from 20-foot waves; but at 20-foot significant wave heights, occasional waves may be expected that are nearly twice as high. In a linear analysis model these waves caused maximum shear values to slightly exceed design values for the 110,000 ton displacement tanker. In linear analysis of the 40,000 ton displacement container ship, these waves caused maximum bending moment and shear that were close to design values; while including nonlinearities raised maximum bending moment closer to design values and caused maximum shear to exceed design values. For the 37,700 ton displacement bulk carrier, no problems were indicated. Stability was not compromised for any of these ships at any of the wave heights tested (Woodward *et al*. 1994).

[80] AQIS 1993b at pp. 46-47, 162; Rigby & Hallegraeff 1994; Prior 1995, cited in Weathers & Reeves 1996; Rigby *et al*. 1993.

[81] Hay *et al*. 1997. Rigby & Hallegraeff 1994 describe this process in a ship in which the configuration of the ballast tanks makes such an exchange particularly difficult.

[82] Weathers and Reeves 1996; Reeves 1998.

[83] Pollutech 1992, Appendix B at p. 16.

[84] Federal Register 1993 at p. 18333, provides a U. S. Coast Guard estimate which adds 10% to fuel costs for wear and tear; also Pickering, U. S. Coast Guard, Marine Safety Office, pers. comm. Anonymous 1998 implies that other costs may be significant, but does not provide details.

[85] Marine Board 1996 at p. 70.

[86] For example, AQIS 1993a at p. 23 (also cited by Reeves 1998) notes that "water treatment equipment would be subject to operation, repair and maintenance by the crew. With the standards of ship maintenance in some cases having slipped badly for both hull and machinery, it may be assumed in these cases that ballast water treatment systems would not be accorded a high priority for maintenance and could be easily by-passed or operated at suboptimal efficiency."

[87] Bolch & Hallegraeff 1994; Carlton *et al*. 1995; Marine Board 1996; Reeves 1998.

[88] Kathon WT 1.5% (Rohm and Haas, Philadelphia) with active ingredient chloro-2-methyl-4-isothiazolin-3-one; recommended dose is 300-500 ppm.

[89] Treatments that kill dinoflagellate cysts are also likely to kill larval zooplankton, copepod eggs and seaweed spores, although possibly not bacterial spores or viral particles (Bolch & Hallegraeff 1993).

[90] Bolch & Hallegraeff 1993, 1994; Rigby *et al*. 1993; also see Ichikawa *et al*. 1992; Montani *et al*. 1995. Germination of cysts treated with chlorine or hydrogen peroxide was reduced to a few percent at concentrations of 500 and 5,000 ppm respectively, and to zero at concentrations of 1,000 and 10,000 ppm.

[91] Bolch & Hallegraeff 1993; Rigby *et al*. 1993; AQIS 1993a at p. 38; Carlton *et al*. 1995 at pp. 145-147.

92 Gauthier & Steel 1996 at p. 40; Marine Board 1996 at p. 80.

93 Reeves 1998 at pp. 19-20.

94 Pollutech 1992; AQIS 1993a; Carlton *et al*. 1995; Marine Board 1996; Reeves 1998 at p. 15, note e.

95 For example, Marine Board 1996 at p. 78 calculated that a media filtration system such as are routinely used on shore would require a 200 m^2 by 2 m deep filter to meet the ballast flow rates on a small bulk carrier or tanker, much too large to be used on board ship. AQIS 1993a at p. 33 calculated that granular filtration in pressure filters would require a footprint of at least 100 m^2 to treat a flow of 4000 m^3/hr.

96 AQIS 1993a; Reeves 1998.

97 Marine Board 1996 at p. 77-79, 87.

98 Pollutech 1992; Carlton *et al*. 1995 at p. 140. The combination of on-board filtration and UV tends to make this a relatively expensive alternative. For example, Pollutech 1992 estimated that filtration to 50 microns alone would cost about 3-5 times as much per gallon as open-ocean exchange, but that filtration with UV would cost about 200 times as much as open-ocean exchange. Reeves 1998 notes that current cost estimates indicate that filtration alone will be prohibitively expensive. He further notes (at p. 18) that "one filter breakthrough or failure to religiously maintain and use the system...throughout the voyages around the world...will contaminate the tank and vitiate the protection to be achieved." AQIS 1993a, b concluded that filtration at a finer scale than strainers (about 50 microns) is impractical for on-board application.

99 Pollutech 1992; Mulvaney 1997.

100 Bolch & Hallegraeff 1993, 1994. These cysts are generally tmore resistant to treatment than many motile organisms.

101 Gauthier & Steel 1996 at p. 39.

102 AQIS 1993a at p. 35 reports an additional 90 MW needed; Carlton *et al*. 1995 at p. 150, cites at second hand a report in *Lloyd's List* stating an additional 45 MW needed.

103 Carlton *et al*. 1995 at p. 149; Gauthier & Steel 1996 at p. 39; Marine Board 1996 at pp. 86-87. Although not mentioned in these reports, one wonders about thermal stress to the crew as well. Pollutech 1992 at pp. 27, 48 and Appendix B, pp. 142-143 found heat treatment to be of low effectiveness, technical practicality and feasibility. AQIS 1993a at p. 35 concluded that heat treatment is not a practicable option.

104 Pollutech 1992; AQIS 1993a at p. 36; Carlton *et al*. 1995 at p. 142; Marine Board 1996 at p. 85. Tests have shown substantial germination of dinoflagellate cysts after 2 hours exposure to UV radiation (Rigby & Tayler in press, citing Montani *et al*. 1995). Organisms not killed by UV exposures may be genetically altered (AQIS 1993a). Reeves (1998 at p. 17) notes in regard to small UV units currently used on ships to treat sewage that "as a matter of practical experience, we have found that many vessel owners forget to conduct the regular monitoring of the UV penetration necessary to guarantee that their marine sanitation devices are actually treating the sewage adequately." See the footnotes in the filtration section for a discussion of costs.

105 Pollutech 1992, Appendix B; Carlton *et al*. 1995 at pp. 143-144; Gauthier & Steel 1996 at p. 39; Marine Board 1996 at pp. 85, 130.

106 Carlton *et al*. 1995 at p. 150.

107 Pollutech 1992, Appendix B at p. 6; Marine Board 1996 at pp. 84, 127-130.

108 Pollutech 1992, Appendix B at p. 6; Carlton *et al*. 1995 at p. 141; Marine Board 1996 at p. 85.

109 Pollutech 1992, Appendix B at pp. 81-89; AQIS 1993a at p. 44; Carlton *et al*. 1995 at p. 150; Gauthier & Steel 1996, at p. 40.

[110] Pollutech 1992; AQIS 1993a.

[111] AQIS 1993a at p. 13.

[112] AQIS 1993a at pp. 31-34.

[113] AQIS 1993a at p. 86 notes that "clearly the provision of centralised treatment in port or land-based facilities will be more economic in capital cost terms than provision of treatment facilities on board each ship." There would also be substantial economies of scale in the costs of monitoring and regulation, which may also be more reliable than for on-board treatment (AQIS 1993a at p. 12).

[114] To consider one aspect of this, recall that about 0.5-1.0 billion gallons of foreign ballast are discharged into the Estuary each year. However, wastewater treatment plants treat and discharge into the Estuary roughly 1 billion gallons of wastewater effluent *per day* (Davis *et al*. 1991 at p. 39). Thus it may be possible, at least in some cases, to combine the relatively small ballast water discharges with the large existing waste streams without unduly altering the character of the waste stream or straining the capacity of the plants to treat it.

[115] This research was never conducted (Kelly 1992 at pp. 77-78; Welch 1996).

[116] Williams *et al*. 1988.

[117] Gauthier & Steel 1996, at p. 5.

[118] E. g. Hallegraeff *et al*. 1990; Hallegraeff & Bolch 1991, 1992; Bolch & Hallegraeff 1994. Australia's guidelines are in part focussed on preventing the introduction of toxic dinoflagellates, whaich are apparently perceived as the major threat.

[119] New Zealand 1998.

[120] See Appendix C. The guidelines and regulations discussed here all relate to the management of "clean" ballast water, carried in segregated or dedicated ballast tanks, that would normally be discharged directly into the environment. Regulations already exist for the management of "dirty" ballast, primarily ballast water that has been carried in the cargo holds of oil tankers and become contaminated with hydrocarbons.

[121] AQIS 1993b at p. 40; Kelly 1992, 1993, citing Someya et al. 1991; New Zealand 1998.

[122] NANPCA 1990; OTA 1993.

[123] NANPCA allows the use of alternative ballast water managment methods if the Secretary of Commerce determines that these methods "are as effective as ballast water exchange in preventing and controlling infestations of aquatic nuisance species" (NANPCA §1101(b)(2)(B)(iii)). There have been no such determinations made or requested. However on four occasions the Coast Guard has allowed ships not in compliance with the regulations to conduct ad hoc alternative treatments: addding salt in the form of liquid sodium chloride (not likely to be approved again), adding chlorine as liquid chlorine and sodium hypochlorite, and heating the water (a capability that few vessels possess) (Kabler 1996; Weathers & Reeves 1996; Reeves 1998).

[124] Federal Register 1991, 1998; McCarthy *et al*. 1992; McCarthy & Khambaty 1994.

[125] NISA §§1101(c) to 1101(f).

[126] NISA at §1101(c)(1) directed that voluntary guidelines were to be issued within 1 year of enactment, or by October 26, 1997. However, draft guidelines were not published for public comment until April 10, 1998 (Federal Register 1998), and the final guidelines have not yet appeared. NISA at §1101(e)(3) also directed that the criteria for determining the adequacy and effectiveness of the guidelines were to be submitted within 18 months of enactment, or by April 26, 1998. However, the committee that is to develop the criteria has not yet been formed.

[127] California's resolution is quoted; Washington's and Alaska's were similar (California 1990; Washington 1991; Alaska 1992).

[128] Hawaii House Resolution No. 396, referenced in Chesapeake Bay Commission 1995.

[129] California 1992.

[130] Washington House Bill 2635, introduced Jan. 15, 1992; and Washington House Bill 1042, introduced Jan. 13, 1993.

[131] Washington 1998.

[132] Federal Register 1996.

[133] Humboldt Bay HRCD 1996; Vancouver 1997. Although the Humboldt Bay resultion states that mid-ocean ballast water exchange is required, it is apparently not an enforceable ordinace, as discussed in Appendix C.

[134] Zaitlin 1998.

[135] Bederman 1991; de Klemm 1994.

[136] Bederman 1991 at pp. 702 and 707.

[137] de Klemm 1994.

[138] San Francisco Bay RWQCB 1988.

[139] California Water Code §§13000 *et seq*.

[140] BayKeeper 1997. Responding to questions similar to those posed by the BayKeeper and DeltaKeeper petitions, the Attorney General of the State of Washington determined that "there is no doubt that water containing exotic microfauna that is potentially harmful to other aquatic life or to public health meets the definition of pollution" in Washington State law, that "ballast water containing harmful microfauna is pollution" under state law, and that "commercially operated vessels are prohibited from discharging waste material—including unwanted ballast waters—into waters of the state, except in accordance with the provisions of a state waste discharge permit" (Washington Attorney General 1993).

[141] Crabs in the genus *Eriocheir* (mitten crabs) and the zebra mussel *Dreissena polymorpha* are listed as injurious animals whose importation and transportation is prohibited (50 CFR 16.13(a)(2)).

Mitten crabs are believed to have been introduced to northern Europe in ballast water and ballast water is one of the two likeliest mechanisms for their introduction into California. Ballast water is probably also responsible for the repeated release of mitten crabs into the Great Lakes, and on single occasions into waters near New Orleans and into the Columbia River. Mitten crabs spawn in estuaries, with individual females producing 250,000 to 1 million eggs, which hatch in the late spring or summer and develop over 3-4 months as small planktonic (floating) larvae. Various forms or species of mitten crabs range from southern China and Taiwan through Korea and Japan, and mitten crabs have become established and are sometimes extraordinarily abundant in northern Europe, especially in Germany, the Netherlands, Belgium and northern France, with populations apparently increasing in England. Thus it is likely that some significant number of ships taking on ballast water in these countries between late spring and early fall are carrying larval mitten crabs. Juvenile or adult crabs, including one mitten crab, have also been collected from ballast sediments (Cohen & Carlton 1997).

The zebra mussel was apparently introduced via ballast water discharges into the Great Lakes of North America, from which it has spread thoughout much of eastern North America and caused substantial economic and environmental damage, as discussed elsewhere in this report. Zebra mussels spawn from spring to early fall, with individual females producing up to 1 million eggs and larvae that spend up to 33 days in the plankton (Sprung 1993). Thus some ships that take on ballast water between April and October at freshwater ports in Europe, the Great Lakes, the Saint Lawrence Seaway, the Hudson River or New Orleans are likely to carry zebra mussel larvae.

[142] California Code of Regulations §671 and California Fish and Game Code §§2116-2118. Each of these two sets of regulations provides its own list of prohibited species. Between them the lists include various fish species, various crayfish species, all species of slugs (although this

may refer only to terrestrial slugs), all species in the genus *Eriocheir* (mitten crabs) and all species in the genus *Dreissena* (zebra mussels). California Fish and Game Commission regulations, codified at CCR §236, also prohibits importing any of the listed species without a permit.

143 16 USC 1531 *et seq*.

144 42 USC 4321 *et seq*.

145 40 CFR 1505.2(c).

146 California Public Resources Code §§21000 *et seq*.

147 California Public Resources Code §21002.

148 The San Francisco BayKeeper, the Pacific Coast Federation of Fisherman's Associations, the Natural Resources Defense Council, ther Golden Gate Audubon Society, the Sierra Club–San Francisco Bay Chapter, the Bay Institute, the Environmental Defense Fund, and the Save San Francisco Bay Association.

149 Comment letters from the Center for Marine Conservation and seven other organizations to the U. S. Army Corps of Engineers, dated March 30, 1998 and June 29, 1998.

150 Dana reports that the mariners of those days also considered regulations controlling the discharge of ballast to be an unnecessary annoyance.

151 Oregon Rev. Stats. §783.600 (1995); Washington Code §88.28.060 (1996) ("Discharging Ballast, When Prohibited"); Alaska Stats. §30.50.020 (1996) ("Discharging Ballast in Navigable Waters").

152 Gen. Laws of Rhode Island Ann. §46-12-1(n) (1994); Alaska Stats. 46.03.750 (1996).

153 *Chevron USA, Inc. v. Hammond*, 726 F. 2d 483 (9th Cir. 1984), *cert denied*, 471 U. S. 1140 (1985).

Appendix A
Species Introduced via Ballast Water

For 27 exotic species established in the Estuary, ballast water appears to be the only likely mechanism for their introduction into Pacific Coast waters (Table A-1); these account for 12 percent of the 234 exotic species known from the Estuary. Another 60 species are possible introductions (Table A-2), for a total of 87 clear or possible ballast water introductions, or 37 percent of the total introductions.

Table A-1.
Exotic Organisms in the San Francisco Estuary Introduced to the Pacific Coast via Ballast Water Discharges

For organisms in this table, there appears to be no other reasonably likely mechanism to account for their introduction to the Pacific Coast other than through ballast water discharges. We include in the category of ballast water transport the possibility of transport in other parts of ships' seawater systems, such as sea chests or pipes. Data updated from Cohen & Carlton 1995 and Cohen 1996.

Organism		Probable Native Region	First Record on the Pacific Coast
Polychaete Worm	*Boccardiella ligerica*	Europe	1935
Korean Shrimp	*Palaemon macrodactylus*	Asia	1957
Chameleon Goby	*Tridentiger trigonocephalus*	Asia	1960
Yellowfin Goby	*Acanthogobius flavimanus*	Asia	1963
Asian Semele Clam	*Theora fragilis*	Asia	1968-69
Amphipod	*Corophium alienense*	unknown	1973
Mysid Shrimp	*Deltamysis holmquistae*	unknown	1977
Copepod	*Sinocalanus doerrii*	China	1978
Copepod	*Limnoithona sinensis*	China	1979
Copepod	*Oithona davisae*	Japan	1979
Cumacean	*Nippoleucon hinumensis*	Japan	1979
Shimofuri Goby	*Tridentiger bifasciatus*	Japan	1985
Asian Clam	*Potamocorbula amurensis*	Asia	1986
Copepod	*Pseudodiaptomus marinus*	Asia	1986
Amphipod	*Corophium heteroceratum*	China	1986
Foraminifer	*Trochammina hadai*	Japan	1986
Copepod	*Pseudodiaptomus forbesi*	China	1987
Polychaete Worm	*Potamilla* sp.	unknown	1989
Polychaete Worm	*Marenzelleria viridis*	Atlantic	1991
Opisthobranch	*Philine auriformis*	NZ, Australia	1992
Nebaliad	*Epinebalia* sp.	unknown	1992
Mysid Shrimp	*Acanthomysis aspera*	Japan	1992
Copepod	*Acartiella sinensis*	China	1993
Copepod	*Limnoithona tetraspina*	China	1993
Copepod	*Tortanus dextrilobatus*	China, Korea	1993
Mysid Shrimp	*Acanthomysis bowmani*	unknown	1993
Shôkihaze Goby	*Tridentiger barbatus*	Asia	1997

Table A-2.
Exotic Organisms in the San Francisco Estuary Possibly Introduced to the Pacific Coast via Ballast Water Discharges

For organisms in this table there are other reasonably likely mechanisms, in addition to ballast water discharges, that could account for their introduction to the Pacific Coast. Data updated from Cohen & Carlton 1995 and Cohen 1996.

Organism		Probable Native Region	First Record on the Pacific Coast
False Angelwing Clam	*Petricolaria pholadiformis*	Atlantic	1927
Polychaete Worm	*Polydora ligni*	Atlantic	1932
Polychaete Worm	*Streblospio benedicti*	Atlantic	1932
Sea Squirt	*Styela clava*	Asia	1933
Anemone	*Diadumene leucolena*	Atlantic	1936
Polychaete Worm	*Heteromastus filiformis*	Atlantic	1936
Mud Crab	*Rhithropanopeus harrisii*	Atlantic	1937
Amphipod	*Melita nitida*	Atlantic	1938
Anemone	*Diadumene franciscana*	unknown	<1940
Amphipod	*Stenothoe valida*	unknown	<1941
Amphipod	*Ampithoe valida*	Atlantic	1941
Amphipod	*Jassa marmorata*	Atlantic	1941
Tanaid	?*Sinelobus* sp.	unknown	1943
Mediterranean Mussel	*Mytilus galloprovincialis*	Mediterranean	1947
Sea Squirt	*Molgula manhattensis*	Atlantic	1949
Hydroid	*Cordylophora caspia*	Black Sea	<1950
Oligochaete Worm	*Branchiura sowerbyi*	Asia	1950
Polychaete Worm	*Pseudopolydora paucibranchiata*	Pacific	1950
Nudibranch	*Okenia plana*	Japan	1950-60
Polychaete Worm	*Sabaco elongatus*	Atlantic	1950s
Polychaete Worm	*Pseudopolydora kempi*	unknown	1951
Bryozoan	*Alcyonidium polyoum*	Atlantic	1951-52
Bryozoan	*Conopeum ?tenuissimum*	Atlantic	1951-52
Nudibranch	*Tenellia adspersa*	Europe	1953
Ostracod	*Eusarsiella zostericola*	Atlantic	1953
Amphipod	*Ampelisca abdita*	Atlantic	1954
Jellyfish	*Corymorpha* sp.	Atlantic	1955-56
Oligochaete Worm	*Limnodrilus monothecus*	Atlantic	1960
Polychaete Worm	*Manayunkia speciosa*	Eastern North America	1961
Oligochaete Worm	*Paranais frici*	Black Sea	1961-62
Oligochaete Worm	*Tubificoides apectinatus*	Atlantic	1961-62
Oligochaete Worm	*Tubificoides brownae*	Atlantic	1961-62
Oligochaete Worm	*Tubificoides wasselli*	Atlantic	1961-62
Nudibranch	*Eubranchus misakiensis*	Japan	1962
Seaweed	*Polysiphonia denudata*	Atlantic	1963-64
Oligochaete Worm	*Potamothrix bavaricus*	Eurasia	<1965
Amphipod	*Grandidierella japonica*	Japan	1966
Polychaete Worm	*Marphysa sanguinea*	Atlantic	1969
Jellyfish	*Blackfordia virginica*	Black Sea	1970
Nudibranch	*Sakuraeolis enosimensis*	Japan	1972

Table A-2 Continued.

Organism		Probable Native Region	First Record on the Pacific Coast
Skeleton Shrimp	*Caprella mutica*	Asia	1973-77
Nudibranch	*Catriona rickettsi*	unknown	1974
Anemone	*Diadumene ?cincta*	Europe	<1975
Nudibranch	*Boonea bisuturalis*	Atlantic	1977
Isopod	*Dynoides dentisinus*	Japan, Korea	1977
Isopod	*Ianiropsis serricaudis*	Japan	1977
Isopod	*Eurylana arcuata*	NZ or Chile	1978
Jellyfish	*Cladonema uchidai*	Japan	1979
Nudibranch	*Cuthona perca*	unknown	1979
Amphipod	*Gammarus daiberi*	Atlantic	1983
Sea Squirt	*Ascidia* sp.	unknown	1983
Sea Squirt	*Ascidia zara*	Japan	1984
Sea Squirt	*Ciona savignyi*	Japan	1985
Isopod	*Munna* sp.	unknown	1989
Jellyfish	*Maeotias inexspectata*	Black Sea	1992
Mitten Crab	*Eriocheir sinensis*	China, Korea	1992
Isopod	*Paranthura* sp.	unknown	1993
Amphipod	*Melita* sp.	unknown	1993
Amphipod	*Paradexamine* sp.	unknown	1993
Isopod	*Sphaeroma walkeri*	Indian Ocean	1994

Appendix B
Calculations of Ballast Water Quantities

Data Sources

1991-92 Shipping Study (Carlton et. al 1995)

The quantities of ballast water carried by ships from foreign ports arriving at selected U. S. ports (including San Francisco and Oakland) was investigated by Carlton *et al*. (1995) for the U. S. Coast Guard and the U. S. Department of Transportation. They defined "acknowledged" ballast water as the ballast water carried by ships declared "in ballast" on Bureau of Census lists, and "unacknowledged" ballast waster as that carried by ships declared "in cargo." The relevant lists are for Monthly Vessel Entrances (number TM-385) and are available on magnetic tape from Trade Data Services Branch, Foreign Trade Division, Bureau of the Census, Washington DC 20233 (phone: 301-457-2242; fax: 301-457-2647).

The study also used data from two surveys of ships. The NABISS (National Biological Invasions Shipping Study) Vessel Survey surveyed 96 foreign-trade commercial vessels at 22 U. S. ports and port systems between January 1 and July 21, 1992. The APHIS (Animal and Plant Health Inspection Service, U. S. Department of Agriculture) survey was conducted by APHIS personnel during routine inspection boardings. They surveyed 1034 foreign-trade commercial vessels August 1992 using an abbreviated version of the NABISS survey form.

The study's estimate of acknowledged ballast for the two Bay Area ports was based on 3 ship types (tankers, bulk freighters and general cargo ships), and made use of data in the report's Appendix D, pages D2, D7 and D12. The calculations were performed as follows:

1. For each port, 5 randomly selected in-ballast ships per month (12 x 5 = 60 total) from the 1991 Monthly Vessel Entrances list were looked up in Lloyd's Register or the Record of the American Bureau of Shipping to determine ship type and size.
2. The proportion represented by each of the 3 targeted ship types was multiplied by the total number of in-ballast arrivals at each port (from the 1991 Monthly Vessel Entrances list) to estimate the number of in-ballast arrivals by type for each port (listed in column 2 of the tables in Appendix D).
3. Then ballast capacities of each of the selected ship types were estimated from regressions of capacity on size based on data from the APHIS survey (n=1034), and estimated mean ballast capacities were calculated for each of the 3 ship types for each port (column 3, Appendix D).
4. The estimated numbers of in-ballast arrivals for each of the 3 ship types in each port were then multiplied by the estimated mean ballast capacities for each ship type in each port to get estimates of total ballast capacities for each ship type and port (column 5, Appendix D).
5. These numbers were then multiplied by the estimated average percentages of total ballast capacity actually carried when arriving in ballast for each ship type, derived nationally from NABISS Vessel Survey data (n=96), to obtain estimates of the total ballast arriving via each ship type into each port (column 6, Appendix D). These were summed to obtain estimates of the total acknowledged ballast carried by the 3 ship types into each port (Table B-1).

The study's estimate of unacknowledged ballast was also based on 3 ship types (tankers, bulk freighters and container ships), and made use of data in Appendix C, page 3 and Appendix E, page 2. The calculations were performed as follows:

1. For each port, the first 48 in-cargo ships listed for every other month (6 x 48 = 288 total) in the 1991 Monthly Vessel Entrances list were looked up in Lloyd's Register to determine ship type and size.

2. The percentages of total ship arrivals in each port that were from foreign ports and in cargo for each of the 3 ship types were estimated from these data (column 2, Appendix E), and multiplied by the total number of arrivals at each port (also from the 1991 Monthly Vessel Entrances list: 1283 for Oakland and 744 for San Francisco) to estimate the numbers of ships arriving from foreign ports and in cargo for each ship type and port (column 3, Appendix E).
3. These numbers were then multiplied by the estimated average ballast carried by each type of ship when in cargo (column 4, Appendix E), which was derived from NABISS Vessel Survey data, to obtain estimates of the amount of ballast carried by each ship type into each port (column 6, Appendix E). These were then summed to obtain estimates of total unacknowledged carried by the 3 ship types into each port (Table B-1).

Table B-1.
"Shipping Study" Estimate of Ballast Water in Ships Entering the Ports of Oakland and San Francisco from Foreign Ports

Each estimate based on 3 ship types (see text). Quantities are million gallons/year.

	Acknowledged Ballast (Ships in Ballast)	Unacknowledged Ballast (Ships in Cargo)	Total Ballast
Oakland	16.9	291.9	308.8
San Francisco	17.9	57.5	75.3
Both Ports	34.7	349.4	384.1

Source: Carlton *et al*. 1995, Appendices D & E. Estimates are based on data gathered in 1991-92.

July 1996 Coast Guard Survey (US Coast Guard 1996)

The San Francisco Bay Marine Safety Office of the U. S. Coast Guard surveyed 83 ships arriving in the Estuary from foreign voyages in July 1996. All ships arriving from foreign voyages were classified as container, bulk freight, tank or passenger ships. Ships were asked about whether they had a ballast water exchange policy and how much ballast water they were discharging. Extrapolating by type of ship to the total number arriving from foreign voyages, the Coast Guard estimated that about 218 MG of ballast water arrived on such ships during that month (Table B-2). Forty-one percent of the ships said they had a ballast water exchange policy, and these ships reported discharging about 21% of the reported ballast water discharge into the Estuary.

Table B-2.
"Coast Guard Survey" Estimate of Ballast Water Discharged into the Estuary by Ships from Foreign Ports

Quantities are estimates for one month.

	Estimated Number of Ships	Ballast Water Discharged million gallons
Ships with Ballast Water Exchange Policy	89	46.3
Ships without Ballast Water Exchange Policy	129	171.3
All Ships	218	217.6

Source: US Coast Guard 1996.

1996 Golden Gate Ship Traffic (Marine Exchange 1997)

The San Francisco Marine Exchange produces an annual summary of shipping information, from which data were taken on the number of ship arrivals in the Estuary by ship type and last port of call.

1988 San Francisco Bay Cargo Forecast (Manalytics 1988)

This cargo forecast was produced for the 1988 update of the San Francisco Bay Area Seaport Plan and was incorporated in the 1996 update, which stated that "growth in maritime cargo has followed the trend predicted in the forecast of maritime cargo prepared for the 1988 update of the Seaport Plan" (BCDC 1996). These data are describedFor example, they may not include Delta ports or terminals in upper San Pablo Bay. Forecast data for 1995 and 2020 were used to estimate the total and net export in various commodity classes, to use with ballast-to-load ratios to make upper and lower estimates of ballast water discharges.

1995 Waterborne Commerce of the U. S. (US Army Corps 1996)

The U. S. Army Corps of Engineers produces an annual series of reports on the quantities of various commodities shipped or received by U. S. ports. Data from all ports in the Estuary were used to estimate the total and net export in various commodity classes, to use with ballast-to-load ratios to make upper and lower estimates of ballast water discharges.

Pacific Maritime Association 1996 Annual Report (Pacific Maritime 1997)

Data on the tonnage of goods in selected commodity classes loaded and discharged from all ports in the Estuary (but not including terminals serving oil refineries, individual companies and military bases) were used to estimate the total and net tonnage loaded, to use with ballast-to-load ratios to make upper and lower estimates of ballast water discharges.

Estimates—Total Ballast Water Arriving or Discharged

The calculations for the estimates are shown in the spreadsheets at the end of this section. The estimates are summarized and described below.

Estimates 1-6

These are estimates of the ballast water carried on ships arriving in the Estuary, based on the information in the Shipping Study (Carlton *et al*. 1995) with a 1991/92 base year.

For Estimates 1-3, I began with the Shipping Study's estimates of ballast carried by 3 types of ships (in either in-ballast or in-cargo condition) that arrived in Oakland and San Francisco from foreign ports, and extrapolated to other types of ships, to all ports in the Estuary, and to ships that arrived from both domestic and foreign ports. For these extrapolations I used the total number of ships that arrived in the Estuary in 1992 (from Marine Exchange data), and the ratio of domestic to foreign ships from the Shipping Study data for San Francisco and Oakland.

Table B-3.
Summary of Estimates of Ballast Water Carried or Discharged into the Estuary

Quantities are millions of gallons per year. See spreadsheets at the end of this section for details of estimates.

	Main data source	Estimate of ballast water...	Base-year for estimate	Foreign ballast	Domestic ballast	All ballast
1	Shipping Study	...carried	1991-92	1,169	3,521	4,691
2	Shipping Study	"	1991-92	1,008	3,036	4,044
3	Shipping Study	"	1991-92	1,247	3,756	5,003
4	Shipping Study	"	1991-92	1,269	3,821	5,090
5	Shipping Study	"	1991-92	1,063	3,200	4,263
6	Shipping Study	"	1991-92	1,181	3,557	4,738
7	Coast Guard Survey	...discharged	1996	2,611	458	3,069
8	Coast Guard Survey	"	1996	653	2,417	3,069
9	Coast Guard Survey	"	1996	765	2,832	3,598
10	Seaport Plan Cargo Forecast	"	1995	420-1,380	1,553-5,109	1,973-6,489
11	Waterborne Commerce	"	1995	559-1,366	42-886	601-2,252
12	Pacific Maritime Association	"	1996	445-722	1,647-2,676	2,092-3,398

For Estimate 4, I simply multiplied these total ship numbers by the average ballast water per ship (from Shipping Study data), averaging over all ship types and conditions and both the San Francisco and Oakland ports.

For Estimates 5 and 6, I multiplied the number of ships of various types that arrived in the Estuary in 1992 (from Marine Exchange data) by the average ballast water for each ship type (from Shipping Study data), averaging over both in-ballast and in-cargo condition and both the San Francisco and Oakland ports; and used the ratio of domestic to foreign ships from the Shipping Study data for San Francisco and Oakland.

All six of these approaches produced estimates of ballast on ships from foreign ports of around 1-1.25 billion gallons/year, and estimates of total ballast arriving of around 4-5 billion gallons/year.

Estimates 7-9

These estimates are of ballast water discharged into the Estuary, based on the July 1996 Coast Guard Survey and using a 1996 base year.

Note that the Coast Guard survey report refers to ships "from foreign voyages." It is not clear if this is the same definition as used in the Shipping Study, which included ships only if their last port of call was foreign, or if it also includes ships on voyages originating from foreign ports but calling at another domestic port before arriving in San Francisco Bay Where the Coast Guard survey report refers to foreign or domestic ships, this means the ship's country of registry.

For Estimate 7, I started with the Coast Guard's estimate of ballast water discharged in July by ships arriving from foreign voyages, multiplied by 12 to get an estimate for the year for ships from foreign voyages, then extrapolated to the total number of ships that arrived in 1996 (from Marine Exchange data), with ships from domestic voyages making up the difference. This method produced a much higher estimate of the proportion of ships from foreign voyages than is indicated by the Marine Exchange data on last ports of call, so for Estimate 8 I started with the same total number of ships arriving and the same amount of ballast water discharged as was derived in

Estimate 7, but used the ratio of ships from foreign and domestic voyages derived from the Marine Exchange data.

For Estimate 9, I multiplied the number of ships of various types that arrived in the Estuary in 1996 (from Marine Exchange data) by the average ballast water for each ship type (from Coast Guard Survey data); and used the ratio of ships from foreign and domestic ports derived from the Marine Exchange data. This is the same method as used in Estimates 5 and 6, but with different data sources and a different base year.

Not counting the results for foreign ballast from Estimate 7 (with its apparent disproportion between ships from foreign and domestic voyages), these approaches produced estimates of ballast discharged by ships from foreign voyages of 0.6-0.8 billion gallons/year, and estimates of total ballast discharged of around 3-3.5 billion gallons/year.

Estimates 10-12

These estimates are of ballast water discharged into the Estuary. For each approach I calculated upper and lower estimates by multiplying total and net tonnage of cargo shipped out of the Estuary's ports by load-to-ballast ratios (ratios reported in Hay *et al*. 1997). I used three different data sources, which group the cargo tonnages by different commodity classes, and in one the data is disaggregated by port. Estimates based on net cargo tonnages shipped (the lower estimates) are likely to underestimate the ballast water discharged, since (1) they only address ballast discharges made to adjust displacement in response to changes in the weight of cargo on board and not discharges made for other purposes, and (2) the aggregation of the tonnage data for individual ships into commodity and port classes will lead to an underestimate unless the incoming and outgoing cargo is distributed between ships in the maximally efficient way to minimize the amount of ballast discharged—and this will rarely be achieved in practice except at ports that are dominated by the export or import of one type of cargo. Estimates based on total cargo tonnages shipped (the upper estimates) may overestimate the ballast water discharge, if the data are complete and the distortion from data aggregation is not too acute.

Estimate 10 is based on data from the cargo forecast for 1995 made for the 1988 update of the Bay Area Seaport Plan (Manalytics 1988) and incorporated in the 1996 update (BCDC 1996). Use of these data may produce an underestimate because, as noted above, it is not clear whether these data include ports in the Delta and various terminals. The data are for trade with foreign ports. I extrapolated the resulting estimate to ballast discharge from all trade by using the ratio of ships arriving from foreign versus domestic ports, derived from 1996 Marine Exchange data.

Estimate 11 is based on cargo data for 1995 from the Waterborne Commerce report (US Army Corps 1995). This is the only one of these calculations in which the estimate of the quantity of domestic ballast water is based directly on data on domestic ships or cargo—all of the other approaches estimate domestic ballast water by extrapolation using ratios between domestic and foreign ship arrivals. Interestingly, this calculation also produces the the lowest estimate for domestic ballast water (except for Estimate 7, with its apparent disproportion between foreign and domestic shipping). If this is a more realistic estimate for domestic ballast water, then the total ballast estimates in Estimates 1-10 may be a few billion gallons too high.

Estimate 12 is based on cargo data for 1996 from the Annual Report of the Pacific Maritime Association. Use of these data may produce an underestimate because they only cover some types of cargo and some terminals—for example, they do not include petroleum and petroleum products shipped through the Bay Area's oil terminals. The data are for foreign and domestic trade combined. I allocated the resulting estimate between the two by using the ratio of ships arriving from foreign versus domestic ports, derived from 1996 Marine Exchange data.

These three approaches produce lower estimates of foreign ballast discharged of about 0.4-0.6 billion gallons/year, and upper estimates of about 0.7-1.4 billion gallons/year. They produce lower estimates of total ballast discharged of about 0.6-2.1 billion gallons/year, and upper estimates of about 3.4-6.5 billion gallons/year.

Estimate 13

For Estimate 13, I employed the same methods and data sources as in Estimate 10, but used the international cargo forecast data for 2020 rather than 1995. The results suggest that ballast water discharges into the Estuary will roughly double over this period if no action is taken to reduce them (Table B-4).

Table B-4.
Year 1995 and 2020 Estimates of Ballast Water Discharged into the Estuary

Quantities are millions of gallons per year. Estimates are based on cargo forecast data in Manalytics 1988. See spreadsheets at the end of this section for details.

Estimate	Forecast year	Foreign ballast	Domestic ballast	All ballast
10	1995	420-1,380	1,553-5,109	1,973-6,489
13	2020	990-2,555	3,666-9,461	4,656-12,016

Estimates—Ballast Water Arriving or Discharged per Ship

From the total ballast water estimates, I calculated the average ballast water carried or discharged per ship arriving in the Estuary (Table B-5). These estimates are generally within the lower portion of the range of similar estimates made for other regions of the world (Table B-6). Ports in those regions that fall within the higher range of estimates (Prince William Sound, Australia, Pacific Canada) are dominated by export trade in bulk resources, characterized by large tankers or bulk freighters sailing out-bound loaded with cargo and in-bound carrying only ballast. These ports would therefore be expected to have a relatively large average quantity of ballast water per ship. The San Francisco Estuary estimates are generally consistent with those from other regions.

Table B-5.
Estimates of Average Ballast Water Discharged per Cargo Ship for the San Francisco Estuary

Estimates	Base Year	Number of Ships	MG/yr	MG/ship
1-6	1992	3646	4,044 to 5,090	1.1 to 1.4
7-9	1996	3075	3,069 to 3,598	1.0 to 1.2
10-11	1995	3177	601 to 6,489	0.2 to 2.0
12	1996	3075	2,092 to 3,398	0.7 to 1.1

Table B-6.
Estimates of Average Ballast Water Discharged per Cargo Ship for Different Regions

	Based on:	MG/ship
Prince William Sound, Alaska[1]	oil tankers	8.8
Australia[2]	ships from foreign ports	6.7
Australia[2]	ships from domestic ports	3.9
Pacific Canada[3]	ships from outside the NE Pacific	3.0
Atlantic Canada[3]	ships from outside the NW Atlantic	1.9
Great Lakes[3]	ships from outside the NW Atlantic	0.9
United States[4]	ships from foreign ports	0.9
New Zealand[5]	ships from foreign ports	0.7
New Zealand[6]	ships from foreign ports	0.5
Great Lakes/St. Lawrence Seaway[7]	ships from foreign ports	0.4
England and Wales[8]	ships excluding ferries	0.4

1 Based on segregated ballast water, estimate made in 1996 (Ruiz & Hines 1997).
2 Based on 1991 arrivals (Gauthier & Steel 1996, p. 24).
3 Based on 1991 and 1993 arrivals (Gauthier & Steel 1996, p. 4).
4 Based on 984 arriving ships surveyed in August 1992. Average discharge per ship included 80,000 gallons for 218 container ships, 2,300,000 gallons for 320 bulk freighters, and 400,000 gallons for 186 tankers (Carlton *et al*. 1995, p. 83).
5 Based on 1992-95 arrivals (Gauthier & Steel 1996, p. 30).
6 Based on 1996-97 arrivals (Hay *et al*. 1997, pp. 10-11).
7 Based on 1990 arrivals (Locke *et al*. 1993, p 10).
8 Based on survey of port authorities (Laing, in press).

ESTIMATE 1

port	ship status	A ships	B MG	C ships	D ships	E ships	F ships	G MG	H MG	I MG
San Francisco	in ballast	10	18	734	18	46	36	0.790	28	46
	in cargo	48	57	734	73	186	138	1.197	165	223
Oakland	in ballast	12	17	1283	5	22	10	0.676	7	24
	in cargo	205	292	1283	56	249	44	1.424	63	355
Both ports	all ships	275	384	2017	–	503	228	–	263	647

	J ships	K MG
Ships from foreign ports	909	1169
Ships from domestic ports	2737	3521
All ships	3646	4691

A Shipping Study's estimate of the number of 3 types of ships arriving at the ports of San Francisco and Oakland from foreign ports in 1991 (Carlton et al. 1995, pp. D-2, D-7, D-12 and E-2).
B Shipping Study's estimate (using survey data from 1992) of the total amount of ballast water carried by those ships (Carlton et al. 1995, pp. D-2, D-7, D-12 and E-2).
C Total number of ships arrived in 1991 (including both "in cargo" and "in ballast" ships) from both foreign and domestic ports, from Census Bureau data (Carlton et al. 1995, p. C-3).
D Number of ships arrived from foreign ports in a sample of 288 ships from the Census Bureau data (Carlton et al. 1995, pp. G-39 and G-41).
E Estimated number of ships that arrived from foreign ports in 1991 [C x (D ÷ 288)].
F Ships from foreign ports not counted in the Shipping Study's estimate [E - A].
G Estimated average ballast water carried per ship for these ships. For in-ballast ships, based on the Shipping Study's estimated average ballast water carried by in-ballast general cargo ships from foreign ports. For in-cargo ships, based on a weighted average of the estimated average ballast water carried by all three ship types for ships arriving in cargo from foreign ports.
H Estimated ballast water carried by ships from foreign ports other than the 3 ship types included in the Shipping Study's estimates [F x G].
I Estimated ballast water carried by ships from foreign ports [B + H].
J Estimate of number of ships arriving at all ports in the Estuary, extrapolating the ratio of ships from foreign and domestic ports arriving in San Francisco and Oakland to the total number of ship arrivals (3646) in the Estuary in 1992 (from Marine Exchange 1997).
K Estimate of ballast water arriving at all ports in the Estuary, by extrapolating to the numbers given in J.

ESTIMATE 2

A variant of Estimate 1, in which the estimated average ballast water for general cargo ships is used for in-cargo ships as well as for in-ballast ships in column G.

port	ship status	A ships	B MG	C ships	D ships	E ships	F ships	G MG	H MG	I MG
San Francisco	in ballast	10	18	734	18	46	36	0.790	28	46
	in cargo	48	57	734	73	186	138	0.790	109	166
Oakland	in ballast	12	17	1283	5	22	10	0.676	7	24
	in cargo	205	292	1283	56	249	44	0.676	30	322
Both ports	all ships	275	384	2017	–	503	228	–	174	558

	J ships	K MG
Ships from foreign ports	909	1008
Ships from domestic ports	2737	3036
All ships	3646	4044

ESTIMATE 3

Another variant of Estimate 1, in which weighted averages of the estimated average ballast water carried are used for both in-ballast and in-cargo ships in column G.

		A	B	C	D	E	F	G	H	I
port	ship status	ships	MG	ships	ships	ships	ships	MG	MG	MG
San Francisco	in ballast	10	18	734	18	46	36	1.786	64	82
	in cargo	48	57	734	73	186	138	1.197	165	223
Oakland	in ballast	12	17	1283	5	22	10	1.406	14	31
	in cargo	205	292	1283	56	249	44	1.424	63	355
Both ports	all ships	275	384	2017	–	503	228	–	306	690

	J	K
	ships	MG
Ships from foreign ports	909	1247
Ships from domestic ports	2737	3756
All ships	3646	5003

ESTIMATE 4

An estimate produced by multiplying the estimated number of ships, from column J above, by the Shipping Study's weighted average amount of ballast water per ship arriving at San Francisco and Oakland (384 MG ÷ 275 ships = 1.396 MG/ship).

Ships from foreign ports	909	ships	x	1.396	MG/ship	=	1269	MG
Ships from domestic ports	2737	ships	x	1.396	MG/ship	=	3821	MG
All ships	3646	ships	x	1.396	MG/ship	=	5090	MG

ESTIMATE 5

	A	B	C
	ships	MG	MG
Bulk Freighters	366	1.671	612
Container Ships	1506	1.380	2078
Tankers	1093	1.004	1097
Other Vessel Types	681	0.698	475
All ships	3646	–	4263

	D
	MG
Ships from foreign ports	1063
Ships from domestic ports	3200
All ships	4263

A Number of ships that arrived in the Estuary in 1992, estimated from graph in Marine Exchange (1997).
B Estimate of ballast water carried for each ship type, weighted averages of data from Shipping Study (Carlton et al. 1995, pp. D-2, D-7, D-12 and E-2). General cargo ship data is used for Other Vessel Types.
C Estimated ballast water carried per ship type [A x B].
D Total ballast water in column C allocated to ships from foreign and domestic ports according to numbers of ships in column J above.

ESTIMATE 6

A variant of Estimate 5, in which the weighted average of ballast carried for all 3 ship types is used for Other Vessel Types in column B.

	A ships	B MG	C MG
Bulk Freighters	366	1.671	612
Container Ships	1506	1.380	2078
Tankers	1093	1.004	1097
Other Vessel Types	681	1.396	951
All ships	3646	–	4738

	D MG
Ships from foreign ports	1181
Ships from domestic ports	3557
All ships	4738

ESTIMATE 7

The July 1996 Coast Guard Survey estimated just under 218 MG discharged into the Estuary by 218 ships arrived from foreign voyages. Extrapolating to 12 months and to 3075 total ships arrived in 1996 (Marine Exchange 1997) produces the following estimate:

	ships	MG
Ships arrived from foreign voyages	2616	2611
Ships arrived from domestic voyages	459	458
All ships	3075	3069

ESTIMATE 8

In Estimate 7, ships from foreign ports make up nearly 85% of the total number of ships arriving in the Estuary in 1996. However, Marine Exchange (1997) showed ships with a foreign last port of call (LPOC) accounting for only 21.3% of the total in 1996. Using this latter ratio produces the following estimate:

	ships	MG
Ships arrived from foreign voyages	654	653
Ships arrived from domestic voyages	2421	2417
All ships	3075	3069

ESTIMATE 9

	A ships	B MG	C MG
Bulk Freighters	410	0.682	279
Container Ships	1569	0.545	854
Tankers	810	2.742	2221
Passenger Ships	43	0.000	0
Other Vessel Types	243	0.998	243
All ships	3075	–	3598

	D ships	E MG
Ships from foreign ports	654	765
Ships from domestic ports	2421	2832
All ships	3075	3598

A Number of ships that arrived in the Estuary in 1996 (Marine Exchange 1997).
B Estimate of ballast water carried for each ship type, from Coast Guard Survey. The weighted average for all ship types is used for Other Vessel Types.
C Estimated ballast water carried per ship type [A x B].
D Total ballast water in column C allocated to ships from foreign and domestic ports according to ratios for 1996 in Marine Exchange (1997).

ESTIMATE 10

Total and net export tonnage for categories of goods, in million metric tons (MMT). Data are forecast data for Bay Area ports for 1995, from Manalytics 1988. ni = net import.								
	total	net		total	net		total	net
Containerized Goods	7.156	4.410	Grains	0.234	0.134	Other Dry Bulk	0.028	ni
Break Bulk	0.246	0.110	Iron/Steel Scrap	0.730	0.730	Petro/Petro Products	7.031	ni
Autos & Trucks	0.008	ni	Petroleum Coke	0.702	0.702	Other Liquid Bulk	0.191	ni
Iron/Steel Products	0.027	ni	Sugar	0.023	0.002			
Newsprint	0.001	ni	Non-metallic minerals	0.898	0.210			

Lower Bound Estimate					
	A MMT	B	C MG		D MG
Containerized Goods	4.410	0.200	233	Ships from foreign ports	420
All other goods with net export	1.886	0.375	187	Ships from domestic ports	1553
Total	6.296	–	420	All ships	1973

Upper Bound Estimate					
	A MMT	B	C MG		D MG
Containerized Goods	7.156	0.200	378	Ships from foreign ports	1380
All other goods	10.119	0.375	1002	Ships from domestic ports	5109
Total	17.274	–	1380	All ships	6489

A Data from upper table.
B Ballast-to-load factor, based on Hay et al. 1997, who reported ratios of 0.15-0.25 for container ships and 0.35-0.40 for small to medium bulk carriers.
C A x B, converted from metric tons to gallons.
D Total ballast water in column C allocated to ships from foreign and domestic ports according to ratios for 1996 in Marine Exchange (1997).

ESTIMATE 11

Total and net export of major categories of goods, in million metric tons (MMT). Data are for all ports in the San Francisco Estuary for 1995, from US Army Corps 1996. ni = net import.

	Canadian		Other Foreign		Domestic	
	total	net	total	net	total	net
Coal	0.000	0.000	0.004	ni	0.000	0.000
Petroleum & Petroleum Products	0.117	ni	5.430	0.867	7.859	ni
Chemicals & Related Products	0.002	ni	0.759	ni	0.105	ni
Crude Materials	0.018	0.018	2.924	1.829	0.262	0.244
Primary Manufactured Goods	0.001	ni	0.397	ni	0.109	0.093
Food & Farm Products	0.002	ni	3.992	2.931	0.464	ni
Equipment & Machinery	0.001	0.001	0.613	ni	0.344	0.221
Other Goods	0.000	0.000	0.021	0.006	0.026	0.022

Lower Bound Estimate

	A MMT	B	C MG
Container Ship			
Export to foreign ports	0.007	0.200	0
Export to domestic ports	0.336	0.200	18
Bulk Carrier			
Export to foreign ports	5.645	0.375	559
Export to domestic ports	0.244	0.375	24
Ships trading to foreign ports	5.652	–	559
Ships trading to domestic ports	0.580	–	42
All ships	6.232	–	601

Upper Bound Estimate

	A MMT	B	C MG
Container Ship			
Export to foreign ports	1.033	0.200	55
Export to domestic ports	0.479	0.200	25
Bulk Carrier			
Export to foreign ports	13.248	0.375	1312
Export to domestic ports	8.690	0.375	860
Ships trading to foreign ports	14.281	–	1366
Ships trading to domestic ports	9.169	–	886
All ships	23.450	–	2252

A Categories of goods from table on left sorted onto ship types as follows: Manufactured Goods, Equipment & Machinery, and Other Goods on Container Ships; all other goods on Bulk Carriers.
B Ballast-to-load factor, based on Hay et al. 1997, who reported ratios of 0.15-0.25 for container ships and 0.35-0.40 for small to medium bulk carriers.
C A x B, converted from metric tons to gallons.

ESTIMATE 12

Total and net cargo loaded from San Francisco Estuary ports, for selected categories of goods. Data are for 1996, from Pacific Maritime 1997. Data are for ports only (not terminals serving oil refineries and other individual companies). Container data converted from revenue units at 10 MT/unit. nd = net discharge.

	Total Cargo		Containers		Cars & Trucks		Bulk Cargo		General Cargo		Lumber & Logs	
	total	net	total	net	total	net	total	net	total	net	total	net
San Francisco	0.025	nd	0.013	nd	0.000	nd	0.000	0.000	0.004	nd	0.000	0.000
Alameda	0.004	nd	0.000	0.000	0.000	0.000	0.004	0.004	0.000	nd	0.000	0.000
Oakland	12.850	6.775	7.281	3.902	0.445	0.305	0.000	0.000	0.036	nd	0.000	0.000
Richmond	0.077	nd	0.040	0.026	0.000	nd	0.000	0.000	0.009	nd	0.000	nd
Crockett	0.007	nd	0.000	0.000	0.000	0.000	0.000	nd	0.007	0.007	0.000	0.000
Pittsburg	0.560	0.540	0.000	0.000	0.000	0.000	0.560	0.541	0.000	0.000	0.000	0.000
Antioch	0.000	nd	0.000	0.000	0.000	0.000	0.000	nd	0.000	0.000	0.000	0.000
Stockton	0.562	0.206	0.000	0.000	0.000	0.000	0.479	0.137	0.083	0.069	0.000	0.000
Sacramento	0.822	0.643	0.020	0.020	0.000	0.000	0.649	0.491	0.161	0.143	0.013	0.008
Benicia	0.925	0.682	0.000	0.000	0.656	0.413	0.270	0.270	0.000	0.000	0.000	0.000

Lower Bound Estimate

	A	B	C		D
	MMT		MG		MG
Container Ship	3.947	0.200	208	Ships from foreign ports	445
Bulk Carrier	2.388	0.375	236	Ships from domestic ports	1647
All ships	6.335	–	445	All ships	2092

Upper Bound Estimate

	A	B	C		D
	MMT		MG		MG
Container Ship	7.353	0.200	388	Ships from foreign ports	722
Bulk Carrier	3.376	0.375	334	Ships from domestic ports	2676
All ships	10.729	–	722	All ships	3398

A Data from upper table.
B Ballast-to-load factor, based on Hay et al. 1997, who reported ratios of 0.15-0.25 for container ships and 0.35-0.40 for small to medium bulk carriers.
C A x B, converted from metric tons to gallons.
D Total ballast water in column C allocated to ships from foreign and domestic ports according to ratios for 1996 in Marine Exchange (1997).

ESTIMATE 13

Total and net export tonnage for categories of goods, in million metric tons (MMT). Data are forecast data for Bay Area ports for 2020, from Manalytics 1988. ni = net import.

Total and net export tonnage for categories of goods, in million metric tons (MMT). Data are forecast data for Bay Area ports for 2020, from Manalytics 1988. ni = net import.

	total	net		total	net		total	net
Containerized Goods	22.422	14.956	Grains	0.418	0.255	Other Dry Bulk	0.042	ni
Break Bulk	0.493	0.103	Iron/Steel Scrap	0.914	0.914	Petro/Petro Products	8.825	ni
Autos & Trucks	0.023	ni	Petroleum Coke	0.607	0.607	Other Liquid Bulk	0.559	0.136
Iron/Steel Products	0.040	ni	Sugar	0.052	0.007			
Newsprint	0.001	ni	Non-metallic minerals	1.870	ni			

Lower Bound Estimate

	A MMT	B	C MG		D MG
Containerized Goods	14.956	0.200	790	Ships from foreign ports	990
All other goods with net export	2.021	0.375	200	Ships from domestic ports	3666
Total	16.978	–	990	All ships	4656

Upper Bound Estimate

	A MMT	B	C MG		D MG
Containerized Goods	22.422	0.200	1184	Ships from foreign ports	2555
All other goods	13.845	0.375	1371	Ships from domestic ports	9461
Total	36.267	–	2555	All ships	12016

A Data from upper table.
B Ballast-to-load factor, based on Hay et al. 1997, who reported ratios of 0.15-0.25 for container ships and0.35-0.40 for small to medium bulk carriers.
C A x B, converted from metric tons to gallons.
D Total ballast water in column C allocated to ships from foreign and domestic ports according to ratios for 1996 in Marine Exchange (1997).

Appendix C.

Laws and Regulations (including Voluntary Guidelines and Resolutions) Related to Controlling Ballast Water Introductions

International Actions

United Nations, 1973

Resolution 18 of the U. N.'s 1973 International Conference on Marine Pollution requested the World Health Organization to conduct research on "the role of ballast water as a medium for the spreading of epidemic disease bacteria." This research was never conducted.[1]

United Nations, 1991

"International Guidelines for Preventing the Introduction of Unwanted Aquatic Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges" were adopted by the Marine Environmental Protection Committee (MEPC) of the U. N.'s International Maritime Organization (IMO) on July 4, 1991 (Resolution (50)31), and by the IMO as a whole on Nov. 4, 1993 (Resolution A.774(18)). These guidelines recommend the exchange of coastal ballast water in water at least 2,000 meters deep, along with various operational procedures related to loading and discharging ballast water and sediment. The Guidelines note that Member States or their Port State Authorities may adopt ballast water or sediment management requirements, or may develop shore reception facilities for disposing of ballast water and ballast sediment and may implement fees for their use. In 1994 MEPC established a working group on ballast water which is currently developing these guidelines as a possible annex to MARPOL 73/78 (the International Convention for the Prevention of Pollution from Ships 1973 and the Protocol of 1978 related thereto).[2]

United States—Federal Actions

United States, 1989

Section 207 of the Great Lakes Exotic Species Prevention Act (adopted as Public Law 101-225 in 1989) directed the U. S. Coast Guard to report on methods to prevent the introduction of exotic species in ballast water.[3]

United States, 1990

The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (known as NANPCA, adopted as Public Law 101-646, 104 Stat. 4761 on Nov. 29, 1990, and codified at 16 USC 4701-4751) set voluntary ballast water guidelines (which went into effect on Mar. 15, 1991) and then mandatory requirements (which went into effect May 10, 1993) for vessels entering the Great Lakes after operating outside the U. S. and Canadian Exclusive Economic Zone (EEZ). For such vessels intending to discharge ballst water, NANPCA requires the exchange of ballast water outside the EEZ or in other designated areas, or alternative ballast water management methods determined to be as effective. These regulations are to be implemented by the U. S. Coast Guard, with authority to prohibit a vessel's operation on the Great Lakes or revoke the vessel's clearance if not in compliance. Violation of these regulations constitutes a felony, with civil penalties of up to $25,000 per day.[4]

United States, 1992

An amendment to NANPCA (adopted as Public Law 102-587 on Nov. 4, 1992, and codified at 16 USC 4701-4751) applied the 1990 NANPCA's mandatory requirements to vessels entering the Hudson River north of the George Washington Bridge. These regulations went into effect on Jan. 30, 1994.[5]

United States, 1994

In 1994 the U. S. Navy adopted procedures requiring that ballast water taken on in harbors, rivers, inlets, bays, land-locked waters or in the ocean within 12 miles of the entrances to these water bodies be exchanged more than 12 miles from shore before returning to within 12 miles from shore.[6]

United States, 1996

A Presidential Memorandum of April 28, 1996, and a Final Rule published in the Federal Register on May 31, 1996 (Final Rule on Exports of Alaskan North Slope Crude Oil, Relating to Public Law 104-58, Bureau of Export Administration, Department of Commerce, Export Administration Regulations Part 754.2(j)(iii)(A)), requires tankers exporting Trans-Alaska Pipeline oil to exchange their ballast water in water at least 2,000 meters deep.[7]

United States, 1996

The National Invasive Species Act of 1996 (known as NISA, passed as Public Law 104-332, 110 Stat. 4073, on Oct. 26, 1996, and codified at 16 USC 4701-4751) set voluntary ballast water guidelines (to be issued within 12 months) for vessels entering the U. S. after operating outside the EEZ. These guidelines recommend that ships exchange their ballast water outside the EEZ or in other designated areas, or employ alternative ballast water management methods that are determined to be as effective. Passenger vessels with treatment systems designed to kill aquatic organisms in ballast water, and crude oil tankers engaged in coastwise trade were exempted from the guidelines. The voluntary guidelines were to be issued by Oct. 26, 1997.

NISA also directed that criteria for determining the adequacy and effectiveness of the voluntary guidelines were to be submitted to the Secretary of Commerce by Apr. 16, 1988; that the Secretary is to submit a report to Congress on the rate of compliance with and the effectiveness of the guidelines by Apr. 16, 2000; and that if the rate of compliance is inadequate, or if the reporting by vessels pursuant to the guidelines is inadequate to assess compliance, then the voluntary guidelines are to be made mandatory, on either a regional or nationwide basis.[8]

Legislative or Regulatory Actions by Other Countries

Canada, 1982

In 1982 the Canadian Coast Guard issued Notice to Mariners No. 995, which prohibited ships bound for the Grande-Entree Lagoon of the Iles-de-la-Madeleine in the Gulf of St. Lawrence from discharging ballast water within 10 miles of the islands, unless the ballast water had been loaded in a defined area of Canada's east coast at least five miles from shore.[9]

Canada, 1989

The Canadian Coast Guard adopted "Voluntary Guidelines for the Control of Ballast Water Discharges from Ships Proceeding via the St. Lawrence Seaway to the Great Lakes" on May 1, 1989. The guidelines recommended that vessels bound for St. Lawrence River and Great Lakes ports west of 63°W longitude (modified to 64°W in 1995) exchange their ballast water at sea in water greater than 2,000 meters deep, or if unable to do so then exchange it in an area in the Lower St. Lawrence Estuary east of 64°W in depths of over 340 meters.[10] The guidelines also appear to require that ballast tank sediments from foreign-going ships to be disposed of on land.[11]

Australia, 1990

The Australian Quarantine and Inspection Service adopted "Voluntary Guidelines for Ballast Water and Sediment Discharge from Overseas Vessels Entering Australian Waters" on Feb. 1, 1990.[12] These guidelines recommend that vessels entering Australian ports either:

- not discharge ballast water in Australian waters;
- exchange ballast water at sea;
- treat the ballast water on-board or on-shore to eliminate harmful organisms;
- obtain a certificate from an appropriate overseas authority certifying that the the port of origin was free of toxic dinoflagellates when the ballast water was loaded; or
- enter into a "Compliance Agreement" to maintain ballast tanks in clean conditions.[13]

Under the authority of these guidelines, Australia has apparently prevented some ships from discharging ballast water in Australian ports and on at least one occasion required a ship to leave Australian waters and discharge its ballast water outside the EEZ.[14] (Also see Triabunna, Tasmania under *Regional Actions* below.)

New Zealand, 1992

In March 1992 New Zealand adopted voluntary controls on ballast water discharges recommending that vessels either:

- not discharge ballast water in New Zealand waters;
- exchange or load ballast water in the open ocean (details of the exchange and of the original source of water must be provided to an inspector; ballast water loaded within the territorial waters of another country cannot be discharged without first reporting it to an inspector);
- disinfect the ballast water (no vessel has used this option, although a few have taken on treated water from a municipal water system as ballast);
- discharge to an on-shore facility (none exist);
- provide a certificate from the relevant overseas authority certifying that the ballast water is clean;
- discharge to an approved area in New Zealand (none have been designated).
- have the ballast water tested to show that it is not a risk (an option not used to date).[15]

The guidelines did prohibit the discharge of sediments from ballast tanks and anchor systems into New Zealand waters.[16]

New Zealand, 1993, 1998

The Biosecurity Act passed by the New Zealand Parliament in 1993 provided government authority to prohibit the discharge of any ballast water believed to put New Zealand organisms at risk of exposure to damage, disease, loss or harm, or to risk interference with the diagnosis, management or treatment of pests or unwanted organisms. A vessel entering New Zealand waters can be required to post a bond of $10,000 to ensure compliance. Non-compliance with the Act may carry penalties of up to $200,000 in fines and five years imprisonment.[17] Until 1998 these powers had been used only to obtain information about ballasting operations, to prevent the discharge of Tasmanian ballast water during months when larvae of the North Pacific seastar *Asteria amurensis* may be in the water, and to prevent the discharge of ballast sediments into New Zealand waters.[18]

In May 1998, New Zealand adopted an Import Health Standard for ballast water under the 1993 Biosecurity Act.[19] This Standard prohibits the discharge of foreign ballast water into New Zealand waters without a permit, which will be issued only if the ballast water:

- has been exchanged *en route* to New Zealand in areas free from coastal influences, prefereably on the high seas;
- is fresh water (< 2.5 ppt of NaCl);
- has been treated by an approved shipboard treatment system (none are approved);
- is discharged to an approved area or on-shore treatment facility (there are no approved discharge areas or treatment facilities).

The Standard states that Tasmania and Port Philip Bay in Australia "are considered higher risk areas [and] ballast water loaded in these areas may not be discharged into New Zealand waters under any circumstances;"[20] but if the ballast water is from elsewhere, exemptions will generally be granted if the construction of the ship makes ballast water exchange impossible, or if the construction of the ship combined with weather conditions makes ballast water exchange unsafe.The Standard also requires that sediment that has settled in ballast tanks, ballasted cargo holds, sechests, anchor lockers or other equipment must be taken to an approved landfill; and that ballast reporting forms must be completed and submitted.

Israel, 1994

Israel issued Notice to Mariners No. 5/94 in 1994, later amended as by Notice to Mariners No. 4/96 of Jan. 5, 1996, which requires open ocean exchange of ballast water (beyond the continental shelf and the effect of freshwater currents) for all ships destined for Israeli ports. Vessels not in compliance will not be allowed to discharge ballast water in Israeli ports or along the Israeli coast.[21]

Chile, 1995

Chile adopted orders in 1995 that require ships coming from abroad to renew their ballast water at least 12 miles from shore.[22]

Japan

Rule 24 of the Japanese Ports and Harbor Act prohibits discharging ballast water or sediment within 10,000 meters (6.2 miles) of a port area.[23]

Other Countries

Other limited control measures or ballast water exchange requirements have reportedly been adopted in the United Kingdom, Germany, Sweden, Brazil and Peru.[24]

United States—State Actions

California, 1990

Assembly Joint Resolution No. 88, adopted on July 12, 1990, found that California's sport and commercial fisheries "are threatened by the introduction of aquatic organisms from foreign ports brought in by means of the ballast water of freighters and tankers" and requested "the United States Coast Guard to adopt a regulation prohibiting the dumping of ballast water originating in foreign ports in any west coast river, estuary, bay or coastal area to protect native fisheries and ecosystems of the Pacific States. Any such ballast should be dumped at sea and exchanged for open ocean water prior to entry into the waters of the state."[25]

Alaska, 1992

Legislative Resolve No. 85, adopted on June 8, 1992, stated that "fishery resources and other aquatic resources of the state are threatened by the introduction of exotic aquatic organisms brought into Alaska in the ballast water of tankers and freighters arriving from foreign ports" and requested the U. S. Coast Guard to prohibit "the discharge of ballast water that originated in a foreign port into a river, estuary, bay or coastal water of Alaska."[26]

California, 1992

The Aquatic Nuisance Species Prevention and Control Act (ANSPCA) (passed as Assembly Bill 3207, Chapter 840, Statutes of 1992, on Sept. 22, 1992, codified at California Fish and Game Code §§6430-6439), found that California's sport and commercial fisheries "are threatened by the introduction of aquatic organisms from foreign ports brought in by means of the ballast water of freighters and tankers," and that "the people of the state have a primary interest in the regulation of the dumping of ballast water originating in foreign ports in any river, estuary, bay or coastal area of this state."[27] It adopted the IMO guidelines as the policy of the state, and required that after Jan. 1, 1994 all operators of vessels carrying ballast water and entering a California port would complete a ballast water control report, with failure to do so subject to fines. This reporting requirement was to be implemented by the Department of Fish and Game, but it never was.

Maryland, Pennsylvania and Virginia, 1995

These three states passed resolutions asking Congress to implement various programs and fund research to prevent the introduction of nonindigenous species via ballast water into Chesapeake Bay and other coastal regions, and that Chesapeake Bay be explicitly designated as a site for the development and demonstration of ballast water management technologies and practices.[28]

California, 1997

An amendment to the 1992 ANSPCA (passed as Senate Bill 1003, Chapter 490, Statutes of 1997, on Sept. 25, 1997), rather than directing the Department of Fish and Game to develop, distribute and collect ballast water reporting forms, instead directed the Department to obtain information from the U. S. Coast Guard, which under NISA is expected to start distributing and collecting such forms.

Hawaii, 1997

House Bill No. 1965–Relating to Harmful Aquatic Life passed on June 17, 1997. It enables the Department of Land and Natural Resources to inspect all incoming vessels, and if the inspection reveals nonnative organisms that could cause harm to Hawaii's aquatic environment, to require that the ballast water or hull of the vessel be treated.[29]

Regional Actions

Triabunna, Tasmania, 1976

As early as 1976 ships bound for the port of Triabunna on the island of Tasmania in Australia were required by the Tasmania State Government to exchange their ballast water in mid-ocean (referring at least to ships arriving from Japan).[30]

Red Sea Ports, 1994

Oil tankers calling at Red Sea ports have been required by the General Authority of Petroleum to discharge all their ballast water to onshore facilities, both oily ballast carried in cargo tanks and uncontaminated ballast carried in segregated ballast tanks.[31]

Odessa, Ukraine, 1994

Regulations require ships to exchange their ballast water on entering the Black Sea; ships failing to do so may apparently be prohibited from discharging ballast at the port of Odessa.[32]

Humboldt Bay, 1996

On Nov. 14, 1996 the Humboldt Bay Harbor, Recreation and Conservation District adopted Resolution No. 96-9 which states that vessels entering Humboldt Bay with ballast water originating from ports outside of the west coast of North America are required to conduct a mid-ocean exchange of ballast water.[33] However, the resolution contains no enforcement provisions or penalties. Accompanying documents indicate that this resolution is not an enforceable ordinance, but that an enforceable ordinance will be adopted if objectives are not met.

Vancouver, BC, 1997

The Port of Vancouver in British Columbia issued a Harbor Master Department Standing Order on Feb. 12, 1997 that requires mid-ocean ballast water exchange for all vessels destined to arrive at the Port and discharging more than 1,000 metric tons of ballast water. The order went into effect on Mar. 1, 1997, and after Jan. 1, 1998 those vessels not in compliance and having ballast water that does not meet Port test standards will be required to depart port and exchange their ballast water on the outgoing tide in the Strait of San Juan de Fuca. The order does not apply to ballast water from the west coast of North America north of Cape Mendocino.[34]

Notes for Appendix C

1 Kelly 1992 at pp. 77-78; Welch 1996.
2 IMO 1991; Federal Register 1991; Marine Board 1996 at pp. 57-59.
3 Kelly 1992 at p. 86.
4 NANPCA 1990; Federal Register 1993.
5 Chesapeake Bay Commission 1995.
6 Chesapeake Bay Commission 1995; Marine Board 1996 at p. 60.
7 Federal Register 1996.
8 NISA 1996.
9 Gauthier & Steel 1996 at p. 5.
10 Locke et al. 1991, Appendix A; Pollutech 1992, Appendix A; Gauthier & Steel 1996.
11 Section 5 of the guidelines reads: "Tank Sediment Disposal: Sediment from the ballast tanks of foreign-going ships is to be disposed of only in land dumpsites" (Locke et al. 1991, Appendix A, p. 49).
12 The guidelines were issued as a notice in 1990, modified in 1992, by the Australian Quarantine and Inspection Service (AQIS 1992).
13 Bolch & Hallegraeff 1994; Rigby & Hallegraeff 1994; Gauthier & Steel 1996.
14 Hutchings 1992; Hay et al. 1997 at p. 6.
15 Gauthier & Steel 1996; Hay et al. 1997; Hayden in press; Dodgshun, pers. comm. Guidelines as updated in July 1992 are provided in AQIS 1993b at pp. 114-121.
16 Hayden in press.
17 Hayden in press. The background document accompanying the Import Health Standard describes lesser penalties: up to $15,000 in fines ($75,000 for a corporation) and one year imprisonment for providing incorrect information on the ballast reporting forms; and up to $1,000 in fines ($15,000 for a corporation) for noncompliance.
18 Hayden in press.
19 New Zealand 1998.
20 These areas are considered high risk because of the presence of the seastar *Asterias amurensis*. The presence of the European green crab *Carcinus maenas* in these areas was not a factor in listing them (B Hayden, pers. comm.). Additional areas may be listed as information becomes available.
21 Gauthier & Steele 1996; Israel 1996.
22 Gauthier & Steel 1996.
23 Kelly 1992, 1993, citing Someya et al. 1991
24 Federal Register 1998 at p. 17783; Anonymous 1998.
25 California 1990.
26 Alaska 1992.
27 California 1992.
28 Pennsylvania 1995.
29 Hawaii 1997.
30 Williams et al. 1988. Inquiries have failed to clarify the original authority for or the current status of this requirement.
31 INTERTANKO 1994.
32 INTERTANKO 1994.

[33] Humboldt Bay HRCD 1996.
[34] Vancouver 1997.

Appendix D.

Examples of International Conventions and U. S. Laws that Might Apply to Ballast Water Introductions

International Conventions

Convention between the United States and Japan on Migratory Birds (1972)

Article VI of the Convention (24 UST 3329) states that both signatories must attempt to control the importation of organisms that are determined to be hazardous to the birds protected by the treaty, or that could disturb the ecological balance of unique island environments.[1]

Convention on the Conservation of Migratory Species of Wild Animals (Bonn, 1979)

The Bonn Convention obligates signatories to "the extent feasible and appropriate... [to] strictly controlling the introduction of, or controlling and elimianting, already introduced exotic species" that endanger or are likely to further endanger migratory species; and for migratory species in "unfavorable conservation status" that require international agreements for their conservation, theagreements should provide "strict control of the introduction of, or control of already introduced, exotic species detrimental to the migratory species."[2]

Convention on the Law of the Sea (1982)

In 1982 the United Nations adopted the Convention on the Law of the Sea (UNCLOS). Article 196 directed that "States shall take all measures necessary to prevent, reduce and control pollution of the marine environment resulting from the use of technologies under their jurisdiction or control, or the intentional or accidental introduction of species, alien or new, to any particular part of the marine environment, which may cause significant or harmful changes thereto."[3]

Convention on Biodiversity (1992)

Article 8(h) of the Convention on Biodiversity requires the Contracting Parties, as far as possible and appropriate, to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species."[4]

United States Laws, Etc.

Lacey Act (1900, amended 1981)

The Lacey Act was originally passed in 1900 and amended in 1981.[5] The Act (at 18 USC 42) and its regulations (at 50 CFR 16.11 to 16. 13) prohibit the "importation, transportation or acquisition" of certain organisms listed as injurious, authorizing the Secretary of the Interior to add any wild mammals, wild birds, reptiles, amphibians, fishes, mollusks or crustaceans, or their offspring or eggs, that are determined "to be injurious to human beings, to the interests of agriculture, horticulture, forestry or to wildlife or the wildlife resources of the United States." The aquatic species on the prohibited list are: live or dead fish in the salmon family, live walking catfish or their eggs (family Clariidae), live mitten crabs or their eggs (genus *Eriocheir*), or the zebra mussel *Dreissena polymorpha*.[6] The regulations (at 50 CFR 16.13(a)(1)) further prohibit the release of any imported fish, mollusk, crustacean or their progeny or eggs without prior written permission from the State wildlife conservation agency that has jurisdiction over the area of release. The Act also (at 16 USC 3371-3378) makes it an offense to "import, export, transport, sell, receive, acquire or purchase" or possess any animal that is "taken, possessed transported or sold" in violation of any law, treaty, or regulation of the United States, any Indian tribal law, or any State law or regulation, or any foreign law.

Marine Protection, Research and Sanctuaries Act (1972)

Regulations issued under this Act in 1977, intended to be advisory, prohibited the discharge of wastes containing living organisms at sea that would "endanger human health or that of domestic animals, fish, shellfish and wildlife by extending the range of biological pests, viruses, pathogenic organisms or other agents... [or by] introducing viable species not indigenous to an area."[7]

Clean Water Act (1972, amended 1977)

The Clean Water Act (also known as the Federal Water Pollution Control Act, 33 USC 1251 et seq.) may potentially apply to the introduction of exotic organisms in ballast water as a discharge of biological pollutants. For example, in February 1998 the San Francisco Bay Regional Water Quality Control Board compiled a list of the water bodies with impaired water quality in the region, as is required every two years by Section 303(d) of the Act. The Board listed exotic species discharged in ballast water as a priority pollutant causing impairment of the waters of San Francisco Bay. This listing initiates a process for determining, allocating and implementing the effluent limitations that will be needed to eliminate the impairment of water quality.[8]

Endangered Species Act (1973)

The Endangered Species Act (16 USC 1531-1543) provides mechanisms in Sections 7 (consultation requirements) and 10 (permit requirements) for prohibiting the introduction of organisms if it can be determined that the introduction is likely to jeopardize a listed species.[9]

Presidential Executive Order 11987 (1977)

Signed by President Carter on May 24, 1997, Executive Order 11987 directed federal agencies, to the extent authorized or permitted by law, to restrict the introduction of exotic species into natural ecosystems, and restrict the export of native species for introduction into ecosystems where they do not naturally occur. Rules or regulations needed to implement the order have never been published, although the U. S. Fish and Wildlife Service did prepare draft regulations.[10] The Administration is currently drafting a new executive order on exotic species.

Notes for Appendix D

1 Peoples et al. 1992.

2 Bederman 1991; de Klemm 1994.

3 Bederman 1991; de Klemm 1994.

4 de Klemm 1994.

5 The Lacey Act Amendments of 1981 consolidated certain provisions of the 1900 Lacey Act and the 1926 Black Bass Act, and partially repealed those acts (Bederman 1991; Bean 1991; Peoples et al. 1992).

6 50 CFR 16.13. Fish in tha salmonid family (e. g. trout and salmon) or their eggs may be imported if the shipment is certified by an appropriate official and by specified procedures to be free of certain viruses.

7 Bederman 1991.

8 San Francisco RWQCB 1998.

9 Peoples et al. 1992. Introduced aquatic organisms are reported as a cause of the decline or as an ongoing threat for at least 54 listed species, including 70% of the listed fish for which there is data (Bean 1991; ANS Task Force 1994, Appendix D).

10 Bean 1991; Bederman 1991; Peoples et al. 1992.

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