A SURVEY OF NON-INDIGENOUS AQUATIC SPECIES IN THE COASTAL AND ESTUARINE WATERS OF CALIFORNIA

Submitted to the
CALIFORNIA STATE LEGISLATURE
as Required by the Ballast Water Management Act of 1999

Prepared and submitted by the Department of Fish and Game, Office of Spill Prevention and Response

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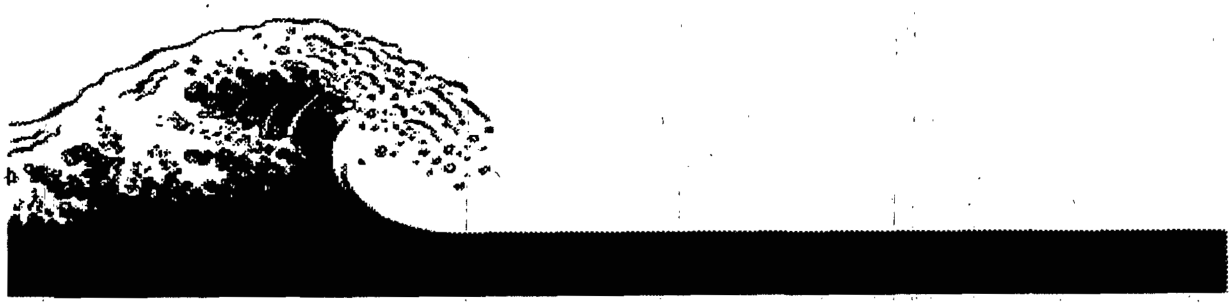
Click here for the Table of Contents



CONTENTS

TABLES

FIGURES

MAPS

DEFINITIONS:

Terms used in this report will be defined as follows:

Ballast water **is water used onboard a ship to increase the draft, change the trim, regulate the stability, or maintain stress loads within acceptable limits. Ballast water also includes the sediment that accumulates in the ballast tanks (National Research Council 1996).**

Bioinvasion **is a human-assisted introduction of an invasive species.**

Cryptogenic species **are those that are neither demonstrably native or introduced (Cohen and Carlton, 1995). These species have been identified but their native range or region is unknown.**

Distinct Taxa **are those for which sufficient information was available to identify an organism to the species level and make a determination as to whether the species was introduced, cryptogenic or nativeX. (Ode 2002)**

Epifaunal **species are those found above the sediment-water interface, usually attached to solid surfaces (substrate) like pilings, piers and rip-rap. Because of the tendency to 'foul' these surfaces, these species are often referred to as fouling organisms or part of a 'fouling community'.**

Fouling organisms **are animals and plants, such as barnacles, mussels, and seaweeds, that attach to surfaces such as piers, docks, sea-walls, and the bottoms of ships.**

Infaunal **species are those found below the sediment-water interface, that is in the soft muddy sea bottom (substrate) of the near shore environment.**

Introduced species **are those that have been transported by human activities - intentionally or unintentionally - into a region in which they did not occur in historic time and in which they are now reproducing.**

Invasive species **are those whose introduction does or is likely to cause economic or environmental harm or harm to human health.**

NativeX **is a term coined by researchers at Moss Landing Marine Labs to describe species that have been classified as native to California but are now found in an area where they had not previously been recorded. The *nativeX* designation connotes a possible range extension for these species which may or may not have been facilitated by human action.**

Non-Distinct Taxa **are those that could not be unambiguously identified to the species level. Some of these taxa are identified to the genus or a higher taxonomic level, others have been named to the species level but there is still some question regarding the accuracy of the identification. (Ode 2002).**

Non-indigenous species **are those plants and animals that are living outside their natural geographic boundaries.**

Range extension is the natural expansion of the area in which a species can live and reproduce.

Taxa or Taxon: A "taxon" (the singular form of "taxa") is a taxonomic group at any level of classification in a formal system of nomenclature. The term "taxa" is used to refer to groups for which the taxonomic level is not specified or is mixed. For example, if some specimens are identified at the species level, others at the genus level and a few at a higher level, one can refer to counts of all of these specimens as "taxa" rather than saying " 45 species, 10 genera and 1 family".

I. EXECUTIVE SUMMARY

- Purpose of Report -

In response to the potential threat posed by the introduction of non-indigenous species from the ballast of ships into the marine waters of the state, the Legislature passed the Ballast Water Management Act of 1999 (the Act). Under the Act, the California Department of Fish and Game, as the primary agency responsible for the management of fish and wildlife and their habitats, was required to conduct a study to determine the location and geographic range of non-indigenous species populations along the California coast. This information will be used as a baseline to determine both the nature and extent of the problem here in California, and to assess the effectiveness of future control measures on species introductions.

- Summary of Results -

This study revealed that all areas of the California coast have experienced some level of invasion by species not native to the state or not native to the area of the coast where they have recently been discovered. The survey found 747 organisms (or taxa) that are introduced or most likely introduced. The taxa have been categorized according to the degree of certainty with which they could be identified and their native status determined. Researchers felt confident enough in the taxonomy to characterize 360 species as 'introduced'. The remaining 387 were placed into one of three categories. There are 247 taxa considered to be 'cryptogenic', that is they are neither demonstrably native or introduced, but are likely introduced as they have not been identified previously. Fourteen species are classified as nativeX, meaning that they are most likely introduced to the habitats where they were found during this investigation but are considered native to other regions of California. It is not known whether they have spread to their new locations naturally or through some human activity. The remaining 126 taxa are what have been designated as 'non-distinct'. The taxonomists could not identify these organisms to the species level and therefore were uncertain as to whether or not they are native, however, in the researchers best judgement the species are most likely non-indigenous to California.

As expected, the species totals are greatest in the two major commercial ports, San Francisco and L.A./Long Beach. These receive the greatest ship traffic and therefore have the greatest exposure to vessel-related pathways of introduction. However, the smaller commercial ports (Humboldt Bay, the Sacramento/San Joaquin Delta, the Inland Ports, Port Hueneme and San Diego) and the many small harbors and bays along the coast have a significant number of non-indigenous species as well. Indeed all areas sampled showed some evidence of introduction. Whether the non-indigenous species are introduced directly to these smaller sites or spread from the larger ports is not fully understood and should be investigated further.
The time and resources that were available to do this survey only allowed us to compile

the data, create a species inventory and report the information as presented. Analysis of the environmental or economic risk posed by non-indigenous species, refining the taxonomy to definitively identify all the organisms that were found, and determining the pathways and origins with a greater degree of certainty will require future research. This survey, however, provides the basis for that research and is an essential first step to a more comprehensive look at the impact these animals and plants may have on the health of the aquatic environment of which they are now such an integral part.

- Summary of Recommendations -

The results of this study have pointed to the need for additional research in a number of areas. Further investigation is needed to both refine the data generated by this survey and to provide additional information on the effects of present invasions as well as methods to prevent future introductions. The following research is recommended:

On-going surveys for non-indigenous aquatic species (NAS): In order to determine the effectiveness of any ballast control measures that are implemented at the state or federal level, continued biological surveys are necessary to monitor for any additional introductions or spread of existing non-indigenous species populations. Such surveys should be conducted in the estuarine and coastal waters in such a way that all the various habitats along the entire coastline are sampled at least once every three years. The results of the survey would be used to determine what modifications may be necessary to make any existing ballast control requirements more effective, or target control efforts to 'hot spots' or problem areas.

Pathway of Introduction: For many of the species found in this study, the mechanism for introduction could not be determined definitively. Many species are thought to have arrived via multiple pathways. Further research could provide a more accurate picture of the routes of introduction making it possible to more effectively target prevention measures to the most problematic vectors.

Refine Taxonomy: Many of the species identified as part of this study have been categorized as 'cryptogenic' in large part because there is insufficient information about the species to determine their origin. This problem can only be remedied with further investigation by qualified taxonomists. More conclusive identification is essential to further our knowledge of the species present in California waters.

Research specified in the Ballast Water Management Act: In addition to the research outlined above, the Act envisioned additional studies using the data generated by this survey. These studies could help establish effective prevention and control measures in any future ballast management program, and include:

> *Alternative discharge zones:* a study to determine the areas along the coast that could safely be used by vessels that are unable to discharge ballast in mid-ocean due to safety or structural constraints.
>
> *Areas to be avoided:* the delineation of environmentally sensitive areas that vessels should avoid when taking on or discharging ballast.
>
> *Risk zones*: determining those areas where ballast uptake must be prohibited because of the risk of taking on contaminated water or water with a high level of non-native species that could then be transported to other ports in California, or from California to ports and harbors along the west coast or in foreign nations.

II. INTRODUCTION

- Background and Overview -

Non-indigenous aquatic animals and plants have had a profound impact on the ecology of the marine and freshwater regions of California. Several transport vectors have been implicated in the spread of non-indigenous aquatic species (NAS), however, a primary method for marine and estuarine introductions is thought to be from the ballast water of ocean-going ships. A modem day cargo ship can take enormous quantities of water into its ballast tanks to achieve proper buoyancy and trim. Large vessels can carry in excess of 200,000 m^3 of ballast (National Research Council). This water may later be discharged in another port, perhaps thousands of miles from its source, before the vessel takes on additional cargo. The ballast water can contain numerous species in great abundance such as, phytoplankton, zooplankton, and the eggs, larvae or adults of clams, crabs, shrimp, worms and other marine species. Within a few hours, tens of millions of living non-indigenous organisms may be de-ballasted from a single ship.

Rate of Introduction: It is estimated that more than 10,000 marine species are transported each day around the globe in the ballast water of cargo ships, (Carlton 1999). The volume of water is so enormous, and the transit time that organisms spend in the ballast water tank is so short, that the number of species successfully invading new habitats via shipping pathways is increasing at an ever higher rate, (Cohen and Carlton 1998). A study of the introduction of aquatic species in the San Francisco Bay, (Cohen and Carlton 1998), found that the average rate of invasion from 1851 to 1960 was one new species established every 55 weeks. Between 1961 to 1995 the rate of introduction increased to an estimated one new species every 14 weeks.

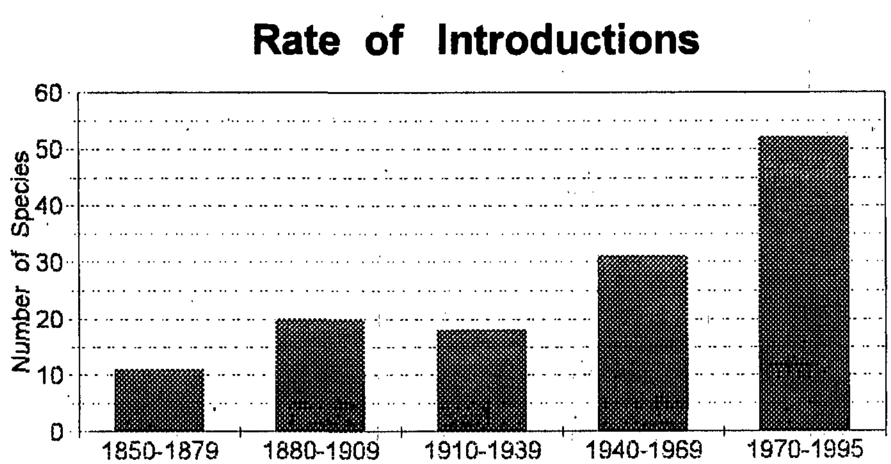


Figure 1: The rate of introductions of non-indigenous aquatic plants and animals to the San Francisco Bay region. (EPA Study, 2001)

- **Impacts of Non-Indigenous Species** -

The problem of ballast introductions has become all the more urgent as international commerce increases, resulting in a corresponding increase in the speed with which NAS are transported and introduced. The introduction of NAS has created serious ecological, operational, and engineering problems in many areas of the United States, and non-indigenous species are commonly reported in many of the harbors and bays of California.

Economic Effects: The economic impacts of introductions can be severe. The Congressional Office of Technology Assessment studied the impact of a number of species, both aquatic and terrestrial, and estimated the cost to the nation to be over $96 billion. This figure does not include impacts of many harmful non-indigenous species for which data were unavailable.

Table 1 Estimated Cumulative Losses to the United States from Selected, Harmful, Non-Indigenous Species, 1906-1991

Category	Species analyzed (number)	Cumulative loss estimates (millions of dollars, 1991)
Plants (not including agricultural weeds)	15	$ 603
Terrestrial vertebrates	43	$ 92,658
Fish	3	$ 467
Aquatic invertebrates	3	$ 1207
Plant pathogens	5	$ 867
Other	79	$ 917
TOTAL	*79*	*$ 96,944*

Report from the U.S. Congress, Office of Technology Assessment, *Harmful Non-Indigenous Species in the United States, OTA-F-565* (Washington, DC: U.S. Government Printing Office, September 1993).

Examples of Economic Impacts

- Zebra mussels are one of the most notorious examples of the economic impact that can result from the invasion of aquatic non-indigenous species. By the late 18th and early 19th centuries, zebra mussels had spread to most of the major watersheds of Europe because of widespread construction of canal systems. They first appeared in Great Britain in 1824 where they are now well established. Since then, zebra mussels have expanded their range into Denmark, Sweden, Finland, Ireland, Italy, and the rest of western Europe.

Transported from Europe in the ballast water of transoceanic ships, zebra mussels (*Dreissena sp.*) were first discovered in North America in 1988. The first account of an established population came from the Canadian waters of Lake St. Clair, a small water body connecting Lake Huron and Lake Erie. By 1990, zebra mussels had been found in all the Great Lakes. The following year, zebra mussels escaped the Great Lakes basin and found their way into the Illinois and Hudson rivers (USGS 2002). By 2000, the mussels were inhabiting the waters of at least 20 states and the Canadian provinces of Ontario and Québec. The prolific mollusk colonizes pipes, constricting flow and thereby reducing the intake in heat exchangers, condensers, fire fighting equipment, and air conditioning and cooling systems. Densities were as high as 700,000/m2 at one power plant in Michigan, and the diameters of pipes had been reduced by two-thirds at some water treatment facilities. One estimate puts the cost of scraping mussels from pipes in the Great Lakes region alone at $50 to $100 million a year (Maryland SeaGrant 2002). The mussel also attaches to boat hulls, docks, locks, breakwaters and navigation aids, increasing maintenance costs and impeding waterborne transport. (SeaGrant 2002).

- Mitten crabs were first collected in San Pablo Bay in fall 1994. By 1998, they were found in the Sacramento River as far north as Colusa, and in the San Joaquin River as far south as the San Luis National Wildlife Refuge. The most probable mechanisms of introduction to the estuary were either deliberate release to establish a fishery or accidental release via ballast water. Based on the impacts of mitten crabs in their native range and in Europe, they pose several possible threats: they are a secondary intermediate host for the Oriental lung fluke that can infect mammals including humans; burrowing that may accelerate the erosion of banks and levees; damaging rice crops by consuming the young rice shoots; and damaging commercial fishing nets and reducing the size of the catch when the crabs are caught in high numbers (it is very costly and time consuming for the fishermen to remove the crabs from the nets). (Hieb and Veldhuizen 1998)

- In agricultural production, non-indigenous plants compete with crops for soil and water resources, reduce crop quality, interfere with harvesting operations, and reduce land values. The U.S. Department of Agriculture studied the impacts of non-indigenous species on 64 crops and estimated the annual productivity loss at $7.4 billion. On rangelands, invasive plants such as cheatgrass crowd out more desirable and nutritious forage, cause soil erosion, poison some wildlife species as well as livestock and significantly modify the fire regimen and threaten native plants. In natural areas, nonnative plants, such as purple loosestrife, reduce habitat for native and endangered species, degrade riparian areas, create fire hazards, and interfere with recreational activities. (Ecological Society of America 2002)

<u>Ecological Effects:</u> Non-indigenous species may out-compete or alter local habitats to such an extent that they make it impossible for native species to survive. Introduced species are often predators, competitors or parasites and many introduced species can cause or carry disease. Regardless of the direct or indirect nature of the effect, NAS can significantly impact human health, devastate fishery and aquaculture resources, and severely disrupt habitat and ecosystem stability.

Examples of Ecological Impacts

- Algae that have caused toxic algal blooms or 'red tides' are among the better known and documented instances of successful invaders causing great harm at a considerable cost. About one fourth of bloom-causing species produce toxins that may harm or kill zooplankton, shellfish, fish, birds, marine mammals, and even humans that feed either directly or indirectly on the algae. Even those bloom-causing species that do not produce toxins can still have a devastating impact on the surrounding ecosystem by decreasing light penetration or by depleting oxygen concentrations. Many of the algae causing harmful red tides are thought to have been transported into new areas in the ballast water of coastal and transoceanic vessels (ORTEP 2002).

- *Caulerpa taxifolia*, a non-indigenous seaweed, was first discovered in June 2000 in a coastal lagoon in Carlsbad, California, within San Diego County. It is a green alga native to tropical waters where it typically grows to small size and in limited patches. In the late 1970s this species attracted attention as a fast-growing and decorative aquarium plant that became popular in the saltwater aquarium trade. In the early 1980's it apparently escaped or was released from an aquarium in Germany into Mediterranean waters, and by 1989 had spread from an initial patch of about one square yard to over two acres. By 1997 it blanketed more than 11,000 acres of the northern Mediterranean coastline and has recently been reported off northern Africa. The first confirmed occurrence of this invasive species here in California has caused considerable alarm. If it becomes established, it can cause ecological and economic devastation by overgrowing and eliminating native seaweeds, sea grasses, reefs, and other communities. In the Mediterranean, it is reported to have harmed tourism and pleasure boating, devastated recreational diving, and had a costly impact on commercial fishing both by altering the distribution of fish as well as creating a considerable impediment to net fisheries. In Southern California, this alga poses a substantial threat to marine ecosystems, particularly to the extensive eelgrass beds and other benthic environments that make our coastal waters such a rich and productive environment for fish and birds. (Woodfield 2002).

- The European green crab (*Carcinus maenas*) has been introduced to the east and west coasts of the US, as well as to the waters of Australia, Brazil, Panama and South Africa (Grosholz and Ruiz 1996). Introductions to the US are likely the result of ballast water or from crabs clinging to heavily fouled ship hulls. They were first detected on the West Coast in San Francisco Bay in the late 1980's, and found in Humboldt Bay in 1995. During trapping studies in Humboldt Bay in 1996-97 a few (9) crabs were caught. By 1998 large numbers were found in the intertidal areas of the Bay where their habitat and feeding preferences overlap many of the indigenous species, primarily those of the Dungeness crab. Documented destruction of shellfish resources on the Eastern Atlantic Coast by green crabs caused concern among Humboldt resource managers and fishermen. Green crabs may impact juvenile Dungeness crabs that settle by the thousands in Humboldt Bay and may also prey upon juvenile cultured oysters, clams and mussels. (Green Crab Study 2001)

- NAS impact on biodiversity can also be enormous. Fully half of all threatened or endangered species are imperiled by introduced species, making non-indigenous species second only to habitat loss as the greatest threat to endangered species. (Wilcove, et al. 1998) In the San Francisco estuary, the environmental damage attributable to introduced species includes: reduction or local extinction of native species (some Bay waters now contain virtually no native species); disruption of the *aquatic food chain through elimination of phytoplankton by highly efficient introduced* filter feeders; erosion of shorelines by introduced burrowers; and other ecosystem alterations which extend to bird and wildlife populations. (Cohen and Carlton 1995).

Table 2 Contribution of Non-Indigenous Species (NIS) to Threatened and Endangered Status of Species Listed by the U.S. Fish and Wildlife Service [a] (M. Bean 1991)

		Category of impact on threatened and endangered species		
	Total threatened and endangered species (number)	Species where NIS contributed to listing (number, percent)	Species where NIS are a major cause of listing (number, percent)	Species where NIS are *the* major cause of listing (number, percent)
Plants...........	250	39 (16%)	--	14 (6%)
Terrestrial vertebrates...	182	47 (26%)	3 (2%)	19 (10%)
Insects [b]........	25	7 (28%)	--	2 (8%)
Fish..............	86	44 (51%)	8 (9%)	5 (6%)
Invertebrates [c]	70	23 (33%)	1 (1%)	1 (1%)
Total.............	613	160	12	41

[a] Includes species listed through June 1991. [b] Includes arachnids. [c] Includes mollusks and crustaceans

It should be noted that species extinctions do not have to occur for biological communities to be radically and permanently altered. Nor are extinctions necessary for California to experience a significant decline in the abundance, diversity, and aesthetic value of its biological resources as populations of indigenous species shrink and numbers of NAS increase.

STATUTORY FRAMEWORK

In California, as the impact and source of non-indigenous aquatic species became better understood, a program was developed to address the introductions from the ballast of ocean-going ships. This program was an outgrowth of the initial efforts at the federal level to combat the problem in the Great Lakes and elsewhere. Following is a discussion of the federal effort and the subsequent California initiative.

- Federal Ballast Water Management Initiatives -

In 1996, Congress re-authorized the Nonindigenous Aquatic Nuisance Species Prevention and Control Act of 1990 (NANPCA), re-titled as the National Invasive Species Act of 1996 (NISA). The new law established a national ballast management program that included provisions for mandatory ballast water control procedures for vessels traveling in the Great Lakes, but voluntary procedures for vessels entering other ports in the U.S. The law required that the Secretary of Transportation report to Congress by the end of 2001 regarding the level of compliance with the voluntary ballast management guidelines. If the rate of compliance was not adequate, NISA provided the U.S. Coast Guard the authority to make the voluntary guidelines mandatory.

In May 2002, the USCG issued a report to Congress as required under NISA. The report assessed the effectiveness and rate of compliance with the ballast water management requirements since the passage of the law in 1996. The report found that only about 40% of vessels complied with mandatory ballast reporting requirements, and of those only about half (51.2%) conducted a mid-ocean exchange of ballast water. Based on these results, the USCG determined, in part, that

> ". . . the next regulatory actions with regard to BWM (Ballast Water Management) are to make the voluntary guidelines mandatory and provide for their enforcement. Balancing the ecological, social, safety and economic concerns of the affected parties, the Coast Guard will implement a robust national BWM program that maximizes the use of existing BWM techniques by all vessels, while fostering the development of new BWT (Ballast Water Treatment) technologies". (USCG Report to Congress on the Voluntary National Guidelines for Ballast Water Management 2001)

Based on the findings in their report, the Coast Guard is preparing to transition to a mandatory program. They estimate that regulations to establish penalties for reporting violations will be implemented in the autumn of 2003; that mandatory ballast water management will be instituted in the summer of 2004; and that a standard to serve as a benchmark for ballast water management options will be promulgated in the autumn of 2004, (tentative dates as presented at the Congressional hearing, May 2002).

In addition to the Coast Guard actions, re-authorization of NISA is being considered. A draft of the new statute has been developed under the title, National Aquatic Invasive Species Act (NAISA) of 2002. This statute, if passed, would, among other provisions, require all ships (transoceanic and coastal) to: (a) prepare Ship Invasive Species Management Plans outlining procedures to prevent introductions of invasive organisms; (b) report all ballast operations, treatment and management practices; (c) carry out Best Management Practices to reduce the movement of species by ships; (d) install approved ballast treatment technologies if the ship enters service after January 1, 2002; and (e) meet final whole ship requirements by 2011 unless the ships ply exclusively in homogeneous coastal areas, (NAISA summary courtesy of Northeast-Midwest Institute, as of August 7, 2002).

- California Ballast Water Management Act -

In California, concern was raised over the adequacy of the federal program. The voluntary nature of the current federal provisions, and the lack of funding for research on more effective methods to prevent species introductions, convinced the California legislature to enact a program to better protect the marine resources of the state.

The Ballast Water Management Act (Act) was passed in 1999, and established a multi-agency program to address the issue of species introductions by making ballast water management mandatory for all vessels entering California marine waters with ballast from foreign ports. The Act also provided funding for a study to evaluate alternative technologies and treatment options for effectively controlling NAS introductions, and required a biological assessment of the current baseline of introduced species in the coastal waters of the state. This is an interim program designed to control ballast introductions and determine the current level of species invasions while researching alternatives to the present control strategies. The Act sunsets in January 2004. Studies required under the Act are due to the Legislature in December 2002 and are to be used to craft a new, long-term program which would be adopted before the current law expires.

There are three agencies responsible for implementing the various provisions of the Act: the Department of Fish and Game, the State Water Resources Control Board, and the State Lands Commission.

Agency Responsibilities under the Act:

The California State Lands Commission (CSLC) was required to monitor and evaluate compliance with the ballast exchange requirements. Ballast water exchange is the most widely accepted method of ballast management, and indeed the only method that can be characterized as currently in common practice. Exchange is required of all vessels entering California marine waters from outside the Exclusive Economic Zone and must be completed in 'mid-ocean', that is, at a distance greater than 200 nautical miles from shore, and in water greater than 2000 meters deep.

The State Water Resources Control Board (SWRCB) was tasked with studying the available alternatives to mid-ocean exchange. Such technologies include; filtration of ballast water, centrifugal separation of larger organisms, ultraviolet irradiation of the water as it's taken on-board, various biocide treatments, chemical disinfectants such as chlorination, and the infusion of ozone or nitrogen. Finding an alternative is considered important because mid-ocean exchange is not as effective as many had hoped. Given weather and sea conditions, it is not always safe for a vessel to conduct such an exchange in deep seas, and even when the exchange is carried out, there is considerable water and sediment that remain in the tanks. This water and sediment can contain literally thousands of organisms that may still be discharged into the receiving port (Carlton 1999).

The Department of Fish and Game (Department) was given the responsibility of determining the current location and extent of non-indigenous aquatic species populations in the estuarine and coastal waters of the state. To gather this information, a biological survey was conducted to sample the many habitats where species introduced from the ballast of ships would most likely occur. This information will be used as a baseline to determine both the nature and extent of the problem here in California, and to assess the effectiveness of future control measures on species introductions. In addition, the Act anticipated that the data generated by this survey would be used in future studies, such as: the determination of alternative discharge zones; the delineation of environmentally sensitive areas to be avoided for uptake or discharge of ballast; and an assessment of potential risk zones where uptake must be prohibited.

The Department's Office of Spill Prevention and Response (OSPR) was tasked with completing the biological survey, and approached the study with the understanding that the statutory time lines would limit the scope of the research and provide results that only reflect a brief snapshot in time. Given the vast geographic expanse of the state coastline and the rich abundance and diversity of species and habitats, a comprehensive study of the aquatic biota would likely take many years to complete. The time-frames imposed by the statute resulted in a more restricted effort than would be optimal. However, within that limitation, the OSPR was able to augment existing data and complementary studies with a sampling program that targeted areas most likely to be impacted by ballast introductions.

III. STUDY PLAN: Habitats sampled, types of species collected, survey methodologies.

The OSPR study plan focused on those areas of the coast that had not been surveyed specifically for NAS in past investigations and then, within those areas, concentrated on the regions most likely to be impacted by ballast introductions. The sampling data from these sites were supplemented by information generated from an extensive literature review, as well as data from comparable studies being conducted independently during the same period by other organizations.

The study initially targeted the seven major ports along the California coast. These are the sites where large vessels enter state waters and were chosen as the most likely locations where ballast-related introductions would have occurred. The seven port areas are: San Diego, Los Angeles/Long Beach, Port Huememe, Stockton, Sacramento, San Francisco Bay, and Humboldt Bay. Sampling and identification of NAS was done in all these port areas except San Francisco Bay which had already been extensively studied in recent years, most notably by Cohen and Carlton in 1995. The information for San Francisco was compiled from these previous studies. Most of the sampling in the remaining six port areas was conducted in 2000.

Subsequent to the survey in the major ports, additional sampling was undertaken in many of the smaller ports and bays along the coast during the summer of 2001. This portion of the survey was done to establish a more complete inventory of non-indigenous organisms and to ascertain the level of invasion in these areas. The information gathered about the introduced species at these sites may be used for future studies to help determine which NAS, found in the larger ports, have migrated or been transported to the bays and estuaries not directly impacted by introductions from large ocean-going vessels.

A comprehensive species list was compiled from the literature review and the results of OSPR's sampling program. This list is included in this report in Appendix D, and will be put on the Department of Fish and Game's (CDFG) website (http://www.dfg.ca.gov on the 'Spill Prevention and Response' link). It is hoped that other researchers and future CDFG studies will continue to add to and refine the list as more is learned about NAS along our coast.

Study Limitations:
Though every effort was made to conduct a comprehensive examination of California's marine and estuarine environment, the time constraints established by the Act resulted in some limitations in the study design. When the sampling program was initially developed for the fouling and infaunal habitats in the major ports, it was determined that there would only be sufficient time to collect one set of samples from these biological communities. The samples were, however, collected during the mid to late summer in order to avoid the presence of large numbers of juvenile specimens which occur in the spring months and are often difficult to identify. Settling plates (standardized PVC panels used to collect 'fouling' organisms that cling to hard materials like docks and jetties) used in Humboldt Bay revealed that there are many fouling community species that establish themselves in the spring and disappear by mid to late summer; thus it is possible that due to our sampling design we may have missed some NAS species that occur in the fouling community only during the spring.

With the time and resources available, the design for sampling in the minor ports, bays and marinas along the coast could only focus on one community. The fouling community was chosen because it is likely to be a habitat greatly affected by ballast introductions. As such, the sampling effort may have under-represented the full NAS impact in these areas.

Two habitats, the crevices within the rocks and rip-rap of break-waters and the hard bottom benthic substrate were not sampled successfully. Attempts were made to trap the fish species that often live in rocky crevices, but no specimens were caught. The crevice habitat should be examined in further in any future NAS studies.

The hard bottom substrate was sampled in the Los Angeles/Long Beach Harbors but there was not sufficient time to sample this habitat in other areas of the state. As this habitat typically supports a diverse community, efforts should be made to collect samples from these areas in any future research.

Sampling of the plankton community was focused on zooplankton (animal fraction) during this investigation. As the phytoplankton (plant) community is easily transported by ballast water, there is a potential for introduced phytoplankton species occurring in our bays and estuaries. Phytoplankton species are the cause of some of the detrimental blooms along the east coast of the United States which have resulted in major fish kills. This community should be studied in future investigations.

Terminology:

The terminology associated with non-indigenous species varies wildly. Introduced species are known as exotic, invasive, alien, non-native, and non-indigenous. These terms are often treated synonymously, though at times each can have a very different meaning. The term "invasive species" refers to a broadly defined group of introduced species that could cause a generally negative impact on the environment if they become resident. The federal Executive Order 13112 (1998) defines "invasive species" as "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health". The term 'invasive' has come to be used commonly by federal and state governments as well as various commissions, panels and councils. Any use of the term in this report will follow the federal definition for invasive, though generally that term is avoided because it is so subjective. Instead, the term 'introduced' is more commonly applied.

Species Identification and Voucher Collection:

Determining whether a species is native or introduced can be a controversial assessment. To the extent possible, the identification of the species listed in this report and their status as nativeX, introduced or cryptogenic has been verified and agreed to by the taxonomic specialists hired to do the identification work. However, even specialists disagree, and additional studies and better information may change these identifications in the future. Understanding that, voucher specimens have been kept of all samples taken for this study and can be made available for future research and to individuals and organizations interested in refining any data presented herein. Location of the voucher samples is specified in each of the reports appended to this document.

- **Study Partners and Contractors** -

OSPR contracted with three scientific research groups to assist with the sample collection and literature review. With some overlap, these three groups were responsible for collection and identification of species in various habitats and different port areas. All began their research with a comprehensive literature review. The review was used to develop a list of non-indigenous organisms in the marine and estuarine waters of their respective study areas. The literature review was based on extant information (both published and unpublished), including scientific papers, graduate theses, government reports, regional monographic studies, keys, floras, field guides and check lists, as well as museum and personal collections and records. Information from the literature was used to inform the field surveys and, in turn, the field work was used to both verify the information developed through the literature review and determine the current status of reported populations of introduced species.

The sampling design and habitats surveyed by each research team is described briefly below, and in greater detail in the reports appended to this document.

Moss Landing Marine Lab (MLML): The majority of the sampling effort undertaken for this survey was done by MLML. The principle investigator for this work was Mr. Russell Fairey. The MLML study was wide ranging both geographically and in terms of the various habitats that were sampled. The survey collected samples from 21 harbors (at over 450 stations): epifaunal samples were taken in all locations, infaunal communities were sampled in four harbors, plankton were identified from samples taken in Humboldt Bay, Port Hueneme, LA/LB Harbor and San Diego Bay, and fish surveys were conducted in Sacramento, Stockton and Port Hueneme. This sampling program was designed to supplement existing information and data being collected by other researchers.

The field work began with numerous reconnaissance surveys to identify and prioritize sampling sites. The research team focused on the areas within the harbors and bays that had a high potential for ballast water release, on calm backwaters where species would collect and flourish, on recently established docks which could provide a comparison to growth on older docks, and on habitats at the harbor entrances.

When sampling began, priority was given to active and inactive shipping berths, fishing vessel docks, recreational marinas, aquaculture facilities and newly constructed structures. Sample sites were spread throughout each port, harbor or bay to give spatial representation and to accommodate differences in tidal flushing and mixing. And, because habitat differences can influence larval recruitment and subsequent colonization, the sampling strategy also encompassed multiple depths, substrates and light exposure conditions.

A more detailed discussion of the study design and sampling results for the portion of the survey conducted by Moss Landing Marine Lab can be found in Appendix A.

Humboldt State University Foundation (HSUF): The principle investigator for the study in Humboldt Bay was Dr. Milton J. Boyd, with assistance from Drs. Tim J. Mulligan and Frank J. Shaughnessy. The focus of the work in Humboldt was the fish, benthic and fouling communities, with additional sampling of the planktonic community completed by staff from the OSPR.

Beginning in July 2000, HSUF researchers collected benthic samples at 87 stations, epifaunal samples at 21 intertidal and 5 marina locations, and visited over 300 locations throughout the Bay as part of the fish survey. All samples collected in the field were brought back to the laboratory for sorting and identification. The specimens were examined by a number of taxonomic specialists with expertise in the marine invertebrate species of Humboldt Bay, as well as the benthic species of the Bay and adjacent outer coast.

Sampling for algae occurred at 58 sites. The sites selected for sampling had a hard substrata where green, red and brown algae might grow. In addition, several soft-bottom sites were selected as potential locations where the flowering plant Zostera japonica (a suspected invader in the Bay) could flourish.

A more detailed discussion of the study design and sampling results for the Humboldt Bay portion of the survey can be found in Appendix B.

In addition to the work done by HSUF, a plankton survey was also conducted in Humboldt Bay. This portion of the study was conducted by OSPR staff. Plankton samples were collected on a quarterly basis over the course of one year beginning in the Spring of 2001. These samples were sent to Moss Landing Marine Lab (MLML) for identification and have been included in the MLML report in Appendix A.

San Francisco Estuary Institute (SFEI): Dr. Andrew Cohen was the principle investigator for the Rapid Assessment Survey conducted by SFEI at a number of sites in Southern California. This study was funded jointly by OSPR and the State Water Resources Control Board with some additional funding from the National Fish and Wildlife Foundation. The survey focused primarily on the fouling community in selected sheltered waters from San Diego to Oxnard, with sampling sites chosen to represent conditions in the three major port areas of the region, San Diego, Los Angeles/Long Beach and Port Hueneme.

A team of taxonomic experts was assembled to conduct the sampling and identification of organisms at twenty-two primary and three secondary sites in the study area. Samples were collected primarily from the fouling community on docks and pilings, with some additional samples from the adjacent soft benthos, nearby intertidal and selected subtidal habitats. Specimens were identified in the field followed by examination in the laboratory by the expedition team as well as taxonomic specialists at the Los Angeles County Museum of Natural History (Polychaete Collection) and the San Diego Ocean Monitoring Laboratory.

Representative voucher specimens are being held at the LA County Museum of Natural History. A more detailed discussion of the study design and sampling results for the portion of the survey conducted by SFEI can be found in Appendix C.

Other Organizations: *To the extent possible, this study took advantage of other surveys* recently completed or being conducted concurrently in order to maximize the resources available to collect data and complete the picture of NAS invasions along the California coast. Data from the studies below have been, or will be, incorporated into the database developed from the direct sampling and literature review undertaken by the research organizations named above.

LA/LB Baseline Study: In the last thirty years, the Ports of Long Beach and Los Angeles (LA/LB) have undertaken long range development efforts in their respective harbors. Several separate biological studies were conducted during the 1980s and 1990s in support of these anticipated harbor modifications. In 2000, a joint environmental study was conducted in both harbors which was intended to provide an update of the quantitative information on physical/chemical and biological conditions within the different marine habitats of the entire port complex. The specific objectives of the study included, among other things, establishing a baseline for the benthic invertebrate community and the larval, juvenile, and adult fish populations, as well as to update the description of the fouling communities attached to rocky rip-rap habitats. As part of the sample collection and identification, the study also identified the introduced species found among the native populations.

The list of the introduced species identified in the LA/LB Study (MEC 2002) have been included as part of this report and incorporated into the list in Appendices D and E. This information will also be included in the exotic species database which will be placed on the CDFG website.

SERC Settling Plate Study: Under NISA, the Smithsonian Environmental Research Center (SERC) was required to develop a clearinghouse for the analysis and synthesis of data related to ballast water management and species introductions from ballast discharges. They were also tasked with conducting studies to determine the patterns and rates of marine and estuarine invasions. One of these, the *Study of Temporal Variability and Non-indigenous Species in the Fouling Community of San Francisco Bay* was begun at about the time the CDFG survey was initiated. The SERC study focused on San Francisco, but also did some limited work in San Diego Bay. The study was designed to examine seasonal patterns and year-to-year variation in the community makeup of fouling organisms. SERC used 'settling plates', standardized PVC (polyvinyl chloride) panels, which were deployed for varying lengths of time throughout the study area and then retrieved. The plates are brought back to the lab where the biomass that has accumulated on the plate surfaces is estimated, patterns of coverage are measured, and each taxon present is identified. Plates remain in the water for one month or longer, with intervals ranging up to one year.

To augment the information that SERC would collect from the two targeted bays in California, the CDFG did a comparable fouling plate study in Humboldt Bay. The data from the Humboldt portion of the study is included in this report as part of the MLML survey, and was incorporated into the database developed for this report. The data from the SERC study was not available at the time of this writing, but will be added to the CDFG database when identification and analysis are complete.

SCCWRP Infaunal Data: The Southern California Coastal Water Research Project Authority (SCCWRP) is a joint powers agency with representatives from city, county, state, and federal government entities. The agency focus is on marine environmental research. They have done various studies to determine, generally, the effects of wastewater and other discharges on the Southern California coastal marine environment Most recently, they embarked on a project to assess the nature and relative magnitude of seasonal and climatic variation in benthic invertebrate populations as part of the Southern California Bight 1998 Regional Marine Monitoring Survey (Bight '98). Infaunal samples taken for this monitoring effort were analyzed, and a list of species developed which MLML then used to identify the NAS found in the sampling area.

Database: In addition to the data sources above, the database for this report also includes information obtained from the U.S. Environmental Protection Agency's Western Environmental Monitoring and Assessment Program (WEMAP), and the Bay Protection and Toxic Cleanup Program (BPTCP).

WEMAP was a regional program designed to collect coastal and estuarine samples from the states of California, Oregon, and Washington. In California, infaunal samples were collected along the length of the state and at various depths between July 1999 and October 1999.

The BPTCP was a statewide program that sampled over 300 marine and estuarine sites along the California coastline, beginning in July 1992 and ending in December of that year. A targeted design focusing on anthropogenic activities and hot spots was used in selecting stations.

Introduced, cryptogenic and nativeX species were identified from the data sets of each these studies by MLML, and have been added to the general database developed for this report.

Table 3 Principle Source of Data for Each of the Major Harbors

An asterisks (*) denotes research funded as part of this survey.

	Infaunal	Epifaunal	Fish	Plankton
San Diego Harbor	SCCWRP; Bay Protection Study;	*SFEI Rapid Assessment Survey; SERC	SCCWRP	*MLML Introduced Species Survey
LA / LB Harbors	LA/LB Baseline Study;	*Back harbor areas - MLML; All other areas - LA/LB Baseline Study with some additional sampling by *SFEI;	LA/LB Baseline Study	*MLML Introduced Species Survey
San Francisco Bay	*Literature Survey	SERC; *Literature Survey	*Literature Survey	CDFG Bay/Delta program; *Literature Survey
Port of Stockton	*MLML Introduced Species Survey	*MLML Introduced Species Survey	*MLML Introduced Species Survey	
Port of Sacramento	*MLML Introduced Species Survey	*MLML Introduced Species Survey	*MLML Introduced Species Survey	
Port Hueneme	*MLML Introduced Species Survey;	*MLML Introduced Species Survey; *SFEI Rapid Assessment Survey	*MLML Introduced Species Survey	*MLML Introduced Species Survey
Humboldt Bay	*Humboldt State University NIS Study	*MLML settling plate sampling, *Humboldt State University NIS Study	*Humboldt State University NIS Study	*CDFG and MLML

Abbreviations used in Table 3:

SCCWRP - Southern California Coastal Water Resource Program
SERC = Smithsonian Environmental Research Center
SFEI - San Francisco Estuary Institute
MLML - Moss Landing Marine Lab
LA / LB: Los Angeles / Long Beach
HSUF - Humboldt State University Foundation
CDFG: California Department of Fish and Game

IV. RESULTS and DISCUSSION

The data summarized in this report represent the findings of both the biological survey and the information acquired from a comprehensive literature review. For many reasons, taxonomic determinations were not always reported at the same level in all data sources (individual specimens may have been immature in some locations, species-level taxonomic keys may not have always been available, recent advances in taxonomic resources may have improved discrimination, etc.). As a result, species identifications were often inconsistently applied or left at a higher taxonomic level. For example, some species were only identified to the genus level. If the species from a particular genus are all non-indigenous to California, it could be assumed that any species from that genus found in California was most likely introduced. However, many genera identified in the study have at least one species that *is* indigenous to California. Thus, it is often unclear whether an organism identified as "Genus sp." represents a unique (or distinct) species and/or whether that species is native or introduced.

We have attempted to account for this in our summary tables by using the qualifier, "Distinct Taxon", to indicate taxa that unambiguously represent species level determinations. This results in a somewhat conservative listing of introduced and cryptogenic species, but avoids the problems associated with counting a genus as a distinct taxon when it may not be. All taxa are coded in the database as either "Distinct" or "Non-Distinct". Unless otherwise noted, we have reported only 'distinct' taxa in the summary tables and graphs that follow. However, both distinct and non-distinct species are listed in the data tables found in Appendices D and E.

- SUMMARY TABLES AND GRAPHS -

The results of this study are presented first at a state-wide level and then broken down to show some detail for the major harbor areas and the minor ports and bays. Various assumptions were made when putting species into general categories, and those assumptions are explained below. For a detailed list of all the species, the locations where found, the reported native range and other specific information used to generate the summary tables, please refer to Appendices D and E.

State-Wide Totals

The focus for this survey was to develop an inventory of non-indigenous species and get a general idea of where the species are located. It was not possible with the time and resources available to determine the relative abundance of these species or the proportion of native to non-native taxa. Such information would be useful in determining the extent of the impact that introduced organisms are having on the native biota and coastal ecosystems, and would give us a better basis for determining the relative risk that certain species may pose should they spread to other areas of the state.

MLML was able to provide information regarding relative abundance for some of the sites that they sampled (see Appendix A). Future research to develop a similar assessment of all the coastal areas discussed in this report would be an invaluable addition to the baseline knowledge of NAS in our waters.

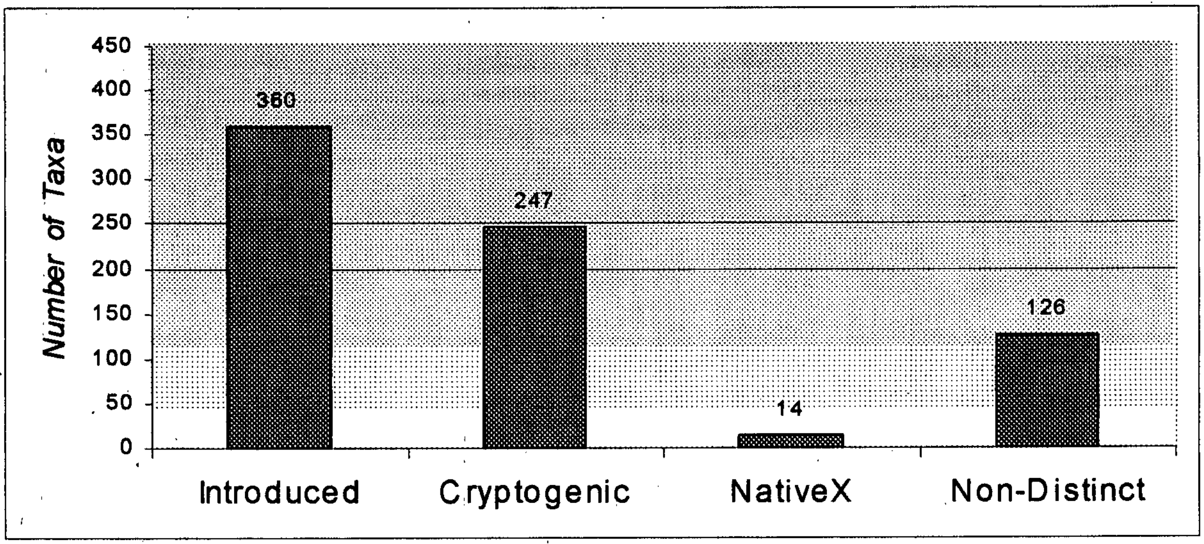
The state wide totals summarized on the following pages show the number of individual taxa recorded during the sampling effort or identified in the literature. Every effort was made to sample or record information for a broad range of habitats in the many areas studied. It was not possible, however, to sample in all possible subtidal and intertidal habitats or include all communities in the study design. As a result, the numbers presented here may, to a certain extent, underestimate the true populations of non-indigenous organisms.

Species Composition: A total of 621 distinct taxa were identified from the literature and field investigations during the course of this investigation. Annelids (aquatic worms), primarily polychaete worms were the dominant taxon comprising 32.9 % of the species identified. A total of 51 introduced and 149 cryptogenic annelids were identified by this investigation.

Arthropods (crabs, shrimp, etc) were the second most abundant taxon identified, comprising 21.7% of the species. A total of 92 introduced and 40 cryptogenic arthropods were identified for the marine and estuarine waters of the state. Amphipods were the most common group of arthropods identified during this study. Other common taxa identified included molluscs (clams, snails, etc.) (10.3%), fish (9.7%) , and cnidarians (5.1%). Unlike the remaining taxonomic groups, a vast majority of the fish species were identified from fresh water habitats including the Sacramento-San Joaquin Delta and the location of two primary study sites, the Ports of Sacramento and Stockton.

New Species: A number of species were identified that had not been found in previous studies including: in Humboldt Bay; *Boccardiella hamata, Euchone limnicola, Fabricia sabella, Incisocalliope nipponennis, and Zostera japonica (* which was found subsequent to the sampling effort for this study*).* In northern California: *Alderia modesta.* In Port Hueneme: *Phtisica marina.* In LA/Long Beach Harbor: *Munnogonium wilsoni..* In Avalon Harbor: *Pleurocope floridensis.* In San Diego County: *Caulerpa taxifolia.* Along the California coast: *Eulimnadia texana.*

Figure 2 Total Number of Taxa



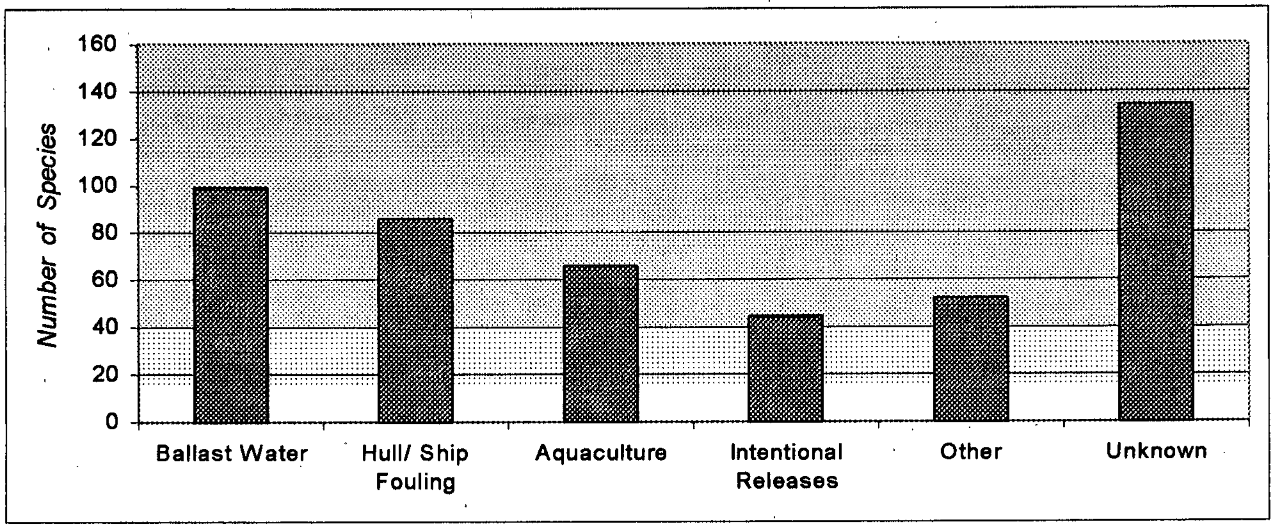
As Figure 2 shows, 747 taxa were found and categorized during this survey. Of that number researchers felt confident enough in the taxonomy to characterize 360 species as introduced, but put the remaining 387 into one of three categories that denote varying levels of certainty regarding the identification and natural history of the specimens collected. Of the 387, there are 247 taxa considered to be cryptogenic. These are specimens that were identified to the species level but not enough is known about them to unambiguously determine if they are introduced or native. They are included here because, in the researchers best judgement, they are *most likely* introduced. Likewise, the 14 species classified as nativeX are most likely introduced to the habitats where they were found in this survey but are considered native to other regions of California. It is not known whether they have spread to their new locations naturally or by way of some human activity.

The remaining 126 taxa are categorized in the 'non-distinct' category. These taxa could not be identified to the species level with any degree of certainty. The taxonomists that worked on the identification were able to determine enough about the species to categorize them as being, most likely, new to California but not enough to definitively name them or unambiguously determine their introduction status.

As this graph demonstrates, there are a significant number of species in our coastal waters that are clearly introduced to the habitats where they were found. There are also, however, a large number of species that, though likely non-indigenous, must be analyzed further before we can say definitively whether they are part of the native biota or are newly introduced taxa.

For a detailed list of all the species included in this summary and their status of introduction, see Appendix D.

Figure 3 Potential Pathways of Introduction



* **Intentional releases** are those conducted by a government agency to enhance a local fishery or for bio-control actions.
* The '**Other**' category includes a number of potential methods of introduction including: aquarium releases, fish market dumping, escape from cultivation, accidental introduction with ornamental plants or game fish, and solid ballast.

Figure 3 displays the number of the species (categorized in Figure 2 as 'introduced') that were reported for each of the most common potential pathways of introduction. This graph does not include those taxa that were considered to be possibly introduced (e.g., cryptogenic or nativeX), nor the ones from the non-distinct category. In many cases, the literature indicated a potential pathway for species in these latter categories. However, it was considered too speculative to discuss the pathway of introduction for species without being certain as to whether or not they are truly introduced.

It should be noted that a number of species have been counted more than once for this summary because the literature indicated that they could have been introduced by more than one method or pathway. In those cases the species have been counted in all the pathway categories that could potentially apply. Since species can and probably have been introduced more than once, and by more than one mechanism, presenting the information in this manner indicates which of the pathways pose the greatest potential for introducing organisms into the marine and estuarine waters of the state.

The pathway data also has a significant number classified as 'unknown' (~28%). It is often difficult, and in many cases may be impossible, to determine the mechanism of transport with a high degree of certainty. However, further study could reduce the 'unknown' element of this question and provide us with a clearer picture of how species are moved from one bay or harbor to the next. Based on what is known, though, shipping traffic plays a significant role in dispersal through a combination of ballast discharges and hull fouling. Aquaculture is also an important vector, and intentional introductions, primarily of fish, add significantly to the overall total. For a detailed listing of all the species and the potential pathways of introduction, see Appendix D.

Figure 4 Regions of Origin of Introduced Species

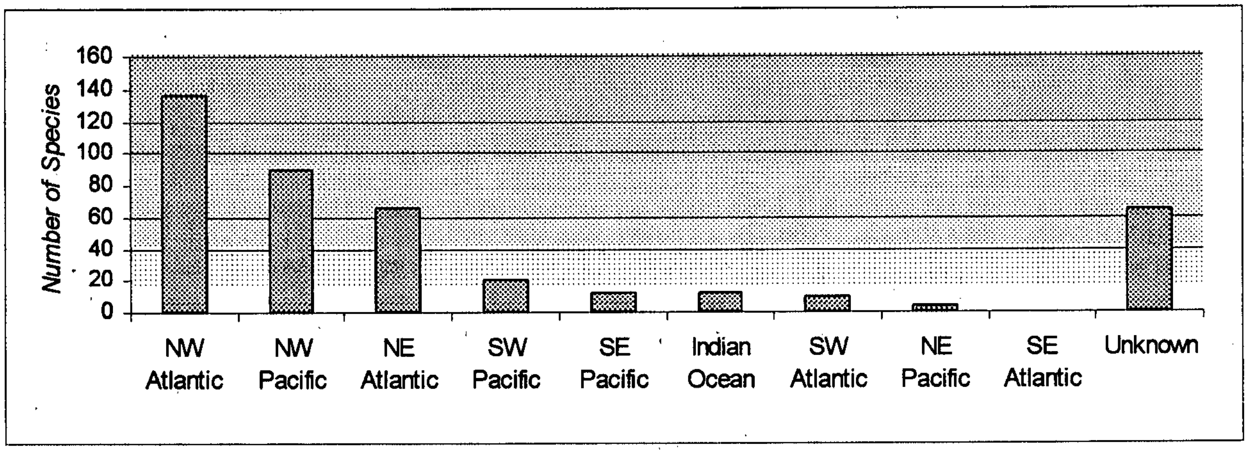


Figure 4 summarizes the number of introduced species that originate from various regions of the world organized by major oceanic quadrants. It's important to note that the data regarding the nation or region of origin for many species was quite speculative or very general in nature. Some data sources listed very generic possible origins, such as 'Atlantic' or 'Asia' or, more difficult still, listed a number of potential native ranges that spanned most of the globe. Trying to summarize these data and pinpoint a probable native range posed numerous problems. Rather than placing a species in one of several categories or distributing it proportionally among all the potential regions, such species are included in each of the regions of possible origin identified in the literature. This approach has limitations of its own but provides a general sense of the potential regions from which the non-indigenous species do or at least can originate. This is an area that warrants considerable additional study before it can be determined with authority which region contributes the greatest number of species to the coastal waters of California.

Based on the information as reported, the majority of the species introduced to California appear to have come from the northwest Atlantic, the northwest Pacific and the northeast Atlantic. These are also the regions of the world from which California receives a considerable amount of ship traffic as well as the source materials for much of our aquaculture.

For more specific information regarding the individual nation or areas of the world where each species is thought to be native, see Appendix D.

Harbor-specific Results

Following is a discussion regarding the numbers of species and pathways of introduction for the major harbor areas and the minor ports, bays and estuaries along the coast. The native range or region of origin for the species introduced to these areas is not presented because the pattern was generally the same as that for the state-wide summary above.

Major Harbor Areas

The seven major ports along the California coast that receive most of the commercial shipping traffic are the sites where large vessels enter state waters, and were chosen as the most likely locations where ballast-related introductions would have occurred. These areas are comprised of numerous ports, bays, estuaries and lagoons where sampling was conducted or about which information was available from the literature, and are referred to as the 'major harbor areas' in the summary tables presented below. The specific sites included in each of the general regions are highlighted in the Locations Tables in Appendix E.

Many of the species included in the discussion to follow were collected from more than one site within the specified harbor areas but, unless otherwise noted, will be counted only once in the summary charts and graphs. A map of the harbor areas and a complete list of the species and the locations where they were found is provided in Appendix E.

Figure 5 **Number of Non-Indigenous Species in the Major Harbor Areas**

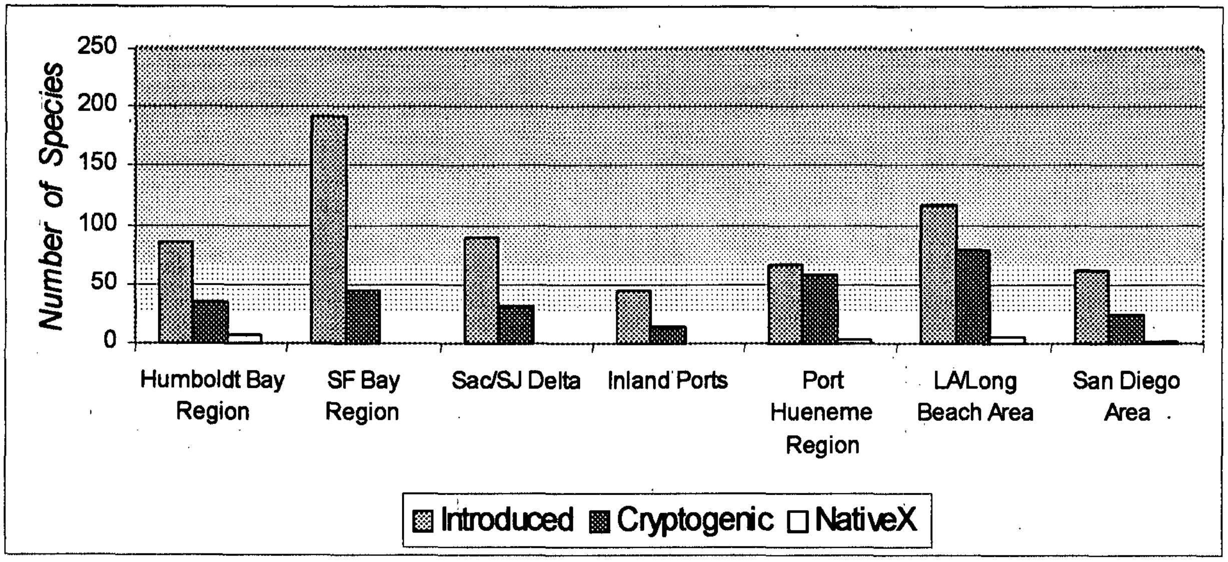
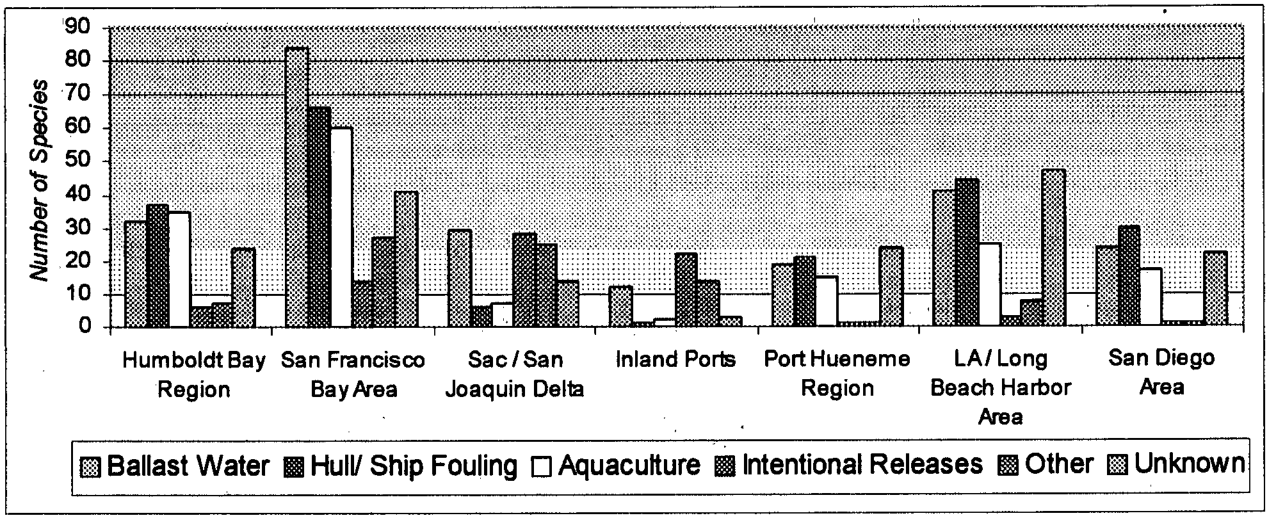


Figure 5 shows the total number of species either found in this survey or reported in the literature for each of the major commercial harbor areas of the state (see Appendix E for a breakdown of the specific areas encompassed by each of these general harbor categories). The graph reflects only those species that we have designated as 'distinct taxa' and may, therefore, present a conservative picture of the number of introductions. Nevertheless, in each harbor area there are from 50 to nearly 250 species that are either clearly introduced or considered to be very likely introduced to the local environment. As with the state-wide summary, additional work is needed to refine the taxonomy and make a more definitive determination regarding whether or not the 'cryptogenic' and 'nativeX' species are native to these areas.

The data suggest that San Francisco Bay continues to be, as once described, one of the most invaded ecosystems in California, if not the world (Carlton and Cohen 1995). The other major port, L.A./Long Beach, is not far behind, however. And, in fact, this study has shown that all the major ports as well as most of the smaller bays and estuaries in the state have significant numbers of non-indigenous organisms. Indeed all areas sampled showed some evidence of introductions.

Figure 6 **Primary Pathways of Introduction in the Major Harbor Areas**



* **Intentional releases** are those conducted by a government agency to enhance a local fishery or for bio-control actions.
* The '**Other**' category includes a number of potential methods of introduction including: aquarium releases, fish market dumping, escape from cultivation, accidental introduction with ornamental plants or game fish, and solid ballast.

As Figure 6 shows, the primary introduction pathways differ somewhat for each of the major harbor areas. As was also true in the previous summaries, the 'unknown' category for this information is not insignificant. Further investigation of those species that arrived by an unknown vector may change the relative importance of each pathway listed. However, based on what is currently known, the combination of ballast discharges and hull fouling appear to be the primary potential mechanisms of introduction in all areas except the freshwater ports of Sacramento and Stockton (called "Inland Ports" on the graph) and the Sacramento/San Joaquin Delta. Intentional introduction, primarily of fish species, is the leading vector in the Inland Ports and the second leading pathway in the Delta.

Hull fouling, which is a dominant source of introductions elsewhere, seems to have had less of an impact in the Delta and Inland Ports. Hull fouling is, however, the most common pathway in four harbors, Humboldt Bay, Port Hueneme, L.A. Long Beach and San Diego. Ballast water is not far behind in any of these regions but has not been cited as the dominant vector in any area but San Francisco.

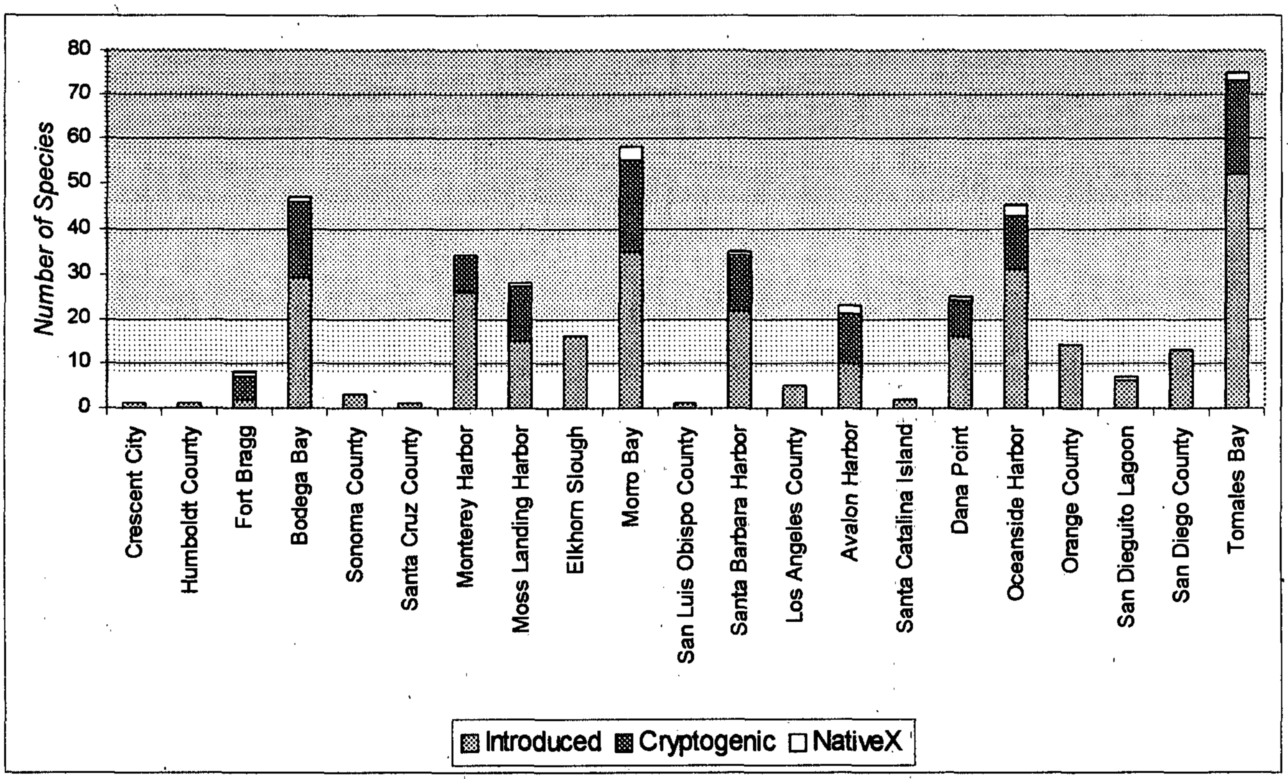
Aquaculture is the second leading vector in Humboldt Bay and the third most important source of introductions in San Francisco, Port Hueneme, L.A./Long Beach, and San Diego. This is a mechanism of introduction that may warrant additional research to determine to what extent the problem is an historical one and how much of an influence it continues to have today.

The data presented here indicates the potential pathway of initial introduction but may not reflect how species have moved from one area to another within the state. Additional study is needed to more fully refine our understanding of secondary mechanisms of introduction or spread of NAS.

Minor Ports, Bays and Estuaries

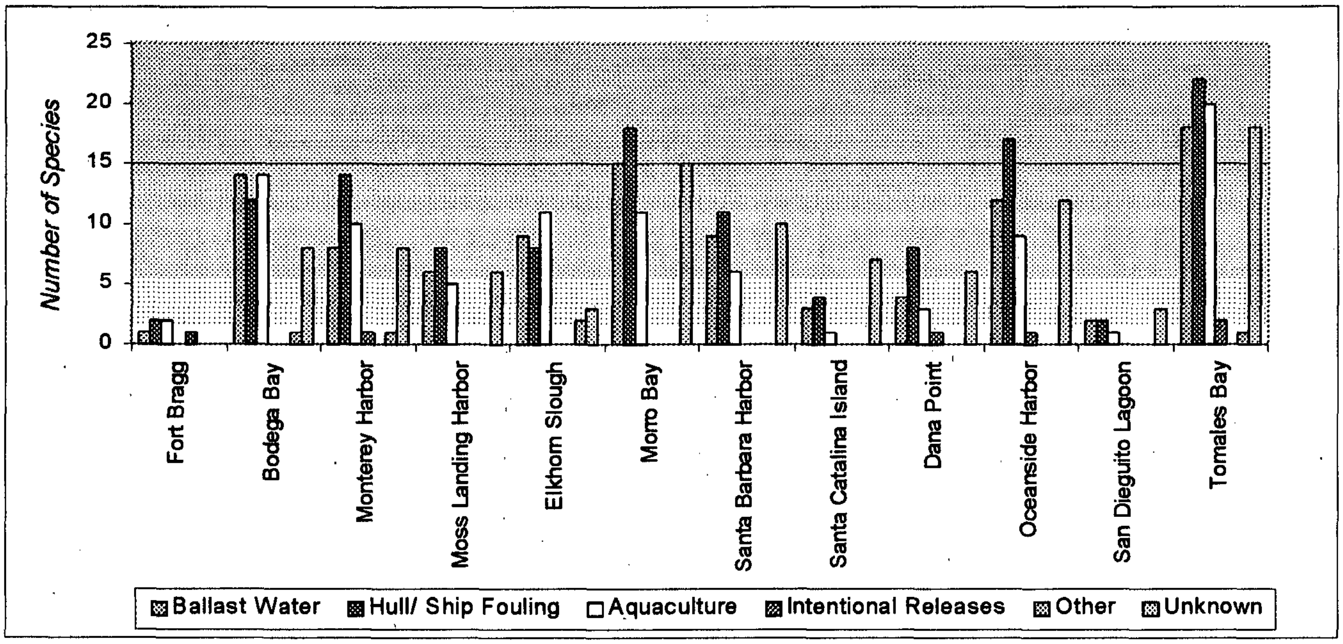
Numerous small ports, bays and estuaries were also sampled for this survey. Information regarding the 'fouling' communities was the principle focus of these collection efforts, though the literature provided information regarding other taxa in these areas as well. A map of all the sampling sites and any locations noted from previous studies, is included in Appendix E along with a listing of all the individual species identified during this investigation.

Figure 7 Number of Non-Indigenous Species in Minor Ports, Bays and Estuaries



It is apparent from Figure 7 that even the smaller ports and bays along the coast have significant numbers of non-indigenous species. As with the previous summary graphs, the information reflected here was obtained from both the sampling effort and from the literature review. Some of the species described in the literature did not have very clear or specific information regarding where a specimen had been found during earlier studies and investigations. Some of the location descriptions were quite broad, such as 'California coast', others were slightly more descriptive and would indicate a county or general region like 'north of Humboldt Bay'. Where there was some indication of a local region, we included those species under headings such as 'Humboldt County'. Where the location was described as 'coast-wide' the species is only included in our state-wide totals. Additional research is needed to more accurately pinpoint the locations for a number of the species included here.

Figure 8 Primary Pathway of Introduction in Selected Ports, Bays and Estuaries



* **Intentional releases** are those conducted by a government agency to enhance a local fishery or for bio-control actions.
* The '**Other**' category includes a number of potential methods of introduction including: aquarium releases, fish market dumping, escape from cultivation, accidental introduction with ornamental plants or game fish, and solid ballast.

As with the other summary graphs of pathway information (state-wide and for the major harbors), the data for Figure 8 includes some species in more than one category if the literature indicated that they could have been introduced by more than one vector. The graph shows the potential mechanisms of introduction for the species present in these locations, rather than the only route they could have traveled. Given that, it appears that hull fouling may play an even more important role in the smaller ports than in the larger harbors. Fouling is the leading vector in eight of the selected harbors and the second leading vector in the remaining four areas presented. It also appears that aquaculture has the same or an even greater impact than ballast water discharges outside the major harbor areas.

The unknown category is once again an important element. Additional research could help to provide a more accurate picture of the source of introductions in these and all areas of the state. The current state of knowledge does, however, make it quite apparent that there are a number of vectors that must be controlled in order to limit the introduction of non-indigenous species into Califomia.

As with pathway data presented previously, this figure may not fully reflect the secondary routes of introduction but only the initial mechanism for introducing an organism to state waters. Further research is needed to refine our understanding of the movement of species from one area to another once they are established in the coastal environment.

V. SUMMARY

This survey has revealed that there have been a significant number of aquatic species introduced to coastal ecosystems of California. The San Francisco Bay has long been labeled as one of the most highly invaded ecosystems in the world (Carlton and Cohen 1995), but the data from this study indicates that the other ports and harbors in the state are not far behind. Many of the introductions have come from the ballast of ships, but hull fouling, aquaculture, and intentional introductions are important vectors as well. All of these vectors need to be addressed in a comprehensive program to prevent the introduction of additional species to the bays and estuaries of the state.

As expected, the species totals are generally highest in the two major commercial ports, San Francisco, and L.A./Long Beach. These ports receive the largest amount of ship traffic and therefore have the greatest exposure to vessel-related pathways of introduction. However, the smaller commercial ports (Humboldt Bay, the Sacramento/San Joaquin Delta, the Inland Ports, Port Hueneme and San Diego) and the many small harbors, bays and estuaries along the coast have a significant number of non-indigenous species as well. Whether the non-indigenous species are introduced directly to these smaller sites or spread from the larger ports is not fully understood and should be investigated further.

Pathway and native range data can give us a general idea about where non-indigenous species originate and how they may have arrived on the west coast of North America, *initially*. However, additional research into the transport of species between various west coast ports will help discern how much of the problem in California may result from intra-coastal traffic. Likewise, the native range information can tell us where species originate but not whether they made it to California directly from a foreign port or from some intermediate location. In addition, cross inoculation within the Exclusive Economic Zone may be the result of pathways other than the major ones discussed above. Initial introductions might come from the ballast of a large vessel, for example, with subsequent spread of an introduced species by way of fishing or recreational boats that move between the large harbors and smaller bays. Refining our understanding of the secondary pathways is important to effectively controlling such species movement. The control of populations already established in one harbor can only be accomplished if we know how to prevent the spread to nearby ports, bays and estuaries.

The time and resources that were available to do this survey only allowed us to compile the data, create a species inventory and report the information as presented. Analysis of the environmental or economic risk posed by non-indigenous species, refining the taxonomy to definitively identify all the organisms that were found, and determining the pathways and origins with a greater degree of certainty will require future research. This survey, however, provides the basis for that research and is an essential first step to a more comprehensive look at the impact these animals and plants may have on the health of the aquatic environment of which they are now such an integral part.

VI. RECOMMENDATIONS

The results of this study point to the need for additional research in a number of areas. Such research is needed to refine the data generated by this survey, provide additional information on the effects of current invasions and develop methods to prevent future introductions. The following research is recommended:

On-going surveys for NAS: In order to determine the effectiveness of any ballast control measures that are implemented at the state or federal level, continued biological surveys are necessary to monitor for any additional introductions or spread of existing non-indigenous species populations. Such surveys should be conducted in the estuarine and coastal waters in such a way that all the various habitats along the entire coastline are sampled at least once every three years. At the end of each three-year cycle a report would be generated. The results of these surveys would be used to determine what modifications may be necessary to make any existing ballast control requirements more effective, or target control efforts to 'hot spots' or problem areas.

Pathway of Introduction: For many of the species found in this study, the mechanism for introduction could not be determined definitively. Many species were listed as arriving via one or more potential pathways. Further research will provide a more accurate picture of the routes of introduction making it possible to more effectively target prevention measures to the most problematic vectors. In addition, once pathways are better documented, a shipping study should be conducted. Such a study would correlate ship movement to species introductions to help answer questions regarding the prevalence and importance of cross-inoculation from other west coast ports, as opposed to introductions from foreign sources. Current law only covers the management of ballast from ships arriving from foreign ports under the assumption that this is the most likely source of non-indigenous species. Introductions to and from the other major harbors within the Exclusive Economic Zone may, however, be comparably important and therefore the focus for future control efforts.

In addition, the spread of NAS within the state should be studied further to determine to what extent such dispersal may be the result of pathways other than the major ones discussed in this report. Initial introductions from ballast, hull fouling, aquaculture or intentional introductions may be exacerbated by fishing or recreational boats that move between the large harbors and smaller bays. Refining our understanding of the secondary pathways is important to effectively controlling such species movement.

Refine Taxonomy: Many of the species identified as part of this study have been categorized as 'cryptogenic' in large part because there is insufficient information about the species to determine their origin. In many cases, researchers could not accurately differentiate one species from another within a given genus or family. This problem can only be remedied with further investigation by qualified taxonomists. More conclusive identification is essential to further our knowledge of the species present on our shores. Complete speciation allows us to find not only non-indigenous species that may cause ecological or economic damage, but also to identify beneficial species that may help us combat some of these same problems.

Research specified in the Ballast Water Management Act:

In addition to the research outlined above, the Act envisioned additional studies using the data generated by this survey. These studies (described below) could help establish effective prevention and control measures in any future ballast management program.

Alternative discharge zones: a study to determine areas along the coast that could safely be used by vessels that are unable to discharge ballast in mid-ocean due to safety or structural constraints. These zones would be areas where any non-indigenous species that may be discharged in a ship's ballast would have an extremely low chance of survival.

Areas to be avoided: the delineation of environmentally sensitive areas that vessels should avoid when taking on or discharging ballast.

Risk zones: determining those areas where ballast uptake must be prohibited because of the risk of taking on contaminated water or water with a high level of non-native species that could then be transported to other ports in California, or from California to ports and harbors along the west coast or in foreign nations.

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