

**BIOLOGICAL INVASIONS OF COLD-WATER COASTAL ECOSYSTEMS:
BALLAST-MEDIATED INTRODUCTIONS IN
PORT VALDEZ / PRINCE WILLIAM SOUND, ALASKA**

FINAL PROJECT REPORT

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EXECUTIVE SUMMARY

PROJECT OVERVIEW

This study assesses the risk of biological invasion by nonindigenous species (NIS) associated with oil tanker traffic and ballast water management for Port Valdez / Prince William Sound (PWS), Alaska. This study included 8 major components:

- Review of risk factors for NIS invasions and ship-mediated transfer of species relevant to PWS, a high latitude, cold-water marine ecosystem.
- Analysis of ballast water delivery patterns and plankton communities associated with ballast water on tankers that arrived to PWS.
- Experimental analysis of initial survivorship of ballast water organisms in temperature-salinity combinations typical of receiving waters of Port Valdez.
- Experimental measurements of the effect of ballast water exchange and voyage duration on plankton communities arriving on tankers to PWS.
- Characterization of organisms fouling hulls and in sea chests of crude oil tankers.
- Characterization of organisms in sediments of tanker ballast tanks.
- Determination of NIS established within Alaska, as detected by field surveys and reviews of existing collections and literature conducted by experienced naturalists and taxonomic experts.
- Analysis of the biodiversity of PWS.

This study advances our understanding of invasion processes in many significant ways.

- Our study provides the most comprehensive analysis worldwide of the abundance and taxonomic composition of plankton communities in the segregated ballast water of tankers as well as domestic ballast transfer by any vessel type.
- We have undertaken an ambitious set of experimental and quantitative measures to (a) compare directly, for the first time, the relative efficiency of exchange methods (Empty–Refill and Flow-Through) for any vessel type or taxon, and (b) the effect of voyage duration on plankton survivorship in the ballast water of oil tankers.
- We provide the first synthesis of NIS known in Alaska, resulting from an extensive literature review and field-based surveys.
- The large scope of this study provides an unusually comprehensive analysis of the risks, mechanisms, and patterns of invasion in PWS.

The project represents a cooperative and successful partnership of industry, citizen, agency, and scientific groups. This strong cooperative program addresses critical gaps in our understanding of invasion risks, as well as facilitates information exchange and participation among a broad spectrum of industry, citizen, agency, and scientific groups.

- From a science perspective, this program results in a comprehensive analysis of invasion processes and risks for PWS, representing the first such study in the world for a high-latitude / cold-water marine ecosystem.

- From an industry and management perspective, this program assesses the effectiveness and trade-offs involved for various management strategies that are now required in Prince William Sound, and are being promoted on a national and international scale.
- From a public perspective, this program disseminates findings and serves as a key source of information, especially through groups like the Smithsonian Environmental Research Center, the Regional Citizens' Advisory Council of Prince William Sound, U.S. Fish & Wildlife Service, and NOAA Sea Grant.

RESULTS

Background

Biological invasions of marine ecosystems in Alaska are a major environmental concern.

- Biological invasions of coastal bays and estuaries are common throughout the world and are having significant ecological and economic impacts.
- High-latitude / cold-water regions are also subject to biological invasions by many species with potential ecological and economic consequences similar to those reported for more temperate latitudes.
- Transport of coastal planktonic organisms in ballast water of commercial ships appears to be the major source of new invasions worldwide in recent years.
- Tankers arriving to Port Valdez release the third largest volume of ballast water of any U.S. port.

BW Delivery Patterns and Biological Characteristics

A large quantity of ballast water arrives to PWS in oil tankers.

- For the past decade, tanker arrivals to Port Valdez have averaged 713 ships per year.
- Tankers arriving to PWS in 1998 carried an estimated average of 65,775m³ of total ballast water, including both segregated (non-oily) and nonsegregated (or oily) ballast water.
- Segregated ballast water comprised an average of 54.7% of the total ballast water arriving to PWS in tankers.
- Overall, an estimated 17,000,000 m³ of segregated ballast water (an average of 32,715 m³ per arrival) was discharged into PWS by oil tankers in 1998.

Most ballast water delivered to PWS by crude oil tankers originates from U.S. domestic ports.

- Tankers arriving directly from western U.S. ports accounted for 95.8% of the total tanker traffic, and 96% of the total segregated ballast water delivered by tankers, to PWS in 1998.
- Arrivals from Puget Sound, San Francisco, and Long Beach comprised approximately 82.7% of all tanker traffic, as well as 86% of all segregated ballast water delivered by tankers, to PWS in 1998.
- Most (69.6%) of the tankers arriving to Port Valdez from overseas came directly from Korea in 1998.
- Tankers arriving from domestic ports transfer ballast water directly from that port to PWS, whereas foreign arrivals have replaced coastal ballast water with open-ocean exchange prior to their arrival.

The voyage duration of tankers arriving to Port Valdez is relatively short compared to traffic arriving at other commercial ports, where invasions are common.

- Ballast water spent an average of 6.6 days in the ballast tanks of oil tankers before arrival to Port Valdez, ranging between 4.8 to 10.2 days.

A large quantity of planktonic organisms is released into PWS with segregated ballast water from oil tankers.

- An average of 12,637 total organisms per m³ (excluding chain-forming diatoms) was measured in our ballast water samples from 169 tanker arrivals, including those from both domestic and foreign source ports.
- Overall, we estimate that roughly 264 billion organisms were delivered to PWS in the segregated ballast water of oil tankers during 1998.
- Importantly, these estimates include only the largest plankton and miss many small planktonic organisms (e.g., bacteria, viruses, and other microorganisms), that would likely increase overall densities many fold.

The abundance of planktonic organisms was greater in segregated ballast water from domestic source ports compared to that from foreign source ports.

- Total density (across all taxonomic groups) of organisms was greatest on average in segregated ballast water from domestic arrivals compared to foreign arrivals.
- Average densities of most taxonomic groups were 10- to 100-fold greater in segregated ballast water from domestic versus foreign sources.
- The magnitude of density differences between domestic and foreign sources was much less for copepods and solitary diatoms.
- Dinoflagellates were a notable exception to the general pattern, as average density was greatest in ballast water of the foreign arrivals.

Significant variation existed in abundance of taxonomic groups in the segregated ballast water arriving from the major source ports.

- Total density of organisms was lowest on average in ballast water from foreign arrivals compared to arrivals from each of the three major domestic ports (Puget Sound, San Francisco, and Long Beach)
- Total density on average declined among the four major ports with increasing voyage duration.
- In contrast, the greatest average densities for individual taxonomic groups (e.g., protozoans, brachyuran crabs, and bryozoans) did not always correspond to the shortest voyage duration.

The abundance of plankton arriving in segregated ballast water from the major domestic ports varied both spatially and temporally.

- The greatest densities occurred for all taxonomic groups, individually and combined, during the spring and summer months.
- However, the timing of peak densities differed among taxonomic groups and among source ports.

- The magnitude of seasonal variation in plankton densities also differed among source ports, being greatest for Puget Sound and San Francisco Bay compared to Long Beach.
- Furthermore, significant annual variation also existed in the densities of plankton arriving to PWS from each of the major domestic source ports.

NIS are present in the segregated ballast water released by oil tankers in PWS.

- We identified 14 different nonindigenous species (13 crustaceans and 1 fish) arriving to Port Valdez in the ballast water of oil tankers.
- To date, all of these identified NIS have been in ballast water from San Francisco Bay or Long Beach.
- Importantly, these numbers are clearly underestimates, since only a subset of the plankton can be identified to species and only the largest fraction of planktonic organisms were included in our analyses.

Organisms discharged in tanker ballast water, including known NIS, have high potential of initial survival in the salinity-temperature conditions of Port Valdez and PWS.

- Seasonal cycles of salinities and temperatures in Port Valdez waters encompass the range of salinities and temperatures of arriving ballast water, providing a good match between source ports and receiving waters.
- Laboratory experiments indicate that a wide range of ballast water species (including some NIS) can survive the salinity and temperature conditions of Port Valdez upon initial discharge from tankers.

Other Mechanisms of NIS Transport by Tankers

Tankers also transfer organisms that are not in ballast water and that may become established in PWS.

- Tanker hulls and sea chests sampled in dry dock sometimes carried a diverse array of fouling and nektonic organisms, including several NIS.
- Sediment taken into ballast tanks during ballasting in shallow ports sometimes carried diverse and abundant bottom-dwelling organisms, including reproductive adult individuals.

Ballast Water Exchange Experiments

Preliminary experimental results suggest that ballast water exchange is as effective for oil tankers as for other vessel types.

- Initial analyses suggest roughly 80-99% of the resident water is replaced per ballast water exchange event.
- The efficacy of exchange appears to differ between exchange method, with Empty–Refill Exchange replacing the greatest proportion of water.
- The efficacy of exchange also appears to differ among taxa.
- Importantly, all analyses for the exchange experiments are still underway, and final results / conclusions are therefore pending project completion (anticipated in June 2000).

Summary of NIS in Prince William Sound and Alaska

A diverse array of NIS have been introduced into PWS and Alaska.

- There are 24 species of NIS plants and animals in marine and estuarine ecosystems in Alaska, including 15 species recorded in PWS.
- These NIS are taxonomically diverse and occupy a wide range of ecological niches and habitats, although there appear to be more NIS associated with boat harbors and with aquaculture activities.
- Our focal taxonomic collections provided the first records of 7 NIS in Alaska, including some species that appear to be very recent introductions.
- Many of the Alaskan NIS have larval stages which could be transported in ballast water.
- None of the Alaskan NIS is clearly associated with ballast water of oil tankers as a primary mechanism of introduction, even though many NIS are frequently found in ballast water arriving to Port Valdez.
- Instead, the transfer of NIS may have resulted from any one of multiple transfer mechanisms, including ballast water, ship fouling communities, and aquaculture.
- Finally, it is important to note that many additional Alaskan marine species are cryptogenic (possibly introduced), as the historical baseline of biogeographic and taxonomic information is very limited for this biota. For example, we identified at least 29 cryptogenic species in Alaska (including 24 in PWS), exhibiting either wide global distributions often associated with spread by early shipping traffic or a variety of characteristics common to NIS.

Biodiversity of Prince William Sound

Taxonomy and biogeography of species in Alaskan marine ecosystems have received poor levels of study and understanding.

- We discovered 10 new, previously undescribed species, as well as recorded range extensions for 74 other species from a diverse array of taxonomic groups.
- It is now apparent that a large portion of many major groups remain undocumented, as well as cryptogenic in origin, due to limited surveys and historical analysis of the Alaskan biota.

We have now initiated a biodiversity data base for marine species in PWS.

- We have established a comprehensive data base for marine invertebrates in PWS.
- The scope of this data base will be expanded to include algae, fish, mammals and birds in the next year.

CONCLUSIONS

Multiple risk factors exist that favor the establishment of NIS in PWS.

- Approximately 550 tankers currently arrive per year to PWS and release an estimated 17,000,000 metric tons of segregated ballast water.
- Tankers repeatedly deliver ballast water from the same, limited source ports, providing repeated inoculations of the same species.

- The voyage duration of these tankers is usually short (3-7 days), favoring high survivorship of transported plankton and resulting in the dense inoculation of competent organisms into PWS.
- Environmental conditions of source ports match those in PWS for some portions of the year, and many organisms arriving in ballast water can tolerate conditions in receiving waters.
- Most (95.6%) of arriving tankers do not undergo ballast water exchange, a process which can limit the transfer rate of NIS.
- A large number (tens-to-hundreds) of NIS are known from the domestic ports that are the source of unexchanged ballast water arriving to PWS in oil tankers.
- NIS are present in this domestic ballast water arriving to PWS in oil tankers.

Ballast water exchange appears effective at reducing resident plankton on tankers, although a risk of invasion still exists.

- Ballast exchange experiments suggest that tankers arriving to Port Valdez from foreign ports have reduced resident coastal organisms by > 90% through the current exchange practices.
- Abundance of coastal organisms was 10-100 fold lower for oil tankers that were foreign arrivals (that underwent ballast water exchange) compared to domestic arrivals (that do not undergo exchange).
- Although roughly equivalent to efficacy of exchange estimated for other vessel types, both data sets suggest that tens to hundreds of thousands of organisms/ship still arrive with exchanged ballast water.

Alaskan waters, and those of PWS, are susceptible to invasion by NIS.

- It is now evident that a diverse array of taxa have become established in Alaska and PWS.
- These NIS occupy a broad range of marine and estuarine habitats.

The number of marine NIS in Alaska appears to be significantly lower than other marine ecosystems at lower latitude.

- Our surveys of PWS and Alaska were intensive and failed to detect many NIS known from the domestic source ports of oil tankers.
- However, the limited historical record and scope of past surveys limits direct comparisons with low latitude marine ecosystems, for which extensive surveys and knowledge have been developed over decades to centuries of biological research.

In general, the poor resolution of taxonomic and biogeographic data in Alaskan marine ecosystems is a substantial impediment for analysis of environmental impacts.

- To date, we have been able to provide only a minimum estimate of NIS, as many species remain undescribed or cryptogenic until further analysis.
- Assessment of other environmental impacts, such as oil spills, may also be limited without adequate baseline data on species composition and abundance.
- We recommend a program of standardized surveys across multiple sites in PWS and Alaska to both improve the existing knowledge of NIS and provide a regional baseline of data.

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