# Characterizing Risk Associated with Vessel Fouling and Non-indigenous Species in Prince William Sound

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# Executive Summary

Little is known about the organisms associated with the hulls of ships entering the coastal waters of Alaska, but fouling biota on ship's hulls elsewhere have been shown to be diverse and contain species that are not native to many of the regions visited by the ships. An initial step in assessing the potential risk of invasions by non-indigenous species (NIS) associated with ship's hulls is to characterize vessel arrivals with regard to risk factors such as voyage history, time spent in port, vessel type, and the distribution and nature of shipping intensity among ports. Another information-gathering step is to summarize information about hull cleaning and maintenance practices of major vessel types that comprise potential vectors for NIS. This information can be used to evaluate the scale of risk of introductions by fouling organisms among vessel types, routes, and ports, and can help identify regions likely to contribute NIS. This approach can help to focus subsequent efforts targeting specific risk factors. Understanding hull fouling associated invasion risk ultimately requires measuring biota associated with hulls. This type of analysis can range from low resolution data gathered from archived hull maintenance video to comprehensive remote-operated vehicle or diver surveys (the latter can include physical samples of fouling communities), but costs for these kinds of analyses increase as the data quality and quantity increases. Thus, analyzing shipping patterns, hull maintenance practices, and the pros and cons of various hull fouling sampling methods can help prioritize how to focus more intensive and comprehensive sampling efforts. In this report, we examine these factors, with particular regard to Prince William Sound, Alaska.

The overall goals of this project were as follows:

- Evaluate 2005-2008 vessel arrival data for ports in Prince William Sound and the Ports of Kodiak and Seward (henceforth termed ports of interest).
- Conduct an initial assessment of tankers traveling to Prince William Sound, by evaluating maintenance schedules and periodicity and location of hull cleaning.
- Summarize the literature on hull fouling studies and hull sampling techniques.
- Based on the results, evaluate and recommend sampling and analysis protocols that can be used in studies of hull fouling in the region.

## Shipping Patterns

In order to evaluate shipping patterns, we obtained vessel arrival data from the US Coast Guard's Shipping Arrival Notification System (SANS) for the years 2005-2008, for the ports of interest—Cape Hinchinbrook, College Fjord, Cordova, Kodiak, Prince William Sound (No port given), Seward, Tatitlek, Valdez, and Whittier. The data received included information on the port of arrival, date and time of arrival, vessel name, date and time of departure, previous ports visited, and the time of arrival to and departure from the previous ports.

In addition to examining patterns of all vessel arrivals combined, arrival data for individual vessel visits were categorized by voyage type, vessel type, time spent in port, and voyage history. The main findings from the vessel arrival data were as follows:

- Total vessel arrivals declined from 2005 to 2008, with the sharpest drop in 2006.
- Most arrivals were tank and passenger vessels originating from the west coast, followed by domestic (within Alaska) and transpacific voyages.
- The most commonly visited way-points on voyages were in the Puget Sound area and British Columbia, followed by the San Francisco Bay area and Southern California.
- The majority of arrivals stayed in port for less than 24 hours, but there was a small subset of vessels that stayed in port more than 72 hours consisting mostly of tank ships (2005), passenger vessels (2006) and fishing boats (2007 and 2008). In each year, there was at least one arrival that stayed more than 72 hours for most of the vessel categories.
- Valdez had the majority of arrivals, followed by much lower arrival numbers, in decreasing order at Whittier, Kodiak, Seward, Prince William Sound (No port given), Cordova, Cape Hinchinbrook, College Fjord, and Tatitlek.
- Ports of interest with relatively high shipping activity had different patterns based on vessel types visiting: Valdez was dominated by tank ships, Whittier by passenger and towing vessels, Kodiak by fishing and freight vessels, and Seward by passenger vessels.
- Ports with high shipping activity also varied by voyage type of arriving vessels: those arriving in Kodiak came mainly from within Alaska, while those arriving to Valdez, Whittier, and Seward were mostly from elsewhere on the west coast of North America.
- Ports that had relatively high proportions of arrivals that had visited potential NIS “hot spots” in their voyage histories included Valdez, Cape Hinchinbrook (San Francisco Bay), Seward and Kodiak (Asia).
- Ship types that had relatively high proportions of arrivals that had visited potential NIS “hot

spots” in their voyage histories included tank ships (San Francisco Bay), passenger vessels and freight ships (Asia).

The analysis identified two categories of vessels: those that have set routes and make numerous brief return trips to the same port, and those that return to port infrequently but stay in port for long periods of time. The first type presents a risk of repeat inoculations of NIS (potential high propagule frequency), and the second represents risk based on less frequent inoculations with longer “incubation” time for NIS to release propagules (potential high propagule volume). Tank ships and passenger vessels represent the high frequency risk category, while freight and fishing vessels represent the high volume risk category.

Several ports probably have relatively higher risk of NIS being introduced from hull fouling. Valdez has the highest overall amount of vessel traffic, with relatively high numbers of vessels that had previously visited potential NIS “hot spots” in Puget Sound, San Francisco Bay, and Southern California. Whittier and Seward may be at risk from the high volume of passenger vessel and towing vessel traffic arriving from elsewhere on the Pacific coast of North America. Fouling organisms may have better survival rates on these vessel types due to relatively short voyages in coastal waters hospitable to the organisms. Towing vessels may also have higher survival rates because of slow average voyage speeds. A relatively large proportion of passenger vessels had stops in Mexico and Asia that may be sources of NIS, they operate in the summer months when propagule pressure may be high, and the high return rate of the vessels allows for potential repeat inoculations.

Domestic freight ships and fishing boats may present a risk to the port of Kodiak from secondary invasion by already introduced NIS arriving from other Alaskan ports. Relatively long “residence time” of fishing boats and freight ships may allow for the accumulation and/or release of fouling organisms.

## Hull Maintenance

Currently, there is little federal regulation regarding hull husbandry practices: vessels are only required to rinse anchors and anchor chains to remove organisms and remove fouling organisms from hull, piping, and tanks on a regular basis. However, the main ship type traveling to Prince William Sound waters, crude oil tankers engaged in coastwise trade, are exempt from these requirements. Tank ship companies conduct voluntary high pressure washing of hulls, usually in conjunction with dry dock inspections that are typically required every five years, but this cleaning is conducted for operational reasons, and fouling that does not interfere with ship operations may be allowed to persist.

Several factors related to hull maintenance are important with regard to the risk of transporting fouling NIS, including time since last cleaning and re-painting, use of anti-fouling treatment systems, maintenance of “hot spots” such as sea chests, cleaning method, and where the ship has been since being cleaned.  In order to collect preliminary data on these factors, we evaluated maintenance information from 18 of the 26 tank ships operating Prince William Sound from 2005 to 2008. This information was acquired by the California Marine Invasives Program at the California State Lands Commission (CSLC), from reporting forms submitted to the CSLC by ship operators. The data collected includes:

1. Dates and location of last out of water maintenance.
2. Date of last full or partial coat of anti-fouling paint application, type of biocide used, and locations of the hull where applied.
3. Whether Marine Growth Protection Systems have been installed in the sea-chests.
4. Dates of in water cleaning, if applicable.
5. Whether the vessel has, since the last cleaning: recently visited freshwater or tropical areas, been through the Panama Canal, or stayed ten consecutive days in a single port.

Of the 18 vessels, the greatest duration of time since last maintenance or build was five years, and the average time since last maintenance or build was two years. All of the shipping companies interviewed reported conducting hull cleanings with a high pressure wash on dry dock at least once every five years.

### Hull Fouling Sampling Methods and Recommendations

Five techniques have been commonly used to sample biofouling on hulls: (1) evaluating archival video footage of under water in lieu of Drydock (UWILD) inspections; (2) conducting above-water visual rank assessment;  (3) collecting specimens and photo quadrats immediately after a vessel has been drydocked; (4) using divers to collect specimens and conduct underwater photo quadrats; and (5) using remotely operated vehicles (ROVs) to conduct video transects.

Inspection of archived maintenance videos can yield broad patterns of fouling across numerous ships, and is relatively inexpensive to process. On the down side, videos are usually taken near the end of a ship's maintenance cycle, and thus may be biased toward the most highly fouled conditions, and most species cannot be identified in videos. Likewise, visual rank assessment, using a ranking of 0 to 5 for intensity of fouling, can yield large amounts of data at low expense, but yields biased data in that only small vessels and the parts of the hull visible from above the water can be assessed.

Collecting data during scheduled dry-docking events is also a relatively inexpensive option, and could allow for collection of specimens for species-level identifications. However, because tank ships in the northeast Pacific usually drydock in Asia, costs would include travel to Asian drydock facilities that service the tank ships. As with videos, sampling drydocked vessels may also yield biased samples because they are at the end of a maintenance cycle, and access to a hull in drydock could be non-uniform: for example, if specimens could only be collected from areas accessible by ladder, the majority of the hull would not be characterized.

The use of divers and ROVs are the most expensive options, but costs may be lowered if divers or an ROV are available within the institution conducting the sampling. Diver and ROV surveys can be conducted at any point in a vessel's maintenance schedule, and thus provide a more representative sampling regime. They can also be done on predetermined transects and/or "hot spots" of interest. ROVs can stay in the water indefinitely, while divers are time-limited. However, in addition to visual surveys, divers can collect quantitative samples of biota for species level identification, including focusing on observed "hot spots".

We recommend a three-level sampling strategy for evaluating hull fouling. The first level would utilize UWILD video footage from vessels arriving to Prince William Sound. If the videos contain enough footage to sufficiently cover vessel types and underwater surfaces, a set number of quadrats from still frames would be randomly examined on each hull, along with semi-random quadrats on non-hull "hot spot" surfaces. Taxa richness and percentage cover data would then be analyzed. If enough adequate footage is found, this level would yield information on the extent of biofouling across a large subset of vessels arriving to Prince William Sound, but would not provide information on specific NIS. If the data from archival footage supplies enough information to detect fouling patterns associated with vessel types, voyage types, etc., then studies may proceed to a smaller more focused level three study. If meaningful patterns cannot be detected due to limitations of the archived video, a level two study may be conducted.

In a level two study, ROV or diver video surveys would be conducted that offer more ability to target ports, vessel types, or voyage types of interest, and specific areas on an individual hull. The control afforded by this method allows vessels to be directly compared in a uniform manner. Divers or ROVs would conduct several transects along the length of a vessel's hull, followed by special attention “hot spots”. A real-time video feed may also be viewed by biologists who could identify areas to be sampled. During post-processing of videos taken at this level, videos could be paused at both random points and targeted focal points to obtain percent cover and presence/absence of organisms at broad taxonomic levels. As with archived video, a level two study would not provide much species-level identification of potential NIS.

Level three study would involve targeted biological sampling that could be conducted on vessels of interest. This sampling could also be done in conjunction with level two sampling, if it is conducted by divers. This method is the most costly and might best be conducted by strategically narrowing the subset of vessels to be sampled to those that are hypothesized to be high risk vectors, as determined by level one and two sampling. Divers would collect representative samples of fouling observed along transects on vessel hulls, and video or visual assessment could also be conducted. Transects could be saved as video files and analyzed extensively. Biological samples could be rapidly assessed while alive, but most species identifications would be done from samples that are fixed and sent to taxonomic experts. Level three sampling yields high resolution information on specific fouling organisms and potential and known NIS found in hull samples. Percent cover can also be obtained, though due to limitations in the time divers can spend in the water, this data may be limited to only portions of a vessel.

# Introduction

Though little studied in comparison to ship's ballast waters, fouling biota on ship's hulls have been shown to be diverse and in some cases comprised of numerous species that are not native to many of the regions visited by the ships. For example, Drake and Lodge (2007) found that a single ship entering the Great Lakes from Algeria had 74 marine and freshwater taxa, at least eight of which had never been seen in the Great Lakes; hull fouling may be responsible for at least 75% of the ship-mediated NIS in Port Philip Bay, Australia (Hewitt 2004); a recent sampling of biota scraped from hulls of commercial vessels in Germany showed NIS on 96% of the 131 ships examined (Gollasch 2002); a survey of 8 vessels in Hawaii found NIS on the hulls of a majority of the vessels, despite low levels of fouling (Godwin 2003); and a single inspection of a relatively clean passenger vessel in Australia found a number of NIS in protected areas of the ship, including the European green crab *Carcinus maenus (*Coutts et al 2003). A series of rapid assessment surveys in Washington, Oregon and California consistently found significant levels of invasive fouling organisms on docks, pilings and other intertidal structures (Cohen et al. 1998, 2001, 2002, 2005a, 2005b). Other papers, such as Davidson et al. (2006a) and Coutts and Taylor (2004), while not addressing specific NIS species assemblages, point out the biosecurity risks posed by hull fouling.

Recent studies of ships as vectors of NIS in Alaska have focused on ballast water (Ruiz et al. 2000, McGee et al. 2006). Very little is known about the organisms associated with the hulls of ships entering the coastal waters of Alaska, though an examination by Ruiz et al. (2000) of the hulls of two tankers entering Valdez, Alaska, found a diverse fouling assemblage including one NIS mussel species on the vessel that had not been recently cleaned. An initial step in assessing the potential risk of invasions by NIS associated with ship's hulls is to characterize ship arrivals with regard to risk factors such as voyage history, time spent in port, vessel type, and the distribution and nature of shipping intensity among ports. Another information-gathering step is to summarize information about hull cleaning and maintenance practices of major vessel types that comprise potential vectors for NIS. This information can be used to evaluate the scale of risk of introductions by fouling organisms among various vessel types, routes, and ports, and can help to identify the regions likely to contribute NIS. This approach can help to focus subsequent efforts that target specific risk factors. Understanding hull fouling associated invasion risk ultimately requires measuring biota associated with hulls. This type of analysis can range from low resolution data gathered from archived hull maintenance video to comprehensive remote-operated vehicle or diver surveys (the latter can include physical samples of fouling communities), but costs for these kinds of analyses increase greatly with increases in data quality and quantity. Thus, initial analyses of shipping patterns, hull maintenance practices, and the pros and cons of various hull fouling sampling methods can help prioritize how to focus more intensive and comprehensive sampling efforts. In this report, we examine these factors, with particular regard to Prince William Sound, Alaska.

The overall goals of this project were as follows:

- Evaluate 2005-2008 vessel arrival data for ports in Prince William Sound and the Ports of Kodiak and Seward (henceforth termed ports of interest).
- Conduct an initial assessment of tankers traveling to Prince William Sound, by evaluating maintenance schedules and periodicity and location of hull cleaning.
- Summarize the literature on hull fouling studies and hull sampling techniques, and related topics such as remote assays of organisms for other purposes.
- Based on the results, evaluate and recommend sampling and analysis protocols that can be used in studies of hull fouling in the region.

# Shipping Data

## *Methods*

The Ship Arrival Notification System (SANS) is a database that provides advance notice of arrival and departure information from vessels coming to port in the United States. Vessel Notice of Arrival Reports (NOA) that are compiled by SANS record information received from a vessel's owner, operator, or agent relating to the arrival and departure of vessels. Data includes details about vessels, reporting party, arrival and departure times, voyage information, crew, passenger and cargo manifest, previous ports visited, and ship security and safety certifications. According to 33 CFR 160, certain vessels are required to submit NOAs to the National Vessel Movement Center (NVMC), operated by the US Coast Guard. All US and foreign vessels bound for or departing from ports or places the US must submit NOAs; however there are numerous exemptions. Vessels that are not required to submit NOAs include, but are not limited to: (1) US recreational vehicles; (2) passenger and supply vessels engaged in the exploration for or removal of oil, gas, or mineral resources on the continental shelf; (3) oil spill recovery vessels engaged in spill response operations or exercises; (4) vessels 300 gross tons or less, unless carrying dangerous cargo; (5) vessels operating exclusively within a Captain of the Port Zone, unless carrying dangerous cargo; (6) towing vessels and barges operating solely between ports or places within the continental US, unless carrying dangerous cargo; and (7) public vessels. Due to these exemptions, gaps in the data may exist and the SANS database should not be considered an exhaustive record of all shipping traffic. The SANS database is, however, the most extensive database available.

Ship arrival data was obtained from the SANS for the years 2005-2008. We specifically requested data for the ports of Cape Hinchinbrook, College Fjord, Cordova, Kodiak, Prince William Sound (No port given), Seward, Tatitlek, Valdez and Whittier. These ports are henceforth referred to as the ports of interest.

The raw data received included information on the port of arrival, date and time of arrival, vessel name, date and time of departure, previous ports visited, and the time of arrival to and departure from the previous ports. The data was processed to eliminate repeat entries, and to ensure that arrival and departure times were in logical sequence.

Each entry was assigned one of the following voyage types: domestic, west coast, transpacific, other, west coast-domestic, transpacific-domestic and transpacific-west coast-domestic. Domestic voyages were those that had not reported visiting ports outside of Alaska. West coast voyages were those confined to the east Pacific. Transpacific voyages were those that had crossed a significant portion of the Pacific, including Asia, Australia, French Polynesia, and Hawaii. 'Other' voyages were those that did not fit into the other main categories, and included Europe, the Gulf of Mexico, and Africa. The multiple voyage type categories (west coast-domestic, transpacific domestic, and transpacific-west coast-domestic) were of special note, as the hulls of vessels from these types of voyages might have been exposed to a diverse array of potential fouling organisms.

Each entry was also assigned a vessel category which included fishing boat, tank ship, freight ship, passenger vessel, towing vessel, and other. Freight ships included any type of cargo ship. The “other” category was used for any vessel that did not fit into the other main categories, and included recreational vessels, research vessels, and cable ships.

A second database was created in which all previous port entries were tagged with a keyword. The keywords included Northwest (NW); British Columbia (BC); Puget Sound area (Puget); Oregon (OR); San Francisco Bay area (San Francisco); Mexico; South America; Central America; Pacific Islands and Australia (South Pacific); Asia; Japan; South Korea; Singapore; China; India; Russia; Malaysia; and Vietnam.

## Data Categories

The data was arranged in a the following ways to highlight potential trends :

- total number of vessel arrivals per year.
- total number of different voyage types for all arrivals per year.
- voyage history of all arrivals per year.
- duration of time in port for each arrival, per year.
- total number of vessel arrivals per year, by port.
- average number of each vessel type arriving to each port of interest.
- average number of different voyage types for each port of interest.
- average voyage history of all arrivals, by Port.
- total number of vessel arrivals per year, by vessel type.
- average number of repeat visits for each vessel type.
- duration of time in port for each arrival of each vessel type, per year.

- average number of different voyage types for each vessel type.
- average voyage history of all arrivals, by vessel type.

# Results

## *All ports combined*

### Ship arrivals by year.

The number of total vessel arrivals declined from 2005 to 2008, with the sharpest drop in 2006 (Figure 1).

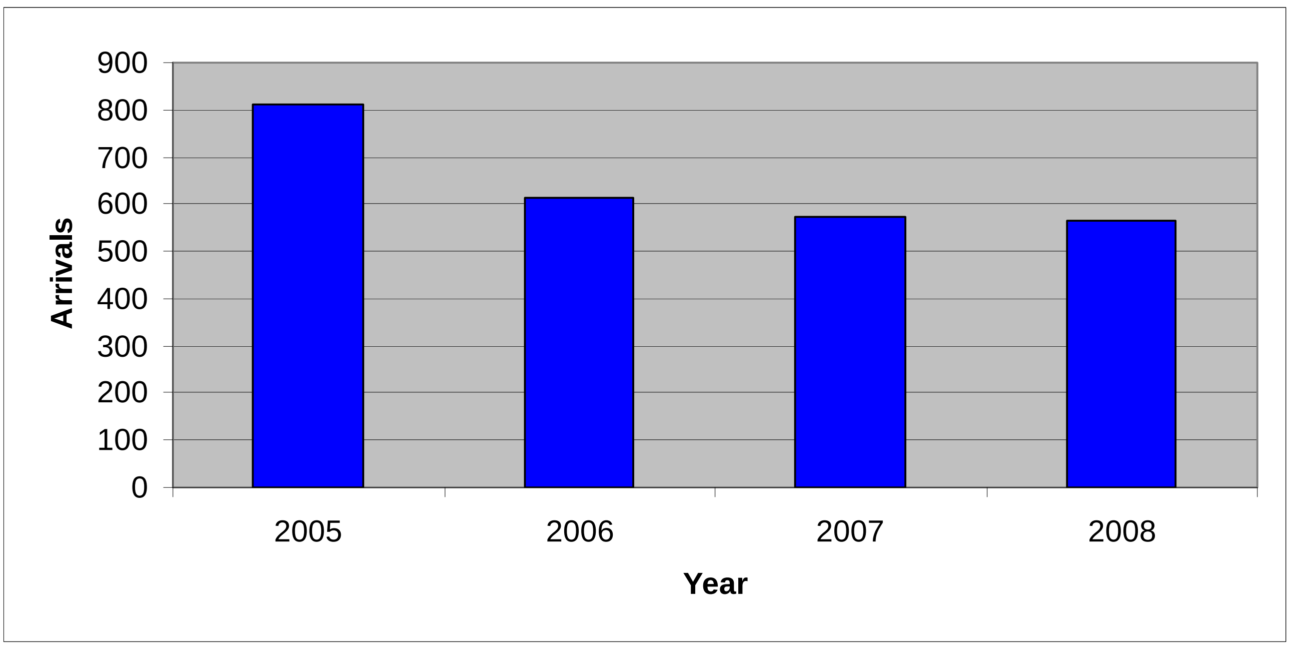


Figure 1. Total vessel arrivals per year to Alaska ports of interest 2005-2008.

### Voyage types by year

The majority of incoming arrivals originated from the west coast. Domestic voyages were the next most common type of arrival, followed by transpacific voyages. Total west coast voyages (which include west coast-domestic voyages) decreased in 2006, and then stabilized. Total domestic voyages decreased in 2007 and stabilized in 2008. Total transpacific voyages (which include all multiple voyage types that had a transpacific component) did not change through the study period (Figure 2).

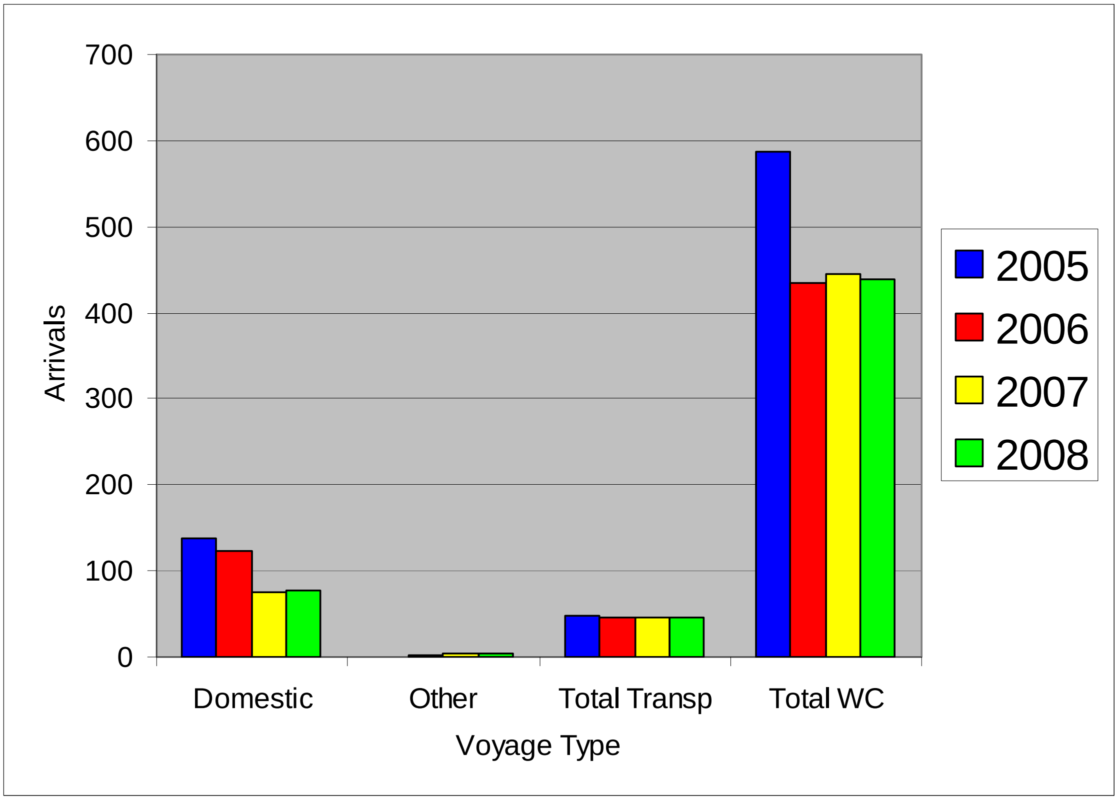


Figure 2. Number of voyage types per year to Alaska ports of interest 2005-2008. Domestic = voyages within Alaska, Transp = transpacific voyages, WC = voyages from the west coast of North America, excluding domestic voyages.

### Voyage histories

The most commonly visited way-points on voyages were located in the Pacific Northwest region of the United States and British Columbia (PNW), with an average of 469 visits (Figure 3, Appendix Table 1). Within this region, the Puget Sound area was the most commonly visited with 253-390 visits per year, followed by British Columbia with 153-195 visits per year, and Oregon with 13-39 visits per year (Figure 4, Appendix Table 1). The San Francisco Bay area was the next most commonly visited region with an average of 165 visits, followed by Southern California with an average of 100 visits. There was little difference in the visit frequencies of the other four regions; Asia had an average of 34 visits, Mexico an average of 24 visits, the South Pacific an average of 19 visits and ‘other’ locations had an average of 13.5 visits (Figures 3, 5, Appendix Table 1). There was a general decline in waypoint visits over the study period to the Pacific Northwest, San Francisco, Southern California, and Asia regions, and a small increase in visits over the study period to the South Pacific, Mexico and ‘other’ regions (Figure 3, Appendix Table 1).

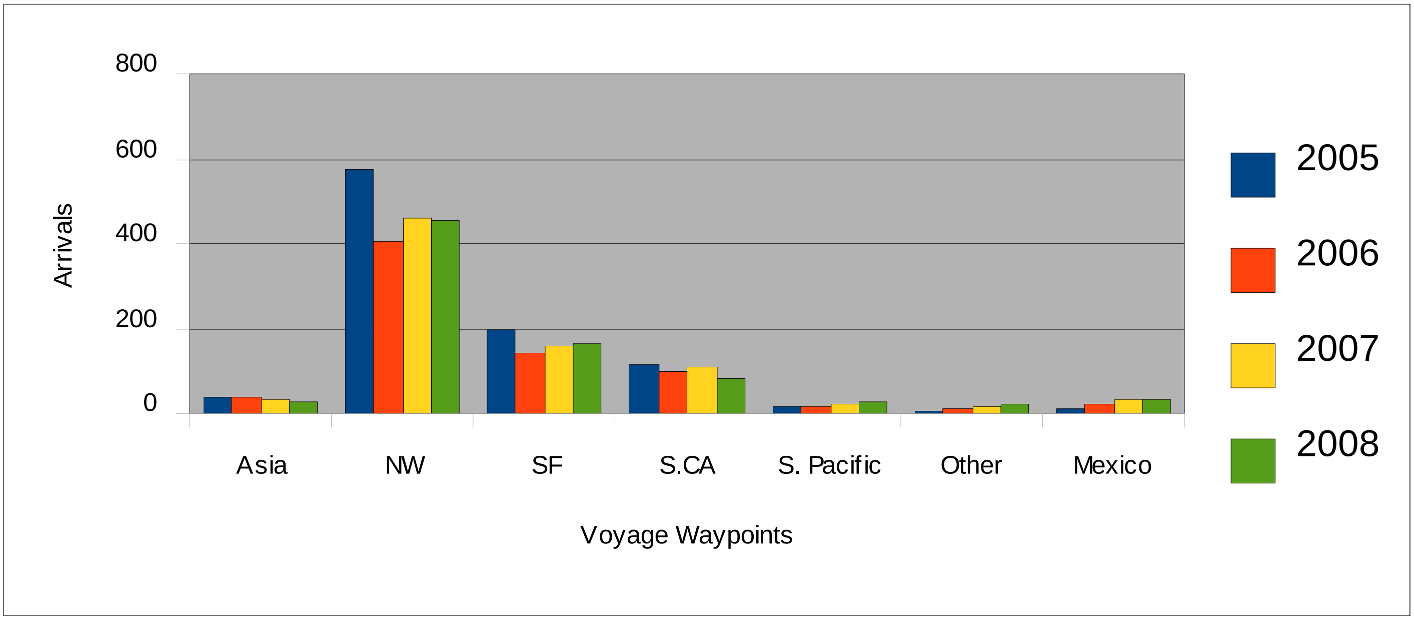


Figure 3. Voyage history of all arrivals per year to Alaska ports of interest 2005-2008. NW = Pacific northwest of United States + British Columbia, SF = San Francisco Bay area, S. CA = southern California.

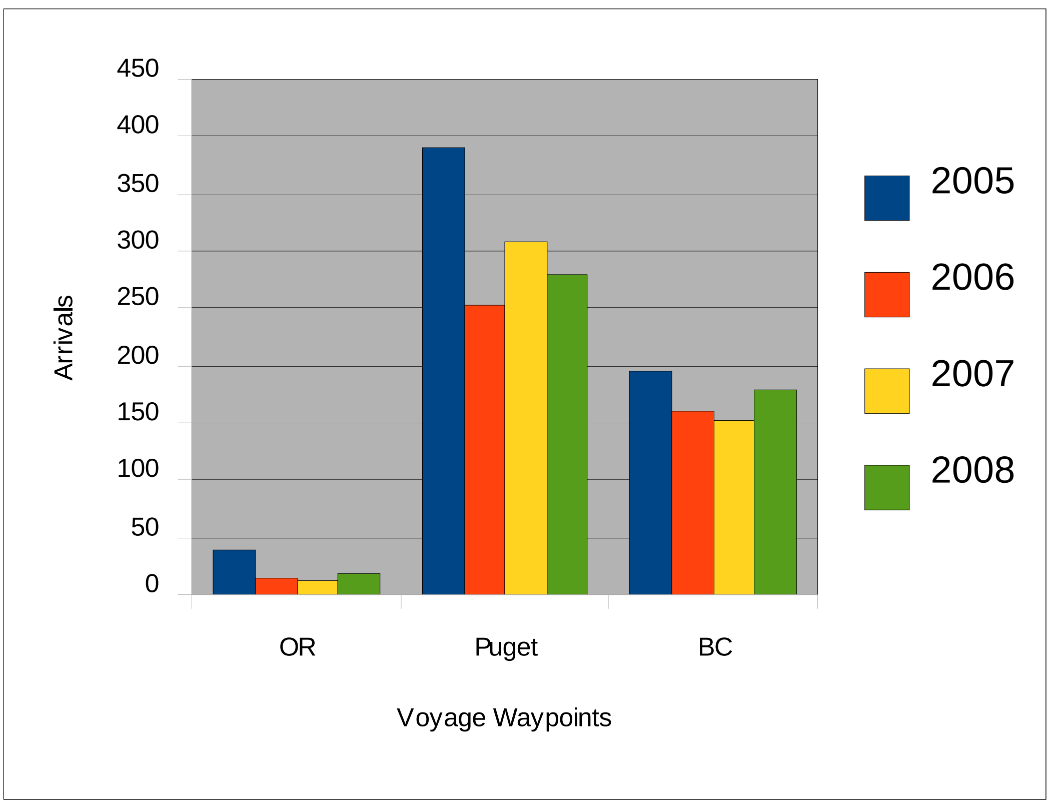


Figure 4. Voyage histories of vessels entering Alaskan ports of interest from the Pacific northwest United States and British Columbia 2005-2008. OR = Oregon, Puget = Puget Sound, Washington, BC = British Columbia.

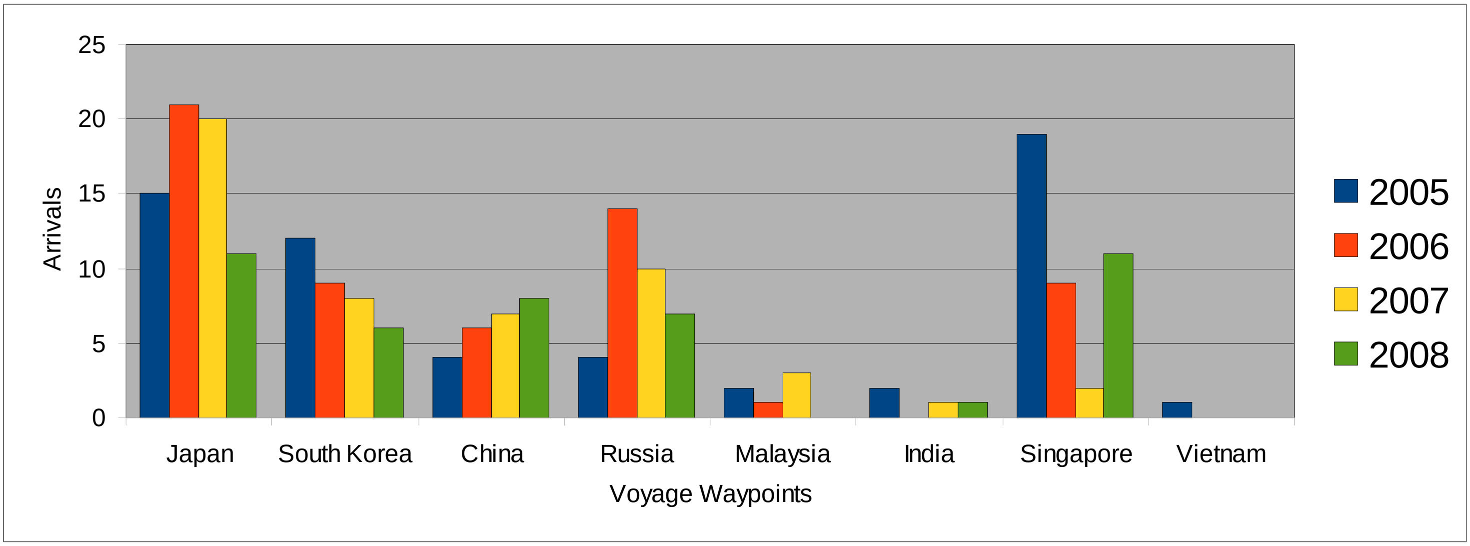


Figure 5. Voyage histories of vessels entering Alaskan ports of interest from Asia 2005-2008.

### Duration of time in port

The majority of arrivals stayed in port for less than 24 hours (455-572 arrivals per year). The number of vessels in port for 24-48 hours was much lower (44-131 arrivals per year) and the lowest number of vessels were in port for 48-72 hours (9-25 arrivals). There was a small increase in the number of arrivals staying in port for longer than 72 hours (30-39 arrivals). There was a general decrease over the course of the study period in number of vessels staying in port for 0-24, 24-48, and 48-72 hours, while the numbers of vessels in the >72 hour category was similar among years. The sharpest decreases occurred in 2006 (Figure 6)

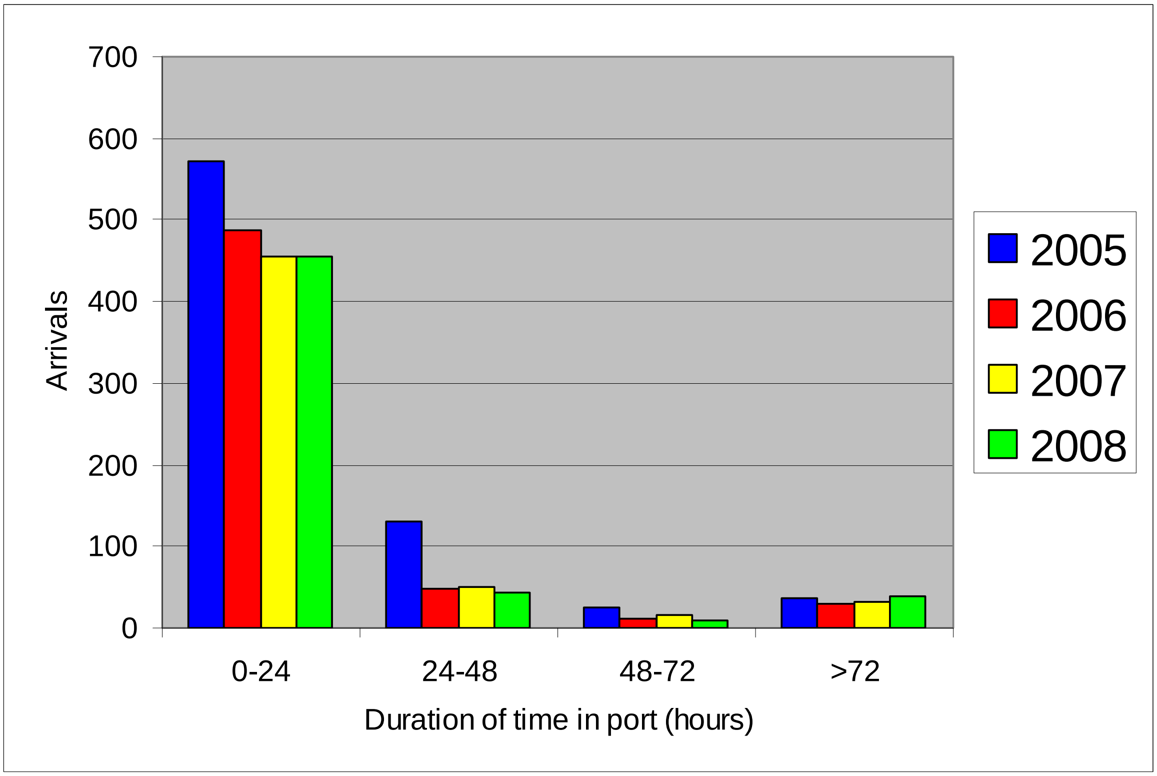


Figure 6. Duration in port of all vessel arrivals to Alaskan ports of interest, 2005-2008.

## *By port*

### Ship arrivals by year and port.

Valdez had the majority of arrivals from 2005-2008 (299-414 arrivals, average = 335.75 per year), followed by much lower arrival numbers at Whittier (87-122 arrivals, average = 103.5 per year), Kodiak (75-138 arrivals, average = 97.5 per year), and Seward (64-81 arrivals, average = 72.75 per year) (Figure 7). Ports of interest with the lowest arrival rates were: Prince William Sound (11-16 arrivals, average = 13.25 per year), Cordova (4-12 arrivals, average = 7.25 per year), Cape Hinchinbrook (1-16 arrivals, average = 5.75 per year), College Fjord (0-16 arrivals, average = 4.25 per year) and Tatilek (0-6 arrivals, average = 1.5 per year). There was a general decrease in arrivals over the course of the study in the ports of Valdez, Kodiak and Whittier. The majority of this drop occurred in 2006, with Valdez experiencing the largest decrease in arrivals (Appendix Table 2).

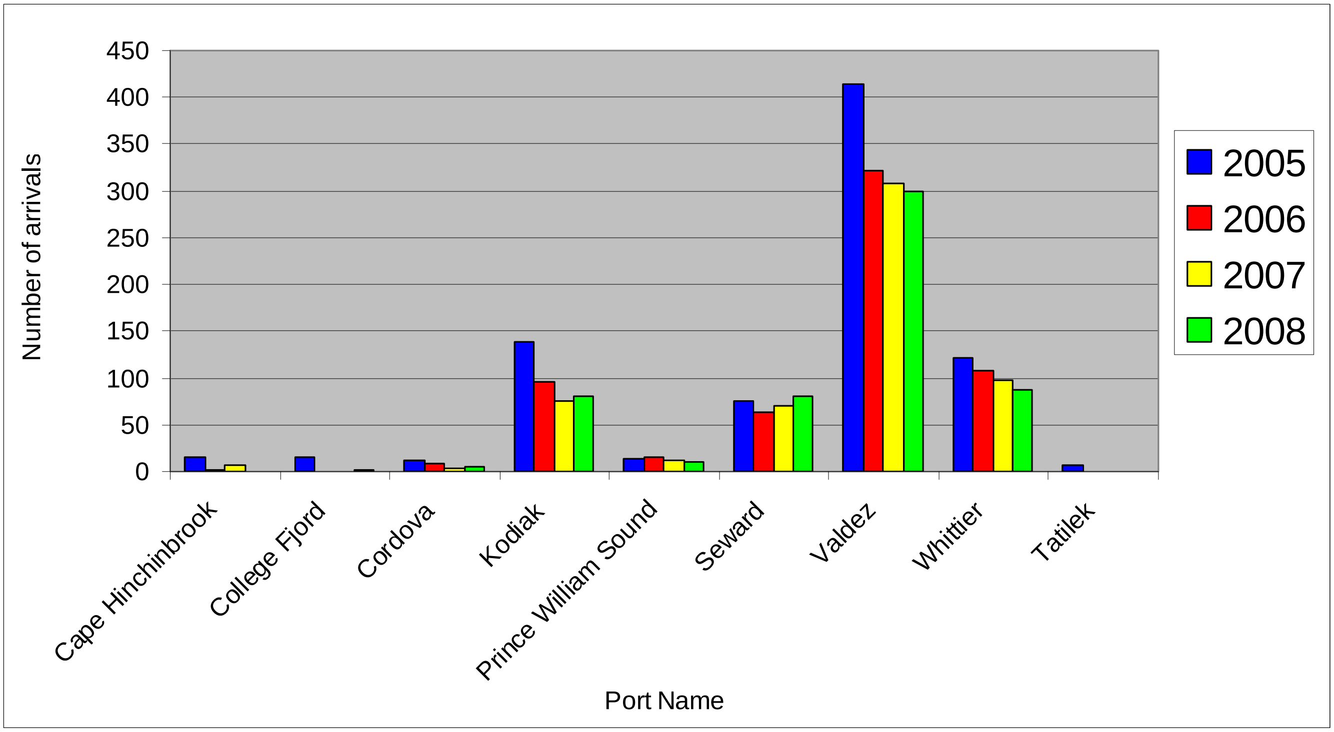


Figure 7. Total arrivals to each port of interest per year, 2005-2008.

**Ship types by port**

Tank ships comprised the greatest proportion of arrivals on average in Valdez (94.7% of the total), which represented 96.7% of total tank ship arrivals (Table 1, Figure 8). Whittier's arrivals on average were almost exclusively passenger vessels and towing vessels (63.0% and 35.0% of Whittier traffic, respectively) which represented 45.0% of total passenger vessel arrivals and 65.9% of total towing vessel arrivals. The largest proportion of arrivals to Kodiak were freight ships, followed by fishing boats (53.6% and 27.4% of Kodiak traffic, respectively), which represented 79.5% of the total freight ship arrivals and 63.3% of fishing boat arrivals. Seward's traffic was mainly composed of passenger vessels (77.3% of Seward traffic), which represented 38.8% of total passenger vessel arrivals. (See Appendix Table 2 for yearly counts).

Table 1. Average number of each vessel type per year arriving to Alaskan ports of interest, 2005-2008.

| Ship Type | Cape Hinchinbrook | College Fjord | Cordova | Kodiak | PWS | Seward | Valdez | Whittier | Tatilek | Total Result |
|---|---|---|---|---|---|---|---|---|---|---|
| Fishing | 0.0 | 0.0 | 3.0 | 26.8 | 5.8 | 3.3 | 2.3 | 1.3 | 0.0 | 42.3 |
| Freight | 0.0 | 0.0 | 0.3 | 52.3 | 2.0 | 7.5 | 3.3 | 0.5 | 0.0 | 65.8 |
| Passenger | 0.0 | 4.3 | 2.0 | 10.3 | 0.5 | 56.3 | 5.0 | 65.3 | 1.5 | 145.0 |
| Tank | 5.8 | 0.0 | 0.0 | 0.0 | 4.8 | 0.3 | 318.0 | 0.3 | 0.0 | 329.0 |
| Towing | 0.0 | 0.0 | 1.8 | 6.0 | 0.0 | 3.8 | 7.3 | 36.3 | 0.0 | 55.0 |
| Other | 0.0 | 0.0 | 0.3 | 2.3 | 0.3 | 1.8 | 0.0 | 0.0 | 0.0 | 4.5 |
| Grand Total | 5.8 | 4.3 | 7.3 | 97.5 | 13.3 | 72.8 | 335.8 | 103.5 | 1.5 | 641.5 |

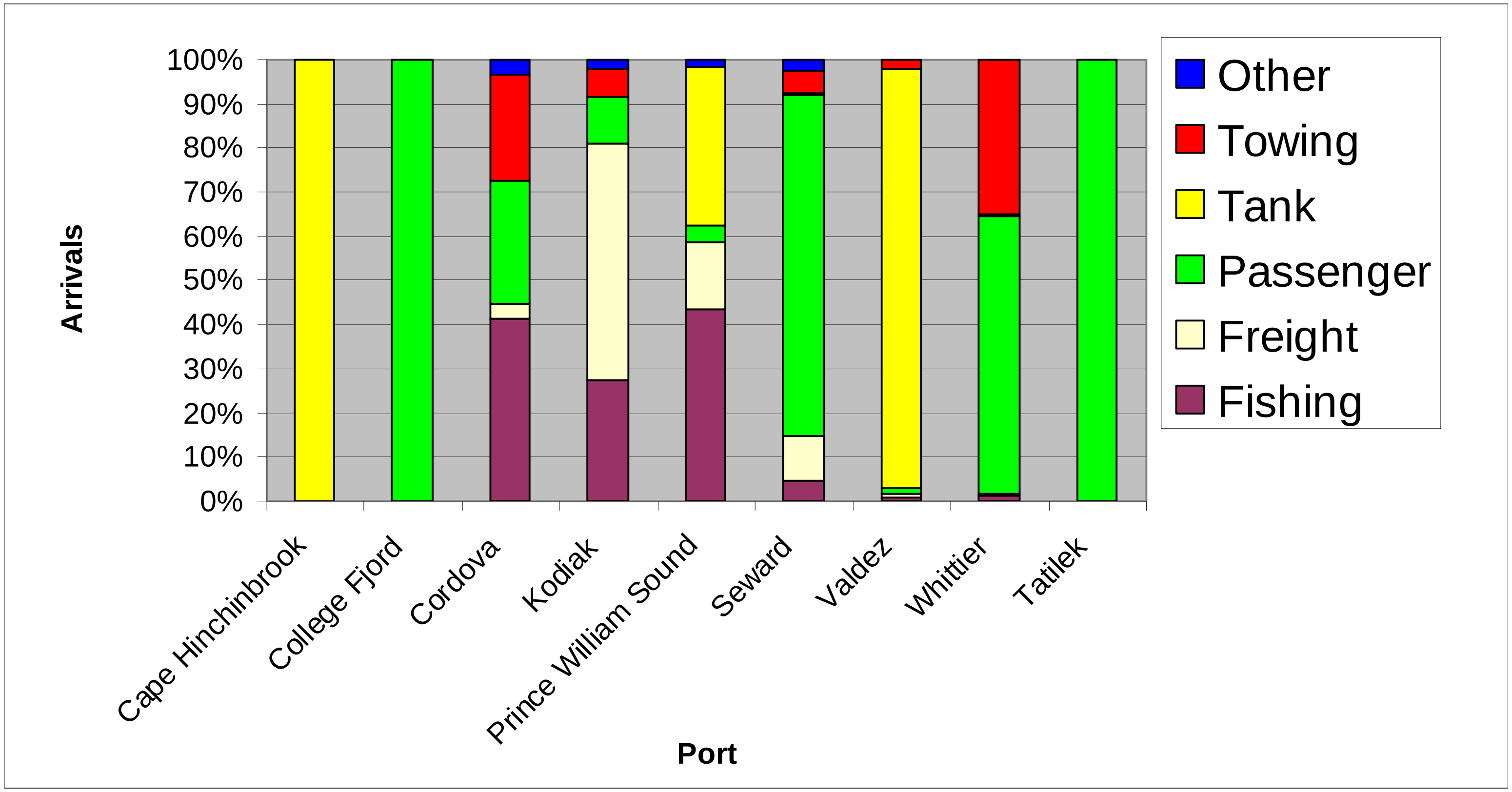


Figure 8. Percent composition of vessel traffic to Alaskan ports of interest, 2005-2008.

### Voyage types by port

Total west coast voyages (combining west coast and west coast-domestic voyages) accounted for the majority of arrivals in Valdez, Whittier, Seward, Prince William Sound (No port given), College Fjord, Cape Hinchinbrook and Tatilek. Cordova and Kodiak were the only two ports where domestic voyages accounted for the majority of arrivals. Total transpacific voyages arrived mainly to (in order of prevalence) the ports of Valdez, Seward, Whittier and Kodiak (Figure 9). (See Appendix Table 3 for yearly counts).

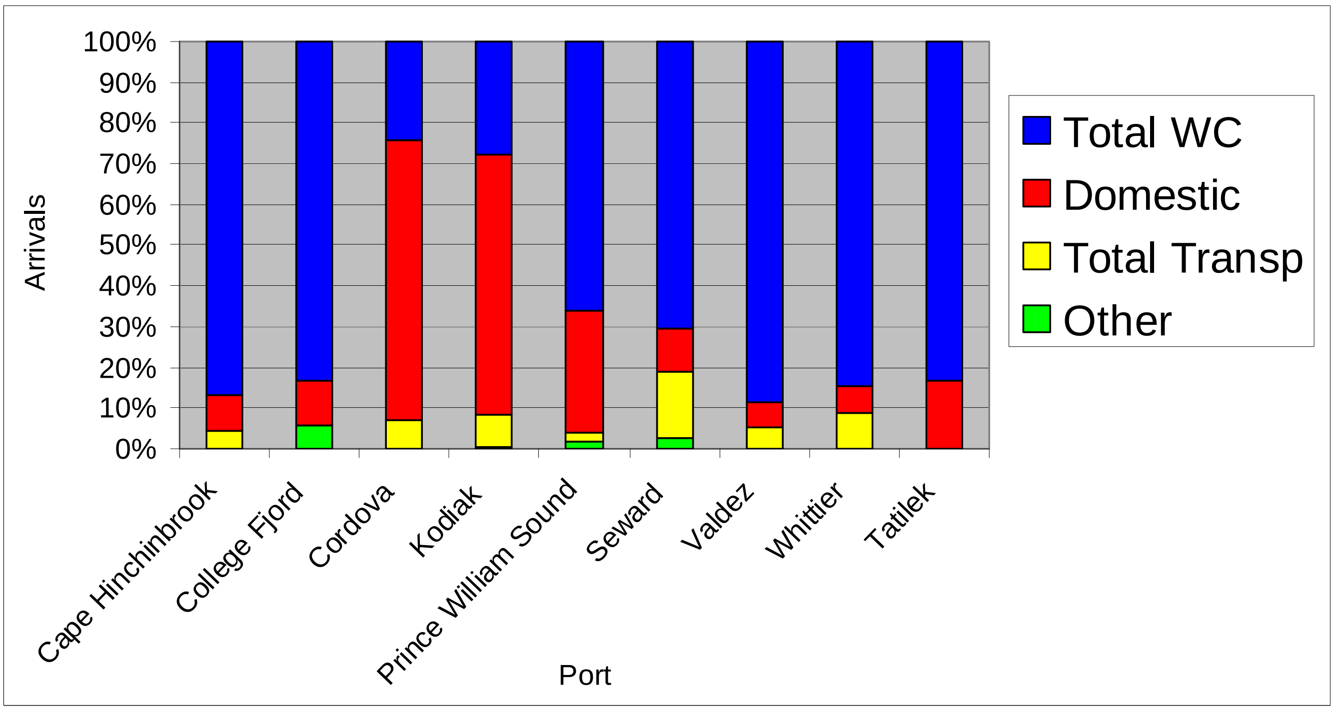


Figure 9. Percent composition of voyage types for vessels entering Alaskan ports of interest, 2005-2008. Domestic = voyages within Alaska, Transp = transpacific voyages, WC = voyages from the west coast of North America, excluding domestic voyages.

### Voyage histories by port

On average, vessels that stopped in the PNW were the most frequent contributors to total arrivals at every port of interest (Figure 10). Valdez received the large majority of these vessels, followed by Whittier, Seward and Kodiak. Vessels that stopped in the San Francisco region were on average the next most frequent contributors to total arrivals, and most of these entered Valdez (Figure 10). Vessels that stopped in the Southern California region were the third most frequent contributor to total arrivals, and also visited Valdez almost exclusively (Figure 10). Vessels that stopped in Asia, Mexico, and ‘other’ areas contributed a small fraction to total arrivals. Vessels from Asia arrived mainly to Valdez, Seward, Kodiak and Whittier; vessels from Mexico arrived mainly to Seward and Whittier; and vessels from ‘other’ regions arrived mainly to Seward and Whittier (Figure 10).

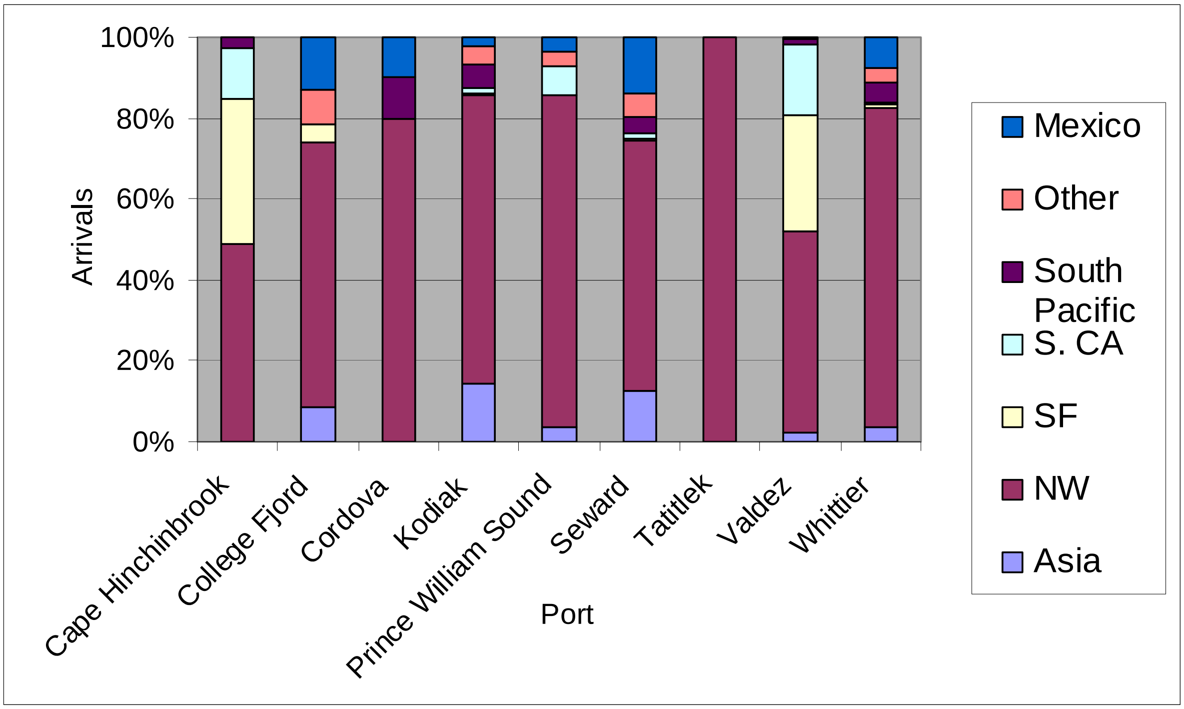


Figure 10. Percent composition of voyage histories for vessels entering Alaskan ports of interest, 2005-2008. NW = Pacific northwest of United States + British Columbia, SF = San Francisco Bay area, S. CA = southern California.

## *Voyage histories by vessel type*

### Number of arrivals by year

Tank ships were the largest contributors to total arrivals from 2005 to 2008, followed by passenger vessels, freight ships, towing vessels, fishing boats, and ‘other’ types of vessels, respectively (Appendix Table 2, Figure 11). There was a decline in 2006 in total arrivals of tank, passenger, freight and towing vessels, while arrivals of fishing boats and ‘other’ vessels were similar throughout the study period. Tank ship arrivals declined throughout the study period and had the greatest decrease (Appendix Table 2, Figure 11).

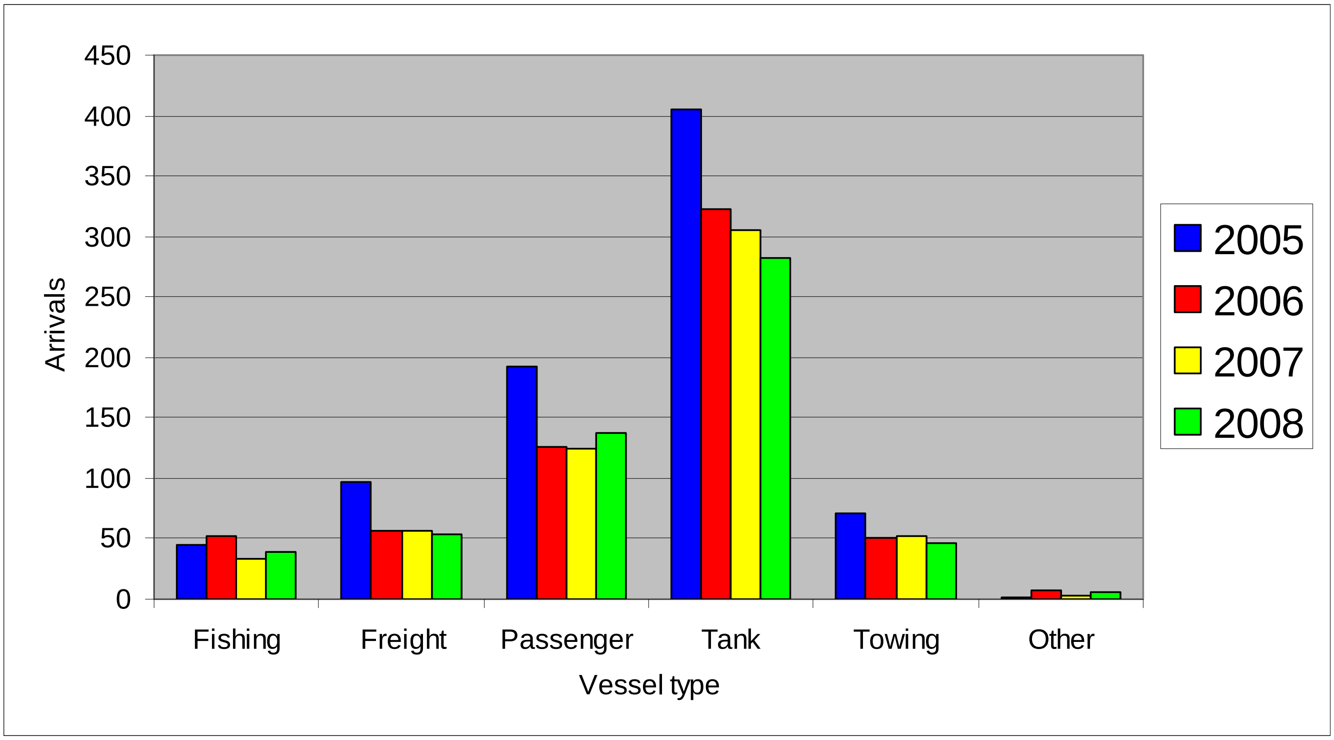


Figure 11. The total arrivals of each vessel type per year for vessels entering Alaskan ports of interest, 2005-2008.

**Number of repeat visits by vessel type.**

Tank ships had the highest rate of repeat visits for 2005 to 2008 (average = 13.46 – 17.6 visits per year per vessel, maximum = 24 – 30 visits per year—Table 2). Passenger vessels had the next highest rate of repeat visits (average = 6.2 – 7.4 visits per year per vessel, maximum = 10 – 25 visits per year). Towing and freight vessels had similar rates of repeat visits (Towing: average = 3.7 – 5.1 visits per year per vessel, maximum = 21 – 31 visits per year; freight: average = 3.1 – 5.1 visits per year per vessel, maximum = 31 – 34 visits per year; Table 2.

Table 2. Average and maximum number of visits to Alaskan ports of interest 2005-2008 by vessel type.

| Average | | Fishing | Freight | Passenger | Tank | Towing |
|---|---|---|---|---|---|---|
| | 2005 | 1.47 | 5.09 | 7.41 | 15.92 | 5.07 |
| | 2006 | 2.00 | 3.23 | 6.63 | 13.46 | 4.33 |
| | 2007 | 1.26 | 3.56 | 6.20 | 16.11 | 3.71 |
| | 2008 | 2.00 | 3.11 | 6.23 | 17.63 | 4.08 |

| Maximum | | Fishing | Freight | Passenger | Tank | Towing |
|---|---|---|---|---|---|---|
| | 2005 | 8 | 34 | 25 | 30 | 25 |
| | 2006 | 5 | 31 | 11 | 26 | 21 |
| | 2007 | 3 | 33 | 10 | 28 | 31 |
| | 2008 | 6 | 33 | 23 | 24 | 22 |

## Duration of time in port

The majority of tank ships left port in less than 24 hours (61%-86%). The number of arrivals staying in port 24-48 hours decreased to 10-31% of the arrivals (Table 3). The number of tank ship arrivals staying in port continued to decrease as time increased. There was a dramatic drop in total tank ship arrivals in 2006, mostly in the 24-48 hours category (Table 3).

Almost all passenger vessels over the course of the study left port in less than 24 hours (89%-99%) (Table 3).

The majority of freight ships left port in less than 24 hours (69%-84%) (Table 3). The number of freight vessels remaining in port was relatively low for the other time categories, but increased slightly in the >72 hour category (12%-20%).

The majority of towing vessels left port in less than 24 hours (74%-90%) (Table 3).

In 2005 and 2006, the majority of fishing boats left port in less than 24 hours, but the number dropped sharply in 2007 and 2008 (76%-30%) (Table 3). The number of fishing boats remaining in port was relatively low for the other time categories, except in 2007 and 2008, when a large portion of fishing boats stayed in port longer than 72 hours (Table 3).

Vessels staying in port more than 72 hours were comprised mainly of tank ships in 2005 (Table 3,

Figure 12). In 2006, this category was made up of mostly passenger vessels. In 2007 and 2008, fishing vessels had the greatest number of arrivals staying more than 72 hours. Freight ships had the most consistent among-year numbers of arrivals staying more than 72 hours.

Table 3. Duration in port (hours) of arrivals to Alaskan ports of interest 2005-2008 by vessel type.

| **2005** | **Fishing** | **Freight** | **Passenger** | **Other** | **Tank** | **Towing** | **Total Result** |
|---|---|---|---|---|---|---|---|
| **0-24** | 25 | 78 | 177 | 0 | 239 | 53 | 572 |
| **24-48** | 2 | 1 | 3 | 0 | 121 | 4 | 131 |
| **48-72** | 2 | 3 | 1 | 0 | 19 | 0 | 25 |
| **>72** | 5 | 11 | 3 | 1 | 14 | 2 | 36 |
| | | | | | | | |
| **2006** | **Fishing** | **Freight** | **Passenger** | **Other** | **Tank** | **Towing** | **Total Result** |
| **0-24** | 28 | 40 | 116 | 0 | 264 | 39 | 487 |
| **24-48** | 3 | 4 | 1 | 1 | 33 | 6 | 48 |
| **48-72** | 1 | 1 | 1 | 0 | 7 | 1 | 11 |
| **>72** | 5 | 6 | 12 | 4 | 3 | 0 | 30 |
| | | | | | | | |
| **2007** | **Fishing** | **Freight** | **Passenger** | **Other** | **Tank** | **Towing** | **Total Result** |
| **0-24** | 15 | 43 | 116 | 1 | 243 | 37 | 455 |
| **24-48** | 3 | 0 | 2 | 1 | 41 | 6 | 53 |
| **48-72** | 0 | 4 | 0 | 1 | 11 | 1 | 17 |
| **>72** | 12 | 9 | 1 | 0 | 5 | 4 | 31 |
| | | | | | | | |
| **2008** | **Fishing** | **Freight** | **Passenger** | **Other** | **Tank** | **Towing** | **Total Result** |
| **0-24** | 7 | 40 | 136 | 0 | 239 | 34 | 456 |
| **24-48** | 5 | 0 | 1 | 1 | 29 | 8 | 44 |
| **48-72** | 1 | 2 | 0 | 1 | 3 | 2 | 9 |
| **>72** | 16 | 12 | 0 | 4 | 6 | 1 | 39 |

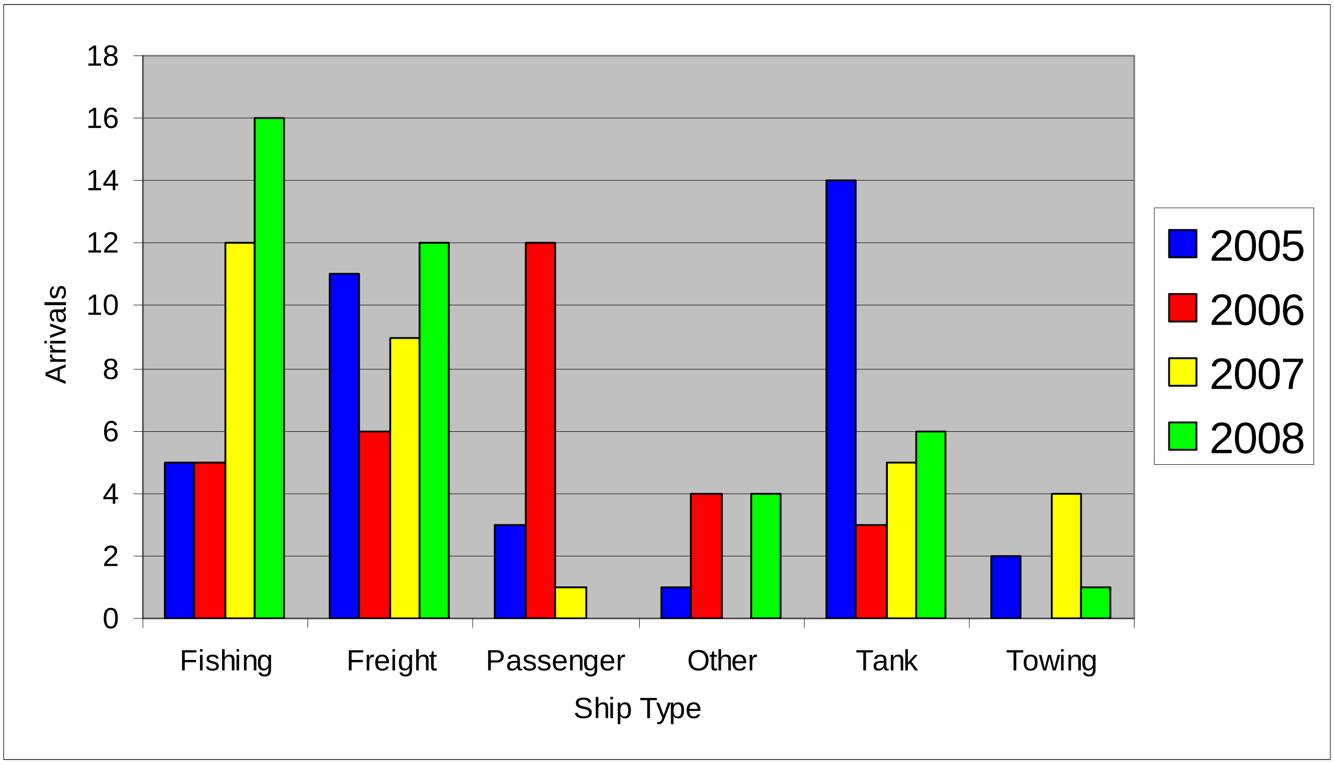


Figure 12. The number of arrivals of each vessel type staying in port more than 72 hours, for vessels entering Alaskan ports of interest, 2005-2008.

### Voyage types by vessel type

Total west coast voyages (combining west coast and west coast-domestic voyages) accounted for the majority of tank, passenger, and towing vessel arrivals (Table 4, Figure 13). Domestic voyages accounted for the majority of freight and fishing vessel arrivals. Total transpacific voyages accounted for the majority of 'other' types of vessels, although most of the transpacific voyages occurred in passenger, tank and freight vessels. (See Appendix Table 4 for yearly counts).

Table 4. Average number of each voyage type by vessel type, for arrivals to Alaskan ports of interest 2005-2008. Transp = transpacific voyages, WC = voyages from the west coast of North America, excluding domestic voyages.

| | Other | Fishing | Freight | Passenger | Tank Ship | Towing | **Total** |
|---|---|---|---|---|---|---|---|
| Domestic | 0 | 24.75 | 39.75 | 16.25 | 15.25 | 7.5 | 103.5 |
| Other | 0.5 | 0 | 0.25 | 1.5 | 0.25 | 0.75 | 3.25 |
| Total Transp | 2.75 | 0.25 | 11.5 | 16.75 | 14 | 1.5 | 46.75 |
| Total WC | 1.25 | 16.25 | 11.25 | 110.5 | 292 | 45.25 | 476.5 |

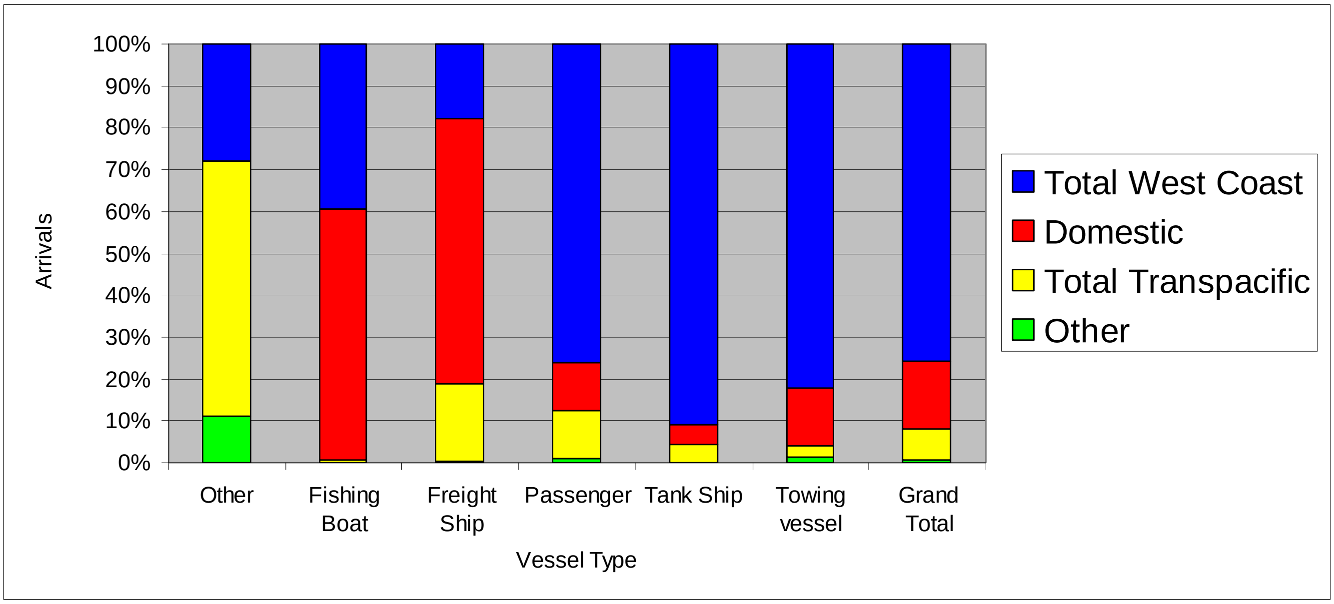


Figure 13. Percent composition of voyage types by vessel type, for vessels entering Alaskan ports of interest, 2005-2008.

### Voyage history by vessel type

Vessels that had stopped in the PNW accounted for the greatest portion of arrivals in all vessel types. The next highest contributors to total arrivals were vessels that had stopped in the San Francisco Bay area, and these vessels were almost exclusively tank ships. Vessels stopping in the Southern California region were the third highest contributors to total arrivals, and these also occurred almost exclusively in tank ships. Vessels stopping in Asia, Mexico and 'other' regions contributed only a small fraction to total arrivals. Vessels from Asia were mostly freight, passenger and tank vessels and those from Mexico were mostly passenger vessels. Vessels from 'other' regions were mostly passenger and freight vessels (Table 5, Figure 14). (See Appendix Table 5 for yearly counts).

Table 5. Average numbers of each voyage history type for arrivals to Alaskan ports of interest 2005-2008 by vessel type. NW = Pacific northwest of United States + British Columbia, SF = San Francisco Bay area, S. CA = southern California.

| | Fishing | Freight | Passenger | Tank | Towing | Other | Total |
|---|---|---|---|---|---|---|---|
| **Asia** | 0.25 | 11.5 | 11.25 | 9 | 0.5 | 1.5 | 34 |
| **NW** | 12.5 | 13.5 | 125.75 | 269 | 47 | 1.75 | 469.5 |
| **SF** | 0.25 | 0 | 1.25 | 163 | 0.5 | 0 | 165 |
| **S. CA** | 0 | 0.5 | 1.5 | 98.25 | 0 | 0.5 | 100.75 |
| **South Pacific** | 0.25 | 1.5 | 7.25 | 6.5 | 1.25 | 2.25 | 19 |
| **Other** | 0.25 | 2.75 | 6.75 | 0.25 | 2 | 1.5 | 13.5 |
| **Mexico** | 0 | 0.75 | 21 | 0.25 | 0.75 | 1.25 | 24 |

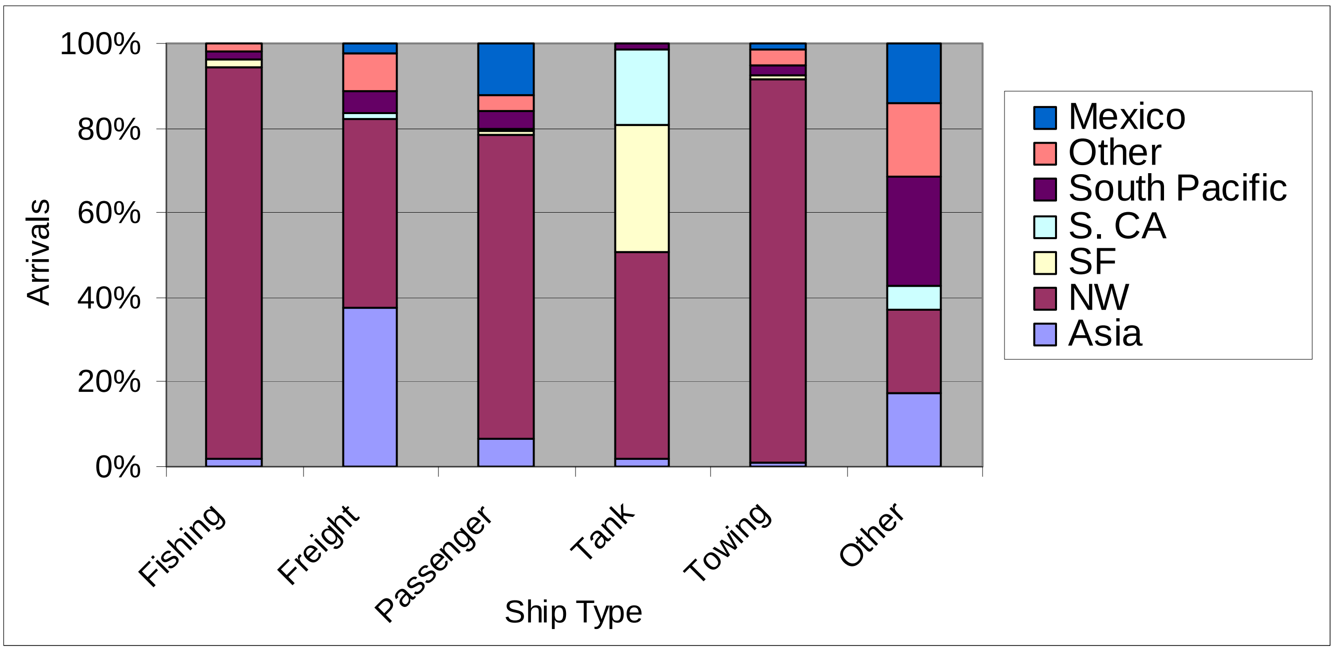


Figure 14. Percent composition of voyage histories by vessel type, for vessels entering Alaskan ports of interest, 2005-2008. NW = Pacific northwest of United States + British Columbia, SF = San Francisco Bay area, S. CA = southern California.

## Conclusions

The most striking observation of this study is the large drop in all types of vessel arrivals to all ports of interest in 2006, except for fishing boats and the port of Prince William Sound (No port given). These two categories of arrivals remained at similar levels through the study period. The only total arrival category showing increase in arrivals from 2005-2008 was the port of Seward, and the increase was small. The ports of Cape Hinchinbrook, College Fjord, Cordova, Kodiak, Valdez and Tatilek all experienced decreasing arrivals from 2005-2008, as have the ship categories of freight, passenger, tank and towing vessels. The largest decreases were in tank ship arrivals to the port of Valdez.

The largest drop in tank ship arrivals occurred in 2006, which was accompanied by a decrease in tank ship repeat visits. It is possible that in 2006 there was the same number of tank ships as in 2005, but making fewer visits. In 2007, it appears that the tank ships returned to a normal visitation schedule, though arrival numbers continued to shrink. This continued shrinking may be due to a decline in the number of different tank ships operating within the area. A similar story may account for the case of freight ships as well.

It should also be noted that the number of fishing vessel arrivals may be artificially low, due to the absence of SANS data for vessels weighing less than 300 gross tons. Small vessels may play an important role as vectors of hull fouling, but poor documentation makes their relative importance difficult to quantify. Some fishing vessel arrival information may be obtained from catch reports and by requesting documents from individual harbormasters, but this would be difficult and labor-intensive. Similarly undocumented in the SANS data are privately owned recreational vessels weighing less than 300 gross tons. Floerl (2002) noted the high potential for recreational vehicles to act as fouling vectors, since such vessels typically have long harbor residency times, and because there is less financial incentive to regularly clean underwater surfaces and maintain the anti-fouling paint. Out of 70 private vessels surveyed in the 2002 study, 38% had over 75% of their hulls fouled (Floerl 2002). While it is known that many fishing and private vessels travel to Alaska from other US west coast ports, further study is needed to assess the potential risks posed by these vessels.

### Risk based on visitation patterns (time in port vs frequency)

There appears to be an inverse relationship between the amount of time spent in port by a vessel, and the frequency of that vessel’s return. This is indicative of two categories of vessels: those that have set routes and make numerous brief return trips to the same port, and those that return to port infrequently but stay in port for long periods of time. The first type presents a risk of repeat inoculations of NIS (potential high propagule frequency), and the second represents risk based on less frequent potential inoculations with longer “incubation” time for NIS to release numerous propagules (potential high propagule volume).

Tank ships and passenger vessels represent the high frequency risk category. Tank ships had by far the highest average return frequencies, but also had very low times spent in-port (up to 96% of all tank ships left port in less than 48 hours and up to 86% left port in under 24 hours). Passenger vessels had high average return frequencies and low times spent in port (up to 99% of all passenger vessels leave port in less than 24 hours). Thus, these two vessel types represent relatively high risk based on potential frequency of inoculation and relatively low risk based on potential per-vessel volume of inoculation. Another risk factor for these two vessel types is that they are most often from west coast/west coast-domestic voyages. These types of voyages are shorter than transpacific voyages, with shorter exposure to oligotrophic, open ocean water that may be detrimental to coastal fouling organisms. Most tank ship arrivals have originated or stopped in Southern California, the San Francisco Bay area, or Puget Sound—which are among the most heavily NIS-invaded regions on the west coast of the United States (Cohen and Carlton 1995, Wonham and Carlton 2005, Cohen et al. 2005). Many passenger vessels arriving in Alaska had stops in Mexico and Asia, as well as the South Pacific and ‘other’ regions—Asia, in particular has been the source of most of the aquatic invasive species in the northeast Pacific (Wonham and Carlton 2005). While passenger vessels and tank ships generally maintain their hulls in such a fashion as to minimize fouling, the sheer numbers of these vessels repeatedly arriving to the Prince William Sound region greatly increases the possibility of accidental introduction.

Freight and fishing vessels represent the high propagule volume risk category, in having relatively irregular but long visits to Alaskan ports. Fishing boats had the lowest average return frequency, and over the course of the study their time spent in port changed dramatically. In 2005 and 2006 the majority (76% in 2006) of fishing boat arrivals stayed in port for less than 24 hours, but by 2007 this had dropped to only 50%. 2008 saw the majority of fishing boat arrivals staying in port for longer than 72 hours (74% in 2008). Freight ships also had a low average return frequency (though the average is skewed upward by one ship, which returned to Kodiak over 30 times per year). While total freight vessel arrivals decreased over time, the number of vessels staying over 72 hours did not change. For vessels that stayed in port longer than 72 hours, freight ships had the consistently highest numbers, and fishing boats had the most rapidly growing numbers. Arrivals from these types of vessels were most often from domestic voyages, and represent a relatively low risk of introducing new NIS. However, in the future they may act as vectors for secondary introductions by transporting previously introduced species from one Alaskan port to another. Also, many freight ships previously stopped in Asian ports before coming to Alaska and could represent a source of NIS from that region.

Towing vessels generally did not fall into either risk category. On one hand, towing vessels did not have a high average return frequency, though the average was skewed upward by one vessel that visited over 20 times per year. On the other hand, up to 97% of all towing vessels leave port in under 48 hours (up to 90% in under 24 hours). Towing vessel arrivals are most often from west coast/west coast-domestic voyages, which as previously stated, may experience higher organism survival rates. Also many towing vessels stopped in the Southern California and San Francisco regions that have extensive invasive fouling communities. Another factor that should be considered is that towing vessels usually travel at slower speeds than other vessel types, which may reduce the mortality of fouling organisms while underway. They may also haul barges that contain a high density of fouling organisms, though there is no data available as to what percentage of towing vessels are hauling barges.

### Risk based on port

The threat of invasion is not uniform for all ports due to the varying composition of arrivals to each port of interest, and the different risks posed by each vessel type as discussed above. Of the nine ports of interest, Valdez, Whittier, Seward and Kodiak have the highest potential risk for NIS being introduced from hull fouling.

The risk posed to Valdez comes from the large volume of traffic from San Francisco Bay, Southern California, and the Puget Sound. Valdez traffic is composed almost exclusively of tank ships, which have an accumulated risk associated with them from repeat inoculations. While tank ship operators maintain clean hulls to reduce drag and cut fuel costs, 'functionally clean' may not translate into ecologically clean. Small communities of fouling organisms may persist in sea-chests, around propellers and other complex areas of the hull. Furthermore, the repeat inoculations may occur across an array of weather conditions and seasons, thus increasing the likelihood of an introduction in ‘ideal’ conditions.

Whittier is at risk from the high volume of passenger vessel and towing vessel traffic from the PNW. Vessels arriving from the PNW may experience higher fouling survival rates due to shorter voyage durations, and fewer changes in the physical environment. Towing vessels may also have higher survival rates from because of slow average voyage speeds and from hauling possibly contaminated barges. A relatively large proportion of passenger vessel arrivals have also stopped in Mexico and a variety of transpacific locations that may be sources of NIS; they occur in the summer months when propagule pressure is generally highest; and the high return rate of the vessels allows for potential repeat inoculations across a variety of conditions.

Seward, like Whittier, is at risk from passenger vessels arriving from west coast and transpacific voyages. The majority of passenger vessels arriving to Seward come via the PNW and a large proportion of these vessels have also stopped in Asia and/or Mexico. Passenger vessels from these regions, as discussed above are a risk for primary introductions from repeat inoculations.

Domestic freight ships and fishing boats may present a risk to the port of Kodiak from secondary invasion by already introduced NIS arriving from other Alaskan ports. Wasson et al (2001) found that regional traffic was a significant vector for secondary invasions to non-commercial harbors. It was concluded that resident fishing boats and pleasure crafts act as ‘stepping stones’ for exotic species to spread out of San Francisco Bay into nearby regions. In Kodiak, the long “residence time” of fishing boats and freight ships may allow for the accumulation of extensive fouling communities, or allow pre-existing fouling to release large numbers of propagules into the surrounding port waters. Additionally, freight ship arrivals from transpacific and west coast voyages to Kodiak may also present some risk of primary NIS introductions.

# Hull Maintenance

## *Hull Maintenance Overview*

Currently, there is little regulation regarding hull husbandry practices. Section 2.2.23 of the EPA's Vessel General Permit includes the most specific requirements:

> *"Vessel owner/operators must minimize the transport of attached living organisms when they travel into U.S. waters from outside the U.S. economic zone or when traveling between COTP zones.*
>
> *Whenever possible, rigorous hull-cleaning activities should take place in drydock, or another land-based facility where the removal of fouling organisms or spent antifouling coatings paint can be contained. If water-pressure based systems are used to clean the hull and remove old paint, use facilities which treat the wash water prior to discharge to remove the antifouling compound(s) and fouling growth from the wash water.*
>
> *Vessel owner/operators who remove fouling organisms from hulls while the vessel is waterborne must employ methods that minimize the discharge of fouling organisms and antifouling hull coatings…"*

Any non-compliance with the requirements of the VGP constitutes a violation of the Clean Water Act. For discharges incidental to normal operations (i.e. discharges that are not ballast), the Vessel General Permit (VGP) applies to non-recreational vessels 79 feet or longer, with the exemption of commercial fishing vessels. The exemption of fishing vessels in ship husbandry requirements may pose a significant risk to the ports of Alaska, where commercial fishing is prevalent and economically important. Numerous domestic and west coast fishing vessels arrive to and from Alaskan ports each year, though due to poor documentation it is difficult to quantify the potential risk.

The issue of hull fouling is also addressed briefly in Title 33 of the Code of Federal Regulations, Part 151, which concerns vessels carrying oil, noxious liquid substances, garbage, municipal or commercial waste, and ballast water. Two lines that are in sub-section 2035, concerning required ballast water management practices, cover a commercial ship's responsibility regarding hull fouling:

*(5) Rinse anchors and anchor chains when you retrieve the anchor to remove organisms and sediments at their place of origin.*

*(6) Remove fouling organisms from hull, piping, and tanks on a regular basis and dispose of any removed substances in accordance with local, State and Federal regulations.*

According to 33 CFR 151.2007, any violation of this sub-part is subject to a civil penalty of up to $27,500 per day of continuing violation, and any person who knowingly violates this sub-part is guilty of a class C felony (Showalter and Savarese 2004). However, the regulations go on in 33 CFR 151.2010 to exempt certain vessels from the required ballast water practices:

*Two types of vessels are exempt from the requirements in §§151.2035, 151.2040, and 151.2045:*

*(1) A crude oil tanker engaged in the coastwise trade.*

*(2) A Department of Defense or Coast Guard vessel subject to the requirements of section 1103 of the Act, or any vessel of the Armed Forces, as defined in the Federal Water Pollution Control Act (33 U.S.C. 1322(a)) that is subject to the "Uniform National Discharge Standards for Vessels of the Armed Forces" (33 U.S.C. 1322(n)).*

This exemption covers the majority of tank ships that travel to and from Alaska. However, tank ship companies conduct voluntary hull maintenance operations, generally in conjunction with regular dry dock inspections mandated by Merchant Class Societies such as the International Association of Classification Societies, Ltd (IACS), and the US Coast Guard. These two entities typically require at least one dry dock inspection of a ship's hull every five years (Takata et al 2006). Depending on the classification and age of the ship, dry dock inspections sometimes occur twice every five years (IACS REC 076, 088, 096). While these inspections are largely only for structural and safety purposes, vessel operators generally use the opportunity to clean the hull and re-apply anti-fouling paint as needed. Because extensive fouling may reduce the fuel efficiency of a vessel, operators may also sometimes opt to conduct interim in-water cleanings between required five year dry dock inspections (Takata et al 2006). It should be noted that the vessel operators clean hulls based on functional necessity rather than environmental reasons; as such, a level of fouling that does not interfere with ship operations may be allowed to persist. Tank ships that operate in Prince William Sound are generally cleaned by high water pressure washing on dry dock at least once every five years (Takata et al 2006, Personal Communication).

## *Hull Maintenance Procedure*

Hull maintenance operations in a dry dock facility are usually conducted in a similar manner. For large vessels such as tank ships, the ship is maneuvered through gates into an enclosed dock. The dock gates are then shut, and the water slowly drained. In smaller vessels, the ship may be physically lifted from the water to the work area. In either case, blocks are placed on either side of the hull to support the vessel while it is out of the water. The vessel is then blasted with a high pressure wash (3000-8000 psi) to remove fouling organisms, before being assessed for damage and paint wear. Often, the operators opt for a full or partial reapplication of the anti-fouling paint. It is important to note that the areas that are covered by the hull supports cannot be painted, creating the possibility that certain areas of the hull go up to ten years without a fresh application of paint, which may decrease the anti-fouling properties of those areas (Davidson et al 2006c, Takata et al 2006).

In-water cleanings are performed by divers either manually scraping and suctioning fouling off the hull, or by using mechanical brush systems such as the Submerged Cleaning and Maintenance Platform (SCAMP). While the SCAMP and other systems provide prevention against detritus falling to the sea-floor, the effectiveness of containment is variable. In addition, many in-water cleanings on smaller vessels provide no containment at all, allowing fouling organisms to escape to the surrounding water or sink to the bottom. Floerl et al (2005) found that while in-water cleanings may minimize fouling in the short term, it poses a large biosecurity risk, and may actually encourage the spread of fouling organisms if the effluent is not properly contained.

## *Anti-Fouling Systems*

Until recently, and for the last 30 years, the most commonly applied anti-fouling paints contained tributyl tin (TBT), a highly effective biocidal agent. However, findings that linked TBT leaching from ship hulls to a number of negative ecological consequences led to a ban of TBT use in the United States in 1988, followed by a global phase-out and world wide ban in January 2008 by the International Maritime Organization (Takata et al 2006, Davidson et al 2006c, Showalter & Savarese 2004, Savarese

2005). Other kinds of anti-fouling paints have since been introduced as replacements, though they are generally considered less effective. The paints are divided into two main categories: TBT-free biocidal paints that utilize zinc or copper, and silicon based non-biocidal paints that are extremely smooth. In the first category, the paints simply replace TBT with copper or zinc as the active ingredient. In the latter category, the slippery silicon based paints make it difficult for organisms to adhere to the surface, especially while underway (Takata et al 2006).

Vessels also often have specialized Marine Growth Protection Systems (MGPS) installed in their sea-chests. The primary purpose of a MGPS is to eliminate biofouling in seawater circulation systems. Through the use of strategically placed anodes and cathodes, in-coming seawater is electrolyzed with either copper or hypochlorite ions, depending on the manufacturer (ClearFlo System Operation, Wilson Walton; Sanilec, Severn Trent De Nora). The resulting solutions provide an inhospitable environment for fouling organisms. MGPS may be essential treatments for NIS, because sea chests can host aggregations of fouling organisms: within a single sea-chest Coutts et al (2003) found not only typical fouling organisms, but also such surprising finds as the introduced European clam (*Corbula gibba*), and three introduced Green crabs (*Carcinus maenas*), two of which were ovigerous females capable of releasing viable propagules. The same paper also mentions that the unique habitat provided by a sea-chest has yielded an invasive sea-star, *Asterias amurensis*, and several species of small fish. In a later paper, Coutts & Dodgshun (2007) found that while MGPS systems significantly reduce fouling by sessile and sedentary organisms, the systems have little influence on the occurrence of mobile species within sea-chests; therefore, MGPS may reduce, but not eliminate entirely, the risk of sea-chests as vectors for introductions.

## *Hot Spots*

Because a vessel's hull is not uniform, hull fouling does not occur evenly. Areas that have either higher complexity like heterogeneous surfaces or areas of uneven paint, or areas of low water velocity create conditions that encourage fouling organisms. These areas include sheltered areas around the propellers, bilge keels, rudders, bow thrusters, intake pumps, and sea chests, and also the dry docking support strips and waterlines where anti-fouling paint is applied irregularly (Coutts et al 2003; Coutts & Taylor 2004; Davidson et al 2006c). In vessels that travel at high speeds (above 15 kt) very little fouling is observed on the laminar parts of the hull, but fouling may still persist in the areas mentioned above where organisms can be shielded from strong shearing forces. In vessels that travel slower than 10 kt, there is a greater incidence of fouling organisms surviving on all parts of the hull (Takata et al 2006, Davidson et al 2006).

### *Other Risk Factors*

Besides hull complexity, vessel speed, and the condition of anti-fouling paint, other factors contribute to the level of fouling found on a ship's hull. Vessels that experience rapid and drastic changes in salinity and temperature, such as those that pass through both marine and fresh water or conduct trans-equatorial voyages may experience reduced survivorship of fouling organisms by subjecting them to a range of conditions outside their physiological limits (Davidson et al 2006c, Takata et al 2006). On the other hand, Coutts & Taylor (2004) found that vessels that travel through similar latitudes may experience increased survivorship of fouling organisms by retaining relatively consistent temperature and salinity levels. Shorter voyages may also be beneficial to coastal fouling organisms, because they would be exposed for a shorter time to oceanic conditions before arriving at port. A combination of these two factors may mean that there is a higher risk of secondary contamination of Alaskan waters from vessels traveling on coast-wise voyages (e.g., from Puget Sound or San Francisco Bay) than of primary contamination from vessels traveling from more exotic locations. Traveling to a wide range of locations may also be a risk factor because it increases the odds that an organism with a broad range of tolerances will attach to the hull.

Furthermore, in addition to voyage routes, invasion risk may be influenced by the organisms encountered in each port. A number of fouling organisms have been introduced far outside their places of origin, and are becoming pandemic. In these cases, the rate of new introductions is accelerating, in part due to increasing sources for secondary introductions, and the spread of physiologically tolerant NIS (Cohen & Carlton 1998). Secondary introduction poses a risk to Alaska from domestic and coast-wise ports where introduced species have already demonstrated an ability to successfully invade. For an index of invasive species and the regions they have been recorded in, see Appendix Table 6.

The level of fouling accumulated is related to the amount of time a vessel has spent in port. Because larval settlement may be prevented by speeds as slow as 2 KTS (Davidson et al 2006c), accumulation occurs while a vessel is docked, and increases over time. This is especially true in protected ports with restricted flow and poor flushing where propagules may be retained in the water column for long periods of time (Takata et al 2006). Due to reproductive periodicity of fouling organisms, propagule amounts can vary by season, with summer and spring typically having higher propagule numbers than winter and fall (Davidson et al 2006c).

Perhaps the most important factor contributing to fouling on hulls in the amount of time passed since the last hull cleaning. Coutts and Taylor (2004) hypothesized that the relatively high levels of fouling they observed in archived maintenance videos was because the vessels sampled were all near the end of their maintenance cycles. Ruiz et al. (2000) sampled the fouling communities of two tank ships: one had not been cleaned in dry dock for approximately 2 years; one had been cleaned in dry dock within about 6 months. The two ships exhibited extremes in the quantity and diversity of organisms: the ship that had not been cleaned in approximately 2 years had an extensive fouling community, with abundant mussels and associated worms, crustaceans, and sediments (including one NIS), while the ship that had been cleaned recently had few mainly present in the sea chest.

### *Example Hull Maintenance Schedules*

Detailed maintenance information was obtained for 18 of the 26 tank ships known to operate within Prince William Sound from 2005 to 2008. This information was acquired through the California Marine Invasives Program at the California State Lands Commission. Since January 2008, the CSLC has maintained an extensive database of the maintenance histories of vessels arriving to California. The data presented here represents a small subset of total vessels within that database, including those tank ships within our study that have been to California since the Marine Invasives Program began (Table 6).

The CSLC obtains the information from the maritime industry by providing comprehensive reporting forms. The vessel operators must complete and submit the form within 60 days of receiving a request from the commission. Among the information included in the data:

1. Dates and location of last out of water maintenance.
2. Date of last full or partial coat of anti-fouling paint application, type of biocide used, and locations of the hull where applied.
3. Whether Marine Growth Protection Systems have been installed in the sea-chests.
4. Dates of in water cleaning, if applicable.
5. Whether the vessel has, since the last cleaning: recently visited freshwater or tropical areas, been through the Panama Canal, or stayed ten consecutive days in a single port.

Furthermore, several shipping companies known to operate within Prince William Sound were contacted directly and interviewed regarding their maintenance policies. Alaska Tanker Company, SeaRiver Maritime Inc, Polar Tankers and Seabulk Tankers Inc are responsible for the majority of tank ship traffic arriving to Prince William Sound. Of these four, only SeaRiver Maritime Inc could not be successfully reached; however, sufficient data regarding SeaRiver Maritime's maintenance practices was obtained from the CSLC database.

All of the shipping companies interviewed reported conducting hull cleanings with a high pressure wash on dry dock at least once every five years. Of the 18 vessels, the greatest duration of time since last maintenance or build was five years, and the average time since last maintenance or build was two years (Table 6). As noted in the sections above, two years is enough time for extensive fouling to accumulate (Ruiz et al 2000). Only two vessels underwent in-water cleanings since the last reported drydock. The majority of the vessels had Marine Growth Protection Systems installed in sea-chests, and also had a full coat of anti-fouling paint reapplied at the last drydocked maintenance (Table 6). However, many of the vessels did not paint non-hull surfaces such as thrusters and rope guards, or the previous dry dock support strips (For specific areas of the hull painted and the type of paint used, see Appendix Table 7). As discussed earlier, these areas may act as refuges for small groups of fouling organisms. Furthermore, many vessels spent over 10 consecutive days in a single port, thereby increasing the risk of fouling accumulation. The ports where the 10+ day stays occurred are places where NIS are known to be established. The majority of vessels rarely visited tropical ports or the Panama Canal, and are therefore less likely to transport invasive species from these areas. Only three vessels have regularly visited freshwater ports, and are likely to have significantly less fouling due to the rapid salinity changes (Table 6). As a whole, the 18 vessels may present risk associated with secondary introductions, by carrying fouling organisms on irregularly painted surfaces.

*Table 6. Hull maintenance of tank ships operating in Alaskan ports of interest*

| ReportYear | Vessel Name | Vessel Delivery Date | Out Of Water Maintenance Date | Out Of Water Maintenance Country | In Water Cleaning Date | Years since maintenance or delivery | Coating Level | Last Full Coat Date | Sea Chests MGPS Installed ? | Days in FW Port Visit since last cleaning | Days in Tropical Port Visit since last cleaning | Days in Panama Canal Visit since last cleaning? | Ten Day Stay since last cleaning? | Days In Port | Ten Day Stay Port |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2008 | ALASKAN EXPLORER | 21-Mar-05 | | | | 3 | Full Coat Applied | | Y | | | | Y | 11 | LA-LB |
| 2009 | ALASKAN EXPLORER | 21-Mar-05 | | | | 4 | Full Coat Applied | | Y | | | | Y | 27 | Port Angeles |
| 2008 | ALASKAN FRONTIER | 11-Aug-04 | | | | 4 | Full Coat Applied | | Y | 1 | | | Y | 14 | PORTLAND |
| 2009 | ALASKAN FRONTIER | 11-Aug-04 | | | | 5 | Full Coat Applied | | Y | 1 | | | Y | 21 | Puget Sound |
| 2008 | ALASKAN LEGEND | 18-Aug-06 | | | | 2 | Full Coat Applied | | Y | 1 | | | Y | 21 | Port Angeles |
| 2009 | ALASKAN LEGEND | 18-Aug-06 | | | | 3 | Full Coat Applied | | Y | 1 | | | Y | 21 | Port Angeles |
| 2008 | ALASKAN NAVIGATOR | 23-Nov-05 | | | | 3 | Full Coat Applied | | Y | 1 | | | Y | 14 | Port Angeles |
| 2009 | ALASKAN NAVIGATOR | 23-Nov-05 | | | | 4 | Full Coat Applied | | Y | 1 | | | Y | 30 | PORTLAND |
| 2009 | CAPTAIN H. A. DOWNING | | 23-Sep-06 | Canada | | 3 | Full Coat Applied | | N | 26 | 20 | | Y | 13 | San Francisco |
| 2008 | KODIAK | | 16-Nov-05 | Singapore | | 3 | Full Coat Applied | | Y | | | | N | | |
| 2009 | KODIAK | | 16-Apr-08 | USA | | 0 | Full Coat Applied | | Y | | | | N | | |
| 2008 | MISSISSIPPI VOYAGER | | 01-Mar-07 | USA | | 1 | Full Coat Applied | | | 3 | 3 | | Y | 17 | San Francisco |
| 2009 | MISSISSIPPI VOYAGER | | 12-Sep-09 | USA | | 0 | Full Coat Applied | | | 1 | | | N | | |
| 2009 | OVERSEAS NEW YORK | 11-Apr-08 | | | | 1 | Full Coat Applied | | Y | 26 | 1 | 1 | N | | |
| 2008 | POLAR ADVENTURE | 01-Sep-04 | | | | 4 | Full Coat Applied | | N | | | | | | |
| 2008 | POLAR DISCOVERY | | 01-Jun-06 | Singapore | NA | 2 | Full Coat Applied | | N | | | | | | |
| 2009 | POLAR DISCOVERY | | 01-Jun-06 | Singapore | 10-Oct-06 | 3 | Full Coat Applied | | Y | 9 | 1 | | Y | 20 | Port Angeles |
| 2008 | POLAR ENDEAVOUR | | 01-Jun-04 | Singapore | | 4 | Full Coat Applied | | N | | | | | | |
| 2009 | POLAR ENDEAVOUR | | 21-Aug-09 | Singapore | 7-Dec-08 | 0 | Partial Coat | 21-May-09 | Y | | | | N | | |
| 2008 | POLAR ENTERPRISE | 01-Jan-06 | | | | 2 | Full Coat Applied | | N | | | | | | |
| 2009 | POLAR ENTERPRISE | | 23-Oct-06 | Spain | | 3 | Full Coat Applied | | Y | 1 | 1 | | Y | 27 | Portland |
| 2008 | POLAR RESOLUTION | | 1-Aug-05 | Singapore | | 3 | Full Coat Applied | | Y | | | | Y | 43 | Port Angeles |
| 2009 | POLAR RESOLUTION | | 3-Aug-05 | Singapore | | 4 | Full Coat Applied | | N | | | | Y | 26 | Port Angeles |
| 2008 | S/R BAYTOWN | | 07-Sep-06 | Singapore | | 2 | Full Coat Applied | | Y | 1 | 1 | 1 | Y | 30 | PORTLAND |
| 2009 | S/R BAYTOWN | | 25-Aug-06 | Singapore | | 3 | Full Coat Applied | | Y | 39 | | 2 | Y | 13.94 | Houston |
| 2008 | S/R LONG BEACH | | 15-May-07 | Singapore | | 1 | Full Coat Applied | | Y | | 2 | | N | | |
| 2009 | S/R LONG BEACH | | 15-May-07 | Singapore | | 1 | Full Coat Applied | | Y | | 1 | | N | | |
| 2008 | SEABULK ARCTIC | | 29-Aug-06 | Panama | | 2 | Full Coat Applied | | | 4 | 1 | | Y | 10 | Cook Inlet |
| 2009 | SEABULK ARCTIC | | 07-Jul-08 | Singapore | | 1 | Full Coat Applied | | N | | 1 | | N | | |
| 2008 | SEABULK PRIDE | | 27-Feb-06 | USA | | 2 | Full Coat Applied | | N | 2 | 1 | | N | | |
| 2009 | SEABULK PRIDE | | 12-Sep-08 | Singapore | | 1 | Full Coat Applied | | N | 1 | | | N | | |
| 2008 | SIERRA | | 24-Jul-06 | Singapore | | 2 | Full Coat Applied | | Y | | | | N | | |
| 2009 | SIERRA | | 18-Dec-08 | Singapore | | 0 | Full Coat Applied | | Y | | 1 | | N | | |

# Hull fouling sampling methods and recommendations

## *Introduction*

Studies of biofouling on ship's hulls have employed various sampling and analysis techniques (summarized in Table 7). However, aside from Davidson et al. (2006b), there are few studies that evaluate and compare the efficiency and effectiveness of several techniques. Four techniques have been commonly used to sample hulls: (1) using divers to collect specimens and conduct underwater photo quadrats; (2) collecting specimens and photo quadrats immediately after a vessel has been drydocked; (3) using archival video footage of under water in lieu of Drydock (UWILD) inspections; and (4) using remotely operated vehicles (ROVs) to conduct video transects. By utilizing existing literature and prior experiences, Davidson et al (2006b) qualitatively assessed these four techniques for strengths and weaknesses across ten criteria. These criteria included: representativeness of vessel population; representativeness of vessel arrivals to a specific port; possible constraints on measuring biofouling extent; possible constraints on measuring species composition; possible constraints on measuring viability; possible constraints on accessing sea-chests; availability of vessel history; access to vessels; sampling duration; and cost. Of the ten criteria Davidson et al. (2006b) used, we will summarize those likely to be most relevant to this study: (1) cost; (2) representativeness of sampling; and (3) type and quality of data obtained.

## *Methods*

### Visual Rank Assessment

A rank scale of fouling intensity has been developed and used along with hull maintenance questionnaires to evaluate fouling on smaller vessels such as pleasure yachts (Floerl et al. 2002, 2005, Ashton et al. 2006). The scale is based on approximate percentage cover on hull surfaces visible from the surface and number of different identifiable taxa of marine invertebrates and plants comprising fouling assemblages and ranges from 0 (no fouling) to 5 (very heavy fouling). This type of assessment may be useful in broadly evaluating fouling and risk patterns associated with smaller vessels (e.g., recreational and fishing boats) entering Alaska.

### Diving

Divers have been used in a number of studies to conduct surveys (Cohen et al. 1998, 2001, 2002, 2005a, 2005b; Godwin 2003; Mineur et al. 2007; Ruiz and Smith 2005; Davidson et al 2006c). Many of these studies have been cursory, noting only presence-absence (e.g., Cohen et al. references cited above) or focused on individual taxa or groups (e.g., Mineur et al., surveying algae on hulls). Ruiz and Smith (2005) surveyed nine vessels over a two week period, in April 2004 in the Port of Oakland, California. Divers collected biota and video data from transects along selected parts of the hull, and obtained species presence/absence data, live/dead data and surface area data. While they found a notable paucity of organisms on all of the hulls inspected, only one vessel was without any visual fouling. The extent of fouling varied greatly from one vessel to the next, leading the authors to conclude that further studies with larger sample sizes are needed; however they also observed that non-hull underwater locations were the most important sites for biota abundance and diversity.

### Dry Dock

Surveys conducted on drydock have also been conducted in a number of studies (Gollasch 2002; Minchin and Gollasch 2003; Davidson et al 2006a; Drake and Lodge 2007; Coutts et al. 2003). In the most comprehensive of these studies, Gollasch et al. (2002) sampled vessels visiting German ports for 3 years, from 1992 to 1995. Over the course of the study, a variety of locations on 186 ships were sampled, including 131 hull samples obtained by using scrapers immediately after a vessel was dry-docked. Samples were identified and assigned to four different categories: native, established non-native, non-established non-native, and cryptogenic. They found that 74% of all species found in hull samples were non-native to the North Sea. Furthermore, 96% of all samples taken included at least one NIS. While they found that the majority of the non-native species found were from warmer climates and therefore unlikely to become established, 22% of total non-native species found were considered to pose a risk of successful introduction.

### Archival Video Footage

Several studies have used archival hull inspection video footage to extract fouling data (Coutts and Taylor 2004; Davidson et al. 2006c). Coutts and Taylor (2004) obtained underwater video for 30 randomly selected vessels from commercial diving libraries. Eight locations on the vessels were chosen to investigate: the hull, propeller, bulbous bow, bilge keel, rudder, rope guard, sea-chest grating, and support block strips. In each of the eight locations, the video was randomly paused 5 times on as many vessels as possible. Biofouling organisms were identified to broad taxa (i.e. green algae, brown algae) and assigned to four categories representing the spectrum of fouling progression: A= no fouling, B= fine algae/slime C= encrusting organisms, D= macrofauna. The study found that while 54% of the quadrat areas surveyed had no visible fouling, category B organisms were found in high concentrations on propellers, bulbous bows, bilge keels, rudders and rope guards. The study concluded that using video footage may be a cost effective method of assessing risk, though issues with clarity prevented finer taxonomic resolution.

## ROV

The use of ROVs to conduct hull fouling surveys is a relatively new technique. While it has been used in a number of benthic habitat surveys (Pacunski et al. 2008; Parry et al. 2003; Parry et al. 2002), hull fouling studies using ROVs are relatively rare (Davidson et al 2009). However, the commercial use of ROVs to inspect the hulls of ships for structural damage is more common in the shipping industry (Lynn and Bolander 1999; Harris and Slate 1999), and ROV services are often offered by the commercial dive companies that perform inspections. In one of the few hull fouling studies to make use of ROVs, Davidson et al (2009) conducted ROV video surveys on 13 containerships docked at the Port of Oakland in May 2006. Using a three person team to monitor and control the ROV, the researchers examined the hulls, rudders, propellers and stern tubes of all vessels surveyed over a series of transects. Wherever possible, the team also inspected bulbous bows, bow thruster gratings and intake gratings. Video was used for coarse taxonomic identification; divers were deployed on a subset of vessels to obtain biological samples for finer resolution. The researchers found low levels of observable fouling on the majority of the vessels surveyed, and also found that rudders, bow thrusters and stern tubes were fouled more frequently than other submerged areas. While noting that many factors play a role in fouling accumulation, the researchers found a significant positive relationship between taxa richness and time out of dry dock.

Table 7. Hull fouling studies and methods

| *Authors* | *Number of ships sampled* | *Location* | *Types of ships* | *Technique used* | *Data Collected* | *Species level ID?* |
|---|---|---|---|---|---|---|
| Ashton G, Boos K, Shucksmith R, Cook E (2006) | *866* | *Scotland* | *Private Yacht* | *Visual rank assessment* | *Percent cover, vessel history* | *N* |
| Coutts ADM, Moore KM, Hewitt CL (2003) | 1 | Sydney, Australia | Passenger | Dry dock collection | presence/absence | Y |
| Coutts ADM, Taylor MD (2004) | 30 | New Zealand | Merchant vessels | Archival video footage | Taxa richness, percent cover | N |
| Coutts ADM, Dodgshun TJ (2007) | 42 | New Zealand | Miscellaneous commercial vessels | Dry dock collection | Presence/absence, vessel history, organism mobility, taxa richness | Y |
| Davidson I, Sytsma M, Ruiz G (2006a) | 17 | Columbia River, OR | Miscellaneous commercial vessels | Dry dock sampling, archival video | Taxa richness, taxa density, percent cover, vessel history | Y |
| Davidson I, Ruiz G, Sytsma M, Fofonoff (2006c) | 2 | Suisun Bay, CA | Obsolete National Reserve Defense Fleet vessels | Diver photo quadrats, specimen collections | Species richness, percent cover, species abundance | Y |
| Davidson I, Brown C, Sytsma M, Ruiz G (2009) | 22 | Port of Oakland, CA | container ships | Diver and ROV video surveys, limited specimen collections | Presence/absence and percent cover at broad taxonomic levels, species richness, vessel history | Y |
| Drake JM, Lodge DM (2007) | 1 | Lake Ontario | Bulk carrier | Dry dock collection | Species richness, taxa abundance | Y |
| Farrapeira CM, de Melo AV, Barbosa DF, Silva HM (2007) | 32 | Recife, Brazil | Miscellaneous commercial vessels | Diver specimen collections | Presence/absence, species richness | Y |
| Floerl O, Inglis GJ, Hayden BJ (2002) | 783 | New Zealand | Private yacht | Visual rank assessment, video transects | Percent cover, vessel history | N |
| Godwin LS (2003) | 8 | Oahu, HI | Barges | Diver specimen collections | Presence/absence | Y |
| Gollasch S (2002) | 186 | German ports along North Sea | Container ships, and miscellaneous commercial vessels | Dry dock collection | Species richness | Y |
| Mineur F, Johnson MP, Maggs CA, Stegenga H (2007) | 22 | Sete, France | Unspecified commercial vessels | Algae collections while snorkelingl | Presence/absence, vessel history | Y |
| Ruiz GM, Smith G (2005) | 9 | Port of Oakland, CA | container ships | Diver video surveys and specimen collections | Presence/absence, percent cover, taxa richness, size distribution of organisms | Y |

## *Pros and Cons*

### Cost

Using archival video footage from UWILD inspections is the least expensive option, because the video has already been taken and the footage must simply be requested from the video inspection company after obtaining permission from vessel owner/operators. (Davidson et al 2006b). Collecting data during a scheduled dry-docking event is also a relatively inexpensive option. However, because tank ships in the northeast Pacific usually drydock in Asia, costs would include travel to Asian drydock facilities that service the tank ships. Smaller vessels such as fishing boats and barges could be sampled at regional drydock facilities. Visual rank assessment is also relatively inexpensive, and can be conducted by volunteers, resulting in a large amount of data (e.g., 866 vessels sampled by Ashton et al. 2006). The use of divers and ROVs are the most expensive options, but costs may be lowered if divers are available within the institution conducting the sampling: otherwise, commercial divers would have to be contracted. ROV costs may also be mitigated by using an institution that has one or more ROVs available or partnering with such an institution (e.g., the Washington Department of Fish and Wildlife has an ROV). If a relatively long-term project is anticipated, purchase of an ROV may also be cost-effective. Both drydock and diver surveys could yield biological samples that would require fixation, transport, and identification by taxonomic experts that would add additional costs.

### Representativeness

To prevent bias from being introduced into the study, samples should be representative of the vessel population being sampled. Dry-docking events and archived video inspections occur at regular intervals when fouling is most likely, i.e., every five years for dry-docking, and once between dry docks for underwater video inspections (Davidson et al 2006b). Sampling of vessels at the end of their maintenance routines may bias studies toward the most fouled conditions, and should accordingly be identified as such. On the other hand, diver and ROV surveys can be conducted at any point in a vessel's maintenance schedule, and provide a more representative sampling regime. Visual rank assessment is the least representative method, as it can only be conducted reliably on small vessels, and is limited to parts of the hull that can be seen from the surface.

### Data Type and Quality

The type and quality of data obtained are the most important criteria when considering the overall goals of the study.  ROVs, archival video footage, and visual rank assessment can provide a large quantity of data, but, because of limitations in resolution, there is a limited ability to interpret the information. In this case, fouling organisms must be grouped into broad categories, accompanied by abundance counts or percent cover for each category. ROV and archival video footage may be adequate at providing a gross measure of how much fouling is present, but cannot identify all of the species present or quantify the abundance of each species. Archival footage and visual rank assessments may be less effective than ROV video because there is no control over what areas of the hull are recorded in the archived footage, while ROV video can be taken on predetermined transects and/or "hot spots" of interest. Thus, it would be difficult to devise a uniform study design using archival video. Diver and drydock surveys, on the other hand, provide lower quantities of higher quality data. These two methods allow for sample collection and identification of biota to low taxonomic levels. This information may be accompanied by other quantitative information about representative sections of a given vessel hull (e.g., visual assessments to accompany biota samples), though gathering of such data may be limited to the accessible parts of the hull. In the case of drydock surveys, only certain portions of a vessel's hull will be accessible for collecting biological samples.  For example, if specimens could only be collected from areas accessible by ladder, the majority of the hull would not be characterized. Also, during the dry-docking procedure, some mobile organisms associated with the fouling assemblage (e.g., copepods, amphipods, shrimp) may leave the hull, and other organisms may die and begin to decompose before sampling is conducted.

If a general measure of total amount of hull fouling in broad taxonomic categories is the goal, then drydock surveys and archival video footage may be possible options for hull fouling surveys. However, drydock surveys may be impractical for vessels entering Alaska ports, because dry-docking of the major vessel type, tankers, is done at foreign facilities.  Archival footage is problematical because of the potential lack of resolution and control over sample design, but may be useful in refining a subset of vessels to focus higher resolution studies on (see recommendations section).  Likewise, visual rank assessment is useful only for identifying broad taxonomic categories on small vessels.  These methods may introduce unacceptable bias to a hull fouling study if the study goal is to assess representative cross sections of individual hulls and/or a vessel population.  The two other options, ROV and diver surveys, are examined in more detail.

## *Assessment of ROV and Diver Sampling*

### ROV

ROVs can provide data that is more extensive than that which can be taken within the depth, spatial, and time limits of diver collections. While diver time underwater is limited by physiological and air supply constraints, ROVs have no such limits and may survey the entire hull of a vessel with relative ease. Without people in the water, safety restrictions are also less stringent, and it may be easier to receive port and vessel permissions to conduct surveys (Davidson et al. 2006b). Effective ROV surveys also require fewer support personnel than diving surveys. Operation of the ROV requires at least 3 people: a pilot, someone to manage the umbilical lines, and someone to monitor the video. A diving survey requires at least two divers, a land coordinator for safety, and if samples are collected, a team of biologists to immediately sort and preserve specimens. For visual surveys, ROV data appears to be comparable to diver observations.  For example, in a study of the abundances and distribution of burrowing megafauna, Parry et al. (2002) found that there was no significant difference in total abundance counts between a ROV and a research diver, and the ROV may have actually outperformed the divers, because of the divers' tendency to overestimate the size of objects. Raw data may be collected at speeds comparable to or exceeding that of divers, averaging between 0.14m and 0.6m per second (Pacunski et al. 2008).

Images from ROVs may be analyzed both quantitatively and qualitatively for fauna greater than 1cm in diameter. While this may hinder the identification of small or cryptic species, larger fauna may be readily identifiable to at least a higher taxonomic level. In the Parry et al. (2003) study, the highest resolution of the ROV camera was 1.1mm +/- 0.1mm per pixel; that portion of the study was conducted in 2001 and resolution has improved since then. A unique strength of an ROV survey is that it allows the user to quickly generate percent cover, species presence/absence and count data without any need for rapid sample identification, preservation or live-dead assays.

ROVs are costly and unwieldy to use. Leasing the equipment costs approximately $1000 per day (plus cost of crew); purchasing a small ROV costs between $10,000 and $100,000 dollars as a base price (Pacunski et al. 2008**)**. Ancillary equipment, such as laser scaling systems, navigation systems, pressure sensors and flood lights can increase the price an additional $15,000-$150,000 (Pacunski et al. 2008). ROV technology also requires the availability of a skilled operator and maintenance personnel. Pacunski et al (2008) found that ROV technology is prone to mechanical, electrical, and software problems. Furthermore, the quality of data obtained appears to be directly related to the experience level of the operator, and biased estimates may result from differing fly-over heights or an uneven attitude towards the study surface (Pacunski et al 2008, Parry et al 2003).

## Diver Surveys

Because of the combination of maneuverability and physical access, divers can deliver the highest resolution data in a variety of conditions. While ROVs are limited in feature dense or topographically complex areas of the hull, divers have the flexibility to access and collect from most areas of the hull, and to pinpoint and sample areas of special interest, such as sea-chests. Divers can also collect dense multi-layered organism assemblages and return samples to the surface where all the layers can be analyzed. Once brought to the surface and sorted, the sample can be identified to the species level for all taxa, including smaller mobile epifauna such as copepods and amphipods, and even for microscopic organisms. Organism viability (i.e. live/dead status) can be assessed either on site by divers or shortly after reaching the surface, which is not possible for ROV samples except in the most obvious cases.

Diver surveys may be conducted in several ways. Godwin (2003) surveyed hulls using two divers that swam bow to stern on either side of a vessel, sampling each type of organism seen. Davidson et al (2006c) used a combination of randomized photo-quadrats and sample collections, with the surface team directing the divers via real-time audio and video feeds. Ruiz et al. (2005) surveyed in a non-random manner using divers with real-time audio and video feeds to the surface team, collecting all observed organisms along a transect and gathering presence/absence data from visual scans. In all of these cases, once samples were delivered to the surface they were rapidly processed by a team of biologists in a similar fashion. Samples were put on ice and transported back to the lab for sorting within a few hours of the original collection. Representative samples were then preserved and either identified to the lowest possible taxon on site, or sent to experts for further identification. The flexibility of diver surveys to use photo quadrats, specimen collections, and video transects allows the collection of a wide array of data including percent cover, presence/absence and abundance counts.

Dive surveys, while yielding potentially large amounts of usable data, require considerable logistics before samples can be taken. Due to safety concerns, permission must be granted by port authorities, terminal operators and vessel operators prior to the start of the survey (Davidson et al 2006b). Further, the vessel's in-water activities must be altered for the duration of the survey, including turning off intake pumps, propellers, and electrolytic marine growth protection systems (Ruiz et al 2005). Before a survey is scheduled, availability of taxonomic experts will need to be arranged if immediate species identification and live-dead assays are to be conducted. Divers are subject to limitations when diving. Though depth would rarely be a concern for the majority of vessels, limitations such as time, air supply and surface connections (if applicable) would require several dives per surveyed vessel depending on its size (Davidson et al 2006c), and diver endurance would also affect the amount of work that could be conducted. This could translate into to a slower turnover time per vessel, as compared to ROV sampling, unless a team of four or more divers were used.

## *Recommendations*

Analyzing shipping patterns provides an initial assessment of vessel types, routes, and voyage histories that are most likely to pose risks of introducing hull fouling NIS. This type of analysis can also identify individual ports that may be at more risk of receiving NIS. However, a more complete understanding of NIS risk requires more detailed studies of the biota on vessel hulls in order to “ground truth” the findings of the shipping pattern analyses. Because biotic surveys are labor and cost intensive, shipping pattern analyses can help to streamline the research by providing focal points on which to initially concentrate effort. Also, there are several levels of effort that can be applied to biotic surveys, with considerable differences in cost and quality/quantity of results. Here, referring to the previous section on sampling methods, we outline a multi-level and iterative study design that is intended to be cost effective and allow for continuously more focused and targeted studies

The first level is an exploratory survey using archival video footage of from Under Water in Lieu of Drydock (UWILD) inspections to generate a broad understanding of the extent of fouling among vessels visiting Alaskan ports, and further identify potential areas of NIS risk, including areas on individual vessel hulls. The second level, which would be conducted on a narrower field of vessels, would use ROV or diver based video surveys. This step may be bypassed depending on the quality of data obtained in the first level. In addition, at either level one or two, visual rank assessment could be conducted on smaller vessels to provide general fouling patterns for that subset of vessels. The third level is a highly targeted series of diver based specimen collections to obtain high resolution species data. As previously mentioned, samples could also be taken while vessels are at drydock, but this would probably not yield representative samples, because most dry-docking of larger vessels is done overseas.

## Level one—Archived video

For this level of study, archival UWILD video footage from vessels that arrive to Prince William Sound would be examined. To access these videos, permission to release the files must first be obtained from vessel owner/operators, and then requested from the libraries of the commercial diving companies that conducted the inspection surveys. Since the majority of vessel traffic to Prince William Sound arrives via the Pacific Northwest, several commercial dive companies in Oregon, Washington and British Columbia were contacted regarding their inspection services. These companies reported performing inspections on a wide array of large vessels, including tank ships, cruise ships, bulkers, container ships, large fishing vessels, Navy and Coast Guard vessels. Most commercial diving companies keep copies of all inspection videos for at least three years, while some companies may retain copies indefinitely. If the videos are numerous and extensive, viewing could be prioritized based on the risk criteria identified in the analysis of the SANS data base provided in this report. The videos may then be analyzed for percent cover and presence/absence of organisms at broad taxonomic levels. Videos must contain enough footage to sufficiently cover all parts of a vessel's underwater surfaces. We recommend that a set number of quadrats from still frames be conducted randomly on the hull, along with semi-random quadrats on non-hull surfaces, if possible. Because non-hull surfaces may act as a refuge for fouling organisms, these areas may warrant special focus. If videos are high enough quality, some quantitative measures of biota can be made. For example, Coutts and Taylor (2004) assessed taxa richness and percentage cover for each quadrat by estimating the size of the image, and using 50 random points superimposed over the video monitor. Taxa richness and percentage cover data were then analyzed using statistical methods such as general linear mixed models, pair-wise comparisons of means, and multivariate analyses, with "vessel type" and "hull location" as fixed factors.

The factors that should be evaluated after video is obtained and reviewed are:

- Is the range of vessel types and ports adequate to answer the questions being asked?
- Is the resolution high enough to identify fouling patterns?
- Do videos of individual vessel hulls adequately cover the hull surface?

In the best case, if enough adequate footage is found, this level would yield information on the extent of biofouling across a large subset of vessels arriving to Prince William Sound. It would likely not, however, provide useful information on specific NIS. If the data obtained at this level is deemed sufficient for the purposes of the study, the study may be restricted to only archival video analysis. If higher species resolution is desired, data from the level one archival footage should be evaluated to determine if it supplies enough information to detect fouling patterns associated with vessel types, voyage types, etc. If such a pattern is evident and appears representative, hull fouling studies may proceed to level three, where a smaller more focused study can be done by divers. If meaningful patterns cannot be detected due to limitations of the archived video, the study may proceed to level 2, where directed video may be obtained by divers or an ROV.

## Level two—ROV and diver video surveys

ROV and diver video surveys offer a step up from UWILD video in that there is more ability to control what is sampled. Sampling can be targeted at ports, vessel types, or voyage types of interest, and specific areas on an individual vessel hull can also be targeted. At this level, researchers may use either divers with video feeds or an ROV to conduct directed video surveys. The control afforded by this method allows vessels to be directly compared in a uniform manner. We recommend the divers or ROV perform several transects along the length of a vessel's hull, followed by special attention to support-block strips and non-hull areas where fouling may accumulate (forward of propellers, rudder, bilge keels, sea-chest grating, etc). A real-time video feed may also be viewed by biologists who can identify areas to be sampled (see level three). During post-processing of videos taken at this level, videos can be paused at both random points and targeted focal points to obtain percent cover and presence/absence of organisms at broad taxonomic levels. This data may then be analyzed statistically using general linear models, multivariate analyses, pair-wise comparisons of means (e.g., Coutts and Taylor 2004) and analysis of similarities (ANOSIM) (Davidson et al 2009).

Level two sampling would allow more controlled data to be gathered on the extent and location of biofouling across a range of vessels, but as with level one sampling, would not provide much information on specific NIS. However, the likelihood of level two sampling providing meaningful data that would help to target level three sampling is likely higher than that obtained with level one sampling.

## Level three—targeted biological sampling by divers

After level one and two analyses, targeted biological sampling can be conducted on vessels of interest.

This sampling could also be done in conjunction with level two sampling, if it is conducted by divers. This method is the most complicated with respect to access, safety, and time considerations, and is the most labor and cost-intensive method. Thus, level three sampling might best be conducted by strategically narrowing the subset of vessels to be sampled to those that are hypothesized to be high risk vectors, as determined by level one and two sampling. For this level of sampling, divers would collect representative samples of fouling observed along transects on vessel hulls. Biofouling would also be visually assessed as in level two. If budgets allow, divers could be connected via live video with biologists that could direct targeted sampling. Transects could be saved as video files and analyzed extensively. The samples can be rapidly assessed while alive. However, most species identifications would be done from samples that are fixed and sent to taxonomic experts.

Level three sampling yields high resolution information on specific fouling organisms and potential and known NIS found in hull samples. Percent cover can also be obtained, though due to limitations in the time divers can spend in the water, this data may be limited to only portions of a vessel. To analyze species composition, a presence/absence matrix is generated using voucher specimens. Post-processing of percent cover data is accomplished by the point count method of superimposing 100 random dots over each quadrat. Statistical methods that can be used to analyze the species composition and percentage cover data include univariate analysis, multivariate analysis, analysis of similarities (ANOSIM), and an accumulation curve to provide an indication of whether all species present were likely sampled (Davidson et al 2006c).

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Appendix Table 1. Voyage histories of vessels entering Alaskan ports of interest, 2005-2008. NW = Pacific northwest of United States + British Columbia, SF = San Francisco Bay area, S. CA = southern California.

| **2005** | | | **2006** | | |
|---|---|---|---|---|---|
| Total | | 814 | Total | | 617 |
| Asia | | 39 | Asia | | 39 |
| | Japan | 15 | | Japan | 21 |
| | South Korea | 12 | | South Korea | 9 |
| | China | 4 | | China | 6 |
| | Russia | 4 | | Russia | 14 |
| | Malaysia | 2 | | Malaysia | 1 |
| | India | 2 | | India | 0 |
| | Singapore | 19 | | Singapore | 9 |
| | Vietnam | 1 | | Vietnam | 0 |
| NW | | 574 | NW | | 404 |
| | Oregon | 39 | | Oregon | 15 |
| | Puget Sound | 390 | | Puget Sound | 253 |
| | British Columbia | 195 | | British Columbia | 160 |
| SF | | 195 | SF | | 142 |
| S.CA | | 113 | S.CA | | 100 |
| S. Pacific | | 14 | S. Pacific | | 15 |
| Other | | 7 | Other | | 11 |
| Mexico | | 10 | Mexico | | 24 |

| **2007** | | | **2008** | | |
|---|---|---|---|---|---|
| Total | | 578 | Total | | 575 |
| Asia | | 32 | Asia | | 28 |
| | Japan | 20 | | Japan | 11 |
| | South Korea | 8 | | South Korea | 6 |
| | China | 7 | | China | 8 |
| | Russia | 10 | | Russia | 7 |
| | Malaysia | 3 | | Malaysia | 0 |
| | India | 1 | | India | 1 |
| | Singapore | 2 | | Singapore | 11 |
| | Vietnam | 0 | | Vietnam | 0 |
| NW | | 460 | NW | | 453 |
| | Oregon | 13 | | Oregon | 19 |
| | Puget Sound | 136 | | Puget Sound | 280 |
| | British Columbia | 153 | | British Columbia | 179 |
| SF | | 160 | SF | | 163 |
| S.CA | | 108 | S.CA | | 83 |
| S. Pacific | | 24 | S. Pacific | | 25 |
| Other | | 19 | Other | | 24 |
| Mexico | | 32 | Mexico | | 31 |

Appendix Table 2. Number of arrivals to Alaskan ports of interest 2005-2008 by vessel type.

| **2005** | Cape Hinchinbrook | College Fjord | Cordova | Kodiak | PWS | Seward | Valdez | Whittier | Tatilek | Total Result |
|---|---|---|---|---|---|---|---|---|---|---|
| Fishing | 0 | 0 | 2 | 30 | 4 | 2 | 5 | 2 | 0 | 45 |
| Freight | 0 | 0 | 0 | 81 | 2 | 9 | 4 | 1 | 0 | 97 |
| Passenger | 0 | 16 | 6 | 15 | 1 | 60 | 11 | 78 | 6 | 193 |
| Tank | 16 | 0 | 0 | 0 | 7 | 0 | 382 | 0 | 0 | 405 |
| Towing | 0 | 0 | 4 | 10 | 0 | 4 | 12 | 41 | 0 | 71 |
| Other | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| Grand Total | 16 | 16 | 12 | 138 | 14 | 75 | 414 | 122 | 6 | 813 |
| | | | | | | | | | | |
| **2006** | Cape Hinchinbrook | College Fjord | Cordova | Kodiak | PWS | Seward | Valdez | Whittier | Tatilek | Total Result |
| Fishing | 0 | 0 | 4 | 36 | 4 | 5 | 1 | 2 | 0 | 52 |
| Freight | 0 | 0 | 0 | 43 | 2 | 8 | 3 | 0 | 0 | 56 |
| Passenger | 0 | 0 | 2 | 10 | 1 | 43 | 1 | 69 | 0 | 126 |
| Tank | 1 | 0 | 0 | 0 | 9 | 0 | 312 | 1 | 0 | 323 |
| Towing | 0 | 0 | 1 | 4 | 0 | 5 | 5 | 35 | 0 | 50 |
| Other | 0 | 0 | 1 | 3 | 0 | 3 | 0 | 0 | 0 | 7 |
| Grand Total | 1 | 0 | 8 | 96 | 16 | 64 | 322 | 107 | 0 | 614 |
| | | | | | | | | | | |
| **2007** | Cape Hinchinbrook | College Fjord | Cordova | Kodiak | PWS | Seward | Valdez | Whittier | Tatilek | Total Result |
| Fishing | 0 | 0 | 3 | 18 | 7 | 5 | 0 | 0 | 0 | 33 |
| Freight | 0 | 0 | 0 | 45 | 2 | 4 | 5 | 0 | 0 | 56 |
| Passenger | 0 | 0 | 0 | 4 | 0 | 56 | 0 | 64 | 0 | 124 |
| Tank | 6 | 0 | 0 | 0 | 3 | 1 | 296 | 0 | 0 | 306 |
| Towing | 0 | 0 | 1 | 5 | 0 | 5 | 7 | 34 | 0 | 52 |
| Other | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 3 |
| Grand Total | 6 | 0 | 4 | 75 | 12 | 71 | 308 | 98 | 0 | 574 |
| | | | | | | | | | | |
| **2008** | Cape Hinchinbrook | College Fjord | Cordova | Kodiak | PWS | Seward | Valdez | Whittier | Tatilek | Total Result |
| Fishing | 0 | 0 | 3 | 23 | 8 | 1 | 3 | 1 | 0 | 39 |
| Freight | 0 | 0 | 1 | 40 | 2 | 9 | 1 | 1 | 0 | 54 |
| Passenger | 0 | 1 | 0 | 12 | 0 | 66 | 8 | 50 | 0 | 137 |
| Tank | 0 | 0 | 0 | 0 | 0 | 0 | 282 | 0 | 0 | 282 |
| Towing | 0 | 0 | 1 | 5 | 0 | 1 | 5 | 35 | 0 | 47 |
| Other | 0 | 0 | 0 | 1 | 1 | 4 | 0 | 0 | 0 | 6 |
| Grand Total | 0 | 1 | 5 | 81 | 11 | 81 | 299 | 87 | 0 | 565 |

Appendix Table 3. Voyage types of arrivals by port, 2005-2008, for vessels entering Alaskan ports of interest, 2005-2008.

| | Voyage Type by Port | | | | |
|---|---|---|---|---|---|
| 2005 | Domestic | Other | Total WC | Total Transp | Grand Total |
| Cape Hinchinbrook | 2 | 0 | 13 | 1 | 16 |
| College Fjord | 1 | 0 | 15 | 0 | 16 |
| Cordova | 9 | 0 | 3 | 0 | 12 |
| Kodiak | 70 | 0 | 45 | 7 | 122 |
| Prince William Sound | 1 | 0 | 12 | 1 | 14 |
| Seward | 9 | 1 | 55 | 11 | 76 |
| Valdez | 29 | 0 | 335 | 27 | 391 |
| Whittier | 16 | 0 | 104 | 2 | 122 |
| Tatilek | 1 | 0 | 5 | 0 | 6 |
| Total Result | 138 | 1 | 587 | 49 | 775 |
| 2006 | Domestic | Other | Total WC | Total Transp | Grand Total |
| Cape Hinchinbrook | 0 | 0 | 1 | 0 | 1 |
| College Fjord | 0 | 0 | 0 | 0 | 0 |
| Cordova | 5 | 0 | 2 | 1 | 8 |
| Kodiak | 64 | 0 | 21 | 11 | 96 |
| Prince William Sound | 4 | 0 | 12 | 0 | 16 |
| Seward | 15 | 2 | 39 | 7 | 63 |
| Valdez | 34 | 1 | 266 | 16 | 317 |
| Whittier | 2 | 0 | 94 | 11 | 107 |
| Tatilek | 0 | 0 | 0 | 0 | 0 |
| Total Result | 124 | 3 | 435 | 46 | 608 |
| 2007 | Domestic | Other | Total WC | Total Transp | Grand Total |
| Cape Hinchinbrook | 0 | 0 | 6 | 0 | 6 |
| College Fjord | 0 | 0 | 0 | 0 | 0 |
| Cordova | 3 | 0 | 0 | 1 | 4 |
| Kodiak | 51 | 0 | 17 | 7 | 75 |
| Prince William Sound | 6 | 0 | 6 | 0 | 12 |
| Seward | 4 | 3 | 52 | 13 | 72 |
| Valdez | 6 | 1 | 288 | 11 | 306 |
| Whittier | 6 | 0 | 76 | 16 | 98 |
| Tatilek | 0 | 0 | 0 | 0 | 0 |
| Total Result | 76 | 4 | 445 | 48 | 573 |
| 2008 | Domestic | Other | Total WC | Total Transp | Grand Total |
| Cape Hinchinbrook | 0 | 0 | 0 | 0 | 0 |
| College Fjord | 0 | 1 | 0 | 0 | 1 |
| Cordova | 3 | 0 | 2 | 0 | 5 |
| Kodiak | 55 | 1 | 20 | 5 | 81 |
| Prince William Sound | 5 | 1 | 5 | 0 | 11 |
| Seward | 3 | 2 | 60 | 16 | 81 |
| Valdez | 8 | 0 | 275 | 16 | 299 |
| Whittier | 3 | 0 | 76 | 8 | 87 |
| Tatilek | 0 | 0 | 0 | 0 | 0 |
| Total Result | 77 | 5 | 438 | 45 | 565 |

Appendix Table 4. Voyage types of incoming arrivals by vessel type, 2005-2008, for vessels entering Alaskan ports of interest, 2005-2008.

| | Voyage Types | | | | | | |
|---|---|---|---|---|---|---|---|
| 2005 | Other | Fishing | Freight | Passenger | Tank | Towing | Total |
| Domestic | 0 | 30 | 31 | 43 | 19 | 14 | 137 |
| Other | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Total Transp | 2 | 0 | 15 | 7 | 23 | 2 | 49 |
| Total WC | 0 | 14 | 37 | 142 | 340 | 55 | 588 |
| Total Result | 2 | 44 | 83 | 193 | 382 | 71 | 775 |
| | | | | | | | |
| 2006 | Other | Fishing Boat | Freight Ship | Passenger | Tank Ship | Towing vessel | Total |
| Domestic | 0 | 33 | 36 | 14 | 32 | 9 | 124 |
| Other | 0 | 0 | 1 | 1 | 1 | 0 | 3 |
| Total Transp | 4 | 1 | 11 | 18 | 12 | 0 | 46 |
| Total WC | 3 | 20 | 5 | 93 | 273 | 41 | 435 |
| Total Result | 7 | 54 | 53 | 126 | 318 | 50 | 608 |
| | | | | | | | |
| 2007 | Other | Fishing Boat | Freight Ship | Passenger | Tank Ship | Towing vessel | Total |
| Domestic | 0 | 16 | 48 | 6 | 5 | 1 | 76 |
| Other | 0 | 0 | 0 | 1 | 0 | 3 | 4 |
| Total Transp | 2 | 0 | 10 | 23 | 8 | 4 | 47 |
| Total WC | 1 | 14 | 1 | 94 | 291 | 44 | 445 |
| Total Result | 3 | 30 | 59 | 124 | 304 | 52 | 572 |
| | | | | | | | |
| 2008 | Other | Fishing Boat | Freight Ship | Passenger | Tank Ship | Towing vessel | Total |
| Domestic | 0 | 20 | 44 | 2 | 5 | 6 | 77 |
| Other | 2 | 0 | 0 | 3 | 0 | 0 | 5 |
| Total Transp | 3 | 0 | 10 | 19 | 13 | 0 | 45 |
| Total WC | 1 | 17 | 2 | 113 | 264 | 41 | 438 |
| Total Result | 6 | 37 | 56 | 137 | 282 | 47 | 565 |

Appendix Table 5. Voyage history of incoming arrivals to Alaskan ports of interest 2005-2008 by vessel type.

| Voyage history per year by ship type | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2005 | Fishing | Freight | Passenger | Tank | Towing | Other | Total |
| Asia | 0 | 15 | 7 | 14 | 2 | 1 | 39 |
| NW | 14 | 42 | 146 | 312 | 58 | 0 | 572 |
| SF | 0 | 0 | 4 | 191 | 0 | 0 | 195 |
| S. CA | 0 | 0 | 6 | 107 | 0 | 0 | 113 |
| South Pacific | 0 | 0 | 1 | 12 | 0 | 1 | 14 |
| Other | 0 | 3 | 4 | 0 | 0 | 0 | 7 |
| Mexico | 0 | 1 | 9 | 0 | 0 | 0 | 10 |
| | | | | | | | |
| 2006 | Fishing | Freight | Passenger | Tank | Towing | Other | Total |
| Asia | 1 | 12 | 14 | 9 | 0 | 3 | 39 |
| NW | 15 | 5 | 109 | 233 | 42 | 2 | 406 |
| SF | 0 | 0 | 1 | 141 | 0 | 0 | 142 |
| S. CA | 0 | 2 | 0 | 98 | 0 | 0 | 100 |
| South Pacific | 1 | 2 | 5 | 4 | 0 | 3 | 15 |
| Other | 0 | 3 | 3 | 1 | 0 | 2 | 9 |
| Mexico | 0 | 1 | 20 | 1 | 0 | 2 | 24 |
| | | | | | | | |
| 2007 | Fishing | Freight | Passenger | Tank | Towing | Other | Total |
| Asia | 0 | 10 | 14 | 4 | 0 | 2 | 30 |
| NW | 11 | 3 | 116 | 276 | 46 | 1 | 453 |
| SF | 0 | 0 | 0 | 158 | 2 | 0 | 160 |
| S. CA | 0 | 0 | 0 | 108 | 0 | 0 | 108 |
| South Pacific | 0 | 0 | 12 | 4 | 4 | 2 | 22 |
| Other | 1 | 1 | 8 | 0 | 4 | 1 | 15 |
| Mexico | 0 | 0 | 28 | 0 | 3 | 1 | 32 |
| | | | | | | | |
| 2008 | Fishing | Freight | Passenger | Tank | Towing | Other | Total |
| Asia | 0 | 9 | 10 | 9 | 0 | 0 | 28 |
| NW | 10 | 4 | 132 | 255 | 42 | 4 | 447 |
| SF | 1 | 0 | 0 | 162 | 0 | 0 | 163 |
| S. CA | 0 | 0 | 0 | 80 | 0 | 2 | 82 |
| South Pacific | 0 | 4 | 11 | 6 | 1 | 3 | 25 |
| Other | 0 | 4 | 12 | 0 | 4 | 3 | 23 |
| Mexico | 0 | 1 | 27 | 0 | 0 | 2 | 30 |

Appendix Table 6. Distribution of fouling organisms outside their native ranges.

*Organisms notated with a 'B' are primarily benthic/epibenthic species that have been associated with hull fouling in other studies. WA= Washington, OR=Oregon, HB= Humboldt Bay, Socal= Southern California, Chspk= Chesapeake Bay, NE-US=Northeast US, Gmex= Gulf of Mexico, AU= Australia, HI= Hawaii, MED= Mediterranean, Neuro= Northern Europe, BC= British Columbia, AK= Alaska*

| | | | WA | OR | HB | Socal | SF | Chspk | NE-US | Gmex | AU | HI | MED | Neuro | BC | AK | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ascidians | *Botrylloides violaceus* | x | x | x | x | x | x | x | | | | | | | x | 8 |
| | Ascidians | *Botryllus schlosseri* | x | x | x | x | x | x | x | x | | | | | | x | 9 |
| | Ascidians | *Ciona savignyi* | x | | x | x | x | | | | | | | | | | 4 |
| | Ascidians | *Didemnum vexillum* | x | | x | x | x | | x | | | | | | | | 5 |
| | Ascidians | *Molgula manhattensis* | x | x | x | x | x | x | | | x | | | x | | | 8 |
| | Ascidians | *Styela clava* | x | x | x | x | x | | x | | x | | | x | x | | 9 |
| | | | | | | | | | | | | | | | | | |
| | Bryozoans | *Bugula stolonifera* | x | | | | x | | | x | x | x | | | | | 5 |
| | Bryozoans | *Watersipora subtorquata* | | x | x | x | x | | | | x | x | x | | | | 7 |
| | Byrozoans | *Bowerbankia gracilis* | x | x | x | x | x | | | x | x | | | x | | | 8 |
| | Byrozoans | *Bugula neritina* | x | x | x | x | x | x | x | x | x | x | x | x | | | 12 |
| | Byrozoans | *Conopeum tenuissimum* | | x | | | x | | | | | | | | | | 2 |
| | Byrozoans | *Cryptosula pallasiana* | x | x | x | x | x | | | | x | | x | x | x | x | 10 |
| | Byrozoans | *Schizoporella unicornis (japonica)* | x | x | x | x | x | | | x | x | x | x | x | x | x | 12 |
| | | | | | | | | | | | | | | | | | |
| | Sponges | *Halichondria bowerbanki* | x | x | x | | | | | | | | | | | | 3 |
| | Sponges | *Haliclona spp* | x | x | x | | | | | | | | | | | | 3 |
| | Sponges | *Microciona (Clathria) prolifera* | x | | x | | x | | | | | | | | | | 3 |
| | | | | | | | | | | | | | | | | | |
| | Cnidarians- Anthozoans | *Diadumene cincta* | | | x | | x | | | | | | | x | | | 3 |
| | Cnidarians-anthozoan | *Diadumene leucolena* | | x | x | | x | | | | | x | | | | | 4 |
| | Cnidarians-anthozoan | *Diadumene lineata* | x | x | x | x | x | x | x | | | x | | | x | x | 10 |
| | Cnidarians-hydrozoans | *Blackfordia virginica* | | x | | | x | x | x | | | | | | | | 4 |
| | Cnidarians-hydrozoans | *Cladonema radiatum* | x | | | | | | | | | | | | | | 1 |
| | Cnidarians-hydrozoans | *Cordylophora caspia* | x | x | x | | x | x | x | | x | | | x | | | 8 |
| | Cnidarians-hydrozoans | *Ectopleura (tubularia) (pinauay) crocea* | x | x | x | x | x | | | | x | | | | | x | 7 |
| | Cnidarians-hydrozoans | *Garveia franciscana* | | | | | x | x | x | | | | | | | x | 4 |
| | | | | | | | | | | | | | | | | | |

| | | | WA | OR | HB | Socal | SF | Chspk | NE-US | Gmex | AU | HI | MED | Neuro | BC | AK | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Entoprocta | *Barentsia benedeni* | x | x | | | x | x | x | | x | | | | | x | 7 |
| | Foraminiferans | *Trochahammina hadai* | x | | x | | | | | | | | | | | x | 3 |
| | | | | | | | | | | | | | | | | | |
| | Mollusc-bivalvia | *Mytilus edulis* | x | | | | | | | | | | | | x | | 2 |
| | Mollusc-bivalvia | *Mytilus galloprovincialis* | x | x | | x | x | | x | | | x | | | x | | 7 |
| | Molluscs-bivalvia | *Teredo navalis* | x | x | | | x | x | | | x | | | x | | | 6 |
| B | Molluscs-gastropods | *Myosotella myosotis* | x | x | x | x | x | x | x | | | | | | | | 7 |
| B | Molluscs-nudibranch | *Tenellia adspersa* | | x | | | x | x | x | | | | | | | | 4 |
| | | | | | | | | | | | | | | | | | |
| B | Polychaetes | *Heteromastus filiformis* | x | x | x | x | x | | | | x | | x | | x | x | 9 |
| B | Polychaetes | *Neanthes succinea* | x | x | | | x | | | | | | | x | | | 4 |
| B | Polychaetes | *Polydora cornuta* | x | x | x | x | x | | | x | x | | | | x | | 8 |
| B | Polychaetes | *Pseudopolydora kempi* | x | x | x | x | x | | | | x | | | | x | | 7 |
| B | Polychaetes | *Pseudopolydora paucibranchiata* | x | x | x | x | x | | | | x | | | | | | 6 |
| B | Polychaetes | *Streblospio benedicti* | x | x | x | x | x | | | x | | | | x | | | 7 |
| | | | | | | | | | | | | | | | | | |
| B | Arthropods-Amphipods | *Ampithoe valida* | x | x | x | x | x | | | x | | | | | x | | 7 |
| B | Arthropods-Amphipods | *Caprella mutica* | x | x | x | x | x | | | | | | | x | | x | 7 |
| B | Arthropods-Amphipods | *Chelura terebrans* | x | | x | x | x | | | | | | | | | | 4 |
| B | Arthropods-Amphipods | *Incisocalliope (Parapleustes) derzhavini* | x | x | x | | x | | | | | | | | | | 4 |
| B | Arthropods-Amphipods | *Jassa marmorata* | x | x | x | x | x | | | | x | | | | | x | 7 |
| B | Arthropods-Amphipods | *Melita nitida* | x | x | x | x | x | | | | | | | | x | | 6 |
| B | Arthropods-Amphipods | *Monocorphium acherusicum* | x | x | x | x | x | x | | | x | x | x | x | x | x | 12 |
| B | Arthropods-Amphipods | *Monocorphium insidiosum* | x | x | x | x | x | | | | x | x | | | x | | 8 |
| B | Arthropods-barnacles | *Balanus improvisus* | x | x | | | | | | | x | | | x | | | 4 |
| B | Arthropods-decapods | *Rhithropanopeus harrisii* | | x | | | x | | | | | | | x | | | 3 |
| B | Arthropods-Isopods | *Iais californica* | x | x | x | x | x | | | | | | | | | | 5 |
| B | Arthropods-Isopods | *Limnoria quadripunctata* | | | x | | x | | | | | | | x | | | 3 |
| B | Arthropods-isopods | *Limnoria tripunctata* | x | x | x | x | | | | | | | | | | | 4 |
| B | Arthropods-Isopods | *Sphaeroma quoyanum* | | x | x | x | x | | | | | | | | | | 4 |
| B | Arthropods-isopods | *Synidotea laevidorsalis* | x | | | | x | x | x | | | | | | | | 4 |
| B | Arthropods-Tanaids | *Sinelobus stanfordi* | x | x | x | x | x | | | x | | | x | x | | | 8 |

Sources: *National Introduced Pest Information System (CSIRO), National Benthic Inventory (NOAA), North European and Baltic Network on Invasive Alien Species (NOBANIS), National Exotic Marine and Estuarine Species Information System (SERC), Non-indigenous Aquatic*

*Species (USGS), Guidebook of Introduced Marine Species of Hawaii (Hawaii Biological Survey), Non-native Aquatic Species in the Gulf of Mexico and South Atlantic Regions (Gulf State Marine Fisheries Commission), Atlas of Exotic Species in the Mediterranean (CIESM), NIS Fact Sheet (PWSRCAC), Ashton et al (2008), Boyd et al (2002), Cohen (2004), Cohen & Carlton (1995, 1998), Cohen et al (1998, 2001, 2002, 2005a, 2005b, 2005c), Hines & Ruiz (2000), McGee et al (2006), Ray (2005) (ANSRP), Ruiz et al (2006), Wonham & Carlton (2005).*

Appendix Table 7. Anti-fouling paints used and hull locations where applied.

| ReportYear | Vessel Name | Manufacturer | Antifouling Product Name | Biocide1 | Biocide2 | Hull Sides | Hull Bottom | Sea Chests | Sea Chest Gratings | Propeller | Rope Guard Propeller Shaft | Previous Docking Blocks | Thrusters | Rudder | Bilge Keels |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2008 | ALASKAN EXPLORER | International Paint Ltd. | Interclene 245NA (BRA570, 572) | Cuprous Oxide | | TRUE | TRUE | TRUE | TRUE | **FALSE** | TRUE | **FALSE** | **FALSE** | TRUE | TRUE |
| 2009 | ALASKAN EXPLORER | International Paint Ltd. | Interclene 245NA (BRA570, 572) | Cuprous Oxide | | TRUE | TRUE | TRUE | TRUE | **FALSE** | TRUE | **FALSE** | **FALSE** | TRUE | TRUE |
| 2008 | ALASKAN FRONTIER | International Paint Ltd. | Interclene 245NA (BRA570, 572) | Cuprous Oxide | | TRUE | TRUE | TRUE | TRUE | **FALSE** | TRUE | **FALSE** | **FALSE** | TRUE | TRUE |
| 2009 | ALASKAN FRONTIER | International Paint Ltd. | Interclene 245NA (BRA570, 572) | Cuprous Oxide | | TRUE | TRUE | TRUE | TRUE | **FALSE** | TRUE | **FALSE** | **FALSE** | TRUE | TRUE |
| 2008 | ALASKAN LEGEND | International Paint Ltd. | Interclene 245NA (BRA570, 572) | Cuprous Oxide | | TRUE | TRUE | TRUE | TRUE | **FALSE** | TRUE | **FALSE** | **FALSE** | TRUE | TRUE |
| 2009 | ALASKAN LEGEND | International Paint Ltd. | Interclene 245NA (BRA570, 572) | Cuprous Oxide | | TRUE | TRUE | TRUE | TRUE | **FALSE** | TRUE | **FALSE** | **FALSE** | TRUE | TRUE |
| 2008 | ALASKAN NAVIGATOR | International Paint Ltd. | Interclene 245NA (BRA570, 572) | Cuprous Oxide | | TRUE | TRUE | TRUE | TRUE | **FALSE** | TRUE | **FALSE** | **FALSE** | TRUE | TRUE |
| 2009 | ALASKAN NAVIGATOR | International Paint Ltd. | Interclene 245 | Cuprous Oxide | Zineb | TRUE | TRUE | TRUE | TRUE | **FALSE** | TRUE | **FALSE** | **FALSE** | TRUE | TRUE |
| 2009 | CAPTAIN H. A. DOWNING | Jotun Paints | Hydroclean (AKA SeaGuardian) | Cuprous Oxide | | TRUE | TRUE | TRUE | TRUE | **FALSE** | **FALSE** | TRUE | **FALSE** | TRUE | **FALSE** |
| 2008 | KODIAK | International Paint Ltd. | Interspeed 340 (BQA 341-344, 346, 347, 349) | Cuprous Oxide | Zineb | TRUE | **FALSE** | TRUE | TRUE | **FALSE** | TRUE | **FALSE** | **FALSE** | TRUE | TRUE |
| 2009 | KODIAK | International Paint Ltd. | Interspeed 340 (BQA 341-344, 346, 347, 349) | Cuprous Oxide | Zineb | TRUE | **FALSE** | TRUE | TRUE | TRUE | **FALSE** | TRUE | **FALSE** | TRUE | TRUE |
| 2008 | MISSISSIPPI VOYAGER | International Paint Ltd. | Interspeed 640 (BRA 640-644) | Cuprous Oxide | | TRUE | TRUE | **FALSE** | **FALSE** | **FALSE** | TRUE | TRUE | **FALSE** | TRUE | TRUE |
| 2009 | MISSISSIPPI VOYAGER | International Paint Ltd. | Interspeed 640 (BRA 640-644) | Cuprous Oxide | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | **FALSE** | TRUE | TRUE |
| 2009 | OVERSEAS NEW YORK | Chugoku Marine Paint | Sea Grandprix 500, 500M | Cuprous Oxide | Copper Pyrithione | TRUE | TRUE | TRUE | TRUE | **FALSE** | **FALSE** | **FALSE** | **FALSE** | TRUE | TRUE |
| 2008 | POLAR ADVENTURE | International Paint Ltd. | Intersleek (none specified) | Biocide-free Silicone | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| 2008 | POLAR DISCOVERY | International Paint Ltd. | Intersleek (none specified) | Biocide-free Silicone | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| 2009 | POLAR DISCOVERY | International Paint Ltd. | Intersleek 757 | Biocide-free Silicone topcoat | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| 2008 | POLAR ENDEAVOUR | International Paint Ltd. | Intersleek (none specified) | Biocide-free Silicone | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| 2009 | POLAR ENDEAVOUR | International Paint Ltd. | Intersleek 757 | Biocide-free Silicone topcoat | | TRUE | TRUE | TRUE | TRUE | **FALSE** | TRUE | TRUE | TRUE | TRUE | TRUE |
| 2008 | POLAR ENTERPRISE | International Paint Ltd. | Intersleek (none specified) | Biocide-free Silicone | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| 2009 | POLAR ENTERPRISE | International Paint Ltd. | Intersleek 757 | Biocide-free Silicone topcoat | | **FALSE** | TRUE | TRUE | TRUE | **FALSE** | TRUE | TRUE | TRUE | TRUE | TRUE |
| 2008 | POLAR RESOLUTION | International Paint Ltd. | Intersleek 757 | Biocide-free Silicone topcoat | | **FALSE** | TRUE | TRUE | TRUE | **FALSE** | TRUE | TRUE | TRUE | TRUE | TRUE |
| 2009 | POLAR RESOLUTION | International Paint Ltd. | Intersleek 757 | Biocide-free Silicone topcoat | | TRUE | TRUE | TRUE | TRUE | **FALSE** | **FALSE** | **FALSE** | **FALSE** | TRUE | **FALSE** |
| 2008 | S/R BAYTOWN | International Paint Ltd. | Intersleek 737 | Biocide-free Silicone intermediate coat | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| 2009 | S/R BAYTOWN | International Paint Ltd. | Intersleek 737 | Biocide-free Silicone intermediate coat | | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE | TRUE |
| 2008 | S/R LONG BEACH | International Paint Ltd. | Interspeed 340 (BQA 341-344, 346, 347, 349) | Cuprous Oxide | Zineb | TRUE | **FALSE** | TRUE | TRUE | **FALSE** | TRUE | **FALSE** | **FALSE** | TRUE | TRUE |
| 2009 | S/R LONG BEACH | International Paint Ltd. | Interspeed 340 (BQA 341-344, 346, 347, 349) | Cuprous Oxide | Zineb | TRUE | **FALSE** | TRUE | **FALSE** | **FALSE** | **FALSE** | **FALSE** | **FALSE** | **FALSE** | **FALSE** |
| 2008 | SEABULK ARCTIC | International Paint Ltd. | Interclene 245NA (BRA570, 572) | Cuprous Oxide | | TRUE | TRUE | TRUE | TRUE | **FALSE** | **FALSE** | TRUE | **FALSE** | TRUE | TRUE |
| 2009 | SEABULK ARCTIC | International Paint Ltd. | Interspeed 340 | Cuprous Oxide | Zineb | TRUE | **FALSE** | **FALSE** | **FALSE** | **FALSE** | **FALSE** | **FALSE** | **FALSE** | **FALSE** | **FALSE** |
| 2008 | SEABULK PRIDE | International Paint Ltd. | Interclene 245NA (BRA570, 572) | Cuprous Oxide | | TRUE | TRUE | TRUE | TRUE | **FALSE** | **FALSE** | TRUE | **FALSE** | TRUE | TRUE |
| 2009 | SEABULK PRIDE | International Paint Ltd. | Interclene 245NA (BRA570, 572) | Cuprous Oxide | | TRUE | TRUE | TRUE | TRUE | **FALSE** | TRUE | TRUE | TRUE | TRUE | TRUE |
| 2008 | SIERRA | International Paint Ltd. | Interspeed 340 (BQA 341-344, 346, 347, 349) | Cuprous Oxide | Zineb | TRUE | **FALSE** | TRUE | TRUE | **FALSE** | TRUE | **FALSE** | **FALSE** | TRUE | TRUE |
| 2009 | SIERRA | International Paint Ltd. | Intersleek 900 | Biocide-free fluoropolymer | | TRUE | **FALSE** | TRUE | TRUE | TRUE | **FALSE** | TRUE | FALSE | TRUE | TRUE |