Chapter 2. Ballast Water Delivery Patterns

Gregory M. Ruiz, Smithsonian Environmental Research Center
Anson H. Hines, Smithsonian Environmental Research Center
George Smith, Smithsonian Environmental Research Center
Melissa A. Frey, Smithsonian Environmental Research Center

2A. Purpose

The primary goal of this portion of the study was to characterize the traffic patterns and volumes of ballast water discharged into Port Valdez and Prince William Sound (PWS) by oil tankers. Since ballast water is a major mechanism for the transfer of NIS, we wished to describe the delivery patterns of the ballast water to the region by season, source region, voyage duration. Analysis of the biota associated with the tankers' ballast water is discussed in the next chapter.

2B. Methods

We obtained data on ship arrivals and ballast water histories in two ways. First, we obtained information about the long-term (10-year) pattern of arrivals to Port Valdez from Alyeska and RCAC. Second, to characterize current patterns, we collected detailed data from vessels arriving to Port Valdez over the one-year period of 1998. Our goal in this latter approach was to collect comprehensive information on the origin (i.e., last port of call), date of arrival, and ballast water histories for as many arriving vessels as possible. Most of these data were collected by SERC staff, during interviews aboard vessels (see below). Additional data were sent to us by the ships' personnel and shipping agents.

Beginning December 1997, we implemented a sampling scheme to estimate the amount of segregated ballast water delivered to Prince William Sound and Port Valdez by source port and season. For tankers arriving to Port Valdez from each of the three primary domestic source port systems (Los Angeles, San Francisco Bay, Puget Sound), we boarded approximately 3 tankers per month (i.e., 10 per quarter x 3 source ports = 30 per quarter). In addition, we attempted to board most tankers arriving to Port Valdez from foreign ports.

Upon boarding, we conducted an interview of the ships' personnel to collect information on the quantity, age, source region, and management of all ballast water. Following the interview, we proceeded to sample the segregated ballast water to characterize temperature, salinity, and resident biota (see Chapter 3).

We excluded non-segregated ballast water from most of our current analyses. Although this can account for roughly 50% of the total ballast water aboard tankers arriving to Prince William Sound (see below), previous analyses indicated that very few viable organisms were present in this ballast water, which often includes some residual oil. Furthermore, the nonsegregated ballast water is pumped to an on-shore treatment facility at the Alyeska terminal. For review of previous results, as well as description of the treatment process, see Ruiz and Hines 1997.

Since vessels with double bottoms are difficult to sample for biota, we focused our sampling effort primarily on vessels without double bottoms. Thus, to characterize the entire fleet (i.e., all

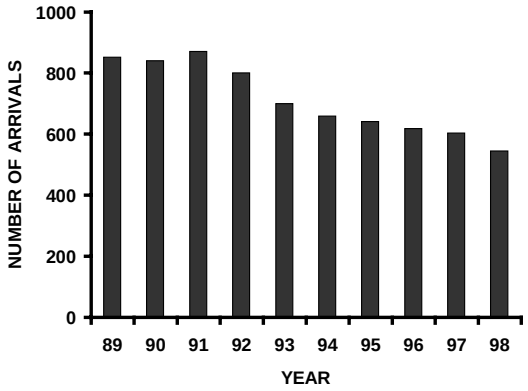
arrivals), we obtained additional data on ballast water histories of nearly all oil tankers arriving to Port Valdez in 1998. Ships' personnel and shipping agents generously provided these data.

2C. Results

2C1. Number and Source of Tanker Arrivals to PWS

Over the past decade (1989-98), tanker arrivals to Port Valdez have averaged 713 (se=37.2) ships per year**,** ranging from 870 to 549 (Fig. 2.1). There has been a noticeable decline in arrivals since 1991, with each year having fewer arrivals than the previous one.

Figure 2.1. Annual number of oil tankers arriving to Port Valdez, 1989-1998. Data as provided by Alyeska.



Using 1998 to examine spatial and temporal patterns, tanker arrivals to Port Valdez were both distributed evenly among seasons and dominated by arrivals from U.S. domestic ports (Fig. 2.2). An average of 137.3 (s.e.=2.98) vessels arrived each quarter, and 95.8% (s.e. = 0.82 %) of all arrivals came directly from a U.S. port. Of all tanker arrivals, 82.7% came from one of three domestic ports (Fig. 2.3): Puget Sound, Washington (43.0%); San Francisco Bay, California (28.8.%); and Long Beach, California (10.9%). The residual came from Oregon, Hawaii, Alaska, or foreign ports. Among arrivals from foreign ports, most (69.6%) came directly from Korea (Fig. 2.4).

Figure 2.2. Number of oil tankers arriving to Port Valdez from foreign and domestic source ports by season in 1998. Seasons include: Winter (January-March), Spring (April-June), Summer (July-September), and Fall (October-December). Data based upon boarding interviews and reports from ships' personnel (see text).

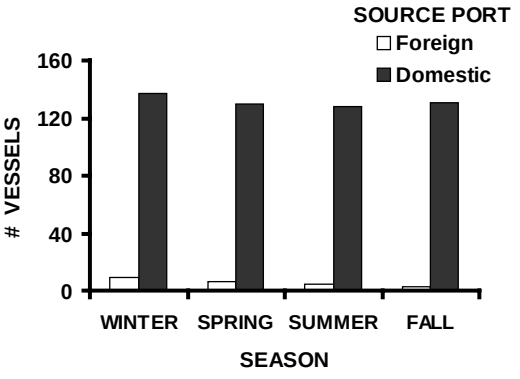


Figure 2.3 Number of oil tankers arriving to Port Valdez from each domestic source port by season in 1998. Source ports include: Puget Sound, WA (PS); San Francisco Bay, CA (SF); Long Beach, CA (LB); Columbia River, Oregon (OR); Cook Inlet, Alaska (AK); and Barbers Point, Hawaii (HI). Seasons include: Winter (January-March), Spring (April-June), Summer (July-September), and Fall (October-December). Data based upon boarding interviews and reports from ships' personnel (see text).

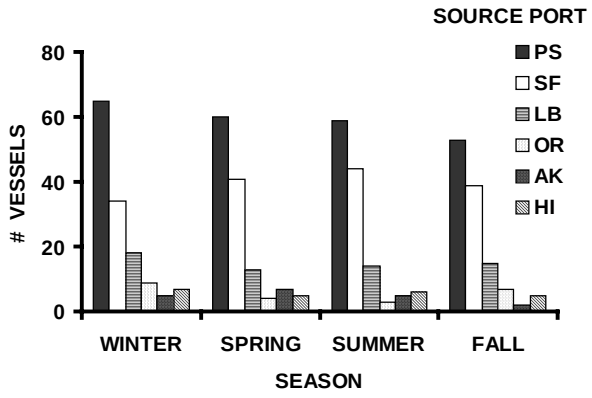
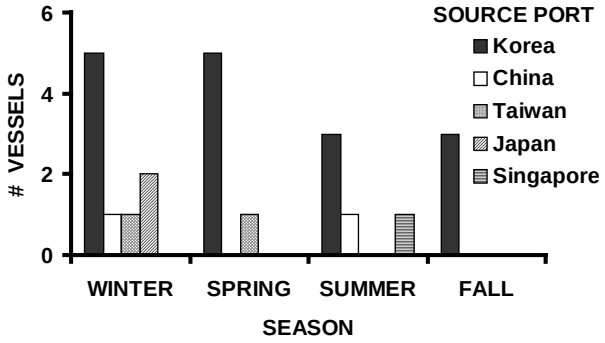


Figure 2.4. Number of oil tankers arriving to Port Valdez from each foreign source port by season in 1998. Seasons Include: Winter (January-March), Spring (April-June), Summer (July-September), and Fall (October-December). Data based upon boarding interviews and reports from ships' personnel (see text).



2C2. Volume of Ballast Water delivered to PWS

During 1998, oil tankers arriving to PWS carried an estimated average of 65,775m^3 (s.e.=1,252; n=472) of total ballast water, the combination of segregated and nonsegregated ballast water. Segregated ballast water comprised an average of 54.7% (s.e.=2.1%; n=472) of the total among tankers.

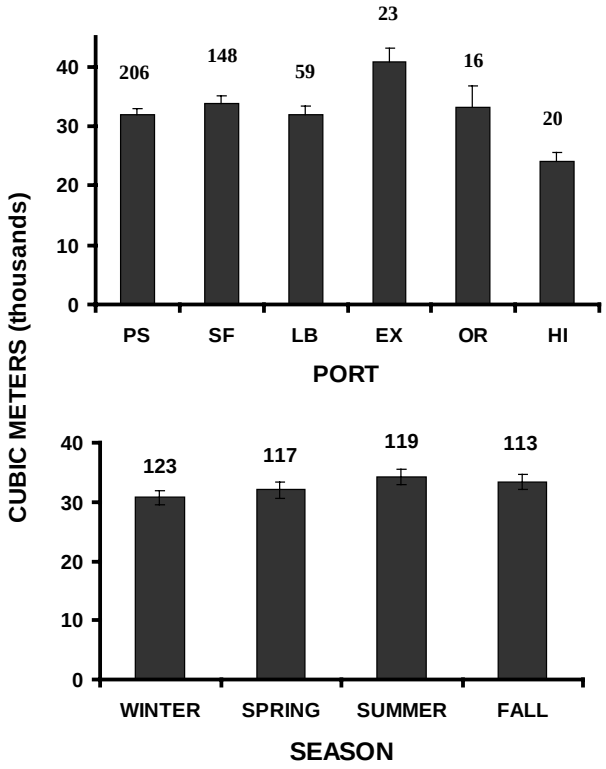
Across all vessels, tankers discharged an average of 32,715 m^3 (s.e.= 645; n=472) of segregated ballast water upon arrival to PWS (Table 2.1). Although there were no seasonal differences in the average amount of ballast water per tanker, there was a significant difference by source port (Fig. 2.5; 2-way ANOVA, $F_{(3 \text{ (seasons)}, 5 \text{ (port source)}, 517 \text{ obs})} = 3.52$, $P = 0.004$). Specifically, the mean volume was significantly greater for arrivals from foreign ports compared to arrivals from all other ports, and the mean volume was significantly lower for tankers from Hawaii relative to all other sources.

Table 2.1. Estimated volume of ballast water delivered by oil tankers to Port Valdez and PWS in 1998. Shown by source port and season are: (1) the estimated mean volume of ballast water arriving per tanker, including the standard error and sample size (n=number of vessels for which we have volume estimates), (2) the total number of tanker arrivals which is shown as N, (3) the total estimated volume of ballast water (calculated as mean volume X total arrivals). The bottom row (Overall) estimates the total ballast water volume and number of arrivals for all ships combined. Source ports include: Puget Sound, WA (PS); San Francisco Bay, CA (SF); Long Beach, CA (LB); Foreign port with open-ocean exchange (EX); Columbia River, Oregon (OR); and Barbers Point, Hawaii (HI). Seasons include: Winter (January-March), Spring (April-May), Summer (July-September), and Fall (October-December). Source of data on volumes and arrivals as described in text.

		BW vol. (m^3)			
Port/Source	**Season**	**Mean(se)**	**n**	**N**	**Total**
	Winter	28163(1734)	56	64	1,802,432
	Spring	31421(2095)	51	60	1,885,260
PS	Summer	34448(1901)	53	59	2,032,432
	Fall	33894(2199)	46	53	1,796,382
	Grand total		206	236	7,516,506
	Winter	31841(2798)	31	34	1,082,594
	Spring	32809(2984)	40	41	1,345,169
SF	Summer	35765(2361)	40	44	1,573,660
	Fall	34371(2372)	37	39	1,340,469
	Grand total		148	158	5,341,892
	Winter	32526(3237)	18	18	585,468
	Spring	30399(2902)	12	13	395,187
LB	Summer	36045(3633)	14	14	504,630
	Fall	28850(1346)	15	15	390,180
	Grand total		59	60	1,875,465
	Winter	42153(4093)	9	9	379,377
	Spring	44294(3775)	6	6	265,764
EX	Summer	29856(3689)	5	5	149,280
	Fall	47056(5199)	3	3	141,168
	Grand total		23	23	935,589
	Winter	29182(6929)	4	9	262,638
	Spring	28250(2169)	4	4	113,000
OR	Summer	32429(1631)	2	3	97,287
	Fall	39138(5740)	6	7	273,966
	Grand total		16	23	746,891
	Winter	27142(2279)	6	7	189,994
	Spring	22229(1651)	4	5	111,145
HI	Summer	23766(4197)	6	6	142,596
	Fall	21729(1544)	4	5	108,370
	Grand Total		20	23	552,105
Overall		32,715	472	523	16,968,448

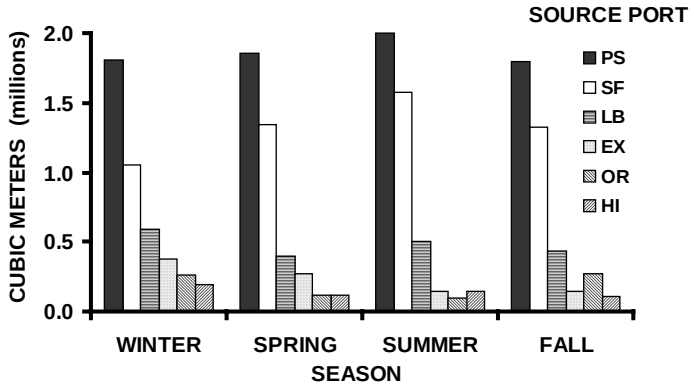
Note: Not included in the table are arrivals from Nikiski, AK (19) which provided no data, and other arrivals (7) for which port data are unavailable.

Figure 2.5. Mean volume of segregated ballast water per tanker arriving to Port Valdez and PWS by source port and season, 1998. The mean volumes are estimated for: (A) Each source port across all seasons; (B) Each season across all source ports. Standard error and sample size is shown above each bar; see Table 2.1 for further information. Source ports include: Puget Sound, WA (PS); San Francisco Bay, CA (SF); Long Beach, CA (LB); Foreign port with open-ocean exchange (EX); Columbia River, Oregon (OR); and Barbers Point, Hawaii (HI). Seasons include: Winter (January-March), Spring (April-June), Summer (July-September), and Fall (October-December). Data based upon boarding interviews and reports from ships' personnel (see text).



We estimated the total amount of segregated ballast water discharged into Prince William Sound during 1998 was approximately 17,000,000 m^3 (no. arrivals x average ballast water volume) for source port by season (see Table 2.1). The relative contribution of different source ports to the total varied greatly, reflecting variation in the number of arrivals (Fig. 2.6; Table 2.1). As a result, Puget Sound contributed approximately 44% of the total, followed by San Francisco 31% and Long Beach 11%.

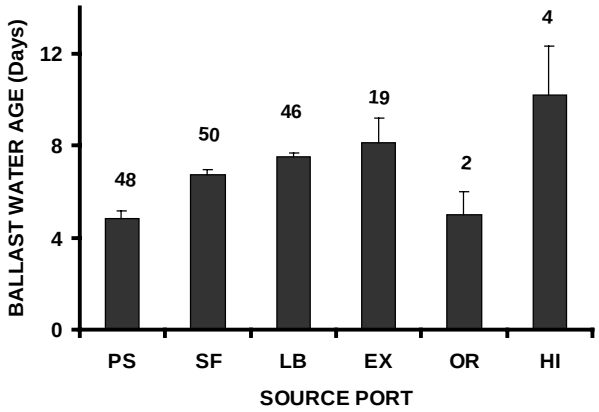
Figure 2.6. Cumulative volume of ballast water arriving to Port Valdez and PWS by source port and season, 1998. The cumulative volumes are estimated for season by source port (see Table 2.1 for further detail). Source ports include: Puget Sound, WA (PS); San Francisco Bay, CA (SF); Long Beach, CA (LB); Foreign port with open-ocean exchange (EX); Columbia River, Oregon (OR); and Barbers Point, Hawaii (HI). Seasons include: Winter (January-March), Spring (April-June), Summer (July-September), and Fall (October-December). Data based upon boarding interviews and reports from ships' personnel (see text).



2C3. Age and Management of Ballast Water delivered to PWS

The average age of ballast water arriving in tankers varied among source ports, ranging between 4.8 to 10.2 days (Fig. 2.7). The mean age among all arrivals was 6.6 days (s.e.= 0.2). For domestic source ports, the age of water was correlated with distance from Port Valdez to the source port, as ballast water came directly from the last port of call (the exception was for experiments conducted at our request, as described in Chapter 4). In contrast, all foreign arrivals exchanged their ballast water at sea, so the age of water was less than the voyage duration. Thus, for foreign arrivals, the actual source was considered open ocean exchange (EX) instead of the last port of call.

Figure 2.7. Mean age (voyage duration) for ballast water arriving to Port Valdez by source port. The mean age is estimated for each source port based upon all boarding data (December 1997-July 1999). Standard error and sample size is shown above each bar. Source ports include: Puget Sound, WA (PS); San Francisco Bay, CA (SF); Long Beach, CA (LB); Foreign port with open-ocean exchange (EX); Columbia River, Oregon (OR); and Barbers Point, Hawaii (HI).



2D. Discussion

Over the past decade, Prince William Sound and Port Valdez together have received approximately 23.3 million m^3 (= 713 arrivals/yr x 32,610 m^3/arrival) of segregated ballast water

each year from oil tankers arriving to the Alyeska terminal. Although most of this water is released in Port Valdez, ships will sometimes begin discharging upon entering Prince William Sound en route for the Port. Thus, organisms released with this ballast water may experience a broader range of conditions outside of Port Valdez than we had originally considered.

The total volume of ballast water delivered to Prince William Sound by tankers greatly exceeds the estimated quantity of ballast water arriving to other western U.S. ports (Carlton et al. 1995). However, it is important to recognize that existing estimates for the other ports have included only the ballast water from foreign sources. In contrast, our estimates for Prince William Sound included both foreign and domestic sources, but were dominated by the latter. The amount of domestic ballast water released in other U.S. ports is only now being estimated. Nonetheless, even when we can include data on domestic sources for all ports, it appears likely that the total volume of ballast water released to PWS will still exceed that for the other western ports, due to the absence of extensive domestic tanker and bulker traffic (i.e., those vessels that discharge the greatest quantities of ballast water) at the other ports. Instead, the domestic traffic for other western U.S. ports is dominated by container ships, which release relatively small amounts of ballast water (Carlton et al. 1995; National Ballast Water Information Clearinghouse, unpubl. data).

The total amount of ballast water arriving to Prince William Sound in tankers is also relatively large on a global scale. Within the U.S., PWS is third only to Chesapeake Bay and New Orleans in estimated ballast water discharge for 1991 (Carlton et al. 1995, Smith et al. 1999). In a similar estimate of ballast water discharged to 46 Australian ports in 1991, only that for the port of Dampier exceeded the volume for PWS (Kerr 1994). As above, estimates for the both the U.S. and Australian ports were restricted to arrivals from foreign ports. Although these totals would clearly increase when including domestic arrivals, the overall patterns provide a useful context, suggesting PWS is on the extreme end of the spectrum for amount of ballast water discharge.

It is also important to recognize the present level of tanker activity, and the magnitude of ballast water delivery, as a recent development in Port Valdez. The terminal began transporting oil via tankers in 1977. Based upon the arrivals rate and discharge volumes observed in this decade, we estimate over 700 million m^3 of segregated ballast water have been delivered over the past 3 decades of operation. This large cumulative volume underscores the potential importance of ballast water as a vector for the transfer of species. Unlike many other commercial ports, however, the volume of ballast water prior to oil exportation was virtually absent, as very few other vessels currently deliver ballast water to the Port (Ruiz et al., unpubl. data).

Furthermore, the foreign export of oil from Port Valdez has only occurred since 1996, following authorization by U.S. Congress. Prior to this time, all oil export was only to domestic U.S. ports, which were therefore the source of ballast water delivery to PWS and Port Valdez. Although tankers now export oil to foreign ports from PWS, the delivery of ballast water from foreign traffic remains a small fraction (<5%) of the total annual volume. In addition, tankers arriving from foreign ports are required to undergo ballast water exchange, further reducing the actual amount of ballast water and organisms coming from coastal habitats surrounding foreign ports (see Chapters 3 and 4 for further discussion of biota).

2E. References

Carlton, J.T., D. Reid and H. van Leeuwen. 1995. The role of shipping in the introduction of nonindigenous aquatic organisms to the coastal waters of the United States (other than the Great Lakes) and an analysis of control options. Report to U.S. Coast Guard, Marine Environment Protection Division, Washington, DC. 215 pp.

Kerr, S. 1994. Ballast water ports and shipping study. Australian Quarantine and Inspection Service, Report No. 5, Canberra.

Ruiz, G.M. and A.H. Hines. 1997. Patterns of nonindigenous species transfer and invasion in Prince William Sound, Alaska: Pilot Study. Report Submitted to the Prince William Sound Citizens' Advisory Council. 80pp.

Smith, L.D., M.J. Wonham, L.D. MCann, D.M. Reid, G.M. Ruiz and J.T. Carlton. 1996. Biological invasions by nonindigenous species in United States waters: Quantifying the role of ballast water and sediments. Parts I and II. Final Report to the U.S. Coast Guard and the U.S. Department of Transportation. 246 pp.

Smith, L.D., M.J. Wonham, L.D. McCann, G.M. Ruiz, A.H. Hines and J.T. Carlton. 1999. Invasion pressure to a ballast-flooded estuary and an assessment of inoculant survival. Biol. Invasions 1: 67-87.