Chapter 4. Predicting Initial Survival of Ballast Water Organisms

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4A. Purpose

When ballast water is discharged into the receiving waters, the associated plankton encounters new conditions without time to acclimate. Survival may depend on short-term tolerances to accute variation in salinity-temperature combinations. If temperature-salinity conditions of ballast water closely match those of the receiving waters, then initial survival is predicted to be higher than when the conditions do not match closely. To determine if NIS arriving in ballast water can survive the initial exposure to temperature-salinity conditions in Prince William Sound, we tested the match of conditions between ballast water and ship-side water, and the short-term survival of ballast organisms in representative combinations.

4B. Temperature & Salinity: Match of Source and Receiving Ports

4B1. Methods

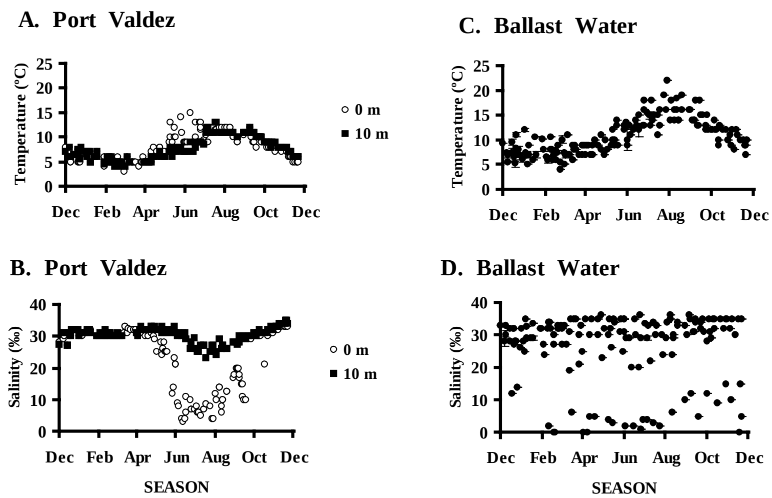
Samples of ballast water were collected from segregated ballast tanks and from ambient waters adjacent to each ship sampled for ballast water plankton. A small niskin bottle lowered through hatch covers into the ballast tanks and lowered off the end of the ship's berth to collect samples from the water surface and 10 m depth, which was determined to be below a potential thermocline or pycnocline. Salinity was determined to the nearest ppt with a refractometer and temperature to the nearest 0.5 ^{o}C with a hand-held thermometer.

4B2. Results

Temperature and salinity of the receiving waters of Port Valdez exhibit a distinct seasonal pattern (Fig. 4.1a, b). Water temperatures of Port Valdez at 10 m depth cycle seasonally from a low of 4 ^{o}C in February to a high of 13^{o}C in July. Surface water temperatures are more variable and 1-5 ^{o}C warmer than deep water in the spring. Salinity during December to April was about 31 ppt and the water column was well mixed. Water in Port Valdez was sharply stratified by depth as snow melted from late April to September, with salinities of surface waters dropping to 4-15 ppt while salinities at 10m depth declined only to about 25 ppt.

Water in the segregated ballast tanks rarely exhibited much depth stratification. Temperatures of segregated ballast water varied seasonally with a winter mean low of about 7.5 ^{o}C (+-3^{o}C) and a summer high of about 16^{o}C (+-3^{o}C) (Fig. 4.1c). Salinities of ballast water did not exhibit a seasonal pattern, but salinities fell into two distinct ranges, depending on the source port of the tanker (Fig. 4.1d). Most tankers delivered high salinity ballast water (ca. 30 ppt, range 20-36 ppt). In contrast, about 20% of the tankers throughout the year released ballast water of low salinity (ca. 4 ppt, range 0-14 ppt, mainly from Benicia in San Francisco Bay, especially during the heavy El Niño rains in 1998).

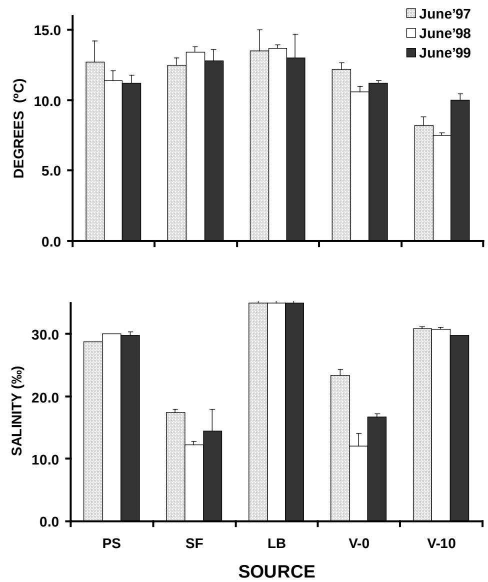
Figure 4.1 Seasonal Cycles of Temperatures and Salinities of Receiving and Ballast Water. Shown above are temperatures (A) and salinities of Port Valdez, Alaska at 0m and 10m depth. Shown below are average temperatures (C) and salinities (D) of ballast water discharged into Port Valdez by tankers. Averages are for two tank depths (0m and 10m depth) combined.



Annual variation in temperature and salinity among source ports and receiving waters of Port Valdez was compared in June of 1997, 1998, and 1999 (Fig. 4.2). Temperature of ballast water from Long Beach (13-14^{o}C) and San Francisco(13-14^{o}C) was about a degree warmer than from Puget Sound (11-12^{o}C), but temperature of ballast water from Puget Sound was similar to the surface water of Port Valdez (11-12^{o}C), which was 1-3^{o}C warmer than water at 10 m depth (7-9^{o}C). However, there were no significant differences in temperatures among years. Salinity of ballast water from Long Beach (33ppt) was highest of the source ports, while that from San Francisco (10-14 ppt) was the lowest, and Puget Sound was intermediate (29-30 ppt). Surface salinity at the surface of Port Valdez (10-21ppt) was similar to ballast water from San Francisco Bay, while salinity at 10 m depth in Port Valdez (29-30 ppt) was similar to ballast water from Puget Sound. Salinity of ballast water from Long Beach and Puget Sound, as well as deep water at Port Valdez, did not differ among years. However, salinity of ballast water from San Francisco Bay and at the surface in Port Valdez was lowest in 1998, highest in 1997 and intermediate in 1999.

Thus, there was often a good correspondence of physical characteristics between ballast water and receiving water, depending on the source port, time of year and water depth in Port Valdez. Temperatures of ballast water were a bit higher than of receiving waters, but the differences were not great, and there was considerable overlap between ballast and receiving water throughout the year. Higher salinities of ballast water from most source ports were similar to deeper water of Port Valdez throughout the year and similar to surface water during winter and early spring. During summer the vertical stratification in Port Valdez resulted in ballast water from both high and low salinities having good correspondence in major areas of the receiving waters. Based on these physical characteristics of ballast and receiving water, temperatures of Port Valdez would not appear to prevent survival of organisms from most source ports. Nonindigenous species from nearly fresh water, estuarine and full-strength sea water may also find corresponding salinities in Port Valdez.

Figure 4.2 Annual Variation in Temperature and Salinity of Ballast and Receiving Water. Shown are temperatures (top) and salinities (bottom) of ballast water arriving to Port Valdez in tankers from west-coast source ports (PS = Puget Sound, WA; SF = San Francisco, CA; LB = Long Beach, CA), and of recieving waters of Port Valdez at surface (V-0) and 10m depth (V-10). Bars indicate means and S.E. for June 1997, 1998, 1999.

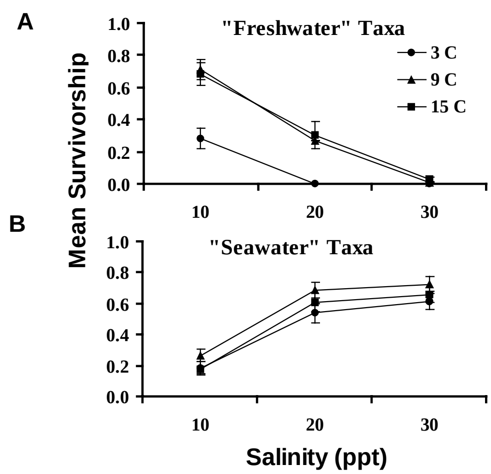


4C. Temperature-Salinity Tolerance Experiments of Ballast Water Plankton

4C1. Methods

We conducted experiments at the SERC laboratory in Valdez to test for temperature x salinity tolerance of selected planktonic organisms arriving in segregated ballast water. Based on the two salinity categories of segregated ballast water released into Port Valdez (see above, Fig. 4.1a, b), we grouped the experimental organisms into "freshwater taxa" and "seawater taxa" (Fig. 4.3).

Figure 4.3. Survivorship of Ballast Water Organisms in Salinity x Temperture Experiments. Survivorship of ballast water organisms at 96 hour exposure to 9 combinations of salinity and temperature in laboratory experiments. Three salinities (10, 20, 30 ppt) and three temperatures (3, 9, 15ºC) were tested to represent the range of seasonal variation in Port Valdez. (A) Trials with organisms from ballast water with fresh water sources (n = 9). (B) Trials with organisms from ballast water with seawater sources (n = 15).



Nine combinations of three temperatures (3, 9, and 15 ^{o}C) and three salinities (10, 20, and 30 ppt) were selected to represent the seasonal range of conditions for Port Valdez. Organisms used in the experiments are collected from the common species of plankton arriving in tanker ballast water. For each experiment, 10 individuals were placed in each of 3 replicate culture dishes at each of the 9 treatment combinations. Thus, there were 27 trials in each experiment (9 treatments x 3 replicates). The test organisms were sorted in the lab and transferred directly to culture dishes maintained in incubators for 96 hrs, simulating release of ballast water into conditions of the Sound. Phytoplankton or brine shrimp nauplii were supplied as food to the cultures during the test period.

Experiments (n = 24) were completed with organisms from the following taxonomic categories:

Tintinnid protistan	1 experiment
Nemertean worm larvae	2 experiments
Spionid polychaete worm larvae	3 experiments
Gastropod veliger larvae	1 experiment
Copepods	
calanoid	4 experiments
harpacticoid	1 experiment
cyclopoid (*Oithona* spp.)	6 experiments
Barnacle nauplii	3 experiments
Crab zoea	1 experiment
Mysid shrimp	2 experiments

Nine of these were "freshwater taxa" and 15 were "seawater taxa". We intentionally selected copepods especially *Oithona* spp., for many of our experiments, because we recognized these as NIS arriving in apparently good condition from San Francisco Bay.

4C2. Results

Short-term survivorship of these ballast water organisms was high (>50%) for fresh water taxa at 10 ppt, and for seawater taxa at 20-30 ppt. These short-term experiments also showed that the ballast organisms had distinct, but quite broad tolerances that clearly overlap conditions of temperature and salinities in Port Valdez. For example, although there was considerable variation in survivorship among individual experiments, mean survivorship of calanoid copepods varied from about 20-80% for each test salinity, but survivorship of calanoids in most experiments increased with salinity (Fig. 4.3). *Oithona* spp. (which include known NIS copepods) were able to tolerate salinity-temperature conditions they would encounter in the receiving waters of Port Valdez.

The freshwater and seawater taxa differed substantially in their patterns of temperature x salinity tolerance (Fig. 4.3). The survivorship of seawater taxa at any of the 3 test temperatures generally increased with increasing salinity, and there were not great differences in survivorship among temperatures. However, survivorship of freshwater taxa at all temperatures generally declined sharply with increasing salinity, and survivorship at 3^{o}C was markedly lower than at 9 or 15^{o}C.

4D. Conclusions

Planktonic species arriving to Port Valdez in ballast water have high potential of surviving the salinity-temperature conditions that they encounter during initial discharge from the ship. Although some taxa will not tolerate some salinity layers in the seasonally stratified conditions in the Port, the overlap of ballast water with Port conditions at some strata is high. Plankton in the ballast water, including known NIS such as *Oithona* spp., should be able to tolerate these conditions. Conditions other than initial salinity-temperature combinations probably determine whether or not these organisms survive to become established within Prince William Sound.