*Exxon Valdez* Oil Spill
Restoration Project Final Report

# Assessing Prey and Competitor/Predators of Pink Salmon Fry

Restoration Project 01452
Final Report

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**Study History:**
A program to monitor the juvenile pink salmon food supply and predators in Prince William Sound was initiated in FYOO with support from the Oil Spill Recovery Institute (OSRI), in cooperation with the Alaska Dept. of Fish and Game and the Ship Escort/Response Vessel System (SERVS). Project 01452 is the result of supplemental funds from the EVOS TC during 2001. The supplemental funds allowed spatial and temporal expansion of the monitoring effort as well as additional investigation of inshore/offshore trends.


**Abstract:**
Multi-frequency acoustic/net sampling assessments of the pink salmon food supply and predators were conducted in Prince William Sound during spring 2001. Five cruises were completed between April 18 and June 15,200 1. The results of this monitoring were in sharp contrast with observations from the previous year. Overall the abundance of large copepods (primarily Neocalanus) was much lower in 2001. The abundance was highest at the beginning of the monitoring in mid-April, but progressively declined rather than increased as was seen in 2000. Highest biomasses were observed above the deep hole adjacent to Naked Island, and the lowest biomass within protected bays, including the locations of Esther and Main Bay hatcheries. The pattern of fish abundance and distribution was generally similar both years. Highest fish abundance was in the main basin and relatively deep. Abundance in the pink salmon out-migration corridor increased slightly over the spring, but was low overall. However, fish in the out-migration corridor showed strong near-shore orientation in 2001, a pattern not seen in 2000. The results of this monitoring should provide valuable insights into the complex environmental conditions that govern juvenile salmon survival. Such information is becoming more important as Alaska's salmon hatchery programs come under increasing scrutiny.



**Key Words:** Neocalanus, pink salmon survival, Prince William Sound, zooplankton


**Project Data:** *Description of data*-Spatially-detailed abundance of zooplankton and fish in Prince William Sound during spring 2001. *Format*-Excel spreadsheets. *Custodian*-Contact Richard E. Thorne, Prince William Sound Science Center, P.O. Box 705, Cordova, AK 99574. *Availability*-Contact Custodian for details.


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# Executive Summary


Zooplankton abundance is a critical ecosystem parameter. During spring in Prince William Sound, zooplankton biomass is typically dominated by large calanoid copepods of the genus *Neocalanus*. Previous research has shown that the survival of pink salmon fry in Prince William Sound is positively correlated with *Neocalanus* abundance and negatively correlated with the abundance of walleye pollock (*Theragra chalcogramma*), which functions both as a predator on juvenile pink salmon and as a competitor for the *Neocalanus* food supply.

A program to monitor the juvenile pink salmon food supply and predators in Prince William Sound was initiated in FY00 with support from the Oil Spill Recovery Institute (OSRI), in cooperation with the Alaska Dept. of Fish and Game and the Ship Escort/Response Vessel System (SERVS). EVOS TC contributed to expansion of the monitoring program in 2001. The monitoring program utilizes multiple-frequency (38, 120 and 420 kHz) acoustic technology combined with optimized plankton net sampling. The high sampling power of the acoustics and the capability to synoptically measure both zooplankton and fish abundance provide a cost effective approach to estimation of pink salmon food supply and predator abundance.

Five cruises were conducted during spring 2001. Three broad-scale cruises covered much of Prince William Sound including documented areas of juvenile pink salmon out-migration. Two additional cruises focused on inshore areas, but also provided additional temporal coverage of the out-migration area. The sampling period extended from April 18 to June 15.

The abundance of large copepods, primarily *Neocalanus*, was much lower during spring 2001 than that observed the previous spring. The lower abundance was detected in both the acoustics and the plankton net catches. Copepods dominated the zooplankton both years. However, the relative proportion of small and large copepods changed considerably between 2000 and 2001. Small copepods numerically dominated the catch both years. However, small copepods were also the largest biomass component in 2001, 45% compared to 28% in 2000. In contrast, the biomass composition of large copepods, primarily *Neocalanus*, decreased from 68% in 2000 to only 39% in 2001.

Overall, the highest composition of large-bodied copepods observed during spring 2001 was found above the deep hole adjacent to Naked Island (52% by weight), and the lowest composition in the protected bays (Lake Bay, Main Bay, South Bay and Herring Bay). Total *Neocalanus* abundance showed a similar trend to that of composition, with highest densities found near Naked Island and the lowest in protected bays. Highest abundance was found in April, and the abundance declined throughout the spring. This trend contrasted with that observed during 2000, when peak densities were observed in the out-migration corridor in late May.

The patterns of fish distribution and abundance were generally similar to that observed the previous year. Biomass was considerably higher in the main basin, but deceased after mid-May. Densities were initially very low in the out-migration corridor, but increased slightly after mid-May. The pattern in Montague Strait and southeast of Knight Island was similar to that of the main basin. Fish

abundance was high initially, but declined over time. The most pronounced spatial trend in the fish distribution in the out-migration corridor was a strong shoreward bias on both sides of the corridor. This trend contrasted from the observations in 2000, when the fish were more evenly distributed.

Two factors stand out with regard to the potential success of hatchery operations. One is the substantial difference in large copepod abundance between 2000 and 2001, and the second is the relatively low fish abundance in the out-migration corridor. Average large copepod abundance during 2001 in the out-migration corridor ranged from 14 $g/m^2$ in April to slightly over 1 $g/m^2$ in June. In contrast, the range in May 2000 was between 30 $g/m^2$ and 70 $g/m^2$. The physical characteristics of the water column, including temperature and stratification, may contribute to the interannual variability in zooplankton abundance. Near-surface water temperatures measured during the 2001 cruises were relatively cool, and stratification was weak. In contrast, stratification was much stronger in 2000, and surface water temperature was much warmer.

Previous investigations have indicated that herring and adult pollock switch to alternate prey when copepod densities fall below 0.2 $g/m^3$. This value corresponds to 10 $g/m^2$ as the data were obtained from 50 m vertical tows. The actual value is probably higher as the net sampling is unlikely to be 100% efficient. The value implies that the large copepod densities we observed in the out-migration corridor were adequate for herring and adult pollock in 2000, but not in 2001. That difference may be reflected in the contrasting fish distributions seen in the out-migration corridor during the two years. In 2000, fish were more uniformly distributed, following the zooplankton trend. In 2001, fish distribution was strongly oriented toward shorelines, where pink salmon fry and other juvenile fishes are known to be concentrated.

The fundamental goal of the zooplankton-monitoring program is to develop and apply a cost effective approach to estimation of pink salmon food supply and predator abundance. The results from the first two years of this program indicate that the multiple-frequency acoustic system, supported by plankton net samples and CTD measurements, can provide a viable methodology, combining high quantification with the extremely high sampling power that is required to obtain sufficient detail in a reasonable time and cost framework. The substantial differences in large-bodied copepod abundance between 2000 and 2001 will provide an early indication of the role of large-bodied copepod abundance in juvenile salmon survival. The impacts of temporal and spatial variability in concert with hatchery release operations are more complex. A more complete understanding of the complex environmental conditions that govern juvenile salmon survival will only be obtained by long-term acquisition of this type of information. Future refinements will depend upon comparisons between the monitoring data and subsequent pink salmon survival characteristics.

While the objectives of this program focus on pink salmon survival, the abundance of zooplankton is critical for many other species, such as herring and pollock. This type of information, collected as part of a cost-effective, long-term monitoring program, has the potential to reap many future benefits. Ultimately, such monitoring needs to be incorporated into the Gulf Ecosystem Monitoring program (GEM) for GEM to adequately address impacts of secondary production in the Gulf ecosystem.

## Introduction

Previous EVOS TC-funded research in Prince William Sound documented two critical factors in juvenile pink salmon (*Oncorhynchus gorbuscha*) survival: (1) the availability of large calanoid copepods (genus *Neocalanus*), and (2) the abundance of walleye pollock (*Theragra chalcogramma*). The large calanoid copepods reproduce at depth in late winter. Their progeny migrate to the surface layer to graze for a brief period in late April and May (Cooney et al. 1995, 2001). Willette et al. (1999a,b, 2001) showed that both survival and early growth rates of pink salmon were correlated with the duration of the *Neocalanus* spring bloom. Survival of juvenile pink salmon is also negatively correlated with abundance of walleye pollock. Adult pollock feed on *Neocalanus*, thus are competitors of juvenile pink salmon for this food source. However, when *Neocalanus* abundance is low, pollock become piscivorous and are the dominant pelagic predator of pink salmon fry (Willette et al. 1999a,b, 2001). The interannual variation in abundance of *Neocalanus* and its distribution, including inshore/offshore density gradients, and the distribution and abundance of pollock are all documented as factors in the growth rates of and predation rates on juvenile pink salmon. Willette et al. (1999a,b, 2001) also showed that Pacific herring (*Clupea pallasi*) had the same prey switching behavior between *Neocalanus* and pink salmon fry as the walleye pollock and are probably an important factor in the pink salmon mortality.

The importance of zooplankton abundance to the growth and survival of pink salmon fry has been recognized by the Prince William Sound Aquaculture Corporation (PWSAC). PWSAC developed a "Plankton Watch" program to govern the release timing of juvenile pink salmon from hatcheries. The Plankton Watch program simply monitors the settled zooplankton volume from 0.243 mm, 0.5 m ring net vertical hauls in the vicinity of hatcheries. While settled zooplankton volume has on occasion correlated with pink salmon survival (Cooney et al. 1995, 2001), the discrete nature of this sampling technique limits it to providing only an imprecise index of zooplankton availability, and the limited vertical extent of the sample (surface to 20 m) may add error by underestimating deeper concentrations of zooplankton.

Another potential index of zooplankton abundance is the hydrocarbon, pristane. Pristane is naturally produced by *Neocalanus* copepods. Initial studies of pristane concentrations in mussels have indicated a positive correlation with marine survival of hatchery pink salmon (Short and Harris 1999). The hypothetical mechanism for this is:

- the pink salmon fry feed on pristane-rich *Neocalanus* copepods;
- the pink salmon fry are the dominant zooplantivores in mussel bed habitats;
- the pink salmon fry defecate pristane-rich feces near the mussel beds,
- the pristane-rich feces are ingested by mussels,
- the pristane accumulates in the mussel tissues in proportion to the amount of feeding by the fry on the copepods.

Potential limitations of pristane as an index of pink salmon survival are the limited locations of samples (selected near-shore areas) and alternate sources of pristane in mussels, such as herring and other abundant nearshore fishes, which also feed on *Neocalanus*.

A program to monitor the juvenile pink salmon food supply and predators in Prince William Sound was initiated in FY00 with support from the Oil Spill Recovery Institute (OSRI), in cooperation with the Alaska Dept. of Fish and Game and the Ship Escort/Response Vessel System (SERVS) (Thorne and Thomas 2000a; Thorne and Thomas 2001). EVOS TC contributed to expansion of the monitoring program in 2001. This report is specifically prepared to fulfill requirements of the EVOS TC grant. However, it provides a comprehensive documentation of the results of the entire 2001 monitoring program. The spatial and temporal expansion of the monitoring effort that was conducted as a result of the supplemental funding has little meaning outside the context of the monitoring program as a whole.

The monitoring program is designed to obtain information on the zooplankton abundance, especially the large-bodied copepods, over much larger spatial scales than either the Plankton Watch or the pristane index, as well as monitor the abundance of fish. The goals of the program are to acquire:

- Spring estimates of macro zooplankton density, distribution and abundance using echo integration and optimized plankton net sampling,
- Synoptic estimates of predator abundance,
- Predict present and future recruitment events for pink salmon using the above information in conjunction with pink salmon process models developed for PWS.

The objectives and characteristics of this monitoring program are based on the knowledge of the PWS ecosystem gained through the SEA program (Thomas and Cox 2000; Pearcy 2001). The *Neocalanus* copepod life history strategy anticipates the timing of the spring bloom by placing the earliest life stages in the water column before plant production is initiated each spring (Cooney et al. 1995, 2001), providing an ideal food source for pink salmon fry. Peak biomass of *Neocalanus* copepods in the upper 50 m normally occurs during the month of May. In June, *Neocalanus* copepods migrate to deeper waters. Consequently, the monitoring program focuses on this critical spring period.

Although advanced acoustic-optical techniques were available (GLOBEC 1991a), the zooplankton studies of the EVOS TC-funded SEA program primarily relied on an extensive, labor-intensive net sampling program (Cooney et al 1995, 2001). This discrete sampling approach is not cost effective and also lacks the sampling power necessary to accurately document the important time and space scales of zooplankton distributions (GLOBEC 1991a,b; Thomas and Kirsch 2000; Thorne and Thomas 2002). This study, in contrast, employed multiple-frequency acoustic systems that collected data continually along a systematic line-transect survey. The acoustic systems sample at a rate tens of thousands times higher than standard plankton net tows. This approach also provides a more powerful index than the Plankton Watch program: one that could ultimately provide better guidance to hatcheries for salmon releases by obtaining a more representative measure of the real zooplankton distribution and abundance.

A recent report critical of Alaska hatchery operations (Kelly 2001) underscores the importance of long-term environmental monitoring programs that can provide the information needed to improve hatchery management, and also address environmental impacts of hatchery operations.

This project addresses several needs specifically noted in the report: (1) to provide scientific guidance to hatchery release strategies, (2) address carrying capacity issues, and (3) evaluate impacts on predator populations.

## Methods

Five cruises were conducted during spring 2001 (Table 1). Three of the cruises were broad scale, while two focused on inshore/offshore trends in the vicinity of pink salmon hatcheries and pristane sample locations. The broad scale surveys consisted of nine groups or clusters of four transects (Fig. 1). Six of these locations were identical to those surveyed the previous year in the OSRI program: three clusters (twelve transects) extended along the main basin of PWS from Bligh Island to the Hinchinbrook Entrance and three more clusters along the primary pink salmon out-migration corridor extending from Perry Island Passage and out through Knight Island Passage. The additional three clusters sampled in 2001 were located above the deep hole adjacent to Naked Island, off the southeast side of Knight Island and in Montague Strait (Fig. 1). The design used by the OSRI program in 2000 was based on several criteria: (1) coverage of the historic area of juvenile pink salmon out-migration and hatchery locations, (2) contrast between this area, termed the "out-migration corridor", and the eastern side or main basin of Prince William Sound, and (3) an area that could be covered within a two-day survey. Transects were

Table 1. Dates and types of data collected at various locations during 2001 cruises. Key: A=Acoustic, Z=Zooplankton, C=CTD, A* no 120 kHz data, A**, no 38 kHz data Numbers in parentheses refer to locations in Figure 1.

| Location | April 18-21 | May 6-8 | May 11-13 | May 18-20 | June 13-14 |
|---|---|---|---|---|---|
| Main-North (1) | A,Z,C | | A,Z,C | | A**,Z,C |
| Main-Central (2) | A,Z | | A,Z | | A**,Z |
| Main-South (3) | A,Z,C | | A,Z,C | | A**,Z,C |
| Perry Passage (4) | A,Z | A,Z,C | A,Z,C | A* | A,Z,C |
| North Knight Is. Pass (5) | A,Z,C | A,Z,C | A,Z | A*,Z | A,Z |
| South Knight Is. Pass (6) | A,Z,C | A,Z,C | A,Z,C | A*Z | A,Z,C |
| Naked Island (7) | A,Z,C | A,Z,C | A,Z,C | A* | A,Z,C |
| S.E. Knight Island (8) | A,Z,C | | A,Z,C | | A**,Z |
| Montague Strait (9) | A,Z,C | | A,Z,C | | A,Z,C |
| Lake Bay | | A,Z,C | | A*,Z | |
| Main Bay | | A,Z | | A* | |
| South Bay | | A,Z | | A*Z | |
| Herring Bay | | A,Z | | A*,Z | |
| Applegate Island | | A,Z | | A*,Z | |
| Point Eleanor | | A,Z | | A,Z | |

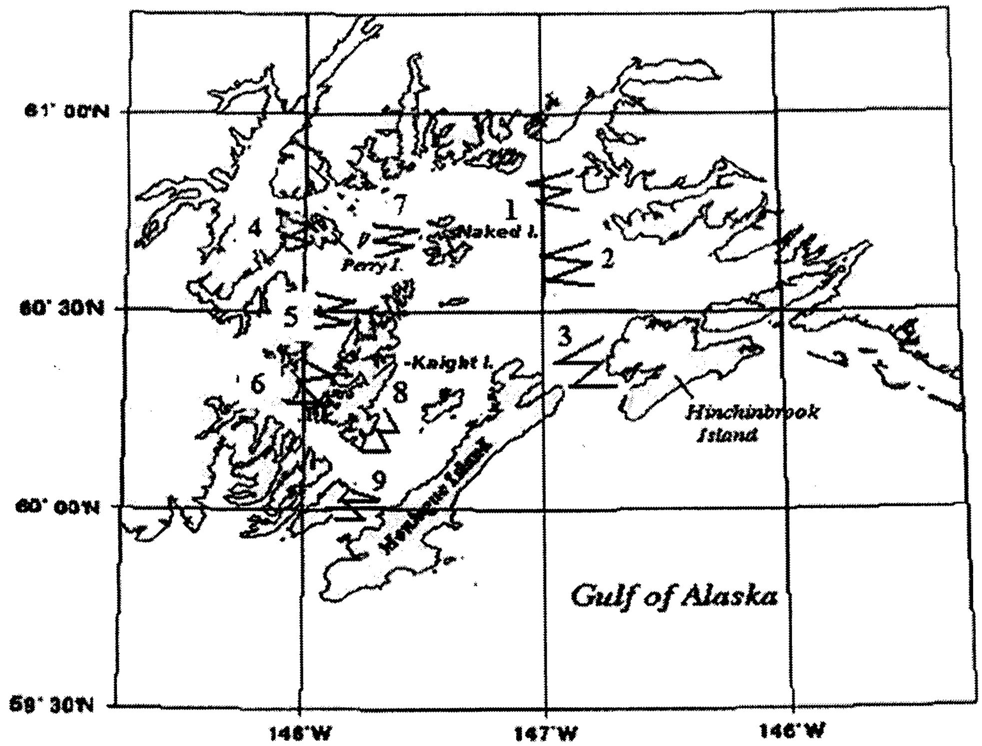



Figure 1. Locations of transects for broad scale surveys in 2001. Numbers refer to locations in Table 1.

designed to be able to contrast inshore and offshore areas as well as north/south trends. The 2001 addition of three clusters added an additional day to each survey, but provided broader spatial coverage, and in particular, coverage of the deep hole adjacent to Naked Island that is hypothesized to be the major over-wintering location of *Neocalanus*.

The two smaller scale surveys that were conducted in 2001 sampled six inshore areas: (1) Lake Bay, (2) Main Bay, (3) South Bay, Perry Island, (4) Herring Bay, (5) Applegate Island, and (6) Pt Eleanor (Table 1). The first four were classified as protected bays, the latter two as open, inshore locations. In addition, these two cruises also sampled the Naked Island and Knight Island/Perry Passage locations, adding to the temporal coverage of these sites (Fig. 2). Cruise periods were April 18-20, May 11-13 and June 13-15 for the broad scale surveys, and May 6-8 and 18-20 for the focused surveys.

For the broad scale surveys, volume backscatter measurements were obtained from three acoustic frequencies. The acoustic systems, a BioSonics 38 kHz DT4000 with a 6-degree transducer, a 120 kHz BioSonics Model 101 with a 7-degree transducer and a BioSonics 420 kHz Model 102 with a 6-degree transducer, were all mounted on an 8' towing vehicle. For the focused surveys, a two-frequency BioSonics DT 4000 was used with 6-degree transducers at 120 kHz and 420 kHz. All systems were calibrated with standard targets following procedures of Foote et al. (1987). The 38 kHz is the most widely used frequency in fisheries acoustics. The 120 kHz is probably the second most used, and is also the primary frequency used in euphausid assessments. The 420 kHz frequency is optimally matched to the large copepod size and is commonly used in zooplankton research.

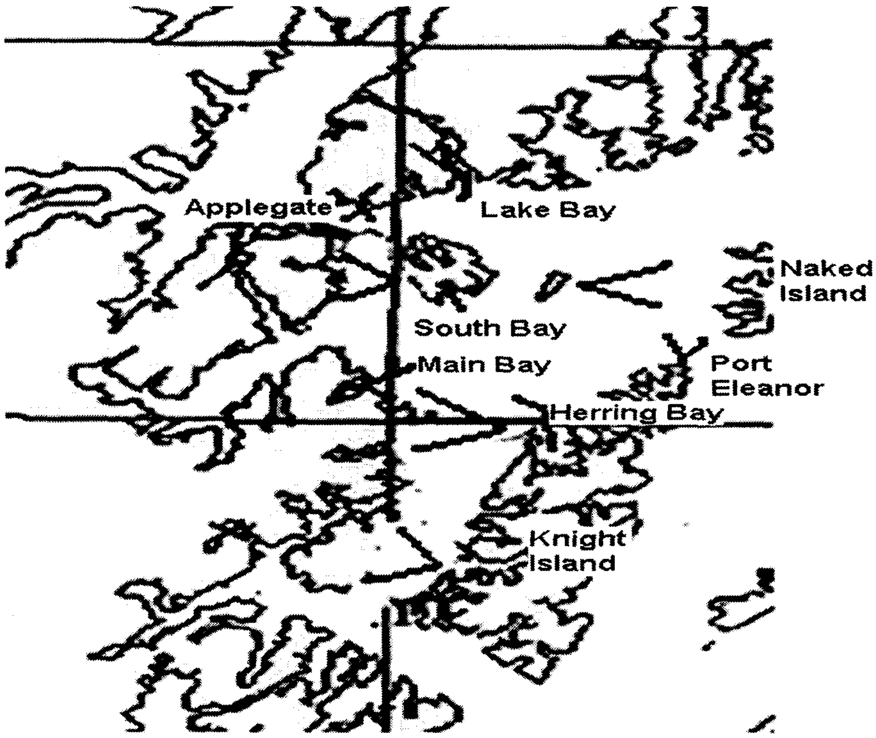



Figure 2. Location of transects during focused cruises, May 2001

Periodic station data provided zooplankton composition and salinity/temperature profiles (Table 1; Appendix Table 1). The routine procedure during broad scale surveys was to complete the acoustic data collection along a four-transect cluster, and then backtrack to sample at selected locations for zooplankton composition, salinity and temperature measurements. Usually these station locations were where the higher zooplankton densities were observed, but occasionally low-density locations were selected for contrast. At least one zooplankton tow was made at each four-transect cluster.

The zooplankton sampling was a 50 m vertical tow using a 0.335-mm 0.5 m-ring net, following procedures of Cooney et al. (1995). Samples are preserved in the field in 10% formalin. Supplemental sampling was conducted using a 2-m RMT with multiple mesh sizes. Temperature and salinity data were acquired using a SeaBird Electronics Model 19.03 CTD. Typically, 6-7 CTD stations were taken each cruise and were arrayed to provide inshore/offshore and north/south trends. Data collection was limited to daytime hours for consistency. SERVS provided the 123 ft oil skimmer M/V *Valdez Star* for the broad scale surveys, while the F/V *Kyle David*, a 55 ft purse seiner, was used for the focus surveys.

The plankton samples were analyzed to determine both size and frequency of the major components following procedures detailed in Kirsch et al. (2000). Quantitative sub-samples were taken using a Hensen-Stempel pipette. For purposes of this study, the term, "large-bodied", was used to refer to stage IV and V *Neocalanus,* or equivalent size copepods. In practice, this typically corresponds to copepods above 2 mm length. Numerical abundance was converted to estimates of biomass using average wet weights by category following Cooney et al. (2001).

The acoustic data were analyzed using standard echo integration techniques (Thorne 1983a,b). The DT4000 stores raw digital echo information directly on computer hard-drive. These data were analyzed using BioSonics Echo Integration Analyzer Program Version 4.02. The 420-kHz data were analyzed in real-time using a BioSonics Model 221 Echo Signal Processor (ESP). Volume backscattering measurements were made in 2-m intervals every 30 seconds of transect. Final calibration and acoustic cross-section information were added in post processing. The 120-kHz data were recorded on digital audio tape (DAT) and later processed using the BioSonics ESP. The DT4000 (38 kHz) and DAT (120 kHz) data were analyzed at two thresholds to separate fish and zooplankton as described below. For the 420 kHz data, all 2 m by 30 ping analysis cells with fish signals were deleted. The analysis was facilitated by comparing signals from all three frequencies to determine presence or absence of signals from fish. The depth strata that were analyzed depended on the frequency. However, for purposes of this study, zooplankton biomass estimates were obtained for the upper 50 m, while fish biomass was estimated for the upper 150 m.

Although all three frequencies were examined to improve understanding of scattering characteristics of various organisms and to facilitate separation of fish and zooplankton components, the actual biomass estimates for zooplankton were derived from the 420 kHz data and fish densities from the 120-kHz data. Scattering values for the major zooplankton components at 420 kHz were available from Kirsch et al. (2000). Similarly, most assessments of fish in PWS have been conducted using 120 kHz. The fish component to the scattering was estimated by thresholding the acoustic returns at –40 dB (Steinhart et al. unpublished). A generalized acoustic cross-section equivalent to –32 dB/kg was used to estimate fish biomass from the thresholded returns (Thorne 1983b).

Kirsch et al. (2000) determined the acoustic scattering characteristics of large-bodied copepods, pteropods and euphausids. Values for the remaining components were estimated by a forward problem analysis (Holliday and Pieper 1995; Wiebe et al. 1997). Rather than assuming that the net catches are 100% efficient, as the case with most approaches, we assumed that the relative abundances were correct and used differing catch proportions and different average backscattering values from various regions to solve for the scattering values through multiple regression.

# Results

## Zooplankton Composition

Copepods dominated the zooplankton net catches both numerically and in biomass in 2001 (Tables 2 and 3), as was also the case in 2000. However, the relative proportion of small and large copepods changed considerably between 2000 and 2001 (Table 4). Small copepods numerically dominated the catch both years. However, small copepods were also the largest biomass component in 2001, 45% compared to 28% in 2000. In contrast, the biomass composition of large copepods, primarily *Neocalanus*, decreased from 68% in 2000 to only 39% in 2001, including 33% in the main basin and out-migration corridor.

Table 2. Numerical composition of zooplankton catches during 2001 surveys. Montague Strait location includes S.E. Knight Island.

| | | % Numerical Composition | | | | | |
|---|---|---|---|---|---|---|---|
| Cruise | Location | Small copepods | Large copepods | Oikopleura | Pteropod | Euphausid | Other |
| 1 | Outmigration Cor. | 91.9 | 5.9 | 0.9 | 0.1 | 0.3 | 0.9 |
| | Main | 94.7 | 3.8 | 0.5 | 0.1 | 0.2 | 0.7 |
| | Naked Island | 86.6 | 11.7 | 0.6 | 0.3 | 0.2 | 0.5 |
| | Montague Strait | 93.6 | 4.4 | 0.6 | 0.1 | 0.1 | 1.1 |
| | Average | 91.7 | 6.5 | 0.7 | 0.1 | 0.2 | 0.8 |
| 2 | Outmigration Cor. | 87.8 | 1.6 | 8.6 | 0.8 | 0.6 | 0.6 |
| | Bays | 86.1 | 2.5 | 8.2 | 0.6 | 1.2 | 1.5 |
| | Naked Island | 88.6 | 3.4 | 6.5 | 0.5 | 0.9 | 0.2 |
| | Open Inshore | 86.8 | 4.8 | 6.3 | 0.5 | 0.9 | 0.7 |
| | Average | 87.3 | 3.0 | 7.4 | 0.6 | 0.9 | 0.7 |
| 3 | Outmigration Cor. | 86.0 | 3.0 | 5.9 | 0.7 | 1.0 | 3.4 |
| | Main | 93.3 | 1.6 | 1.8 | 0.3 | 0.7 | 2.3 |
| | Naked Island | 87.4 | 5.7 | 1.9 | 0.8 | 1.3 | 2.8 |
| | Montague Strait | 89.1 | 3.7 | 4.1 | 0.6 | 0.5 | 2.0 |
| | Average | 88.9 | 3.5 | 3.4 | 0.6 | 0.9 | 2.6 |
| 4 | Outmigration Cor. | 78.1 | 2.6 | 16.1 | 0.4 | 0.8 | 2.1 |
| | Bays | 73.7 | 1.3 | 7.5 | 0.2 | 1.5 | 15.7 |
| | Naked Island | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. |
| | Open Inshore | 83.6 | 4.1 | 7.4 | 2.1 | 1.5 | 1.4 |
| | Average | 78.4 | 2.7 | 10.3 | 0.9 | 1.3 | 6.4 |
| 5 | Outmigration Cor. | 57.2 | 2.4 | 4.6 | 24.1 | 1.9 | 9.9 |
| | Main | 66.9 | 2.9 | 4.0 | 7.4 | 1.0 | 17.7 |
| | Naked Island | 55.8 | 6.2 | 5.4 | 30.7 | 1.7 | 0.2 |
| | Montague Strait | 55.5 | 4.3 | 4.6 | 5.4 | 0.6 | 29.6 |
| | Average | 58.8 | 4.0 | 4.7 | 16.9 | 1.3 | 14.3 |
| All | Outmigration Cor. | 80.2 | 3.1 | 7.2 | 5.2 | 0.9 | 3.4 |
| Cruises | Main | 85.0 | 2.8 | 2.1 | 2.6 | 0.6 | 6.9 |
| | Naked Island | 79.6 | 6.7 | 3.6 | 8.1 | 1.0 | 0.9 |
| | Montague Strait | 79.4 | 4.1 | 3.1 | 2.0 | 0.4 | 10.9 |
| | Bays | 79.9 | 1.9 | 7.8 | 0.4 | 1.4 | 8.6 |
| | Open Inshore | 82.6 | 3.7 | 8.3 | 0.7 | 1.1 | 3.5 |
| | Average | 81.1 | 3.9 | 5.3 | 3.8 | 0.9 | 5.0 |

Overall, the highest composition of large bodied copepods was found above the deep hole adjacent to Naked Island (52% by weight), and the lowest composition in the protected bays (Lake Bay, Main Bay, South Bay and Herring Bay). Pteropod abundance also differed between years: 3.8% numerically in 2001 compared to 0.4% in 2000. However, the greater proportion of pteropods in 2001 was the result of a major increase (17%) from the June cruise. The month of June was not sampled in 2000, and the pattern of increased pteropod abundance in June was expected from historical observations. Other components were similar: Oikopleura was 5.3% numerically in 2001 compared to 4.6% in 2000, while euphausids were only about 1% both years. However, the pooled other zooplankton category was 5% numerically in 2001 compared with 1% in 2000. The higher percentage may reflect the more diverse habitats sampled in 2001.

Table 3. Biomass composition (%) of zooplankton catches during 2001 surveys

| Cruise | Location | Small copepods | Large copepods | Oikopleura | Pteropod | Euphausid | Other |
|---|---|---|---|---|---|---|---|
| 1 | Outmigration Cor. | 42.9 | 54.8 | 0.9 | 0.1 | 0.9 | 0.4 |
| | Main | 54.3 | 43.9 | 0.6 | 0.1 | 0.6 | 0.4 |
| | Naked Island | 26.6 | 72.2 | 0.4 | 0.2 | 0.5 | 0.2 |
| | Montague Strait | 50.6 | 47.4 | 0.7 | 0.1 | 0.5 | 0.6 |
| | Average | 43.6 | 54.6 | 0.6 | 0.1 | 0.6 | 0.4 |
| 2 | Outmigration Cor. | 61.0 | 22.3 | 11.9 | 1.4 | 3.0 | 0.4 |
| | Bays | 52.9 | 30.2 | 10.0 | 0.9 | 5.1 | 0.9 |
| | Naked Island | 50.3 | 38.1 | 7.3 | 0.7 | 3.4 | 0.1 |
| | Open Inshore | 42.8 | 46.9 | 6.2 | 0.6 | 3.2 | 0.3 |
| | Average | 51.7 | 34.4 | 8.9 | 0.9 | 3.7 | 0.4 |
| 3 | Outmigration Cor. | 50.6 | 35.2 | 7.0 | 1.0 | 4.2 | 2.0 |
| | Main | 68.6 | 22.8 | 2.6 | 0.6 | 3.7 | 1.7 |
| | Naked Island | 39.8 | 52.0 | 1.7 | 0.9 | 4.2 | 1.3 |
| | Montague Strait | 50.0 | 41.5 | 4.6 | 0.9 | 1.9 | 1.1 |
| | Average | 52.2 | 37.9 | 4.0 | 0.8 | 3.5 | 1.5 |
| 4 | Outmigration Cor. | 45.8 | 30.4 | 18.9 | 0.6 | 3.1 | 1.2 |
| | Bays | 51.7 | 18.6 | 10.6 | 0.4 | 7.6 | 11.0 |
| | Naked Island | nd | nd | nd | nd | nd | nd |
| | Open Inshore | 42.3 | 41.5 | 7.5 | 2.6 | 5.3 | 0.7 |
| | Average | 46.6 | 30.2 | 12.3 | 1.2 | 5.3 | 4.3 |
| 5 | Outmigration Cor. | 29.0 | 23.9 | 4.7 | 30.5 | 6.8 | 5.0 |
| | Main | 37.7 | 33.2 | 4.5 | 10.5 | 4.1 | 10.0 |
| | Naked Island | 20.0 | 44.3 | 3.9 | 27.5 | 4.2 | 0.1 |
| | Montague Strait | 27.9 | 43.7 | 4.6 | 6.7 | 2.2 | 14.9 |
| | Average | 28.7 | 36.3 | 4.4 | 18.8 | 4.3 | 7.5 |
| All Cruises | Outmigration Cor. | 45.9 | 33.3 | 8.7 | 6.7 | 3.6 | 1.8 |
| | Main | 53.5 | 33.3 | 2.6 | 3.7 | 2.8 | 4.0 |
| | Naked Island | 34.2 | 51.7 | 3.3 | 7.3 | 3.1 | 0.4 |
| | Montague Strait | 42.8 | 44.2 | 3.3 | 2.6 | 1.6 | 5.5 |
| | Bays | 52.3 | 24.4 | 10.3 | 0.6 | 6.4 | 6.0 |
| | Open Inshore | 42.6 | 44.2 | 6.8 | 1.6 | 4.2 | 0.5 |
| | Average | 44.6 | 38.7 | 6.0 | 4.4 | 3.5 | 2.8 |

As was the case for the composition, the highest catches per tow of large copepods were obtained near Naked Island and the lowest catches were in the protected bays (Fig. 3). Catches of small copepods were low near Naked Island and highest in the outmigration corridor and Montague Strait. Catches of *Oikopleura* were also highest in the outmigration corridor and were lowest in the main basin. The strongest seasonal trend was for pteropods, which increased dramatically in June. The catches of large copepods in the outmigration corridor consistently decreased during the season, and the catches near Naked Island were also highest during the first cruise.

Table 4. Changes in percent biomass of small and large copepods and other zooplankton components from the out-migration corridor and main basin for 2000 and 2001.

| | Copepods | | |
|---|---|---|---|
| **2000** | **Small** | **Large** | **Other** |
| Corridor | 20 | 73 | 7 |
| Main | 36 | 58 | 6 |
| **2001** | | | |
| Corridor | 46 | 33 | 21 |
| Main | 54 | 33 | 13 |

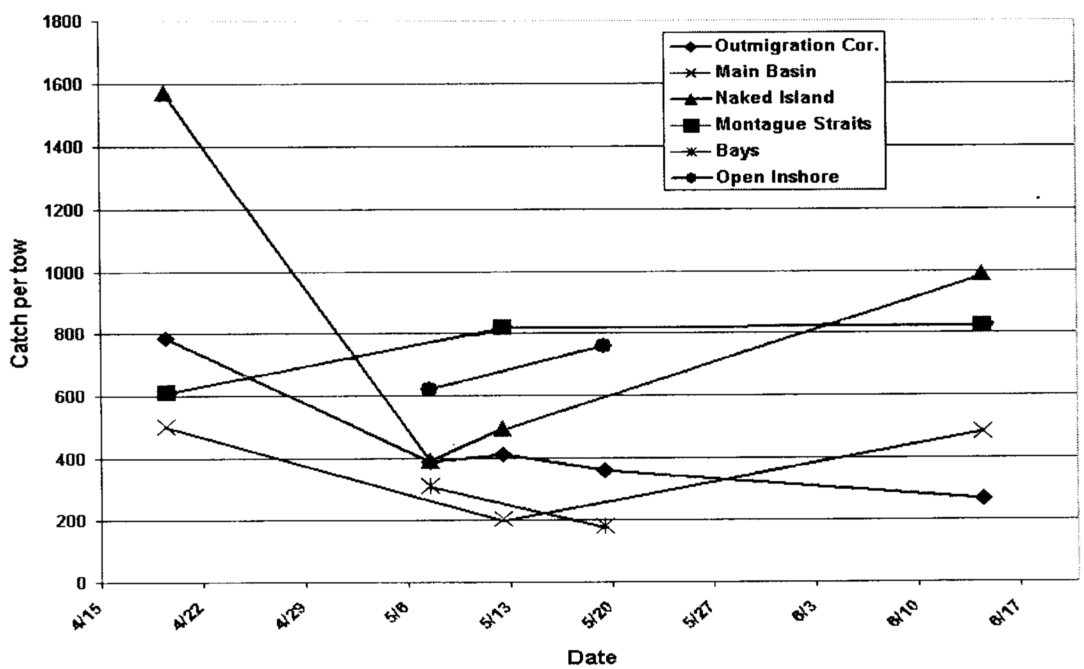



Figure 3. Catches of large copepods by cruise date and location

Acoustic Backscattering

Although the large-bodied copepods were not as dominant in the catches as the previous year, they still appeared to dominate the volume backscattering at the higher frequencies. For 420 kHz, both the catch of large-bodied copepods and 0-50 m area backscattering showed almost identical trends between 2000 and 2001 in both the out-migration corridor and the main basin (Fig. 4). A similar trend was seen in the 120 kHz data (Fig. 5). The correlation at 120 was very strong for the out-migration corridor, but weaker for the main basin. Area backscattering at 38 kHz did not track the catches of the large-bodied copepods (Fig. 6). The 38 kHz area backscattering in the out-migration corridor showed only a slight decline between the two years, while 38 kHz area backscattering in the main basin showed a slightly increasing trend. The 2000 study indicated that 38 kHz was most responsive to the abundance of *Oikopleura* among the zooplankters. In contrast to the large copepods, there was very little difference in *Oikopleura* abundance in either the out-migration corridor or main basin between 2000 and 2001. The 38 kHz frequency is known to be an indicator of the abundance of gelatinous zooplanktors (Alvarez, Mianzan and Madirolas (2002).

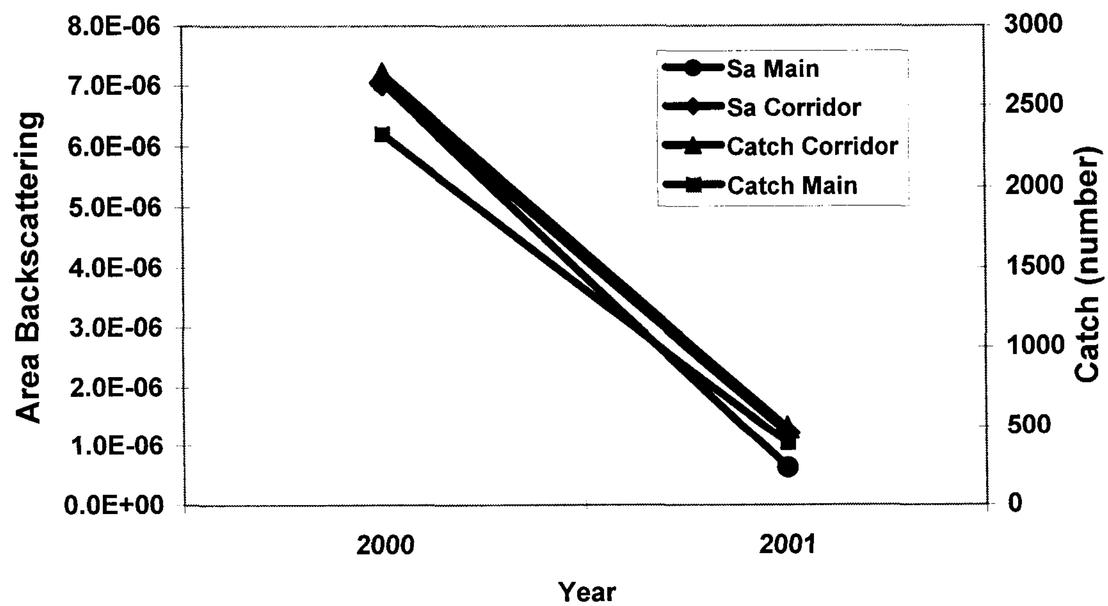



Figure 4. Comparison of average 420 kHz area backscatter and average catch of large copepods in the out-migration corridor and main basin of Prince William Sound, spring 2000 and 2001

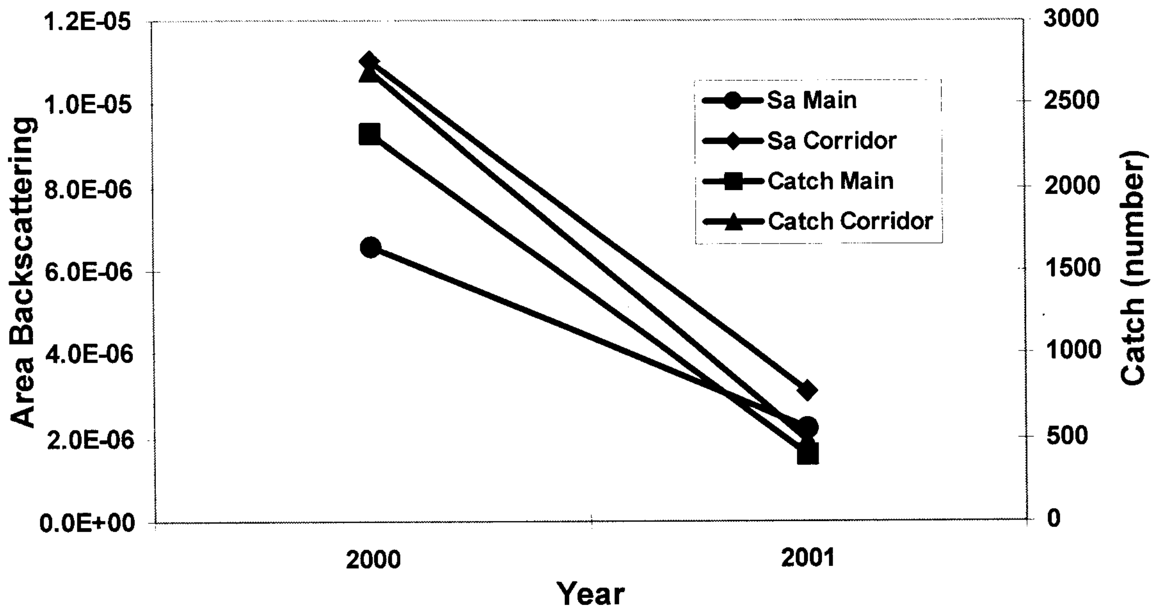



Figure 5. Comparison of average 120 kHz area backscatter and average catch of large copepods in the out-migration corridor and main basin of Prince William Sound, spring 2000 and 2001

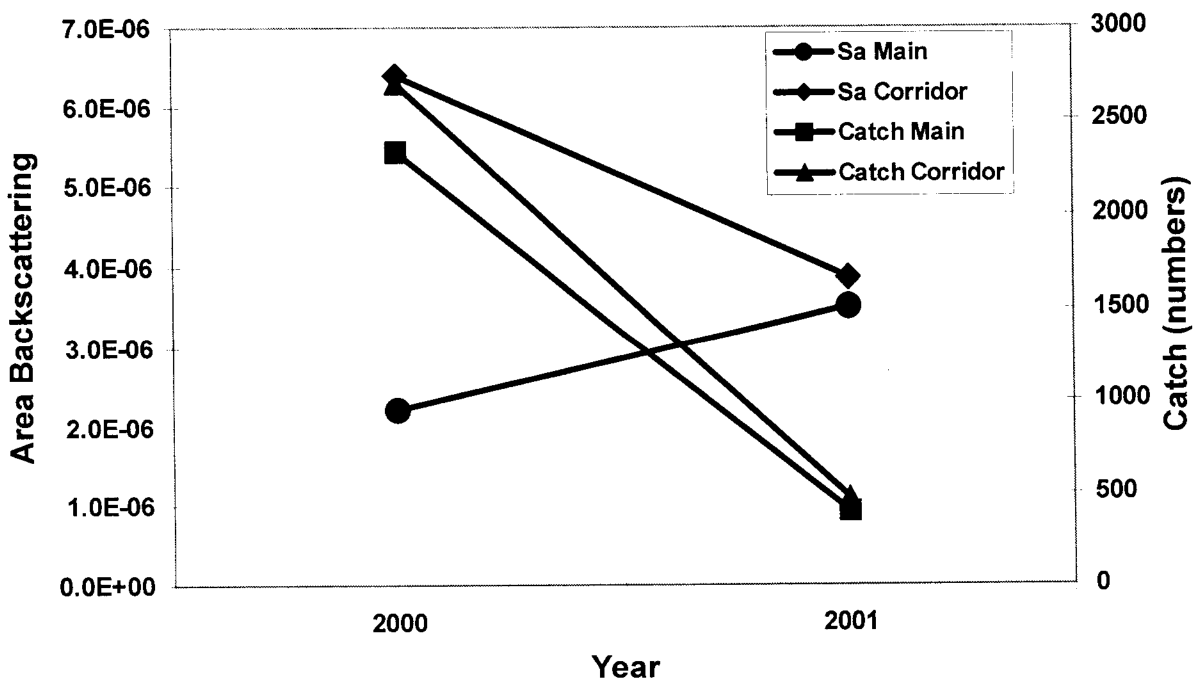



Figure 6. Comparison of average 38 kHz area backscatter with average catch of large copepods in the main basin and out-migration corridor of Prince William Sound, spring 2000 and 2001

Large Copepod Biomass

The 420 kHz volume backscattering was converted to estimates of absolute density using the target strength values listed in Table 5. Values for large copepods, pteropods and euphausids are derived from Kirsch et al. (2000), the others from the forward analysis. The combination of decreasing volume backscattering and decreasing percent of large copepods in the net catches resulted in a steep decline of estimated large copepod biomass during the study period for all areas. Large copepod abundance was considerably less than that observed the previous year in both the out-migration corridor and the main basin of PWS (Fig. 7).

Table 5. Estimated target strengths and sizes of various components of the zooplankton

| | Target Strength (dB) | | | | |
|---|---|---|---|---|---|
| Frequency | Large Copepods | Small Copepods | Pteropods | Oikopleura | Euphausids |
| 420 | -97 | -113 | -95 | -107 | -97 |
| Size (mm) | 3.7 | n.d. | 0.8 | n.d. | 3.7 |

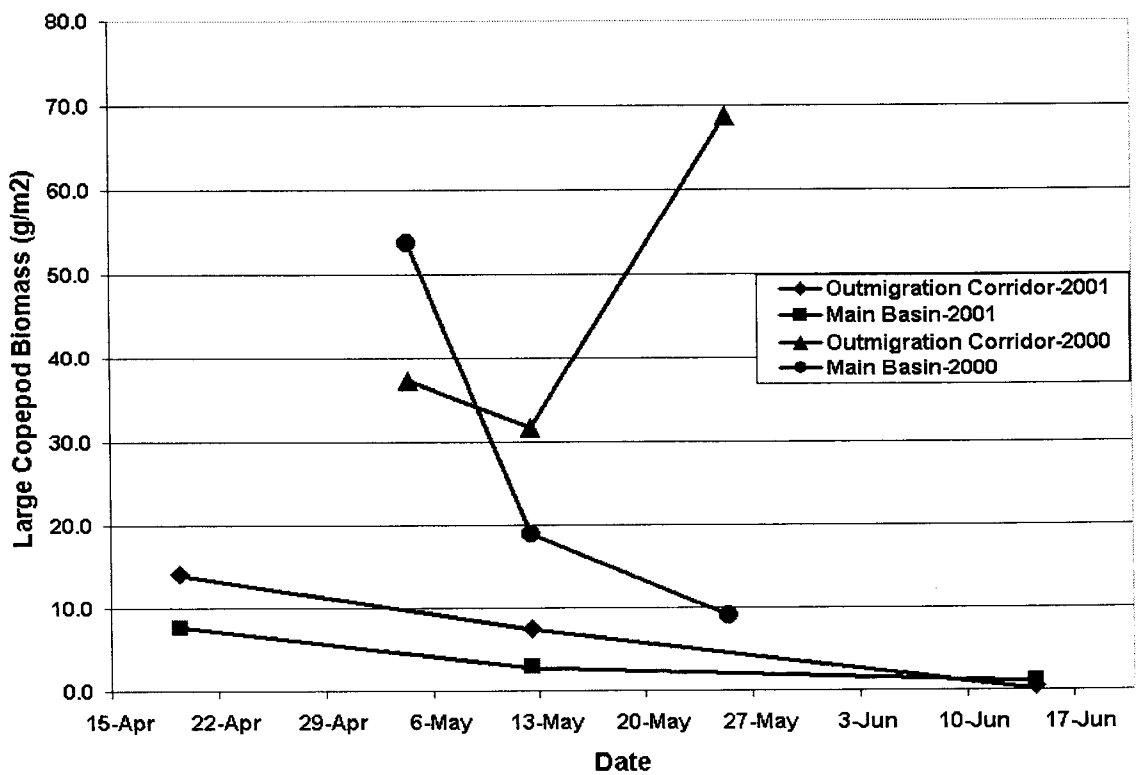



Figure 7. Comparison of large copepod biomass estimates for the out-migration corridor and main basin during 2000 and 2001 surveys.

Vertical Distributions

The vertical distribution of backscattering typically showed two depth layers (Figs. 8-10). The upper scattering layer, between the surface and 50 m, was the primary zooplankton scattering layer. The

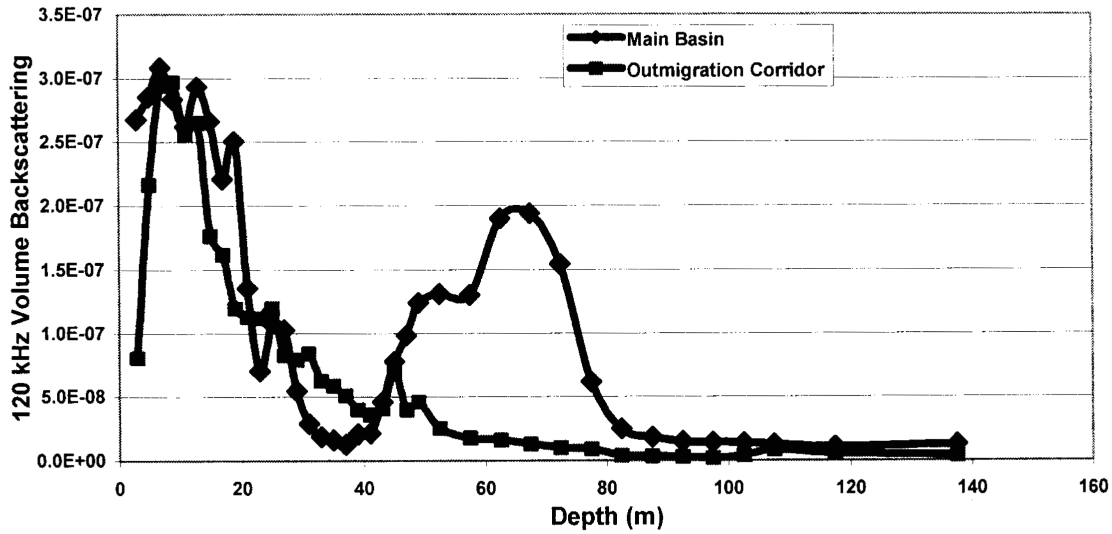



Figure 8. Vertical distribution of 120 kHz volume backscattering in the main basin and out-migration corridor of PWS during cruise 1.

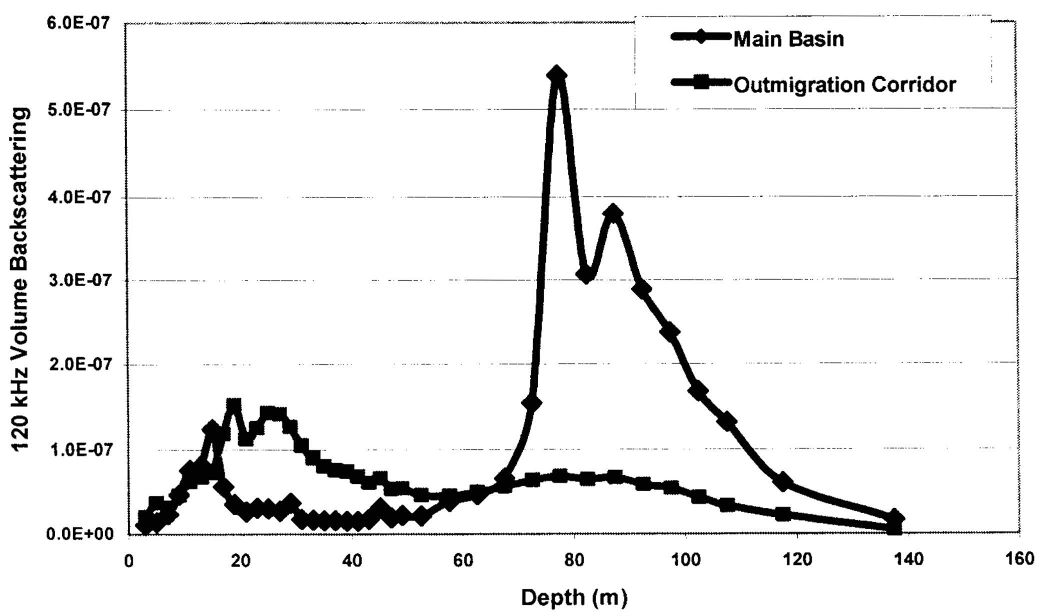



Figure 9. Vertical distribution of 120 kHz volume backscattering in the main basin and out-migration corridor of PWS during cruise 3.

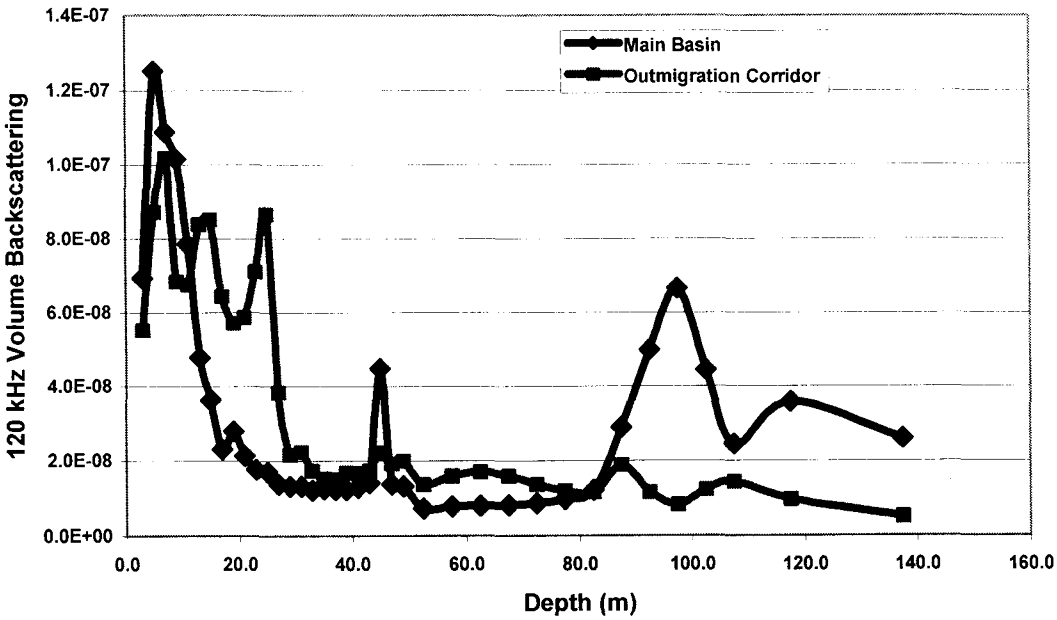



Figure 10. Vertical distribution of 120 kHz volume backscattering in the main basin and out-migration corridor of PWS during cruise 5.

depth and vertical extent of this layer was variable, sometimes near surface, and sometimes centered 25-30 m below the surface. A second scattering layer was often present, particularly in the main basin. Previous net sampling has shown that the primary scatterers in this deeper layer were pollock and euphausids. The depth of this layer typically varied from 60 to 120 m.

## Spatial Differences

There were no strong north/south trends in either the out-migration corridor or main basin during 2001. Highest acoustic backscatter was observed in the middle of the out-migration corridor during the mid-April and mid-May surveys, and the lowest backscatter was measured in the southern portion all three surveys, but the differences were less pronounced than those observed the previous year. North/south trends were also not consistent in the main basin.

During the May 2000 surveys, consistently higher zooplankton densities were observed along the eastern side of the out-migration corridor. This trend was not as pronounced during the 2001 surveys. Only the mid-May cruise showed a strong trend of increasing zooplankton density from west to east.

Lower abundance was observed in the protected bays and the inshore areas during the first focused cruise (May 6-8) than in more open areas (Fig. 11.) By the second focused cruise (May 18-20) abundance was similar among these locations. Bays had the lowest overall composition of large copepods.

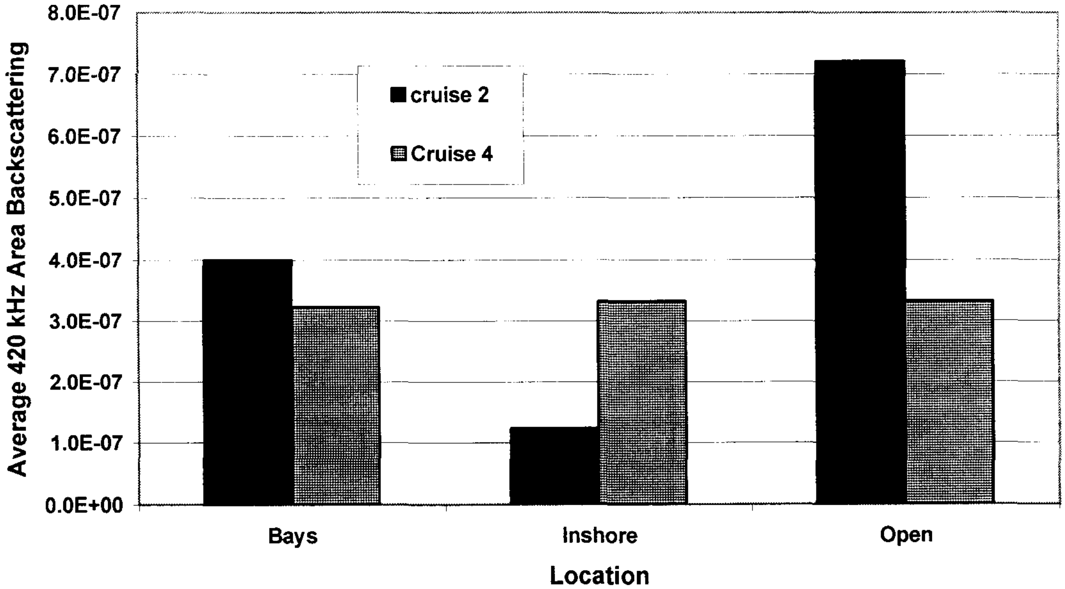



Figure 11. Comparison of average 420 kHz area backscattering from protected bays, inshore locations and open water locations (Naked Island, Knight Island Passage and Perry Passage) during the two focused cruises.

Frequency Differences

During the 2001 surveys, the lowest frequency had the highest return and the highest frequency had the lowest return. With small organisms such as zooplankton, the opposite result might be expected. However, several studies have shown that gelatinous organisms may reflect disproportionately higher at the lower frequencies, including 120 kHz and 38 kHz (Alvarez et al. 2002). In the 2000 survey, backscattering among the frequencies was relatively similar. However, it was noted in 2000 that *Oikopleura* scattered proportionately higher at 38 kHz. While the large zooplankton abundance was much lower in 2001, the *Oikopleura* abundance did not decline between the two years. It is likely that the strong contribution of *Oikopleura* to the low frequency scattering caused a relatively higher return at 38 kHz, and may have contributed to higher scattering at 120 kHz. Other gelatinous organisms may be under represented in the sample analysis because of their fragility.

Fish Abundance and Distribution

The patterns of fish distribution and abundance were generally similar to that observed the previous year (Fig. 12). Biomass was considerably higher in the main basin, but deceased after mid-May. Densities were initially very low in the out-migration corridor, but increased slightly after mid-May. The pattern in Montague Strait and southeast of Knight Island was similar to that of the main basin. Fish abundance was high initially, but declined over time.

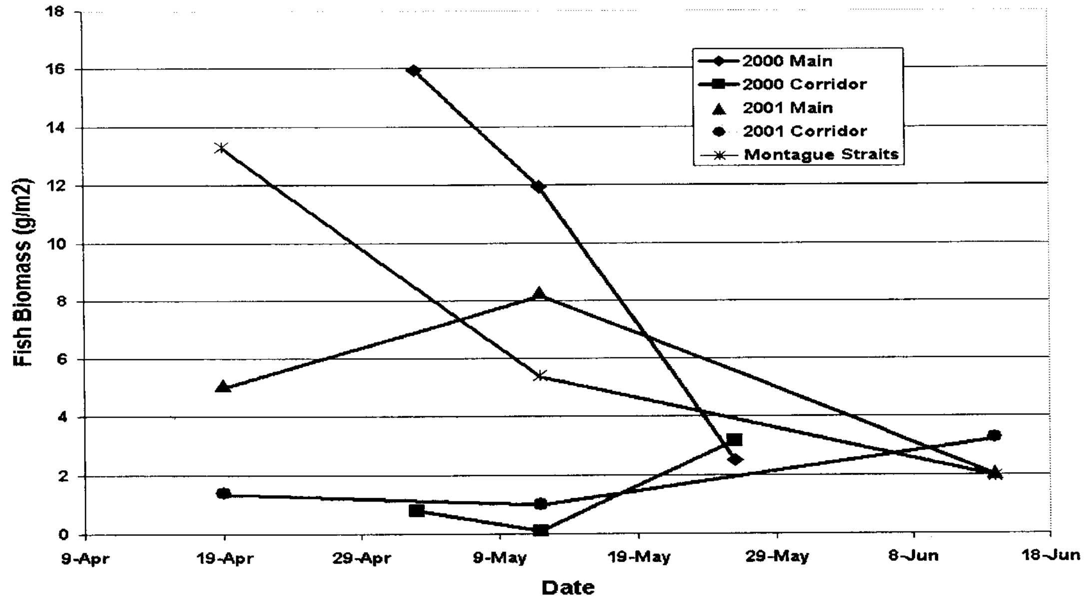



Figure 12. Comparison of fish biomass estimates in various locations of Prince William Sound from cruises in 2000 and 2001.

The most pronounced spatial trend in the fish distribution in the out-migration corridor during 2001 was a shoreward bias. The degree of bias toward shore progressively increased from mid-April, when it was weak, to mid-June when it was relatively strong (Fig. 13). In contrast, across-transect trends in fish biomass in the out-migration corridor were non-detectable for all cruises in 2000.

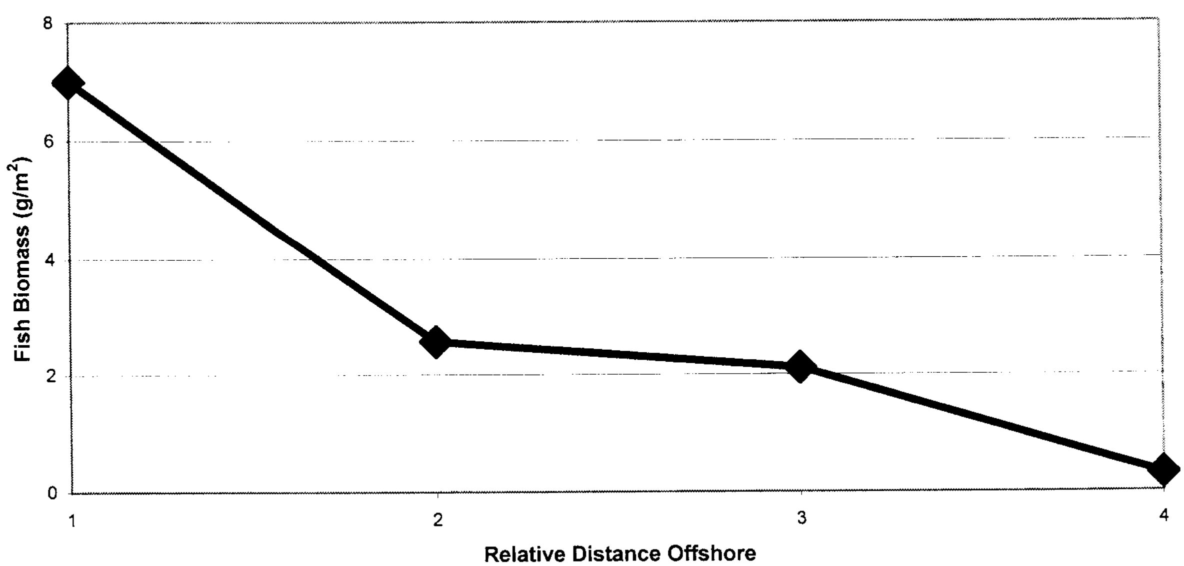



Figure 13. Relation between fish biomass and distance offshore for out-migration corridor during cruise 5 in June 2001. Point 1 is all-transect average biomass from shoreside to 1/8 distance offshore. Point 4 is all-transect average from 3/8 distance offshore to transect mid-point.

## Discussion

### Zooplankton Backscattering

The capability of acoustic techniques to accurately measure zooplankton abundance is well documented (GLOBEC 1991a; Wiebe et al. 1997; Kirsch et al. 2000; Thomas and Kirsch 2000). An important factor in the success of acoustic applications, whether for fish or zooplankton, is dominance of the target organism (Thorne and Thomas 2002). In this study, the primary goal was to measure the abundance of large copepods. The dominance of this component was expected from previous observations (Cooney et al. 1995, 2001; Kirsch et al. 2000). Despite the lower abundance of large-bodied copepods in 2001, they still dominated the backscatter at the higher frequencies. The dominance by these organisms simplified the estimation of the absolute biomass. The target strength characteristics of the large-bodied copepods were well established at 420 kHz from previous studies. Among the other organisms with appreciable contribution to the backscatter, only *Oikopleura* was relatively undocumented. The forward problem analysis appeared to be able to readily determine the target strength characteristics of *Oikopleura* because its abundance varied considerably among locations and its backscatter was highly frequency dependent. In contrast, the forward problem analysis indicated that small copepods contributed weakly to the overall backscatter because of low target strengths. This result suggests that either a higher frequency or an alternative approach might be required if the focus were on small copepods. While the 38 kHz frequency was not directly used for estimation of either zooplankton or fish, it was useful to facilitate separation of signals from fish and zooplankton and as an indicator of the abundance of gelatinous zooplankton.

Another important factor in the success of acoustic applications is the verification process, including species composition. This process is particularly important for zooplankton because of the greater diversity of scatterers. Consequently, net sampling is a critical part of zooplankton acoustic applications both for species allocation and for allocation of scattering components. We followed the historical zooplankton sampling procedures in Prince William Sound, 50 m vertical tows using a 0.335-mm 0.5 m-ring net (Cooney et al. 1995, 2001). Many researchers prefer horizontally stratified tows with an opening/closing net (Wiebe et al. 1985; Kirsch et al. 2000). We were constrained by cost and platform considerations. The vertical tows provided a rapid means to obtain integrated species composition information in the upper 50 m. In addition, a relatively simple species composition had been documented for the spring period. Our main concern with the technique would be errors caused by the selectivity of the net. However, the mean length of the large bodied copepods from our samples both years has been similar that obtained by Kirsch et al. (2000) using a MOCNESS sampler (Wiebe et al. 1985). Sampling with the 2-m RMT did not collect any additional organisms not captured by the 0.5 m-ring net, but the euphausids captured by the RMT included larger specimens than any found in the ring net samples. However, these were in very low abundance.

Theoretically, a 0.5-m net will intercept about 10 $m^3$ of water in a 50 m vertical tow. Using the 420 kHz acoustic backscattering cross-sections from Table 5, we can account for 100% of the volume backscattering through our forward analysis in a sample volume slightly less than 5 $m^3$. This result is reasonable since we know the actual filtering efficiency is less than 100%.

Acoustic and Net Comparisons

Both 420 kHz and 120 kHz backscattering correlated well with synoptic plankton samples (Thorne and Thomas 2000a). However, the net samples were not intended as a quantitative measure of overall zooplankton abundance. The sampling power of the nets was not considered adequate for this purpose, nor was the sample design appropriate for such application since it was biased toward higher density concentrations. Nevertheless, comparisons between the acoustic scattering and the net catches reinforce substantial differences between 2000 and 2001. Despite the limitations to the zooplankton sampling, the trend in catches between the two years showed the same large differences as seen in both the 420 kHz and 120 kHz backscattering. In addition, the reduced portion of large copepods in the 2001 samples provides further evidence of a substantial reduction in large copepod biomass.

Fish and Zooplankton

With few exceptions, the zooplankton and fish components of the backscatter were readily separable. There were deep layers (70-120 m) of adult pollock in the main basin that may have masked the presence of some zooplankton, especially euphausids. This was not a problem since our objectives focused on the large copepods in the upper 50 m. We attributed this deep scatter entirely to fish, as any euphausid backscatter would be minor relative to that from the adult pollock. We measured fish densities down to 150 m as these fish vertically migrated into the upper 50 m at night, thus qualifying as predators on the zooplankton and juvenile salmon. During winter, adult pollock are typically layered between 175 and 250 m. However, few targets were observed below 150 m during these spring cruises. Adult pollock move up in the water column during the spring months, initially remaining in relatively deep daytime layers, but later moving into the upper 50 m as individuals (Steinhart et al., unpublished). Net sampling for fish was not conducted as part of this monitoring effort. However, sufficient net and acoustic comparisons have been made that species can be identified in most cases with high confidence. OSRI supports an extensive, annual net sampling program for fish in PWS that takes place during the February/March time period.

We used scaling factors equivalent to –33.4 dB/kg for adult pollock and –32.2 dB/kg for adult herring during the over-wintering surveys of those stocks (Thorne and Thomas 2000b). Target strength per weight values of juvenile fishes are generally higher (Thorne 1983b). For convenience, we applied an intermediate scaling factor equivalent to –32 dB/kg to estimate fish biomass in this study. The scaling factor should provide a reasonable approximation and could be refined if future circumstances warrant a more detailed partition. However, that refinement and the direct capture sampling that would be required to fully support it do not appear to be warranted at this stage.

Willette et al. (1999a,b, 2001) indicated that herring and adult pollock switch to alternate prey (nekton) when large copepod densities fall below 0.2 g/m$^3$. This value corresponds to 10 g/m$^2$ as the data were obtained from 50 m vertical tows. The actual value is probably higher as the net sampling is unlikely to be 100% efficient. The value implies that the large copepod densities we observed in the out-migration corridor were adequate for herring and adult pollock in 2000, but not in 2001 (Fig 7). That difference may be reflected in the contrasting fish distributions seen in the out-migration corridor during the two years. In 2001, fish distribution was oriented toward shorelines, where pink salmon fry and other juvenile fishes are normally concentrated.

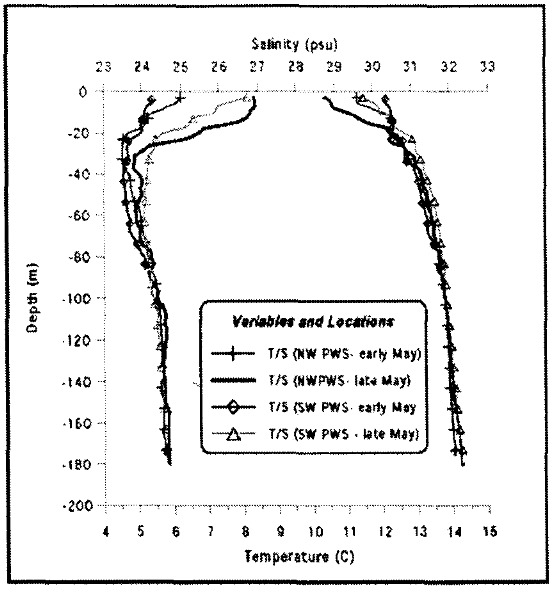
Potential Impacts on Hatchery Success

Two factors stand out with regard to the potential success of hatchery operations. One is the substantial difference in large copepod abundance between 2000 and 2001, and the second is the relatively low fish abundance in the out-migration corridor. Average large copepod abundance during 2001 in the out-migration corridor ranged from 14 g/m$^2$ in April to slightly above 1 g/m$^2$ in June. In contrast, the range in May 2000 was between 30 g/m$^2$ and 70 g/m$^2$. It is difficult to put either year in historical perspective because of the lack of quantitative historical data on zooplankton abundance. Previous estimates were limited to those from zooplankton catches and lacked adequate sample coverage. Steinhart et al. (unpublished) reported mean net catches of *Neocalanus* corresponding to 20 g/m$^2$ in April and 3.5 g/m$^2$ in May for a 1995 survey. Pooled catch of *Neocalanus* in May for 1994-97 from SEA observations corresponds to 7.5 g/m$^2$. The net estimates would be expected to underestimate actual density because of the catching efficiency of the net. These limited numbers would imply that the abundance of zooplankton during spring 2000 was higher than usual, while that in 2001 may have been slightly lower than normal.

The fivefold difference between 2000 and 2001 is not unprecedented. Settled zooplankton volumes from AFK hatchery varied sixfold from 1981 to 1998. While such differences can be monitored, substantially greater understanding of the sources of variability, including the sources of the large-bodied copepods, is needed to achieve any reasonable level of prediction. The physical characteristics of the water column, including temperature and stratification, may contribute to the interannual variability in zooplankton abundance. Near-surface water temperatures measured during the 2001 cruises were relatively cool, and stratification was weak (Fig. 14). In contrast, stratification was much stronger in 2000, and surface water temperature was much warmer. Halderson et al. (2002) reported that higher zooplankton abundance in Prince William Sound in 1998 compared to 1997 was associated with stronger water column stratification in 1998.

Satellite observations provide additional evidence of a difference in productivity in 2000 compared to 2001 (Brickley et al. 2002). Florescence measurements from space showed high productivity in the Northern Gulf of Alaska during 2000. In contrast, the spring bloom in 2001 was weak and occurred relatively late.

The distribution of zooplankton in relation to hatchery releases and out-migration patterns will also affect pink salmon survival. These factors are even more difficult to assess without an extensive analysis of hatchery releases. Factors that need to be considered include the greater abundance of zooplankton along the eastern edge of Knight Island passage noted in 2000 (Thorne and Thomas 2000a) and the lower abundance of large copepods in bays noted in this report.



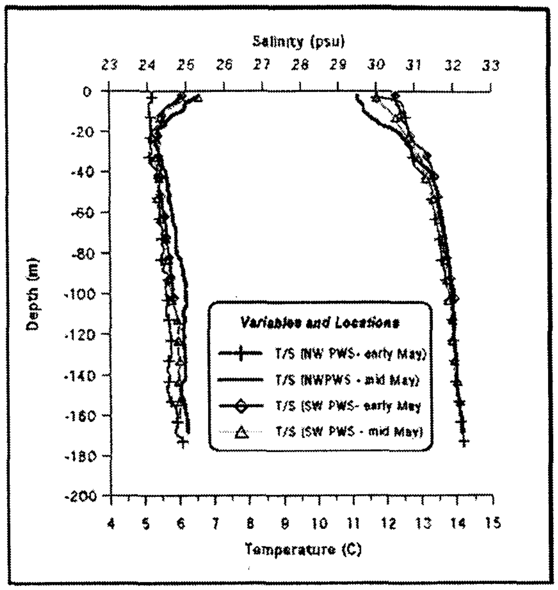




Figure 14. Comparison of salinity and temperature profiles between 2000 (left) and 2001 (right).

The lack of fish predators in the Knight Island/Perry Passage area, noted both years, would seem to favor juvenile salmon survival. One predator, herring, is at historic lows (Thorne and Thomas 2000b), while the pollock remained primarily in the central basin until the end of the month. However, the shoreward bias in the 2001 fish distribution does imply piscivorous feeding behavior.

Zooplankton Monitoring and Pristane

Detailed zooplankton abundance information is available for comparison with results of pristane sampling during spring 2001. We did observe that zooplankton densities were lower in the protected bays and inshore locations where pristane samples are collected. However, preliminary results indicate that the major trend in large copepod abundance was captured in both studies. The pristane levels dropped considerably between 2000 and 2001 (Jeff Short, personal communication). While the result is encouraging, long-term monitoring of both parameters would be required to sufficiently understand the relationship between the two and how well each functions as predictors of juvenile pink salmon survival.

Benefits of Expanded Spatial and Temporal Coverage

The EVOS TC funding for 2001 allowed expansion of spatial and temporal coverage of the zooplankton monitoring compared to the initial 2000 coverage. The differences in both abundance and seasonal trends between 2000 and 2001 indicate that seasonal characteristics may be complex and require greater temporal coverage. The coverage of three additional areas in Prince William Sound provided additional information on spatial distributions. However, the most significant benefit from the second year of monitoring was the capability to examine interannual variability. One-time additions in coverage provide minimal benefits. Ultimately, the value of the expanded coverage in 2001 will depend upon the extent that additional coverage is repeated in future years. As additional EVOS TC funding is not anticipated, the benefits of the expanded coverage will depend upon the extent that OSRI incorporates such expansion in future surveys.

Future Considerations

Other considerations for future surveys include the role of multiple frequencies, the resolution of the data and transition to real-time analysis. Continuation of the existing three-frequency data acquisition seems reasonable even though the use of the 38 kHz data has been minor. The 38 kHz does provide an important measure of the input from gelatinous zooplanktors that may be underrepresented in the net tows. The 420 kHz seems ideal for the large-bodied copepods. It adequately covers the upper 50 m. A higher frequency may provide better return from small zooplankton, but would be too limited in depth coverage. Replacement of the current 120 and 420 kHz analog systems may become necessary as the ESP analysis system is no longer supported by the manufacturer.

Currently, the data are analyzed at a relatively high resolution, typically 2-m depth intervals in the upper 50 m and 30 second time intervals. That resolution has not utilized in the analysis to date except to facilitate deletion of fish signals in the 420 kHz data. However, such high resolution may be useful in future research. For example, the upper 50-m has been used as the critical measure of zooplankton abundance primarily because historic practices have centered around the 50-m vertical plankton tow. The reality may be more complex. However, refinements of the basic hypotheses will need to await a larger data set of pink salmon survival data.

If clear relationships between these data and pink salmon survivals can be established, then it is logical to transition to real time analysis and reporting as a guide to hatchery release strategies. That ultimate goal is incorporated in the current approach that stresses cost-effective collection and analysis methods. The experience from the first two years indicates that it would be possible to report large-bodied copepod abundance and distribution within one week of data collection.

## Conclusions

The goal of the OSRI zooplankton-monitoring program is to develop and apply a cost effective approach to estimation of pink salmon food supply and predator abundance. The results from the first two years of this program indicate that the multiple-frequency acoustic system, supported by plankton net samples and CTD measurements, can provide a viable methodology, combining high quantification with the extremely high sampling power that is required to obtain sufficient detail in a reasonable time and cost framework. The large differences in zooplankton abundance between 2000 and 2001 will provide an early indication of the role of total zooplankton abundance in juvenile salmon survival. The impacts of temporal and spatial variability in concert with hatchery release operations are more complex. A more complete understanding of the complex environmental conditions that govern juvenile salmon survival will only be obtained by long-term acquisition of this type of information.

The basic OSRI monitoring program was conducted for under $75k, excluding the complementary use of the M.V. *Valdez Star.* The contribution from EVOS TC provided additional spatial and temporal coverage, and allowed a one-time examination of selected inshore locations where pristane samples were collected. Projected effort for 2002 will revert to the basic OSRI-funded coverage. Future refinements will depend upon comparisons between the monitoring data and subsequent pink salmon survival characteristics.

While the objectives of this program focus on pink salmon survival, the abundance of zooplankton is critical for many other species. This type of information, collected as part of a cost-effective, long-term monitoring program, has the potential to reap many future benefits. Ultimately, such monitoring needs to be incorporated into the Gulf Ecosystem Monitoring program (GEM) for GEM to adequately address impacts of secondary production in the Gulf ecosystem.

Critics of Alaskan hatchery programs have identified the lack of scientific basis for hatchery operations as a serious deficiency. It will be important for the result of this on-going monitoring program to be incorporated into management programs. Existing salmon forecast models need to be adapted to incorporate the data-rich format of the monitoring. Hatchery operations need to coordinate with monitoring programs to develop better and more scientifically-based release strategies. Ultimately, ecosystem modeling needs to develop the capability to understand and predict the substantial interannual variability that is detected by the monitoring program.

## Acknowledgements

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## Appendix Table 1. Locations of various zooplankton tows and CTD casts

| Cruise # | Date | Zooplankton Station | CTD Station | Location |
|---|---|---|---|---|
| 1 | 18-Apr | Zoop # 1-1,2 | CTD # 1-1 | Main North |
| | | Zoop # 1-3 | | Main Central |
| | | Zoop # 1-4 | CTD # 1-2 | Main South |
| | 19-Apr | Zoop # 1-5 | CTD # 1-3 | S.E. Knight I. |
| | | Zoop # 1-6 | CTD # 1-4 | Montague Strait |
| | | Zoop # 1-7 | CTD # 1-5 | South Knight I. Pass |
| | 20-Apr | Zoop # 1-8,9 | CTD # 1-6 | Naked Island |
| | | Zoop # 1-10 | CTD # 1-7 | Perry Island Pass |
| | | Zoop # 1-11 | | North Knight I. Pass |
| 2 | 6-May | Zoop # 2-1,2 | | Lake Bay |
| | | Zoop # 2-3 | | South Bay |
| | | Zoop # 2-4 | CTD # 2-1 | Perry Island Pass |
| | 7-May | Zoop # 2-5 | CTD # 2-2 | Naked Island |
| | | Zoop # 2-6 | | Pt. Eleanor |
| | | Zoop # 2-7 | | Applegate Island |
| | 8-May | Zoop # 2-8 | | Main Bay |
| | | Zoop # 2-9 | | North Knight I. Pass |
| | | Zoop # 2-10 | | Herring Bay |
| | | Zoop # 2-11 | CTD # 2-3 | South Knight I. Pass |
| 3 | 11-May | Zoop # 3-1 | CTD # 3-1 | Main North |
| | 12-May | Zoop # 3-2,3 | CTD # 3-2 | Naked Island |
| | | Zoop # 3-4 | CTD # 3-3 | Perry Island Pass |
| | | Zoop # 3-5 | | North Knight I. Pass |
| | 13-May | Zoop # 3-6,7 | CTD # 3-4 | South Knight I. Pass |
| | | Zoop # 3-8 | | Montague Strait |
| | | Zoop # 3-9 | CTD # 3-5 | S.E. Knight I. |
| | 14-May | Zoop # 3-10 | CTD # 3-6 | Main South |
| | | Zoop # 3-11 | | Main Central |
| 4 | 18-May | Zoop # 4-1 | | Pt. Eleanor |
| | 19-May | Zoop # 4-2,3 | | Lake Bay |
| | | Zoop #4-4 | | South Bay |
| | | Zoop # 4-5,6 | | Applegate Island |
| | | Zoop # 4-7 | | Main Bay |
| | | Zoop # 4-8 | | Herring Bay |
| | 20-May | Zoop # 4-9 | | South Knight I. Pass |
| 5 | 13-Jun | Zoop # 5-1 | CTD # 5-1 | Naked Island |
| | | Zoop # 5-2 | CTD # 5-2 | Perry Island Pass |
| | | Zoop # 5-3 | | North Knight I. Pass |
| | 14-Jun | Zoop # 5-4 | CTD # 5-3 | South Knight I. Pass |
| | | Zoop # 5-5 | CTD # 5-4 | Montague Strait |
| | | Zoop # 5-6 | | S.E. Knight I. |
| | 15-Jun | Zoop # 5-7 | CTD # 5-5 | Main South |
| | | Zoop # 5-8 | CTD # 5-6 | Main North |
| | | Zoop # 5-9 | | Main Central |