Annual Progress Report – Oil Spill Recovery Institute

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Name of Awardee: Richard E. Thorne, Prince William Sound Science Center

OSRI Contract Number: 03-10-22

Project Title: Biological Monitoring of Spring Zooplankton and Nekton in Prince William Sound

Dates this progress report covers: January 1, 2003-January 31, 2004

Abstract:

A program to monitor the pink salmon food supply and predators in Prince William Sound was initiated by the Oil Spill Recovery Institute (OSRI) in 2000. This report describes the results of monitoring during the fourth year of the study.

Three cruises were conducted between April 28 and June 11, 2003. The first two sampled eight locations including the main basin of PWS, Perry and Knight Island Passages, an area west of Naked Island, and in Montague Strait. The SERVS vessel Valdez Star became unavailable just before the beginning of the sampling season due to security issues surrounding the Iraq war. Due to vessel limitations, data collection during the third cruise was limited to net tows in only three of the eight locations.

The contribution of large copepods to the total catch was the smallest for the four year period, averaging only 30% of the biomass. Catch rates of large copepods in the plankton nets were also low. Only larvacae abundance was above average, and the role of larvacae in pink salmon survival is not well understood. The fish distribution was similar to that seen most years, including movement from the main basin into the out-migration corridor and an indication of a near-shore orientation. Other than the unknown impact of high larvacae abundance, the only mitigating factor against what appears to be a poor survival environment was the limited survey coverage during the critical third cruise, which may have be insufficient to adequately represent PWS.

Adult pink salmon returns to PWS in 2003 were exceptionally high. Possible reasons for the high survival include a relatively high abundance of large copepods in late spring 2002 and an exceptional abundance of euphausids, which may have provided a prey-sheltering mechanism for the juvenile pink salmon in 2002.

Future surveys may need to be more flexible to accommodate vessel availability. Future sampling needs to look closer at the potential impact of euphausid abundance on pink salmon survival.

Review of objectives:
The overall 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 specific objectives were to measure the abundance of zooplankton as food supply for juvenile pink salmon and the abundance of predators.

Problems encountered:
The late cancellation of the Valdez Star caused both scientific and budgetary problems. Fortunately, an alternate vessel was located for the first two scheduled cruises, although at an unbudgeted cost of over $7,000. Due to scheduling conflicts with the ongoing commercial fishery, the only opening for the third cruise was a single day effort, at an additional $1,300 cost. In addition, one of the three frequencies (420 kHz) failed during the second cruise. Normally, that would have been a minor problem, but its significance increased because of a lack of opportunity to collect acoustic data during the very limited third cruise.

Highlights:
Despite the vessel problems, we successfully collected a third year of distribution and abundance information on both zooplankton and fish. The data will contribute appreciably to our understanding of factors behind pink salmon survival. The large return of adults in 2003 was very enlightening, revealing a possible role of euphausids as a prey shelter for pink salmon fry during spring 2002.

Some results of the study, including analysis of the 2003 adult salmon returns, were presented at the Ocean Sciences meeting in Portland, Oregon in January 2004. A paper on the results was recently published as part of the Proceedings of the 21st Northeast Pacific Pink and Chum Salmon Workshop. As a result of participation in that workshop in 2002, the P.I. has been appointed to the Technical Committee for the next pink and chum salmon workshop, which will be held in Ketchikan in February 2005. The P.I. participated in a workshop on pink salmon in Cordova in March 2004, and has been working closely with a local fishermen's program, the PWS Fisheries Research Applications and Planning (PWSFRAP), to expand the study of pink salmon in PWS with support of the GEM Program (EVOS TC). PWSFRAP has been very supportive of this research.

Conclusions:
We overcame several problems to successfully complete the fourth year of this project. The results are providing valuable insights into the complex environmental conditions that govern juvenile salmon survival. Such information is urgently needed as Alaska's salmon hatchery programs come under increasing scrutiny. Long-term baseline data on zooplankton abundance can address many uncertainties associated with hatchery operations including questions concerning ocean carrying capacity.

A more detailed report on the results of this project is given as Appendix 1 (pages 3-22).

Appendix 1

Monitoring the Juvenile Pink Salmon Food Supply and Predators in Prince William Sound During 2003

Richard E. Thorne

Introduction

Research conducted by the Sound Ecosystem Assessment (SEA) program in the 1990s demonstrated that the survival of pink salmon fry (Oncorhynchus gorbuscha) in Prince William Sound (PWS) is dependent on the zooplankton food availability and predator abundance. Large calanoid copepods, mainly of the genus Neocalanus, typically consist of more than 50% of the biomass of PWS zooplankton in April and May. They are a valuable source of food for many fishes, including pink salmon fry, because of their relatively large size and high energy content (Cooney 1986). Willette et al. (2001) showed that both survival and early growth rates of pink salmon were correlated with the duration of the Neocalanus spring bloom. Cooney et al. (2001a) also showed that most pink salmon fry rearing in PWS are consumed by predators during their initial 45-60 days of early marine residence. The major predator is 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 2001). Pacific herring (Clupea pallasi) exhibit a similar prey switching behavior.

Subsequent to the SEA program, the Prince William Sound Science Center (PWSSC), 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), initiated a program in FY00 to begin monitoring the spring predator and prey densities of juvenile pink salmon (Thorne 2000; Thorne and Thomas 2001; Thorne 2002; Thorne 2003). The PWSSC program was built on the findings of SEA. Specifically, the goals were to monitor the abundance of zooplankton and predators. Multi-frequency acoustic systems provide the primary tool to estimate zooplankton and fish abundance and distribution. The program has completed four years of fieldwork, associated with three subsequent years of pink salmon returns. This report details the results of the fourth year of monitoring and compares the results from the four years, including adult salmon returns from the three earlier years.

Methods

The initial survey design implemented 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. It consisted of six clusters of four transects each. Three of the clusters extended along the main basin of PWS from Bligh Island to the Hinchinbrook Entrance and the other three clusters along the out-migration corridor extending from Perry Island Passage and out through Knight Island Passage (Fig. 1). These locations were surveyed three times during the spring. The surveys were conducted on the Valdez Star, which was provided without cost by SERVS.

In 2001, supplemental funding from the EXXON VALDEZ Oil Spill Trustee Council (EVOS TC) added three more clusters for a total of 36 transects. Without the supplemental funding, subsequent coverage in 2002 and 2003 was adjusted to incorporate two of the three extra locations surveyed in 2001 by reducing the number of transects in each cluster. The two locations that were retained were the deep basin adjacent to Naked Island and Montague Strait (Fig. 1). The Montague Strait location potentially provides additional information on zooplankton exchange with the Gulf of Alaska, while the deep basin adjacent to Naked Island is hypothesized to be the major over-wintering location of Neocalanus.

Three surveys were conducted during spring 2003 as in the previous years. However, shortly before the sampling period, the Valdez Star became unavailable for use because of security issues associated with the Iraq conflict. Consequently, an effort was made to obtain alternate platforms. The purse seiner Kyle David was obtained for the first two surveys, April 28- May 1 and May 15-18. However, no vessel was available for an extended cruise later in the season because of conflicts with the salmon fishery, which was virtually continuous at that time. We obtained the bowpicker, Alena K, for a one-day survey on June 11. The high speed capability of the vessel allowed us to cover three of the eight areas in PWS in a single day, but only to do net sampling and oceanographic observations (Table 1).

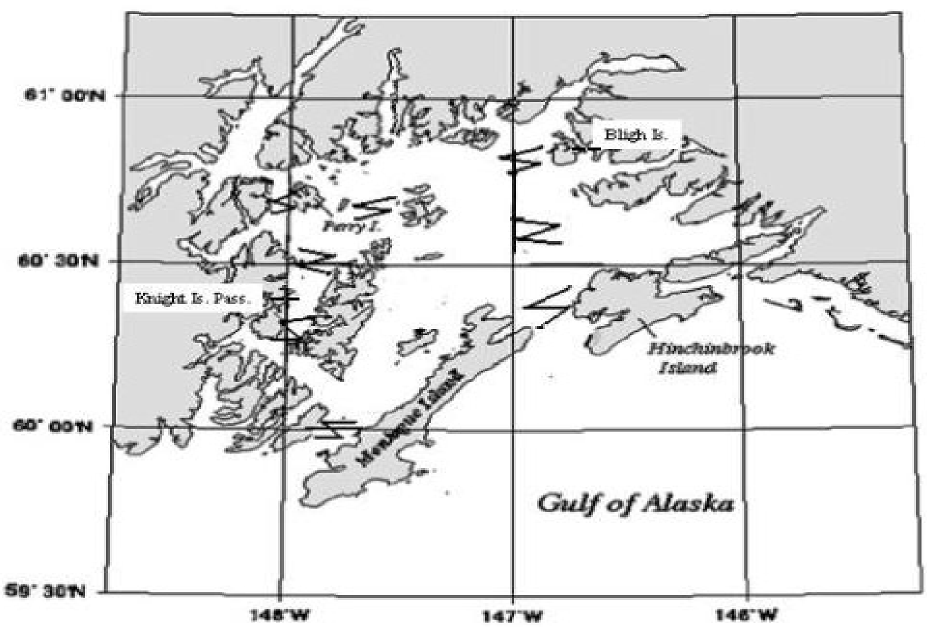

Figure 1. Location of transects for zooplankton surveys.

The acoustic data acquisition consisted of volume backscatter measurements from three acoustic frequencies. The acoustic systems, a BioSonics 70 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' (2.4m) towed vehicle. All systems were calibrated with standard targets following procedures of Foote et al. (1987). The 120 kHz frequency is commonly used in euphausid assessments

Table 1. Dates and types of data collected at various locations during 2003 cruises. Key: A=Acoustic; Z=Zooplankton; C=CTD; n.d. = no data.

Location	April 28-May 1	May 15-18*	June 11
Main-North	A,Z,C	A,Z,C	Z,C
Main-Central	A,Z	A,Z	C
Main-South	A,Z,C	A,Z,C	n.d
Perry Passage	A,Z	A,Z	n.d.
North Knight Is. Pass	A,Z,C	A,Z,C	Z,C
South Knight Is. Pass	A,Z	A,Z,C	n.d.
Naked Island	A,Z,C	A,Z,C	Z,C
S.E. Knight Island	A,Z,C	A,Z,C	n.d.
Montague Strait	A,Z,C	A,Z,C	n.d.

- No 420 kHz data were collected due to equipment failure

(McGehee et al. 1998) as well as fisheries applications. The 420 kHz frequency is well matched to the large copepod size and is commonly used in zooplankton research (Benfield et al 1998; Greene et al. 1998; Kirsch et al. 2000**)**. The 70 kHz system replaces a 38 kHz system that was previously used as the low frequency system to supplement fish detection. Performances of the two low-frequency systems are similar.

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. Temperature and salinity data were acquired using a SeaBird Electronics Model 19.03 CTD. Data collection was limited to daytime hours for consistency.

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", is used to refer to stage IV and V Neocalanus, or equivalent size copepods. In practice, this typically corresponds to copepods above 2 mm length, although some stage III Neocalanus overlap with stage IV. Numerical abundance was converted to estimates of biomass using average wet weights by category following Cooney et al. (2001b).

The acoustic data were analyzed using standard echo integration techniques (Thorne 1983a,b; MacLennan and Simmonds 1992). 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 measurements 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 (70 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.

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).

Results

Zooplankton Composition

Copepods dominated the zooplankton net catches both numerically and in biomass in 2003 (Tables 2 and 3), as was also the case in previous years. Small copepods numerically dominated the catch all three years. Large copepods were the dominant biomass in 2002 (51%) and in 2000 (68%), but the overall average in 2003 was under

30%, compared to 55% for small copepods. The contribution of large copepods to the total catch was the smallest for the four year period (Table 4).

Table 2. Numerical composition of zooplankton catches during 2003 surveys

Cruise	Location	Small copepods	Large copepods	Larvacea	Pteropod	Euphausid	Other
1	Outmigration Cor.	83.8	2.1	8.2	0.9	0.5	4.4
	Main	88.8	3.1	4.3	1.4	0.5	1.8
	Naked Island	82.4	3.6	10.2	1.3	0.3	2.3
	Montague Strait	88.4	1.7	5.3	0.8	1.6	2.3
	Average	85.9	2.6	7.0	1.1	0.7	2.7
2	Outmigration Cor.	73.0	7.3	11.6	0.8	2.5	4.8
	Main	88.6	1.8	2.9	1.5	1.2	4.0
	Naked Island	78.6	9.9	5.8	1.7	1.3	2.6
	Montague Strait	87.4	1.0	7.1	1.1	1.0	2.4
	Average	81.9	5.0	6.9	1.3	1.5	3.4
3*	Outmigration Cor.	85.4	1.7	6.6	0.5	4.2	1.5
	Main	98.3	0.0	1.0	0.1	0.2	0.3
	Naked Island	89.7	2.3	3.8	1.0	2.2	1.0
	Montague Strait	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Average	91.1	1.4	3.8	0.6	2.2	0.9
All	Outmigration Cor.	80.7	3.7	8.8	0.8	2.4	3.6
Cruises	Main	91.9	1.6	2.7	1.0	0.6	2.1
	Naked Island	83.6	5.3	6.6	1.3	1.3	1.9
	Montague Straits	87.9	1.3	6.2	1.0	1.3	2.3
	Average	86.0	3.0	6.1	1.0	1.4	2.5

*limited coverage

Table 3. Biomass composition (%) of zooplankton catches during 2003 surveys

Cruise	Location	Small copepods	Large copepods	Larvacea	Pteropod	Euphausid	Other
1	Outmigration Cor.	54.9	27.6	10.7	1.5	2.4	2.9
	Main	52.8	36.7	5.2	2.1	2.1	1.1
	Naked Island	45.2	39.7	11.1	1.7	1.0	1.3
	Montague Straits	60.0	22.5	7.1	1.4	7.4	1.6
	average	53.2	31.6	8.5	1.7	3.2	1.7
2	Outmigration Cor.	27.4	54.6	8.7	0.8	6.6	1.8
	Main	60.7	24.2	4.0	2.6	5.7	2.8
	Naked Island	25.8	65.0	3.8	1.4	3.1	0.8
	Montague Straits	65.1	15.2	10.6	2.1	5.2	1.8
	average	44.8	39.8	6.8	1.7	5.2	1.8
3*	Outmigration Cor.	51.7	20.7	8.0	0.8	17.9	0.9
	Main	95.2	0.7	1.9	0.4	1.5	0.3
	Naked Island	55.3	28.4	4.7	1.5	9.5	0.6
	Montague Straits	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	average	67.4	16.6	4.9	0.9	9.6	0.6
All	Outmigration Cor.	44.7	34.3	9.1	1.0	9.0	1.9
Cruises	Main	69.6	20.6	3.7	1.7	3.1	1.4
	Naked Island	42.1	44.4	6.6	1.6	4.5	0.9
	Montague Straits	62.5	18.9	8.9	1.7	6.3	1.7
	Average	54.7	29.5	7.1	1.5	5.7	1.5

*limited coverage

Table 4-Comparison of overall average numerical compositions, 2000-2003

Year	Small copepods	Large copepods	Larvacea	Pteropod	Euphausid	Other
2003	86.0	3.0	6.1	1.0	1.4	2.5
2002	84.3	7.5	1.8	1.9	1.4	3.1
2001	81.0	4.2	4.0	4.5	0.8	5.5
2000	85.5	8.1	4.3	0.6	0.6	0.9

Relative Abundance From Net Catches

The average catch per tow of large copepods in 2003 was considerably below that from spring 2000 and 2002. Cruise averages for 2003 were the lowest of all four years with a single exception: the second cruise of 2003 was higher than the second cruise of 2001 (Fig 2). Catches of small copepods in 2003 were also lowest of the four years, but only slightly below 2001 (Fig 3). In contrast, the average net catch of larvacea was higher than either 2001 and 2002 and was the highest of all four years for the third cruise (Fig. 4), and catches of pteropods were highest for the first two cruises, but did not increase dramatically in cruise three as was the case of 2000 and 2002 (Fig. 5). Overall euphausids catches were comparable to 2001 (Fig. 6).

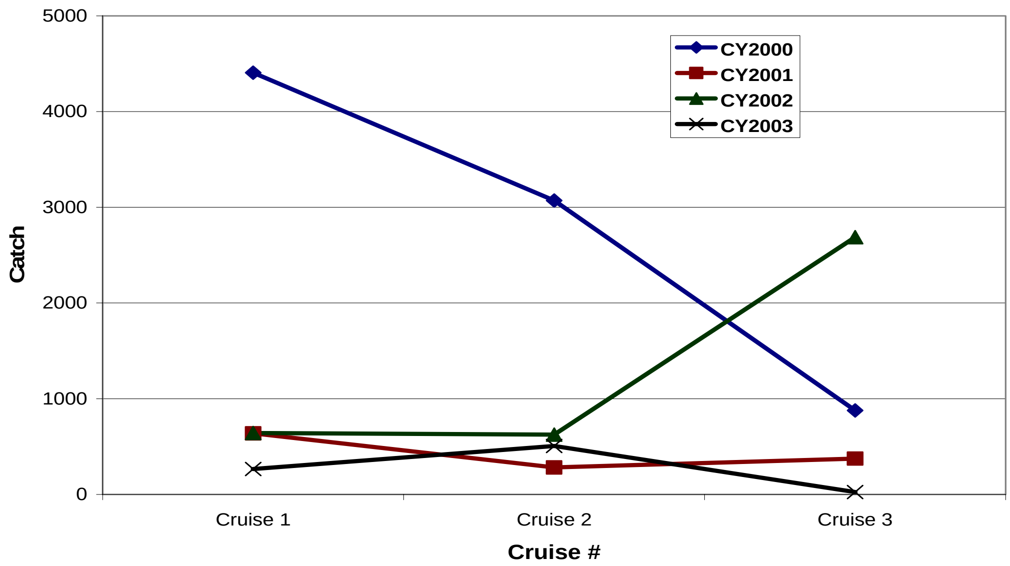

Figure 2. Comparison of Net Catches of Large Copepods during Spring Cruises in Prince William Sound, 2000-2003

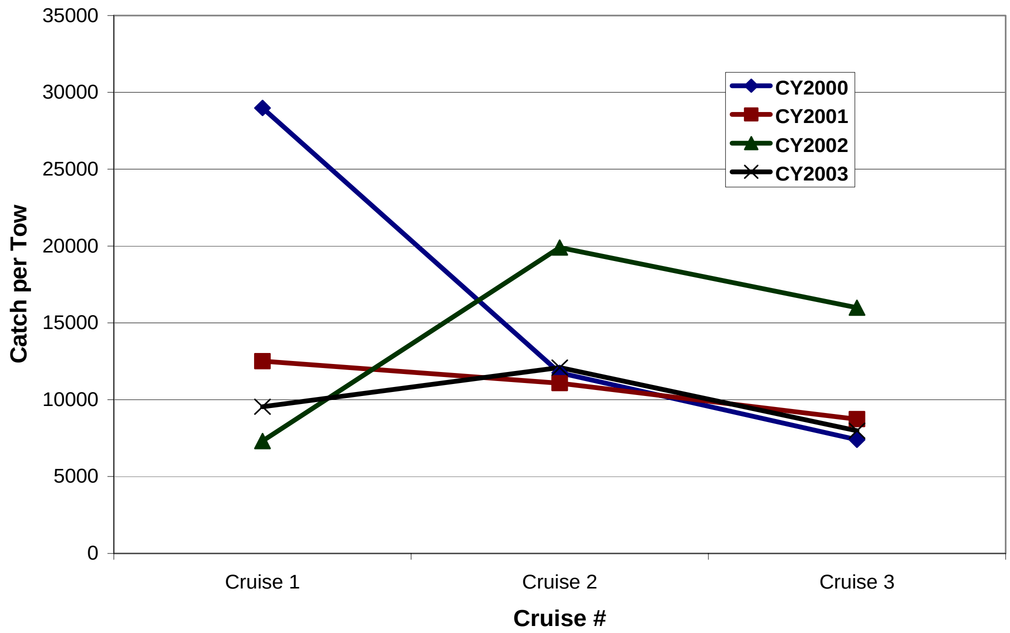

Figure 3. Comparison of Net Catches of Small Copepods during Spring Cruises in Prince William Sound, 2000-2003

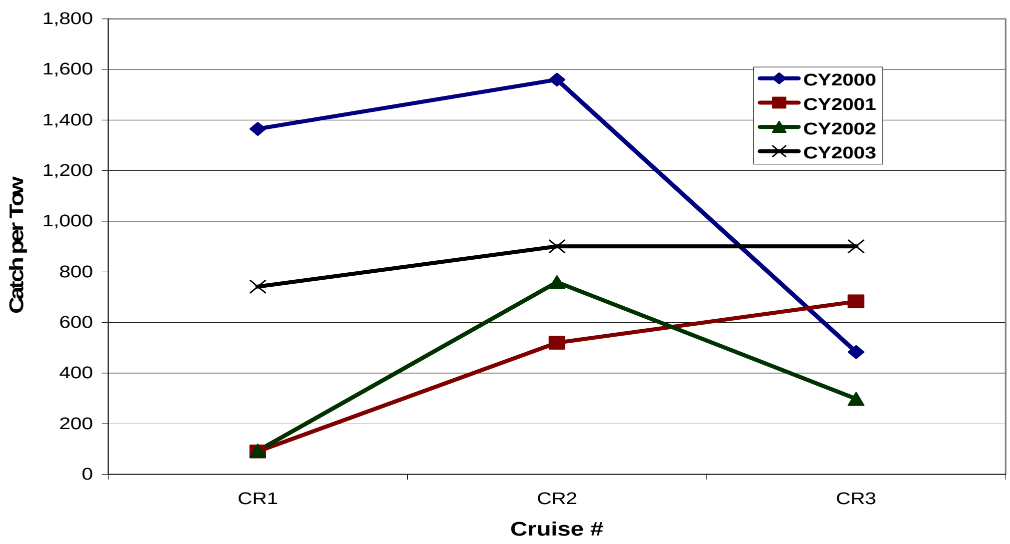

Figure 4. Comparison of Net catches of Larvacea during Spring Cruises in Prince William Sound, 2000-2003

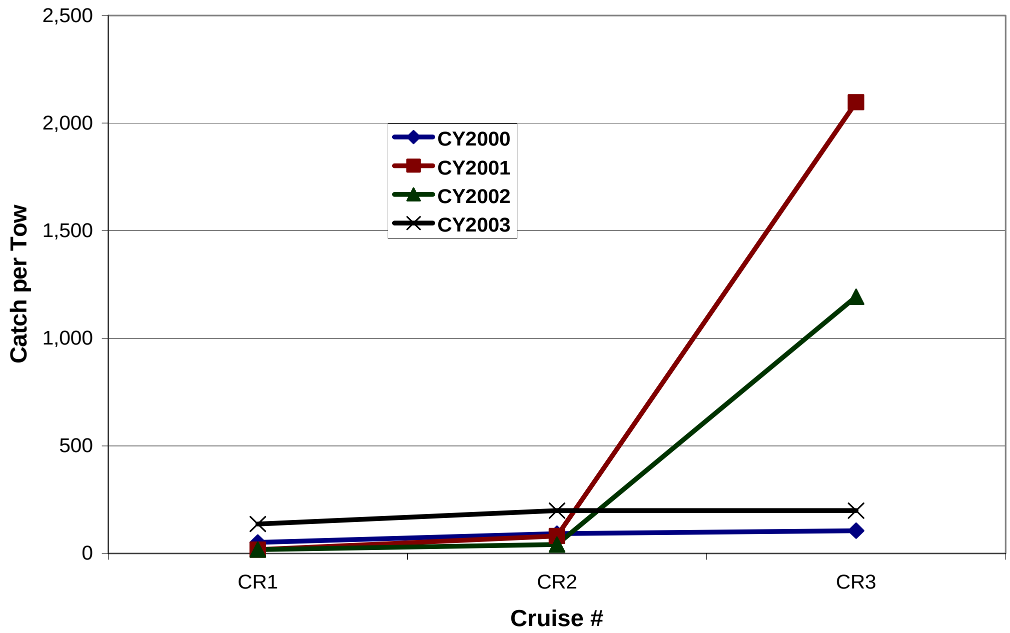

Figure 5. Comparison of Net Catches of Pteropods during Spring Cruise in Prince William Sound 2000-2003

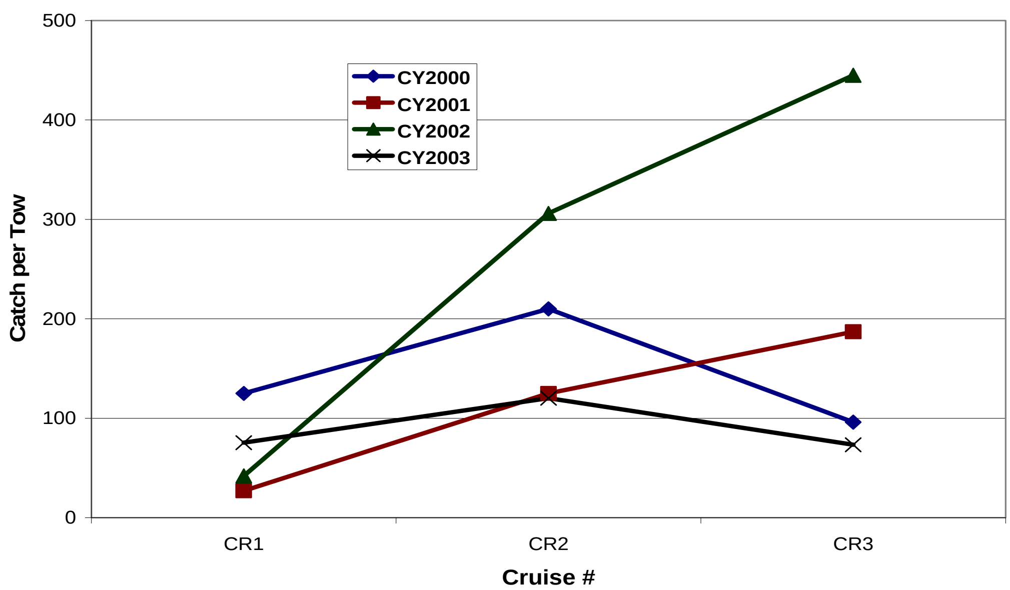

Figure 6. Comparison of Net Catches of Euphausids during Spring Cruises in Prince William Sound, 2000-2003

Acoustic Backscattering

The acoustic data were less comprehensive in 2003, and interpretation was complicated by the lack of a dominant scatterer, a role normally provided by Neocalanus. The 420 kHz frequency is probably the most useful, but was limited to the first cruise. The backscatter at 420 kHz for the first cruise in 2003 was generally similar to that from the other years, excepting the high observations in 2000. Highest 420 kHz backscatter in 2003 was noted in the northern part of the main basin (Fig. 7). The 120 kHz backscatter indicates an overall increase between the first and second cruises of 2003 (Fig 8), as was the case for the net catches of most components. The northern main basin remained relatively high, along with Perry Island Passage and the northern half of Knight Island Passage.

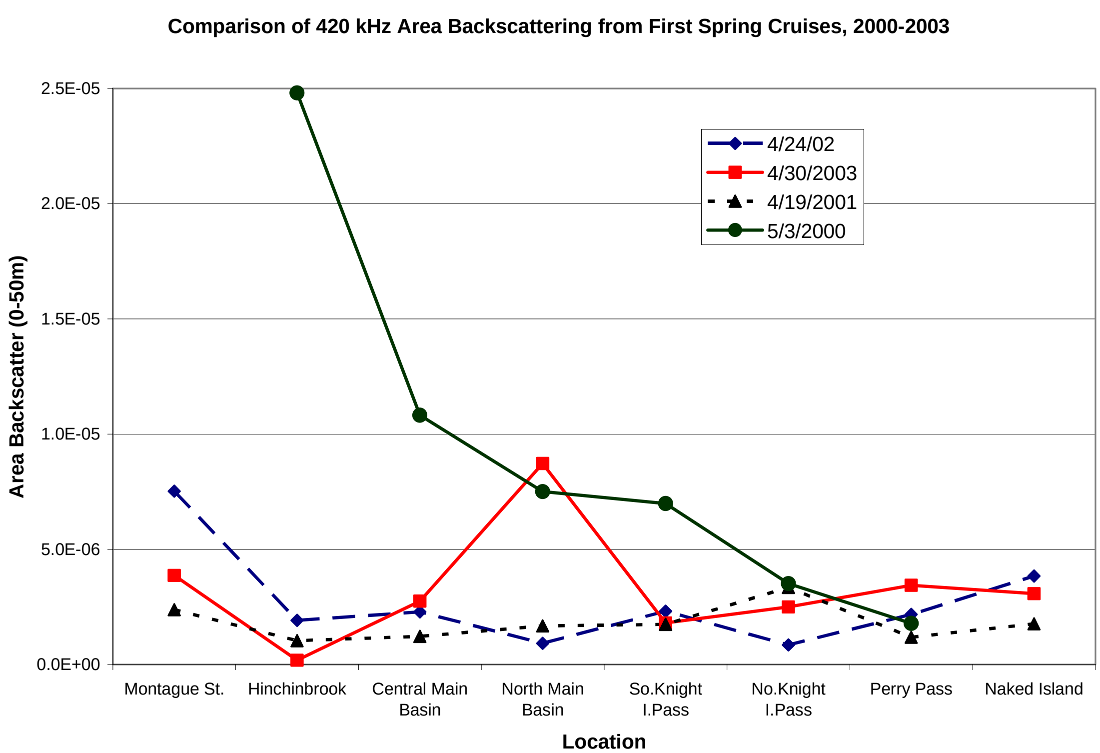

Figure 7. Comparison of 420 kHz backscattering from first cruises, 2000-2003.

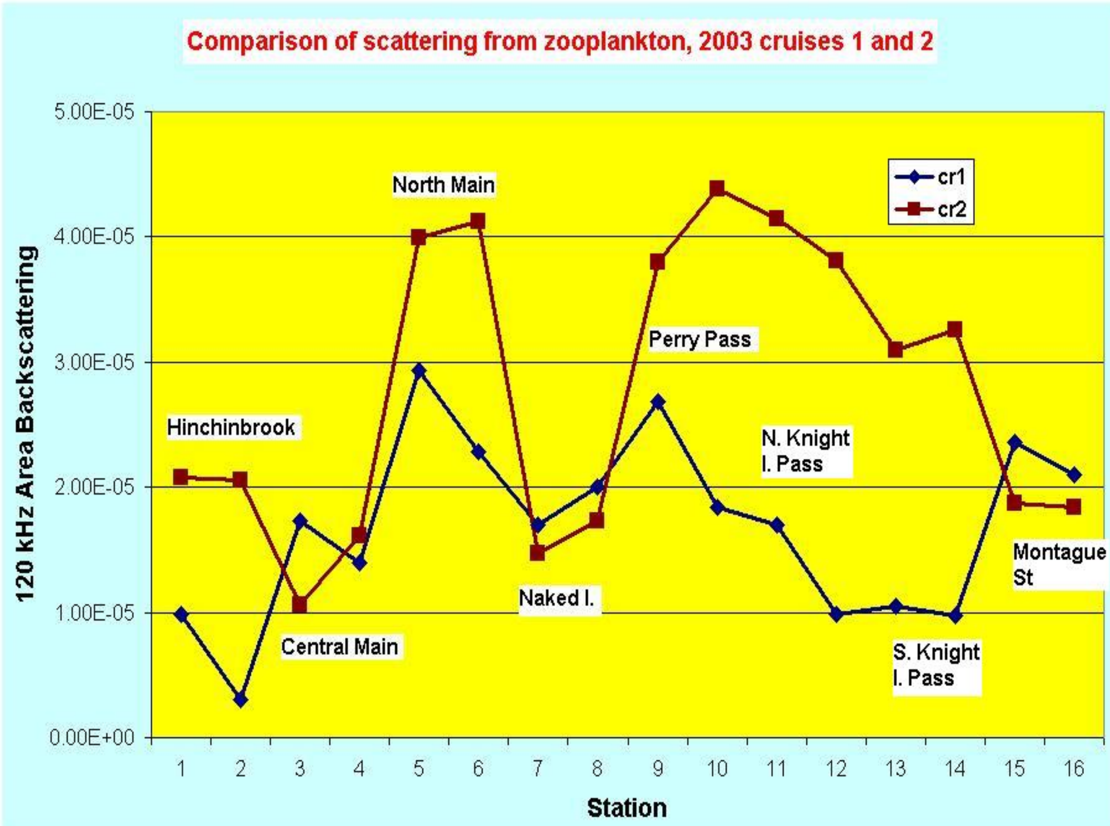

Figure 8. Comparison of 120 kHz backscattering between cruises one and two of 2003.

Fish Abundance and Distribution

Fish abundance was calculated from the 70 kHz data. The general distribution showed similar trends to previous years, with an apparent movement from the main basin into the out-migration corridor (Table 5). Values in the out-migration corridor were similar to those seen in other years, but values in the main basin were lower. The pollock biomass in PWS, from late winter surveys, has generally declined since 1998, while the herring biomass has increased the past two years. Pollock are generally associated with the main basin, but do migrate into near-shore areas later in spring. Biomass in the out-migration corridor in 2003 was slightly higher inshore than offshore (Fig. 9), as has been the trend all years except 2000.

Table 5. Estimates of fish biomass (g/m^2) in Corridor and Main Basin for Cruises 1 and 2 in 2003.

Cruise	Corridor	Main
1	1.1	1.4
2	1.6	1.0

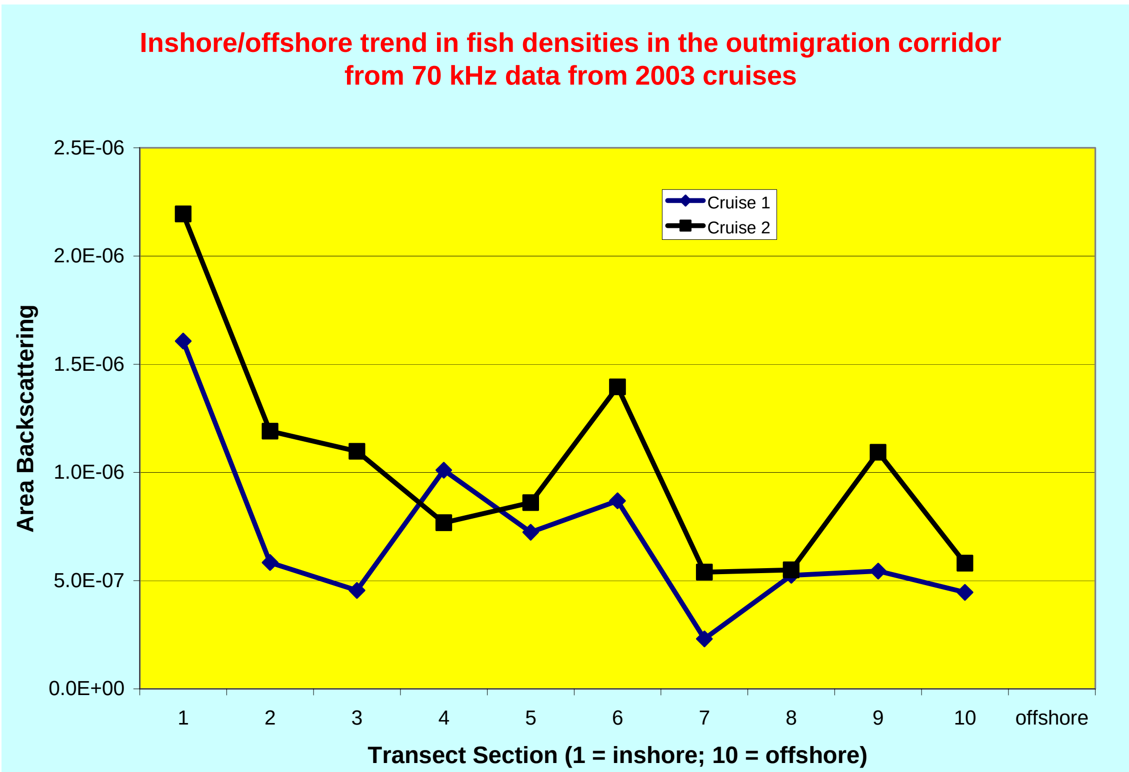

Figure 9. Inshore/offshore trend in fish distribution (70 kHz backscatter) in the out-migration corridor for cruises 1 and 2, 2003.

Comparisons of Zooplankton Abundance and Subsequent Harvests

Pink salmon spend slightly over one year at sea before returning as adults. Returns are available from the 2000 to 2002 nursery years. The return in 2001 from the 2000 nursery year was good, that from 2001 was poor, while that from 2002 was exceptional (Fig. 10). The relative differences between returns in 2001 and 2002 appeared to reflect differences in large copepod abundance (Fig. 11). However, that relationship clearly broke down for the exceptional 2003 return. Large copepod abundance in spring 2002 was only slightly greater than 2001 and far below 2000, although it was the highest of all years for the third cruise (See Fig. 2).

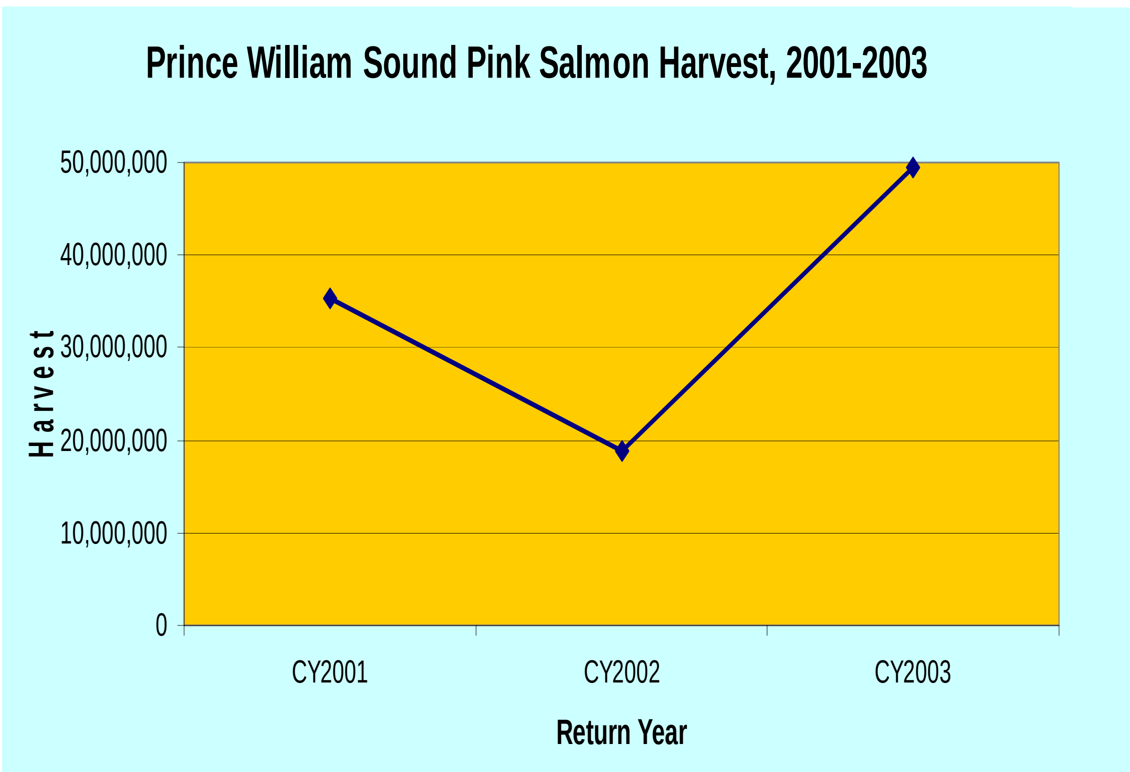

Figure 10. Total PWS pink salmon harvest for return years 2001-03.

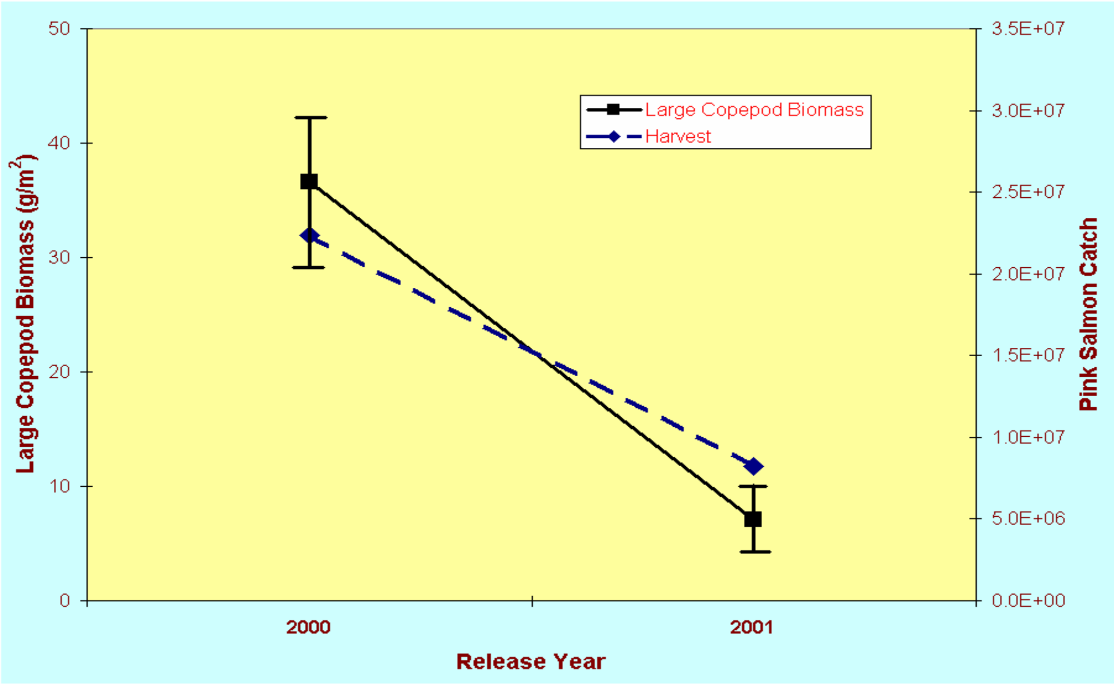

Figure 11. Comparison between estimates of large copepod abundance (with 95% Confidence Intervals) and subsequent common property fishery harvest for nursery years 2000 and 2001.

Several factors may have contributed to the unusually high pink salmon survival in 2002. They include the high late spring abundance of large copepods (See Fig. 2), as well as pteropods (See Fig. 5). Small copepod abundance was also relatively high (See Fig. 3). The most intriguing difference was a relatively high euphausid abundance in the net catches in 2002 (See Fig. 6). Euphausids are a relatively minor component in the net catches, but their relatively high abundance may signal an exceptionally high overall abundance. A high abundance of euphausids clearly caused problems in the estimation of fish biomass during the 2002 cruises, virtually eliminating the usefulness of the 120 kHz frequency for fish biomass estimation (Thorne 2003). Both Cooney et al. (2001a) and Willette et al. (2001) emphasized that predation was the major factor in pink salmon survival. Euphuasids are a favorite target of both walleye pollock and Pacific herring and could provide a mechanism of prey sheltering similar to that demonstrated for Neocalanus. The relative difference in pink salmon harvests among the three years is best matched by the relative difference in euphausid abundance in the net catches (Fig. 12).

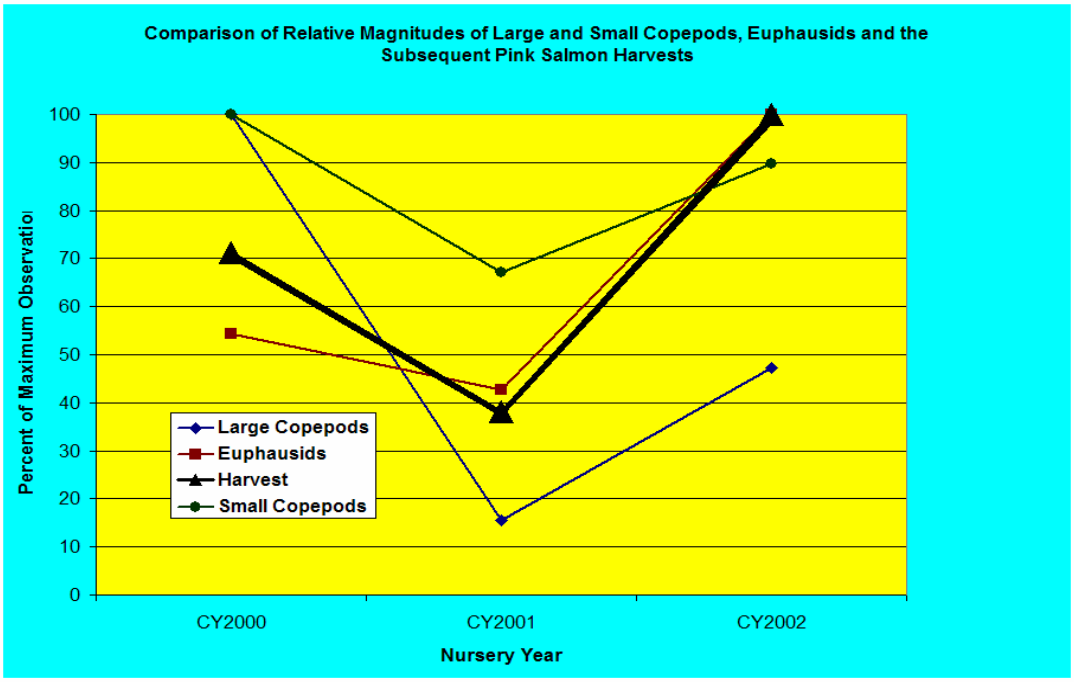

Figure 12. Comparison of relative magnitude of large and small copepods, euphausids and subsequent pink salmon harvest in Prince William Sound

Discussion

Prospects for adult salmon returns in 2004

The abundance of Neocalanus was low throughout spring 2003, which would indicate relatively poor conditions for pink salmon survival. Pink salmon returns from the 2002 nursery year were exceptional even though overall Neocalanus abundance was not. However, Neocalanus abundance in late spring 2002 was exceptional, as were both euphausid abundance and that of small copepods. None of these factors were positive for 2003. The only exceptional features of spring 2003 were a relatively high larvacea abundance and a relatively high early pteropod abundance. The fish abundance in 2003 was not high overall, but was typical of other years in the corridor, including a slight near-shore orientation.

The only mitigating factor against what appears to be a poor survival environment was the limited survey coverage during the critical third cruise: no acoustics and only six net tows in three locations. The coverage may have been too limited to accurately portray the conditions during the late spring.

Future Considerations

Two developments during this fourth year of monitoring are particularly relevant to future sampling. The first is the lost availability of the Valdez Star. At this point, it appears unlikely that the vessel will become available in the near future. Several sampling alternatives have been evaluated. The variability of the data suggests that a reduction of sampled area has less impact than temporal reductions. The current three-survey strategy provides minimal temporal coverage. Reduction to two surveys would have serious ramifications. The most tractable alteration appears to be a reduction of effort back to the original six locations. That coverage would cost $7-10K in vessel time, which could be compensated for by the corresponding 25% reduction of analysis effort.

The second development is the indication of an important role for euphausids in pink salmon survival. The 0-50 m vertical net tows are not designed to monitor euphausid abundance. Euphausids are too mobile to be effectively sampled, and are primarily diel vertical migrators that spend daytime at greater depths. Use of more effective nets, such as the MOCNESS (Wiebe et al. 1985), is not practical or cost effective in this monitoring effort because of vessel limitations. The most viable approach would be to use the 120 kHz acoustic data to monitor changes. Currently, euphausids are thresholded out of that signal in order to measure fish. Changes in analysis procedures to incorporate euphausid assessment would be appreciable, but clearly the most cost-effective approach. Such a change might be considered as a graduate student project, since a backlog of four years of data for that purpose currently exists. Alternately, a solution to the budgetary problems caused by these two developments might be acquisition of supplementary funds through the Gulf Ecosystem Monitoring Program (GEM). A look back at the euphausid contribution may aid interpretation of the fish data as well. The euphausid scattering clearly confounded analysis of the fish data in 2002 and may have obscured trends in the fish distribution that contributed to the exceptional 2003 returns.

Other recommendations for the future include closer cooperation with the Prince William Sound Aquaculture Corporation (PWSAC) and expanded analysis of physical data. Improved coordination with PWSAC is likely through several efforts, including that of the PWS Fisheries Research Applications and Planning Group (PWSFRAP). PWSFRAP might also support acquisition of supplementary funds from GEM. Analysis of the physical data from the CTD measurements is lagging because it currently depends on complementary efforts by PWSSC oceanographic staff.

Conclusions

Despite the vessel problems, we successfully collected a fourth year of distribution and abundance information on both zooplankton and fish. The data will contribute appreciably to our understanding of factors behind pink salmon survival. The large return of adults in 2003 was very enlightening, revealing a possible role of euphausids as a prey shelter for pink salmon fry. The data collected during spring 2003 suggests a poor environment for pink salmon survival except for high abundance of larvacae. Subsequent adult returns should reveal whether larvacae abundance is a factor, although interpretation will be confounded by the limited coverage during the third cruise in 2003.

The possible loss of availability of the Valdez Star and the possible role of euphausids in pink salmon survival need to be considered in future years.

It is important to recognize the value of long-term monitoring. The observations in 2003 further document the complexity of interannual variations in zooplankton production and their impact on juvenile salmon survival, a complexity that can only be resolved through long-term studies. Further insights are gained from each year of salmon returns that can be evaluated against the results of the previous year's monitoring.

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