Acoustic monitoring of the juvenile pink salmon food supply and predators in Prince William Sound, Alaska

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Abstract - **Previous research has indicated that juvenile pink salmon survival in Prince William Sound is positively correlated with the abundance of the large-bodied copepods of the genus Neocalanus. Neocalanus serves both as a valuable food supply for the juveniles and as a prey-sheltering mechanism. In spring 2000, the Prince William Sound Science Center initiated annual monitoring of the spring abundance and distribution of both macrozooplankton and fish predator populations. The monitoring includes multiple frequency acoustic systems and zooplankton net tows. The program has now completed five years of measurements, and there have been four associated adult pink salmon returns. Pink salmon returns were found to be positively correlated with average plankton net catches of both large copepods and euphausids in the nursery year. Some data gaps prevented correlation between acoustic scattering and pink salmon returns, but both 420 kHz and 120 kHz backscatter were positively correlated with the plankton net catches of large copepods. The acoustic data also allowed detailed examination of the spatial trends of the plankton distribution. Patchiness was relatively low, which may explain why the net catches seemed to provide a reasonable measure of overall abundance. Some changes in the monitoring procedures may be necessitated by the indication that euphausid abundance may also be an important factor in pink salmon survival.**

I. INTRODUCTION

Several hatcheries annually release hundreds of millions of juvenile pink salmon (Oncorhynchus gorbuscha) into the waters of Prince William Sound (PWS), Alaska [1]. Previous research has documented two critical factors in the juvenile salmon survival (1) the availability of large-bodied calanoid copepods (genus Neocalanus), and (2) the abundance of walleye pollock (Theragra chalcogramma). The large-bodied 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 [2] [3]. They are an especially valuable source of food for many fishes because of their relatively large size (stage IV and V over 2 mm length) and high energy content [4]. The timing of natural pink salmon fry entry into salt water is adapted to match that of the Neocalanus spring bloom [2] [5]. Willette et al. [6] [7] showed that survival and early growth rates of pink salmon were positively correlated with the duration of the Neocalanus spring bloom, and survival was 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 [6] [7]. Pacific herring (Clupea pallasi) exhibit a similar prey switching behavior. Most pink salmon fry rearing in PWS are consumed by predators during their initial 60 days of early marine residence [2].

Based on these findings, the Prince William Sound Science Center (PWSSC) initiated a program in spring 2000 to monitor the abundance of zooplankton and predators. Kirsch et al. [8] had previously demonstrated that high frequency (420 kHz) acoustic techniques could provide a quantitative assessment of the large-bodied copepods in PWS. We deployed a multi-frequency acoustic system so we could synoptically assess the biomass of both the zooplankton and the fish predators. The program has completed five years of fieldwork, associated with four subsequent years of pink salmon returns. This paper compares the results of the net catches and acoustic backscattering with subsequent adult salmon returns.

II. METHODS

Six areas in Prince William Sound were surveyed all years of study. Sampling in each area included acoustic transects and zooplankton net tows. Three of the areas extended along the main basin of PWS from Bligh Island to the Hinchinbrook Entrance (Fig. 1), and three extended from Perry Island Passage out through Knight Island Passage, a well-documented pink salmon nursery and out-migration corridor [5] [7]. Surveys were conducted three times during the spring between late April and early June. Data collection was limited to daytime hours to reduce confounding effects from diel vertical migrators since hours of darkness are too limited for effective coverage during this season.

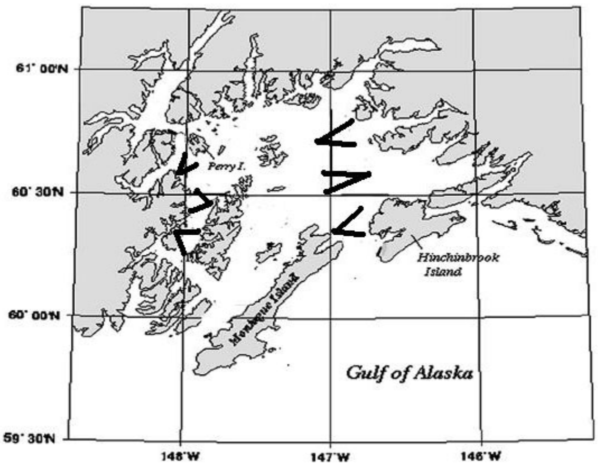

Fig. 1. Location of acoustic transects for zooplankton surveys.

The acoustic data acquisition consisted of volume backscatter measurements from three acoustic frequencies, 420, 120 and 38 kHz. The two higher frequencies were intended to measure zooplankton [8] [9] [10] [11], while the 38 kHz was used for fish assessment [12]. All systems were calibrated with standard targets [13]. The acoustic data were analyzed using standard echo integration techniques [12] [13] [14]. Separate analyses were conducted on the backscatter from fishes, which was then subtracted from the total backscatter to obtain the backscatter from zooplankton. Typically, volume backscattering measurements were made in 2-m intervals every 30 seconds of transect. Area backscattering from zooplankton was calculated for the upper 50 m.

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. [5]. At least two zooplankton tows were made within every area, every cruise. The plankton samples were analyzed to determine both size and frequency of the major components following procedures detailed in Kirsch et al. [8]. Copepods were separated into small and large-bodied categories, where large-bodied was Stage IV and V Neocalanus or equivalent size.

III. RESULTS

Copepods dominated the zooplankton net catches all years. Large copepods ranged from 3.0 to 8.9% numerically, but were often over 50% of the zooplankton biomass. The average net catch of large copepods ranged from a high of 1869 in 2000 to a low of 284 in 2003 (Table 1). Larvacea were the second most abundant category, followed by pteropods and euphausids.

Pink salmon spend slightly over one year at sea before returning as adults. Harvests in PWS were high in 2001 and 2003, low in 2002 and 2004 (Table 2). Two nursery years, 2000 and 2002, had relatively high net catches of large-bodied copepods, while net catches in 2001 and 2003 were relatively low. Pink salmon harvests were positively correlated ($r^2 = 0.61$) with average large-copepod net catches in the nursery year (Fig. 2). Only one other component of the zooplankton net catches, euphausids, showed a high correlation with subsequent pink salmon harvests. The pink salmon harvest in 2003 was exceptional, and higher than expected from abundance of the large-bodied copepods. However, euphausid net catches were relatively high in 2001, resulting in a slightly higher overall correlation with pink salmon returns ($r^2 = 0.70$) than for the large-bodied copepods (Fig. 3). The two components combined were highly correlated with pink salmon harvests. The highest correlation ($r^2 = 0.988$) occurred when the relative abundance of the two components was given equal weighting (Fig. 4).

The average cruise area backscatter at both 120 kHz and 420 kHz showed reasonable correlations with corresponding average net catches of large copepods ($r^2 = 0.62$, n=14 and $r^2 = 0.53$, n=12 respectively). No other component of the zooplankton accounted for more than 17% of the variability around the regressions. Although pink salmon returns were positively correlated with euphausids in net catches, euphausids were a relatively minor component of the zooplankton and did not make a major contribution to the acoustic backscatter. The acoustic data could not be compared with the salmon

TABLE 1
AVERAGE PLANKTON NET CATCHES BY CATEGORY

Year	Small Copepod	Large Copepod	Larvacae	Pteropod	Euphausid
2000	17055	1869	1113	75	109
2001	11071	442	403	689	114
2002	14062	1545	438	425	220
2003	9926	284	596	114	127

TABLE 2
TOTAL PWS PINK SALMON HARVESTS, 2001-04

Year	2001	2002	2003	2004
Harvest (millions)	35.2	18.9	51.1	23.3

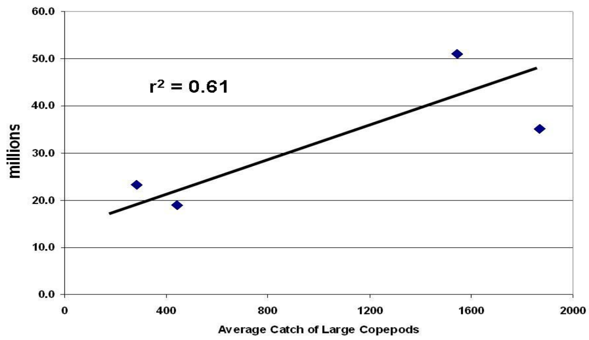

Fig. 2. Comparison of pink salmon harvest with average catch of large-bodied copepods during the nursery year.

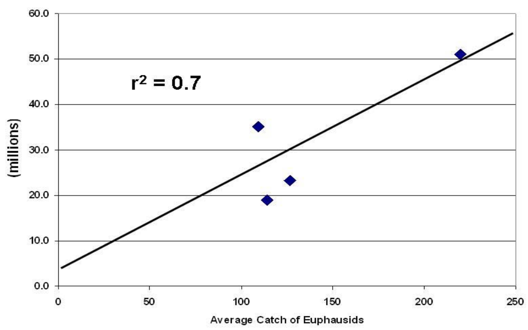

Fig. 3. Comparison of PWS pink salmon harvest with average catch of euphausids during the nursery year.

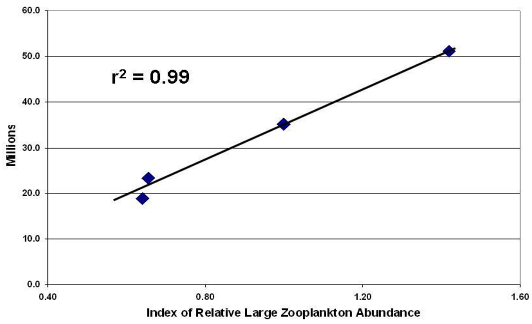

Fig. 4. Relationship between pink salmon harvest and net catches of large-bodied copepods and euphausids during nursery year (equal weighting; spring 2000 conditions equal 1.0).

returns because of data gaps. No vessel of sufficient size could be obtained for the third cruise of 2003, and 420 kHz system was inoperable for two other cruises. Both frequencies tracked the major difference between 2000 and 2001, but neither showed a large increase in backscatter that would account for the large pink salmon return following the 2002 nursery year.

IV. DISCUSSION

Most PWS pink salmon are of hatchery origin and thermally marked, so survival is measured. Hatchery releases are relative consistent from year to year, and wild stocks are a relatively minor component. Harvest has been shown to be a good index of total returns and overall survival [2] [7].

The correlation between large-bodied copepods and subsequent returns of pink salmon is not surprising based on previous research. However, there has been no previous indication that euphausids might be an important factor. The far lower abundance of euphausids compared to Neocalanus in the 50 m vertical tows may have contributed to underestimating the importance of this component. However, euphausids are vertical migrators, and are undoubtedly much more abundant than indicated in the net tows. Furthermore, it is well documented that euphausids are a favored prey of both walleye pollock and herring. If the dominant factor in pink salmon survival is prey sheltering, as previously suggested [7], then the contribution of euphausids to pink salmon survival is understandable.

The zooplankton net catches were originally intended to provide species composition in order to interpret the acoustic backscatter information [16]. They were not intended to be the primary measure of abundance because it was assumed the spatial variability would be too high. However, the trends in net catches among areas have been consistent, indicating reasonable precision. The acoustic data are more complex because of the variation in the zooplankton scatter among several major components. The large-bodied copepods have been sufficiently dominant in the scattering that this problem is relatively minor, and it can be accounted for through deconvolution [17]. However, the program as currently configured is not designed to adequately sample the larger euphausids. The acoustic effort is focused in the upper 50 m on the assumption that the large-bodied copepods are the primary object of interest. The 120 kHz frequency is capable of extending the measurement to the daytime depths of euphausids, but the 0.5 m ring net is not an effective sampler. A larger and more expensive vessel would be required to handle a net that could effectively sample euphausids.

Such an expansion may be unwarranted. The strong correlation between euphausid abundance and pink salmon survival is driven by a single year, and there are alternative hypotheses. While the record harvest in 2003 is associated with unusually high euphausid abundance and cannot be explained by the average Neocalanus abundance, survival may be impacted by more complex spatial and temporal variation than reflected in the average net catches. There were substantial differences in the timing of the Neocalanus abundance between the 2000 and 2002 nursery years. Neocalanus abundance in 2000 was very high during the first cruise (May 1-3), but decreased substantially during the month (Fig. 5). In contrast, abundance in 2002 increased dramatically by the third cruise. These complexities may be important, and can only be resolved through a longer time series. The relative importance of large-bodied copepods and euphausids should be further elucidated by the returns in 2005, since large copepod abundance in 2004 was relatively high, but euphausid abundance was low.

V. CONCLUSIONS

The important role of Neocalanus in PWS pink salmon survival appears to be verified by the zooplankton monitoring that has been conducted during spring since 2000. However, euphausids may play a similarly important role, or the role of Neocalanus may be more complex than seen in simple averages. Resolution of this uncertainty should be obtainable through continuation of the time series.

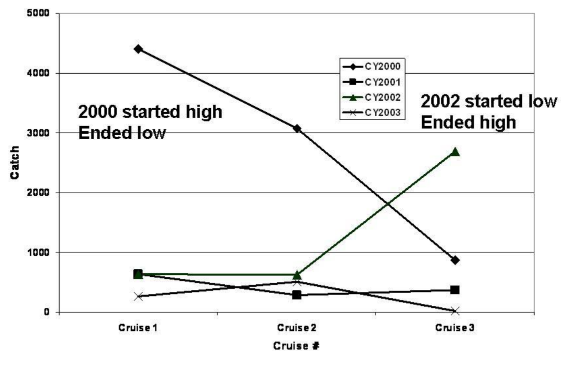

Fig. 5. Variation in timing of large copepod abundance, 2000 to 2003.

The net tows appear to provide a good measure of large-copepod abundance. However, patchiness has been relatively minor. While the acoustic data are more complex, the acoustics does provide far more spatial information on the zooplankton characteristics that could prove to be very important.

The monitoring effort was designed to provide a low-cost, sustainable program. So far the results can explain most of the variability seen in the pink salmon returns. However, longer-term observations will be required to see if the effort has useable forecasting capability and to resolve questions surrounding the relative importance of euphausids versus temporal variation in Neocalanus abundance. The result may require alterations to the program whose costs would have to be carefully weighed against potential gains in forecasting accuracy.

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