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Pacific Herring Biomass in the Knowles Head and Green Island Areas of Prince William Sound, Alaska, in the Fall of 1994

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Abstract

An acoustic-net sampling survey was conducted in the central-eastern (Orca Inlet, Port Gravina, Knowles-Red Head) and the south-western (Montague Strait) areas of Prince William Sound Pacific between October 27 and November 7, 1994 to estimate of the biomass of the Pacific herring. Two commercial purse seiners equipped with search-light sonars were used to reconnaisance these areas to locate herring concentrations. Once a herring concentration was located, they were mapped by running a zig-zag transect cource over the concentration and recording location with GPS. Where the herring concentration was stationary, a series of parallel acoustic transects were conducted using a dual beam scientific sonar to estimate fish density. Commercial purse seines (herring type) were used to collect species and size composition of the fish targets. The total herring biomass observed on this survey was 12,555+/-2,300 tonnes, 3,586+/-654 tonnes (29%) in the central-eastern areas and 8,969+/-1,646 tonnes (71%) in the south-western areas.

Introduction

Acoustic techniques are widely-used throughout the world to assess abundance of pelagic fish stocks, including herring (Maclennan and Simmonds 1992; Thorne 1983a,b). Acoustic echointegration and dual beam processing of target strength are based on sonar theory (Urick 1967; Ehrenberg and Lytle 1972). Basically, scientific echosounders are used to measure the amount of energy reflected from fish concentrations, which can be converted to fish density with information on the energy reflected from a single fish (its target strength) and knowledge of the sample volume (transducer directivity). Net sampling is routinely conducted to subsample the acoustic targets to collect biological information (species, size, etc.) on the ensonified fish (Thomas 1992).

Historically, information on the abundance of Pacific herring, *Clupea pallisi*, in Prince William Sound (the Sound) consists of commercial catch records, aerial estimates of the length of milt patches along beaches and herring spawn deposition surveys (Donaldson et al. 1993; Funk 1994). Single beam acoustic surveys without net sampling support had been used for estimating the biomass in the Sound in the fall from 1980 to 1985 (Merritt et al. 1993). Between 1988-92, the Alaska Department of Fish and Game used spawn deposition surveys in the spring to estimate the biomass of adult herring. A record run of adult herring (134,000 tonnes) was forecast to return in 1993 from the 1992 spawn deposition survey. In 1993, a spawn deposition survey was not conducted.

The spring 1993 aerial survey of the length of milt patches along the beaches suggested that the returning biomass was far less than expected. This in-season assessment was used to limit the commercial harvest to about 1,000 tonnes, substantially lower than in 1992 (about 20,000 tonnes). In addition, the herring spawning stock was found to be infected with a potentially lethal virus, viral hemorrhagic septicemia,VHS (Meyers et al. 1994). A fall hydroacoustic survey conducted in the Sound found about 19,000 tonnes, primarily in the Green Island trench area of Montague Straits (DeCino et al. 1994). The low biomass of herring and the presence of disease raised serious concerns about continued mortality and the long-term viability of the stock. The1994 commercial herring fisheries in the Sound were closed after in-season assessments in the spring of 1994 verified a low spawning biomass. The spring 1994 spawn deposition survey forecasted 27,000 tonnes to return in the spring of 1995.

Harvest management requires 20,000 tonnes of spawning biomass to have a commercial fishery. Given the uncertainty of past spawn deposition forecasts, an acoustic-purse seine survey on fall 1994 overwintering adults was scheduled to provide harvest management information.

Materials and Methods

Study Site

Prince William Sound is a complex fjord/estuary (Schmidt 1977) located at the northern margin of the Gulf of Alaska (Figure 1). The Sound covers an area of about 8800 km with approximately 3200 km of shoreline (Grant and Higgins 1910).

Acoustic survey

The acoustic survey was conducted between 27 October and 6 November 1994 using two commercial purse seiners, the *FV Lady Luck* and *FV Kyle David*. Both of the seiners used commercial search light sonars to locate school concentrations in suspected areas, were equipped with dual beam scientific echo sounders to map and estimate the size and density of schools, and were outfitted with commercial purse seines to sample fish concentrations. One vessel concentrated in the nearshore areas and used a 200 kHz, dual beam echosounder, while the other operated in offshore areas and used 120 kHz, dual beam echosounder. Transducers were mounted on towfins in a down-looking configuration, and towed at about 6 knots at a depths of 1.5-3 m . The purse seine used in the offshore areas was 414 m long and 55 m deep with a mesh size of 3.18 cm stretched, and the nearshore purse seine was 120 m long and 20 m deep.

Survey Design - The acoustic survey was a multistage sampling design (Cochran 1967). The first stage used historical commercial fishing and areas, local fishers knowledge of herring location and behavior, to reduce the search area for herring concentrations in the Sound. The areas to be searched intensively were Orca Inlet and Montague Strait (Figure 1). We assume that the adult herring stock overwinters in the Sound and that the stock has completed this migration by the middle of October (DeCino et al. 1994). In 1993, an interval of small tidal exchange was selected to minimize the probability of inclement conditions. This was not possible in 1994, and the results were confounded by more tidally influenced fish movement.

The second stage of the survey design was to search and locate herring school groups within the eastern and western Sound survey areas. Historical information and fishers knowledge played another role in this stage by identifying specific isobaths wintin which herring schools are found. Hence, herring schools were located by cruising within specific depth contours using commercial search light sonar and down-looking echosounders. The search-light sonar and down-looking sonar were used by the fishermen to assess if there were commercial quantities of herring present.

The third stage of the survey was to map and measure the density of herring schools found in the search areas (Northern Hawkins Is., St. Mathews Bay, Knowles-Red Head, Danger Island, Needles, west of Green Island, east of Green Island, Applegate Rocks, Rocky Bay, Zaikof Bay areas). Mapping was conducted by transecting over the schools and recording GPS information. The density was measured along these transects using a dual beam echosounder. The transects

Interactive Plotting, DLS & ELB, PWSSC 1995

Figure 1. Prince William Sound 1994 herring survey sites.

were run in a zigzag fashion over the school(s), turning when schools were no longer visible on the echosounder (Figure 2). In some cases, the tidal currents and fish were moving such that the school was displaced from its original position so it was necessary to move the location for repeating the measurements.

The fourth and fifth stages of the sampling were to purse seine the acoustically surveyed schools and to subsample the catch for biological information. First, the species composition of the net catch was used to partition the assessment. Second, the length and weight of the fish were used for target strength analysis.

Acoustic Parameters - Target strength information for herring was derived from average length to target strength (in decibels) per kg fish after Thorne (1983b). Thorne's empirical relationship assumes the following logistical equation:

$$\gamma = \frac{\bar{\sigma}}{\bar{W}} = a\bar{l}^{-b} \qquad (1)$$

where σ is the mean acoustic backscattering coefficient, W is the mean weight (in kg), l is the mean length (in cm), and a and b are constants. A value for the constant a was obtained from physical data at the site (temperature and salinity) and the literature (speed of sound). A value for the constant b was obtained from a review by Thorne (1983b) using a linear regression of $\log_{10} l$ versus 10 log (σ/w), where 10 log (σ/w) is referred to as "target strength per kg." The average herring length and weight data were compiled from samples obtained by the Alaska Department of Fish and Game from the net catches and were compared to values obtained in 1993 (De Cino et al. 1993). These measured data were applied to Thorne's (1983b) empirical relationship to obtain the ratio $\gamma = \sigma/w$ and the mean backscatter coefficient (σ).

As a cross check, we generated *in situ* measurements of target strength from a subset of dual beam acoustic data. We compared our *in situ* mean backscatter coefficient with Thorne's (1983b) empirical formula. Parameters of the acoustic equipment used during the fall herring surveys are presented in Table 1.

Biomass estimation - Herring biomass was calculated for each fish concentration found during the large scale survey. The calculation of biomass per unit volume was made using echointegration by single cells *jk* along transects:

$$\beta_{jk} = \rho_{jk} \cdot \bar{w}_{jk} = \frac{C(ei)_{jk} \cdot P_{jk}}{\frac{\bar{\sigma}_{jk}}{\bar{w}_{jk}}} \qquad (2)$$

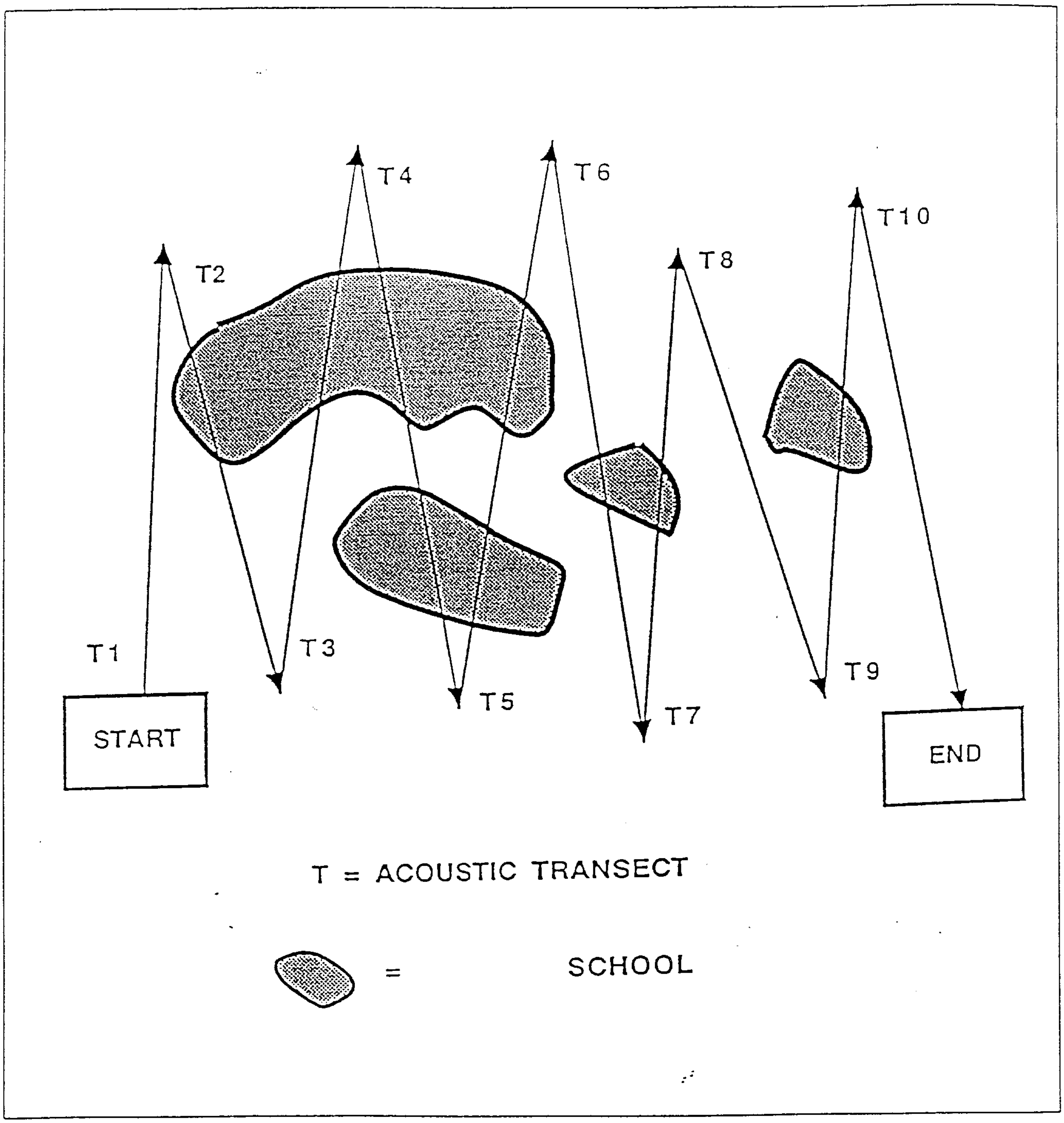

Figure 2. Hypothetical, zig-zag, acoustic transect design used to map herring schools and estimate biomass.

Table 1. Parameters of the acoustic equipment used during the fall 1994 herring survey in Prince William Sound.

SYSTEM	FREQUENCY	SOURCE LEVEL	SYSTEM GAIN	TRANSDUCER DIRECTIVITY	PULSE DURATION
BioS. 101	120 kHz	-225.075 dB	-165.264 dB	.0010718	0.4 ms
BioS. 102	200 kHz	-221.655 dB	-155.756 dB	.0006515	0.4 ms

where β_{jk} is the biomass in weight per unit volume (cubic meters), ρ_{jk} is the number of scatterers per unit volume (unknown at high densities), w_{jk} is mean weight of the scatterers (also unknown), or for practical purposes by C, the acoustic constant (calibration settings ie., gain etc.), ei_{jk} is the mean of the voltage squared from echo integration (in lieu of numbers), P_{jk} is percentage of cell *jk* within the water column (where bottoms or shorelines are encountered) , and σ_{jk} is mean backscattering voltage for the specific targets within cell *jk* per mean weight (dB per kg).

The biomass for a region of surface area (A in square meters) is determined by using a set of line transects across the region of known fish concentration, along which a total of nrs point estimates of biomass per unit area is obtained. Specifically,

$$B=\frac{\sum_{j=1}^{nrs}\sum_{k=1}^{nst}\beta_{jk}}{nrs}\cdot A \qquad (3)$$

where nrs is number of reports (along the line transects), nst is number of one meter depth strata, and A is survey area. Where nst were not one meter bins the appropriate weighting was used to compute means and variances (Seber 1973).

For the herring biomass estimate, we followed Thorne (1983a). Specifically, we assume that σ_{jk}/w_{jk} is independent of cell *jk*, hence, for all *jk* σ_{jk}/w_{jk} is a constant γ, and γ is given by equation 1. With this assumption, equation 2 simplifies to:

$$\beta_{jk}=\frac{C}{\gamma}\cdot(ei)_{jk}P_{jk} \qquad (4)$$

and the herring biomass B in an area is given as

$$B=\frac{C}{\gamma}\frac{\sum_{j}\sum_{k}\cdot(ei)_{jk}P_{jk}}{nrs}\cdot A \qquad (5)$$

As in 1993, when a fish concentration was located, mapped, and surveyed for density, the survey for density was repeated to estimate error. In 1993, this effort was aided by small tidal fluctuation and school movement. In 1994, large tidal currents and coincidental fish school movement did not allow repeated surveys in the area of highest herring densities.

Results and Discussion

Eastern Sound

The *FV Lady Luck* and *FV Kyle David* spent three days searching for herring schools on the east side of the Sound which included one day in Orca Inlet from Windy Bay to the Middle Ground Shoal area on the north side of Hawkins Island and two days in the Knowles-Red Head regions of Port Gravina (Figure 1). A light layer of acoustic targets was observed near the surface along north Hawkins Island. A purse seine catch identified this concentration to be about 60% juvenile herring (96 mm) and 40% juvenile pollock (113 mm).

In the Port Gravina area, two schools were located, mapped, measured and seined. A dense school that was found in St. Mathews Bay contained 766+/-287 tonnes of herring (Table 2). The largest concentration of fish in the central-eastern Sound was found off the Knowles-Red Head area (Figure 3). This school was estimated to contain 2,819+/-367 tonnes of herring (Table 2).

Western Sound

Six days of searching was conducted on the west side of the Sound since this area was known for the highest concentrations of herring in past years (Figure 1). Six aggregations of herring were found, mapped, measured for density and four purse seine sets were made: Montague shoreline east of Needles (6,526+/-1,278 tonnes, Figure 4), East Green Island pass (1,389+/-194 tonnes, Figure 4), Zaikof Bay (454+/-126 tonnes), Danger Island (260+/-29 tonnes), Applegate Rocks (198 tonnes) and West Green Island (142+/-18 tonnes). Table 2 provides biomass estimates with confidence limits for the six western Sound areas.

The mean or estimated lengths (Love 1977), mean weight, the mode of the *in-situ* target strength (dB) and the conversion factor used to transform integrated acoustic backscatter to biomass (dB/kg) of eight survey areas are presented in Table 3. The *in-situ* target strength varied from -80 to -20 dB and displayed dominant modes between -43 and -34 dB (Figures 5 and 6). It was apparent that when dense schools of herring were measured the target strength analysis overestimated the average target strength considerably. It is well known that *in-situ* target strength analysis requires isolation of individual targets in the beam which is problematic with the tightly schooled herring.

There were also other species present in the water column which were more likely to be observed as individual targets, such as capalin, walleye pollock, salmon, sharks, humpback whales and arrowtooth flounder (observed incidentally in the purse seine catch). This was obvious in every survey area but was considered to be a problem for echointegration only in Green and Little Green Island areas where a second, deep mode was observed in the density by depth (Figure 7).

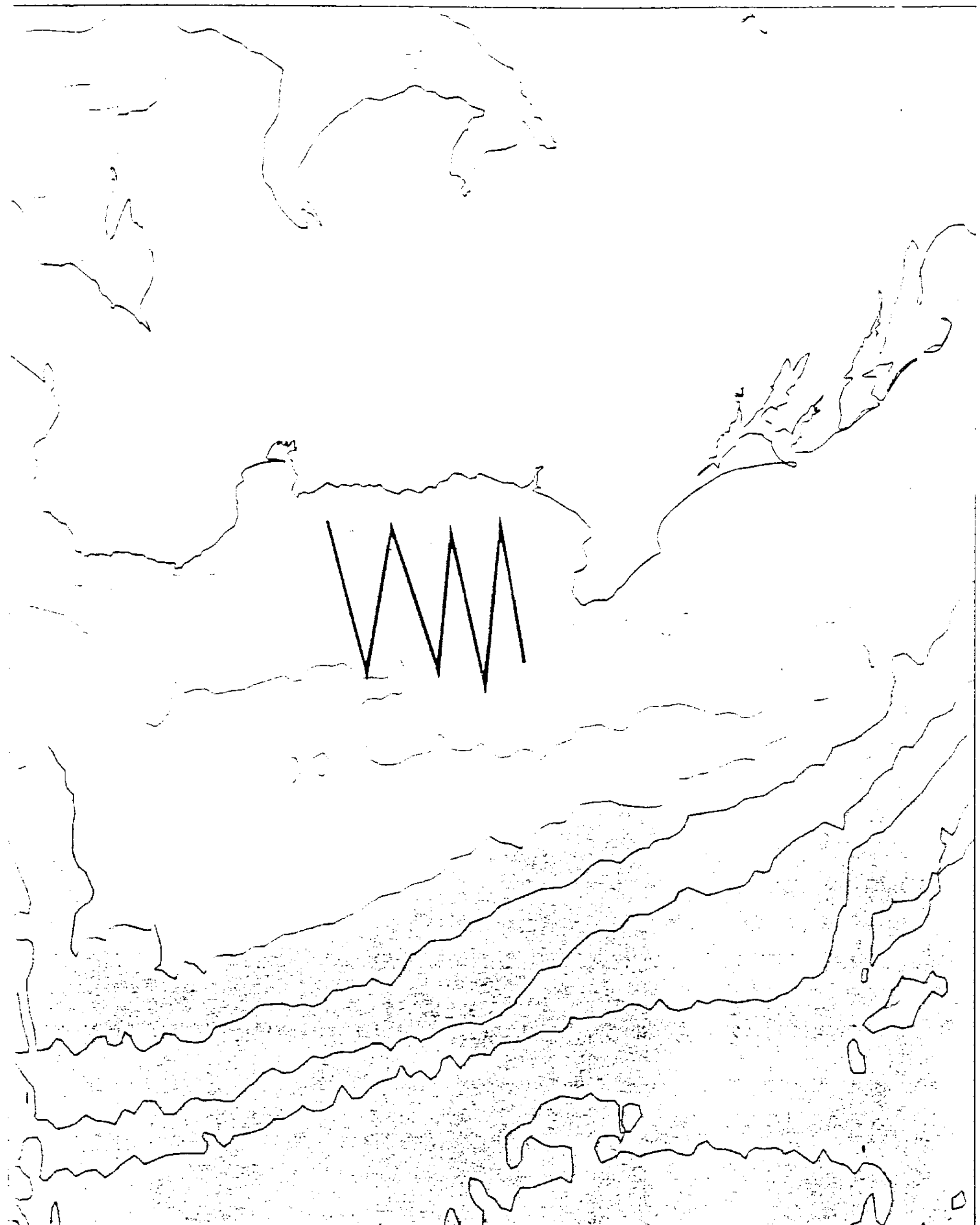

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Figure 3. Knowles-Red Head area 1994 survey site.

Table 2. Herring biomass estimates with 95% confidence limits by survey area in Prince William Sound, Fall 1994.

DATE	VESSEL	SURVEY AREA	TRANSECTS	BIOMASS	95% C.I.
10-28	Lady Luck	St. Matthews Bay	3	767	287
10-29	Lady Luck	Knowles Head	8	2,819	367
10-30	Lady Luck	Zaikof Bay	5	454	125
10-31	Lady Luck	Applegate Rocks	1	198	0
10-31	Kyle David	W. Green Island	18	142	18
11-04	Lady Luck	Needles	14	6,526	1,278
11-05	Kyle David	Danger Island	15	260	29
11-06	Lady Luck	East Green Island	18	1,389	194
Total				**12,555**	**1,299**

Figure 4. Green-Montague Island and Needles area 1994 survey sites.

Table 3. Measured or estimated lengths (Love transformation of in-situ target strengths), measured weights, in-situ target strengths, and dB/kg conversion factor used to estimate biomass from integrated acoustic backscatter (from Thorne 1983b) for Prince William Sound survey areas in the fall of 1994.

DATE	SURVEY AREA	LENGTH (mm-FL)	WEIGHT (grams)	IN-SITU (T.S.)	dB/kg (T.S.)
10-28	Port Gravina	210	89	-	-31.7
10-28	Red Head	158*	-	-41.0	-31.2
10-30	Zaikof Bay	157*	-	-41.0	-31.2
10-31	West Green Island	218	102	-43.0	-31.8
10-31	Applegate Rocks	207	85	-40.0	-31.7
11-04	Needles/Montague	242	145	-38.0	-32.8
11-05	Danger Island	131*	-	-42.5	-31.0
11-06	East Green Island	245	140	-40.0	-32.9

* from Love conversion of in-situ target strength

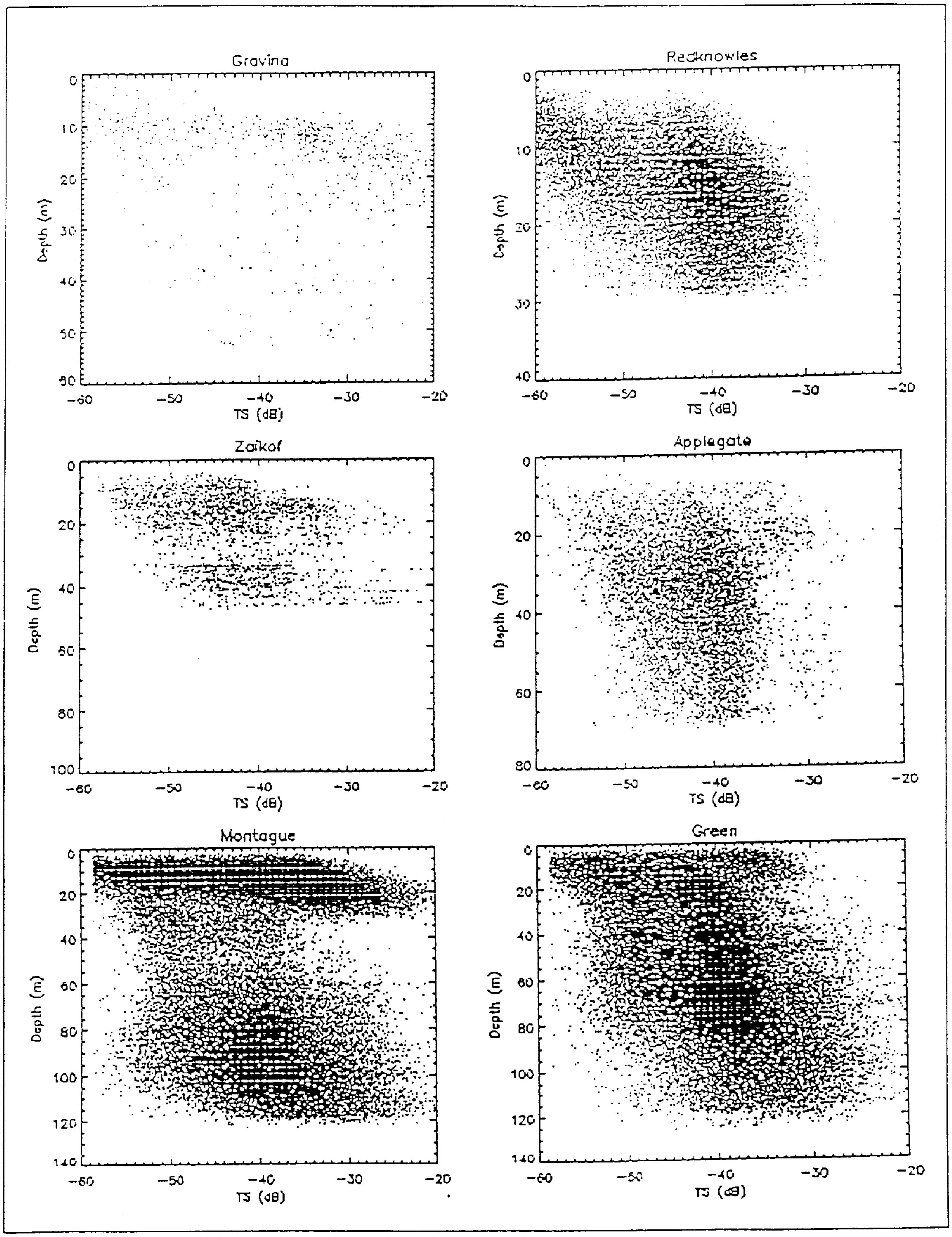

Figure 5. Target Strength (TS) by depth for six survey areas on fall 1994 herring survey.

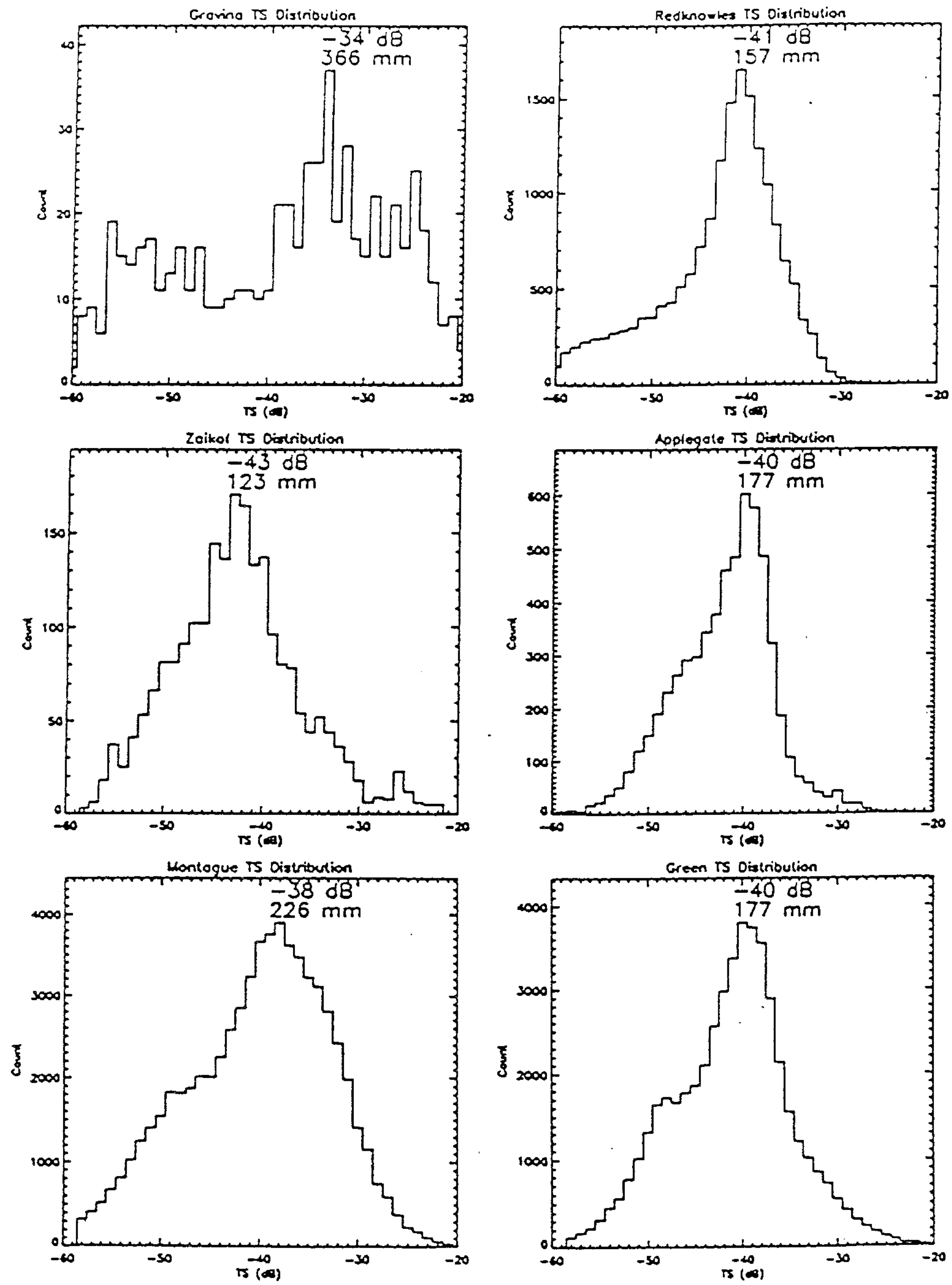

Figure 6. Target Strength (TS) histogram for six survey areas on fall 1994 herring survey.

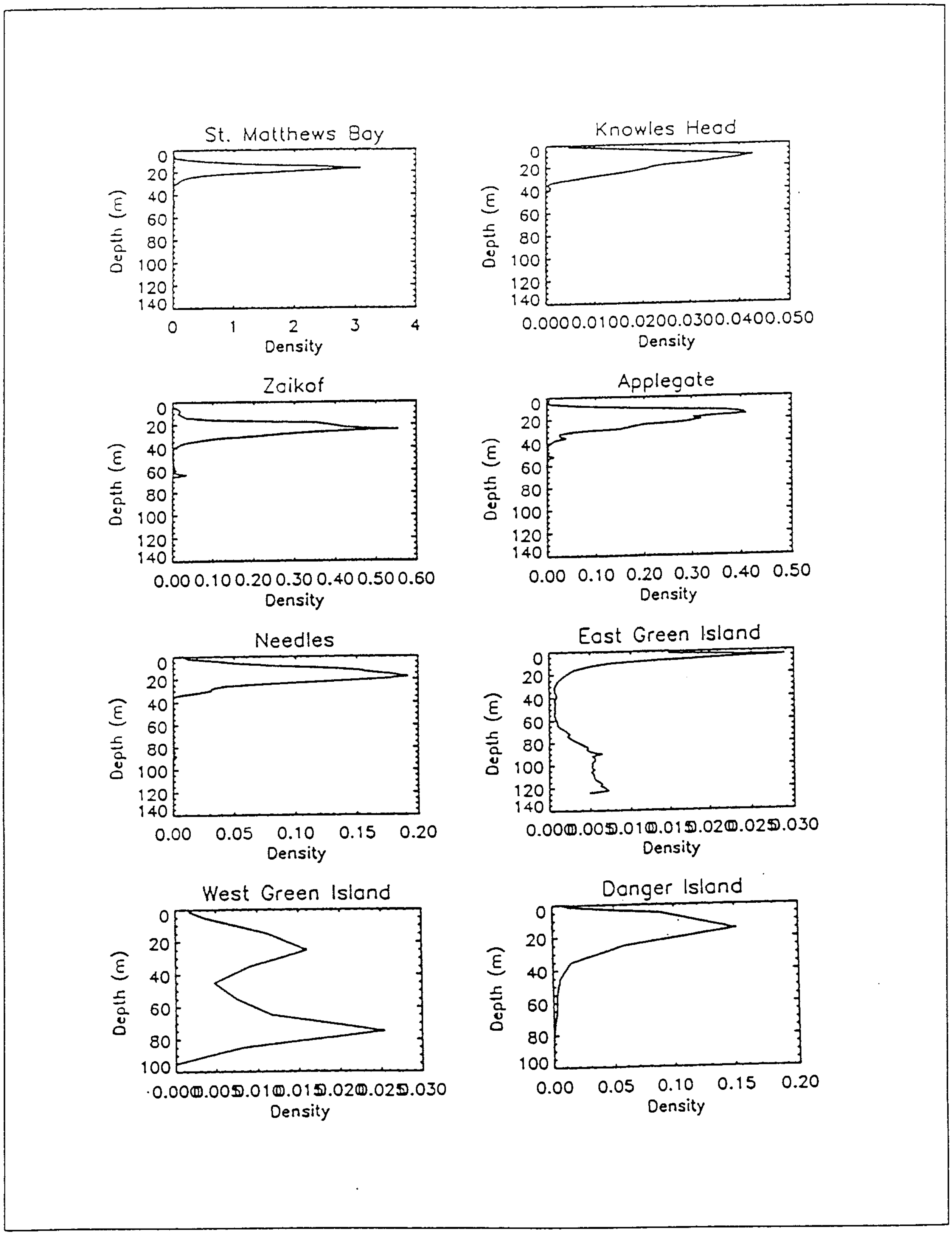

Figure 7. Vertical distribution of acoustic backscatter by depth for eight survey areas on fall 1994 herring cruise.

The deeper layer was dominated by large single targets (-34 dB) which is typical for walleye pollock. Since the expected nighttime distribution of herring, above 50 meters in the water column with peak densities between 20 and 40 meters (Thorne and Thomas 1990; DeCino et al. 1994), estimation of herring biomass was limited to measurements above 50 meters.

Because of the uncertainty over the representation and accuracy of the *in-situ* target strength measures, the mode of the *in-situ* measurements were only used where other information were unavailable for analyses, such as where net catch data were unavailable to determine the size fish in the survey area. This was limited to the Zaikof Bay, Red Head and Danger Island areas (Table 3). As in 1993, the target strength information for herring was derived from average length to target strength (in decibels) per kg fish after Thorne (1983b) to transform the echointegration backscatter to biomass.

Biomass Estimation - The biomass estimates by area with 95% confidence limits are given in Table 2. The total biomass measured in the eastern Sound was about 3,586+/-654 tonnes. The total biomass measured in the western Sound was tons 8,969+/-1,646 tonnes. The total biomass of herring observed on this fall survey was 12,555+/-2,300 tonnes.

As in 1993, we attempted to repeat the transect survey over a school when possible. Although we never found as large a concentration as the 1993 Applegate school, we did repeat surveys over the Green Island and Danger Island groups to assess repeatability of the estimate. In both cases the individual estimates of biomass were outside the 95% confidence limits of the pooled transects: 112 and 165 tonnes for limits of 124 to 160 tonnes for West Green Island (9 transects each) and 188 and 342 tonnes for limits of 231 to 289 tonnes (7-8 transects). Increasing the number of zig zag transects from 8-9 could improve precision of this technique, but conducting the survey during periods of lower tidally influenced movement and on larger schools will probably result in the greatest improvements to precision.

Population Trends

Large aggregations of herring have consistently been observed during late fall and early winter in the northern Montague Strait area in recent years (Donaldson et al. 1993). In the past, it has been assumed that these herring represent between 50 and 75% of the herring biomass in the Sound (Gaudett 1984; Funk 1994; Jim Kallander, Herb Jensen, and Robert Honkola, Cordova District Fisherman United, personal communications). The 1993 survey estimated the herring biomass in this area to be about 18,000tonnes.

In 1993, the commercial fishery located the largest concentration of herring in the Green Island Since there was no commercial fishery in 1994, the survey effort was doubled and extended to search the east side of the Sound. In comparison, no large concentration was found on the west side and the east side contributed about 29% to the biomass estimate. Thus, if you were to compare years you would match the west side measurement in 1994 to the total estimate in 1993. This would suggest a decline in biomass from about 19,000 to 9,000 thousand tonnes, or a 50% reduction in the population holding in the Montague Strait area between years.

Minimum biomass survey design

The multistage sampling design used for estimating fall herring biomass may provide a practical approach for stock assessment. The precision is high with 95% confidence limits varying 18% from the estimate, and repeatability is within the confidence limits under good conditions (low tidal flux and large schools). A bonus is the relatively low cost and robustness of the survey design (less than $50,000) compared to egg deposition surveys (greater than $100,000). Egg deposition surveys use aerial milt survey information to assume that they survey the entire population. As a better quantitative understanding of fall herring distribution is developed via repeated acoustic surveys, acoustic estimates of herring could replace spawning deposition surveys as a less expensive more accurate method.

Although the acoustic survey does not measure the total population size (presumptuous for any assessment technique), the approach is robust since it uses historical and recent fisheries information and experienced fishers to search for and locate fish concentrations. The use of commercial fishers is advantageous since it is in their best interests not to miss fish concentrations that contribute to the population estimate that determines the harvest level. Thus, using fishers to determine the search procedures on a survey is probably the most rapid process to adapt stock assessment to the natural changes in distribution that most populations undergo. Industry participation and the assumption of greater responsibility by the commercial fishers in the assessment process is a theme long overdue in fisheries science.

Acoustic surveys to assess total population size would require systematic measurements over the entire Sound and adjacent Gulf of Alaska, as well as complementary genetic assessment to establish the presence of different stocks. The present survey design estimates the bulk of the population available to the fishery, or in a sense the **minimum biomass estimate** of the population. Future improvements to the survey design may be warranted to improve the exploitation efficiency of the stock on a sustainable basis.

The nesting of quantitative acoustic procedures within semi-quantitative reconnaissance surveys is practical. Albeit commercial fishing sonars and echosounders are not calibrated measurement tools, when coupled with experienced fishers' knowledge, they provide a meaningful judgment on the relative distribution of the fish population. The fact that fishers make a living from these real-time estimates of fish density and distribution makes the reconnaissance step robust and believable. Furthermore, when this reconnaissance is coordinated with quantitative sonars to estimate fish density the design approaches proportional allocation of sampling, which is more efficient (Cochran 1967). Advantages of the multistage, minimum biomass sampling design are that expenses are low, precision is high and the design adapts to changes in the fish distribution.

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