Survey Assessment of Semi–pelagic Gadoids: The Example of Walleye Pollock, *Theragra chalcogramma*, in the Eastern Bering Sea

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ABSTRACT—Assessment of walleye pollock, Theragra chalcogramma, *in the eastern Bering Sea is complicated because the species is semi–pelagic in habit. Annual bottom trawl surveys provide estimates of demersal abundance on the eastern Bering Sea shelf. Every third year (starting in 1979), an extended area of the shelf and slope is surveyed and an echo integration–midwater trawl survey provides estimates of pollock abundance in midwater. Overall age–specific population and biomass estimates are obtained by summing the demersal and midwater results, assuming that the bottom trawl samples only pollock inhabiting the lower 3 m of the water column. Total population estimates have ranged from 134×10^9 fish in 1979 to 27×10^9 fish in 1988. The very high abundance observed in 1979 reflects the appearance of the unusually large 1978 year class. Changes in age–specific abundance estimates have documented the passage of strong (1978, 1982, and 1984) and weak year classes through the fishery. In general, older fish are more demersally oriented and younger fish are more abundant in midwater, but this trend was not always evident in the patterns of abundance of 1– and 2–year–old fish. As the average age of the population has increased, so has the relative proportion of pollock estimated by the demersal surveys. Consequently, it is unlikely that either technique can be used independently to monitor changes in abundance and age composition. Midwater assessment depends on pelagic trawl samples for size and age composition estimates, so both surveys are subject to biases resulting from gear performance and interactions between fish and gear. In this review, we discuss survey methodology and evaluate assumptions regarding catchability and availability as they relate to demersal, midwater, and overall assessment.*

Introduction

Direct assessment provides essential information for the management of many marine fish stocks. Frequently, demersal stocks are assessed by means of bottom trawl surveys, and pelagic stocks are assessed using acoustic techniques together with some form of direct sampling such as midwater trawling. Each approach has its own strengths and limitations but these types of routine surveys provide critical information for many stocks.

When a stock is semi-pelagic (or semi-demersal) in habit, however, it is difficult to accomplish overall assessment with a single technique, and it may be necessary to assess the pelagic and demersal components independently. Because the biases associated with each technique differ, difficulties may be encountered when attempting to combine the data to produce a comprehensive estimate.

To address this problem, survey objectives should be evaluated. If the assessment process requires a survey-based estimate of overall abundance, problems associated with combining the two sets of data require careful consideration. But if it is satisfactory to provide indices of the abundance of certain portions of the stock, such as specific age groups, it may be possible to consider the pelagic and demersal assessments as independent sources of information, and problems associated with combining data sets would then be of less concern.

The walleye pollock, *Theragra chalcogramma*, resource of the continental shelf and slope of the Eastern Bering Sea (EBS) supports major fisheries activities. The species is semipelagic and is generally found in pelagic and demersal regions over bottom depths of 25–400 m, although it does occur in the pelagic zones of deeper waters (Sample and Bakkala, 1989). Greatest abundances are found along the outer continental shelf over water depths of 100–300 m (Wespestad and Megrey, 1990). Scientists from the NMFS Alaska Fisheries Science Center (AFSC) conduct the assessment of this stock. The demersal component of the stock is assessed annually during a multi-species bottom trawl survey of the EBS shelf. Small-scale surveys began in the early 1970's, and the present survey coverage was first established in 1975 and has been done annually since 1979. Also beginning in 1979, an expanded triennial bottom trawl survey has been conducted; this has covered a greater area of the shelf and the waters of the upper continental slope. During the triennial surveys, the pelagic component of the pol-

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lock stock has also been assessed by means of an echo integration—midwater trawl (EIMWT) survey.

In this paper we evaluate the methodology and results of the pollock assessments conducted during the triennial surveys as an example of semi-pelagic gadoid assessment. In considering the sources of bias, we offer suggestions for research and changes in methodology which may lead to improvements.

Methods

Detailed information on survey methodology was presented by Bakkala and Wakabayashi (1985), Bakkala et al. (1985), Walters et al. (1988), and Bakkala et al. (1992). Here we provide an overview of bottom trawl and EIMWT techniques.

Bottom Trawling

Assessment of demersal pollock on the EBS shelf and slope is conducted within the broader objectives of a multispecies bottom trawl survey designed to assess the condition of stocks of several species. Surveys are performed annually during the months of June, July, and August when migratory activities are believed to be minimal. Every third year a more comprehensive survey, covering a larger area of the shelf and slope, is carried out. Details of the triennial survey design are presented by Bakkala (1988) and an illustration of the area sampled is presented in Figure 1.

An Eastern otter trawl (type 83–112) with 900 kg steel V-doors has been used for sampling since 1982 (Table 1). Previously, a similar but smaller net, the 400 mesh Eastern trawl with 570 kg doors, was used. Both trawls were constructed of the same mesh sizes (Table 1), however, the 83–112 was rigged with 30 cm chain extensions on the footrope ends to improve bottom tending characteristics.

Prior to 1988, trawl width (wingspread) measurements were made on only a few tows made by any vessel with a given trawl. The averages of the measured widths were then used for all tows within an annual survey by that vessel and trawl. Beginning in 1988, the acquisition of sufficient mensuration equipment allowed measurements for almost every tow. Examination of these data revealed that trawl operating width is primarily a function of the amount of trawl warp extended (Rose and Walters, 1990). This analysis indicated mean widths-per-tow of 12–20 m over bottom depths of 20–200 m. Warp extended over these depths ranged from 90 to 550 m.

Time on the bottom and the distance fished for each haul were determined from the time and location where the winch brakes were set to the time and location of the beginning of haul back. Based on depth readings from the trawl mensuration equipment, trawl settling time was considered insignificant at depths encountered on the EBS shelf. The locations of the vessel at the start and end of each haul were obtained from LORAN C instruments. Biological information was obtained from the catches so that biomass and population abundance could be estimated by species, size, and age; catches greater than 1 metric ton (t) were subsampled using procedures designed to ensure randomness (Hughes, 1976; Bakkala et al., 1985).

Analytical procedures were described by Wakabayashi et al. (1985). An area swept technique which incorporates the wingspread and distance fished measurements described above, was used to develop biomass, population, and size composition estimates (Alverson and Pereyra, 1969; Doubleday and Rivard, 1981). Each catch was standardized into catch per unit of area. The standardized catches within a stratum were then used to estimate stratum biomass, and the stratum estimates were summed over the entire area. Length-frequency data and age-length keys, developed from fish sampled during the survey and aged from otoliths, were applied to the data to provide stratum and overall survey estimates of size composition and age composition.

Until 1990, the standardized catches of each species by each vessel were compared using a Bayesian approach (Geisser and Eddy, 1979). If significant differences between vessels were found for a particular species, the catches of the least efficient vessel were adjusted to be equivalent to catches from the most efficient vessel for that species by the ratio of the mean catches per unit effort (CPUE). Because this method was based on the estimation of a ratio, it was sensitive to occasional large CPUE values. Beginning in 1990, a new method developed by Kappenman[1] was used to compare the distribution of CPUE values based on a power transformation and develop a scaling factor for adjustment. This method has been applied to the time series of data back through 1982.

Table 1. — Trawls used during the triennial eastern Bering Sea groundfish surveys.

	Bottom trawls		Midwater trawls			
Characteristics	400-mesh Eastern trawl	83–112 trawl	Norsenet trawl	Northern Gold 1200 trawl	Diamond 1000 trawl	Gourock rope wing trawl
Years trawl used	1979	1982–91	1979	1988–91	1982–85	1982
Horizontal opening while fishing (m)	12.2	12–20	35	40–50/Unk.[1]	16.5–18.3	27.4–32.9
Vertical opening while fishing (m)	1.7	2–2.3	27–30	30–40/18–25[1]	16–19	27–33
Headrope Length (m)	21.6	25.3	Unknown	90.8/94.5[1]	54.0	102.1
Footrope Length (m)	28.7	34.1	Unknown	84.9/50[1]	54.0	102.1
Mesh sizes (mm)						
Wing	102	102	1000	Rope	406	Rope
Body	102	102	1000	1630–76	813–89	1626–813
Intermediate	89	89	800–80	96–89	89	406–121
Codend	89	89	46	89	89	89
Codend liner	32	32	38	32	38	32
Door (m)						
Length	2.1	2.7	3.0	2.7	2.1–2.7	6.0
Height	1.5	1.8	2.0	1.8	1.5–1.8	6.0
Dandyline						
Length (m)	45.5	54.9	165	82.3	54.9	91.4

[1] 1988 configuration/1991 configuration.

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[1] Kappenman, R. F. 1992. Estimation of the fishing power correction factor. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Alaska Fish. Sci. Cent. Proc. Rep. 92–01, 10 p.

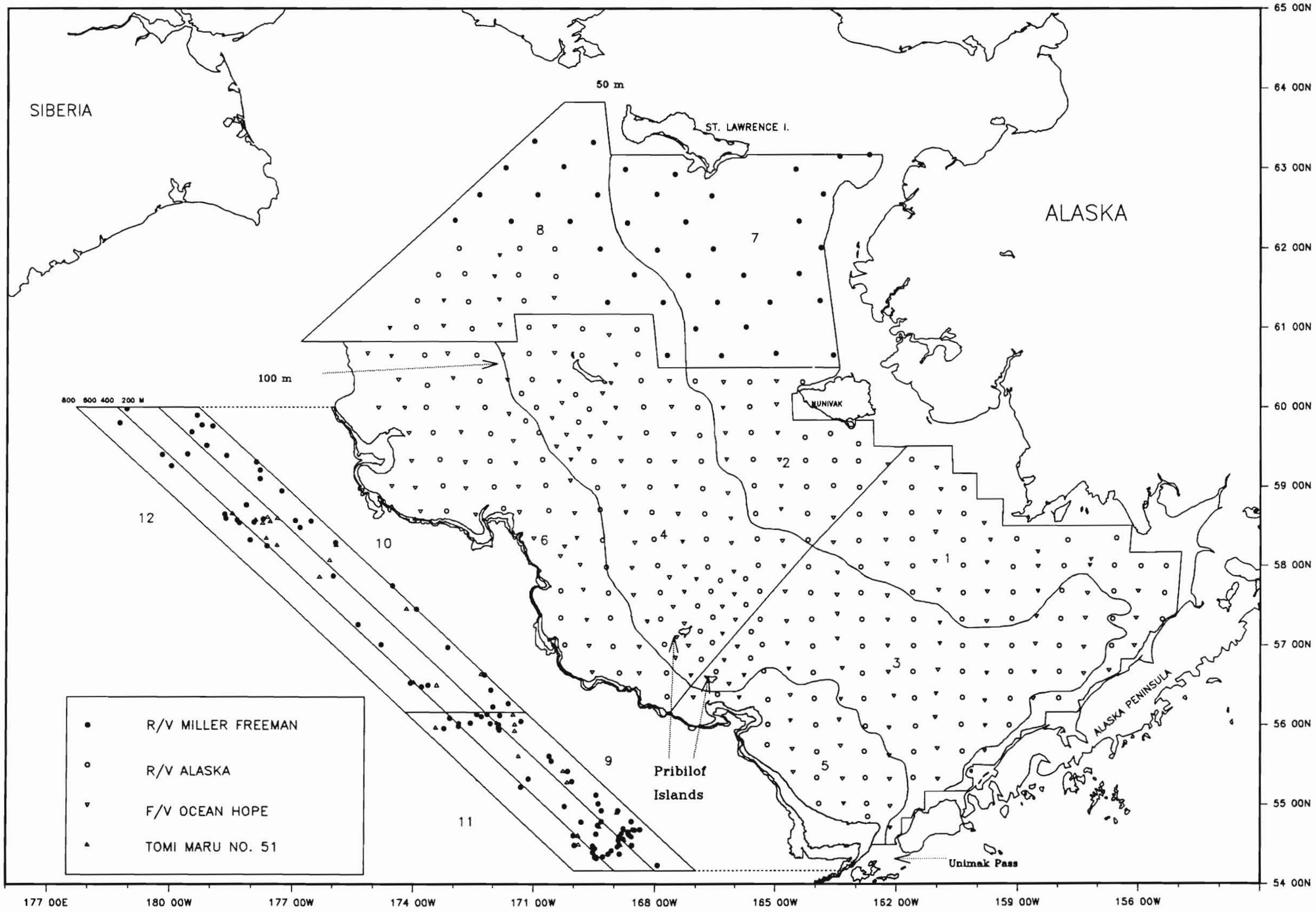

Figure 1. — Trawl stratification and survey design used in 1988 over the eastern Bering Sea shelf and slope.

Acoustic and Midwater Trawl Assessment

The acoustic method for pelagic stock assessment is based on the principle of echo integration. An echo sounding system transmits discrete pulses of sound into the water and waits for a period of time to receive echoes from targets in the insonified volume of water. The received echoes, in the form of voltages, are then fed into an echo integrator which squares and sums the voltage samples. The output of the echo integrator is proportional to the density of the fish insonified (Dragesund and Olsen, 1965; Forbes and Nakken, 1972; Burczynski, 1982).

Conversion of relative to absolute biomass estimates is dependent upon consistent system performance as monitored by calibration procedures and information regarding the acoustic properties of the fish in the form of mean acoustic target strength (TS). TS is dependent on species, size, behavior, and, in some cases, depth. Since small changes in mean TS can give rise to large errors in biomass estimation, direct in situ measurement of TS is generally recommended (Ehrenberg, 1983; Foote, 1991).

Techniques for the U.S. EIMWT surveys were described by Karp and Traynor (1989) and Traynor and Nelson (1985). Additional details were reported by Bakkala et al. (1985) and Walters et al. (1988). Transect lines were surveyed by means of a scientific quality 38 Khz acoustic system consisting of a transmitter, a towed transducer, a receiver, and a computer based digital echo integrator. The acoustic system was installed in a portable van that could be located on the deck of the survey vessel. When conditions were suitable, in situ target strength studies were conducted in order to collect target strength distribution information for a range of fish sizes and behavioral patterns. Dual-beam and split-beam techniques (Traynor and Ehrenberg, 1979) have been employed for this purpose, although most data has been collected with a split-beam system in recent years.

Since we do not yet have sufficient information to enable us to apply field measurements of TS during analysis of survey data, alternative approaches have been used as an interim measure. Before 1988, a TS value of –30 dB/kg was applied in the conversion of integrator values to estimates of biomass; starting in 1988, however, the empirical target strength/length relationship developed by Foote and Traynor (1988) (TS = 20 log (Fork Length (cm)) – 66.0) has been employed and has provided results which are generally consistent with in situ measurements.

The acoustic system was calibrated before and after each survey. The underwater acoustic calibration system available at the University of Washington's Applied Physics Laboratory was employed to conduct standard transmit and receive response and equivalent beam angle measurements. Also, beginning in 1988, the standard target technique, as described by Foote et al. (1987) was adopted and is now carried out in situ to monitor system performance at intervals during each survey.

Midwater trawling was an integral part of each survey. A large midwater trawl was used to collect biological samples when significant echo sign was encountered during the acoustic transects. Midwater trawl types and specifications have changed several times during the period that these surveys have been conducted (Table 1). As indicated in the table, different trawls were used for sampling juvenile and adult pollock sign. The vertical opening of each net was monitored with a netsonde. Towing speed in all surveys was approximately 1.5 m/sec.

Fishing was carried out on an opportunistic basis in order to collect adequate samples from the different types of echo sign encountered throughout the survey area. Since contamination with other species occurred infrequently, the primary objective of this sampling was to provide sufficient data for partitioning the acoustic estimates of biomass by size and age, and developing size and age specific population estimates. The information collected from these trawls was not used to provide quantitative information on abundance. Catches were processed in a manner similar to that described for the demersal trawl surveys. Age composition was determined by means of age-length keys obtained by analyzing otoliths taken from fish sampled randomly from most catches.

All EIMWT triennial surveys have taken place in the summer, during the same general time period as the bottom trawl surveys. In 1979 only the outer portion of the shelf and the upper slope were surveyed (Traynor and Nelson, 1985). In 1982 the entire shelf and upper slope over bottom depths from about 40 to 500 m was surveyed with a zigzag transect design (Bakkala et al., 1985). Subsequent surveys have covered most of the shelf waters deeper than 50 m and the slope. Starting in 1985, equidistantly-spaced parallel transect survey designs (e.g., Fig. 2) have been employed (Walters et al., 1988; Bakkala et al., 1992).

Results

Because the general objective of this contribution is to discuss the methodology for overall pollock assessment in the EBS, this section will concentrate on the types of information produced during the triennial surveys. Results of the 1979, 1982, 1985, and 1988 triennial shelf/slope surveys were reported by Bakkala and Wakabayashi (1985), Bakkala et al. (1985), Walters et al. (1988), and Bakkala et al. (1992), and the results of more detailed analysis of data from these surveys were presented by Karp and Traynor (1989), Sample and Bakkala (1989), and Traynor et al. (1990a). Results of the 1991 survey were not available when this report was prepared. Rather than present detailed figures of pollock distribution for each survey, the 1988 results are provided as an example (Fig. 3–5). Similar figures for the preceding triennial surveys were provided by Karp and Traynor (1989).

The 1988 survey results indicated patterns of distribution similar to those observed during previous triennial surveys. Taken independently, neither the bottom trawl nor the EIMWT survey results provide complete information on the horizontal distribution of pollock (Fig. 3, 4). Most demersal pollock occurred in waters deeper than 100 m, and

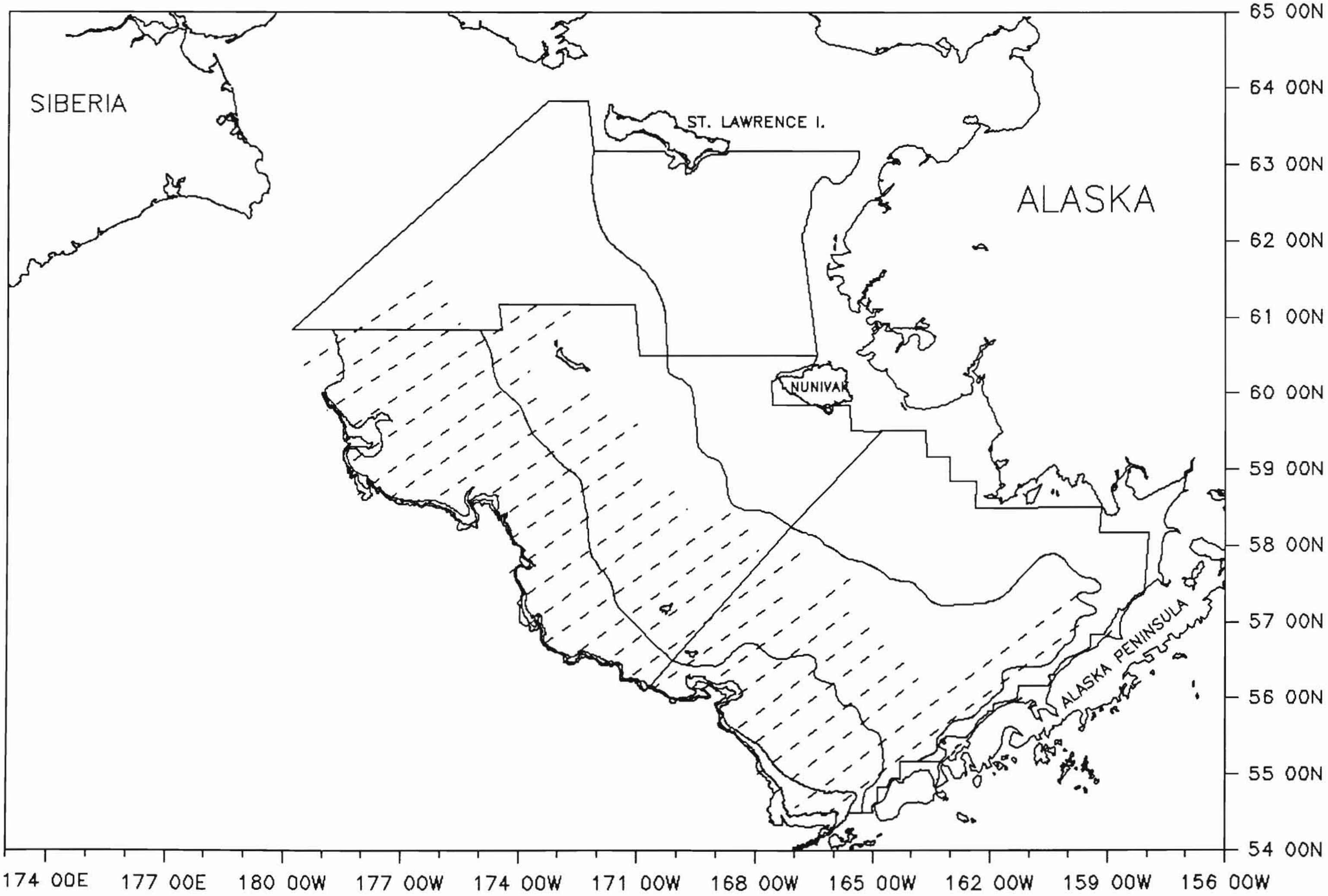

Figure 2. — The echo integration and midwater trawl survey design used in 1988 on the eastern Bering Sea shelf and slope.

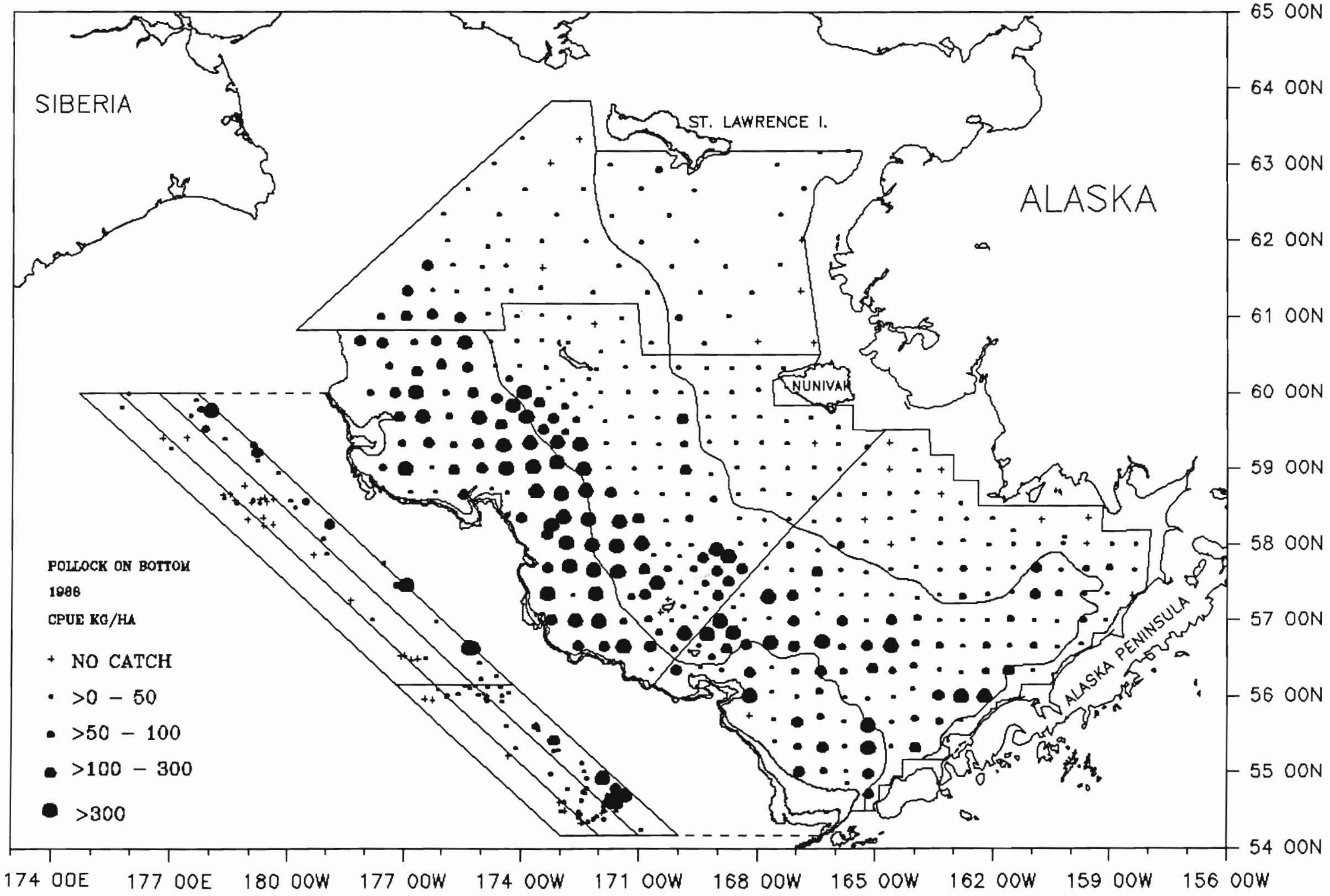

Figure 3. — Distribution and abundance of age 1 and older walleye pollock near bottom as determined during the 1988 triennial eastern Bering Sea shelf and slope bottom trawl survey.

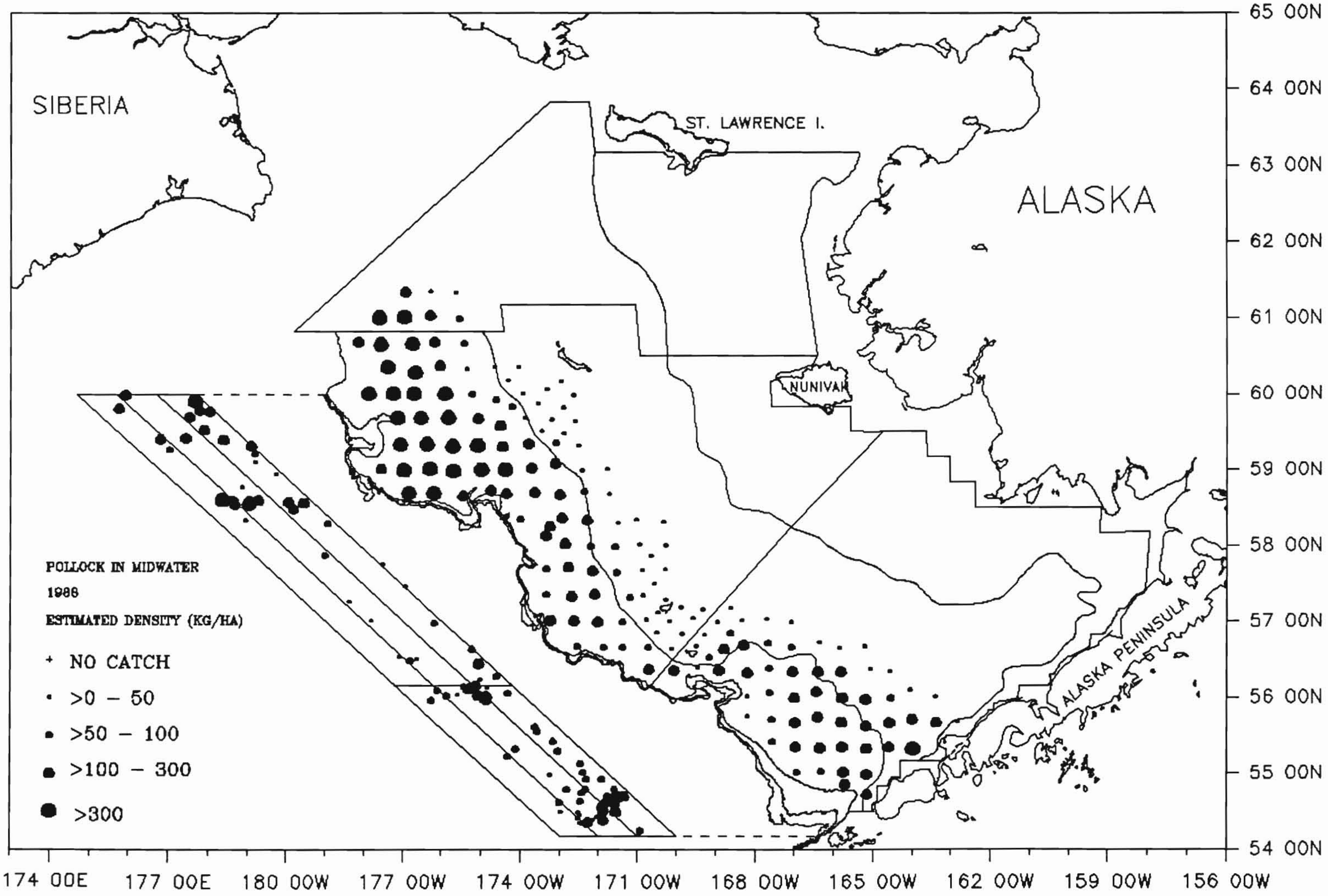

Figure 4. — Distribution and abundance of age 1 and older walleye pollock in midwater as determined during the 1988 triennial eastern Bering Sea shelf and slope EIMWT survey.

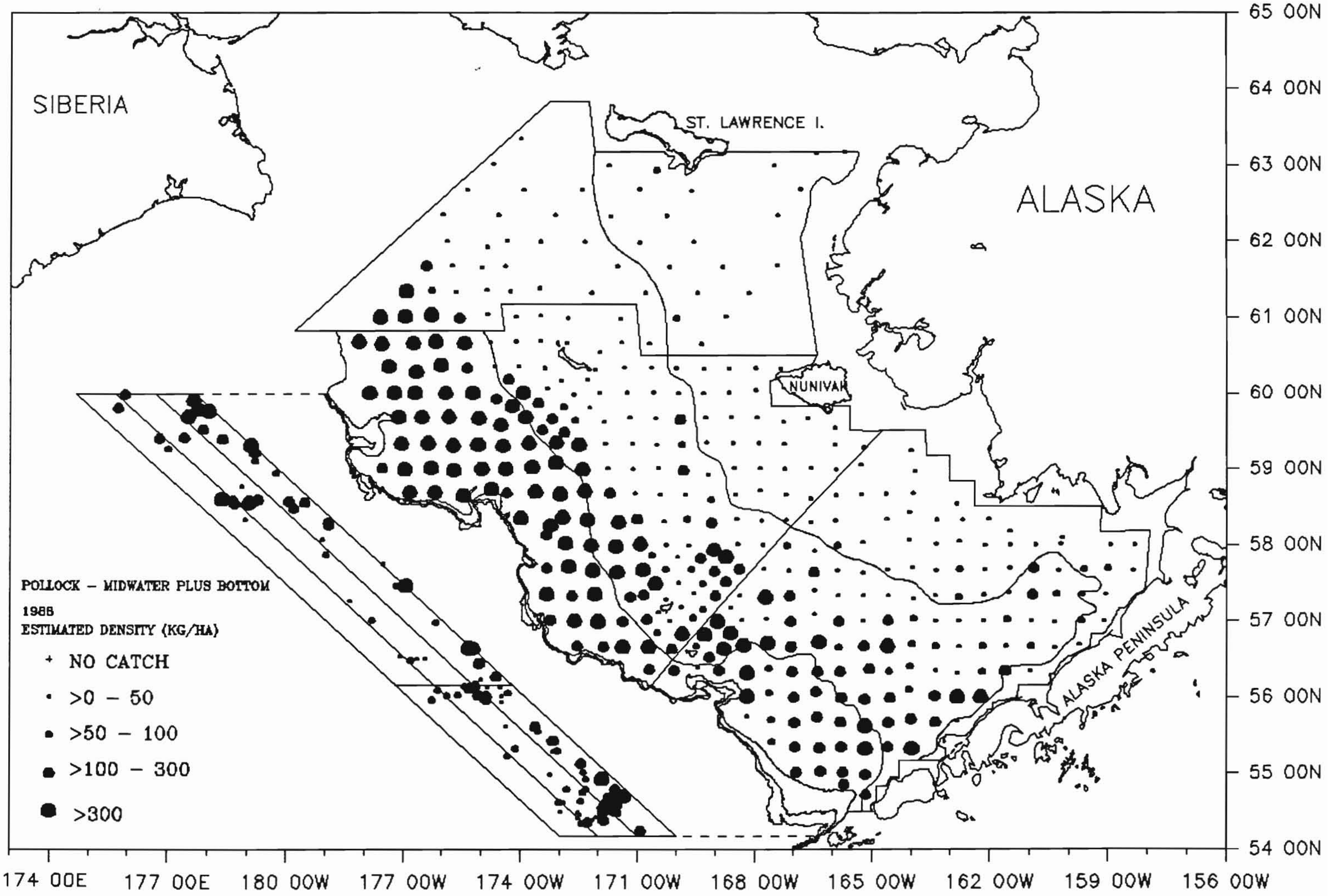

Figure 5. — Distribution and abundance of age 1 and older walleye pollock near bottom and in midwater as determined by combining bottom trawl and EIMWT estimates for the 1988 triennial eastern Bering Sea shelf and slope survey.

few were found in trawls conducted in water shallower than 50 m. Pelagic pollock were more abundant in waters deeper than 100 m. Localized areas of high abundance generally occurred in the vicinity of Unimak Pass and south of the Pribilof Islands, and overall pollock abundance was usually higher to the north and west of the Pribilof Islands than elsewhere (see Figure 1 for location of depth contours and geographic sites). EIMWT surveys alone would not have documented the presence of pollock in shallower waters of the continental shelf, but, by combining the two types of survey data, it was possible to produce a more comprehensive map of distribution which indicated the trend of increasing overall abundance with depth (Fig. 5).

Comparison of results from the four combined demersal trawl and EIMWT surveys conducted over a 10-year period indicates substantial differences in abundance and vertical distribution between years (Fig. 6). Differences in the age-specific proportions of pollock found in midwater and on bottom are also apparent (Fig. 7, 8). For example, the proportion of 1- and 2-year-old fish in midwater was much greater than on bottom in 1979, whereas the proportion of age 1 fish on bottom exceeded that in midwater in subsequent survey years; age 2 and 3 fish were more abundant in midwater than on bottom during each survey, but age 4 fish were more abundant demersally in 1979 and in midwater in 1982, 1985, and 1988. The proportion of fish older than 5 years assessed by bottom trawl always exceeded the EIMWT derived proportion; this supports the perception that demersal orientation is more common for older fish (Fig. 9). The extremely strong 1978 year class undoubtedly influenced the unusual vertical distribution of juvenile fish that was observed in 1979.

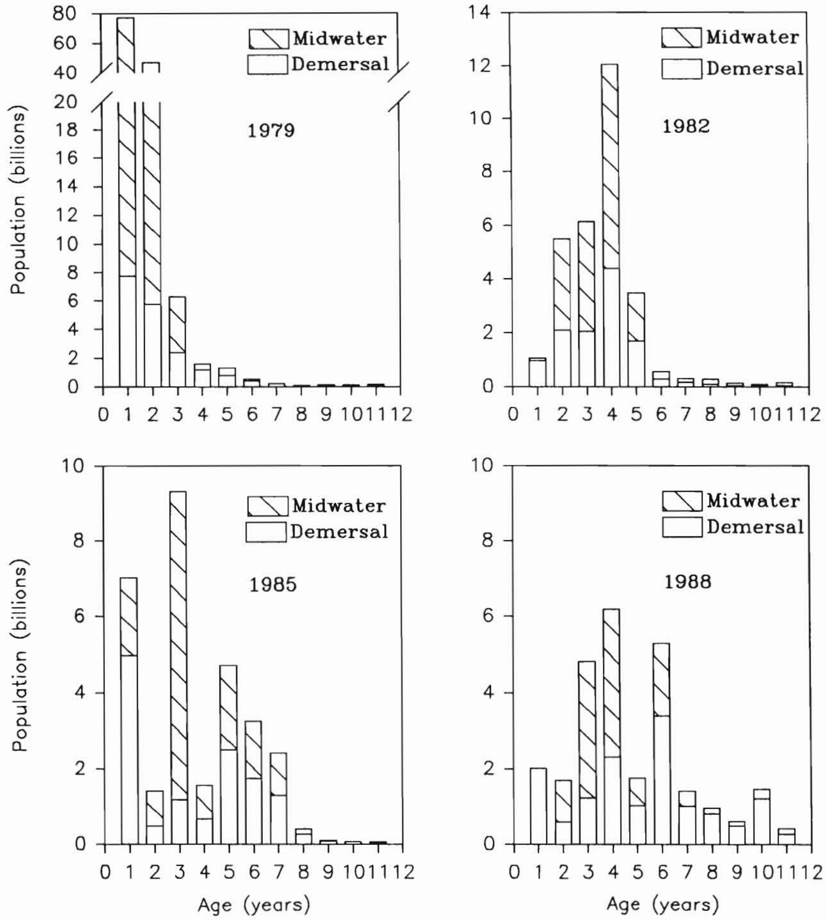

Figure 7. — Age-specific walleye pollock population estimates for midwater and demersal assessments conducted in 1979, 1982, 1985, and 1988.

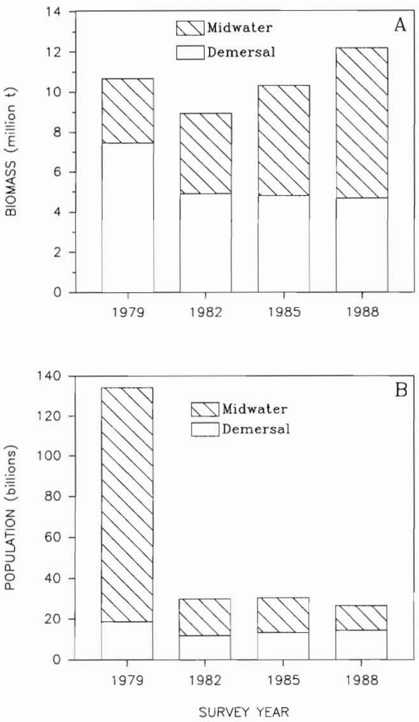

Figure 6. — Eastern Bering Sea shelf and slope walleye pollock biomass (A) and population (B) estimates for 1979, 1982, 1985, and 1988, illustrating proportions of estimates in midwater and near bottom.

Our ability to track the progress of this year class over a 10-year period has been greatly enhanced by the use of both assessment methods. It is apparent that the variability of age-specific distribution in the midwater and demersal zones, overlaid on the general trend of increased demersal orientation with age, could not have been adequately documented by one assessment method alone. In addition, this combined assessment approach has enabled us to better document the progression of the above average year classes of 1982 and 1984. Many of the trends and patterns observed in the time series of data can be reasonably attributed to differences in year class strength, overall abundance, and recruitment to the shelf and slope stocks. Nevertheless, it is likely that some of our perceptions have been influenced by biases that are inherent in our survey techniques. For example, the total abundance of the 1981 year class appeared to increase between 1982 and 1985. This suggests that this year class was not fully available to either (or both) surveys at age 1.

Limitations

Biases of concern to scientists conducting these surveys can be classified into three principal categories: those associated with deficiencies in biological knowledge; those associated with fishing gear, fish behavior, and the catching process; and those associated with the technique of echo integration.

Biological Considerations

The category of biological knowledge includes migratory activities and factors relating to stock identification. Detailed knowledge of patterns of stock distribution in space and time is an essential prerequisite for assessment survey design. Since these surveys have been conducted over relatively short time periods, when EBS pollock are believed to be in a nonmigratory feeding mode, horizontal migrations are not considered to be a serious source of bias. However, assumptions regarding the geographical distribution of the stock are based on limited information and it is generally recognized that the stock extends into unsurveyed areas of the western Bering Sea. Stock identification is of particular concern with regard to the origin of fish caught in the central Bering Sea and adjacent to Bogoslof Island (lat. 54°N, long. 168°W). The midwater and demersal surveys have not always been synchronous. This is a potential source of bias if significant migration does occur.

Vertical migration is also of some concern. The demersal trawl surveys are conducted only during daylight hours to avoid possible inconsistencies. EIMWT surveys have been carried out on a 24 hour per day basis. Even though diel changes in vertical distribution are apparent, it has been assumed that movement between the pelagic and demersal zone is not significant and that possible biases are minimal due to the short darkness period during the summer. Interannual changes in vertical distribution have been observed and the resultant changes in availability to each survey technique are a cause of serious concern.

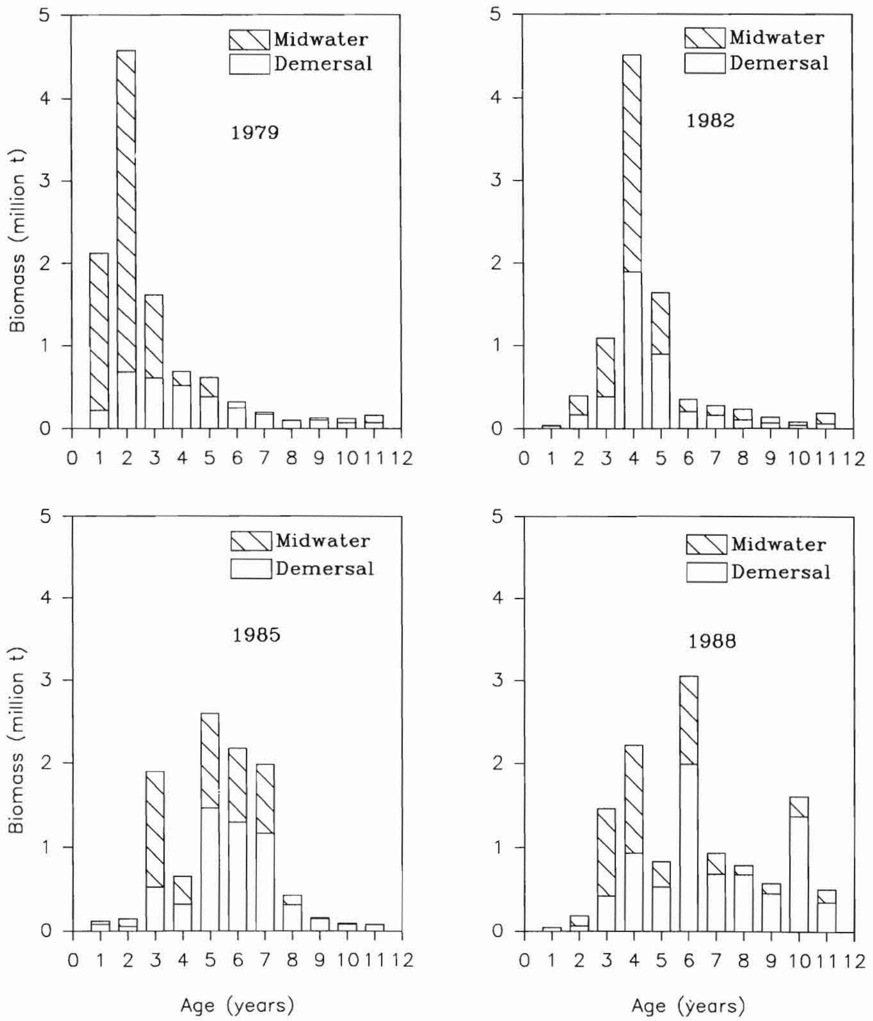

Figure 8. — Age-specific walleye pollock biomass estimates for midwater and demersal assessments conducted in 1979, 1982, 1985, and 1988.

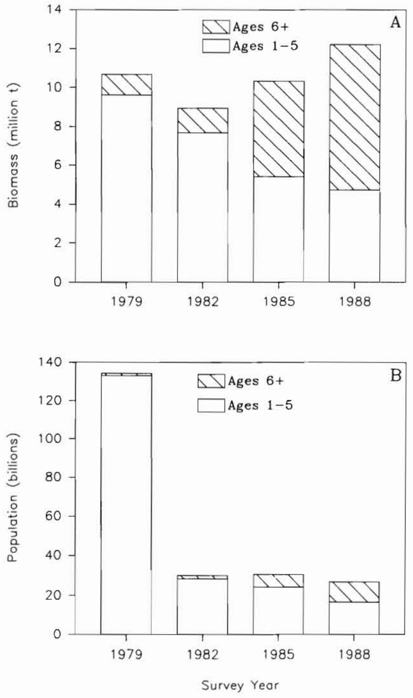

Figure 9. — Eastern Bering Sea shelf and slope walleye pollock biomass (A) and population (B) estimates for 1979, 1982, 1985, 1988, illustrating proportions of estimates of age 1–5 and age 6 and older fish.

Fishing Gear and Fish Behavior

Concerns regarding vessel avoidance, gear performance, and interactions between gear and fish during bottom trawl surveys have received a great deal of attention (Clark, 1979; Engås and Godø, 1986; Koeller, 1991; Olsen, 1990; Ona and Godø, 1990; Wardle, 1986). The development of instruments for monitoring some aspects of gear performance has been of great importance in this context. Such equipment is now used on a routine basis during EBS bottom trawl surveys (Rose and Walters, 1990).

The estimates of wingspread used prior to 1988 introduced bias into the pollock abundance assessment process because they did not account for the effect of varying scope. These early estimates were based on averages of small numbers of measurements taken in various locations, and for each survey the mean wingspread for the net aboard each vessel was used to estimate area swept. Work by Godø and Engås (1989) and Rose and Walters (1990), among others, has demonstrated that trawl width increases with scope. Most pollock are found in deeper water, where scope lengths and, therefore, wingspreads are greater than average. Thus for the greater proportion of pollock catches, net wingspread would have been underestimated and biomass overestimated. Since juvenile pollock are generally found in shallower waters than adults, it is likely that this source of bias incorporates an age-specific component.

In the area-swept calculations, it is assumed that the effective width of the net is equivalent to the wingspread. Work by Engås and Godø (1989a) indicates that the effective width of a demersal trawl used for sampling gadoids is related to fish size. In general, they demonstrated that, as sweep length (distance between trawl doors and net) was increased, catch rates of Atlantic cod, *Gadus morhua*, and haddock, *Melanogrammus aeglefinus*, increased with increasing fish length. They concluded that the herding effect is greater for larger fish. Loss of small fish under the net, as observed by Engås and Godø (1989b) is thought to be minimal in the EBS surveys because the net does not have roller gear and is rigged to dig into the bottom slightly in order to better sample crabs.

The second component of the area-swept estimate is distance travelled along the bottom. Net contact with bottom does not occur until after the winch brakes are set and the gear settles. The rate at which the gear settles is influenced by winch and vessel speed, water currents, depth, and net construction. At the end of the tow the net does not lift off as soon as the winches are turned on. However, the actual forward motion of the net across the bottom during haul back is difficult to determine. Even if the exact distance were known, the degree to which it is appropriate to correct for time off bottom is not clear because of the confounding effect of species and size related patterns of behavior. Beginning in 1993, new techniques will be used to address this problem. By using a time-depth recorder fitted to the net and Global Positioning System (GPS) navigation, exact time and position of settling and lift off can be determined. Thus haul duration can be measured and anomalous gear behavior identified. However, techniques are not yet available for observing how well the gear stays in contact with the bottom (bottom tending). There is also some concern that the area swept is based on distance travelled rather than the quantity of water passing through the net. Gear flowmeters are available to investigate this issue but they have not yet been used during AFSC surveys.

The procedure for fishing power correction (FPC), or standardization of observations to the most efficient vessel-gear combination has also changed in recent years. The new technique is considered to be more statistically appropriate than the method employed previously. However, the FPC procedure considers only species-specific effects and does not take size-specific factors into consideration. Also, the decision to adjust area swept estimates to the most efficient vessel-gear combination is based on the implicit assumption that catchability cannot exceed unity.

Younger pollock tend to remain in the water column and older fish are generally more demersally oriented. Several researchers (e.g., Olsen, 1990; Nunnallee[2]) have demonstrated that gadoids may dive in response to perceived disturbance from vessels and/or trawls. This behavior could lead to changes in relative availability to each assessment method. Size specific differences in patterns of avoidance are also likely. With the exception of 1979, the demersal survey biomass estimate of age 1 fish has always been higher than that obtained by EIMWT. Midwater estimates of age 2 and 3 pollock are generally higher than in the demersal survey, but the reverse is true for most ages greater than 3 in the majority of years. If the demersal trawl gear that was introduced in 1982 sampled age 1 fish with greater efficiency than before, this could partially explain the unusually high proportion of age 1 fish observed by the EIMWT method in 1979. It should be noted, however, that the 1978 year class was extremely large, and its midwater abundance in 1979 was very high. The change in gear type has undoubtedly compromised the integrity of the time series of data in a number of ways. Unfortunately, however, limited resources and inclement weather have precluded any meaningful comparison of the two trawl types.

Size and age composition of the midwater component of the stock is estimated by applying the information obtained from midwater trawling to the echo integration results. Thus, the degree to which the trawl samples represent the actual composition of the echo sign is a fundamental concern. The process of judging echograms and assigning biological characteristics based on trawls is somewhat subjective. Hylen et al.[3] believe the process of assigning bio-

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[2] Nunnallee, E. P. 1991. An investigation of the avoidance reactions of Pacific whiting (*Merluccius productus*) demersal and midwater trawl gear. Pap. pres. to Fish Capture Committee, Int. Counc. Explor. Sea, C.M. 1991, paper/ B:5, Session U.

[3] Hylen, A., O. Nakken, and K. Sunnana. 1986. The use of acoustic and bottom trawl surveys in the assessment of north-east Arctic cod and haddock. *In* M. Alton (Compiler), A workshop on comparative biology, assessment, and management of gadoids from the North Pacific and Atlantic oceans, part II, p. 473–498. Rep. on file at Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115.

logical characteristics to be a principal source of error in the determination of size and species specific acoustic abundance estimates (Aglen, 1989). Errors that result from avoidance, selectivity, or herding will be reflected in the size- and age-specific abundance estimates. Of particular concern are size-specific phenomena such as selectivity, or differences in avoidance reactions. The observations of Engås and Godø (1989b) regarding the greater degree to which larger gadoids are herded into the path of a bottom trawl are probably also applicable in the pelagic zone; one might also expect greater escapement of small fish through the rope wings of the midwater trawl. It is not known if the diving avoidance behavior observed by Nunnallee[2] occurs to a greater degree in larger fish, but their stronger swimming abilities and greater stamina suggest this possibility.

Echo Integration

Calibration is an essential component of a quantitative acoustic assessment program. The system was calibrated frequently, and echo sounder performance was monitored during the surveys.

Due to the limited dynamic range of the echo sounder and the need to set an integration voltage threshold high enough to eliminate extraneous noise, we undoubtedly obscured acoustic returns from low density distributions of pollock during these surveys. The degree to which this resulted in underestimation of abundance is unknown, but our general observations of the pattern of pollock aggregation and distribution suggest that this problem was not severe, especially since the survey area is relatively shallow.

Before 1988, a constant average TS value was used in biomass estimation calculations. Selection of too low a mean TS value would have led to an overestimate of fish abundance; this would have been more likely when smaller fish predominated, such as in 1979. This is because, in general, the TS per unit weight for small fish is greater than for large fish. The use of observed fish length compositions and the empirical TS-length relationship of Foote and Traynor (1988) to compute mean TS in 1988 makes some progress towards addressing the problem but relies heavily on the assumption that the midwater trawl catches accurately represent the size composition of the fish sampled acoustically (further implications of this assumption are discussed below). In the EBS, schools of juvenile fish are generally spatially separate from schools of adults, so that the effects of selectivity may be less severe in this context. Neither TS estimation technique has been able to take into account behavioral and other factors that influence fish target strength (Traynor et al., 1990b).

An accurate measure of the acoustic pulse width is essential if biomass estimates are to be obtained by echo integration. The acoustic pulse width provides one dimension of the computation used to determine the amount of energy transmitted into the water. If uncorrected, an erroneous assumption that the pulse width is too wide will lead an underestimate of abundance. The reverse is also true. A computer program was developed to sample the rectified voltage signal from individual fish targets and calculate the effective integration pulse width (Traynor and Nelson, 1985).

Sound energy decreases with distance from the transducer due to spreading and attenuation. To compensate for this, echo sounder receivers incorporate a time varied gain (TVG) amplifier and provide for an estimate of attenuation due to absorption by seawater. The AFSC acoustic system TVG function is measured using a computer program that samples calibration oscillator signals at 1 m intervals. Deviations from the theoretically correct TVG were determined and corrected as described by Traynor and Nelson (1985). If uncorrected, deviations from the theoretically correct TVG could lead to biased estimates of abundance. Overcorrection (too much gain) would cause overestimation and undercorrection would cause underestimation.

The acoustic system and operating procedures were designed to minimize the effects of self noise. Self noise is the sum of noise components contributed by the vessel and the electronic equipment. Since low-noise, scientific quality instruments were used, the principal potential source of self noise was the survey vessel. During these surveys, vessel noise was minimized by selection of appropriate engine speed and propeller pitch, and, on occasion, suspending survey operations during inclement weather.

Reverberatory noise occurs when the transmitted sound pulse intercepts bubbles or biological sound scatterers (i.e., organisms other than the target species). In general, during the EBS surveys, most ambient or reverberatory sources of noise were eliminated or reduced to an insignificant level by setting an appropriate signal threshold and eliminating data from nontarget species during data processing. It should be noted, however, that the process of setting an appropriate system threshold is one of compromise; setting a threshold high enough to eliminate most extraneous noise will result in the elimination of returns from fish, especially at low levels of density. The transducer was generally towed deep enough to avoid near-surface noise from air bubbles but no deeper than the shallowest expected occurrence of pollock (Traynor et al., 1990b).

Separation of fish echoes from bottom echoes is subject to physical and operational limitations. System parameters limit the absolute ability of an echo sounder to separate near-bottom targets from the bottom itself and fish in contact with the bottom cannot be assessed by echo integration. Provided that echo integration is carried out in small discrete depth intervals, it is usually possible to eliminate unwanted bottom echoes from the data and include acoustic returns from fish within a short distance (2–3 m) of the bottom. This procedure was followed during AFSC data collection and analysis.

The methodology discussed above refers to the AFSC acoustic system that was in use through the 1988 triennial survey. Beginning in 1991, a new set of instruments, with improved stability, dynamic range, and signal-to-noise ratio has been employed (Knudsen, 1990). The basic methodology has not changed, but technical improvements have reduced the potential impact of some of the aforementioned concerns.

Overall Estimates

All the aforementioned biases are of concern when combining the results of the pelagic and demersal assessments. Each method is subject to a series of biases and it is likely that combining the two sets of estimates will exacerbate the effects. The basic assumption implicit in this procedure is that the effective sampling height of the bottom trawl is 3 m, that all demersal fish are fully available only to the bottom trawl, and all pelagic fish are fully available only to the acoustic assessment. It is also assumed that all sizes of fish in each zone have a catchability of unity to the respective assessment method. In the preceding paragraphs we have presented evidence to suggest that these assumptions may not be completely valid. For example, diving avoidance behavior may increase the availability of pelagic fish to the demersal trawl and reduce their availability to the pelagic trawl. This may result in inaccuracies in both demersal and pelagic size and age composition estimates. Godø and Wespestad (1990) postulate that this is indeed the case, and that it led to substantial overestimation of older fish in 1988, as indicated by a divergence of fishery based and survey based estimates in that year. Their argument is plausible because it considers the tendency of the bottom trawl to sample larger fish with greater efficiency in the horizontal plane due to herding and in the vertical plane due to diving avoidance behavior. The diving behavior would probably also lead to an underestimate of the proportion of larger fish in the pelagic region.

Preliminary results of the 1991 triennial survey add further weight to this argument (Williamson)[4]. With the new acoustic assessment system, pelagic pollock biomass estimates covered the water column down to 1.0 m off bottom. The preliminary pelagic biomass estimate was 2.1 million t and the preliminary bottom trawl estimate (covering the lower 3 m) was 5.0 million t. Extrapolation of the echo integration results to the bottom increases the overall EIMWT estimate by a relatively small amount. This suggests that the effective width of the bottom trawl is considerably greater than the distance between wingtips and the effective height is greater than 3 m.

As mentioned earlier, bottom trawl surveys are conducted during daylight, while acoustic and midwater trawl sampling are carried out during daylight and darkness. Much work has been done on the effect of diel changes on fish behavior and assessment results throughout the world (e.g., Engås and Soldal, 1992; Wardle, 1986; Woodhead, 1964) but this phenomenon has not been investigated extensively with regard to Bering Sea pollock assessment. The impact of these phenomena on survey results can be substantial, and considerable research is called for. It also seems reasonable to evaluate the manner in which survey data is used to tune the fishery based analysis; perhaps the demersal and pelagic estimates could be considered as independent estimates of the condition of certain sets of age groups. Sample and Bakkala (1989) demonstrated a highly significant regression when comparing bottom trawl and cohort analysis estimates of age 4–9 pollock abundance for the period 1979–86. Since the population ageing process is gradual, one might expect the size dependent phenomena discussed above to have influenced the annual bottom trawl (and triennial EIMWT) results gradually over a period of years. If this had been the case, it might have been apparent in the work of Sample and Bakkala (1989); it would be interesting to extend their analysis with recently obtained data.

Toward Improved Assessments

As we recognize the various problems associated with bottom trawl and EIMWT surveys we must address them in a systematic manner. In the light of recent work carried out at AFSC and elsewhere, appropriate research is being planned.

Relationships between net width and trawl warp determined by Rose and Walters (1990) have been applied to the historic 83–112 trawl data for which direct width measurements were not made. This enabled us to make corrections in the area swept estimates and investigate the degree of bias associated with assumptions regarding the horizontal opening of the net. Biases leading to overestimates in the earlier analyses (especially for trawls made in deeper water) were apparent in all but one year. Overall, the magnitude of the bias was approximately 3%, a value less than we originally expected. For species with predominantly inshore, shallow-water distributions, underestimation biases were indicated.

The CPUE values have now been used to reevaluate the FPC estimates necessary to complete a new set of biomass estimates for the time series. After applying these two sets of corrections, it will be necessary to review the multi-year data set. It must be recognized that these corrections will not account for all sources of error. For example, if wingspread exceeds design limitations, changes in gear performance can be expected. It has been argued that the FPC approach is no more than an interim solution and will be eliminated when we better understand fish behavior in relation to fishing gear and can take significant phenomena into account in our assessment process (Munro[5]).

Research will be directed towards in situ monitoring of gear performance and establishing techniques for maintaining performance within design limitations. The work of Engås and Ona (1991) on the use of restrictors for door spread shows promise in this regard.

The innovative approach to determining settling and haulback time and distance fished described above will help reduce errors in area swept calculations and enable us to better identify poor

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[4] Williamson, N.J. NMFS Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115. Personal commun. Further information on recent stock assessments is provided in the 1993 stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands, and it is available from the North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

[5] Munro, P. NMFS Alaska Fisheries Science Center, 7600 Sand Point Way N.E., Seattle, WA 98115. Personal commun.

hauls. We are also concerned with the problems of subsampling large catches and interested in the recent work which investigated the advantages and disadvantages of shorter tow durations (Godø et al., 1990).

Other problems in fishing gear technology are more difficult to research and will require a major effort. It is essential that research on gear design and fish behavior in relation to fishing gear be assigned high priority if we are to understand and address the biases in our survey estimates.

The data presented above suggest that larger pollock are more demersally oriented but we are not sure of the extent to which this perception is tainted by interactions between fish and sampling gear. We are now able to collect continuous TS measurements through the water column during the surveys. Provided that suitable target densities can be encountered, and the single target selection algorithm is equally effective through the range of depths sampled, we will be able to use TS measurement data to examine possible trends in size with proximity to the bottom. It should also be possible to design experiments to investigate how such trends are influenced by the passage of a trawl. Because of the influence of fish behavior on TS these types of observations will have to be evaluated with caution.

The work of Engås and Godø (1989a) suggests that we must investigate the effect of sweep length on the size (and species) composition in our catches. This leads to a consideration of priorities. Because the trawl survey is designed to assess a multispecies community, it will probably never be possible to optimize the design with respect to pollock. Since most of the species sampled by the bottom trawl are truly demersal, perhaps we need to develop an alternate technique for assessment of this semi-pelagic species. Regardless, it is essential that we investigate the size and species-specific sampling efficiencies of our sampling trawls.

We believe that it may be possible to develop the EIMWT technique to produce satisfactory total water column estimates of pollock abundance. Recent work on problems of near-bottom detection (Ona, 1988 (cited in Godø and Wespestad, 1990) and Mitson, 1983) suggests that it may be possible to collect useful integration data very close to the bottom and make appropriate corrections for regions of the acoustic beam that are obscured in this near bottom region. While the physical limitations have not changed, our understanding of the limitations has improved, and newly developed tools for collecting and processing echo integration data will make it easier for us to conduct research in this area (Knudsen, 1990; Foote et al., 1991). It is important to bear in mind that this approach will still require us to make assumptions about fish distribution and behavior close to the bottom, and these assumptions may be difficult to test.

We will still be faced with some questions regarding trawl sampling biases when it comes to developing age specific abundance estimates. This will become even more critical if we are to expand our EIMWT method into the demersal zone. An alternative approach would involve using acoustic measurements to investigate and document availability of pollock to demersal gear. Much research remains to be done if we are to develop effective techniques for combining biological information from midwater and bottom trawls while accounting for the biases inherent in the use of each type of gear.

The methods described above are designed to provide estimates of absolute abundance. However, we have presented overwhelming evidence of substantial bias in our survey results. This supports the argument that survey results should be considered as indices of relative abundance that have significance only as elements in a time series. Even under this constraint, we must work under assumptions regarding the consistency of bias which may be difficult to support.

Realistically, however, we must consider the manner in which survey results are applied. Stock assessment models that are used to determine allowable biological catch (ABC) levels for commercial fisheries require a source of absolute abundance information. This can be obtained from analysis of historic fisheries data or from survey results. Analysis of fisheries data requires reliable time series of catch and effort information and realistic estimates of natural mortality and terminal fishing mortality rates.

For some fisheries, data are insufficient, and in other cases assumptions regarding mortality rate estimation may be difficult to support. This leaves us on the horns of a dilemma. Are we more willing to accept the assumptions implicit in developing absolute abundance estimates from survey data than those implicit in the analysis of fishery data? The problem can be resolved by taking a pragmatic approach, recognizing the limitations under which we are forced to work and making best use of the data that is available. Inevitably we will sometimes have no choice but to use survey results as measures of absolute abundance. This serves only to emphasize the need for all scientists involved in stock assessment to understand the limitations in their data and investigate approaches to improving the quality of information used in the stock assessment process.

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