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MONITORING CHANGES IN ABUNDANCE OF GADOIDS WITH VARYING AVAILABILITY TO SURVEYS

by

Olav Rune Godø

Institute of Marine Research, P.O. Box 1870 5024 Bergen, Norway

Vidar G. Wespestad

Alaska Fisheries Center, 7600 Sandpoint Way NE, Seattle, WA 98115 USA

ABSTRACT

The use of scientific survey data for assessing abundance of commercially important fish stocks has become a managerial necessity in many regions. Errors and bias in estimates from such surveys may thus have great economic impact. In the Northeast Atlantic abundance of cod has been estimated from bottom trawl surveys and acoustic surveys since 1981. In the Svalbard area, such survey abundance indices have differed considerably with the discrepancy varying from year to year. At low stock abundance and when the population is comprised of young fish, cod are distributed close to bottom and are thus optimally located for a bottom trawl survey, but are poorly recorded by the acoustic technique. In contrast, when abundant year-classes attain an age of 2-3 years and older, they are more pelagically distributed and clearly available for acoustic observation. Dependency on only one of the survey techniques could seriously underestimate the stock. A combination of estimates from the two methods is at present hindered by the lack of an absolute estimate of abundance, and by uncertainty in the actual volume sampled volume due to movement of fish during survey sampling. The vertical profile of the acoustic recordings and size composition and density of the population are factors which will affect fish availability to the two survey techniques differently. Such variation in availability seems to affect gadoid surveys in general. With a limited amount of additional effort changes in availability-selectivity can be monitored during the survey, and observed changes can be incorporated into analyses to compensate for potential bias due to variation in these parameters.

INTRODUCTION

Errors in abundance estimates for gadoids, primarily from fisheries data, have been extensively studied (Gulland 1964). According to Parrish et al. (1964) a major problem is bias due to the selectivity of fishing operations. Selectivity may operate in three ways: a) through selection properties of the fishing gear, b) through the areal and vertical distribution of fish in relation to the gear, and c) through fish behavior in the vicinity of the fishing gear. The same factors will affect standardized fish surveys which use trawls as a primary sampling tool (Doubleday and Rivard 1981; Hylen et al. 1986).

The stock of northeast Arctic cod (Gadus morhua L.), consisting of a Barents Sea and a Svalbard component (Trout 1957; Garrod 1967) is abundant and economically important. The stock is surveyed annually by the Institute of Marine Research, Bergen (IMR) to derive relative indices of abundance. Combined bottom trawl and acoustic surveys have been conducted since 1981, in January-March in the Barents Sea, and in September-October in the Svalbard area (Hylen et al. 1988 a,b). The individual survey estimates are major inputs to the tuning of virtual population analysis (VPA) (ANON 1989), which supplies the basis for management decisions on quotas and other harvest strategies. Thus, variability and errors in the survey estimates could have serious economic and conservation impacts.

Fish availability to the applied survey technique is a source of uncertainty both in bottom trawl surveys (Byrne et al. 1981, Hylen et al. 1986), and in acoustic surveys (Johannesson and Mitson 1983). The applicability of the methods during the different surveys, and hence the validity of the estimates, should therefore be carefully studied. As used in the tuning of the VPA, the abundance indices from the simultaneous bottom trawl and acoustic surveys are considered independent estimates, and should therefore conform with each other with respect to between year variation in stock abundance. Alternatively, we think that the two methods present different fractions of the true stock picture because their sampling efficiencies suffer from different limitations. In this case the best total estimate would be obtained from a synthesis of the results. The present use of the two data sets in the tuning of VPA do not utilize all available information.

Based on the eight surveys in the Svalbard area, this paper tries to elucidate how availability is affected by variation in stock composition, abundance and distribution, and to what extent and in what way changes in availability affects comparability of the acoustic and bottom trawl abundance indices of cod.

MATERIAL AND METHODS

Survey area characteristics

The Svalbard survey area consists of two sub-areas: The west Spitsbergen shelf and slope (Strata 1-22 in Fig. 1) and the Bear Island Bank and slope (Strata 23-45 in Fig. 1). These areas are separated by the Storfjord Channel which runs from the Norwegian Sea northeast towards Hope Island (Strata 23, 29, 30). Survey depths in both areas vary between 20 and 600 m. A considerable part of the total area (42%) is less than 200 m (Fig. 1).

The hydrographic regime in autumn is characterized by fronts separating cold Arctic water from warm Atlantic water in the eastern part of the Bear Island Bank and in the southern Spitsbergen coastal area (Loeng 1989). The position of the fronts vary substantially both annually and inter-annually (Beverton and Lee 1965).

Based on tagging-recapture results, catch per unit effort analysis and studies of otoliths, the Svalbard and Barents Sea cod are considered separate components before maturation (Maslov 1972, Garrod 1967, Trout 1957). After maturing a flux from the Svalbard area to the Barents Sea has been observed (Trout 1957, Garrod 1967)

Bottom trawl survey indices

Stratified random bottom trawl surveys are carried out to provide data for the management of commercially important demersal fish species in the Svalbard area (here used as the area covered by the survey strata, Fig. 1). The data analyzed were obtained from the surveys carried out in September - October, 1981 - 1988 using a Campelen 1800 mesh shrimp trawl with rubber bobbins, a cod-end mesh size of 40 mm, and sweep wires of 80 m. A standard haul consisted of the trawl being towed for three nautical miles (nm) at a speed of three knots.

The stratified random trawl survey consisted of 22 strata north of 76° N (the northern area, 9700 nm^2) and 23 strata south of this latitude (the southern area, 44600 nm^2). The stratification was done according to depth (0-100 m, 100-200 m, 200-300 m, 300-400 m and more than 400 m), latitude and longitude (Fig. 1). Catch data were used to calculate stratified mean catch in number and weight per haul and the swept area abundance indices were calculated by the following equation:

$$I = \bar{X}_{st} \cdot A/AS$$

where $\bar{X}_{st}$ = stratified mean catch per haul(kg), A = total area of all strata (square n.miles), and AS = the area swept by standard trawl haul (equal the assumed effective path width of 25 m times the standard tow length of 3 nautical miles).

The surveys are conducted using a combination of chartered commercial trawlers and research vessels (Table 1). Normally about 200 trawl stations were occupied every year; however in 1987, only 133 stations were completed because of a lack of commercial trawler effort (Table 1).

Sampling was performed on a 24 hour basis. The species and length compositions of trawl catches were determined either by sorting and measuring the total catch or a representative subsample. Bottom trawl survey methods are fully described in Randa and Smedstad (1982, 1983) and in Hylen et al.(1986).

Acoustic abundance indices

The standard acoustic survey was carried out by the R/V "Michael Sars", R/V "Eldjarn" and R/V "G.O. Sars" (Table 1). R/V "Michael Sars" was equipped with a Simrad EK-S 38 kHz echo sounder and R/V "Eldjarn" and R/V "G.O. Sars" with Simrad EK-400 38 kHz echo sounder. All vessels employed hull mounted transducers and digital integrator systems, developed at the IMR (Blindheim et al. 1982).

The integrator system produces outputs as s_A=area backscattering coefficients in numbers of summed backscattering cross-sections per square nautical mile (m^2/nm^2) for every five nautical mile, which is recorded by depth channels of 50 and 100 m width (Fig. 2). In addition, values were recorded in a bottom related channel. The bottom channel extension was 10 m in the 1981-1984 and 1988 surveys, 5 m in 1985 and 1987 and 2 m in 1986. In 1986 - 1988 integrator values from additional bottom related channels of one to five meter height became available. This information was used to study the distribution pattern close to bottom and to extrapolate the fish distribution into the "dead zone" (Johannesson and Mitson 1983, Mitson 1983).

Biological sampling was accomplished with bottom and pelagic trawls. The bottom trawl was the same as used in the bottom trawl survey. During 1981-1985 a 29x29 m capelin trawl was used to sample the pelagic zone, and in 1987 a Fotø herring trawl model 84 was employed. Size and age composition of the fish species surveyed were determined from the total catch or a representative sample. Age was determined by counting annular rings in broken otolith sections illuminated from the side (Williams and Bedford 1974).

The area was normally covered by random tracks determined by the position of the randomly selected trawl stations. Abundance estimates were calculated for average s_A in squares of 0.5° latitude by 1.0° longitude. Fish which were recorded in the integrator channels above the bottom channel, were defined as pelagically distributed. The integrator values were allocated to fish species, or group of species, according to the characteristics of the fish traces on the echo recording paper and the species composition of trawl catches. One such group of species was comprised of cod and haddock (Gadus aeglefinus L.), and its integrator values were later allocated to species and size group based on the species and length composition recorded from trawl catches. The abundance estimates were calculated using the following effective target strength of cod,

$$\langle TS \rangle = 21.8 \log L - 74.9$$

where L is fish length (cm). A description of the methodology of acoustic surveys is presented by Dalen and Nakken (1983).

RESULTS

Correlation between estimates

The abundance of cod estimated by the stratified bottom trawl survey method increased from a minimum of 50 million specimens or less in the early 1980s to a peak in 1985 and 1986 of about 280 million (Table 2). In 1987 and 1988 the bottom trawl estimate decreased to 214 and 91 million. Indices by weight show a similar pattern.

The echo surveys prior to 1985 were carried out according to standard procedures, but echo traces of gadoids were almost absent these years. Due to the imprecise results obtained under such conditions (Ehrenberg and Lytle 1977), acoustic estimates were not calculated. In the following comparison these numbers are set to zero for the years 1981-1984. The trend in acoustic survey estimates of number of fish shows an increase from 146 million cod in 1985 to 300 million in 1986 (Fig. 3). The estimated abundance then increased dramatically in 1987 to 970 million, followed by a severe reduction to 138 millon in 1988 (Fig. 3).

When using the two indices as independent measurements of abundance, they are expected to exhibit a high degree of correlation over time. However, this was not the case as illustrated by a linear regression which shows the low correlation (r^2=0.25) (Fig. 3). The low correlation, is primarily due to the high 1987 acoustic estimate. A regression without this point improved the correlation (r^2=0.63). Both regressions give slopes below 1.0, and indicate a positive intercept in the bottom trawl index axis, suggesting that the acoustic method was not able to quantify low fish abundance.

Age composition

The age composition of cod taken in surveys varied considerably during the period of investigation (Table 3). The principle cause of variation in the age composition was the occurrence of the abundant 1982, 1983 and 1984 year-classes, of which the 1983 year-class was the strongest.

Areal and vertical distribution

The areal distribution of cod as determined by bottom trawl and acoustic surveys are similar during the period of increasing abundance, except for peripheral areas of distribution where the bottom trawl survey occationally provides an incomplete coverage (Fig. 4). This is because the bottom trawl survey has a fixed stratification which occationally gives an incomplete coverage of the cod distribution, whereas the acoustic survey will continue as long as s_A values are positive. In 1985 and 1986, both surveys showed high densities of cod in the shallow water areas from the Bear Island and northeast towards Hope Island and along the Spitsbergen west coast (Fig. 4 a-b). Similarly in 1987, both surveys showed concentration of fish between the Spitsbergen South Cape and Hope Island, and around and southeast of Bear Island (Fig. 4c). Further, the recordings in 1987 were concentrated along the slopes instead of being distributed on the shelf as in previous years (compare distribution with topography in Fig. 1). The area of dense distribution (catch rate above 100 specimens, s_A >10) in 1987 shrank to about 60% of the 1986 distribution due to a lack of cod off Spitsbergen and in most of the shallow bank areas northeast of Bear Island.

Distribution by depth varied considerably. In 1981, 1985, 1986 and 1988 54-70% of the total bottom trawl index originated from areas shallower than 100 m, while in 1982, 1983 and 1987 the corresponding percentages were equal or less than 35% (Table 2). Similar data from the acoustic surveys show that in 1985 and 1986 65% and 82% of the fish were recorded at bottom depths less than 100 m, but only 35% in 1987 (Fig. 4). Further, 1987 is the only year when a considerable portion (37%) of s_A is found in waters deeper than 200 m. In contrast to 1985 and 1986, cod were recorded above the bottom channel in areas deeper than 100 m in 1987, and peaked at 100-150 m (Fig. 5). In 1988 cod were again distributed close to bottom as in the pre-1987 years (see also Hylen et al. 1989).

Because the height of the bottom channel varied between years, the above observations are not directly comparable. For the years 1985-1988 the following table compares the percentage of s_A recorded above the bottom channel (A), with the corresponding percentage for s_A above the deepest pelagic channel (B) (see definition of A and B in Fig. 2).

YEAR	1985	1986	1987	1988
Bottom channel extention (m)	5	2	5	10
A. Percent of s_A above bottom channel	36	53	63	14
B. Percent of s_A above deepest pel. chan.	25	19	44	4
Bottom trawl index	281	285	214	91

The value of B will better reflect the significance of true pelagic fish recordings and further be more comparable from year to year. It is seen that the value of B more than doubled from 1986 to 1987, which again shows that cod in 1987 were more pelagically distributed than in previous years.

DISCUSSION

Data

The bottom trawl survey in the Svalbard area is conducted following standardized methods which are widely used for assessing variation in abundance of demersal fish (Doubleday and Rivard 1981). Several vessels have been employed over the history of the survey and there is some concern that there may be a vessel effect on the result. However, in areas covered by both participating vessels in 1984-1986, indices of abundance computed for individual ships indicated no specific differences attributable to ship-trawl difference. Trawl experiments conducted with research vessels have shown that irregularities in trawl behavior are potential problems, but observations of normal survey trawl operations have not indicated any ship-trawl effect on trawl geometry (Godø and Engås 1989). We have some concern that reduced survey effort in 1987 may have biased the results in that year, but the data do not indicate any specific anomaly due the exclusion of a commercial trawler and reduced effort in 1987.

The acoustic technique for estimating abundance of gadoids in the Barents Sea has been used since 1976 (Dalen and Smedstad 1983). Improvements in the instrumentation and increased experience account for the lack of standardization during the time series as reflected in "Material and methods". However, a constant practice followed since the inception of the survey has been to calibrate the instruments according to standard procedures (Foote et al. 1987). Cod and haddock, treated as a single category in acoustic terms, are known to display behavioral differences during the capture process (Engås and Godø 1989, Main and Sangster 1981) and the trawl sampling could thus bias the applied species composition. However, this potential error is more or less eliminated in the Svalbard area as haddock are very scarce there. The improvements in the near bottom integration technique (see "Material and methods") might have biased the result in either direction. If biased, most likely the 1986 - 1988 estimates were slightly higher compared to earlier, and associated with a relatively higher proportion of the integrator value allocated to the bottom channel. Another uncertainty is the zero estimates from 1981-1984, which in reality were very low unknown estimates. These estimates were not originally calculated because basic requirements for the recording conditions during the surveys were not satisfied (see Dalen and Smedstad 1983). If calculated, available information suggests that they are lower than the lowest presented estimate, i.e. < 50 mill. specimens. In the present comparison these years are included as we want to study how availability changes during the entire time-series, and the outcome is not considerably dependent on whether zero or very low estimate is used. Except for the above uncertainties, the time series of acoustic estimates is assumed to be relevant (with respect to methodology) for comparison with the results from the bottom trawl survey.

Comparability of abundance indices

Though the two time series of abundance indices are relatively short, the data clearly indicate inconsistency in variation of stock abundance between the two methods. Even if the exceptional 1987 observations are excluded, the two sets of estimates are poorly correlated. The pelagic distribution of fish in 1987 favored the use of the acoustic method, i.e. minimized the effect of the "dead zone" problem (Mitson 1983), and we therefore consider the 1987 estimate to be reliable. Conversely, the bottom trawl method was ineffective, as many fish were distributed far above the headline of the trawl. Due to the poor recruitment in the later years (Table 3, ANON 1989), an increase in abundance was not expected in 1987. The high (yet reliable) 1987 acoustic estimate (more than triple the 1986 estimate), indicates the other acoustic indices to be underestimates and, further, that bottom trawl and acoustic indices are measured with different accuracy.

The age composition of the two indices are similar, since mainly bottom trawl samples were used to determine the age composition of acoustic and bottom trawl samples. Due to the more prominent pelagic distribution of fish in 1987, pelagic trawl catches played a more important role in the calculation of the acoustic indices, but this did not affect the age distributions (Hylen et al. 1988a).

When treating the two indices as independent estimates (as used in the tuning of the VPA), it is required that the availability of fish to the two survey techniques is interannually invariate from species to species and independent of area and size/age, i.e. the condition for abundance estimation (later called "survey condition") is assumed to be constant. However, the present study indicates that high availability for one method creates low availability for the other. If the two estimates are directly combined into one total estimate, the applied effective trawl path and fish target strength have to be assumed correct or equally biased. The problems connected to the above procedures could partly be overcome if fish availability to the two methods was known, and used to minimize the effect of year to year variability in survey indices. In what follows, factors affecting availability are examined with the aim of supplying information to quantify availability for the two surveys.

Factors affecting availability

Age composition: Trawl indices by age do not necessarily give a correct picture of the composition of the stock, but are assumed to reflect changes from year to year. We know, for example, that the true abundance of cod (in numbers) over the history of the survey was greatest in 1984-85 due to the relative abundant 1982-1985 year classes (ANON 1989). The low trawl indices these years are a result of trawl selection, i.e. recruiting year classes are strongly under estimated (rough estimates of the real representation of cod of age 1-3 years are 3%, 35% and 50% respectively (Engås and Godø 1989)). In spite of the high numbers, cod were practically undetected by the acoustic instruments in 1984. Small fish, even at high density, appear to concentrate close to bottom. This fits well with results from trawl experiments, which indicate that small cod and haddock are closely associated with the bottom (Engås and Godø 1989). It appears that cod age 2-3 and older, beginning in 1985, "grew" out of the bottom zone and gradually become more available to the acoustic survey as they aged. If this is generally true then the validity of using raw unmodified length frequency distribution from bottom trawl catches in conversion of acoustic abundance to fish density must be critically examined. In particular, when introducing a new sampling trawl (as done in 1989 in the Norwegian surveys) with improved sampling efficiency on small fish, this has to be considered.

The performance of the acoustic instruments in the bottom zone depends on the bottom conditions and topography. In the survey area, the bottom at depths less than 100 m is mostly smooth and gives a distinct echo. The acoustic integration was adapted accordingly, e.g. by using a shorter integrator back-step, which ensures higher efficiency on fish in the bottom zone (Ona 1988). In deeper water the bottom is more uneven and the bottom signal irregular. To avoid integration of bottom under such conditions, adjustment in the bottom zone integration has to be done, e.g. by using a longer integrator back-step, with consequent possibility of systematic loss of fish at the bottom. At these depths also recordings of redfish, shrimp and krill often add complexity to the interpretation of the bottom recordings. As cod progressively concentrate in shallow water (depth < 100 m) with increasing age up to 3-4 years (IMR unpubl. results), an improving availability to acoustic integration should be expected.

<u>Fish density</u>: At low densities, as demonstrated by low trawl abundance indices, cod are scattered and distributed close to the bottom. Under such conditions cod are difficult to distinguish from other acoustic recordings, i.e. are "hidden" in disturbance caused by bottom conditions and recordings of other species. Further, the integration efficiency can be reduced due to e.g. the bottom conditions or ship movements in bad weather, which will increase the consequences of the "dead zone" problem (Johannesson and Mitson 1983). Also, when low stock levels occur, fish densities are difficult to resolve from acoustic background "noise" if no localized concentrations occur. This is why low stock abundance itself is a limiting factor for the availability to acoustic survey, as indicated by the positive intercept on the bottom trawl axis in the regression (Fig. 3b). Similar findings are presented by Hylen et al. (1986)

and Engås and Godø (1986). Also, at decreasing densities, precision of acoustic estimates is reduced (Ehrenberg and Lytle 1977).

High fish abundance/density may reduce availability to the bottom trawl survey in two ways. First, high density may lead to "gear saturation" with successive loss of fish (see Jones 1954, Godø et al.1990), and, second, fish may become more vertically distributed as seen in the exceptional 1987 situation, and thereby not be available to the bottom trawl at all. In both cases the bottom trawl survey technique will underestimate abundance. The reestablishment of a more "normal" situation in 1988, i.e. less difference between the two indices, could partly be a result of reduced abundance this year.

Areal and vertical distribution: The change in geographic distribution pattern in 1987 might have amplified the density effect discussed above. Cod off the coast of Spitsbergen and on the shallow bank areas northeast of Bear Island in 1986, seem to have migrated southward in 1987 and congregated in more limited areas. The bottom trawl survey estimate of cod abundance in 1987 decreased relative to 1986, but due to the decreased area of distribution, the density in the near bottom zone increased relative to 1986. The more pelagic distribution of cod in 1987 compared to 1986 may to some extent be caused by a "biomass saturation" in the near bottom layer and subsequent migration of fish into the pelagic zone (Engås and Godø 1986). The 1987 distribution demonstrates very well how availability may change from one year to the next.

It has been speculated if the surprisingly high 1987 acoustic estimate could be attributed to immigration of Barents Sea cod. Cod from the Barents Sea and Svalbard area can be distinguished by otolith zonation (Trout 1957). The otolith type is not a diagnostic character for the origin of an individual fish, but an area or year-class might be characterized by a specific frequency of occurrence of the different otolith types. If migration of Barents Sea cod to the Svalbard area were responsible for the dramatic increase in abundance in 1987, we would expect a significant increase in the frequency of Barents Sea otoliths in the Svalbard area. However, the frequency of Barents Sea type otoliths actually decreased (see Fig. 6, IMR, unpub. data), so the migration hypothesis does not appear to account for the unexpected increase in abundance in 1987.

Other factors: Several other factors may potentially influence the distribution and hence the availability of fish to the survey methods. These are: Changes in environment, feeding conditions, and fish behavior relative to the catching process.

The 1987 distribution can be described as an exceptional case of the type Beverton and Lee (1965) consider to be due to straying from the "normal" distribution as a consequence of environmental variation. Observations of temperature distribution during the 1986, 1987 and 1988 surveys exhibited a general increase of the bottom temperature in the Bear Island area and did not indicate 1987 to be exceptional (Hylen et al. 1989). The possibility that differences in oceanographic conditions prior to the survey may have caused an alteration in distribution can not be excluded.

Also, to be considered is that the cod found pelagically in the Svalbard area in 1987 were found to be feeding heavily on amphipods compared to a more varied diet in 1986 (S. Mehl, IMR, pers. comm.). The influence of the distribution and availability of food is unknown, but the unusual pelagic distribution in 1987 suggests that changes in feeding conditions can not be overlooked as a source of significant interannual variability in distribution.

When fish with high swimming capacity like large cod and haddock become pelagically distributed, size selection and great biomass displacement during trawl sampling may lead to unexpected variation in availability. Ona and Godø (1990) have demonstrated that ship noise during trawling in shallow waters (<200 m) causes gadoids to exhibit an avoidance response. Such a response also taking place at cruising speed could lead to underestimation of fish abundance during acoustic surveys caused either by a change in fish orientation, i.e. downward tilt from the horizontal plane, by movement out of the acoustic beam, or by migration into the bottom zone. Such behavior which forces pelagically distributed fish towards bottom, will also increase the availability of fish to bottom trawling. If catching height is assumed to equal the headline height, the bottom trawl abundance indices will reflect an increased availability caused by the downward "herding" effect of the ship. Thus, a depth dependent avoidance reaction may lead to underestimation of abundance in acoustic surveys and a corresponding increase of estimated abundance in bottom trawl survey indices. Due to differences in vertical distribution and fish size (and thus also swimming capacity) from year to year, this phenomenon will cause interannual variability, and may be a major problem in combining estimates from bottom trawl and acoustic surveys.

General applicability of the results

Reliability of survey estimates is often evaluated from estimated precision based on observed within survey variability. The current results demonstrate that this may be misleading with respect to interannual abundance variation if changes in availability are not taken into account (see also Pennington 1986, Aglen 1989). The factors previously discussed, describe the "survey condition", and differential availability of fish to the two survey techniques. These observations are counter to the fundamental basis of most standardized surveys, which assume the abundance estimates to be unaffected by changes in the "survey conditions" both within and between surveys. In practice bottom trawl and acoustic indices of northeast Arctic cod have been treated as independent estimates of abundance (ANON 1989). Also, total survey abundance estimates have been derived by combining results from bottom trawl and acoustic surveys (Hylen and Nakken 1985, Zaferman 1981, Wespestad and Megrey 1990). The results from the Svalbard surveys demonstrate that such procedures may produce severely biased abundance estimates. The incomparability of estimates from the two kind of surveys is due to factors which, in contrast to basic assumption, are neither constants nor random variates. There is no reason to believe that improvements in methods or equipment will fully compensate for the variability in "survey conditions" in the near future. Consequently, a way of improving reliability of survey estimates may be to initiate standardized monitoring for changes in availability based on information about the "survey condition" obtained during the two surveys. In the Svalbard survey this would involve quantitative compensation for e.g. 1) size-, age-, density- dependent availability, 2) vertical distribution and vessel avoidance of fish, 3) variation in target strength, 4) varying feeding behavior.

These problems are not unique to the Svalbard area and are in one way or another universal. Recent divergence in abundance estimates for eastern Bering Sea walleye pollock (Theragra chalcogramma) suggest that similar factors are influencing abundance estimates.

A gross differences in abundance and trends is apparent between VPA and bottom trawl estimates (Fig. 7). Estimates from the bottom trawl survey is only a fraction of the VPA derived estimate and trends in abundance have diverged since 1985. A hydroacoustic survey, conducted triennially since 1979, has monitored the pelagic component of the stock. The hydroacoustic estimates are combined with bottom trawl abundance estimates and the combined estimate of pollock numbers compare favorably with VPA derived estimates (Fig. 7).

The differences among estimates are believed to be due to changes in distribution and behavior with age, i.e. changes in "survey condition" have influenced the survey results. The mean age of pollock in the surveys, VPA and the commercial catch all show an increasing trend through the 1980s resulting from the aging of the dominant 1978 year-class (Fig. 8). The mean age of pollock in the bottom trawl survey is similar to the mean age of the commercial harvest, showing that the bottom trawl primarily captures older pollock which have a greater bottom dwelling tendency than younger pollock. Age in the commercial catch nearly doubled in the period 1980-1988, largely due to the fishery following an extremely abundant 1978 year-class (Fig. 8). Pollock are predominantly pelagic in distribution at early to intermediate ages, and become increasingly demersal with age (Bakkala et al. 1987). The combined hydroacoustic-bottom trawl estimates which include the pelagic portion of the population lowers the mean age to near the population mean as estimated by VPA.

Although the estimates of pollock numbers agree between the combined survey results and VPA, a potential exists of error induced by combining bottom trawl and hydroacoustic estimates which appears to have occurred in 1988. The 1988 survey biomass estimate diverged significantly from the VPA estimate (Fig. 9), and it is suspected that the divergence may be due to the acoustic and bottom trawl surveys counting the same fish, i.e. acoustically recorded fish are also counted during the bottom trawl survey due to fish movement from the pelagic zone into the catching zone of the bottom trawl to avoid vessel-trawling noise. Experimental observations of pollock during trawling indicate that pollock exhibit a diving avoidance reaction similar to that observed for cod (E. Nunnallee, Alaska Fisheries Center, pers. comm.).

When combining acoustic and bottom trawl abundance estimates according to standard procedures, an overestimate is produced due to inaccurate assumptions about availability. As in the Svalbard survey, it appears that fish behavior and stock composition affect distribution and availability of fish, and that the impact of anomalies could be avoided by using information about the "survey condition". Also in the northwestern Atlantic this problem may be significant, as changes in vertical distribution and migration are known to occur for cod and haddock (Beamish 1966).

Developments in acoustic observation techniques together with computer facilities for compiling large quantities of data during surveys, have greatly improved the possibility of monitoring variation in "survey condition" and its effect on the abundance estimates. In gadoid surveys, bottom trawl as well as acoustic, where variability is a major constraint for utilization of the results in assessment and management strategy, such monitoring of the "survey condition" may provide useful supplementary information which will not invalidate a long time series.

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Table 1. Participating vessels in the bottom trawl(B) and acoustics(A) surveys.

	VESSELS			
YEAR	"M.SARS"	"ELDJARN"	"G.O.SARS"	COMM.TRAWLER
1981	A+B			B
1982	A+B			B
1983	A+B			B
1984		A+B		B
1985		A+B		B
1986			A	B
1987	A+B	A+B		-
1988			A	B

Table 2. Distribution of bottom trawl indices on numbers by depth and year and total indices on numbers (TOT N, millions) and weight (TOT W, thousand tons).

	DEPTH INTERVALS						
YEAR	0-100	100-200	200-300	300-400	400-500	TOT N	TOT W
1981	35	5	5	3	2	50	76
1982	11	25	6	2	2	46	64
1983	16	17	9	2	2	46	58
1984	48	32	26	3	3	112	72
1985	165	66	33	11	6	281	166
1986	183	59	21	15	8	285	213
1987	64	80	55	9	6	214	152
1988	49	32	6	3	2	91	114

Table 3. Indices (millins) by age and year. The indices of the 1983 year-class are indicated.

YEAR	AGE 1	2	3	4	5	6	7	8	9	10
1981	0.1	22.2	9.0	5.5	1.3	6.1	3.8	0.7	0.4	0.4
1982	1.5	4.0	22.2	9.3	2.8	1.9	2.9	0.4	0.1	0.1
1983	14.6	5.1	6.2	9.5	3.0	2.5	1.3	1.6	0.4	0.2
1984	52.2	42.7	5.6	4.2	5.3	2.2	0.5	0.5	0.4	0.2
1985	27.0	133.1	74.3	27.9	6.5	7.7	1.4	1.4	0.1	0.3
1986	3.5	50.1	164.0	44.0	18.1	3.2	1.3	0.3	0.1	0.0
1987	3.3	26.2	67.0	94.7	18.1	6.5	0.6	0.1	0.1	0.0
1988	0.2	2.6	15.6	22.8	36.0	11.2	0.8	0.8	0.8	0.2

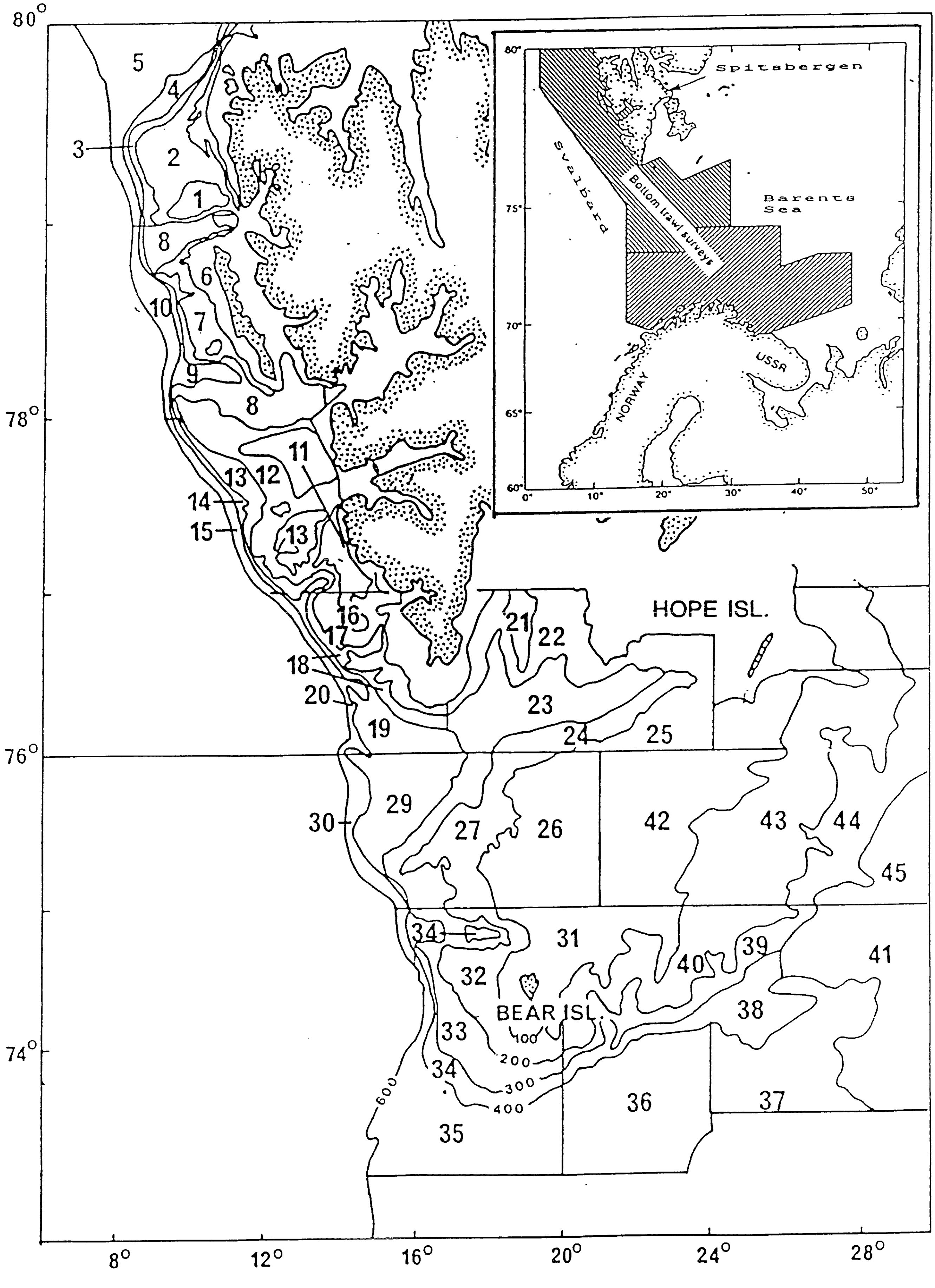


Fig. 1. The total area of distribution of northeast Arctic cod and the two Norwegian survey areas. Enlarged is the Svalbard area with bottom trawl survey strata division which also partly are bottom depth contour lines.

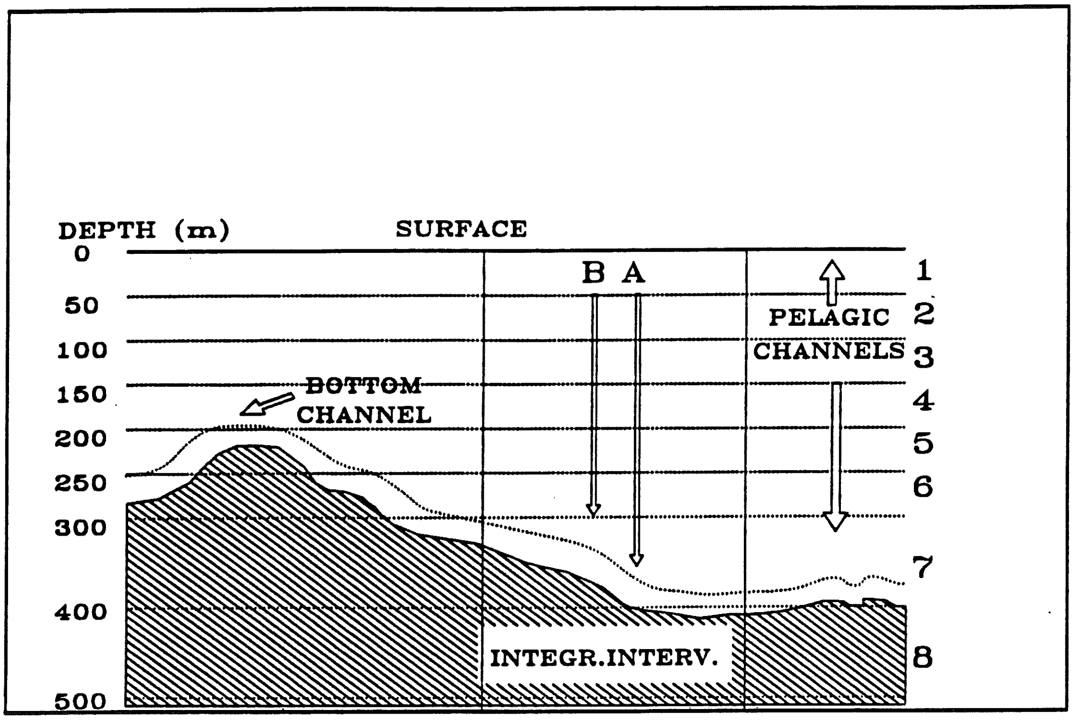


Fig. 2. Schematic presentation of the integrator channels to which the recorded echo abundance was allocated. For explanation of A and B see text page 6.

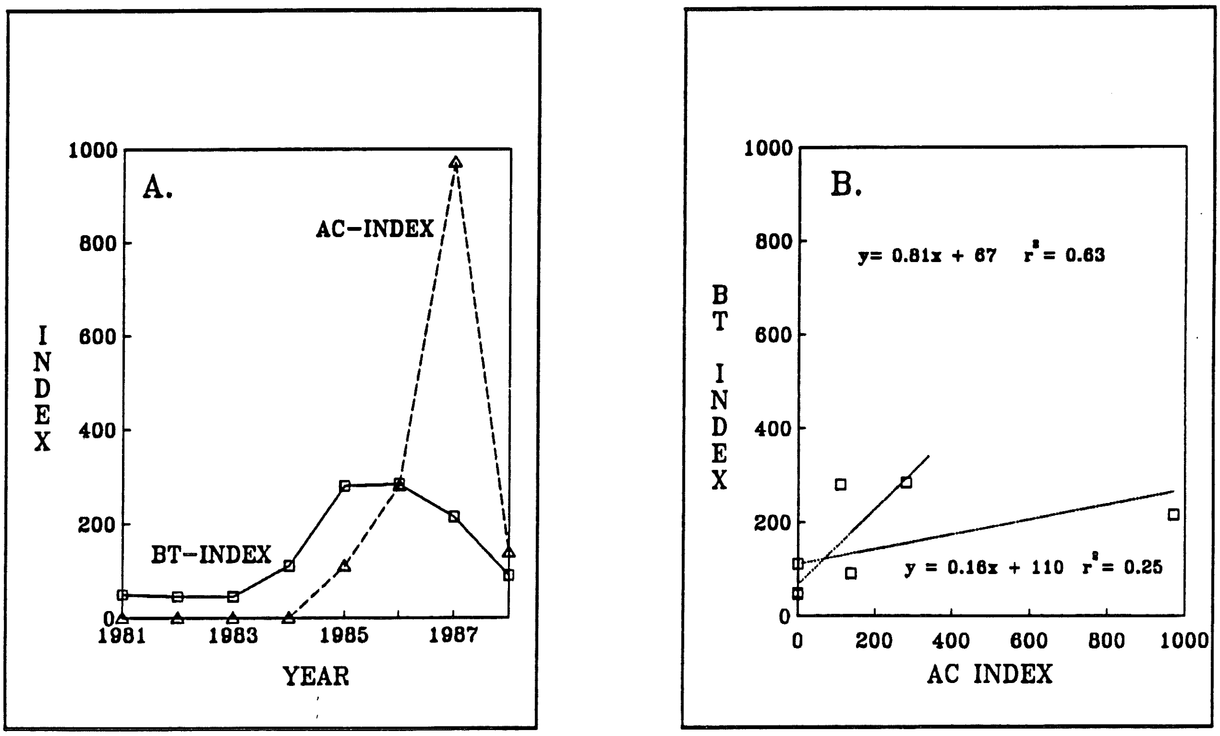
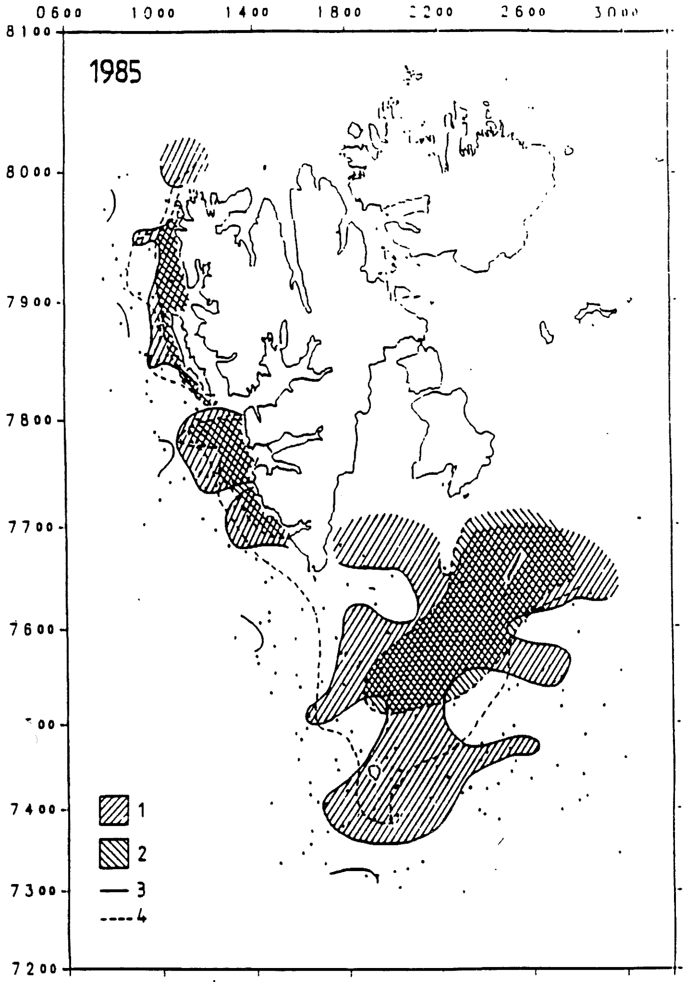


Fig. 3. Abundance estimated by the bottom trawl survey (BT-INDEX) and the acoustic survey (AC-INDEX) by year a) and plotted against each other b). Regression lines including and excluding the 1987 observation are indicated.



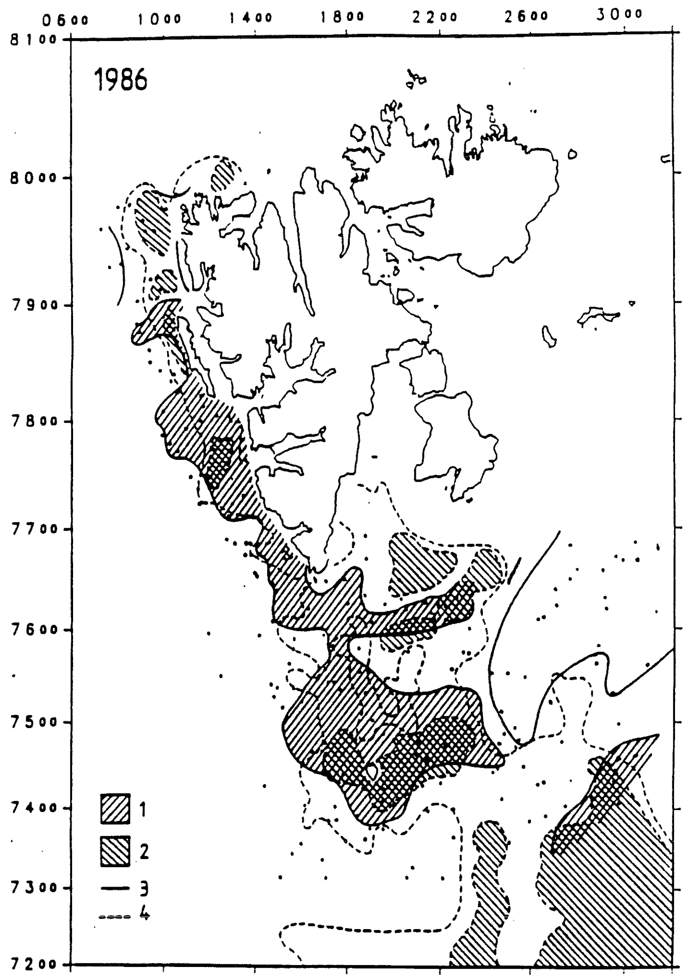
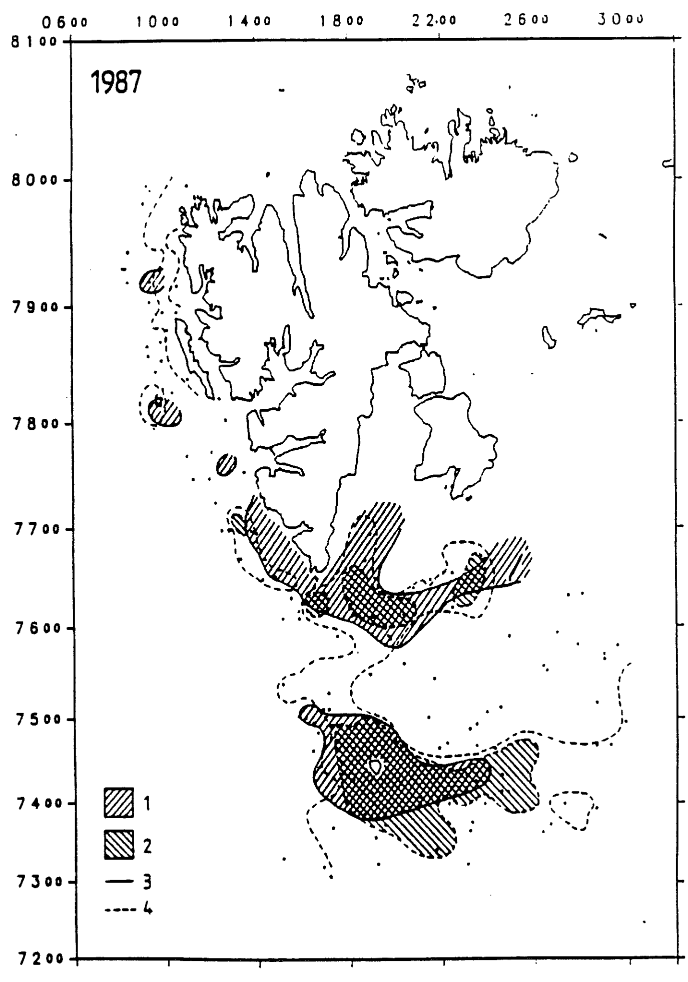


Fig. 4. Areal distribution of cod as determined by the bottom trawl surveys and the acoustic surveys in the years 1985 -1987. Legend: 1) catch > 100 specimen per tow, 2) $s_A > 10$, 3) catch = 0, 4) $s_A = 0$.



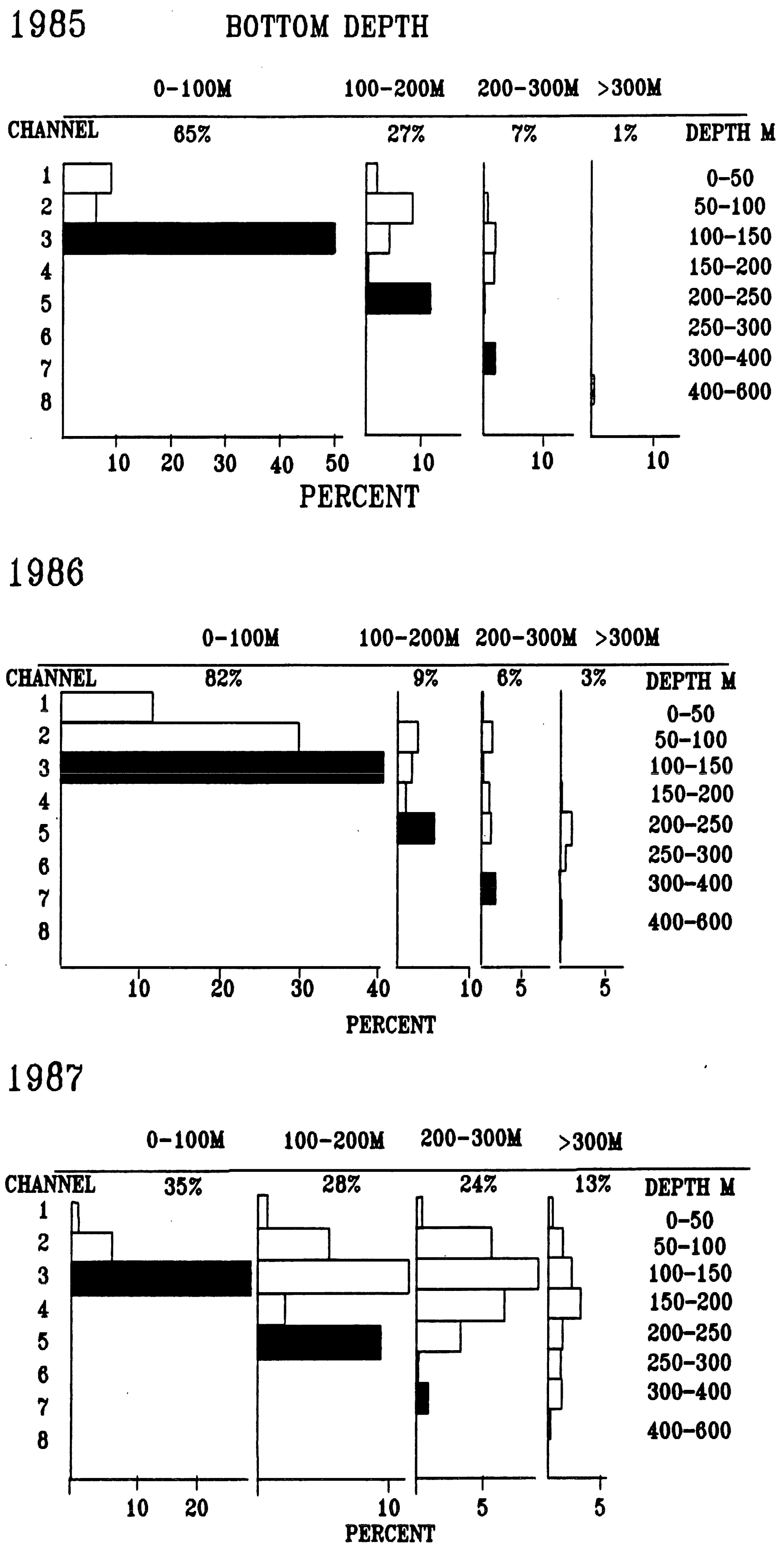


Fig. 5. Vertical distribution of acoustic abundance of cod by bottom depth zone and integrator channel 1985 - 1987. Bottom channel values are indicated by black column.

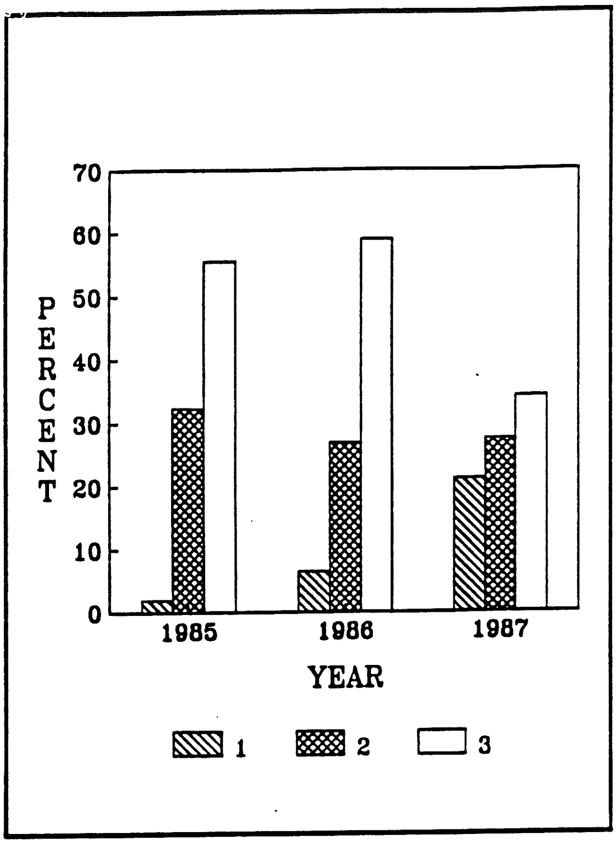


Fig. 6. Variation in the frequency of Barents Sea type otoliths in the in Svalbard area by sub-area: Spitsbergen west coast (1), western slope west and north of Bear Island (2) and the area east-southeast of Bear Island (3), 1985-1987.

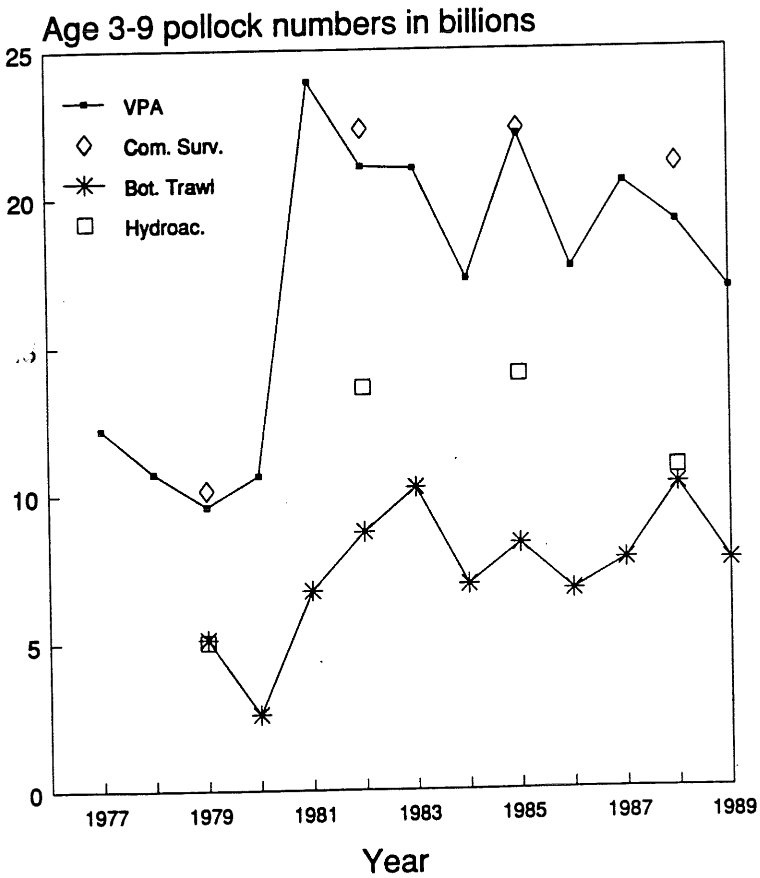


Fig. 7. Estimated number of age 3-9 walleye pollock in the eastern Bering Sea (billions) as estimated by bottom trawl surveys (BT), hydroacoustic surveys, combined hydroacoustic-bottom trawl surveys (COMB), and VPA, 1977-1990.

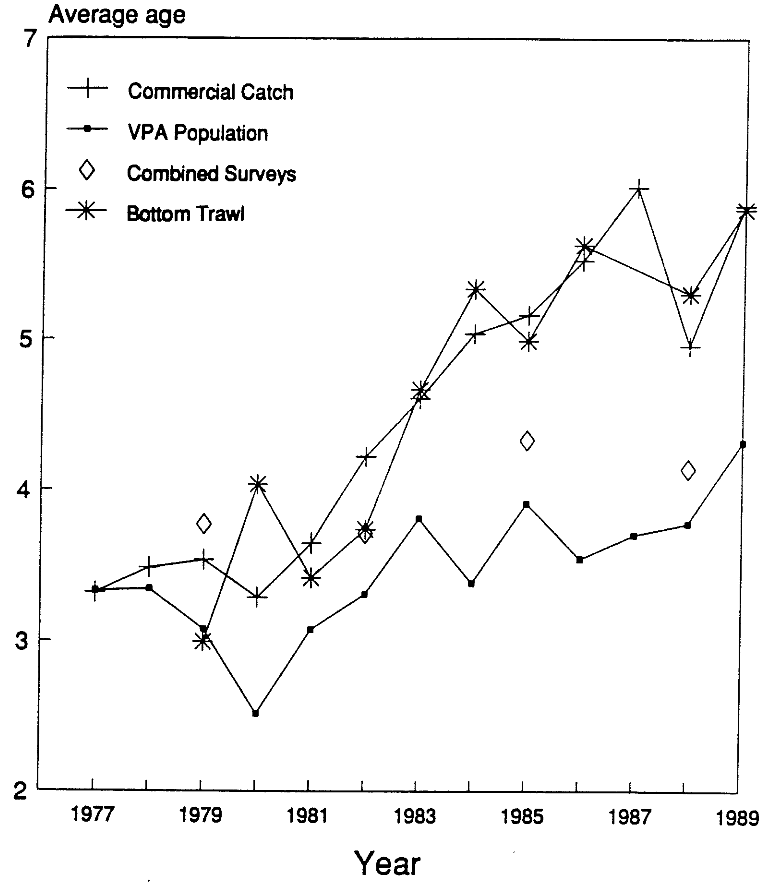


Fig. 8. Estimated mean age of walleye pollock in the eastern Bering Sea in the commercial catch, bottom trawl survey, combined hydroacoustic-bottom trawl survey, and VPA, 1977-1990.

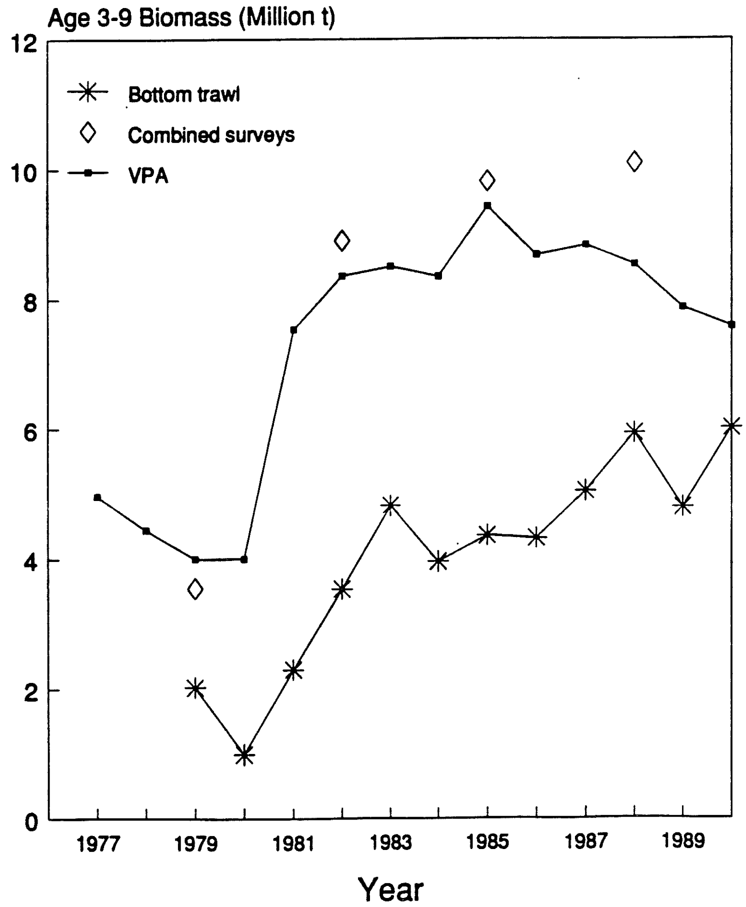


Fig. 9. Estimated biomass of age 3-9 walleye pollock in the eastern Bering Sea (million t) as estimated by bottom trawl surveys (BT), combined hydroacoustic-bottom trawl surveys (COMB), and VPA, 1977-1990.