THE STRAIT OF GEORGIA HERRING FISHERY: A CASE HISTORY OF TIMELY MANAGEMENT AIDED BY HYDROACOUSTIC SURVEYS

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ABSTRACT

A stock assessment program which combines hydroacoustic biomass estimates with midwater trawl sampling, spawning escapement estimates, and daily catch reporting has provided a timely method of managing an intensively fished, Pacific herring population in Puget Sound, Wash. Since 1976, these techniques have been implemented through the spawning season to estimate adult herring biomass, and to set quotas consistent with the biomass. The estimates become available for management use less than a day following completion of an acoustic-trawl survey, which allows for in-season adjustments in fishing.

Acoustic-trawl surveys carried out at regular intervals during the spawning season monitored declines of prespawning adult herring biomass; the declines corresponded to cumulative increases of catch and spawning escapement. After full recruitment to the fishery, the sum of catch, escapement, and acoustic-trawl estimates provided a point estimate of total available adult herring. Within a season, these point estimates varied less than 15%. This stability is a check on the accuracy of acoustic surveys, and confirms that accuracy is sufficient for management purposes.

Management of virtually all fisheries requires information on the abundance of the resource with which to set catch quotas, limit effort, or determine stock condition. The effectiveness of fishery management is often hampered by the need to make decisions based on stock assessment requiring long time periods or doubtful assumptions, or both.

Fisheries on the west coast of the United States and Canada for sac-roe (egg skein) of Pacific herring, *Clupea harengus pallasi*, have a need for rapid management response. The herring migrate from offshore waters to subtidal and intertidal spawning grounds. The fish are harvested just prior to spawning and the sac-roe is subsequently prepared as a caviar product. Total allowable harvests can be taken in very short times, from minutes to days, and prolonged fishing time easily leads to overharvest. An objective of sac-roe herring management is to obtain real time estimates of abundance prior to and during the fishery so that quotas compatible with abundance may be established. Spawning escapement goals must be met without losing the opportunity to catch harvestable fish.

Traditional methods of determining abundance or setting fishing rates are inadequate for the short-duration sac-roe herring fisheries. Catch per unit effort (CPUE), virtual population analysis/cohort analysis (VPA), or yield per recruit (Y/R) provide postharvest information, and often with lags of several years. Problems with effort standardization and harvesting aggregated fish (CPUE), the need for independent estimates of highly variable recruitment (VPA), and sexual maturity being reached after maximum cohort biomass (Y/R) make these methods difficult to apply to in-season sac-roe herring management even without the timeliness factor.

Sac-roe herring management relies heavily on catch records and on spawning escapement estimates. Even though these values ultimately combine to estimate total abundance, they are too late for in-season estimates and in-season management modifications. Abundance estimates before and during the spawning/fishing season can be obtained by use of hydroacoustic techniques, as are used in Washington, Alaska, and British Columbia.

Successful management of the sac-roe herring fishery in the Strait of Georgia, Wash., requires timely information on the abundance of the fishable stock during the fishing season. A fleet composed of purse seiners and gill netters has the capacity to harvest the available quota within 1

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to several days. In addition, allocation to treaty Indian fishermen is required by Federal Court rulings (the Boldt decision), which established separate treaty and nontreaty quotas. Biologists representing Washington State, participating tribes, and the University of Washington agreed that a target quota should be 20% of the total estimated population biomass (Trumble 1980).

The application of hydroacoustic techniques offered timeliness in the Strait of Georgia herring stock assessment program (Thorne 1977a) when combined with midwater trawling, analysis of catch records, and spawning ground surveys. This paper presents results of application of these techniques during 1976-79 to the management of the fishery.

METHODS AND MATERIALS

The concept of the sac-roe herring stock assessment program is to estimate the biomass of adult herring in prespawning condition, and add to this the biomass of adult herring removed by spawning or being caught. Hydroacoustics provided estimates of total pelagic fish biomass, and midwater trawl sampling provided species composition data to identify prespawning adults; the combination of hydroacoustics and midwater trawling will be referred to as "acoustic-trawl." Spawning ground surveys provided estimates of spawning escapement, and catch records tracked the success of the fishery. Catch and escapement estimates provide a postfishery check on the accuracy of the acoustic data, and in conjunction with acoustic-trawl surveys, a series of in-season estimates of the total biomass of mature herring.

Acoustic Survey Equipment and Methods

The hydroacoustic data acquisition system consisted of a modified 105 kHz Ross[3] 200A echosounder, an interface amplifier that reduced the signal frequency from 105 kHz to 5 kHz, a Sony TC-377 tape deck which recorded the 5 kHz data on magnetic tape, and an oscilloscope to monitor system operation. The transducer produced a 7½ degree full angle beam at the half power (−3dB) points. The modifications of the system include an internal calibration oscillator to monitor and measure system gain (Thorne et al. 1972; Nunnallee 1973). The echosounder transmitted a pulse length of 0.6 m s. The echosounder and transducer were periodically calibrated at the Applied Physics Laboratory, University of Washington. Normally, calibration occurred at the beginning and end of each field season.

The acoustic data from the magnetic tapes was processed with a digital echo integration system implemented on a PDP 11/45 computer (Thorne 1977b). A mean target strength of −33 dB/kg was used by the program to scale the integrator data to estimates of fish density. This value was originally established on the basis of both comparisons with net tows and in situ target strength measurements (Thorne 1977a) and the value still appears to be reasonable. Although considerable information has been obtained on the dependence of target strength on fish length (FAO 1978; Thorne in press), the variation in mean fish lengths in the Strait of Georgia is insufficient to warrant using a length-dependent variable instead of a constant for the target strength scaling factor. Herring typically range from 18 to 24 cm SL, and compose 70-90% of the biomass in the acoustic-trawl surveys.

During 1976 and 1977, the University of Washington's 12 m RV *Malka* was used as the acoustic platform, with a hull-mounted transducer. Subsequently, the acoustic program chartered a 10 m gill net vessel and used an over-the-side pole-mount for the transducer.

Acoustic surveys were conducted during April and May (and to the first part of June 1976) in order to bracket the spawning migration of the herring (Lemberg 1978). The surveys were conducted between Point Roberts and Lummi Island on a standardized trackline which had 10 transects, each about 8 km in length (Fig. 1). The surveys were typically conducted at twice weekly intervals around the peak of the migration, and less frequently during the early and late stages of the run.

During the day, herring normally aggregate in tight schools at depths of 40 m or more. At night, the schools disperse and form widespread layers 5-10 m thick at depths of 10-30 m; herring density decreases such that many fish are distinguishable as individual targets. Until actively ready to spawn, herring remain in water deeper than 20 m. The survey area encompassed the prespawning holding area, bounded by the 8-10 fathom contours on the inside, and the 50-60

[3]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

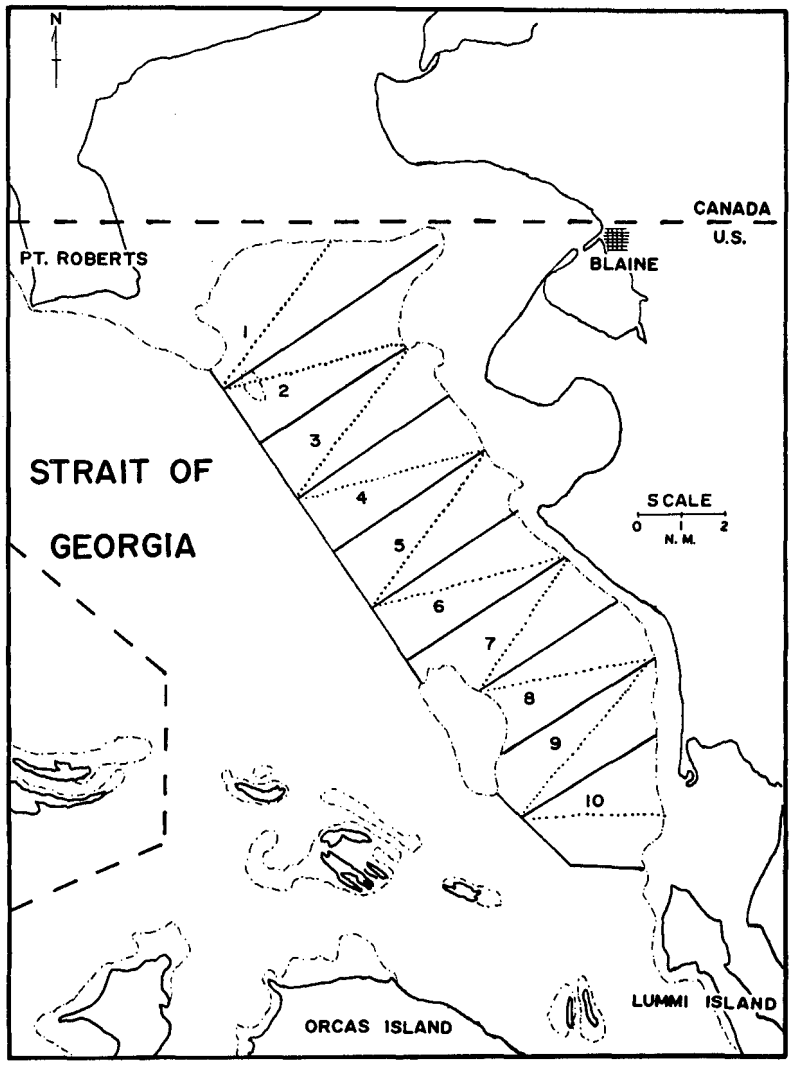

FIGURE 1.—Strait of Georgia standard track line pattern (....). Solid lines and 10-fathom contour (-·-·) define survey subareas (from Lemberg 1978).

fathom contours on the outside. Spawning occurs on adjacent shorelines.

The surveys were conducted at night when the herring were less patchily distributed and further off bottom. Transects were evenly spaced and designed for maximum mileage during hours of darkness. At about 0.5 h per transect, plus turn around and set up time between transects, each survey required the approximately 6 h of darkness.

Data were integrated for density (kg/m^3) at preselected depth intervals for each transect; depth interval densities were accumulated for a depth zone, usually 5-40 m below the surface to calculate an average density (kg/m^2) for each transect. Extrapolation of average density to the surface area represented by each transect, summed over all transects, provided biomass estimates. The acoustic estimates of maturing adult herring biomass were available the afternoon following each survey.

Midwater Trawling Procedures

The midwater trawl sampling was done from chartered 20-24 m commercial fishing trawlers simultaneously with the acoustic surveys. This procedure has two advantages in addition to synopticity. First, the vessel requirements for the acoustic vessel are less demanding so that a smaller, less expensive vessel could be used. Second, it was possible to direct the towing

operation from the acoustic vessel on the basis of target abundance from the echograms in an attempt to approximate optimal sampling allocation (Cochran 1977).

The net employed was a four panel midwater trawl with 9.2 m headrope and footrope and 9.2 m sides designed to open 6.1 m vertically and horizontally; meshes tapered from a 7.6 cm stretch mesh in the wings to a 1.27 cm stretch mesh cod end liner. Head rope floats and chain on the foot rope were used to aid the vertical opening. Trawl doors were metal, V-type, and weighed 31 kg; 55 m dandylines extended from the doors to the side panels. Trawl depth was monitored with a bathykymograph and in 1977, by third wire telemetry to one of the trawl doors.

A typical survey included three to five 30-60 min tows. The number of tows was limited by hours of darkness. Catches were sorted on board by major species, normally herring, dogfish, cod, and smelt, and by incidentals; each species aggregate was weighed separately. Two subsamples of herring were collected from each tow. One subsample was processed on board to determine maturity (prespawning, spent, and immature). The other was returned to the laboratory for length, weight, age, sex, and sexual maturity data.

Spawning Ground Surveys

The herring lay adhesive eggs on lower intertidal and upper subtidal vegetation. The biomass of herring which have spawned can be estimated from the intensity and extent of spawn deposition in conjunction with fecundity, sex ratio, and average weight data (Hourston et al. 1972). The basic procedure is to sample vegetation along the shoreline and note the intensity (number of egg layers) of deposition. A spawning ground survey crew used a small (4-5 m) boat with outboard motor to maneuver nearshore, and a grappling rake to retrieve vegetation at 350-500 m spacing along the spawning grounds. Observations on spawning intensity and extent are then converted to an estimate of the spawning escapement (Trumble et al. 1977; Meyer and Adair 1978). The survey intensity during the spawning period is typically twice weekly for each of four major spawning areas in the Strait of Georgia. During the 2-mo period (April-May) that encompasses the extremes of the spawning period, 15-20 spawning ground surveys are conducted for each of the four areas. The objective to maximize number of surveys to reduce the time between spawn deposition and survey is limited by available personnel.

Catch Records

The Washington Department of Fisheries has a computerized data retrieval system for preliminary catch statistics. Telephone reports of daily estimated catch (soft data) are required from each buyer by noon of the day following the catch. These telephone reports are replaced and updated when fish receiving tickets (hard data) arrive. Management during the fishery used both soft and hard data; this report used final data. Summary reports of daily and cumulative landings by treaty and nontreaty fishermen, and totals for the combined fleet, are available through the catch data retrieval system.

RESULTS

A point estimate of sac-roe herring abundance was made the day following each hydroacoustic survey by incorporating cumulative spawning escapement estimates and cumulative catch up through the date of each hydroacoustic survey. This procedure assumed that acoustic-trawl estimates represent maturing adult fish remaining to spawn, while cumulative catch and escapement account for adult fish removed from the spawning population. The point estimates should be similar once the stock has fully recruited to the area, and will then represent total biomass; as acoustic estimates decline through the season, compensating increases in catch and escapement occur.

1976 Surveys

The total acoustic biomass estimates in the study area during 1976 ranged from an initial value of 1,920 tons 5-8 April to a peak of 21,000 tons on 21-22 April (Table 1). Trawl catches were predominately herring (about 90% by weight). However, a large proportion of the herring biomass was often either juvenile or spawned out fish. Only 58% of the total biomass estimates was maturing herring at the time of the peak estimate. The acoustic-trawl estimates of maturing herring increased from 1,480 tons during the first survey on 5-6 April to a maximum of 12,240 on 21-22 April, and decreased to 0 tons on the last survey, 3-4 June (Fig. 2).

TABLE 1.—Results from hydroacoustic-midwater trawl surveys in the Strait of Georgia, Wash. (weights in short tons), 1976.

Date	Total	Maturing adult herring	Juvenile or spent herring	Miscellaneous	% spawners
4/5-6	1,920	1,480	440	—	77.1
4/13-14	7,030	4,030	2,150	850	57.3
4/21-22	21,100	12,240	6,360	2,500	58.0
4/27-28	10,940	8.370	1,400	1,170	76.5
5/5-6	7,050	3,460	2,170	1,420	49.1
5/19-20	4,530	1,460	1,830	1,240	32.2
6/3-4	2,090	0	990	1,100	0

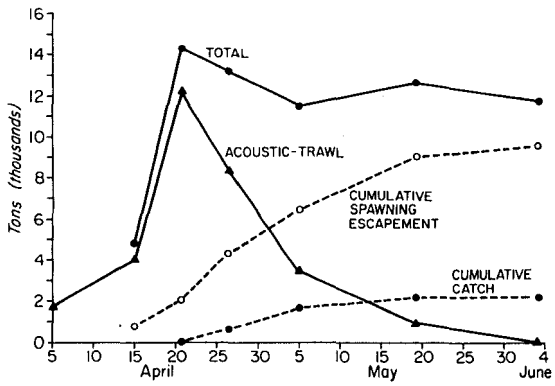

FIGURE 2.—Biomass estimates of adult roe-herring in the Strait of Georgia, 1976.

Fifty-nine spawning ground surveys were conducted between 8 April and 8 June. The total spawning biomass from these surveys was estimated to be 9,590 tons (Fig. 2). The fishery extended from 25 April to 23 May with a total catch of 2,190 tons.

The highest point estimate of total adult herring biomass, on 21-22 April, was slightly over 14,000 tons and was predominately from the acoustic-trawling data. The last estimate, 11,800 tons, was from the spawning escapement estimate plus the total catch. The average of the five estimates between 21-22 April and 3-4 June was 12,700 tons. The fishery harvested 17.4% of the maturing adult biomass, well within the 20% limit.

1977 Surveys

Fish abundance in the study area in 1977 followed the general pattern of 1976, building up to a peak and then declining as the herring moved inshore to spawn. The total acoustic biomass estimates in the study area ranged from a peak value of 10,090 tons on 25-26 April to a minimum value of 3,410 tons on 17-18 May (Table 2). The trawl catches were again predominately herring. The proportion of maturing adult herring ranged from 69% to 84% of the total catch during the first half of the survey period when the acoustic-trawl estimate composed the major component of the total biomass; later in the season proportions decreased. The acoustic-trawling estimate of spawner herring reached a peak of 7,900 tons (Fig. 3).

Seventy-seven spawning ground surveys were conducted from 7 April to 9 June. The estimated spawning escapement was 8,800 tons (Fig. 3). The fishery extended from 11 April to 12 May with a total catch of 2,300 tons.

The timing of the migration differed slightly from 1976. Significant amounts of spawning and substantial catches occurred before the peak of the acoustically measured biomass. Consequently, the first total biomass point estimate after presumably full recruitment, 11,300 tons, included substantial inputs from the spawning ground surveys and catch data, as well as the acoustic (Fig. 3). The last estimate was 11,100 tons, composed of the 8,800 ton spawning escapement estimate and the 2,300 ton catch. The mean of the final catch plus escapement and the five surveys from presumably full recruitment was 11,040 tons. The harvest rate reached 20.8% for 1977.

TABLE 2.—Results from hydroacoustic-midwater trawl surveys in the Strait of Georgia, Wash. (weights in short tons), 1977.

Date	Total	Maturing adult herring	Juvenile or spent herring	Miscellaneous	% spawners
4/5-6	4,530	3,130	1,210	190	69.1
4/12-13	4,340	2,990	1,060	290	68.9
4/18-19	7,480	6,280	710	490	83.9
4/21-22	7,700	5,770	1,230	700	74.9
4/25-26	10,090	7,900	1,430	760	78.3
4/28-29	8,950	5,000	3,160	790	55.9
5/3-4	9,600	4,260	1,610	3,730	44.4
5/10-11	3,560	2,060	1,070	430	57.9
5/17-18	3,410	550	1,960	900	16.1

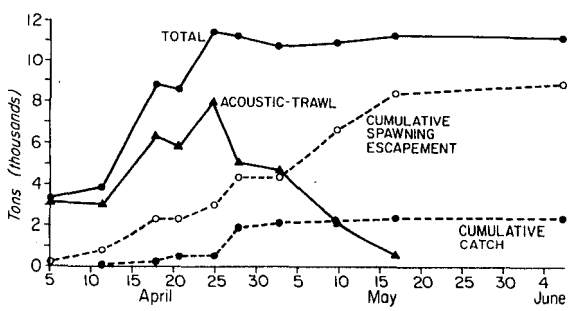

FIGURE 3.—Biomass estimates of adult roe-herring in the Strait of Georgia, 1977.

1978 Surveys

Herring abundance estimated through the 1978 season showed considerably more variability than in other years of the surveys (Fig. 4, Table 3). As expected, abundance was low at the time (11-12 April) of the first acoustic-trawl survey. The following week, 16-22 April, acoustic-trawl estimates of maturing adult herring increased to approximately 13,400 tons in each of two surveys, and the total estimate exceeded 16,000 tons. For the next three surveys, 24 April-1 May, acoustic-trawl estimates of maturing adult herring biomass in the survey corridor dropped considerably, and corresponding total abundance declined to 10,000-11,000 tons. On 4-5 and 8-9 May estimates of total maturing herring increased to 13,000 tons; these latter estimates included 3,500-6,000 tons from acoustic surveys.

The highest biomass estimate occurred just after complete immigration when the estimate comprised mostly acoustic data. The original high values, midseason low values, and intermediate values at the end of the season were composed of at least two similar estimates, which suggests that the changes represent actual occurrences.

The final spawning escapement estimate, based on 67 spawning ground surveys was 8,840 tons. Total catch was 2,120 tons. Cumulative escapement plus catch equaled 10,960 tons. Mean value of the eight population estimates made from the time of completed immigration to the survey area was 12,700 tons. The 16.7% harvest rate, lowest of this 4-yr series, was due to a reduced quota during the midseason period of low abundance estimates.

TABLE 3.—Results from hydroacoustic-midwater trawl surveys in the Strait of Georgia, Wash. (weights in short tons), 1978.

Date	Total	Maturing adult herring	Juvenile or spent herring	Miscellaneous	% spawners
4/11-12	6,340	5,450	700	190	86.0
4/17-18	17,420	13,450	2,540	1,430	77.2
4/20-21	17,420	13,410	3,670	340	77.0
4/24-25	9,100	6,380	1,850	870	70.1
4/26-27	8,820	6,250	1,870	700	70.9
5/1-2	7,310	4,350	1,930	1,030	59.5
5/4-5	9,700	5,960	2,780	960	61.4
5/8-9	6,400	3,650	2,330	420	57.0

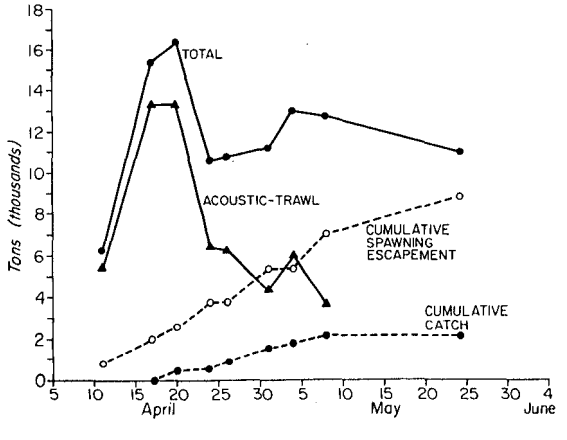

FIGURE 4.—Biomass estimates of adult roe-herring in the Strait of Georgia, 1978.

1979 Surveys

Total all-species acoustic abundance estimates (Table 4) increased from a normal low value of about 3,000 tons in mid-April to a peak of 8,150 tons following presumed full recruitment on 27 April. By the end of the season, estimates were less than 3,000 tons. Maturing adult herring comprised 50-70% of acoustic biomass until the last survey of the season. Early season estimates of 1,000-2,000 tons of adult herring increased to about 5,600 at the peak, and declined to 890 tons on 7-8 May.

Seventy-two spawning ground surveys conducted during 1979 provided an escapement estimate of 8,040 tons. Total harvest was 1,920 tons.

Variation in 1979 seasonal abundance estimates for adult (spawner) herring showed a pattern similar to those observed in 1976 and 1977: biomass increased rapidly early in the season, and remained fairly constant for the duration of sampling (Fig. 5). From the time of full recruitment, total adult herring estimates ranged from 8,000 to 10,000 tons. As in 1977, considerable spawning and catch occurred prior to the peak acoustic estimate, and added considerably to the first estimate following presumed full

TABLE 4.—Results from hydroacoustic-midwater trawl surveys in the Strait of Georgia, Wash. (weights in short tons), 1979.

Date	Total	Maturing adult herring	Juvenile or spent herring	Miscellaneous	% spawners
4/11-12	3,840	2,340	1,460	40	60.9
4/16-17	2,680	1,290	1,370	20	48.1
4/19-20	4,410	2,580	1,530	300	58.5
4/23-24	5,270	3,330	1,730	210	63.2
4/26-27	8,150	5,590	2,200	360	68.6
4/30-5/1	5,750	4,110	1,520	120	71.5
5/3-4	2,510	1,390	1,080	40	55.4
5/7-8	2,870	890	820	1,160	31.0

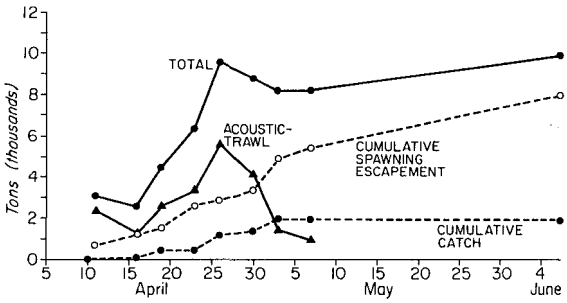

FIGURE 5.—Biomass estimates of adult roe-herring in the Strait of Georgia, 1979.

recruitment. Average estimate of total adult herring biomass was 8,950 tons. The fishery harvested 21.8% of this estimated biomass in 1979.

DISCUSSION AND CONCLUSIONS

The combination of techniques applied in the management of the sac-roe herring fishery provides a timeliness and accuracy greater than any single technique. The catch records are obtained rapidly, but by themselves have little management value. CPUE data are difficult to evaluate in a timely manner and has questionable application in a mixed gill net and purse seine fishery on schooling fishes whose migration patterns and timing vary annually; consequently, CPUE data are not used in the sac-roe herring fishery. The spawning ground surveys provide escapement data, but are not timely for in-season management of the fishery. Conceivably the excess biomass could be harvested after escapement goals have been met, but this approach forces the fishery to the end of the season when fish are younger, smaller, and less valuable than early in the season.

The hydroacoustic-trawling data provide the single most useful information for in-season management. The estimates of potential spawning biomass are available for management decisions by the end of the day following the nighttime survey. The acoustic-trawl data have provided good agreement with the other measure of biomass. The average of the weekly total run size estimates from the sum of all three data sources have varied from 1% to 14% of the final estimate from the catch and spawner escapement estimate (Table 5).

In all 4 yr the peak acoustic-trawling estimate in conjunction with these data has provided a

TABLE 5.—Stock assessment summary, U.S. Strait of Georgia sac-roe herring, 1976-79.

Year	Total catch	Total escapement	Catch + escapement	Average of full recruitment point estimates[1]
1976	2,190	9,590	11,780	12,700
1977	2,300	8,800	11,100	11,040
1978	2,120	8,840	10,960	12,700
1979	1,920	8,040	9,960	8,950

[1]This estimate consists of the average of acoustic-trawl plus cumulative escapement plus cumulative catch point estimates from the time of full recruitment through the final catch plus escapement estimate.

reasonable and timely estimate of total run size. However, the estimate of total run size obtained using the peak acoustic-trawl estimate was higher than the final estimate for all years except 1979, and higher than all in-season point estimates. Variability (random or unsystematic factors) may contribute to the result, but in general the high sampling power of acoustics and the fairly uniform distribution of the herring render this component inconsequential (Saville 1977), and 95% confidence intervals calculated from the acoustic data are typically on the order of ±10%. Variability associated with the trawling data for species composition is probably more important, but is difficult to incorporate. Combined acoustic-trawling variance estimation procedures have been developed for other studies (Thomas 1979; Thomas et al. 1979); however, they were not applied in this study since we were more concerned with the sources of potential error (systematic factors or bias). Three sources of bias may contribute to the observed differences between the peak acoustic-trawling estimate and the final estimate. The acoustic estimates may be biased high because of the target strength assumption, but the acoustic techniques may underestimate later in the run when the fish move into shallow water just prior to spawning. Studies by other investigators indicate that a value of −32 dB/kg (which would result in a 20% lower estimate) may be more reasonable (Nakken and Olsen 1977; FAO 1978) than the −33 dB/kg value used. Alternatively, the estimates from spawning ground data could be biased to the low side.

Clearly more information on target strength is needed to confidently establish the accuracy of the acoustic technique as a measure of fish biomass. The reasonable agreement with the sum of the spawning escapement estimates and catch is reassuring, but the spawning escapement estimates are also subject to bias and uncertainty, and the exploitation rate has been too consistent to give much insight into the magni-

tude and direction of potential bias in these two estimators.

In spite of the present uncertainties in the accuracy of both the spawning escapement and the acoustic-trawl estimates, the results are well suited to the current management plan of the fishery. The objective of present management procedures is to maintain the population at recent historical levels through a combination of a biologically reasonable exploitation rate and a minimum escapement level. The accuracy of the acoustic techniques probably already exceeds our understanding of optimal exploitation rates. Thus, while improvements are conceivable and may be dictated by future developments in the fishery, the present procedures provide a sound interim approach with timeliness which has been rarely achieved in fishery management.

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