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ESTIMATION AND EVALUATION OF A HARVEST THRESHOLD FOR MANAGEMENT OF THE SITKA HERRING SAC ROE FISHERY BASED ON A PERCENTAGE OF AVERAGE UNFISHED BIOMASS

By

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INTRODUCTION

Herring in Southeast Alaska have been managed using a threshold and variable harvest rate policy since 1983. Thresholds are biomass reference levels established for each fishing area. If the spawning biomass at an area is forecast to be below its threshold, no harvest is allowed. When the spawning biomass for an area meets or exceeds the threshold, the exploitation rate is 10% of the estimated spawning biomass. For each incremental increase in the spawning biomass equal to the threshold, the exploitation rate increases by 2%. The maximum 20% exploitation rate is achieved when the spawning biomass is six times the threshold level.

The original goal of the threshold/variable harvest rate policy was to maintain herring populations above the established threshold escapement levels. These levels and the variable harvest rate schedule were intended to protect herring stocks from sharp reductions due to recruitment failure, to maintain adequate abundance of herring as prey for commercially important predator species such as salmon, and to provide for the highest quality commercial herring products.

Initially, area-specific thresholds were established based on: 1) historical estimates of abundance (determined from hydroacoustic surveys, linear miles of spawn, and diver surveys), 2) historical and personal knowledge and judgment of research and area management biologists personal contacts with fishers and other public regarding the relative size and area of various stocks, and 3) biologist's judgment regarding minimum quotas that could be managed and controlled. The thresholds were established with the expressed recognition that the levels would be subject to change as new data and research became available.

Since the original establishment of the thresholds, an additional 13 years of spawning biomass, harvest, fecundity, and growth data have been collected, analyzed, and evaluated for many Southeast Alaska herring populations. Biomass estimates have been improved with the implementation and refinement of diver surveys to estimate total egg deposition. In addition to the availability of more data, recent research on threshold management strategies provides new guidelines for setting harvest thresholds based on more thorough understanding of fish population dynamics.

Quinn et al. (1990) evaluated the influence of threshold management policies on yield, standard deviation of yield, and population rebuilding time of Bering Sea pollock. Assuming that maximizing yield and minimizing the standard deviation of yield were of equal importance, they determined an optimal threshold that generally ranged from 20 to 35% of the average unfished biomass (AUB), with an optimal fishing mortality close to 0.4. Using the same approach of Quinn et al. (1990), Zheng et al. (1993) evaluated threshold management strategies for Pacific herring in Alaska. For herring in the eastern Bering Sea, they determined a median optimal threshold of 20% of AUB, given an exploitation rate of 20%. For Prince William Sound herring they found a median optimal threshold of 15% of pristine biomass given an exploitation rate of 20%. Throughout Alaska, 20% is currently the maximum allowable exploitation rate. Both Quinn et al. and Zheng et al. accounted for environmental variation, possible stock-recruitment relationships, and correlation in recruitment among years (i.e. auto correlation) as part of the process of estimating optimal threshold levels.

Acceptable thresholds in the range of 15 to 35% of AUB have emerged from recent research. Thresholds of 25% of AUB have been used effectively in the management of some Pacific coast herring and groundfish fisheries for as long as eight years. A threshold level of 25% of the average unfished biomass (AUB) is used as a cutoff in the management of herring in British Columbia (Haist and Schweigert, 1990). When British Columbia herring stocks are above thresholds, a straight 20% exploitation rate is used to determine recommended catch. The 25% AUB criterion was used to establish the current 22,000-ton threshold for management of the Prince William Sound herring fisheries. Zheng et al. (1993) suggests that under a 20% exploitation rate a threshold of 25% of AUB provides protection to herring populations and "...approximately maximizes the sustained yields." Funk and Rowell (1995) recently applied the methods of Zheng et al. (1993) to estimate the AUB and recommend a new threshold for management of the Togiak herring fishery consistent with the 25% AUB criterion.

This analysis applies the methods of Zheng et al. (1993) and Funk and Rowell (1995) to estimate the AUB and a 25% AUB threshold for Sitka herring.

METHODS

The AUB of Sitka herring was estimated by simulating a long time series of biomasses in the absence of fishing (Funk and Rowell 1996). Biomasses were simulated by accounting for gains to the mature population from recruitment, maturation and growth, and losses due to natural mortality. Parameter estimates needed to account for changes in biomass were estimated using age-structured analysis (ASA; Carlile et al. 1995, Funk and Sandone 1990). Parameter estimates included the historical time series of numbers of Age-3 recruits, annual survival and age-specific maturity. Weights-at-age were estimated from annual age-weight-length (AWL) sampling at Sitka.

Threshold management policies tacitly assume some density dependent population regulation. However, based on the ASA-estimated Sitka spawner-recruit data (Figure 1, Table 1), the form and strength of the density dependence for Sitka herring cannot be satisfactorily described by conventional spawner-recruit models like a Ricker model. Zheng (1996) reached the same conclusion with respect to most major Southeast Alaska herring populations including Sitka. For this reason, the simulated recruitment time series used for the biomass simulations was generated from an empirical spawner recruit model (Funk and Rowell 1995).

Age-3 recruitment was simulated for 2,500 years by repeated, random sampling of recruits from three strata containing the ASA-estimated age-3 recruits (Figure 1). Strata boundaries at 10,000 and 30,000 tonnes of spawners were determined according to perceived natural breakpoints in the pattern of spawners and recruits. Age-3 recruits for a given year ($N_{3,y}$) were randomly selected from one of three strata based on the value of B_{y-3}, where B_{y-3} is the estimated spawning biomass in year *y-3* (Table 2). This process of recruit selection from specific strata defined the empirical spawner-recruit model used for the simulations.

Annual spawning biomass (B_y) was estimated as:

$$B_y = \sum_a \rho_a \cdot W_a \cdot N_{a,y} \tag{1}$$

where ρ_a is the ASA-estimated proportion of mature herring at age *a*, W_a is the mean annual weight of Sitka herring at age *a* from 1971 to 1996, and $N_{a,y}$ is the number of age *a* herring in year *y*.

The numbers of ages-4 to 8+ fish were estimated as:

$$N_{a,y} = S \cdot N_{a-1,y-1} \tag{2}$$

Average unfished biomass was calculated as the average of the last 2,000 simulated annual spawning biomasses (B_y). The first 500 simulated biomasses were excluded from calculation of AUB to allow the estimates of B_y to stabilize before estimating AUB.

To evaluate the impact of various harvest approaches on catch and biomass we simulated catch under the current Sitka threshold (7,500 tons) and the estimated 25% AUB threshold and for different harvest rate formulas (Table 2). We also explored three different spawner-recruit models based on spawner-recruit estimates from the Sitka ASA model (Figure 1). For the harvest simulations,

$$N_{a+1,y+1} = S \cdot (N_{a,y} - C_{a,y}) \tag{3}$$

Equations for estimating $C_{a,y}$ are provided in Appendix A. Total catch was simulated using the Southeast sliding scale harvest rate formula applied to simulated biomasses. Estimates of seine gear selectivity used in catch simulations were estimated from the ASA. Average fished biomass and catch were simulated for 2,000 years. Each 2,000-year simulation was repeated ten times and the average AFB, catch, coefficient of varions (CV) of catch and percent of years with fisheries was estimated.

A threshold could be implemented into the management of the Sitka herring fishery in various ways. I explored the impacts of alternative harvest scenarios on projected average fished biomass (AFB) and catch, CV of catch and the percent of years with fisheries when compared to the status quo threshold and harvest rate formula (Table 2). Both alternative scenarios use the estimated 25% AUB threshold. The scenarios differ only with respect to the harvest rate formulas. Scenario B includes the status quo 7,500-ton value as part of the harvest rate formula, whereas Scenario C includes the new 25% AUB threshold as part of the harvest rate formula.

Each harvest scenario was evaluated under three slightly different empirical spawner-recruit models. The first spawner-recruit model (S-R Model 1) was the same model used to estimate AUB (Figure 1). The second model (S-R Model 2) differed from the first only in that the number of recruits estimated from the 1976 year class was changed from the ASA-estimated value to the average of the other recruit values in Stratum A. This was done to evaluate the sensitivity of the simulation to this one value. For the third spawner-recruit model (S-R Model 3) I shifted the stratum boundary between Strata B and C from 30,000 tons to 32,000 tons. This shift in the boundary had the effect of shifting the recruit estimates from the 1980 and 1989-year classes from Stratum C to B.

The ASA-estimated annual survival rate (S) was 0.522. Maturities and weights-at-age used for biomass simulations are included in Table 4.

RESULTS

Estimated AUB for Sitka is 67,036 tons (Figure 2). Application of the 25% of AUB criterion for determining thresholds yields a new Sitka threshold of 16,759 tons.

Under S-R Model 1, the AFB for Scenario A (i.e. status quo 7,500 tons threshold and harvest rate formula) was 30,489 tons (Figure 3). When the 25% AUB threshold was combined with the status quo harvest rate formula (Scenario B, Table 3), the AFB decreased to 26,191 tons (Figure 3). The AFB was highest, 40,701 t, under Scenario C. For this S-R Model 1 the average catches among the three harvest scenarios followed a relative pattern similar to the AFB ranging from 3,769 to 6,031 t (Figure 4). The CV of catch was highest for Scenario B (152%), followed by Scenarios C (119%), and A (114%, Figure 5). Scenario A had the highest predicted percentage of years with fisheries (88%, Figure 6). Scenario B had the lowest percentage at 49% and Scenario C was intermediate with 64% of the years with fisheries (Figure 6).

Spawner-Recruit Model 2 differed from Model 1 only by a single S-R data point. For this model the ASA recruit estimate of 1.03 billion was changed to 82.3 million, the mean of the other recruit estimates in Stratum A, to determine the influence of this one data point. The AFBs and average catches were markedly lower under S-R Model 2. For Scenario A the AFB of 30,489 tons under Model 1 declined to 10,117 tons under Model 2 (Figure 3). Similarly, for Scenario B the AFB declined from 26,191 to 11,566 tons and for Scenario C, from 40,701 to 11,470 tons (Figure 3). Average catches under Model 2 also declined markedly to 953, 340, and 260 tons for Scenarios A-C (Figure 4). The CVs of catch increased substantially for Scenarios B and C, but decreased somewhat for Scenario A (Figure 5). Under S-R Model 2, the percentage of years with fisheries decreased for all scenarios. The percentage of years declined from 88 to 68% for Scenario A (Figure 6). The percentages of years with fisheries declined more dramatically under Scenarios B (49% to 14%) and C (64% to 13%, Figure 6).

The AFBs were highest for all scenarios under S-R Model 3. This model differed from Model 1 in that the boundary between Strata B and C was changed from 30,000 to 32,000 tonnes of spawners (Figure 1). This shifted two S-R data points from Strata C into B. In particular, this change resulted in the inclusion of the recruit estimate generated from the 1980-year class (905 million recruits) being shifted from Stratum C into Stratum B. Consequently, the highest estimated number of recruits in Stratum B increased from 269 million under S-R Model 1 to 905 million recruits under Model 3. The AFBs under Model 3 ranged from 35,347 t for Scenario A through 44,370 t for Scenario B to 60,606 t for Scenario C (Figure 3). Average catch varied in the same relative order, from 6,331 to 10,174 t (Figure 4). The CV of catch among the scenarios varied inversely with AFB and catch, from 110 to 80% (Figure 5). The percent of years with fisheries were highest under S-R Model 3, varying from a high of 89% for Scenario A to a low of 74% for Scenario B (Figure 6).

The above results address the possible longer-term results (i.e. over a simulated 2,000-year time horizon) of various threshold and harvest rate approaches under some assumed spawner-recruit models. Figure 7 can be used to help evaluate the possible short-term impact of the various threshold and harvest rate formula approaches. Under the three-different harvest scenarios, if the forecast is between 7,500 and 16,578 tons, harvest would be allowed only under Scenario A, the status quo threshold of 7,500 tons and the status quo harvest rate formula (Figure 7; see also Table 3). Above forecasts of 16,758 tons, harvest would be allowed under all three scenarios. The quotas for Scenarios A and B would be the same, since these scenarios differ only with respect to thresholds. The harvest rate formulas are the same for these scenarios (Table 3). A distinction between Scenarios A and B is that harvest rates for Scenario A can range from 10 to 20%, whereas harvest rates under Scenario B would effectively range from 12.5 to 20%. With forecasts above

16,759 tons, quotas under Scenarios A and B would be greater than those allowed under Scenario C up to a forecast of 102,500 tons, where the quotas converge. Thereafter all quotas would be the same. Note that the highest ASA-estimated Sitka spawning biomass during the period 1980 to 1995 has been about 61,000 tons (Figure 7). When the forecast is above 16,759 t., the maximum difference in quotas between Scenarios A/B and C would be at a forecast of about 45,000 tons, when there would be almost a 3,000-t difference in quotas (Figure 7). Put in a historical context, over the period 1980 to 1995 the ASA-estimated Sitka spawning biomass ranged from a low of 25,000 tons in 1982 to a high of 60,800 tons in 1992, with a median of 38,500 tons.

DISCUSSION

A herring harvest strategy with a harvest rate of 20% when a population is above a threshold of 25% of the AUB has been suggested as an approach that would protect herring populations yet approximately maximize sustained yield (Zheng et al. 1993). This type of harvest strategy is used in British Columbia (Schweigert 1993) and Prince William Sound, Alaska, and has been recommended for use in the Togiak, Alaska herring fishery (Funk and Rowell 1996). Application of the 25% AUB criterion at Sitka with the variable harvest rate, rather than a constant 20% harvest rate, would presumably provide greater protection for the Sitka herring population while reducing the yield.

Assumptions about the possible form of an underlying spawner-recruit relationship at Sitka markedly affected conclusions about the possible long-term impact of a particular harvest strategy. Evaluation of the empirical spawner-recruit relationship with boundaries at 10,000 and 30,000 tons of spawners (S-R Model 1) resulted in higher AFBs and catches under Scenario A than under Scenario B. Scenario A used the status quo 7,500-ton quota and also used the 7,500-ton value in the harvest rate formula. Scenario B used the estimated 25% ABU threshold but retained the 7,500 ton value for the harvest rate formula.

Presumably, Scenario B would be more conservative and result in higher AFBs than for Scenario A, since a higher threshold would need to be attained before any harvest occurred. The unexpected reverse response occurred because of the high number of recruits associated with the 1976 year class in Stratum A of the S-R Model 1 (Figure 1). In the simulations, the more frequent fisheries allowed under the 7,500 ton threshold of Scenario A tended to reduce post-fishery populations to less than 10,000 tonnes more often than did the theoretically more conservative 16,759 tons threshold associated with Scenario B. The more frequent incidence of simulated post-fishery populations ending up in Stratum A apparently increased the probability of randomly selecting the 1.03 billion recruits data value within that stratum, resulting in a higher AFB for Scenario A than Scenario B under S-R Model 1 (Figure 3).

Application of S-R Model 2 confirmed the extreme influence of the 1976 year-class recruit data point. Spawner-recruit Model 2 differed from Model 1 only in that the 1.03 billion recruit value in Stratum A was changed to 82.3 million, the mean value of the other seven recruit data points in the stratum, under Model 2. This was done as a sensitivity analysis to evaluate the influence of the 1.03 billion-recruit data point. The change in value of the 1976 data point had substantial influence on AFB, catch, CV of catch, and percent of years with fisheries. The AFBs for the three threshold-harvest rate scenarios were all lower, by 56 to 72%, under S-R Model 2 compared to Model 1. Among the scenarios, average catches for Model 2 were 82 to 95% lower than for Model 1. Also, the relative sizes of catches for Scenarios A and B were reversed, with a slightly greater catch for Scenario B (Figure 3). Under Model 2 the CVs of catch increased substantially for

Scenarios B and C compared to Model 1 (Figure 5), while the incidence of fisheries dropped substantially for those scenarios.

The substantial influence of a single data point in the spawner-recruit models is reinforced when results of Models 1 and 3 are compared. These two models differed only in the boundary between Strata B and C. In going from Model 1 to 3, the boundary between these two strata shifted from 30,000 to 32,000 tons of spawners. This shifted the 1980 and 1989-year class recruit values from Strata C to B (Figure 1). The principal impact of this change was the shift of the 1980 value of 905 million recruits from Strata C to B. The highest recruit value in Stratum B under Model 1 was 268 million recruits. The inclusion of the 905 million-recruit data point in Stratum B resulted in marked shifts in the levels and patterns of AFB, catch, CV of catch, and percent of years with fisheries when compared to S-R Models 1 and 2. The AFBs, catches and percent of years with fisheries were highest for all scenarios under Model 3. In addition CVs were lowest for all combinations of harvest scenario and S-R models except Scenario A under Model 2. The shift of the 905 million-recruit value into Stratum B had the effect of reducing the incidence of periods of low abundance in the simulated populations and reducing the magnitude of biomass fluctuations. Under Models 1 and 2, simulated post-fishery spawner levels that fell within Stratum B always resulted in recruit values no greater than 268 million, whereas under Model 3, those same levels within Stratum B periodically resulted in random selection of the 905 million recruit level. Once included for a particular simulation year, the 905 million recruits continued to contribute relatively high biomasses for the ensuing five years as that cohort made its way through the annual populations.

Empirical spawner recruit models were used to evaluate the impacts of alternative harvest scenarios due to the pattern of the ASA-estimated spawner recruit values (Figure 1). In part due to the recruits that arose from the 1976-year class, these data do not suggest ready definition of an underlying spawner-recruit using conventional spawner-recruit models such as a Ricker or Beverton-Holt model. Consistent with this general observation, Zheng (1996) found no apparent spawner-recruit relationship for Sitka herring. However, Zebdi and Collie (1993) defined an environmentally dependent Ricker model that incorporated sea surface temperature anomalies and spawners as explanatory variables affecting Sitka herring recruitment.

Despite the difficulty in describing an underlying spawner recruit relationship for Sitka herring using conventional spawner-recruit models, the spawner-recruit data in Figure 3 do suggest a greater probability of higher recruitments with higher levels of spawners. Zheng (1996) reaches a similar conclusion about herring in the North Atlantic and Northeast Pacific Oceans. Myers and Barrowman (1996) reached a similar conclusion about a much wider variety of fish species worldwide.

The general tendency for the highest levels of recruits to be associated with the higher spawner levels contrasts with spawner recruit patterns from Togiak herring. For Togiak herring, Funk and Rowell (1995) found that the highest levels of recruits tended to be associated with lower levels of spawners over the range of spawning biomass for which they had data.

These observations support the merits of maintaining high levels of spawners as a means of promoting high levels of recruitment. Revision of the Sitka herring threshold to be consistent with the 25% AUB convention would be one method of promoting higher levels of spawners. Application of the 25% AUB convention would raise the Sitka threshold from 7,500 to 16,759 tons.

A revised Sitka threshold could be applied in at least two ways within the general context of the Southeast herring management strategy. The current strategy for management of Southeast Alaska herring uses a variable 10-20% harvest rate when a population is above its threshold. The Southeast Alaska variable harvest rate strategy is considered more conservative and conducive to maintaining higher levels of spawners than strategies based on constant 20% harvest rates. The allowable harvest rate within the 10-

20% range is determined by a formula, which includes the population-specific threshold level (Table 3, Harvest Scenario A). Application of the harvest rate formula to include the 16,759 ton threshold level (Table 3, Harvest Scenario C) would reduce the annual quota by as much as 33% compared to the current harvest strategy (Table 3, Harvest Scenario A), when the forecast is above threshold. Harvest Scenario B includes the 25% AUB value for the actual threshold for determining whether or not a fisher will be conducted but maintains the 7,500-threshold value in the harvest rate formula. Harvest Scenario B (Table 3) may be viewed as an intermediate strategy that would provide the added protection of a higher threshold while not decreasing catches when the population forecast is above threshold.

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Table 1. Sitka herring spawner-recruit data estimated from ASA.

Year Class	Biomass (B_{y-3}; tonnes) that spawned Age 3 recruits	Age-3 Recruits (millions)	Stratum for Empirical Spawner-Recruit Model
1974	7,136	49.1	A
1978	6,481	33.1	A
1971	4,918	23.0	A
1975	4,824	195.9	A
1973	4,398	13.6	A
1972	4,105	30.0	A
1977	3,625	231.7	A
1976	3,488	1,030.2	A
1983	27,788	268.0	B
1991	27,605	68.9	B
1986	24,956	13.7	B
1990	21,767	35.1	B
1982	21,286	70.4	B
1979	17,304	134.8	B
1988	47,611	1,707.5	C
1992	43,125	449.4	C
1984	38,715	1,719.0	C
1987	36,103	53.9	C
1981	34,590	335.0	C
1985	33,948	191.3	C
1993	32,434	890.0	C
1980	31,189	905.3	C
1989	31,188	88.7	C

source: RKSIM96x.xls; Spawner-Recruit Data

Table 2. Criteria for selecting Sitka age-3 herring recruits for biomass simulations.

If...	*the recruits are chosen randomly from Stratum:*
$B_{y-3} < 10{,}000$ tonnes	A
10,000 tonnes $< B_{y-3} < 30{,}000$ tonnes	B
$B_{y-3} > 30{,}000$ tonnes	C

source: simway.xls

Table 3. Alternative Sitka herring harvest scenarios.

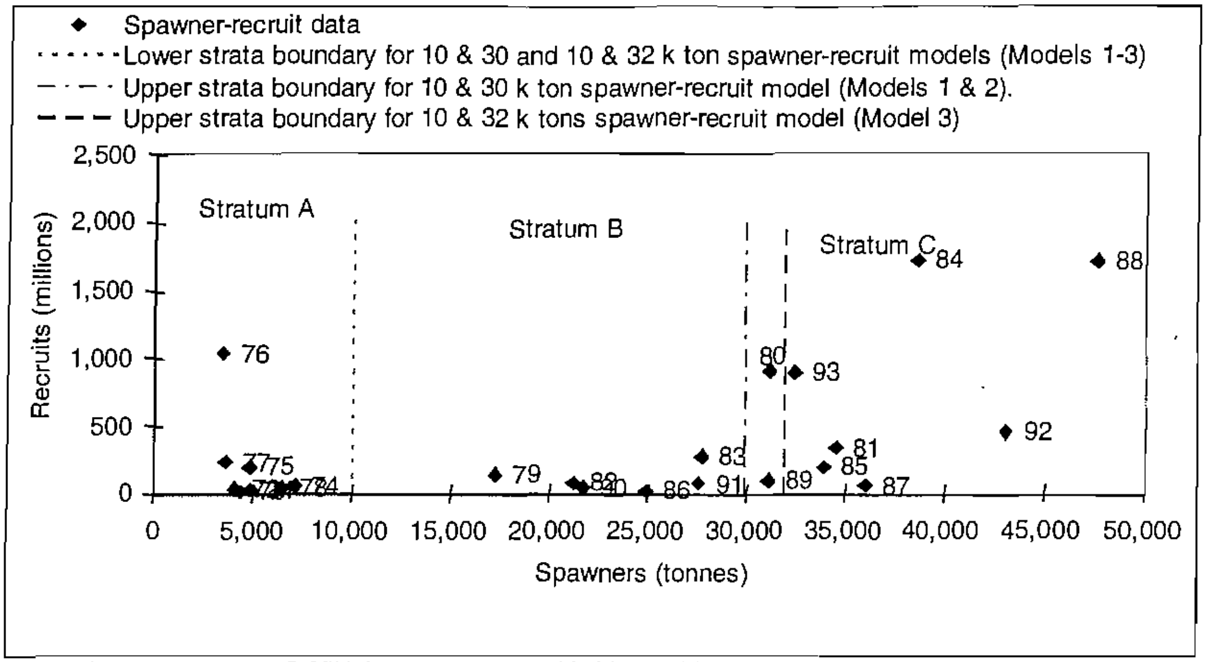
Harvest Scenario Alternative	Threshold (tons)	Harvest Rate Formula
A (status quo)	7,500	$\% \text{ harvest rate} = 8 + 2 \cdot \left(\frac{\text{forecast biomass}}{7{,}500}\right)$
B	16,759 (25% AUB)	$\% \text{ harvest rate} = 8 + 2 \cdot \left(\frac{\text{forecast biomass}}{7{,}500}\right)$
C	16,759 (25% AUB)	$\% \text{ harvest rate} = 8 + 2 \cdot \left(\frac{\text{forecast biomass}}{16{,}759}\right)$

source: altscene.xls; Alternative Harvest Scenarios

Table 4. Sitka herring population parameter estimates used in biomass simulations.

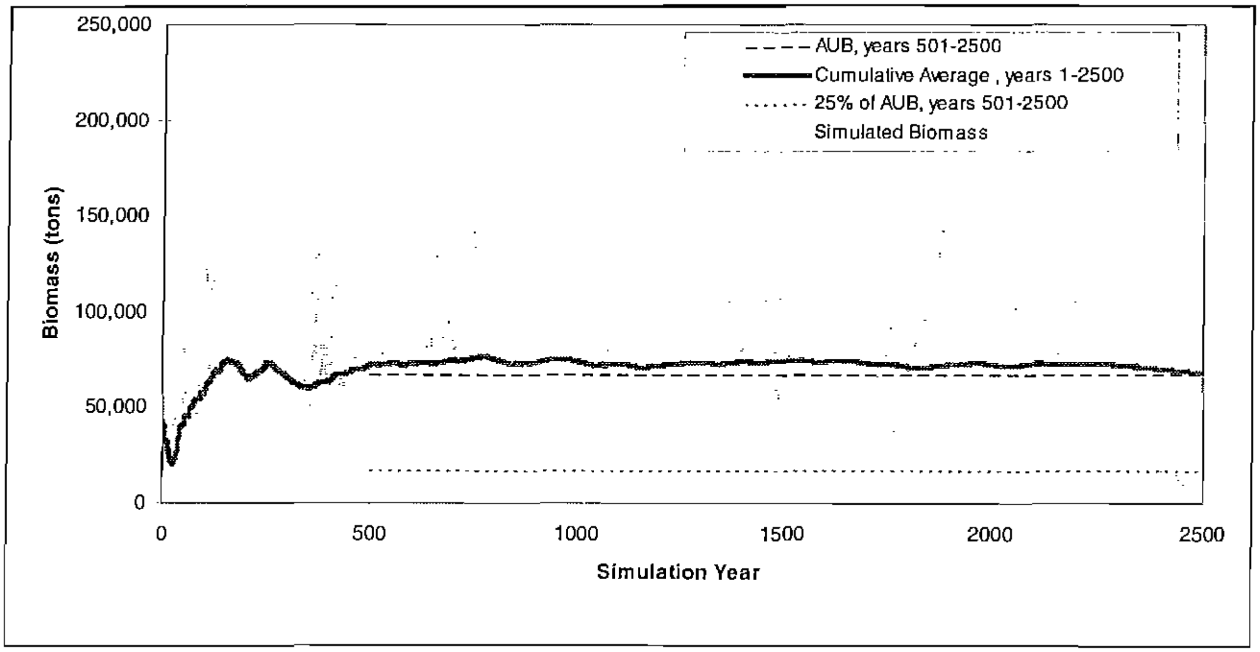
	AGE CATEGORY					
Parameter	3	4	5	6	7	8+
Mean Weight (g) 1971-1996	72.7	92.7	113.7	133.0	149.0	167.9
Proportion Mature	0.19	0.68	0.95	0.99	1.00	1.00

source: RKSIM96X.xls; Spawner-Recruit Data



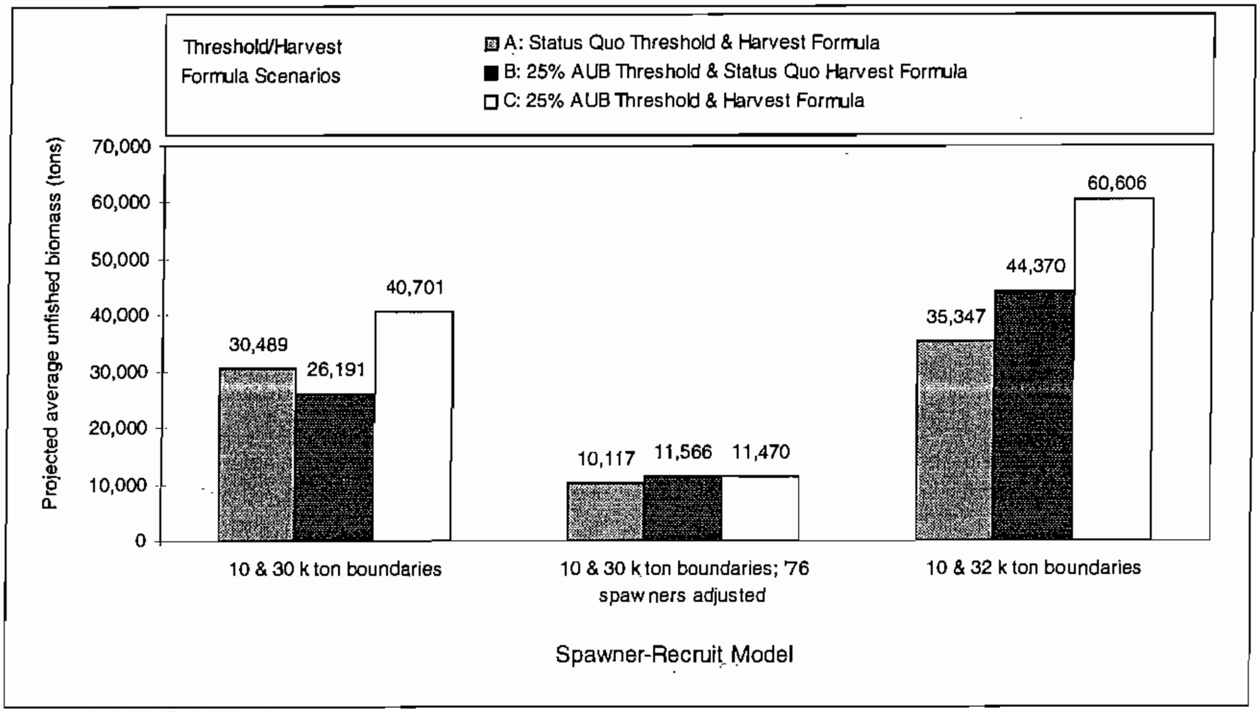
source: c:\her\asa\1997\sitka\new7195\biofore.xls; Graph of Empirical S-R Model.

Figure 1. Sitka herring spawner-recruit data estimated from ASA. Values near each data point are year classes.



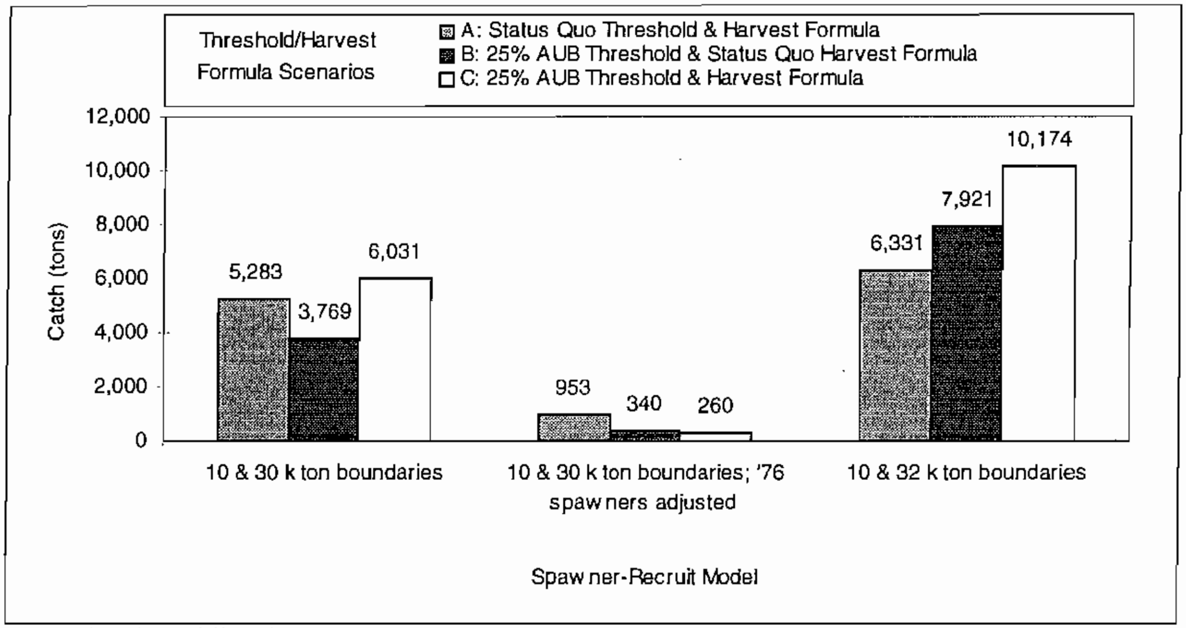
source: RIKSIM96X.xls: AUB Graph for Report

Figure 2. Simulated unfished biomass, AUB and 25% AUB and 25% AUB for Sitka herring based on empirical, 3-strata spawner-recruit model.



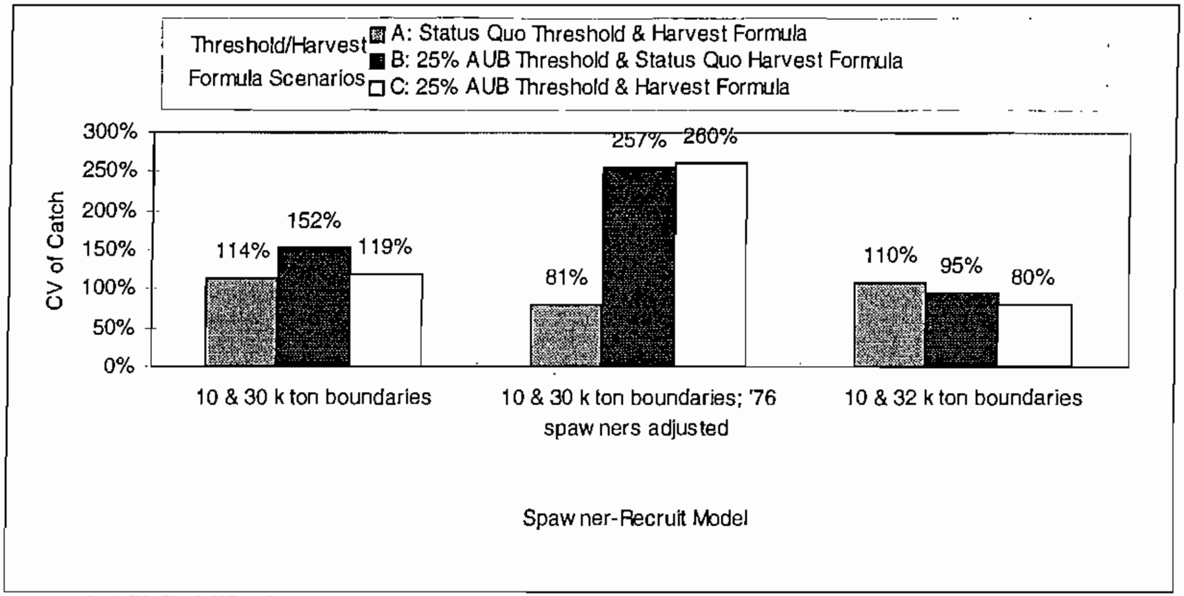
source: scenario.xls: Sitka Threshold Scenarios

Figure 3. Predicted average unfished biomass of Sitka herring under different spawner-recruit models and threshold/harvest rate formula scenarios.



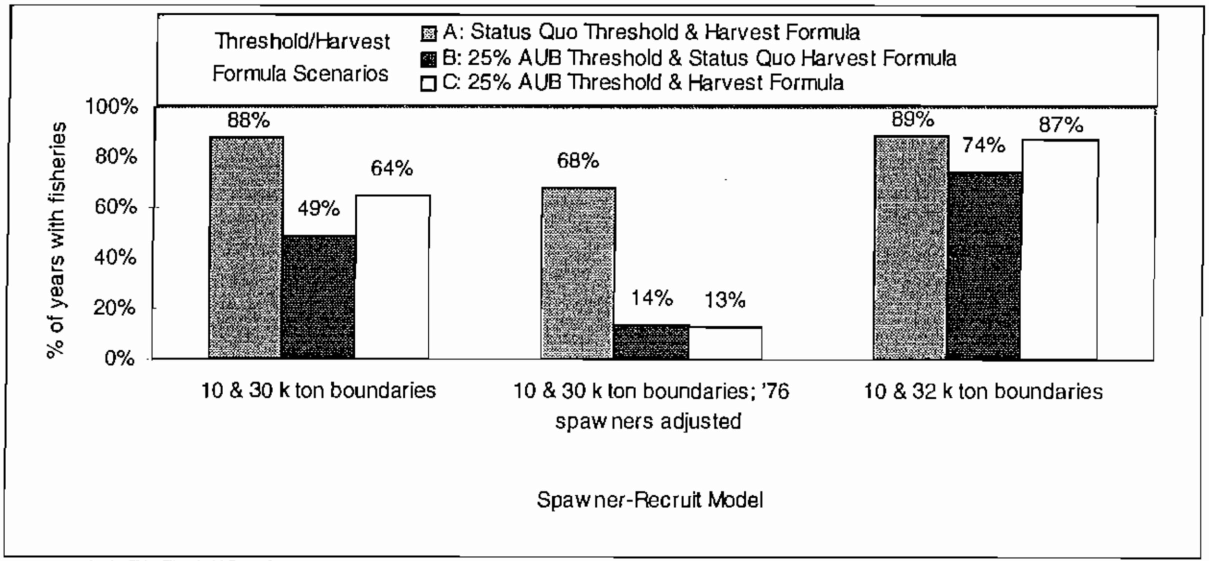
source: scenario.xls: Sitka Threshold Scenarios

Figure 4. Predicted average catch of Sitka herring under different spawner-recruit models and threshold/harvest rate formula scenarios.



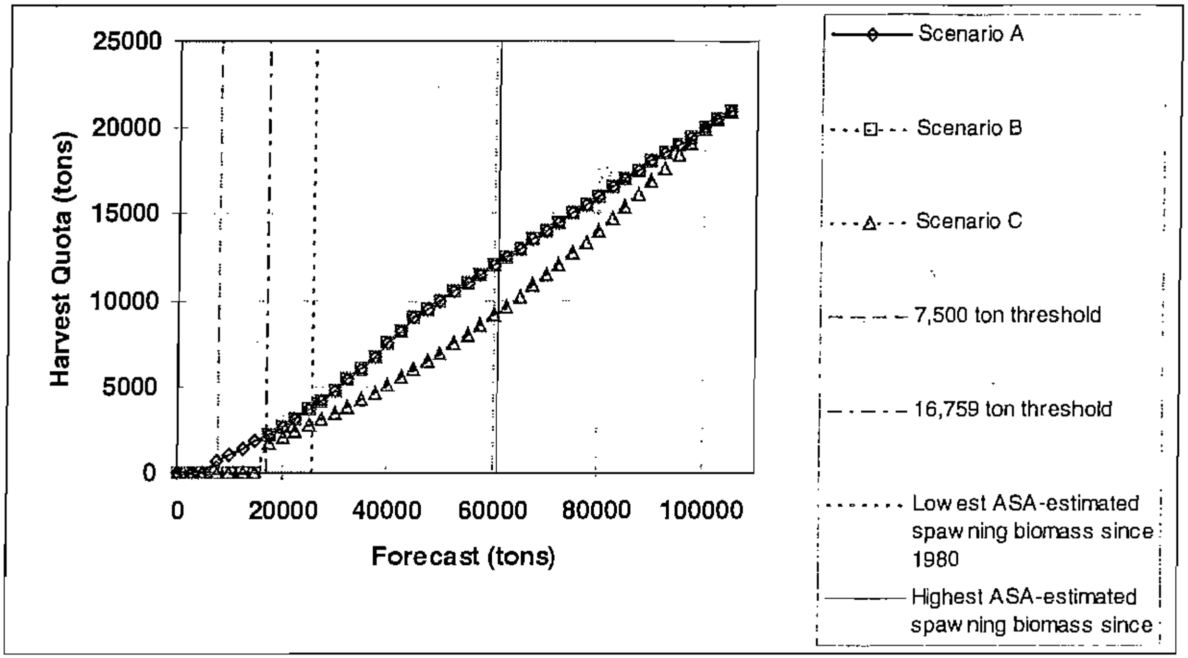
source: scenario.xls; Sitka Threshold Scenarios

Figure 5. Predicted average coefficient of variation in Sitka herring catch under different spawner recruit models and threshold and harvest rate formula scenarios.



source: scenario.xls; Sitka Threshold Scenarios

Figure 6. Predicted average percent of years with Sitka herring fisheries under different spawner-recruit models and threshold and harvest rate formula scenarios.



source: altscene.xls: Alternative Harvest Scenarios

Figure 7. Potential quotas for Sitka herring fishery under alternative harvest scenarios.

APPENDIX

Appendix A. Estimation of catch.

The following equations are used to calculate the catch of age *a* fish in year *y*. These equations yield estimates of catch-at-age in numbers of fish, accounting for exploitation rates that are applied to the biomass.

The catch of age *a*-1 herring in year *y*-1 was estimated as

$$C_{a,y} = \frac{P_{a,y} \cdot \mu_y \cdot B_y}{\sum_a P_{a,y} \cdot W_a}$$

and the proportion of catch-at-age (numbers) is

$$P_{a,y} = \frac{V_a \cdot N_{a,y}}{\sum_a V_a \cdot N_{a,y}}$$

where V_a is the ASA-estimated seine vulnerability for age *a* herring. The exploitation rate in year *y* is

$$\mu_y = 0 \ when \ forecast \prec threshold$$

$$\mu_y = \left[8 + 2 \cdot \left(\frac{forecast}{threshold}\right)\right]^{-100} \ when \ 0.1 \le \left[8 + 2 \cdot \left(\frac{forecast}{threshold}\right)\right]^{-100} \le 0.2$$

$$\mu_y = 0.2 \ when \ \left[8 + 2 \cdot \left(\frac{forecast}{threshold}\right)\right]^{-100} \succ 0.2$$