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Population Model Suggests New Threshold for Managing Alaska's Togiak Fishery for Pacific Herring in Bristol Bay

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ABSTRACT: The threshold biomass for fisheries on Pacific herring *Clupea pallasi* that spawn near Togiak, in Bristol Bay, Alaska, was reviewed based on the data collected in the decade following threshold harvest policy initiation in 1987. The current threshold of 31,752 mt (35,000 tons), below which fishing is precluded, was found to be too low. This threshold had been set at 25% of the spawning biomass during a period that included substantial harvests. A threshold set at 25% of the average unfished biomass (AUB) is widely used in other herring fisheries along the Pacific coast. A 1,000-year simulation of abundance was used to determine AUB under several possible spawner-recruit relationships and sets of stock-assessment data. Four alternative age-structured assessment (ASA) models fit to the available data for Togiak herring under different sets of assumptions were used to represent the uncertainty in the stock-assessment data. A large discrepancy between abundance trends from aerial surveys and trends apparent in age-composition data resulted in a large amount of uncertainty about past biomass levels in the ASA model, which was reflected in the AUB estimates. Ricker and empirical spawner-recruit models fit to the information from the ASA analysis were used to simulate density-dependent effects on recruitment. The uncertainty in the basic population dynamics data provoked a wide range of AUB estimates under different sets of assumptions. AUB estimates ranged from approximately 159,000 to 433,000 mt, and the resulting thresholds ranged from approximately 40,000 to 108,000 mt. Based on this information, we recommend that the Togiak threshold be raised to at least 45,000 to 50,000 mt, pending further resolution of the discrepancies between abundance trends from aerial surveys and abundance trends from age compositions. Setting thresholds at 25% of AUB only rarely triggered fishery closures and these fishery closures produced very little reduction in long-term average yield.

INTRODUCTION

Harvest policies for Pacific herring *Clupea pallasi* fisheries in Alaska include 2 types of management control: thresholds and exploitation rates. When the spawning biomass is below the threshold, no commercial fishing is allowed. When the spawning biomass is above the threshold, exploitation rates are generally 20%. Some fisheries gradually increase the exploitation rate up to a 20% maximum as the biomass increases above the threshold. Two types of thresholds can be defined depending on the rationale used in establishing the threshold. A conservation threshold, below which a population may experience complete reproductive failure, might be defined based on features of a well-understood spawner-recruit relationship. This type of threshold is designed to prevent the extinction of the species or stock. Alternatively, for Pacific herring and many other exploited species, a productivity threshold is defined in terms of quickly rebuilding a population to commercially productive levels. Thresholds defined in terms of productivity are always higher than conservation thresholds designed to merely prevent extinction.

Similar to many harvest policies, the threshold/exploitation rate harvest policy reflects a tradeoff between maximizing the yield from a resource and maintaining stable yields over the long term. For example, a herring exploitation rate > 20% will increase the average yield considerably, but stock size and harvests will be much more variable from year to year. At very high exploitation rates stock size fluctuations can be so pronounced that reproductive failures occur during periods of low abundance. At very low exploitation rates, yields can be more constant from year to year, and stock size will fluctuate less. The 20% exploitation rate for herring is a compromise between the extremes.

A threshold is included in the harvest policy for Pacific herring to combine some advantages of constant

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exploitation rate policies with some advantages of fixed escapement policies. When the biomass is high, a constant exploitation rate is used to provide a balance between average yield and variation of yield. When the biomass drops to low levels, the fixed escapement strategy is adopted to protect the population and more quickly return it to productive levels.

The largest herring fishery in Alaska occurs on herring that spawn along the north shore of Bristol Bay, near the village of Togiak (Figure 1). Catches in this fishery have ranged from 10,000 to 27,000 mt since 1980. The current threshold for the Togiak fishery of 31,752 mt (35,000 tons) was established by regulation in 1987. When this regulation was adopted, only a limited time series of stock assessment information was available for the Togiak herring population. Initial thresholds for Togiak and other Alaskan herring fisheries were established rather arbitrarily, usually based on some proportion of past catches or abundances. At Togiak the threshold level was set at 25% of the average annual aerial survey biomass estimates from 1978 through 1985, excluding 3 years when abundance estimates were unreliable. The purpose of our analysis is to update threshold recommendations for the Togiak herring fishery based on recent stock-assessment information and the contemporary concept of productivity thresholds.

Most threshold analyses express threshold levels as a percentage of a long-term average of annual spawning biomass in the absence of fishing, or average unfished biomass (AUB), which is also referred to as "pristine biomass." Although AUB is an estimate of the long-term average biomass absent fishing, AUB is of necessity based on observed historical data that almost always has been collected under the influence of fishing. Simulation models (e.g., Zheng et al. 1993; Haist 1990; Schwiegert 1993) are usually used to try to remove the effects of fishing on the recruitment level and observed measures of abundance when calculating AUB.

Threshold levels have been set at 25% of AUB for the major British Columbia herring fisheries since 1985 (Haist 1990). The British Columbia threshold criteria was originally based on the simulation model described in Hall et al. (1988), and was subsequently reviewed by Haist (1990) and Schwiegert (1993).

Recently, Zheng et al. (1993) and Zheng (1994) analyzed harvest policies for Pacific herring in Alaska using a much more comprehensive model than earlier studies. This model incorporated stock assessment measurement error, harvest policy implementation error, autocorrelation of environmental effects on recruitment, and alternative forms of spawner-recruit relationships. Thresholds set at 25% of AUB with exploitation rates of 20% were on the conservative side of the recommendations by Zheng et al. (1993) and Zheng (1994). Although setting exploitation rates at 20% was more conservative than their optimal policy, they noted the effect of having such a conservative harvest policy caused little loss in their measure of long-term yield and stability of yield. At a 20% exploitation rate, average yields were maximized when

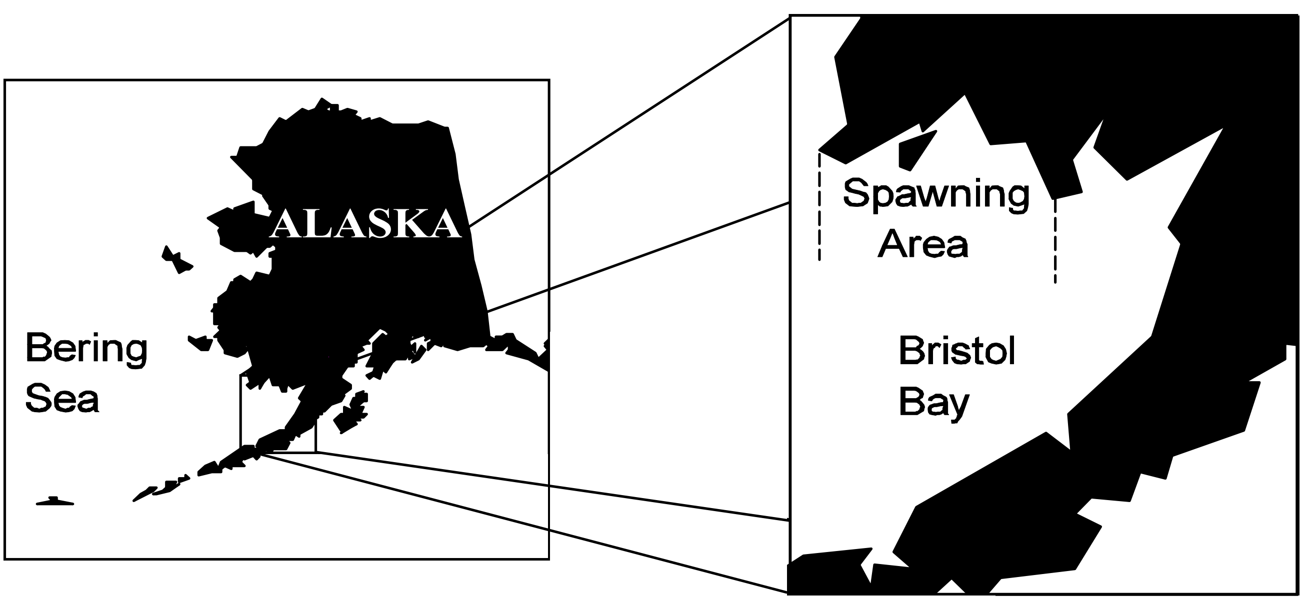

Figure 1. Location of herring spawning and sac roe fishery near Togiak in Bristol Bay.

thresholds were approximately 25% of the AUB (Figure 2). Our analysis applies the methods of Zheng et al. (1993) using a recent time series of abundance data for Togiak herring from an age-structured assessment (ASA) model (Rowell and Funk 1994). The objective of our work was to recommend a revised threshold for management of the Togiak herring fishery that reflects the uncertainty in the stock-assessment information for Togiak herring.

METHODS

Following Zheng et al. (1993) and Zheng (1994), we determined AUB for the Togiak herring population using a population-simulation model based on historical data. The model simulated a herring population undergoing the processes of recruitment, growth, maturation, and natural mortality for a long period. Because all of the pertinent data for Togiak herring were collected after substantial fisheries began, we assumed throughout this analysis that fishing effects were confined to removals from the population. Therefore, we assumed that fishing did not affect growth, natural mortality, maturity, or the relationship between spawning biomass and recruits. Two primary areas of uncertainty about AUB were investigated: (1) uncertainty about the relationship between spawners and recruits, and (2) uncertainty in stock assessment information. A great deal of the uncertainty about the spawner-recruit relationship was due to the relatively

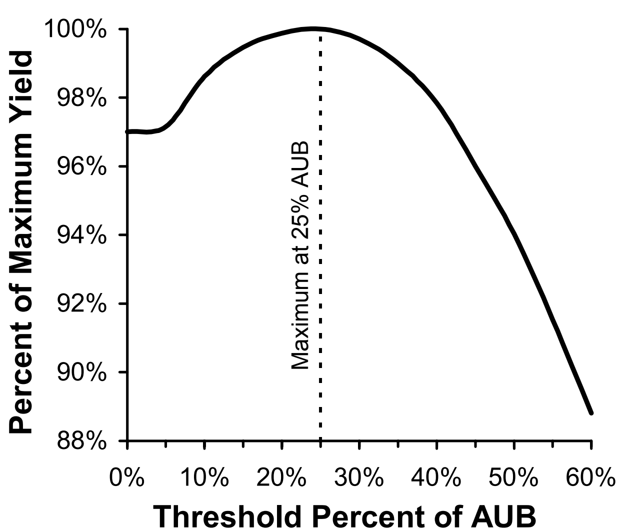

Figure 2. Average yield at a 20% exploitation rate as a function of threshold level where average yield is expressed as a percentage of the maximum yield at a 20% exploitation rate (data from Zheng 1994).

short time series of available data. Consequently, there is a wide range of possible functional forms for the spawner-recruit relationship, as well as a large amount of variability in the relationship. The uncertainty in stock assessment for Togiak herring results primarily from poor correlation between aerial survey abundance trends and long-term abundance trends evident in the time series of age-composition data. Stock-assessment uncertainty also results from a relatively wide range of possible maturity schedules and natural survival and from the effects of aging error on stock-assessment estimates.

Population Dynamics Data Sources

The basic set of population dynamics data came the ASA model used for the 1995 Togiak herring forecast (Rowell and Funk 1994). This ASA model synthesizes the multitude of observed data for 1978 to 1994 (purse seine age compositions, age compositions of the total run, and selected aerial survey biomass estimates) into a single set of estimates of cohort abundance, maturity, purse seine availability, and survival. The central problem in interpreting Togiak stock assessment information is that abundance trends from aerial surveys conflict strongly with abundance trends determined from the time series of age compositions. Biomass estimates from aerial surveys describe very little change in abundance between 1978 to 1994 (Figure 3). However, the time series of age-composition data collected over this period clearly and consistently show the recruitment and senescence of the very large 1977 and 1978 year classes. In contrast to the aerial survey data, age-composition data depict greatly increased abundance during the mid to late 1980s.

Rowell and Funk (1994) attempted to resolve this conflict by selecting a subset of the highest quality annual aerial survey data. In particular, fishery managers had increased confidence in the recent (1992–1994) aerial survey biomass estimates. Rowell and Funk's (1994) strategy was to use only the aerial survey estimates from 1981 and 1992–1994 in their ASA model and to give these aerial survey estimates very low weight. The low weights on aerial surveys were sufficient to stabilize ASA estimates but allowed relative abundance trends to be determined almost entirely from the time series of age-composition data. This effectively constrained biomass estimates early (1981) and late (1992–1994) in the time series but allowed abundance to fluctuate during the middle to late 1980s.

The conflict between aerial survey and age composition abundance trends also increases the

Table 1. Primary differences among the 4 sets of Pacific herring stock-assessment data used for the Togiak population simulations.

Model	Survival Rate	Maturity	Age Range
Highest Assessment	Low	Late	4 to 15+
Medium Assessment	Moderate-High	Moderate	4 to 15+
Med.-Low Assessment	Moderate	Moderate	4 to 9+
Low Assessment	High	Early	4 to 15+

uncertainty about the processes of survival and maturation. In the 1995 Togiak herring forecast analysis described by Rowell and Funk (1994), reasonable fits to the age composition and aerial survey data could be obtained with survival rates as low as 60%, if maturation occurred relatively late, or with survival rates as high as 85%, if maturation occurred early. Survival rates and maturity schedules were very closely correlated. In the 1995 Togiak herring forecast analysis (Rowell and Funk 1994) the effect of aging errors was investigated by pooling herring age 9 years and older into a single category instead of pooling herring age 15 years and older into a single category.

Four sets of population dynamics data resulting from ASA were used to describe the uncertainty in the stock-assessment data and the effect of aging error (Table 1). The 4 sets of stock-assessment data encompassed a relatively wide range of survival and maturity estimates (Figure 4). Changing these assumptions had little effect on recent abundance estimates but strongly affected the magnitude of the run biomass during the high-abundance period of the mid 1980s (Figure 3). With no constraints on maturity or survival, the ASA model resulted in low survival rates, late maturities, and a relatively high peak (1985) biomass estimate of 673,000 mt (highest assessment model). Specifying that maturation occurred at relatively young ages resulted in a high survival rate (constrained at 85%) and produced a peak biomass estimate of only 337,000 mt (lowest assessment model). Pooling all herring age 9 and older into a single category to re-

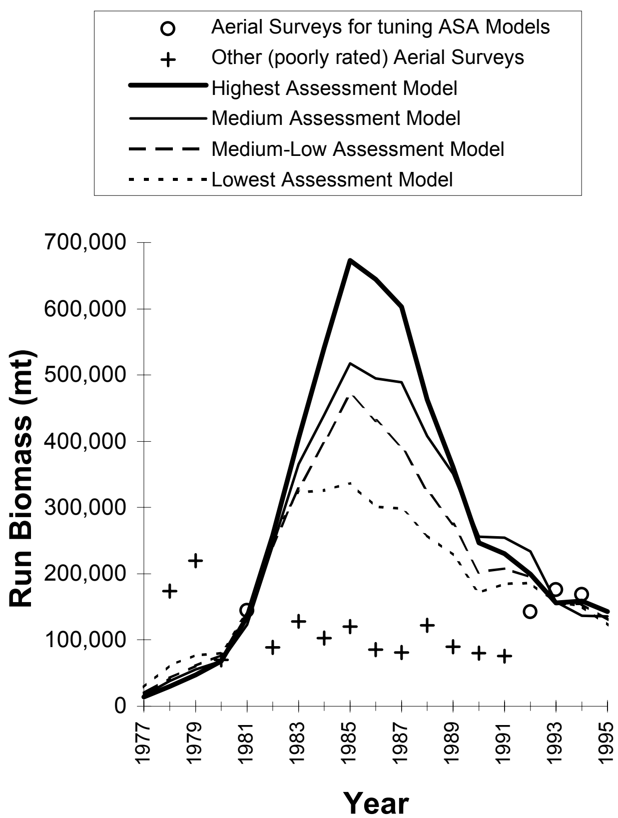

Figure 3. Range of run biomass estimates from the age-structured assessment (ASA) model used for the 1995 Togiak forecast of Pacific herring under various assumptions, and highly and poorly rated aerial survey biomass estimates.

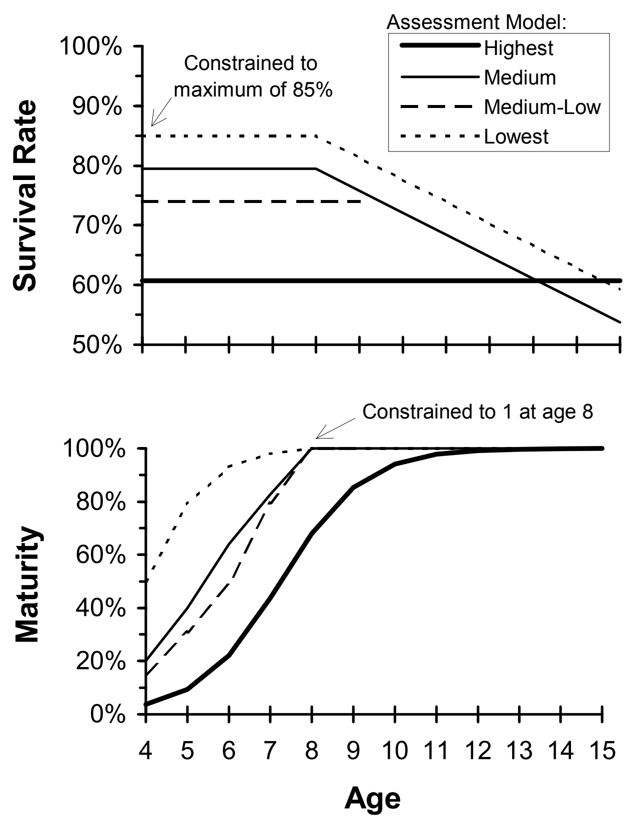

Figure 4. Survival rate (top) and maturity (bottom) estimates from the 4 age-structured assessment models used for the Pacific herring Togiak population simulations.

duce the influence of age determination errors produced a peak biomass estimate of 471,000 mt (medium-low assessment model). Survival rates and maturity schedules in this medium-low estimate were not constrained, and the ASA model produced intermediate values for these parameters. The medium assessment model was used by Rowell and Funk (1994) as the basis for the 1995 Togiak herring forecast. Peak biomass (1985) in this model was 517,000 mt. The maturity schedule was constrained so that maturity at age 4 was at least 20%, but survival and maturity estimates were otherwise unconstrained. The lowest and medium assessment models incorporated age-dependent survival where survival declined linearly starting at age 9. The slope of the decline in survival was estimated by the ASA model.

Much of the uncertainty in the stock-assessment data results from tuning the ASA model only to early (1981) and late (1992–1994) aerial surveys. The recruitment of the 1977 and 1978 year classes was the dominant event in the period studied, visible as the large dome shape in biomass, which reached a peak between 1984 and 1988. After reviewing aerial survey methods and ratings (Brannian et al. 1993), we determined that aerial survey ratings during the mid 1980s were often poor or used different methods than in recent years (1992–1994). As a result, aerial survey biomass estimates from this period may not be comparable to those of recent years. Because there were no comparable or reliable aerial surveys from the mid 1980s, there is considerable uncertainty about the magnitude of the 1984–1988 biomass peak.

Uncertainty about some of the past aerial survey abundance estimates increased the uncertainty about historical biomass trends. In herring aerial surveys, surface area measurements of herring schools were converted to biomass based on a small set of "calibration samples" where observers estimated herring school sizes just before purse seine vessels captured and weighed the entire school (Lebida and Whitmore 1985). The quality of aerial survey abundance estimates was affected by water clarity and length of the survey, both of which are influenced by weather conditions. Good weather conditions in recent years (1992–1994) have increased the confidence in the total aerial survey estimate of abundance compared to those of earlier years.

Spawner-Recruit Analysis

The recruitment process for Togiak herring was simulated using a number of different methods that were all based on the historical recruitment time series generated from 1 of the 4 assessment models (Table 2). The simplest recruitment processes fixed recruitment at the mean or median of the historical recruitment time series. Density-independent recruitment was modeled by selecting 1 of the historical recruitment estimates at random for each year of the simulation. For density-dependent recruitment, a Ricker model was used, where the number of recruits in year y (R_y) was estimated from the run biomass 4 years earlier (B_{y-4}):

$$R_y = B_{y-4}\, e^{a\left(1-\frac{B_{y-4}}{b}\right)} \qquad (1)$$

where a and b are parameters to be estimated. The Ricker model was used both in a deterministic form (equation 1) and in a stochastic form with multiplicative lognormal errors.

Lastly, an empirical spawner-recruit model divided the observed spawner-recruit data into 3 quantiles based on spawning biomass. When the spawning biomass was within a particular quantile, a number of recruits was selected at random from the recruitment data in that quantile.

Average Unfished Biomass Simulations

The Togiak herring population was simulated using an age-structured model with age 4 as the first age in the model. Herring age 15 and older were pooled into a single *oldest* category, except that in simulations based on the medium-low assessment model data, herring age 9 and older were pooled into a single category. The simulation model began with the selection of a starting population, by choosing 1 of the 1978–1994 population estimates at random from 1 of the ASA models (Table 3). The model used annual time steps, aging cohorts using

$$N_{a+1,y+1} = S_a \cdot N_{a,y} \,, \qquad (2)$$

where $N_{a,y}$ is the population size at age a in year y, and S_a is the survival rate for age a from 1 of the 4 assessment models. Run biomass (B_y) in each year was computed as

$$B_y = \sum_a \rho_a \cdot W_a \cdot N_{a,y} \,, \qquad (3)$$

where ρ_a is the estimated proportion mature at age a, and W_a is the weight at age a (Table 3). In each year the number of age-4 recruits ($N_{4,y}$) was selected based on 1 of the spawner-recruit models. The density-

Table 2. Pacific herring year class size at age 4 (millions of fish) estimated from 4 age-structured assessment (ASA) models of the Togiak population and results of spawner-recruit analyses on the data from each model.

Year Class	Year Recruited (at Age 4)	Highest Assessment Model	Medium Assessment Model	Medium-Low Assessment Model	Lowest Assessment Model
1977	1981	8,806	1,642	2,217	822
1978	1982	8,939	1,607	1,752	733
1979	1983	3,563	675	208	277
1980	1984	1,093	213	682	76
1981	1985	1,858	381	411	161
1982	1986	379	95	55	35
1983	1987	1,227	307	255	153
1984	1988	953	244	31	135
1985	1989	95	36	22	24
1986	1990	114	39	624	35
1987	1991	2,200	584	382	317
1988	1992	1,513	308	282	177
1989	1993	247	63	60	85
1990	1994	95	30	22	43
Mean		2,220	445	500	220
Median		1,160	275	269	144
Ricker *a* parameter		-2.479	-3.943	-3.841	-4.612
Ricker *b* parameter		-272,040	-381,936	-310,998	-356,419
Ricker residual mean square:		2.757	1.975	2.308	1.177
Quantile 1-2 boundary					
Empirical 4:5:5 frequency		86,752	80,853	92,936	97,955
Empirical 5:4:5 frequency		179,651	166,893	159,196	144,994
Empirical 5:5:4 frequency		179,651	166,893	159,196	144,994
Quantile 2-3 boundary					
Empirical 4:5:5 frequency		415,215	368,403	307,933	264,813
Empirical 5:4:5 frequency		415,215	368,403	307,933	264,813
Empirical 5:5:4 frequency		487,074	408,820	344,688	285,362

dependent models used the biomass 4 years earlier (B_{y-4}). For the first 3 years following the starting year of simulations with density-dependent recruitment, spawning biomass 4 years earlier was back-calculated from the starting population and the appropriate survival rate schedule.

The Togiak herring population was simulated for 1,000 years. To control the effect of starting conditions, results were averaged over simulations using each of the 17 annual (1978–1994) historical abundance-at-age estimates in the starting year. To further control the effect of starting conditions and to remove the effects of fishing present in the starting populations, AUB was estimated using spawning biomass from equation (3) averaged over simulation-years 251–1,000. Preliminary runs of the model showed that almost all effects of starting conditions were removed within the first 250 years of the simulation.

Exploitation Simulations

Fishery exploitation was added to the unfished biomass simulation to evaluate the long-term consequences of alternative harvest policies. With exploitation, equation (1) became

$$N_{a+1,y=1} = S_a (N_{a,y} - \sum_g C_{a,y,g}) \ . \qquad (4)$$

In the above, $C_{a,y,g}$ is the catch at age a in year y for gear g estimated from

$$C_{a,y,g} = V_{a,g} \cdot \mu_{g,y} \cdot N_{a,y} \ , \qquad (5)$$

where $V_{a,g}$ is the vulnerability at age a to gear g and $\mu_{g,y}$ is the fully recruited exploitation rate for gear g in year y. Exploitation rates were set to zero if the run

Table 3. Total run abundance (millions of recruited and unrecruited) of Pacific herring by year and age, survival (percent surviving by age), and maturity (percent mature) estimates from the age-structured analysis (Medium Assessment Model) used for the 1995 Togiak forecast (Rowell and Funk 1994).

Age (years):	4	5	6	7	8	9	10	11	12	13	14	15+
Abundance:												
1978	296.8	207.2	53.7	0.5	5.5	1.4						
1979	20.7	229.1	152.7	36.5	0.3	4.1						
1980	93.1	14.8	166.5	108.6	24.8	0.1	2.6					
1981	1,642.1	72.0	10.8	109.1	66.7	14.7	0.0	1.4				
1982	1,606.8	1,285.7	54.8	8.0	78.2	47.4	9.9	0.0	0.8			
1983	675.2	1,261.0	985.2	40.8	5.9	56.7	32.5	6.4	0.0	0.3		
1984	213.2	532.5	978.7	748.2	30.4	4.2	38.7	21.5	4.0	0.0	0.2	
1985	381.2	168.7	418.5	759.6	573.3	22.8	2.4	26.6	14.2	2.5	0.0	0.1
1986	94.8	301.6	132.6	324.5	580.3	434.3	16.0	1.4	17.3	8.8	1.5	0.0
1987	306.7	75.1	238.0	103.8	251.4	446.8	318.9	11.1	0.9	10.9	5.2	0.8
1988	243.8	243.1	59.3	186.4	80.4	193.7	328.2	223.7	7.3	0.5	6.5	3.4
1989	35.6	193.3	192.0	46.5	144.6	62.0	141.7	228.3	148.6	4.4	0.3	5.4
1990	39.2	28.2	152.5	150.1	36.0	110.9	45.4	98.7	151.1	93.2	2.6	2.9
1991	584.3	31.0	22.2	118.8	115.4	27.4	80.1	31.3	64.5	93.5	54.5	2.8
1992	307.6	462.1	24.4	17.2	90.4	86.5	19.5	54.4	20.0	39.2	53.8	31.1
1993	63.4	242.2	358.6	18.4	12.4	63.4	57.3	12.5	33.1	11.4	21.4	42.6
1994	30.4	50.0	188.6	273.2	13.6	9.0	43.2	37.2	7.6	19.4	6.2	31.9
Weight (g):	153	200	246	294	334	375	400	416	451	450	485	487

biomass was below threshold for any simulation year. When the run biomass was above threshold, the overall exploitation rate (total catch/run biomass) was set to 20%, and the fully recruited exploitation rate for each gear ($\mu_{g,y}$) was determined by

$$\mu_{g,y} = \frac{0.2 \cdot A_g \cdot B_y}{\sum_a (V_a \cdot W_a \cdot N_{a,y})} , \qquad (6)$$

where A_g is the allocation for gear g (75% purse seine, 25% gillnet) in the current Bristol Bay herring management plan. The small allocation to the Dutch Harbor food-and-bait fishery (7% of the allowable harvest) and the small harvest reduction (159 mt) for spawn-on-kelp fisheries in the current Bristol Bay herring management plan were, for simplicity, not included in the exploitation simulations. Under thresholds that varied from 10 to 50% of AUB, the exploitation simulations tracked average yield ($W_a \cdot C_{a,y,g}$) and percent of years that the fishery was below threshold and closed.

RESULTS

Spawner-Recruit Relationships

All of the spawner-recruit relationships were heavily influenced by the relatively large 1977 and 1978 year classes (Figure 5). Aerial surveys from the late 1970s, while not comparable to current methods, suggest that the ASA model underestimated the spawning biomass in 1977 and 1978. Using somewhat different data and assessment models, Zheng (1994) located the 1977 and 1978 spawner-recruit data pairs at somewhat higher spawning biomass. Results of spawner-recruit analyses are summarized in Table 2. The large amount of contrast among Ricker models fit to the data from the 4 stock-assessment models reflects the wide range of recruitment estimates in the assessments. The 14 spawner-recruit observations could not be equally partitioned into 3 spawning biomass quantiles for the empirical spawner-recruit relationship. Figure 5 depicts quantile boundaries placed at the midpoint between the years with the 5th and 6th lowest spawning biomass and between the years with the 9th and 10th lowest spawning biomass. The lowest quantile contains 5 spawner-recruit observations, the middle quantile contains 4 observations, and the upper quantile contains 5 observations. Quantile boundaries depicted in Figure 5 were labeled "5:4:5" in the AUB analyses. The effect of moving quantile boundaries was investigated by using quantile groups with 4:5:5 and 5:5:4 allocations of the 14 spawner-recruit observations to the 3 spawning biomass groups.

Average Unfished Biomass and Thresholds

In typical AUB simulations, spawning biomass oscillated widely because very strong year classes occurred infrequently (Figure 6). Starting conditions had a large amount of influence during the initial years of the simulation, but the cumulative average spawning biomass became stable before the 250th simulation year. AUB was calculated as an average over simulation-years 251–1000, well after the effect of starting conditions disappeared. An oscillatory, sinusoidal biomass trajectory resulted when the deterministic Ricker model was used with the highest and medium assessment models. Biomass converged to a stable point when the Ricker model was used with the medium-low and lowest assessment models.

Biomass occasionally exceeded 1,000,000 mt in simulations based on the highest assessment model (Figure 7). AUB ranged from a low of 158,853 mt for simulations based on the lowest assessment model with the empirical 4:5:5 spawner-recruit relationship to a high of 433,387 mt for the highest assessment model with the stochastic Ricker spawner-recruit relationship. Setting thresholds at 25% of AUB corresponded to a threshold range of 39,713–108,347 mt. All other combinations of stock-assessment models and spawner-recruit models produced thresholds in excess of 45,000 mt.

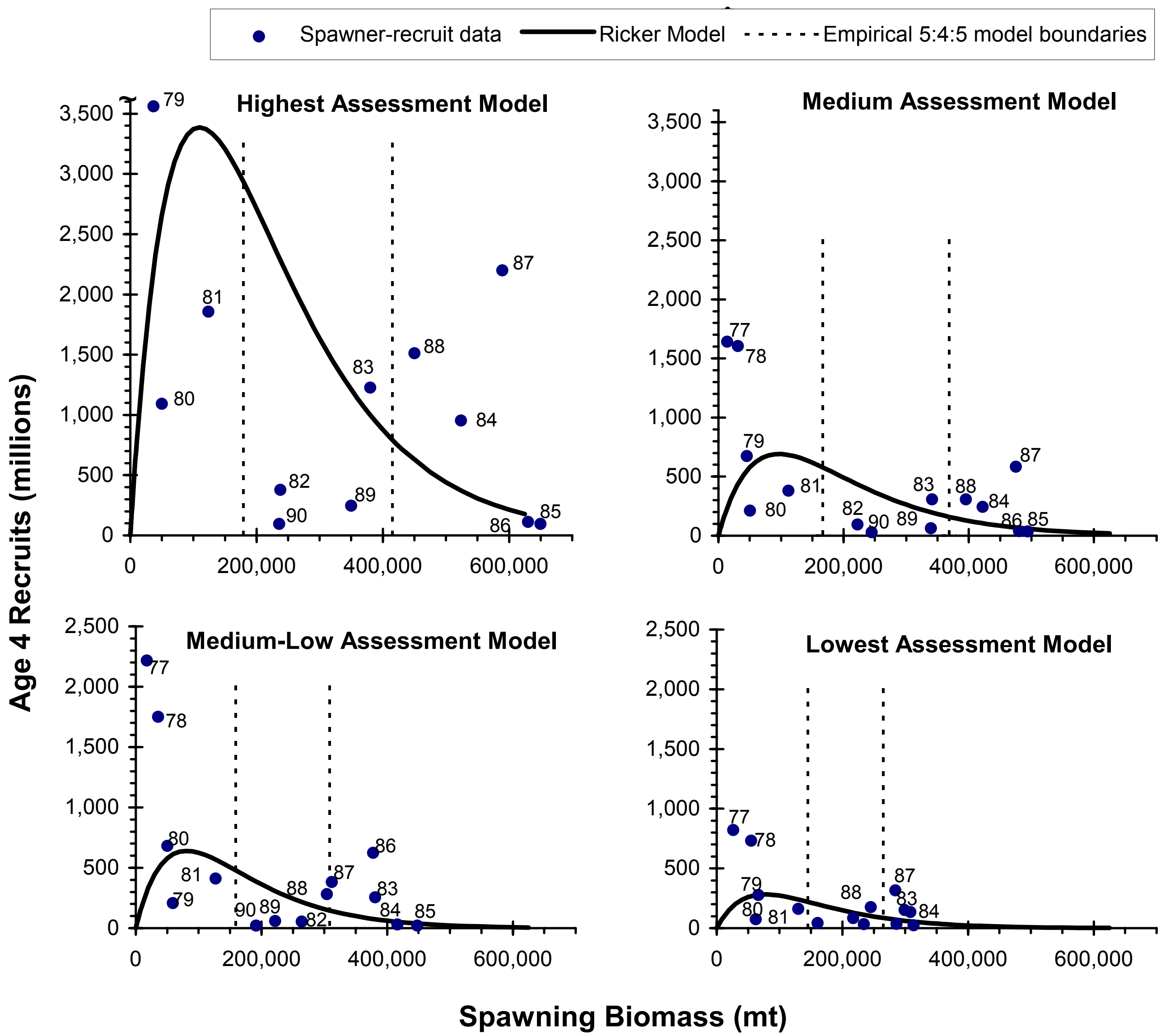

Figure 5. Pacific herring spawner-recruit data from the 4 alternate stock-assessment models for Togiak, showing the Ricker model and boundaries for the empirical spawner-recruit model with a 5:4:5 allocation of spawner-recruit data into 3 spawning biomass intervals.

When fishery exploitation was added to the simulation model, highest average yields occurred with no or very low thresholds (Figure 8). Thresholds only had a positive effect on yield if exploitation rates were high, i.e., > 40%; thresholds had no positive effect on long-term yield at a 20% exploitation rate. This occurred because the ascending limb of the spawner-recruit relationships were shifted so far to the left that biomass never dropped down to the very low levels where recruitment would markedly decline under a 20% exploitation rate. Average yield declined for high thresholds as fishery closures became excessive. With thresholds at 25% of AUB, fishery closures occurred in 2% of the simulation years, averaged over all assessment and spawner-recruit models.

DISCUSSION

Setting thresholds at 25% of the AUB is the current practice for herring fisheries in Canada (Schwiegert 1993) and Prince William Sound, Alaska. Our study found that long-term average yield did not increase under a threshold harvest policy for Togiak herring when combined with a 20% exploitation rate. Setting thresholds at 25% of AUB would only rarely trigger fishery closures, and these closures would not cause an appreciable loss of long-term yield.

Using a very different stock-assessment model and data from the foreign herring fishery during the 1960s and 1970s, Zheng et al. (1993) reported AUB for the entire Bering Sea as 421,000 mt. Assuming 80% of the herring in the eastern Bering Sea spawn at Togiak, as estimated from aerial surveys and by Wespestad (1991), the Togiak AUB would be 336,800 mt. The threshold corresponding to this AUB, using the 25% criterion, would be 84,200 mt. Because the frequency of strong year classes drives the AUB simulations, it is important to note that frequency of strong recruitment events in the relatively short time series in this study (1977–1990 year classes) is similar to the frequency in Zheng's (1994) longer time series model.

The current 31,752 mt (35,000 tons) threshold for Togiak is lower than all of the 25% AUB criteria in our simulations for 3 reasons. First, 1978–1985 aerial survey biomass estimates on which the current threshold is based include a history of fishing. Unfished biomass based on this time series would clearly be higher than these aerial survey estimates. Second, the 1978–1985 period includes a number of aerial survey estimates that are now believed to be too low. Third, the 1978–1985 period under-represents the influence that strong recruitment events (e.g., 1977 and 1978 year classes) have on long-term average biomass. Longer studies of recruitment processes in the Bering Sea (Wespestad 1991; Zheng 1994) indicate that strong year classes occur approximately every 8–12 years. The 1978–1985 period includes data from the initial phase of the biomass buildup resulting from a strong recruitment event. However, because survival rates for

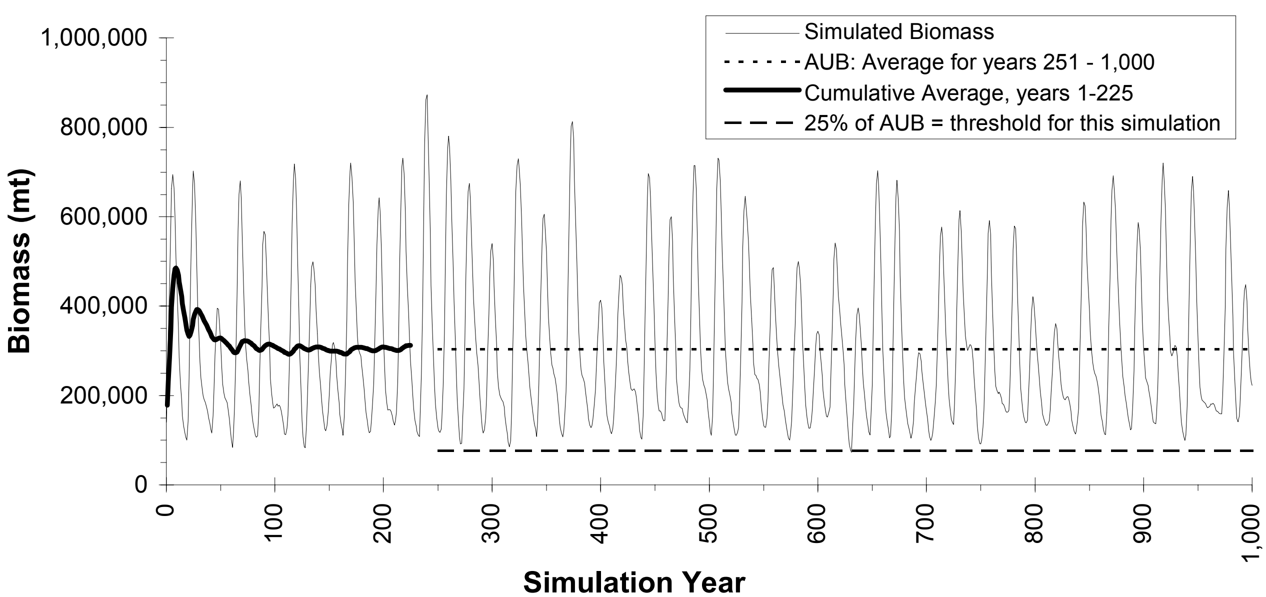

Figure 6. Result of a 1,000-year simulation of the Togiak population of Pacific herring using the empirical 5:4:5 spawner-recruit model and the medium assessment model.

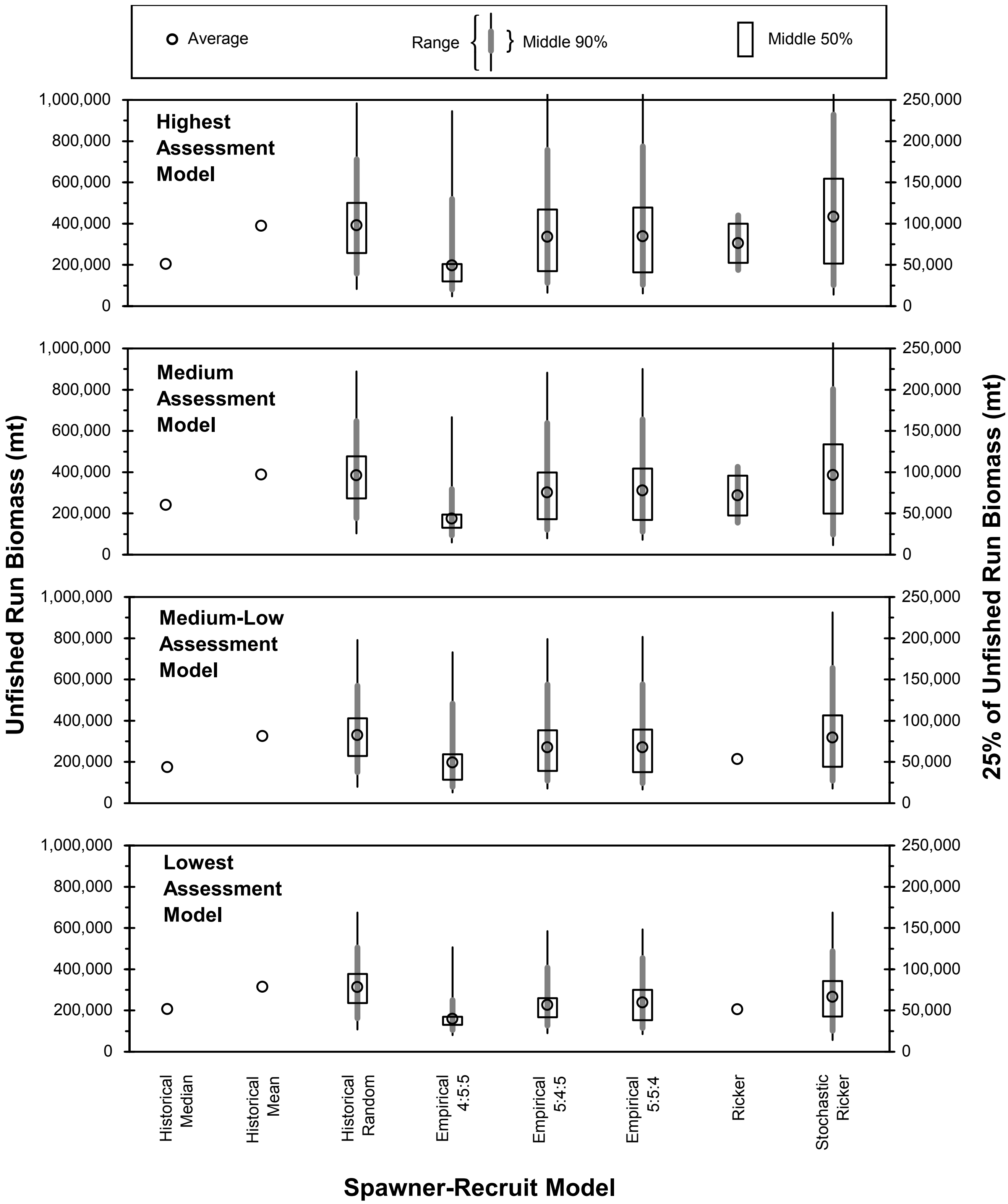

Figure 7. Distribution of unfished Pacific herring run biomass estimates from the Togiak simulation model, under different assumptions about stock-assessment models and spawner-recruit models. Thresholds along the right axes correspond to 25% of average unfished unfished biomass.

Bering Sea herring are relatively high, biomass pulses from strong recruitment events last almost 10 years. Therefore, the 1978–1985 period under-represents the longer-term contribution to average biomass from a strong recruitment event. All our analyses suggest the threshold at Togiak should be increased to be consistent with the 25% AUB criterion. Because of the uncertainty about the peak biomass levels during the mid 1980s and the uncertainty in the spawner-recruit data, threshold recommendations from the simulation model range from 39,713 mt to 108,347 mt. Because the extremes of all the scenarios examined are improbable and the next lowest recommended thresholds were from 45,000 to 50,000 mt, we recommend raising the threshold at Togiak to at least 45,000 to 50,000 mt.

Since the beginning of the Togiak herring stock-assessment program in 1978, the inseason aerial survey estimates were below the proposed threshold levels in only 1 year: 1980 when 44,349 mt were estimated. This estimate was taken when weather conditions and visibility were poor. Currently, when weather conditions do not permit reliable inseason biomass estimates, managers base threshold and quota decisions on the ASA model forecast of biomass. For example, the next lowest aerial survey estimate, 47,000 mt in 1991, was not used to manage the fishery because weather and visibility had been poor; instead the forecasted biomass of 49,689 mt was used. Therefore, increasing the threshold to 45,000–50,000 mt should seldom close the Togiak herring fishery or the Dutch Harbor food-and-bait fishery. In addition, if in the future the Togiak population falls to dangerously low levels, the current threshold would probably impair the fishery for a longer period by delaying recovery;

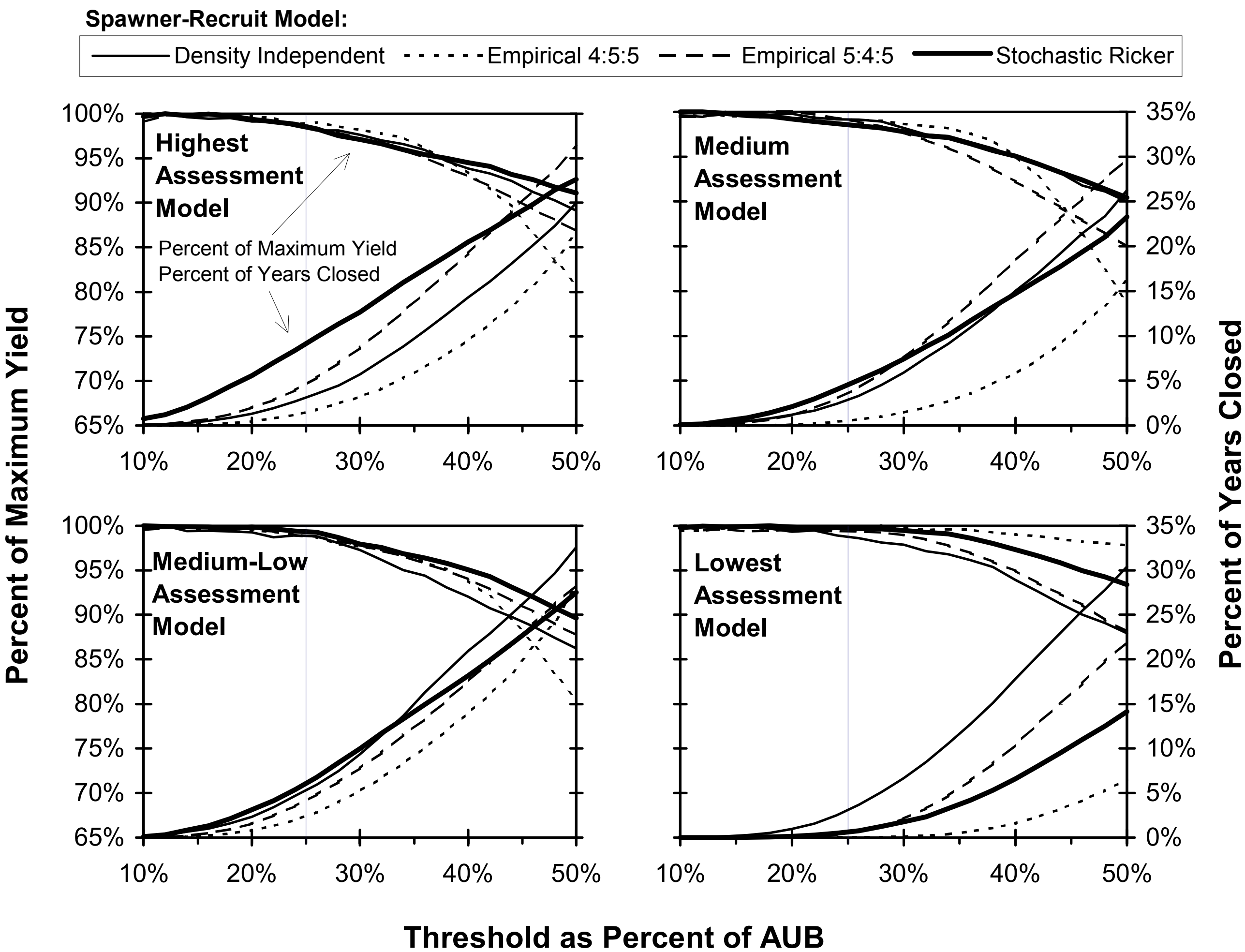

Figure 8. Relationship of average yield of Pacific herring (as a percent of the maximum yield for 20% exploitation rate) and percent of years closed due to subthreshold biomass, expressed as a percent of average biomass (AUB), in the Togiak simulations under 4 alternative stock-assessment models.

conversely the modestly higher threshold should help the stock rebound to robust levels more quickly.

The moderately high current level of abundance and the age composition predominated by the 1987 and 1988 year classes suggest that the population is stable and will not depend on another major recruitment event for sustainability for at least 5 years. Abundance trends based on age compositions have been very consistent and predictable for Togiak herring. As long as funding levels allow representative age-composition sampling, adequate warning should be provided if an unusual decline does occur.

This analysis attempts to include the major sources of uncertainty that would influence the choice of thresholds for the Togiak herring fishery. However, inconsistencies in recording and analyzing aerial surveys over the 1978–1994 period precluded us from properly evaluating the uncertainty resulting from choosing a subset of the highest quality aerial survey estimates of abundance. If further analysis of the historical aerial survey data reduces uncertainty in the stock-assessment information, threshold levels for Togiak herring should be reexamined.

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