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Problems in Assessing the Pelagic Armorhead Stock on the Central North Pacific Seamounts

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ABSTRACT

In this paper we examine catch and effort statistics from Japanese stern trawlers harvesting pelagic armorhead, *Pseudopentaceros wheeleri*, on the central North Pacific seamounts, and consider problems in using them to assess the armorhead stock. We begin by reviewing trends in the fishery. Next, we adopt a set of tentative assumptions about armorhead life history and population biology, and describe a nonlinear autoregressive model of armorhead stock changes based on the catch and effort data.

Trial applications of the model are then discussed. These were hampered by the unavailability of crucial data on Soviet armorhead catches, by technical difficulties in parameter estimation arising from statistical properties of the model, and by model misspecification. Despite these setbacks in applying the model, a cursory visual analysis of the Japanese trawl fishery statistics was ventured. This suggested that high variability in recruitment was probably the chief cause of fluctuations in fishing success through the mid-1970's. Further, it indicated that the collapse of the Japanese fishery in 1978 and subsequent years could not easily be ascribed to excessive trawling effort by Japanese vessels. Although the steady decline in armorhead catch per unit of effort (CPUE) reported by Japanese trawlers after 1972 was inversely correlated with their trawling effort, the behavior of the fishery in earlier years suggested that stock-independent factors may have played a more prominent role in armorhead recruitment.

Soviet catch summaries just recently made available (after the analysis of Japanese data was completed, and this manuscript first drafted) support some conclusions based on Japanese data alone. In particular, they indicate that recruitment fluctuations were largely independent of stock size during the early 1970's. However, they also show that Soviet catches were roughly five times larger than Japanese harvests during this period, suggesting that in later years, for which Soviet data are still unavailable, excessive fishing effort may indeed have played a role in the stock decline. Without a more complete and detailed Soviet record, especially during the period of stock collapse, the effects of exploitation cannot be estimated reliably.

Regardless of the causative factor, the present armorhead spawning stock is apparently at a very low level, and average recruitment may now be stock-limited. Therefore a sharp reduction in fishing mortality may be worth considering as a means to accelerate the stock's recovery.

TRENDS IN THE ARMORHEAD FISHERY

The history of armorhead fishing on the seamounts of the Emperor-Hawaiian Ridge was summarized by Takahashi and Sasaki (1977). According to their account, the resource was discovered by the Soviets in late 1967, and harvested by Russian trawlers for at least a few years. Sakiura (1972) reported that the Russian fleet took 133,400 metric tons (MT) in 1969 alone.

Unfortunately, when our analysis was done, and this paper initially drafted, there was no available record of the extent of Soviet fishing on the seamounts after 1969. However, Soviet research vessels were known to have visited the seamounts in 1976 and Japanese vessels had reported sighting Soviet trawlers operating on the seamounts. Very recently a report by the Soviet scientist Borets has become available which shows that the Soviet trawlers actually made very large catches of armorhead on the seamounts during the mid-1970's (see Boehlert 1986). Between 1968 and 1975, they caught roughly 730,000 MT, about five times the Japanese catch during the same period.

Japanese stern trawling began in August 1969 on the Kimmei Seamounts and the following month on Milwaukee Seamounts, and by the end of 1970 had spread to more southerly seamounts, including Colahan, C-H, and Hancock.[1] Nominal effort, measured in hours of trawling, has fluctuated greatly, particularly on Kimmei and Milwaukee, which have received the heaviest fishing pressure (Table 1; Fig. 1).

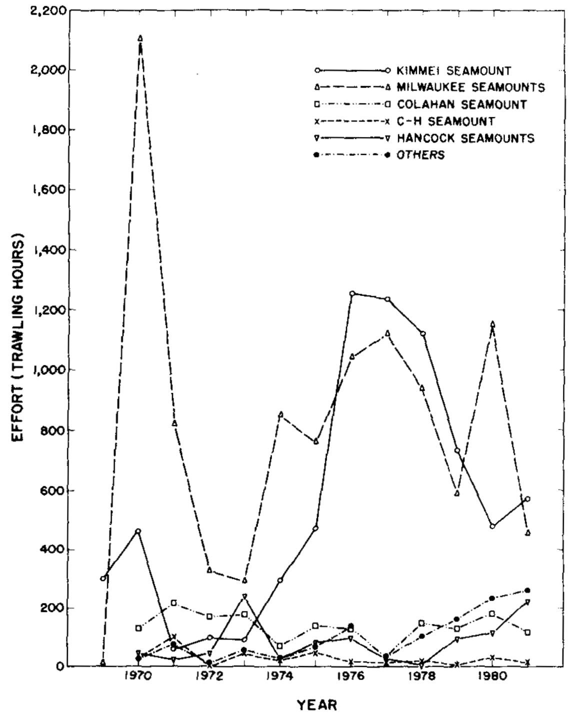

Figure 1.—Annual effort of Japanese trawlers on central North Pacific seamounts (by calendar year).

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[1] Statistics on the Japanese trawl fishery were kindly provided by Takashi Sasaki of the Far Seas Fisheries Research Laboratory, Shimizu.

Likewise, the Japanese armorhead catch has been extremely variable, with about a 10-fold range on most seamounts during the early and mid-1970's (Table 1; Fig. 2). The peak aggregate catches of armorhead by Japanese trawlers were 34,825 MT in calendar year 1972 and 28,356 MT in 1973. (By comparison, the recent summary of Soviet catch statistics shows that Soviet vessels took about 98,000 MT in 1972 and 170,000 MT in 1973.) Despite relatively steady or increasing nominal effort, the Japanese armorhead catch on all seamounts declined sharply after 1976.

The catch per unit of effort (CPUE, in metric tons per hour of trawling) for Japanese vessels decreased on all seamounts during 1969-71, then increased everywhere in 1972, in some cases by a factor of 10 or 20. Beginning in 1973 or 1974 the general trend of CPUE turned downward, and catch rates for armorhead have been severely depressed at all seamounts since 1978 (Fig. 3). This is particularly so at Milwaukee and Kimmei. However, we note that since 1978 the dominant species in the trawl catches has been the alfonsin, *Beryx splendens*, previously only a minor constituent. The CPUE for this species has greatly increased during this period, suggesting either an upsurge in abundance of alfonsin or a switching of target species. If the latter is true, then the Japanese armorhead CPUE's during recent years may exaggerate the decline in the armorhead stock.

Although the Soviet statistics were not included in the modeling and analysis reported here, it is instructive to compare them with the Japanese data *post facto*, particularly to see if CPUE data show the same trends. If we look at annual statistics, the only discrepancy between the Japanese and Soviet CPUE trends is during the period 1969-71, when it appears the fishing power of Japanese trawlers was relatively low compared with later years, or Soviet fishing power relatively high. Both sets of statistics indicate an overall decline in armorhead abundance or availability from 1969 to 1971, a substantial increase in 1972, and a steady decline through 1975 (see data in Boehlert 1986).

Length-frequency statistics from the Japanese trawl catches show that the fishery harvests only a narrow size range of armorhead, generally from about 25 to 35 cm fork length (FL). Individuals of this size are thought to be 2 to 3 years old and sexually mature (see below). Apparently the fishable stock consists almost entirely of recruits, there being few survivors from earlier year classes. The length distributions are remarkably similar on the various seamounts, and vary little from year to year. However, two noticeable changes in the length distributions have occurred. In 1972, when CPUE rose dramatically on all seamounts, the length distribution shifted downwards by about 2 cm. This was especially clear at Milwaukee and Colahan, where the largest samples of armorhead were measured (length-frequency distributions for Milwaukee are given in Fig. 4). More typical distributions were seen the following several years. Then beginning in 1978, when CPUE dropped sharply, the distributions shifted upwards on most seamounts, and broadened. If one assumes no alteration in maturation schedules, the length-frequency shifts could be taken as evidence of density-dependent growth in the pre-recruit stage. Alternatively, if growth rates have been constant, the inverse relationship between mean length of the recruits

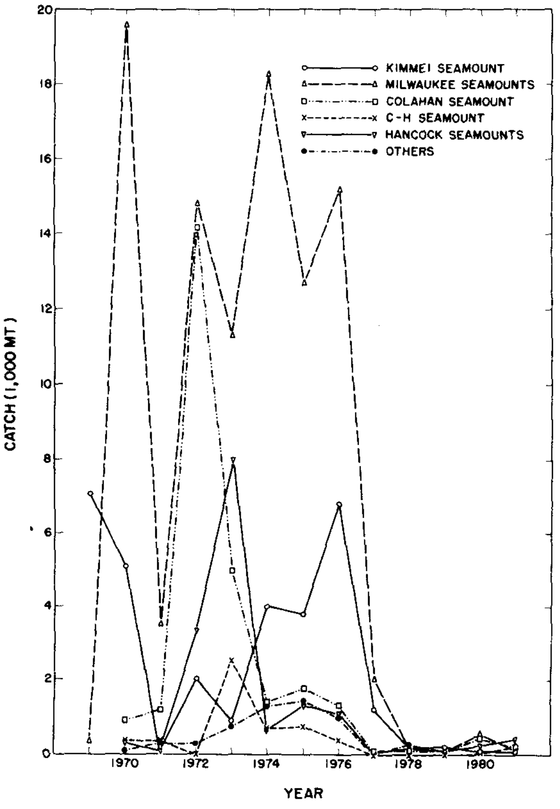

Figure 2.—Annual pelagic armorhead catch by Japanese trawlers on central North Pacific seamounts (by calendar year).

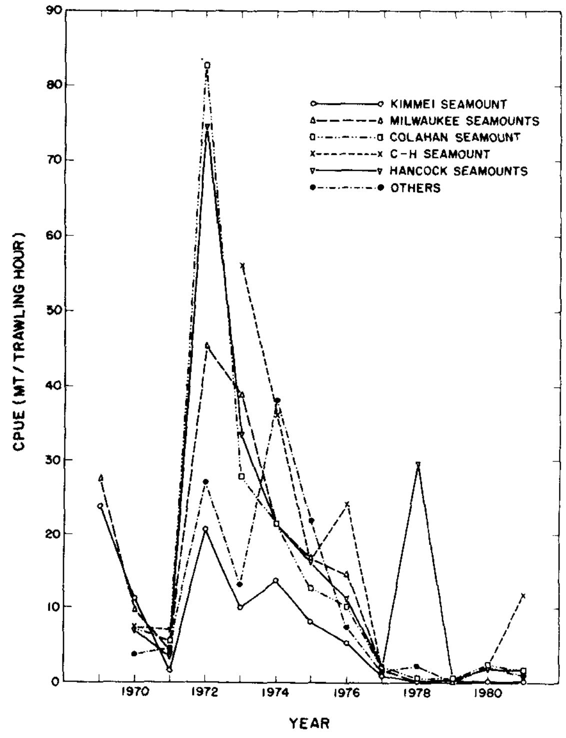

Figure 3.—Annual pelagic armorhead catch per unit of effort (CPUE) for Japanese trawlers on central North Pacific seamounts (by calendar year).

and CPUE may reflect differences in rate of maturation. The latter explanation seems less likely. However, without information on the age composition of the armorhead catches no reliable interpretations can be made.

The annual variability in armorhead CPUE is illustrated by Figure 5, in which yearly CPUE values are expressed as a proportion of the 1981 CPUE at each seamount. Peak CPUE values were in some cases two orders of magnitude greater than in the 1981 index period. Such high variability in abundance is frequently observed in stocks of pelagic fishes, and is usually ascribed to fluctuations in oceanographic processes important to survival of pelagic eggs and larvae. Thus one contending explanation for the apparent rise and fall of the armorhead stock is dramatic environment-driven fluctuation in year-class strength.

Another reasonable hypothesis is that trawling effort by Japanese and Soviet vessels during the 1970's reduced the armorhead spawning stock to such low levels that recruitment has been undermined. If this alternative is true, or if fishery-independent factors have driven spawning biomass down to such critical levels, then a restoration of catch and CPUE to higher levels might require a temporary relaxation of fishing effort.

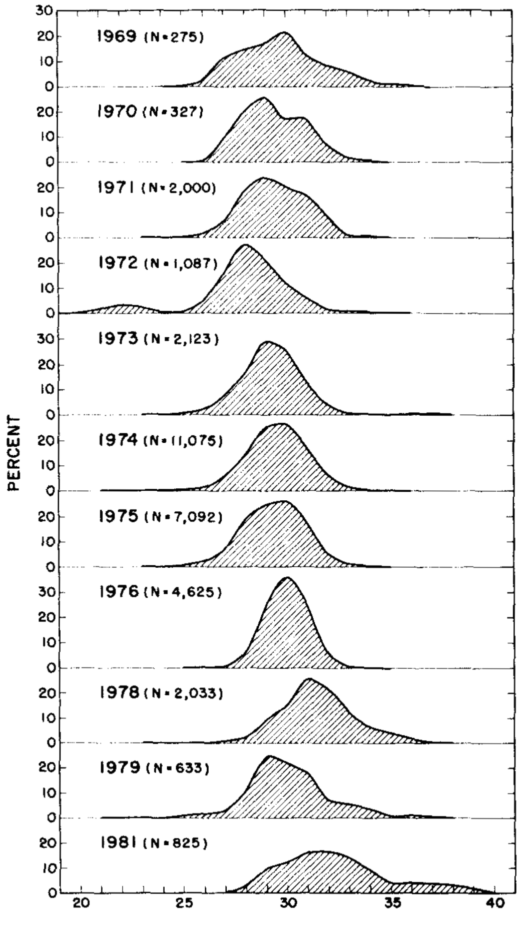

Figure 4.—Percentage frequency distributions of fork length for samples of pelagic armorhead taken by Japanese trawlers on Milwaukee Seamounts.

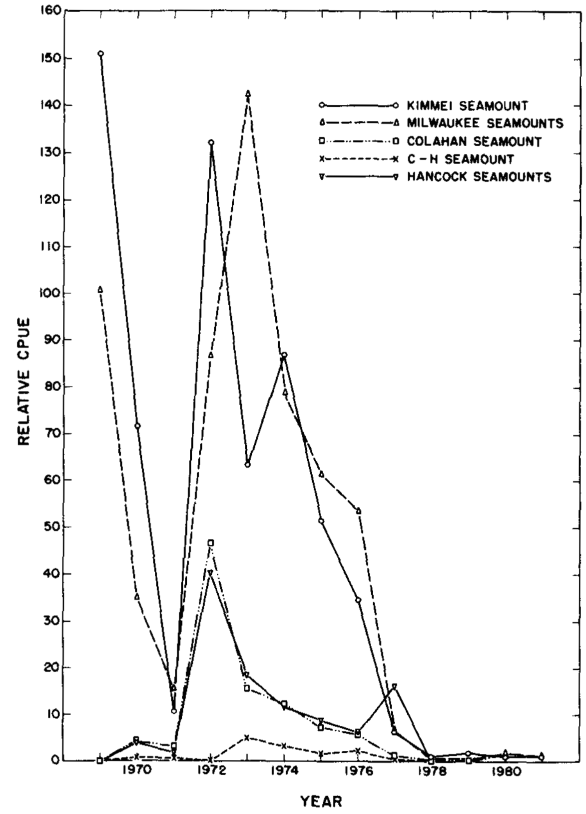

Figure 5.—Annual pelagic armorhead catch per unit of effort (CPUE) for Japanese trawlers on central North Pacific seamounts relative to CPUE in 1981 index period.

ANALYSIS OF STOCK DYNAMICS

To assess the condition of the armorhead stock and evaluate competing hypotheses relating to the impacts of fishing and environmental factors it is useful, if not essential, to construct a quantitative model of the stock dynamics. Using just the Japanese catch and effort statistics, we attempted to construct a model which would account for the observed behavior of the pelagic armorhead fishery and be reasonably consistent with available information and current thinking regarding armorhead life history. In doing so we recognized that our results might be seriously compromised by the absence of data on Soviet catches, and that our sketchy knowledge of armorhead biology would necessitate numerous assumptions.

Biological assumptions

As a basis for the modeling, we made the following assumptions concerning armorhead biology and life history:

1) The armorhead found on the seamounts are derived from a pool of pelagic larvae generated by a common parental spawning biomass. Offspring produced on individual seamounts are distributed widely in the North Pacific and mix thoroughly during their prerecruit stages.

2) Upon reaching sexual maturity at about 2 years of age, armorhead abandon the epipelagic zone inhabited by the juveniles and are recruited to spawning stocks occupying the tops of the seamounts. At the sizes found on the seamounts armorhead are known to be mature, and recent studies at the Honolulu Laboratory on sagittae, vertebral centra, spines, and other hard parts indicate that armorhead 26-32 cm FL are predominantly 2 years of age (J. H. Uchiyama, Southwest Fish. Center Honolulu Lab., unpubl. data). These estimates of age contradict earlier findings by Chikuni (1970), based on scales from two preserved specimens, which assign ages of 3 years to 22 cm fish and 6 years to 32 cm armorhead. Vasil'kov and Borets (1978) also estimated the ages of armorhead. Using a spectral analysis of scale thickness, they suggested that armorhead of 28-33 cm may be as old as 11 years.

3) Over a wide range in abundance of the armorhead spawning stock, the average recruitment is constant. Only at very low spawning stock levels is the average number of recruits stock-dependent. This set of assumptions is consistent with observations on the spawner-recruit relationships in other fishes with pelagic eggs and larvae, such as tunas.

4) The catchability coefficient (the instantaneous fishing mortality inflicted by a unit of trawling effort) may depend on the abundance of armorhead on the seamount. One possibility, for example, is that at low stock densities the catchability coefficient increases. This would be particularly likely if trawlers seek out and target individual schools of armorhead and if reduced armorhead stocks consist of fewer schools.

5) The seamounts are the only spawning ground of the armorhead, so that the CPUE of the trawlers, as some function of the exploitable biomass, provides a measure of the spawning stock.

6) The natural mortality rate of armorhead in the seamount spawning stocks is constant.

7) The temporal changes in armorhead biomass on the Milwaukee Seamounts are representative of trends in the spawning stock as a whole. This assumption seems reasonable enough, although the overall variation in CPUE at Milwaukee is somewhat greater than that at Colahan and Hancock.

8) The fraction of the total annual recruitment which settles out on Milwaukee is constant. Again, this seems generally consistent with the observed patterns of CPUE on the several seamounts.

Autoregressive stock model

With these assumptions, the temporal dynamics of the armorhead spawning stock residing on the seamounts and exploited by the fishery may be approximated by the following simple equation:

$$\underbrace{B_i}_{\substack{\text{Average}\\ \text{spawning}\\ \text{biomass in}\\ \text{period } i}} = \underbrace{W_i}_{\substack{\text{Average}\\ \text{weight of}\\ \text{mature}\\ \text{armorhead}\\ \text{in period } i}} \{\underbrace{N_{i-1}\, S_{i-1,i}}_{\substack{\text{Average}\\ \text{residual}\\ \text{spawning}\\ \text{stock from}\\ \text{period } i\text{-}1}} + \underbrace{R_i\, S_i}_{\substack{\text{Average no.}\\ \text{of recruits}\\ \text{available in}\\ \text{period } i}}\} + \underbrace{\lambda_i}_{\substack{\text{Random}\\ \text{error}\\ \text{term}}}$$

The average armorhead biomass in the i-th time period is assumed equal to the average biomass of fish surviving from the previous period, plus the average biomass of those newly recruited during the period, plus a random error term. The explicit dependence of spawning biomass in one period on the same random variable one period prior classifies this model as "autoregressive." Since the average abundance of armorhead during each interval is approximated by the abundance at the midpoint, the survival rate $S_{i-1,i}$ is considered to be a function of the natural mortality rate and trawling effort in periods i-1 and i, whereas S_i depends only on natural mortality and effort in period i. The total number of fish recruited in period i, R_i, is assumed to depend on the average armorhead spawning biomass δ time periods earlier. In particular, we assumed the following functions for the survival rates and recruitment:

$$S_{i-1,i} = e^{-\{M + [H(N_{i-1})\, E_{i-1} + \mathrm{H}(N_i)\, E_i]/2\}}$$

$$S_i = e^{-\{M + H(N_i)\, E_i\}/2}$$

and

$$R_i = \alpha \left\{1 - e^{-\beta N_{i-\delta}\, W_{i-\delta}}\right\} \varepsilon_i$$

Here α is the average recruitment expected at the highest levels of spawning biomass, and β determines the rate at which average recruitment declines as spawning stock is reduced. The term ε_i is a lognormal random "disturbance" representing the unexplained variability in recruitment.

In the survival functions, the natural mortality coefficient is denoted by M, and the nominal trawling effort in period i by E_i. The catchability coefficient in period i, $H(N_i)$ is written as a function of average stock size during the period, N_i. In particular, we considered the power function

$$H(N_i) = Q\, N_i^{\gamma}$$

now commonly used in models of schooling fish harvested contagiously. In many such cases it has been found that $\gamma < 0$, i.e., catchability is inversely related to average stock size. When $\gamma = 0$, catchability is constant.

The average individual weights in each year, W_i, were estimated from Japanese length-frequency statistics and a length-weight relationship computed from NMFS data. The resulting series of average weights was then smoothed before use in the model.

The random error term ε_i is assumed to have a mean of 1, but a variance which may depend on i and/or the spawning biomass in period i. Further, the ε_i are probably serially correlated. The distributions of the ε_i may also reflect oceanographic processes affecting the survival of armorhead eggs and larvae or the settlement of mature armorhead onto the seamounts. The sequence of error terms λ_i is assumed to have zero mean and a dispersion matrix which depends on a host of factors, including stochastic variation in recruitment, autocorrelation in the series of spawning biomass estimates, and random variation in the mortality processes.

To estimate parameters of the armorhead stock model we made the usual assumption that stock density was measured by some function of CPUE. In our case the appropriate function is

$$N_i = \left\{\frac{\mathrm{CPUE}_i}{W_i\, Q}\right\}^{\frac{1}{\gamma+1}}$$

The complete nonlinear regression model is given in the Appendix.

Estimation procedures

Since there were five parameters to estimate (α, β, γ, Q, M), a long time series of observations was required. Neither annual nor semiannual data would provide sufficient degrees of freedom. Therefore the model was fit to monthly CPUE and effort data. A problem arose here because monthly CPUE time series were not complete, yet lagged spawning biomass estimates were needed for each time period. Instead of circumventing the problem by aggregating the monthly data we developed an iterative EM algorithm (see Dempster et al. 1977) which simultaneously predicted the values of missing observations and computed weighted least squares estimates of the model parameters.

Visual analysis of the Milwaukee Seamounts time series

Because the only suitably complete monthly CPUE time series was for Milwaukee Seamounts, we used those data exclusively for the trial fitting. Restriction of the analysis to Milwaukee Seamounts necessitated assumptions 7 and 8 above. Before attempting to fit the regression model with the EM algorithm, we inspected the monthly time series of CPUE and nominal trawling effort at Milwaukee and the annual CPUE series at all seamounts to see if the model was compatible with the data, to extract initial estimates for the model parameters and to see if we could anticipate any problems in the fitting. A byproduct of this cursory inspection was a preliminary evaluation of the impact of Japanese trawling on the armorhead stock.

The monthly CPUE for Milwaukee is shown in Figure 6, beginning in September 1969 and continuing for 146 months through October 1981. Neglecting the first 4 months, when only 12 h of trawling were done by Japanese vessels, we considered the series beginning in January 1970. In general the monthly data show a considerable amount of variation, but reliability of the CPUE statistics, measured by the corresponding trawling effort, also varies greatly. If the model is correct, declines in average CPUE from month to month are due to an excess of mortality over recruitment, and increases in CPUE reflect the reverse. Without actually fitting the model, it can be seen that the monthly time series of CPUE and Japanese effort (and their annual and semiannual counterparts; see Figs. 1, 3, and 7) are consistent with the proposed model from 1974 through 1981. That is, the general downward trend of CPUE during this period could have resulted from a recruitment which was directly dependent on spawning stock coupled with a catchability inversely related to stock size. But when examined in its entirety the situation appears more complex. Note that the comparatively high recruitments at all seamounts in 1973 were generated from relatively low spawning biomasses 2 years earlier whereas the peak spawning biomasses in 1972 led to relatively weak year-classes, suggesting either stock-independent recruitment or a dome-shaped stock recruitment relationship (e.g., a Ricker model). The latter alternative does not seem appropriate for armorhead. (The Soviet data also suggest that stock-independent recruitment fluctuations were large during the early 1970's; spawning stocks were apparently

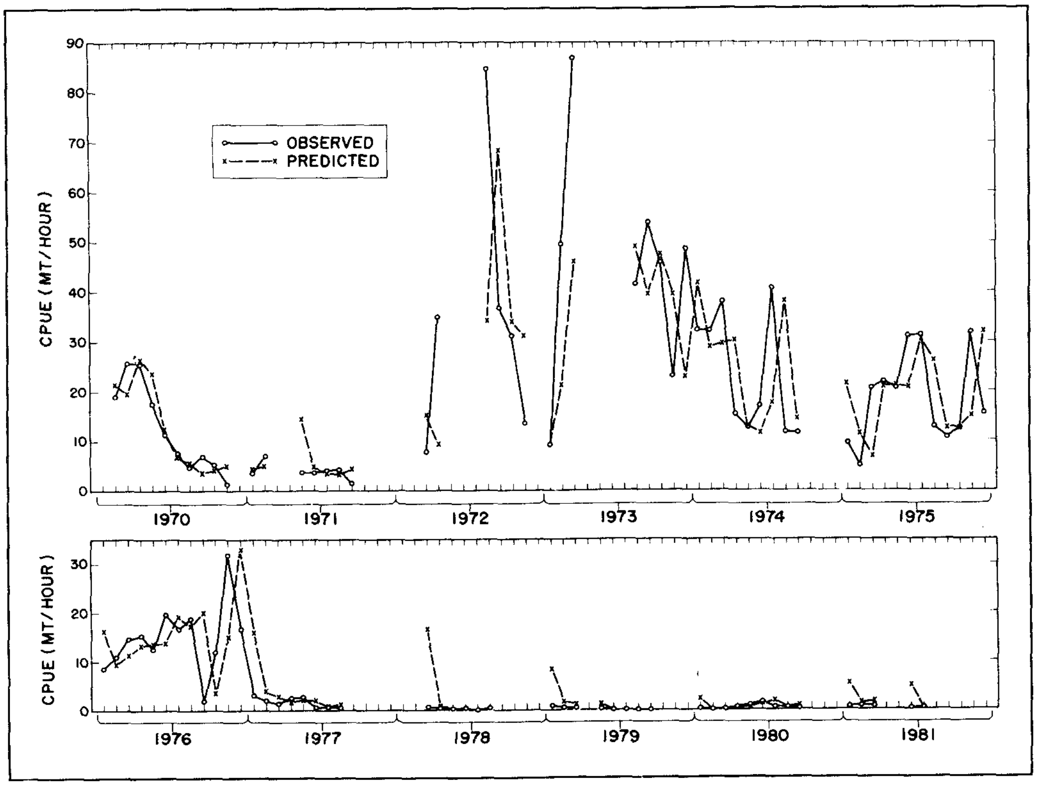

Figure 6.—Observed monthly pelagic armorhead catch per unit of effort (CPUE) by Japanese trawlers on Milwaukee Seamounts and predicted CPUE based on autoregressive model with Ricker spawner-recruit relationship.

about the same size in 1970 and 1973, but resulting recruitments in 1972 and 1975 differed by a factor of 2.5.)

Further analysis yields additional evidence of stock-independent recruitment. For example, relatively modest spawning stocks in 1970 and 1971 (measured by Japanese CPUE) apparently produced large recruitments in 1972 and 1973, whereas spawning stocks of approximately the same size in 1975 and 1976 were unproductive. (This conclusion would be weakened if Japanese trawler catchability increased between 1971 and 1972.) Although the Japanese trawling effort at some seamounts, such as Milwaukee and Kimmei, was substantially greater during the latter period, the difference in fishing intensity could not account for such disparities in the ratios of spawning biomass. (This argument considers only Japanese effort; if a complete record of Soviet effort statistics were available, the conclusion might differ.) Thus it is reasonable to suggest that stock-independent recruitment is the norm for armorhead, except at very low stock levels. The difficult problems are to determine what the critical level is, whether the spawning stock is now below this level and whether a curtailment of fishing would be effective in reversing the trend.

Trial fitting of the model

When the stock model was fit to the monthly Milwaukee time series, only a very poor fit could be obtained. The residuals suggested that the proposed flat-topped stock recruitment relationship was inconsistent with the data. In another attempt a dome-shaped Ricker stock-recruitment model accounted for about 77% of the variation in CPUE (Fig. 6). These results are consistent with the conclusions reached by simple visual inspection of the Japanese CPUE and effort time series. However, despite numerous attempts at fitting the model, stable convergence to a unique set of parameter estimates could not be achieved. Some of the problems in fitting the model are statistical. Consistent and efficient estimation of parameters in models with autocorrelated errors and lagged dependent variables requires that the complex covariance structure of the errors be correctly specified. In our case, it would be necessary to derive the structure analytically and estimate the resulting covariance matrix iteratively as a step in the EM algorithm. Some theoretical work along these lines has been done by Domowitz (1982) for situations involving complete time series, and has been applied to estimation of anchovy stock models.

Further work needs to be done to develop an iteratively reweighted estimation procedure which accounts for the error covariance structure. In our fitting of the model we used statistical weights equal to the nominal effort, assuming this at least provided a measure of the reliability of the spawning biomass indices.

Another problem is that the model is very likely misspecified, particularly regarding recruitment. Our analysis suggests to us that the greatest part of annual variation in recruitment is determined by "random" factors independent of spawning stock, i.e., the term ε_i is of overriding importance. In our simplistic model of recruitment we made use of the only relevant information available, that relating to biomass of the parent stock. However, improved prediction of recruitment might be possible with ancillary data on oceanographic processes, i.e., it might be possible to model ε_i. Two types of processes would likely be important; those that affect survival of armorhead eggs and larvae, and those that influence the congregation of armorhead in the seamount spawning habitat.

Perhaps the most critical problem with the analysis of the Japanese CPUE series is, of course, that only Japanese effort statistics were available. If fishing mortality is an important determinant of stock size, it will be essential to include effort data (or total catch data) from Soviet trawlers. These data will have to be detailed and comprehensive, so that a time series of monthly effort can be constructed for the duration of the fishery.

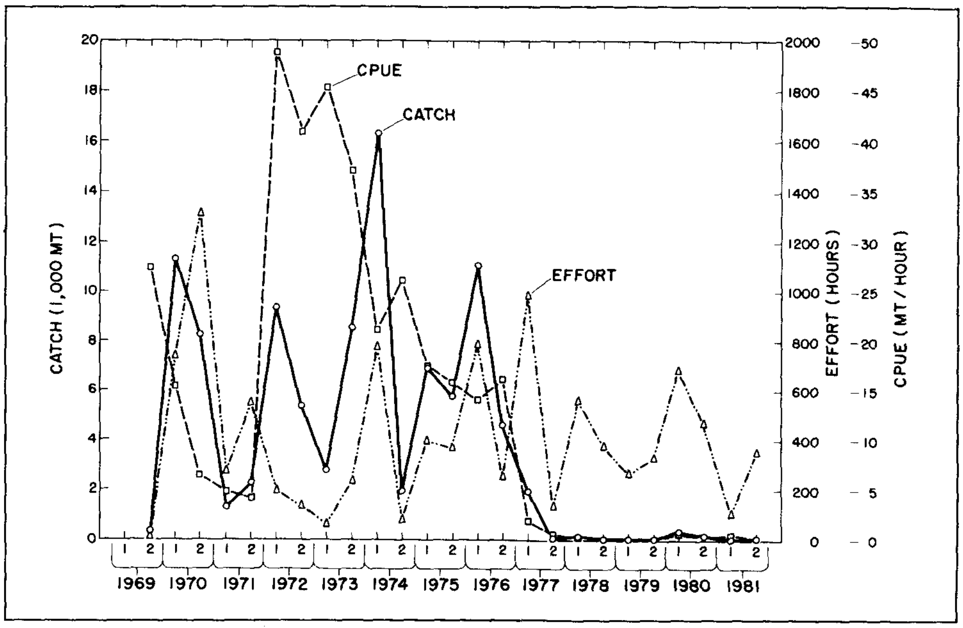

Figure 7.—Semiannual pelagic armorhead catch, effort, and catch per unit of effort (CPUE) for Japanese trawlers on Milwaukee Seamounts.

DIRECTIONS FOR FURTHER RESEARCH

Fish stock assessment is a fairly chancy business under the best of circumstances. It is particularly difficult for armorhead, where we are handicapped by an incomplete record of exploitation and a meager knowledge of basic biology and life history. At this stage our model of stock dynamics consists largely of assumptions, and little in the way of empirical facts. However, we take some comfort in the adage of Box (1979), who noted that "All models are wrong, but some may be useful." We believe our modeling exercise has been helpful, particularly in establishing a context for further investigations of the armorhead stock. Acquisition of more complete fishery statistics and additional biological and hydrographic studies will permit refinements and adjustments.

Several shortcomings of the armorhead stock assessment have been noted, suggesting avenues for further research. The foremost need obviously is to acquire a comprehensive record of the Soviet catch and effort, and repeat the analysis with the full set of fishery statistics. Until then it will not be possible to evaluate the impact of fishing on the armorhead stock.

In addition, we suggest that information on oceanographic processes be examined for clues to the variation in armorhead recruitment. Experience with other species suggests that this will be a difficult task, but worth the effort. Information concerning thermal structure and the behavior of currents in the region of the Emperor-Hawaiian Ridge seems to be in fair abundance, and it would be useful to attempt even rough models of the habitat of armorhead during their critical early stages and the environmental conditions affecting recruitment of adults to the seamounts. One specific objective would be to seek an explanation for the sudden collapse of the armorhead spawning biomass in 1978, and the apparent rise of alfonsin. A starting point may be the finding of Mizuno and White (1983), based on analysis of TRANSPAC XBT casts and IODC data from long. 130°E to 170°W that the Kuroshio meander weakened substantially beginning in 1978 or 1979, accompanied by a southward displacement of the Kuroshio Extension by 2° to lat. 34°N. Associated with this was increased instability in the meander and a doubling of eddy formation.

Other work needs to be done to establish the age distribution and the growth rates of armorhead. We assumed that the spawning stock consisted primarily of fish 2 years of age, so that the CPUE statistics not only provided a measure of spawning biomass in year i but also gave information on the recruitment produced by the parent stock in year i-2. If the larger armorhead on the seamounts are much older, say 5 or 6 years or more, different conclusions might be reached.

Our modeling made no specific mention of the striking morphological variation which has been noted in armorhead. As described by Humphreys and Tagami (1986), immature "fat-type" armorhead are characteristically found in the epipelagic waters of the northeastern Pacific, whereas mature "lean-type" fish occupy the seamounts. One reasonable hypothesis is that the fat-type armorhead are storing energy which is then expended later in reproduction. An important question for population dynamics and ecosystem energetics therefore is, "how long is the reproductive phase?" The autoregressive model simply subtracts mortality and adds recruitment from one period to the next, and makes no assumptions about the number of age groups in the spawning stock. However, if the age estimates by the Honolulu Laboratory are accurate, we are tempted to suggest that armorhead have a short life once they mature and recruit to the seamounts. Such an hypothesis is consistent with the predominance of lean-type armorhead in the spawning stock, and with the occurrence of emaciated, spent fish in the catches. Thus in some respects the life cycle of armorhead may resemble that of salmon or squid, and similar models of the population dynamics may be applicable.

Table 1.—Pelagic armorhead, *Pentaceros richardsoni*, catch (metric tons), effort (hours of trawling), and catch per unit effort (CPUE) (metric tons/hour) by Japanese stern trawlers on the central North Pacific seamounts.

Year/ Month	Catch	Effort	CPUE
Kimmei Seamount			
1969			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	106	28	3.79
Sept.	648	55	11.78
Oct.	2,203	64	34.42
Nov.	2,140	60	35.67
Dec.	1,983	91	21.79
1970			
Jan.	2,485	146	17.02
Feb.	709	24	29.54
Mar.	0	0	—
Apr.	533	68	7.84
May	760	82	9.27
June	20	6	3.33
July	72	9	8.00
Aug.	496	109	4.55
Sept.	0	0	—
Oct.	63	14	4.50
Nov.	0	0	—
Dec.	0	0	—
1971			
Jan.	7	7	1.00
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	88	28	3.14
June	0	0	—
July	0	0	—
Aug.	0	23	0.00
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1972			
Jan.	0	0	—
Feb.	5	11	0.45
Mar.	0	0	—
Apr.	72	1	72.0
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	0	0	—
Sept.	0	0	—
Oct.	0	0	—
Nov.	768	51	15.06
Dec.	1,170	34	34.41
1973			
Jan.	376	38	9.89
Feb.	148	22	6.73
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	0	0	—
Sept.	149	6	24.83
Oct.	52	4	13.00
Nov.	124	10	12.40
Dec.	45	10	4.50
1974			
Jan.	0	0	—
Feb.	124	2	62.00
Mar.	88	6	14.67
Apr.	152	16	9.50
May	397	52	7.63
June	108	12	9.00
July	812	73	11.12
Aug.	1,561	92	16.97
Sept.	773	41	18.85
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1975			
Jan.	0	18	0.00
Feb.	1,071	93	11.52
Mar.	543	56	9.70
Apr.	96	25	3.84
May	0	0	—
June	0	0	—
July	31	11	2.82
Aug.	201	14	14.36
Sept.	877	142	6.18
Oct.	374	44	8.50
Nov.	168	30	5.60
Dec.	429	37	11.59
1976			
Jan.	2	1	2.00
Feb.	206	46	4.48
Mar.	69	10	6.90
Apr.	17	1	17.00
May	1,822	408	4.47
June	1,743	255	6.84
July	606	115	5.27
Aug.	754	181	4.17
Sept.	950	149	6.38
Oct.	50	20	2.50
Nov.	168	30	5.60
Dec.	429	37	11.59
1977			
Jan.	0	0	—
Feb.	155	87	1.78
Mar.	734	773	0.95
Apr.	143	202	0.71
May	160	127	1.26
June	9	30	0.30
July	6	14	0.43
Aug.	0	0	—
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1978			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	132	226	0.58
May	17	312	0.05
June	22	347	0.06
July	6	152	0.04
Aug.	3	83	0.04
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1979			
Jan.	76	121	0.63
Feb.	88	189	0.47
Mar.	24	89	0.27
Apr.	1	15	0.07
May	6	66	0.09
June	1	29	0.03
July	1	58	0.02
Aug.	0	112	0.00
Sept.	2	51	0.04
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1980			
Jan.	1	26	0.04
Feb.	18	141	0.13
Mar.	35	166	0.21
Apr.	10	74	0.14
May	7	32	0.22
June	1	21	0.05
July	1	6	0.17
Aug.	0	5	0.00
Sept.	0	6	0.00
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1981			
Jan	0	4	0.00
Feb.	37	27	1.37
Mar.	12	127	0.09
Apr.	0	0	—
May	0	0	—
June	10	89	0.11
July	13	67	0.19
Aug.	3	32	0.09
Sept.	13	126	0.10
Oct.	1	94	0.01
Milwaukee Seamounts			
1969			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	0	0	—
Sept.	323	10	32.30
Oct.	0	0	—
Nov.	7	2	3.50
Dec.	0	0	—
1970			
Jan.	544	26	20.92
Feb.	1,692	89	19.01
Mar.	1.188	46	25.83
Apr.	821	32	25.66
May	2,619	150	17.46
June	4,481	396	11.32
July	2,495	322	7.75
Aug.	1,073	222	4.83
Sept.	2,794	402	6.95
Oct.	1,885	361	5.22
Nov.	8	6	1.33
Dec.	0	0	—
Milwaukee Seamounts (*cont.*)			
1971			
Jan.	68	19	3.58
Feb.	600	86	6.98
Mar.	0	0	—
Apr.	0	0	—
May	171	46	3.72
June	436	119	3.66
July	989	239	4.14
Aug.	1,213	284	4.27
Sept.	38	25	1.52
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1972			
Jan.	0	0	—
Feb.	0	0	—
Mar.	643	82	7.84
Apr.	2,722	78	34.90
May	6,103	34	179.50
June	0	0	—
July	0	0	—
Aug.	1,693	20	84.65
Sept.	2,120	58	36.55
Oct.	1,465	47	31.17
Nov.	81	6	13.50
Dec.	0	1	0.00
1973			
Jan.	459	24	19.13
Feb.	1,140	23	49.57
Mar.	1,129	13	86.85
Apr.	0	0	—
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	785	19	41.32
Sept.	1,714	32	53.56
Oct.	2,146	47	45.66
Nov.	2,208	97	22.76
Dec.	1,691	35	48.31
1974			
Jan.	3,375	105	32.14
Feb.	2,911	91	31.99
Mar.	2,683	71	37.79
Apr.	2,957	194	15.24
May	2,434	196	12.42
June	1,979	117	16.91
July	1,498	37	40.49
Aug.	339	29	11.69
Sept.	92	8	11.50
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1975			
Jan	838	86	9.74
Feb.	199	40	4.98
Mar.	1,044	51	20.47
Apr.	1,748	80	21.85
May	2,209	108	20.45
June	870	28	31.07
July	1,594	51	31.25
Aug.	2,358	186	12.68
Sept.	782	75	10.43
Oct.	259	21	12.33
Nov.	540	17	31.76
Dec.	246	16	15.38

Table 1.—*Continued.*

Year/ Month	Catch	Effort	CPUE
1976			
Jan.	883	103	8.57
Feb.	1,058	97	10.91
Mar.	2,070	141	14.68
Apr.	4,389	288	15.24
May	787	63	12.49
June	1,910	97	19.69
July	1,716	104	16.50
Aug.	1,178	63	18.70
Sept.	50	26	1.92
Oct.	299	25	11.96
Nov.	540	17	31.76
Dec.	278	17	16.35
1977			
Jan.	428	139	3.08
Feb.	122	65	1.88
Mar.	85	65	1.31
Apr.	540	226	2.39
May	617	237	2.60
June	156	254	0.61
July	69	114	0.61
Aug.	8	19	0.42
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1978			
Jan.	0	0	—
Feb.	0	0	—
Mar.	22	45	0.49
Apr.	45	133	0.34
May	29	191	0.15
June	38	192	0.20
July	38	335	0.11
Aug.	11	41	0.27
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1979			
Jan.	11	13	0.85
Feb.	11	25	0.44
Mar.	9	31	0.29
Apr.	0	0	—
May	11	108	0.10
June	9	85	0.11
July	13	89	0.15
Aug.	9	92	0.10
Sept.	14	144	0.10
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1980			
Jan.	25	113	0.22
Feb.	11	102	0.11
Mar.	31	131	0.24
Apr.	59	157	0.38
May	61	78	0.78
June	173	104	1.66
July	54	150	0.36
Aug.	84	195	0.43
Sept.	38	120	0.32
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1981			
Jan	3	6	0.50
Feb.	30	43	0.70
Mar.	12	18	0.67
Apr.	0	0	—
May	0	0	—
June	8	36	0.22
July	34	112	0.30
Aug.	29	178	0.16
Sept.	8	59	0.14
Oct.	0	2	0.00
Colahan Seamount			
1970			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	206	57	3.61
June	466	42	11.10
July	202	23	8.78
Aug.	3	2	1.50
Sept.	0	0	—
Oct.	39	4	9.75
Nov.	0	0	—
Dec.	0	0	—
1971			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	367	58	6.33
June	339	59	5.75
July	0	0	—
Aug.	0	0	—
Sept.	482	96	5.02
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1972			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	6,552	32	204.75
July	3,815	52	73.37
Aug.	1,212	15	80.80
Sept.	1,265	34	37.21
Oct.	0	0	—
Nov.	700	24	29.17
Dec.	621	14	44.36
1973			
Jan.	169	23	7.35
Feb.	108	2	54.00
Mar.	563	13	43.31
Apr.	791	9	87.89
May	0	0	—
June	644	28	23.00
July	0	0	—
Aug.	482	14	34.43
Sept.	240	16	15.00
Oct.	132	3	44.00
Nov.	1,058	40	26.45
Dec.	732	28	26.14
Colahan Seamount (*cont.*)			
1974			
Jan.	142	9	15.78
Feb.	407	12	33.92
Mar.	255	5	51.00
Apr.	300	15	20.00
May	0	0	—
June	95	11	8.64
July	0	0	—
Aug.	137	7	19.57
Sept.	71	6	11.83
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1975			
Jan.	202	12	16.83
Feb.	143	23	6.22
Mar.	0	0	—
Apr.	148	11	13.45
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	143	14	10.21
Sept.	394	34	11.59
Oct.	175	13	13.46
Nov.	483	22	21.95
Dec.	102	11	9.27
1976			
Jan.	130	21	6.19
Feb.	41	7	5.86
Mar.	23	8	2.88
Apr.	0	0	—
May	50	4	12.50
June	213	8	26.63
July	0	3	0.00
Aug.	0	4	0.00
Sept.	169	24	7.04
Oct.	117	18	6.50
Nov.	483	22	21.95
Dec.	102	11	9.27
1977			
Jan	6	1	6.00
Feb.	33	18	1.83
Mar.	0	0	—
Apr.	5	8	0.63
May	29	7	4.14
June	1	1	1.00
July	0	0	—
Aug.	0	0	—
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1978			
Jan.	0	0	—
Feb.	0	0	—
Mar.	16	32	0.50
Apr.	37	51	0.73
May	27	10	2.70
June	8	30	0.27
July	1	13	0.08
Aug.	2	12	0.17
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1979			
Jan.	28	22	1.27
Feb.	0	4	0.00
Mar.	0	0	—
Apr.	0	0	—
May	4	29	0.14
June	20	25	0.80
July	15	28	0.54
Aug.	6	12	0.50
Sept.	2	9	0.22
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1980			
Jan.	1	7	0.14
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	244	48	5.08
June	41	18	2.28
July	96	26	3.69
Aug.	39	54	0.72
Sept.	12	27	0.44
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1981			
Jan.	116	10	11.60
Feb.	55	22	2.50
Mar.	16	9	1.78
Apr.	0	0	—
May	0	0	—
June	6	20	0.30
July	4	32	0.13
Aug.	2	8	0.25
Sept.	9	12	0.75
Oct.	0	4	0.00
C-H Seamount			
1970			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	0	0	—
July	91	5	18.20
Aug.	0	0	—
Sept.	0	0	—
Oct.	0	0	—
Nov.	102	21	4.86
Dec.	0	0	—
1971			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	130	23	5.65
June	212	26	8.15
July	0	0	—
Aug.	0	0	—
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—

Table 1.—*Continued.*

Year/ Month	Catch	Effort	CPUE	Year/ Month	Catch	Effort	CPUE	Year/ Month	Catch	Effort	CPUE	Year/ Month	Catch	Effort	CPUE
C-H Seamount *(cont.)*								**Hancock Seamounts** *(cont.)*							
1973				1978				1971				1976			
Jan.	0	0	—	Jan.	0	0	—	Jan.	0	0	—	Jan.	112	22	5.09
Feb.	0	0	—	Feb.	0	0	—	Feb.	0	0	—	Feb.	47	4	11.75
Mar.	0	0	—	Mar.	0	0	—	Mar.	0	0	—	Mar.	24	4	6.00
Apr.	0	0	—	Apr.	0	0	—	Apr.	0	0	—	Apr.	0	0	—
May	0	0	—	May	3	5	0.60	May	81	23	3.52	May	0	0	—
June	81	3	27.00	June	1	13	0.08	June	0	0	—	June	163	21	7.76
July	0	0	—	July	0	0	—	July	0	0	—	July	0	0	—
Aug.	469	6	78.17	Aug.	0	0	—	Aug.	0	0	—	Aug.	0	0	—
Sept.	536	9	59.56	Sept.	0	0	—	Sept.	0	0	—	Sept.	30	4	7.50
Oct.	252	4	63.00	Oct.	0	0	—	Oct.	0	0	—	Oct.	67	8	8.38
Nov.	701	14	50.07	Nov.	0	0	—	Nov.	0	0	—	Nov.	404	16	25.25
Dec.	492	9	54.67	Dec.	0	0	—	Dec.	0	0	—	Dec.	265	19	13.95
1974				1979				1972				1977			
Jan.	0	0	—	Jan.	0	0	—	Jan.	0	0	—	Jan.	53	10	5.30
Feb.	283	8	35.38	Feb.	0	0	—	Feb.	0	0	—	Feb.	17	19	0.89
Mar.	154	3	51.33	Mar.	0	0	—	Mar.	0	0	—	Mar.	0	0	—
Apr.	0	0	—	Apr.	0	0	—	Apr.	0	0	—	Apr.	0	0	—
May	0	0	—	May	0	0	—	May	0	0	—	May	0	0	—
June	0	0	—	June	2	3	0.67	June	0	0	—	June	0	0	—
July	0	0	—	July	2	2	1.00	July	1,870	24	77.92	July	0	0	—
Aug.	251	8	31.38	Aug.	0	0	—	Aug.	0	0	—	Aug.	0	0	—
Sept.	0	0	—	Sept.	0	0	—	Sept.	0	0	—	Sept.	0	0	—
Oct.	0	0	—	Oct.	0	0	—	Oct.	0	0	—	Oct.	0	0	—
Nov.	0	0	—	Nov.	0	0	—	Nov.	783	13	60.23	Nov.	0	0	—
Dec.	0	0	—	Dec.	0	0	—	Dec.	705	8	88.13	Dec.	0	0	—
1975				1980				1973				1978			
Jan.	123	4	30.75	Jan.	0	0	—	Jan.	1,320	26	50.77	Jan.	0	0	—
Feb.	0	0	—	Feb.	0	0	—	Feb.	614	5	122.80	Feb.	0	0	—
Mar.	0	0	—	Mar.	0	0	—	Mar.	886	15	59.07	Mar.	0	0	—
Apr.	0	0	—	Apr.	0	0	—	Apr.	0	0	—	Apr.	0	0	—
May	0	0	—	May	37	6	6.17	May	0	0	—	May	178	6	29.67
June	0	0	—	June	4	1	4.00	June	593	12	49.42	June	0	0	—
July	0	0	—	July	1	5	0.20	July	2,296	75	30.61	July	0	0	—
Aug.	62	2	31.00	Aug.	13	10	1.30	Aug.	843	51	16.53	Aug.	0	0	—
Sept.	453	35	12.94	Sept.	8	8	1.00	Sept.	340	7	48.57	Sept.	0	0	—
Oct.	0	0	—	Oct.	0	0	—	Oct.	138	3	46.00	Oct.	0	0	—
Nov.	72	1	72.00	Nov.	0	0	—	Nov.	581	30	19.37	Nov.	0	0	—
Dec.	52	4	13.00	Dec.	0	0	—	Dec.	393	15	26.20	Dec.	0	0	—
1976				1981				1974				1979			
Jan.	63	2	31.50	Jan.	51	5	10.20	Jan.	205	11	18.64	Jan.	0	0	—
Feb.	25	3	8.33	Feb.	99	7	14.14	Feb.	0	0	—	Feb.	0	0	—
Mar.	0	0	—	Mar.	0	0	—	Mar.	219	3	73.00	Mar.	0	0	—
Apr.	0	0	—	Apr.	0	0	—	Apr.	75	6	12.50	Apr.	0	0	—
May	0	0	—	May	0	0	—	May	14	1	14.00	May	23	10	2.30
June	0	0	—	June	2	1	2.00	June	72	4	18.00	June	39	61	0.64
July	0	0	—	July	0	0	—	July	0	0	—	July	5	22	0.23
Aug.	0	0	—	Aug.	0	0	—	Aug.	0	0	—	Aug.	0	0	—
Sept.	0	0	—	Sept.	0	0	—	Sept.	39	4	9.75	Sept.	0	0	—
Oct.	176	6	29.33	Oct.	0	0	—	Oct.	0	0	—	Oct.	0	0	—
Nov.	72	1	72.00					Nov.	0	0	—	Nov.	0	0	—
Dec.	52	4	13.00	**Hancock Seamounts**				Dec.	0	0	—	Dec.	0	0	—
1977				1970				1975				1980			
Jan.	0	0	—	Jan.	0	0	—	Jan.	0	0	—	Jan.	0	0	—
Feb.	0	0	—	Feb.	0	0	—	Feb.	0	0	—	Feb.	0	0	—
Mar.	0	0	—	Mar.	0	0	—	Mar.	0	0	—	Mar.	0	0	—
Apr.	10	6	1.67	Apr.	0	0	—	Apr.	0	0	—	Apr.	0	0	—
May	12	3	4.00	May	41	7	5.86	May	0	0	—	May	0	0	—
June	1	4	0.25	June	15	2	7.50	June	0	0	—	June	0	0	—
July	0	0	—	July	34	4	8.50	July	0	0	—	July	0	0	—
Aug.	0	0	—	Aug.	90	4	22.50	Aug.	169	17	9.94	Aug.	42	11	3.82
Sept.	0	0	—	Sept.	0	0	—	Sept.	265	14	18.93	Sept.	189	102	1.85
Oct.	0	0	—	Oct.	0	0	—	Oct.	218	12	18.17	Oct.	0	0	—
Nov.	0	0	—	Nov.	140	28	5.00	Nov.	404	19	21.26	Nov.	0	0	—
Dec.	0	0	—	Dec.	0	0	—	Dec.	265	19	13.95	Dec.	0	0	—

Table 1.—*Continued.*

Year/ Month	Catch	Effort	CPUE
1981			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	234	46	5.09
July	0	0	—
Aug.	39	61	0.64
Sept.	130	114	1.14
Oct.	0	0	—
Others			
1970			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	0	0	—
Sept.	0	0	—
Oct.	0	0	—
Nov.	95	25	3.80
Dec.	0	0	—
1971			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	6	6	1.00
June	319	61	5.23
July	0	0	—
Aug.	0	4	0.00
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1972			
Jan.	0	0	—
Feb.	5	2	2.50
Mar.	29	5	5.80
Apr.	0	0	—
May	0	0	—
June	25	1	25.00
July	0	0	—
Aug.	123	2	61.50
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	117	1	117.00
1973			
Jan.	21	13	1.62
Feb.	2	14	0.14
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	167	6	27.83
July	169	6	28.17
Aug.	15	3	5.00
Sept.	0	0	—
Oct.	138	1	138.00
Nov.	187	12	15.58
Dec.	42	1	42.00
Others (*cont.*)			
1974			
Jan.	0	0	—
Feb.	64	1	64.00
Mar.	571	6	95.17
Apr.	23	2	11.50
May	57	1	57.00
June	83	8	10.38
July	235	7	33.57
Aug.	0	0	—
Sept.	72	4	18.00
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1975			
Jan.	0	5	0.00
Feb.	0	0	—
Mar.	0	0	—
Apr.	63	3	21.00
May	0	0	—
June	151	5	30.20
July	0	0	—
Aug.	774	35	22.11
Sept.	184	5	36.80
Oct.	241	12	20.08
Nov.	0	0	—
Dec.	32	1	32.00
1976			
Jan.	97	16	6.06
Feb.	39	2	19.50
Mar.	34	7	4.86
Apr.	0	0	—
May	132	28	4.71
June	245	29	8.45
July	71	11	6.46
Aug.	181	15	12.07
Sept.	141	19	7.42
Oct.	59	4	14.75
Nov.	0	3	0.00
Dec.	0	0	—
1977			
Jan.	0	0	—
Feb.	13	9	1.44
Mar.	0	6	0.00
Apr.	8	8	1.00
May	26	6	4.33
June	6	7	0.86
July	0	0	—
Aug.	0	0	—
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1978			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	12	27	0.44
May	231	38	6.08
June	1	13	0.08
July	0	21	0.00
Aug.	0	5	0.00
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1979			
Jan.	0	0	—
Feb.	0	2	0.00
Mar.	0	0	—
Apr.	0	0	—
May	11	17	0.65
June	43	96	0.45
July	14	48	0.29
Aug.	0	0	—
Sept.	0	0	—
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1980			
Jan.	0	0	—
Feb.	2	5	0.40
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	293	71	4.13
Sept.	212	155	1.37
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1981			
Jan.	0	0	—
Feb.	22	8	2.75
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	150	33	4.55
July	12	34	0.35
Aug.	12	58	0.21
Sept.	38	126	0.30
Oct.	1	1	1.00
Total			
1969			
Jan.	0	0	—
Feb.	0	0	—
Mar.	0	0	—
Apr.	0	0	—
May	0	0	—
June	0	0	—
July	0	0	—
Aug.	106	28	3.79
Sept.	971	65	14.94
Oct.	2,203	64	34.42
Nov.	2,147	62	34.63
Dec.	1,983	91	21.79
1970			
Jan.	3,029	172	17.61
Feb.	2,401	113	21.25
Mar.	1,188	46	25.83
Apr.	1,354	100	13.54
May	3,626	296	12.25
June	4,982	446	11.17
July	2,894	363	7.97
Aug.	1,662	337	4.93
Sept.	2,794	402	6.95
Oct.	1,987	379	5.24
Nov.	345	80	4.31
Dec.	0	0	—
Total (*cont.*)			
1971			
Jan.	75	26	2.89
Feb.	600	86	6.98
Mar.	0	0	—
Apr.	0	0	—
May	843	184	4.58
June	1,306	265	4.93
July	989	239	4.14
Aug.	1,213	311	3.90
Sept.	520	121	4.30
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1972			
Jan.	0	0	—
Feb.	10	13	0.77
Mar.	672	87	7.72
Apr.	2,794	79	35.37
May	6,103	34	179.50
June	6,577	33	199.30
July	5,685	76	74.80
Aug.	3,028	37	81.84
Sept.	3,385	92	36.79
Oct.	1,465	47	31.17
Nov.	2,332	94	24.81
Dec.	2,613	58	45.05
1973			
Jan.	2,345	124	18.91
Feb.	2,012	66	30.49
Mar.	2,578	41	62.88
Apr.	791	9	87.89
May	0	0	—
June	1,485	49	30.31
July	2,465	81	30.43
Aug.	2,594	93	27.89
Sept.	2,979	70	42.56
Oct.	2,858	62	46.10
Nov.	4,859	203	23.94
Dec.	3,395	98	34.64
1974			
Jan.	3,722	125	29.78
Feb.	3,789	114	33.24
Mar.	3,970	94	42.23
Apr.	3,507	233	15.05
May	2,902	250	11.61
June	2,337	152	15.38
July	2,545	117	21.75
Aug.	2,288	136	16.82
Sept.	1,047	63	16.62
Oct.	0	0	—
Nov.	0	0	—
Dec.	0	0	—
1975			
Jan.	1,163	125	9.30
Feb.	1,413	156	9.06
Mar.	1,587	107	14.83
Apr.	2,055	119	17.27
May	2,209	108	20.45
June	1,021	33	30.94
July	1,625	62	26.21
Aug.	3,707	268	13.83
Sept.	2,955	305	9.69
Oct.	1,267	102	12.42
Nov.	1,667	89	18.73
Dec.	1,126	88	12.80

Table 1.—*Continued.*

Year/ Month	Catch	Effort	CPUE	Year/ Month	Catch	Effort	CPUE
Total (*cont.*)							
1976				1979			
Jan.	1,287	165	7.80	Jan.	115	156	0.74
Feb.	1,416	159	8.91	Feb.	99	220	0.45
Mar.	2,220	170	13.06	Mar.	33	120	0.28
Apr.	4,406	289	15.25	Apr.	1	15	0.07
May	2,791	503	5.55	May	55	230	0.24
June	4,274	410	10.42	June	114	299	0.38
July	2,393	233	10.27	July	50	247	0.20
Aug.	2,113	263	8.03	Aug.	15	216	0.07
Sept.	1,340	222	6.04	Sept.	18	204	0.09
Oct.	768	81	9.48	Oct.	0	0	—
Nov.	1,667	89	18.73	Nov.	0	0	—
Dec.	1,126	88	12.80	Dec.	0	0	—
1977				1980			
Jan.	487	150	3.25	Jan.	27	146	0.18
Feb.	340	198	1.72	Feb.	31	248	0.13
Mar.	819	844	0.97	Mar.	66	297	0.22
Apr.	706	450	1.57	Apr.	69	231	0.30
May	844	380	2.22	May	349	164	2.13
June	173	296	0.58	June	219	144	1.52
July	75	128	0.59	July	152	187	0.81
Aug.	8	19	0.42	Aug.	471	346	1.36
Sept.	0	0	—	Sept.	459	418	1.10
Oct.	0	0	—	Oct.	0	0	—
Nov.	0	0	—	Nov.	0	0	—
Dec.	0	0	—	Dec.	0	0	—
1978				1981			
Jan.	0	0	—	Jan.	170	25	6.80
Feb.	0	0	—	Feb.	243	107	2.27
Mar.	38	77	0.49	Mar.	40	154	0.26
Apr.	226	437	0.52	Apr.	0	0	—
May	485	562	0.86	May	0	0	—
June	70	595	0.12	June	410	225	1.82
July	45	521	0.09	July	63	245	0.26
Aug.	16	141	0.11	Aug.	85	337	0.25
Sept.	0	0	—	Sept.	198	437	0.45
Oct.	0	0	—	Oct.	2	101	0.02
Nov.	0	0	—				
Dec.	0	0	—				

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Appendix

Parameters of the autoregressive stock model

Parameters of the autoregressive stock model were estimated iteratively by minimizing the weighted sum of squares

$$\Phi = \sum_{i=1}^{n} E_i \, [\mathrm{CPUE}_i - \widehat{\mathrm{CPUE}}_i]^2$$

where n = total number of data points in the time series. The squared residuals were weighted by effort, E_i, so that time periods with no observation of CPUE (i.e., $E_i = 0$) did not contribute to Φ and had no bearing on the parameter estimation.

Predicted CPUE's for every time period (including those with zero effort) were computed at each iteration by

$$\widehat{\mathrm{CPUE}}_i = \left\{ \left(\frac{W_i}{W_{i-1}} \right)^a \mathrm{CPUE}_{i-1}^a \, S_{i-1,i} + R_i \, Q^a \, W_i^a \, S_i \right\}^{\frac{1}{a}}$$

where

$$S_{i-1,i} = \mathrm{e}^{-(M+F_{i-1,i})}$$

$$S_i = \mathrm{e}^{-(M+F_i)/2}$$

$$R_i = \alpha \left[1 - \mathrm{e}^{-\beta P_{i\text{-}\delta}} \right]$$

and the auxilliary variables are defined as

$$F_{i-1,i} = Q^a \left[\left(\frac{\mathrm{CPUE}_{i-1}}{W_{i-1}} \right)^b E_{i-1} + \left(\frac{\mathrm{CPUE}_i}{W_i} \right)^b E_i \right] /2$$

$$F_i = Q^a \left(\frac{\mathrm{CPUE}_i}{W_i} \right)^b E_i$$

$$P_{i-\delta} = W_{i-\delta}^b \left(\frac{\mathrm{CPUE}_{i-\delta}}{Q} \right)^a$$

$$a = 1/(\gamma + 1)$$

$$b = \gamma/(\gamma + 1).$$

Lagged spawning biomasses for the first δ time periods in the observed series were assumed equal to the spawning biomass in period 1.