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Application of a Laevastu-Larkins
Ecosystem Model
for Bering Sea
Groundfish Management

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APPLICATION OF AN ECOSYSTEM MODEL FOR BERING
SEA GROUND FISH ASSESSMENT AND MANAGEMENT

By

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ABSTRACT

The use of ecosystem models to augment traditional species-by-species analyses of fisheries data has taken on a more practical value for the assessment and management of Bering Sea groundfish resources. This paper illustrates the use of a Laevastu-Larkins model, the PROBUB model, to evaluate trends in stock biomass of the various groundfish groups and how the trends can influence their catch quota regulations. The model suggests that catch quotas for four species groups be set different from their estimates derived from single-species analyses. It has illustrated that it may not be realistic to rebuild two stocks to former higher levels because the present low levels are the normal long-term trends. The model also shows that the biomass of the groundfish complex fluctuates by an average of 22% over a 5-6 year cycle. The largest fluctuation for a component species is 50% in 3 years. All other species groups, except the longer-lived rockfish group, show fluctuations of 8-30% over cycles of 5-10 years. Based on these cyclic trends, three stocks with high amplitudes and short periods of fluctuation should be monitored more closely in management and their catches adjusted from year to year. Most of the other stocks have lower amplitudes of change over longer periods and can be managed on a relatively stable basis. The model, therefore, has enhanced the information derived from single-species analyses which is still relied upon to provide a great amount of essential details on the dynamic characteristics of the stocks.

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INTRODUCTION

Large variations in production of neritic fish resources have been well illustrated throughout this meeting. Similar variations, perhaps of smaller amplitude and notoriety, occur commonly in the demersal and semi-demersal fisheries resources as well. A case to be illustrated here is the Bering Sea groundfish resource. Over the past 30 years, catches of groundfish have fluctuated through several distinct cycles (Bakkala et al., 1979). A peak catch of 750,000 metric tons (t) in 1961 dominated by yellowfin sole (Limanda aspera) was attained in the first obvious cycle (Figure 1). This was followed by a record catch of 2.2 million t in 1972 when the dominant species was walleye pollock (Theragra chalcogramma). Since 1977, catches have varied in a relatively narrower range between 1.2 and 1.4 million t, largely as a result of catch quotas. The imposed quotas stabilized catches that might otherwise have followed wide natural fluctuations in abundance of the stocks.

General causes for such natural variations in the production of groundfish in the Bering Sea have been discussed by Laevastu et al. (1982). They noted that besides external factors, such as effects of temperature anomalies and fishing, ecologically internal factors like predation, cannibalism, competition, and migration can contribute significantly to the fluctuations of population biomass.

Specific year-to-year variations can be more readily illustrated by stock assessments made on a species-by-species basis as typically reported in Bakkala and Low (1983)^{1/}. These assessments depend largely on single-species analyses of catch-per-unit-effort trends and their population dynamics. They provide estimates of potential yield for resources that largely reflect current conditions, but lack the consideration of longer term effects of fishing in an ecosystem context.

^{1/} Bakkala, R. G., and L. L. Low (eds.). 1983. Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1982. NOAA Tech. Memo. NMFS F/NWC-42. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., 2725 Montlake Blvd. E., Seattle, WA 98112.

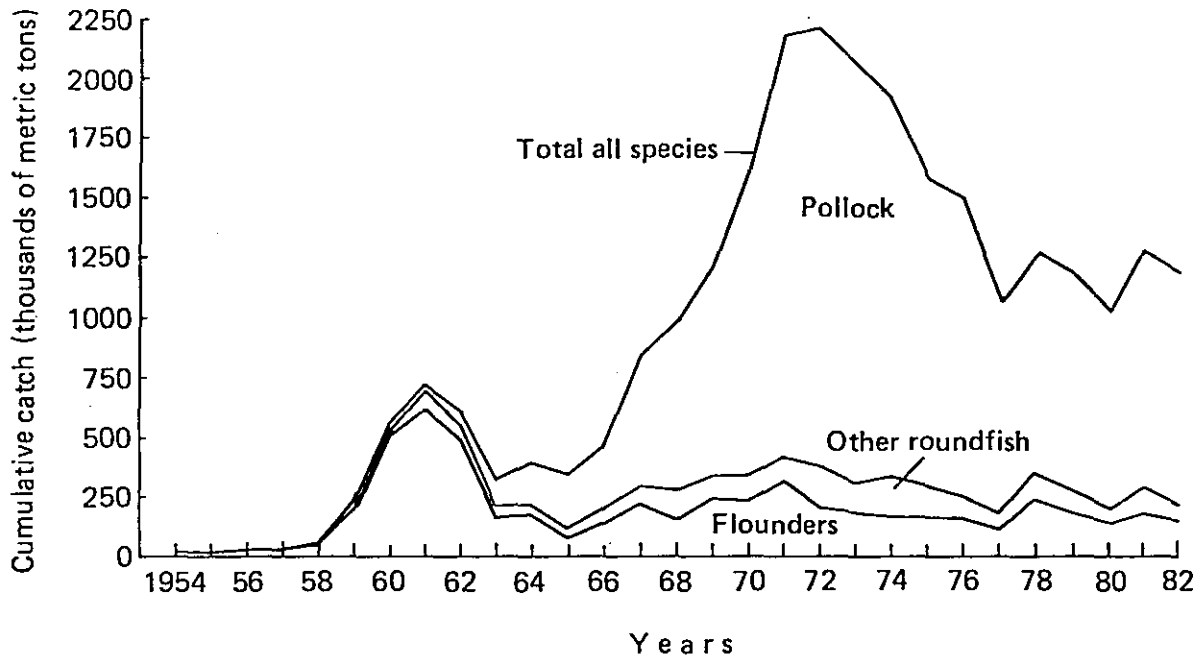


Figure 1.--Groundfish catches in the Bering Sea, 1954 to 1982.

This paper illustrates how an ecosystem model developed at the Northwest and Alaska Fisheries Center in Seattle by Dr. Taivo Laevastu (Laevastu and Larkins, 1981) can be used to evaluate impacts of fishing on groundfish. Application of the Laevastu-Larkins type model has improved the assessment of the stocks which had previously been approached from a species-by-species basis.

STOCK ASSESSMENT AND MANAGEMENT

Although the Bering Sea groundfish fishery is largely a trawl fishery and is multispecies in character, assessment and management of the resources have been approached on a species-by-species basis. The status of individual stocks has been determined for each species group and an optimum yield (OY) set for each unit. These OY's eventually become annual catch quotas for management. When the catch quota for a species is reached, the entire fishery or that of a particular group may be subject to closure, even though abundance of the species may have increased since the quota was originally set a year or two earlier. This management process under the present fishery management plan (FMP) does not, therefore, allow a quick change of the regulations. Instead, the FMP may require a lengthy and elaborate review process to implement a change.

In order to improve on this management system, an amendment to the FMP has been developed to manage the groundfish complex as a unit while allowing adjustments to the catch of individual species in response to fluctuations in their abundance. The amendment allows the annual OY for the groundfish complex to be set within 1.4-2.0 million t at the beginning of each year without a lengthy amendment process. The OY range has been set to reflect the present yield potential of the resource and the current socio-economic preference of the fishing industry and management to harvest at that range. At the time annual OY is set, catch quotas for the individual component species within the complex will be set to reflect ecosystem interactions of the stocks and their current status of stocks.

The latest species-by-species analyses reported by Bakkala and Low (1983)¹/ show that the annual surplus production (ASP) or equilibrium yield of the individual species groups in the groundfish complex add up to more than 2 million t (Table 1). The term ASP is defined as the annual yield that may be taken without appreciably changing the biomass of the stock the following year. The estimates, therefore, reflect the current and short-term potential yield from the resources and may be used to set catch quotas. Notes on abundance trends of the stocks are also included in Table 1.

Pollock is clearly the most dominant and productive species in the groundfish complex. Its ASP of 1.3 million t for 1983 accounts for 63% of the total production. The ASP for Pacific cod (Gadus macrocephalus) is next highest (298,000 t) due to the presence of unusually strong year classes and accounts for 15% of the groundfish production. (In the case of Pacific cod, ASP is actually substantially below 298,000 t, but is set higher to take advantage of the strong year classes that would otherwise die off rapidly due to natural mortality. Therefore, ASP for cod does not conform strictly to its definition.) Yellowfin sole production is a close third at 200,000 t, or 10% of total production. The rest of the flatfishes (turbot and other flatfish) account for an ASP of 205,000 t, or another 10% of total production. The turbot group is made up of arrowtooth flounder (Atheresthes stomias) and Greenland turbot (Reinhardtius hippoglossoides). The other flatfish group is mainly made up of Alaska plaice (Pleuronectes quadrituberculatus), rock sole (Lepidopsetta bilineata), and flathead sole (Hippoglossoides elassodon). The rest of the species--Pacific ocean perch (Sebastes alutus), other rockfishes (Sebastes spp. and Sebastolobus spp.), sablefish (Anoplopoma fimbria), and Atka mackerel (Pleurogrammus monopterygius)--account for the remaining 2% of the total groundfish production.

Table 1.--Estimated annual surplus production for 1983 and abundance trends for the major commercial groundfish species in the Bering Sea.

Species group	Annual surplus production (1,000 t)	Abundance trend
Walleye pollock	1,300.0	Average abundance, on declining trend
Pacific cod	298.0	Historic high abundance, expected to decline rapidly
Yellowfin sole	200.0	Historic high abundance, stable
Turbots	85.0	Average abundance, stable
Other flatfish	120.0	Average abundance, stable
Sablefish	2.9	Low abundance, stable
Pacific Ocean perch	11.7	Low abundance, stable
Other rockfish	14.1	Average abundance, stable
Atka mackerel	26.0	Average abundance, stable
Total groundfish	2,057.7	High abundance, expected to decline slightly

Normally, the species-by-species analyses on the status of stocks and ASP's summarized in Table 1 would serve as the basis for setting catch quotas. Since ecosystem models have been developed to the extent that they can now be used to evaluate the dynamics and long-term trends of the entire groundfish complex, they have been applied here to improve on the single-species analyses.

ECOSYSTEM ANALYSIS

Various computer simulation models have been developed to describe the interrelationship and dynamics of the Bering Sea ecosystem. Two widely tested models are the Prognostic Bulk Biomass (PROBUB) and the Dynamical Numerical Marine Ecosystem Simulation (DYNUMES) models developed at the Northwest and Alaska Fisheries Center and described by Laevastu and Larkins (1981). Both models compute the transfer of material between trophic levels via predation, mortality, growth, and man-induced processes (such as fishing) that occur in the ecosystem. The PROBUB model is a simpler model of the ecosystem while the DYNUMES model is a more detailed representation of its dynamics, including migration routines. In this paper, the PROBUB model is used because of its greater simplicity for showing long-term trends of stock biomass.

PROBUB simulates the dynamics of the ecological components (marine birds, marine mammals, groundfish, pelagic fish, and benthic organisms) and the principal individual species within these components. The model takes into account the biomass of each species group, the prey-predator relationships among these groups and also tracks their change in biomass in specific areas and time steps. The input data required to initiate the simulations were described by Laevastu et al. (1980)^{2/}. These input data are initial estimates of abundance for each species group, their food requirements in terms of species and quantities, and the effects of growth and mortality on the biomass and distribution of species groups.

Several series of simulations were made to evaluate the natural equilibrium and effects of fishing on the ecosystem. There are three series of basic simulations which provide the long-term equilibrium bounds for the populations from which impacts of fishing may be gauged.

Equilibrium Biomass

Starting with the present species makeup, their prey-predator relationships, and other input parameters on growth rates and food requirements, PROBUB was run until the species composition (with emphasis on the groundfish species) reached equilibrium. These simulations produce three sets of equilibrium biomass for the various groups:

(a) A minimum equilibrium biomass using the lowest estimated food requirements and the highest estimated growth rates of predators,

(b) A maximum equilibrium biomass using the highest estimated food requirements and lowest estimated growth rates of predators, and

(c) The mean equilibrium biomass using the most likely mean values for both requirements.

^{2/} Laevastu, T., P. Livingston, and K. Niggol. 1980. Unpub. manusc. Basic inputs to PROBUB model of the eastern Bering Sea and western Gulf of Alaska. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., 2725 Montlake Blvd. E., Seattle, WA 98112.

The estimated levels of minimum and maximum equilibrium biomass for the major groundfish groups taken in the commercial fishery are shown in Table 2. Other details and estimated biomass for the rest of the ecosystem groups are available but not shown here. The equilibrium points provide the lower and upper bounds by which stock biomass are expected to vary. They do not include possible effects of environmental anomalies which may cause unusual changes to the stocks and, therefore, are viewed as average long-term equilibrium levels. The minimum equilibrium biomass for the major groundfish species totals 19 million t. The maximum is 32 million t, indicating a long-term average variation of about 13 million t. It should be noted that the minimum and maximum biomass for each species do not occur concomitantly; maximum for one species can occur when abundance of another species is at a minimum or intermediate level.

The simulations show that if the present composition in the ecosystem is left to interact naturally, pollock will be the most abundant species in the groundfish complex and expected to make up 63% of total biomass, just as its present ASP is of the total groundfish production. Atka mackerel will be the next most abundant species, making up about 9-13% of the biomass. Pacific cod will be third and is followed closely by yellowfin sole; each species will make up about 5-6% of the groundfish biomass. The rest of the species groups will make up the remaining 18-20% of the biomass.

Table 2.--Estimated minimum and maximum equilibrium biomass of the major commercially important groundfish species in the Bering Sea by the PROBUB ecosystem model.

Species group	Minimum biomass (1,000 t)	Maximum biomass (1,000 t)
Walleye pollock	10,600	20,000
Pacific cod	1,160	1,700
Yellowfin sole	980	1,480
Turbots	540	765
Other flatfish	1,785	2,450
Sablefish	140	200
Pacific Ocean perch	420	720
Other rockfish	980	1,680
Atka mackerel	2,400	2,800
Total groundfish	19,005	31,795

Experimental Simulations

After the ecosystem model has been simulated to reach the mean equilibrium state, experimental catch levels, equal to or close to ASP's shown in Table 1, were incorporated into the simulations to determine their effects on groundfish biomass. As examples, three series of catch levels were simulated (Table 3). These series of catch levels are equivalent to first-guess acceptable catch estimates used by Laevastu and Larkins (1981). Series A depicts catch and discard levels in 1980. Series B and C depict alternative catch levels that were selected as possible catch quotas. It is obvious that virtually limitless combinations of catches may be simulated and the proper combination would have to be specifically picked. The model computes the changes to the biomass of each species group given the assumption that from the point of mean equilibrium, the fishery will take a relatively constant catch of each species each year as depicted in Series A to C.

The 10-year trend of the biomass level resulting from the simulations for each groundfish species and the entire groundfish complex are shown in Figures 2-11. The figures show the minimum and maximum equilibrium biomass for each species, the estimated ASP level for 1983, and how the biomass of each species would change if the resources are exploited according to each series of catch levels.

The manner in which the biomass fluctuates about the minimum and maximum equilibrium bounds may be used to evaluate whether a catch level is appropriate and likely to be sustained. Since the PROBUB model is structured to simulate the long-term average condition of the ecosystem, results shown in Figures 2-11 do not account for possible effects of environmental anomalies which may cause unusually high or low recruitment levels. Interpretation of these figures should, therefore, consider the potential for these anomalous factors and other dynamic characteristics of the current populations. These short-term features are more readily revealed by single-species analyses.

In practice, therefore, catch quotas and other regulations have been determined largely from the species-by-species analyses depicted in Table 1, but modified by the effects of longer term simulations such as those depicted in Figures 2-11. A species-by-species interpretation of the figures follows.

Table 3.--Three series of catch levels selected for simulation by the PROBUB ecosystem model and their reference to annual surplus production (ASP) estimated by single-species analysis techniques.

Species group	ASP (1,000 t)	Catch levels in thousand t		
		Series A	Series B	Series C
Walleye pollock	1,300.0	1,500	1,560	1,135
Pacific cod	298.0	100	88	137
Yellowfin sole	200.0	86	120	137
Turbots	85.0	34	53	53
Other flatfish	120.0	66	86	105
Sablefish	2.9	9	9	9
Pacific ocean perch	11.7	9	9	9
Other rockfish	14.1	19	17	19
Atka mackerel	26.0	28	47	28
Total groundfish	2,057.7	1,851	1,989	1,632

Pollock (Figure 2): Abundance of pollock shows the widest level of fluctuation of all the groundfish species, largely due to its cannibalistic characteristics. Simulated catch levels of 1.13 to 1.50 million t resulted in significant difference to the stock biomass. At the higher catch level, the amplitude of variation is smaller and the population biomass is driven lower. The period of the cycle is 6 years. In a matter of 3 years, the stock biomass can drop from peak to trough by about 50% (Table 4). Therefore, catches need to be adjusted accordingly.

The simulations show that the proper level of catch for the fishery should take into account the current point of the abundance cycle. Information from the single-species analyses suggests that the biomass of pollock declined during 1973-76, increased slightly from 1977-81 and may be on a down cycle immediately after a peak. The 1983 ASP of 1.3 million t would, therefore, be on the high side, since biomass is expected to be driven further below the minimum equilibrium level for 3 years before another up cycle is encountered. Therefore, it is suggested that the catch level for 1983 be set below ASP, perhaps even as low as 1.0 million t, to maintain the population biomass at a higher level. This is a case example where the model has suggested a catch level lower than that derived from single species analyses.

Pacific cod (Figure 3): In the case of cod, the long-term sustainable yield is about 100,000 t based on model simulations. The simulations also show that normal variations in cod biomass are not very large ($\pm 8\%$) and have a weak periodicity of 5 years. However, based on single-species analysis, it can be shown that variations can be much higher and that the current biomass of cod is at an unprecedented high level because of unusually strong year classes in the population (Bakkala and Low, 1983)^{1/}. The ASP of 298,000 t is about three times larger than the long-term equilibrium yield. This ASP should provide a better basis for setting the 1983 catch level for the fishery because the strong year classes are expected to remain in the fishery for no more than another 3 years. It is more prudent to take advantage of the available surplus production now before it is lost to natural mortality. This is a case example where model results should be modified for management.

Yellowfin sole (Figure 4): Model simulations show that the long-term equilibrium yield is about 130,000 t and natural fluctuations in biomass are not large ($\pm 12\%$). The period of the cycle is about 5-7 years. From single-species assessments, on the other hand, it was noted that the yellowfin sole population is at an historic high and has been increasing rapidly in abundance since 1979 (Bakkala and Low, 1983)^{1/}. The high level of abundance is attributed to a succession of strong year classes. The 1983 ASP is at least 200,000 t. Since population abundance is substantially above the long-term maximum equilibrium level, it is prudent to harvest at the ASP level to take advantage of high surplus production. The 200,000 t catch level may also be beneficial to the overall ecosystem since it would contribute to drive the population biomass down towards equilibrium. Further simulations of the model should be able to test this premise.

POLLOCK ASP= 1,300,000 t

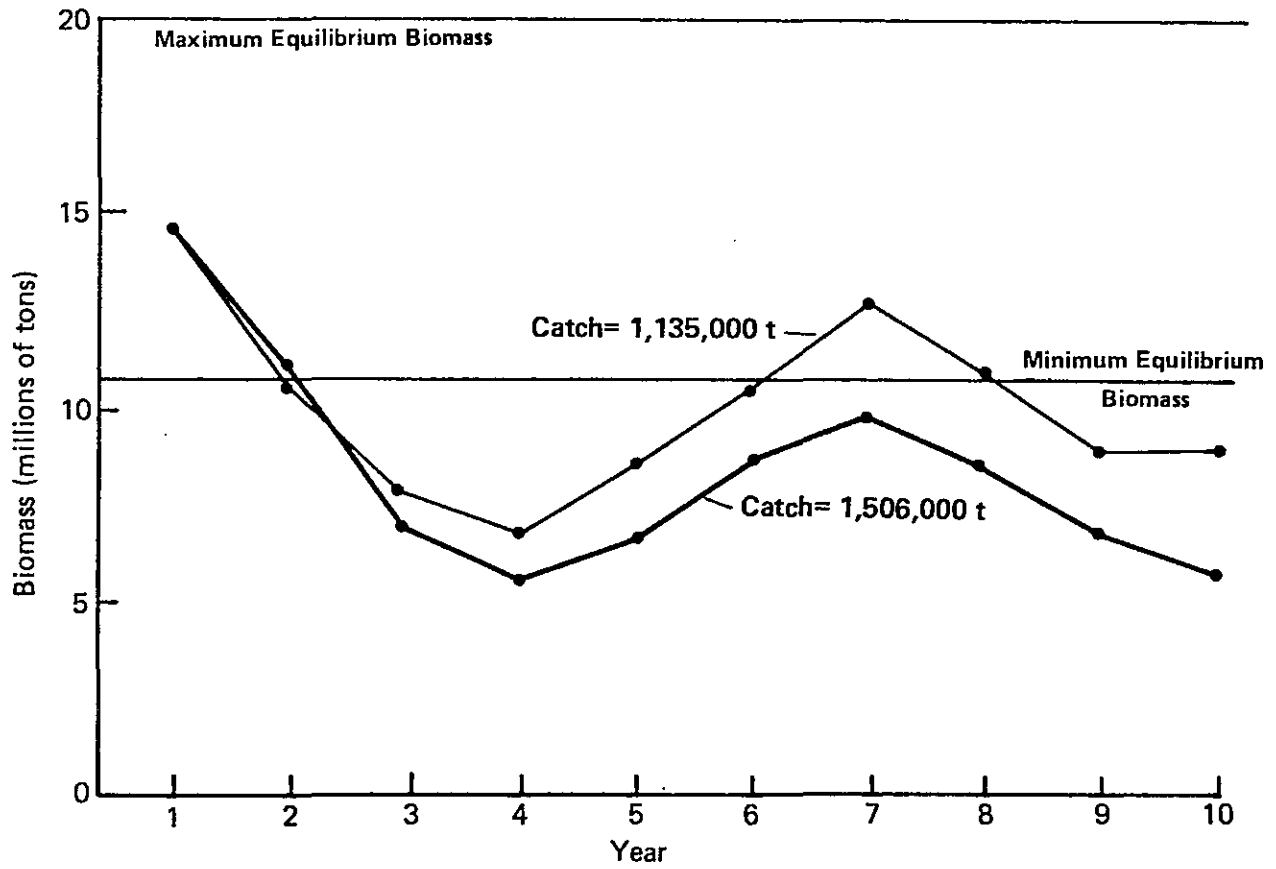


Figure 2.--Annual surplus production (ASP) in 1983 and predicted trends in population biomass at selected catch levels for walleye pollock.

Table 4.--Typical period and magnitude of fluctuations in biomass for the major groundfish groups in the Bering Sea under average conditions.

Species group	Period (years)	Fluctuation (percent)
Walleye pollock	6	50
Pacific cod	5	8
Yellowfin sole	5-7	12
Turbots	7-9	20
Other flatfish	5	10
Sablefish	6	20
Pacific ocean perch	No apparent cycle	
Other rockfish	No apparent cycle	
Atka mackerel	8-10	30
Total groundfish	5-6	22

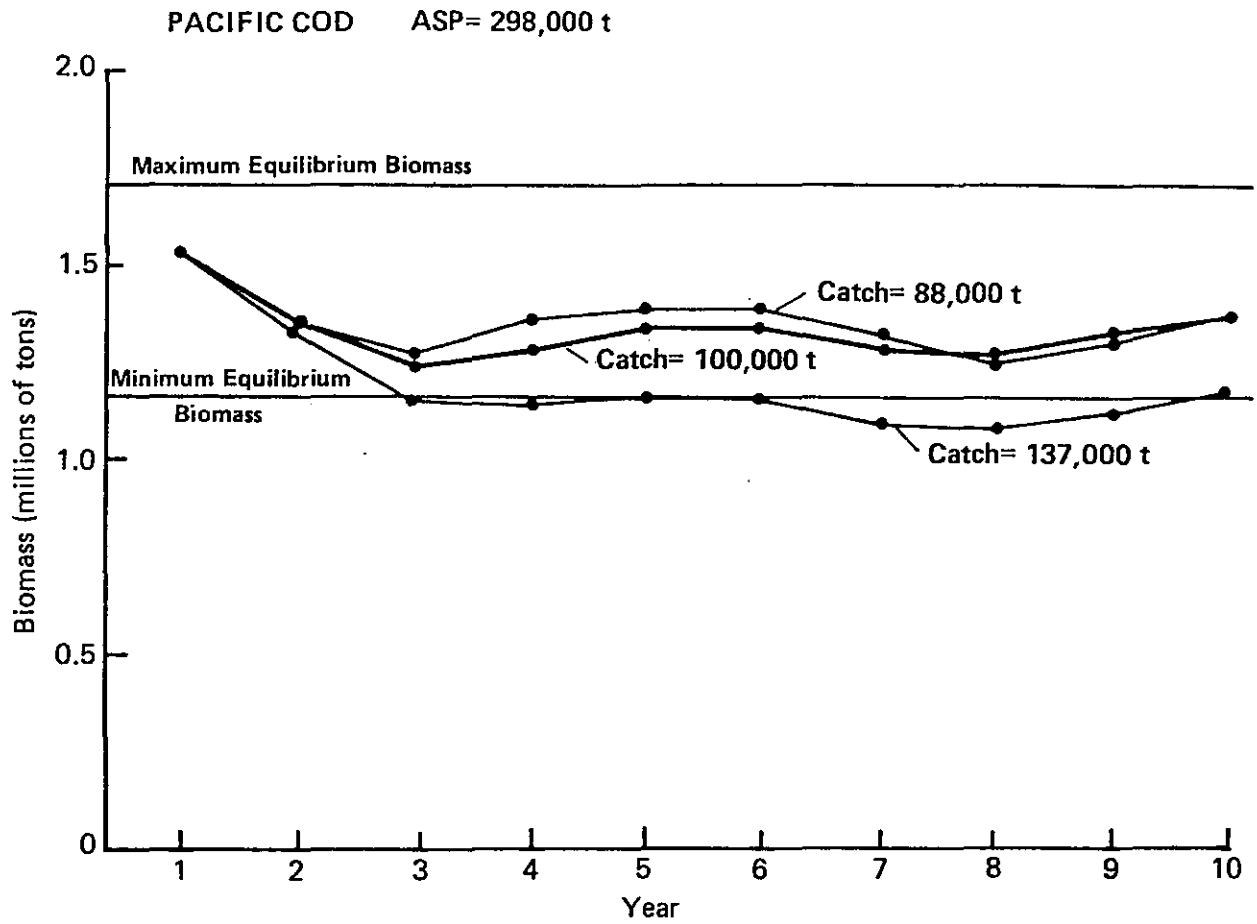


Figure 3.--Annual surplus production (ASP) in 1983 and predicted trends in population biomass at selected catch levels for Pacific cod.

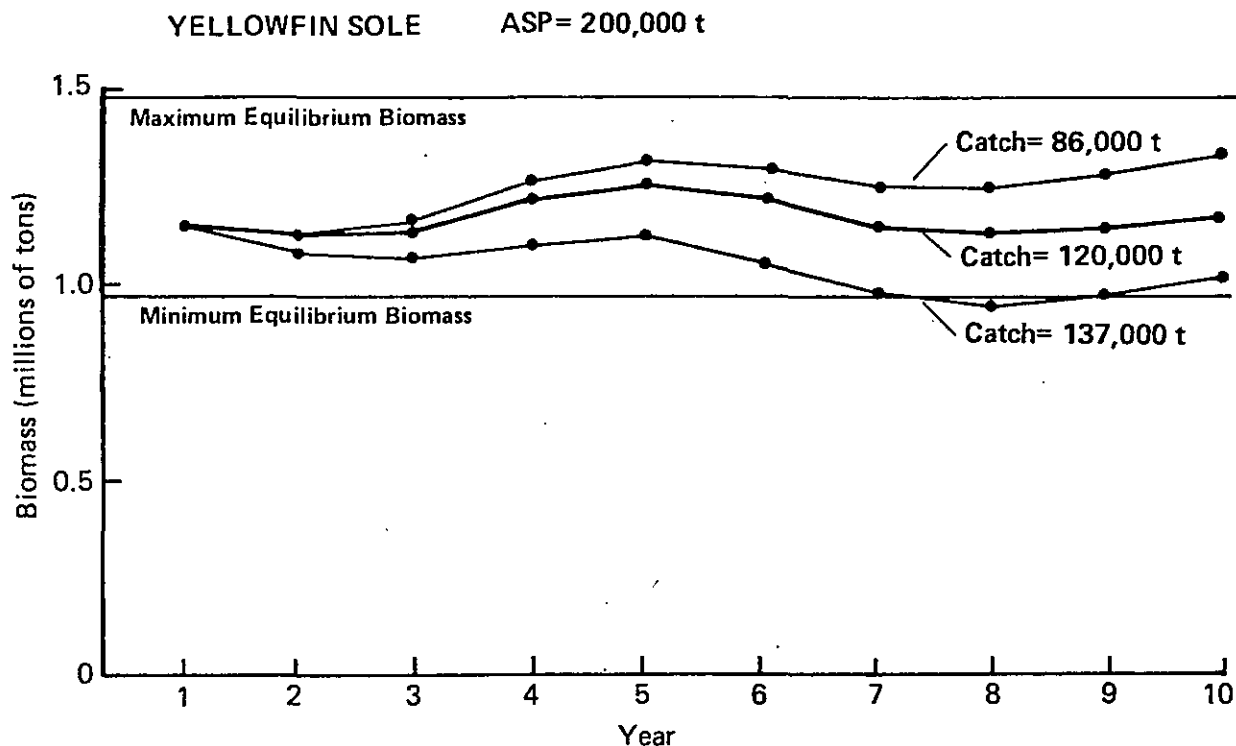


Figure 4.--Annual surplus production (ASP) in 1983 and predicted trends in population biomass at selected catch levels for yellowfin sole.

Turbot (Figure 5): The species-by-species analyses show that ASP for the turbot group in 1983 is about 85,000 t. The PROBUB simulations show that this catch level appears sustainable and will keep the population biomass within its equilibrium bounds. The simulations also indicate that long-term fluctuations in abundance are $\pm 20\%$ over a period of 7-9 years.

Other flatfish (Figure 6): This group is made up of smaller size flatfishes. The 1983 ASP for the group has been estimated to be 120,000 t (Table 1). The PROBUB simulations show that this catch level appears reasonable since it should keep the population biomass within its equilibrium bounds. The simulations also indicate that long-term fluctuations in abundance are $\pm 10\%$ over a period of 5 years.

Sablefish (Figure 7): Single-species analysis shows that abundance of sablefish has declined from former levels of abundance in the 1960's to a relatively low and stable level in recent years. The ASP for 1983 has been estimated at 2,900 t. The PROBUB model, however, shows that the long-term abundance of sablefish is normally lower than the high levels encountered in the 1960's. It also shows that under mean equilibrium conditions, the long-term sustainable yield could be 9,000 t, or three times higher than the 1983 ASP. Since the present level of abundance may be close to the mean equilibrium condition, it is probable that the ASP may have been too conservatively estimated. The model also indicates fluctuations of $\pm 20\%$ over a 6 year cycle, thereby indicating that catches need to be adjusted from year to year.

Pacific Ocean perch (Figure 8): As in the case of sablefish, abundance of ocean perch has declined to a relatively low and stable level from former higher levels of abundance in the early and mid-1960's. The PROBUB model, however, shows that the present level of abundance is the normal long-term equilibrium trend, at least as long as pollock is at its present high level of abundance. Pollock is known to prey on juvenile ocean perch. It also suggests that under long-term conditions, sustainable catches would be lower than the 11,700 t ASP estimated for ocean perch in 1983. Therefore, the catch quota for ocean perch should be set lower than 11,700 t and, perhaps, about 9,000 t as noted in the figure. The model does not show cyclic production in a 10-year span.

Other rockfish (Figure 9): This group of rockfish is made up of more than 14 species of the Sebastes and Sebastolobus genera. The long-term abundance of this group is about twice that of Pacific ocean perch. The ASP for the group has been estimated to be 14,100 t (Table 1) which appears to be an appropriate catch level since the long-term equilibrium catch is likely not much higher. As in the case of ocean perch, the model does not show cyclic production in a 10-year span.

Atka mackerel (Figure 10): The model suggests that Atka mackerel is the second-most abundant commercially important groundfish in the region. The resource makes up about 9-13% of the groundfish complex. Actual catch levels, however, are substantially lower than relative abundance because of its scattered semi-pelagic existence and lower commercial value. Although the ASP level of 26,000 t was empirically estimated from catch trends and preliminary hydroacoustic estimations, the model shows that higher catches are sustainable. The simulations show that catches of 28,000-47,000 t have about the same effects on the overall biomass of the resource. The results also

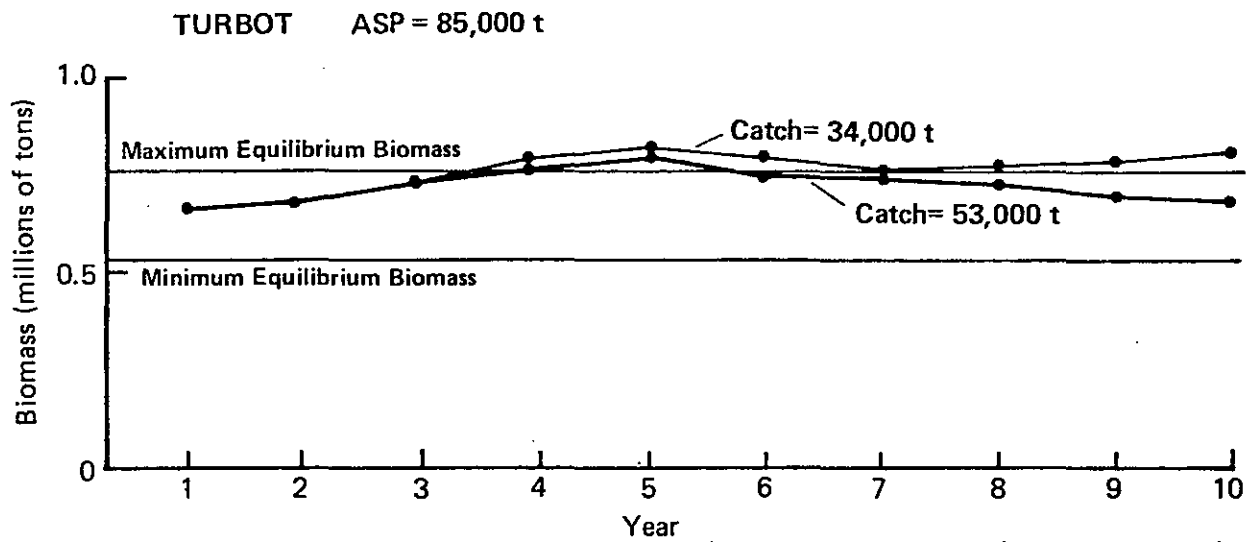


Figure 5.--Annual surplus production (ASP) in 1983 and predicted trends in population biomass at selected catch levels for turbot.

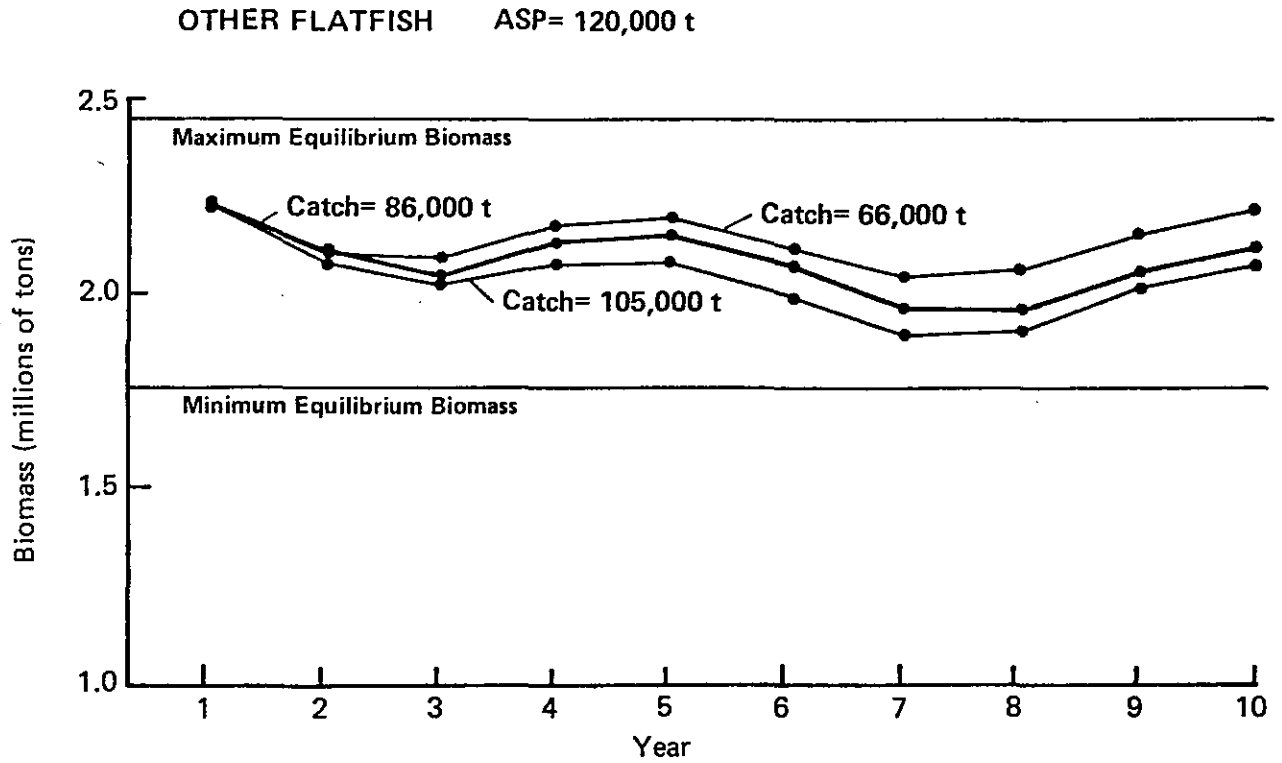


Figure 6.—Annual surplus production (ASP) in 1983 and predicted trends in population biomass at selected catch levels for other flatfish.

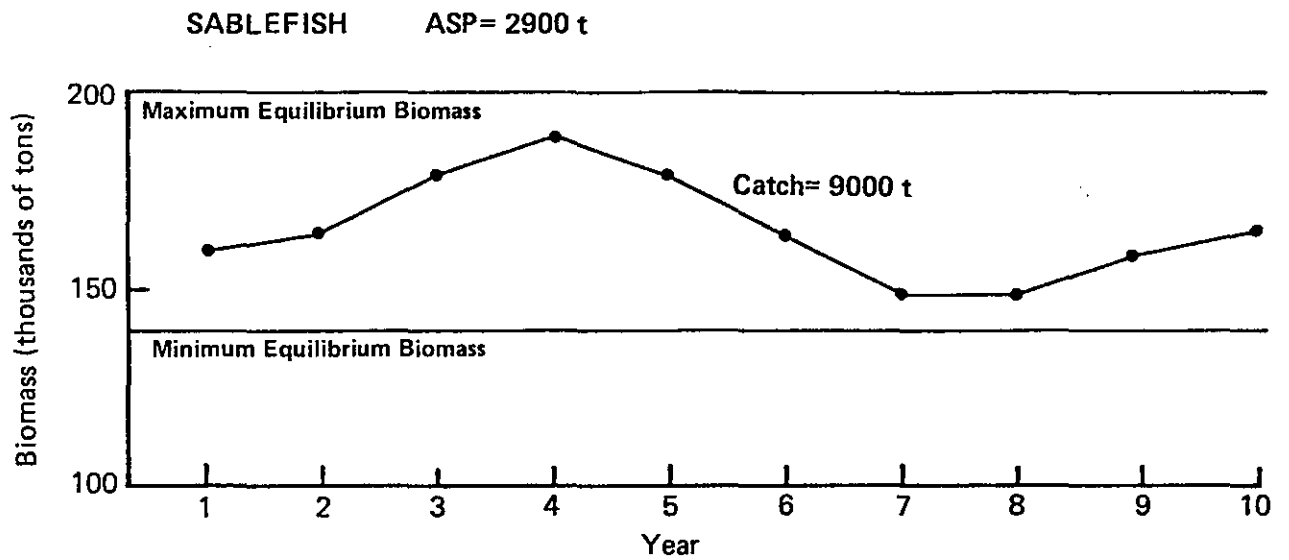


Figure 7.--Annual surplus production (ASP) in 1983 and predicted trends in population biomass at selected catch levels for sablefish.

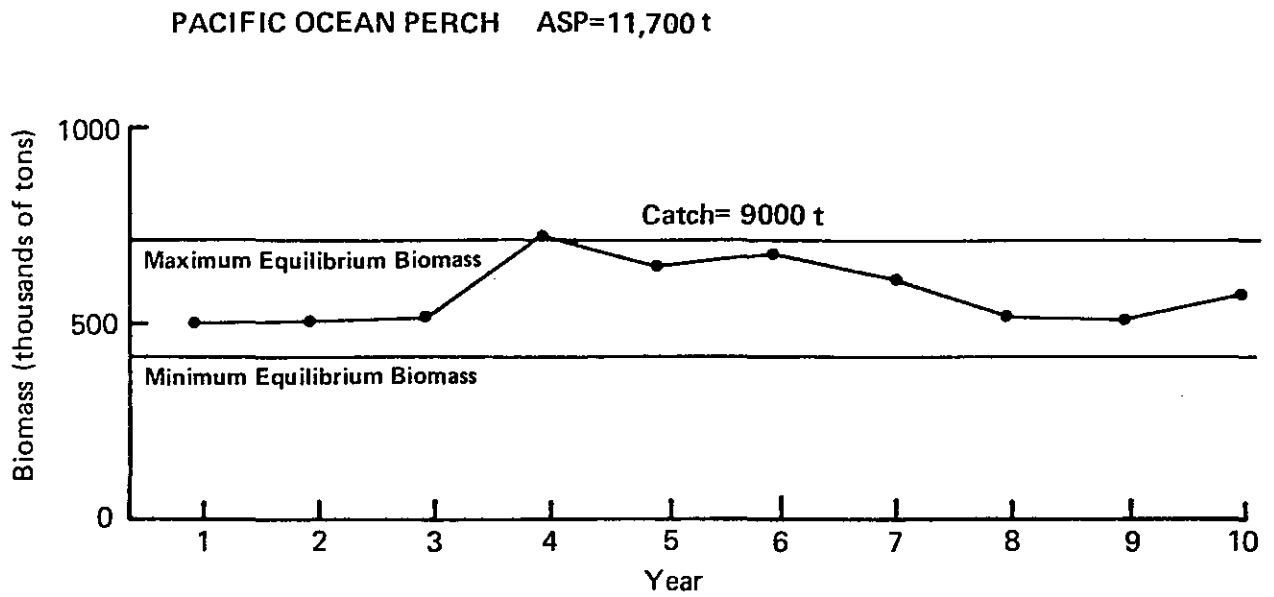


Figure 8.--Annual surplus production (ASP) in 1983 and predicted trends in population biomass at selected catch levels for Pacific ocean perch.

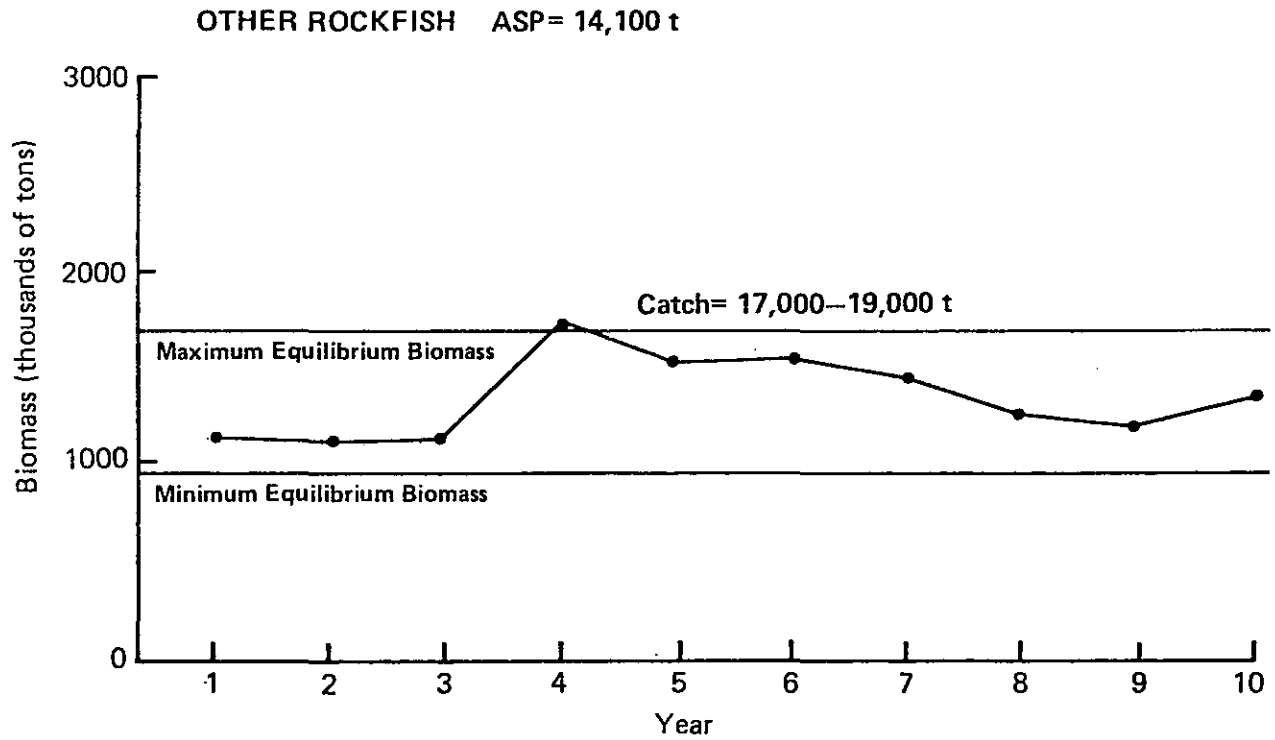


Figure 9.--Annual surplus production (ASP) in 1983 and predicted trends in population biomass at selected catch levels for other rockfish.

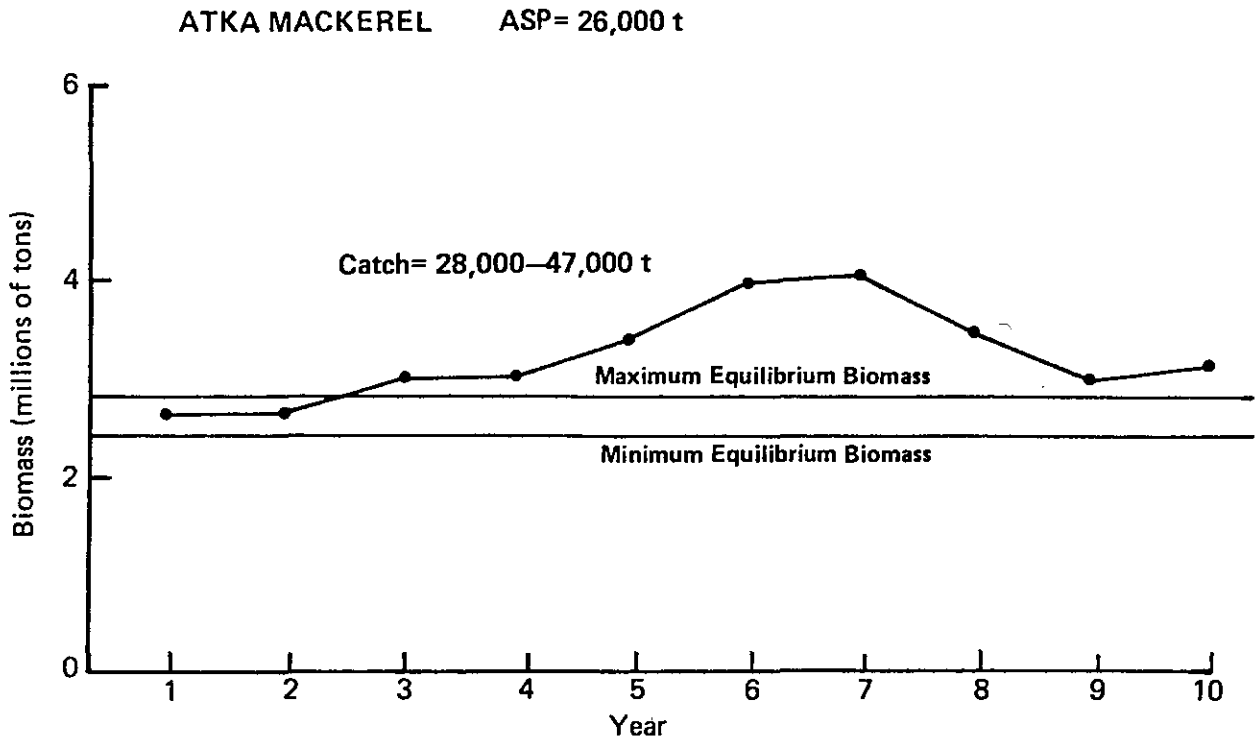


Figure 10.--Annual surplus production (ASP) in 1983 and predicted trends in population biomass at selected catch levels for Atka mackerel.

imply that catches in excess of 47,000 t are possible since the population would be maintained near the maximum equilibrium level. The simulations, however, indicate biomass fluctuations of + 30% over a period of 8-10 years and catches should therefore be varied accordingly.

Total groundfish (Figure 11): The PROBUB model shows that the overall biomass trend for the groundfish complex is strongly influenced by pollock. The total biomass would fluctuate by + 22% over a distinct population cycle of 5-6 years. In general, an overall catch of 1.9-2.0 million t appears to be the long-term upper bound. A lower catch may allow the groundfish complex to achieve higher biomass levels and remain above the minimum equilibrium biomass level. The actual level of catch should take into account the current point of the abundance cycle. From single-species analyses it is believed that abundance of the groundfish complex is very high and a catch of 2.0 million t appears to be possible for 1983. However, the abundance of pollock is projected to be on the decline. Since pollock is the principal component species in the ecosystem, it is suggested that the total 1983 catch from the groundfish complex be set at 1.7-1.8 million t to maintain higher levels of population biomass.

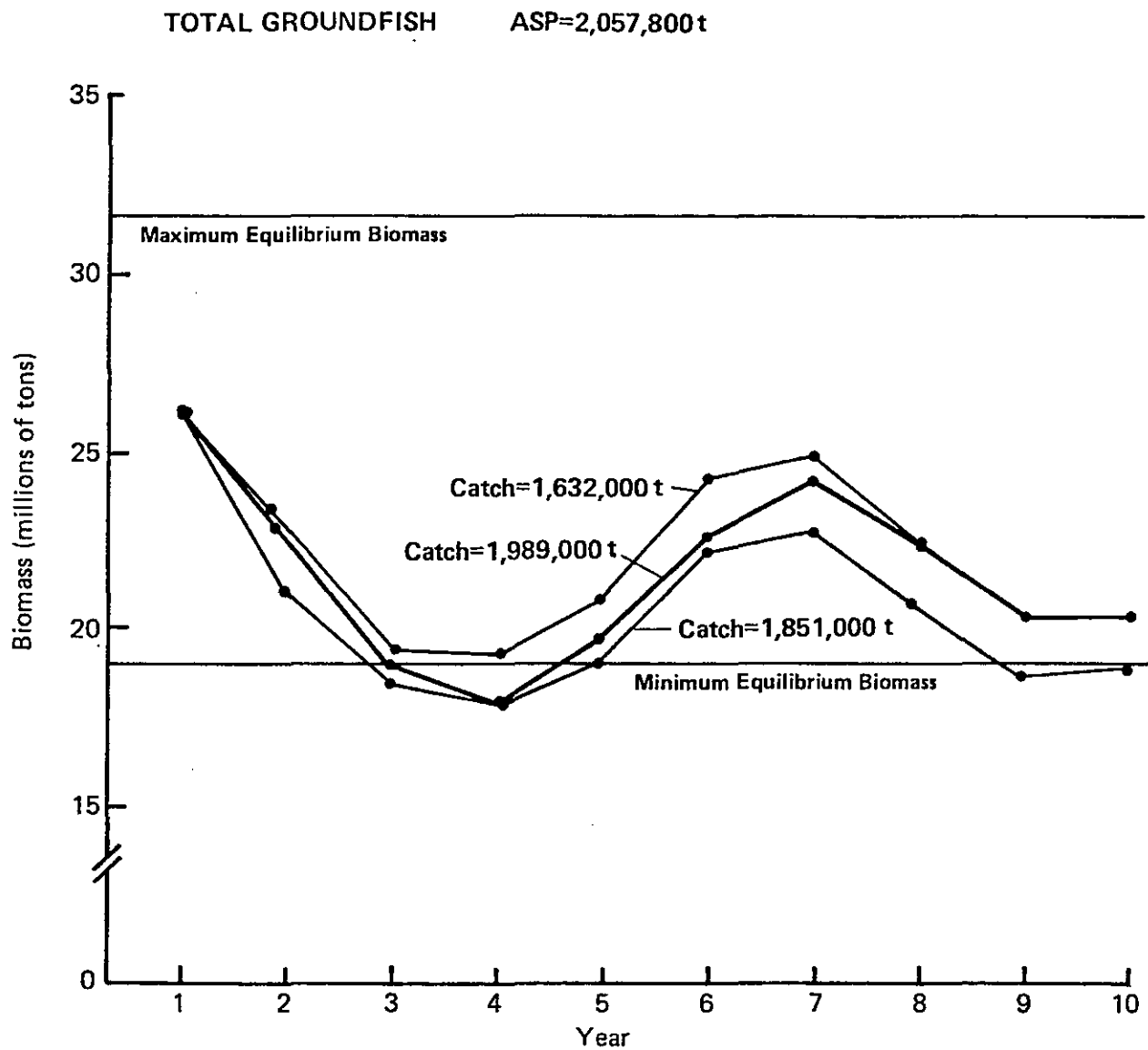


Figure 11.--Annual surplus production (ASP) in 1983 and predicted trends in population biomass at selected catch levels for total groundfish.

DISCUSSION

This paper has illustrated that the PROBUB model may be used to evaluate long-term trends in biomass levels for the component species groups in the groundfish complex and can make a difference for setting regulations. Management, however, must continue to rely heavily on traditional species-by-species analyses for information since these analyses provide a great amount of essential details on current year-to-year changes to the trend, species composition, age structure, and other dynamic characteristics of the stocks.

The use of the PROBUB model has resulted in considerations for setting catch quotas that are different from ASP's estimated for pollock, sablefish, Pacific ocean perch, and Atka mackerel. In the case of sablefish and ocean perch, where abundances have stabilized at relatively low levels, it is a popular reaction to want to rebuild the stocks to former levels of abundance. The model has shown, however, that the present low level of abundance is normal and that former higher levels of abundance may not be duplicated without substantial changes to the species composition of the ecosystem. Therefore, rebuilding of the populations to former levels may not be realistic as long as pollock remains at present high levels. The model has also reaffirmed that the estimated ASP's for turbot, other flatfishes, and other rockfishes are reasonably stable catch levels.

Based on the simulations, the short-term fluctuations in abundance of yellowfin sole and Pacific cod could not be detected without additional model development, particularly to reflect environmental anomalies and their effects on populations. As such, the estimated ASP's via single-species analytical techniques which reflected the presence of strong year classes are better criteria for setting catch quotas.

The PROBUB model is also very informative for indicating fluctuations in production under average conditions. The biomass of pollock follows a distinct cycle of 6 years and can vary by $\pm 50\%$ over this short period (Table 4). Since pollock is the most dominant species in the groundfish complex, the overall trend for the complex follows it. However, the magnitude and period of fluctuations are dampened a little by the presence of other component species to $\pm 22\%$ in a 5-6 year cycle. The model also shows that biomass of Atka mackerel can fluctuate by 30%, sablefish and turbot by 20%, yellowfin sole by 12%, other flatfish by 10%, and Pacific cod by 8%. A biomass cycle is not apparent for rockfishes, at least not over a 10-year period. Since rockfish are known to have substantially longer life spans, any cycle is expected to have a longer period.

The manner in which stock biomass fluctuates is important information for setting catch quotas. Stocks with high amplitudes and short periods of fluctuation, such as in the case of pollock and, perhaps, sablefish and Atka mackerel, should be monitored more closely and their catches varied from year-to-year. Stocks with lower amplitudes of variation and longer periods may be harvested on a relatively constant and sustained basis. These stocks are yellowfin sole, turbot, other flatfishes, and the rockfish complex.

Although the PROBUB model has been used to help set catch quotas, it may also be used to evaluate impacts of exploitation strategies that are not limited to catch quotas. For example, effects of proposed time-area closures to the fishery, changes in the species composition of the groundfish complex, and that of other trophic levels, such as those of marine mammals, can be evaluated through simulations. These simulations would be very useful for formulating management philosophies and policies.

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