Northwest and
Alaska
Fisheries Center

National Marine
Fisheries Service

U.S. DEPARTMENT OF COMMERCE

NWAFC PROCESSED REPORT 84-14

Some Analyses of Consequences of Fisheries Expansion in the Gulf of Alaska and Eastern Bering Sea

May 1984

This report does not constitute a publication and is for information only. All data herein are to be considered provisional.

NOTICE

This document is being made available in .PDF format for the convenience of users; however, the accuracy and correctness of the document can only be certified as was presented in the original hard copy format.

Inaccuracies in the OCR scanning process may influence text searches of the .PDF file. Light or faded ink in the original document may also affect the quality of the scanned document.

Some Analyses of Consequences of Fisheries Expansion in the Gulf of Alaska and Eastern Bering Sea

By

Taivo Laevastu and Richard Marasco
Resource Ecology and Fisheries Management Division

Northwest and Alaska Fisheries Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, WA 98112-2097

May 1984

CONTENTS

		Page
1.	Introduction	1
2.	Stock changes associated with increased fishing	1
3.	Concomitant changes of biomasses of species subject to traditional U.S. fishery	15
4.	Effects of environmental anomalies and fishing on fish stock fluctuations	23
5.	Conclusions	29
6.	References	30

LIST OF TABLES AND FIGURES

Table 1.--Some examples of changes of biomasses six years after initial increased fishing, as computed with PROBUB.

Figure 1.--Computation areas in PROBUB for the eastern Bering Sea and Gulf of Alaska.

Figure 2.--Changes of cod biomasses with time in Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) (kg/km^2). (Initial catches 50K tonnes from the eastern Bering Sea and 17K tonnes from the Gulf of Alaska).

Figure 3.--Same as Figure 2 except initial catches of 97K and 78K tonnes, respectively.

Figure 4.--Same as Figure 2 except initial catches of 141K and 109K tonnes, respectively.

Figure 5.--Changes of pollock biomasses with time in Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) (kg/km^2). (Initial catches 500K tonnes from the eastern Bering Sea and 140K tonnes from the Gulf of Alaska.

Figure 6.--Same as Figure 5 except initial catches of 1370K and 385K tonnes, respectively.

Figure 7.--Same as Figure 5 except initial catches of 1730K and 495K tonnes, respectively.

Figure 8.--Changes of cod biomasses with time in Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) (kg/km^2). (Initial catches 97K tonnes from the eastern Bering Sea and 58K tonnes from the Gulf of Alaska.)

Figure 9.--Changes of catches of cod (Figure A) and pollock (Figure B) from Gulf of Alaska with a constant fishing intensity coefficient, but with changing biomasses. The catches refer to Run 8 (Figures 9 and 10).

Figure 10.--Changes of yellowfin sole (including rock sole and Alaska plaice) biomasses with time in Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) (kg/km^2). (Initial catches 195K tonnes from the eastern Bering Sea and 29K tonnes from the Gulf of Alaska.)

Figure 11.--Changes of halibut and turbot biomasses in the Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) corresponding to Experiment I (Table 1) with increased catches of cod, pollock, and yellowfin sole but no compensation for bycatches of halibut.

Figure 12.--Changes of halibut and turbot biomasses in the Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) corresponding to Experiment III (Figures 8, 9, and 10) with increased catches of cod, pollock, and yellowfin sole and accounting for increased bycatch of halibut (ca 6.5% of additional cod catches).

Figure 13.--Changes of crab biomasses with time in Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) (kg/km^2). (Initital catches of pollock, cod, and yellowfin sole see Table 1, column 3.)

Figure 14.--Changes of crab biomasses with time in Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) (kg/km^2). The fishery on target species of cod, pollock, and yellowfin sole have been increased to: yellowfin - 195K tonnes Bering Sea, 29K tonnes Gulf of Alaska; cod - 97K tonnes Bering Sea, 58K tonnes Gulf of Alaska; pollock - 1,370K tonnes Bering Sea, 385K tonnes Gulf of Alaska.

Figure 15.--Changes of rockfish biomasses with time in Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) (kg/km^2). (Initial catches of pollock see Table 1, column 3.)

Figure 16.--Same as Figure 15 except increased catches of pollock (see Table 1, Experiment II).

Figure 17.--Sea surface temperature anomaly in south-central Bering Sea from 1965 to 1983.

Figure 18.--Twelve-month running mean of surface wind anomaly (N-S component) in south-central Bering Sea from 1965 to 1983.

Figure 19.--Dynamics of yellowfin and rock sole biomasses in Bristol Bay with normal temperature and with temperature anomalies, starting with negative and with positive anomalies.

Figure 20.--Same as Figure 19 except in western Gulf of Alaska.

Figure 21.--Dynamics of pollock biomasses in Bristol Bay with normal temperature and with temperature anomalies, starting with negative and positive anomalies. Fishing intensity increased gradually in first three years to its threefold value as compared to year 0.

Figure 22.--Same as Figure 21 except in western Gulf of Alaska.

1. Introduction

A major concern among fishery managers is knowing how expanded fishing activity will affect fish stocks. Ecosystem models developed at the Northwest and Alaska Fisheries Center are tools that can be used to gain insight into how the ecosystem might respond to management measure change. Two models are currently in use at the Center, DYNUMES and PROBUB. These models have been described elsewhere; therefore, no attempt will be made in this report to describe them (Laevastu and Larkins, 1981). In this study, PROBUB was used to examine the effects of increased catches of pollock, cod and yellowfin sole. Specific objectives of the study were:

1) to determine the highest yields which can be obtained without causing the stock to collapse, and
2) to determine the concomitant changes in the biomasses of the traditional domestic fishery species.

Resulting ecosystem changes in the study were compared to output obtained by fixing "equilibrium catches" at approximately 1980 catch levels. Increased fishing in the numerical experiments was simulated via a fishing intensity coefficient. This coefficient yields a catch that is proportional to the fishing intensity and the biomass present.

2. Stock changes associated with increased fishing

A summary of results obtained from several experiments are reported below. Results obtained from experiment I and II are given in Table 1. Catches of pollock, cod and yellowfin sole in experiment I were approximately 3.2 and 4 times the equilibrium level. In experiment II, catches were increased by factors of about 3, 3 and 5, respectively.

Table 1.--Some examples of changes of biomasses six years after initial increased fishing, as computed with PROBUB

Species/Region	Initial biomass t x 10^3	Catch ("equil.") t x 10^3 1*	Experiment I: Catch, first year t x 10^3 2*	Experiment I: Biomass sixth year t x 10^3	Experiment I: Remarks	Experiment II: Catch, first year t x 10^3	Experiment II: Biomass sixth year t x 10^3	Experiment II: Remarks
Pollock								
E. Bering Sea	5,614	512	1,369	2,735	Biomass level to "half" Biomass recovers Rockfish increase ca 50%	1,729	2,192	Biomass very low Stock near collapse Rockfish increase ca 50%
Aleutian Region	3,126	189	529	2,778	Rockfish increase	682	2,371	Rockfish increase
Gulf of Alaska	1,883	139	385	1,378	Biomass recovers if fishery decreased Rockfish increase	493	978	Biomass level to "half", stock near collapse Rockfish increase
Cod								
E. Bering Sea	798	50	97	765	Crabs increase ca 25% in all regions	141	608	Crabs increase ca 25% in all regions
Aleutian Region	294	22	42	285		61	239	
Gulf of Alaska	181	17	78	44	Stock "collapses" in 4 years	109	25	Stock "collapses" in 2 years
Yellowfin								
E. Bering Sea	669	54	195	448	Crabs increase	253	332	Crabs increase
Aleutian Region	224	11	41	193		55	170	
Gulf of Alaska	136	4	29	120		41	95	

1* -- Approximate catch in 1980

2*--Catches are introduced with fishing intensity coefficient--i.e., proportional to biomass present; thus catches decrease with decreasing biomass in the simulation.

In the first two experiments no increased fishing mortality was programmed for the halibut/turbot group. However, the halibut catch was increased by about 6.5% of the cod and yellowfin sole catch in experiment III to simulate the increased incidental catch that could be associated with expanded fishing. Further, in this last experiment, cod fishing was adjusted so that no "stock collapse" occurred. The results of this experiment are discussed at the end of this section.

Computation areas in PROBUB for the eastern Bering Sea and Gulf of Alaska are shown in Figure 1. The computed fluctuation of the biomass of cod with 1980 fishing in Bristol Bay and in western Gulf of Alaska are shown in Figure 2. The catches in this experiment are 50,000 tonnes from the Bering Sea and 17,000 tonnes from the Gulf of Alaska. When the catches are initially increased to 97K and 78K tonnes, respectively (Figure 3) (Experiment I in Table 1), the cod stock in the western Gulf of Alaska (Region 6) collapses in about 6 years, whereas in the Bristol Bay region (Region 1) the cod biomass decreases only a little. A characteristic effect of the increase of fishing is the suppression of the fluctuations. One of the reasons for small cod biomass changes in Bristol Bay is that there are compensating mechanisms acting against the fishing effect--i.e., the increase of growth rate of biomass ("rejuvenation of population") and decrease in spawning stress (senescent) mortality. Additional increases in the cod catches to 141K and 109K tonnes, respectively (Experiment II in Table 1) (Figure 4), causes the stock in the western Gulf of Alaska to collapse in 3 to 4 years and suppresses the stock in Bristol Bay region to about one-quarter of its original value.

The corresponding changes of the stocks of pollock in Bristol Bay and western Gulf of Alaska regions are shown in Figures 5 to 7. Figure 5 shows the typical, rather pronounced natural fluctuations of pollock with modest

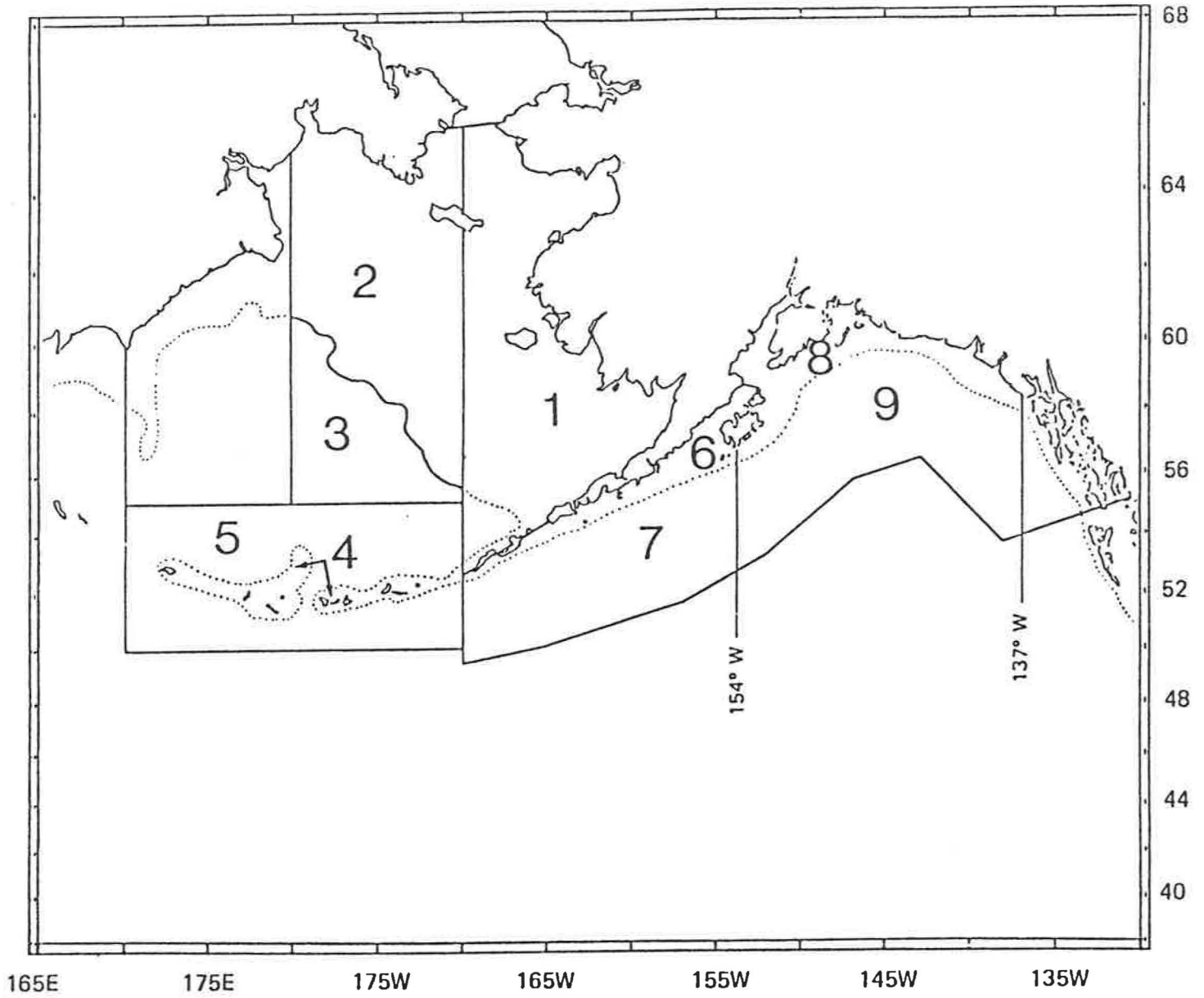

Figure 1.--Computation areas in PROBUB for the eastern Bering Sea and Gulf of Alaska.

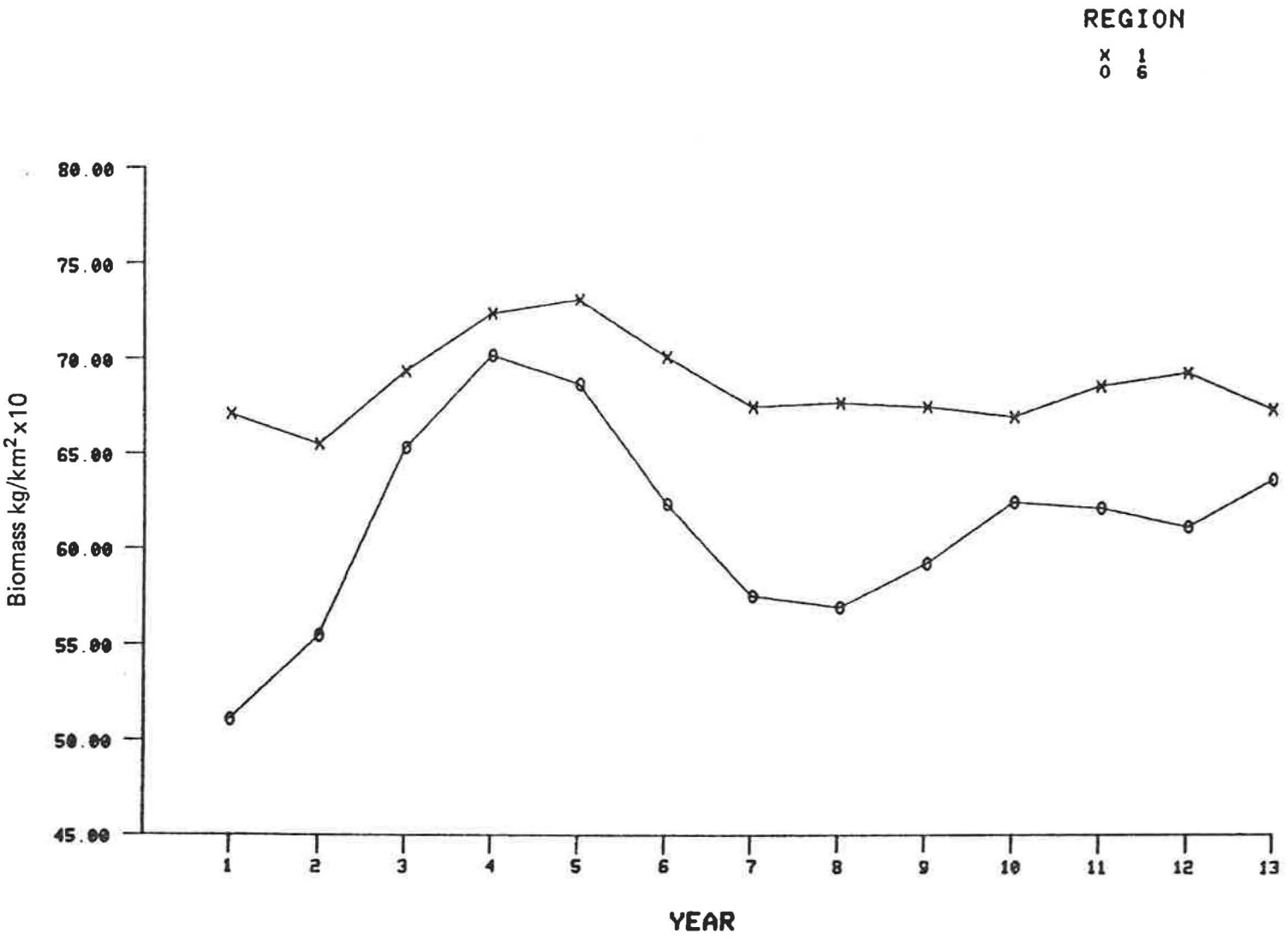

Figure 2.--Changes of cod biomasses with time in Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) (kg/km^2). (Initial catches 50K tonnes from the eastern Bering Sea and 17K tonnes from the Gulf of Alaska).

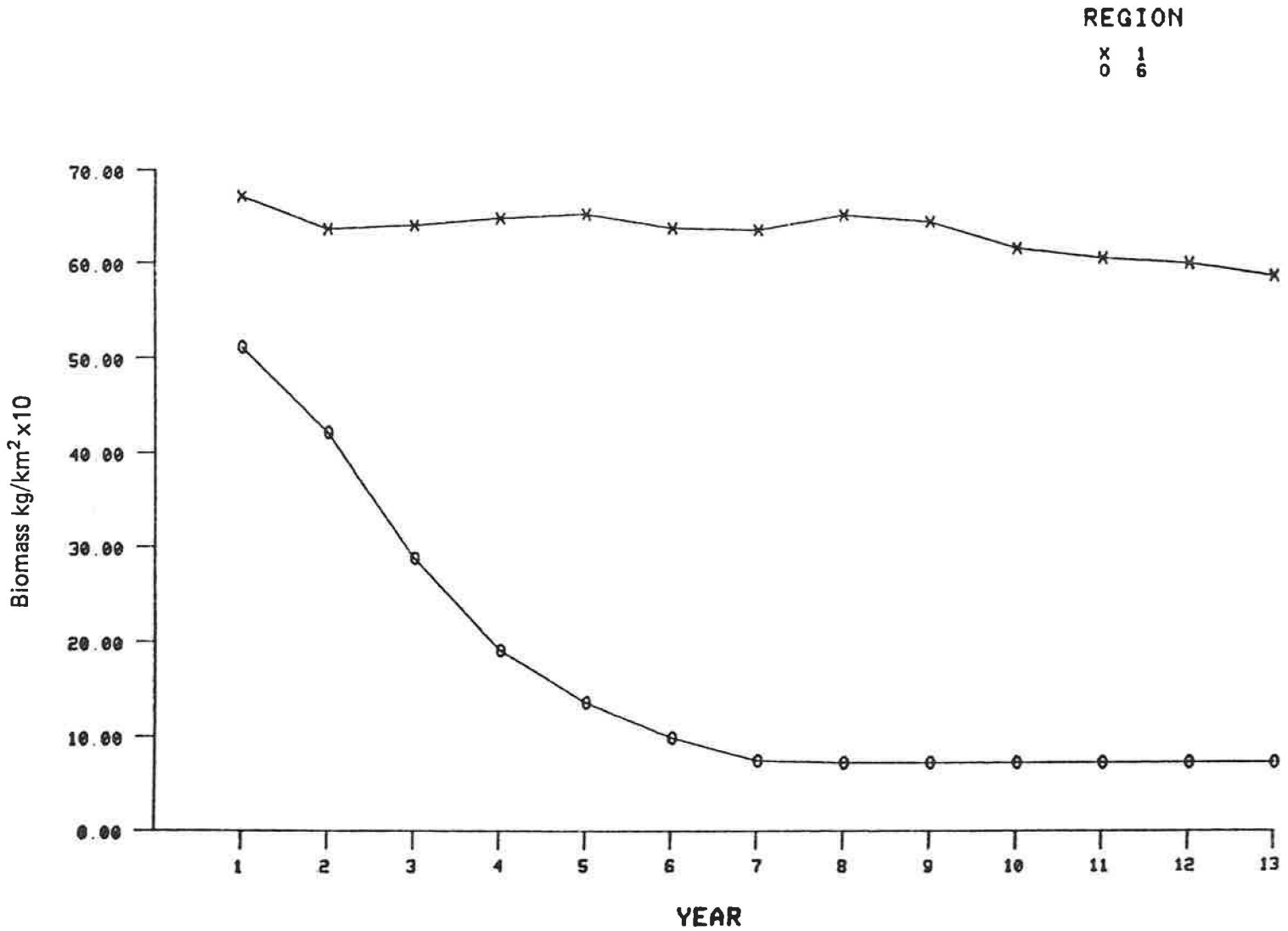

Figure 3.--Same as Figure 2 except initial catches of 97K and 78K tonnes, respectively.

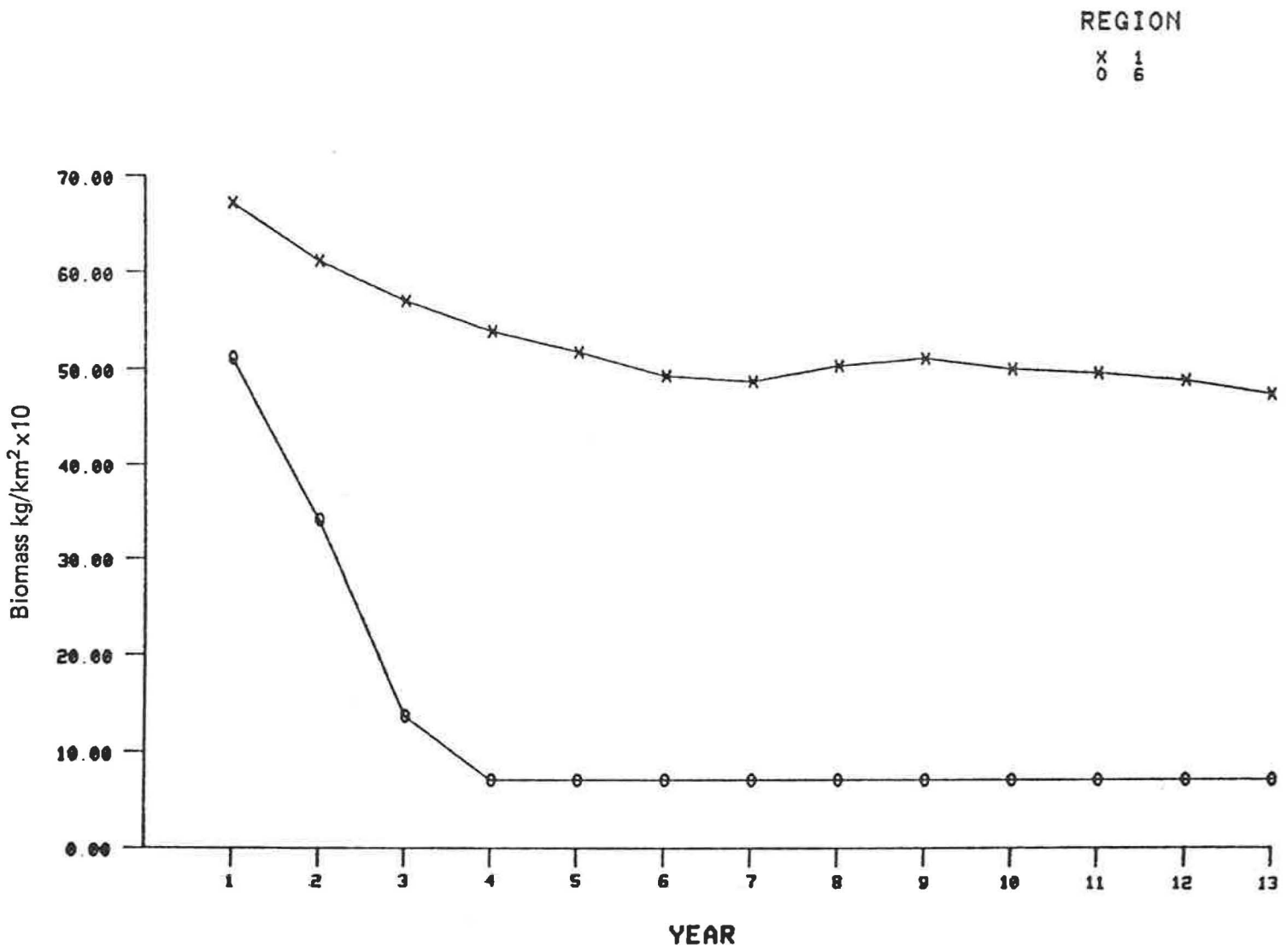

Figure 4.--Same as Figure 2 except initial catches of 141K and 109K tonnes, respectively.

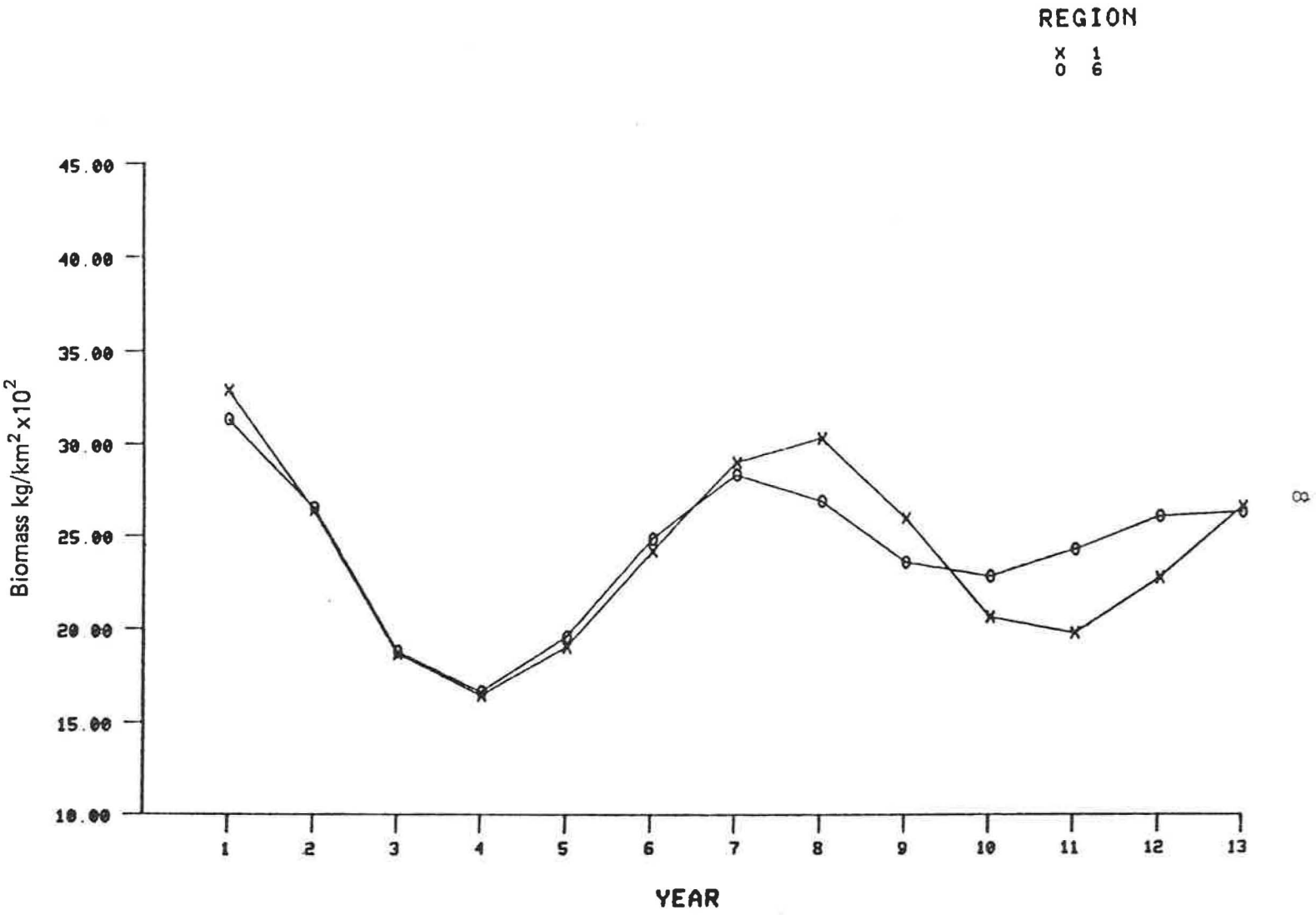

Figure 5.--Changes of pollock biomasses with time in Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) (kg/km^2). (Initial catches 500K tonnes from the eastern Bering Sea and 140K tonnes from the Gulf of Alaska.

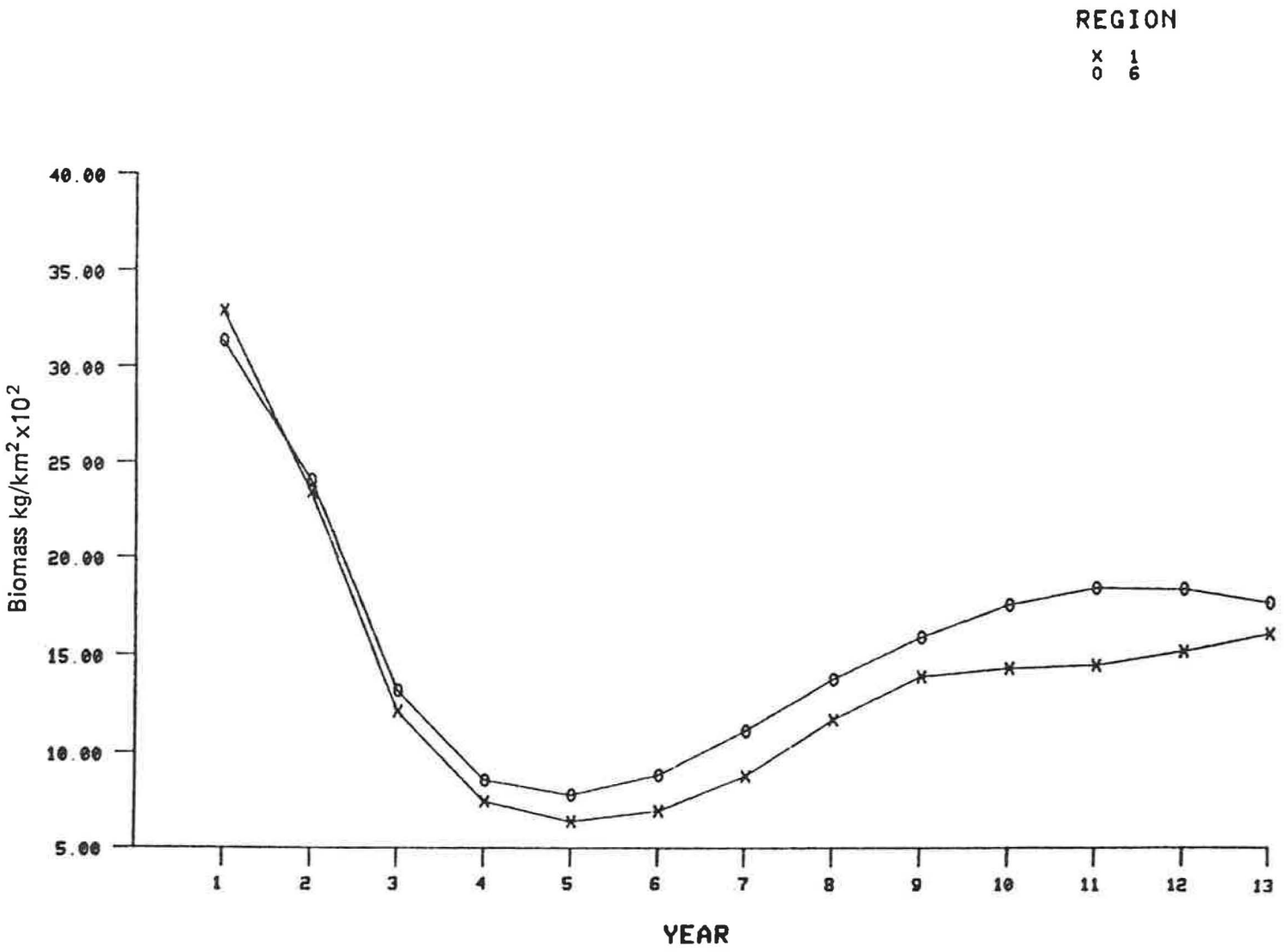

Figure 6.--Same as Figure 5 except initial catches of 1370K and 385K tonnes, respectively.

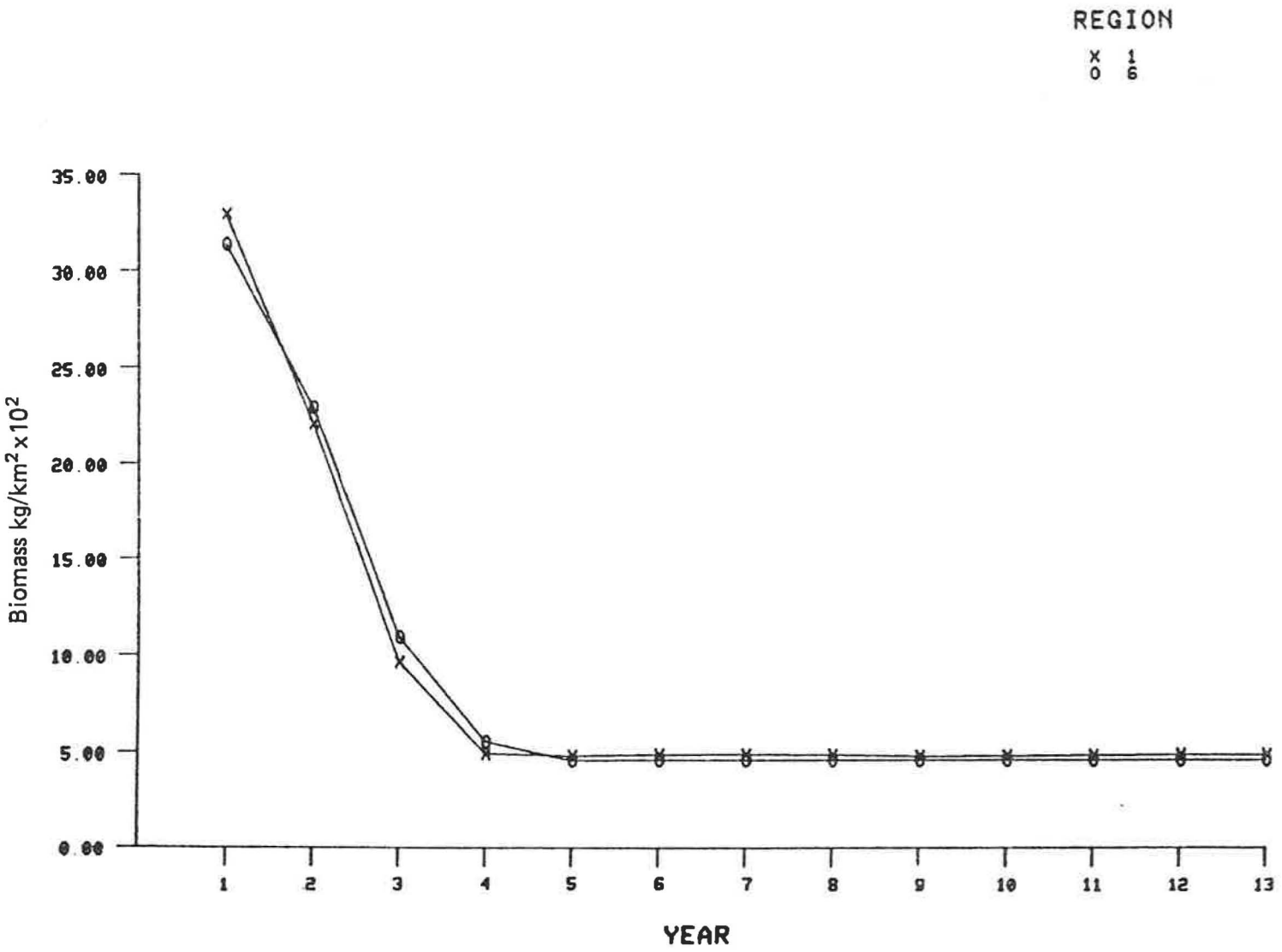

Figure 7.--Same as Figure 5 except initial catches of 1730K and 495K tonnes, respectively.

fishery (500K and 140K in Bering Sea and Gulf of Alaska, respectively) on this large-biomass species. It should be noted that the cod biomass and the pollock biomass fluctuations are about 180° out of phase. More than doubling of the catches (to 1370K and 385K tonnes initially, Experiment I in Table 1) suppresses the stocks to near-collapse and dampens its fluctuation (Figure 6). Further increase of fishing (Experiment II) causes the stocks to collapse in 3 years (Figure 7).

As the cod stocks collapsed with heavy fishing in Experiments I and II, an additional numerical experiment (III) (run 8) was conducted, where the catches of cod were decreased in Gulf of Alaska (97K tonnes from the Bering Sea and 58K tonnes from Gulf of Alaska). The resulting biomass changes with time of cod biomasses are shown in Figure 8. The cod stock decreases in Gulf of Alaska, but does not collapse as in earlier experiments (I and II). The changes of catches of cod and pollock with constant fishing intensity coefficient but with changing biomasses, are shown in Figure 9. The fishing intensity coefficient is proportional to exploitable biomass present, and simulated CPUE changes in nonshoaling species (e.g., in mixed trawl fishery).

The changes of yellowfin sole (including rock sole and Alaska plaice) in Bristol Bay and western Gulf of Alaska regions are shown in Figure 10. The total initial catch of yellowfin sole in this experiment is 195K tonnes from the Bering Sea (mainly from Region 1 - Bristol Bay) and 29K tonnes from the Gulf of Alaska (mainly from Region 6 - Western Gulf of Alaska). The yellowfin sole biomass decreases rapidly in Bristol Bay in the first four years of heavy fishing, but remains thereafter on a reasonably high level of biomass (ca 400 kg/km^2). The decrease of the biomass of this flatfish with modest fishing in western Gulf of Alaska (ca 30K tonnes) is relatively small.

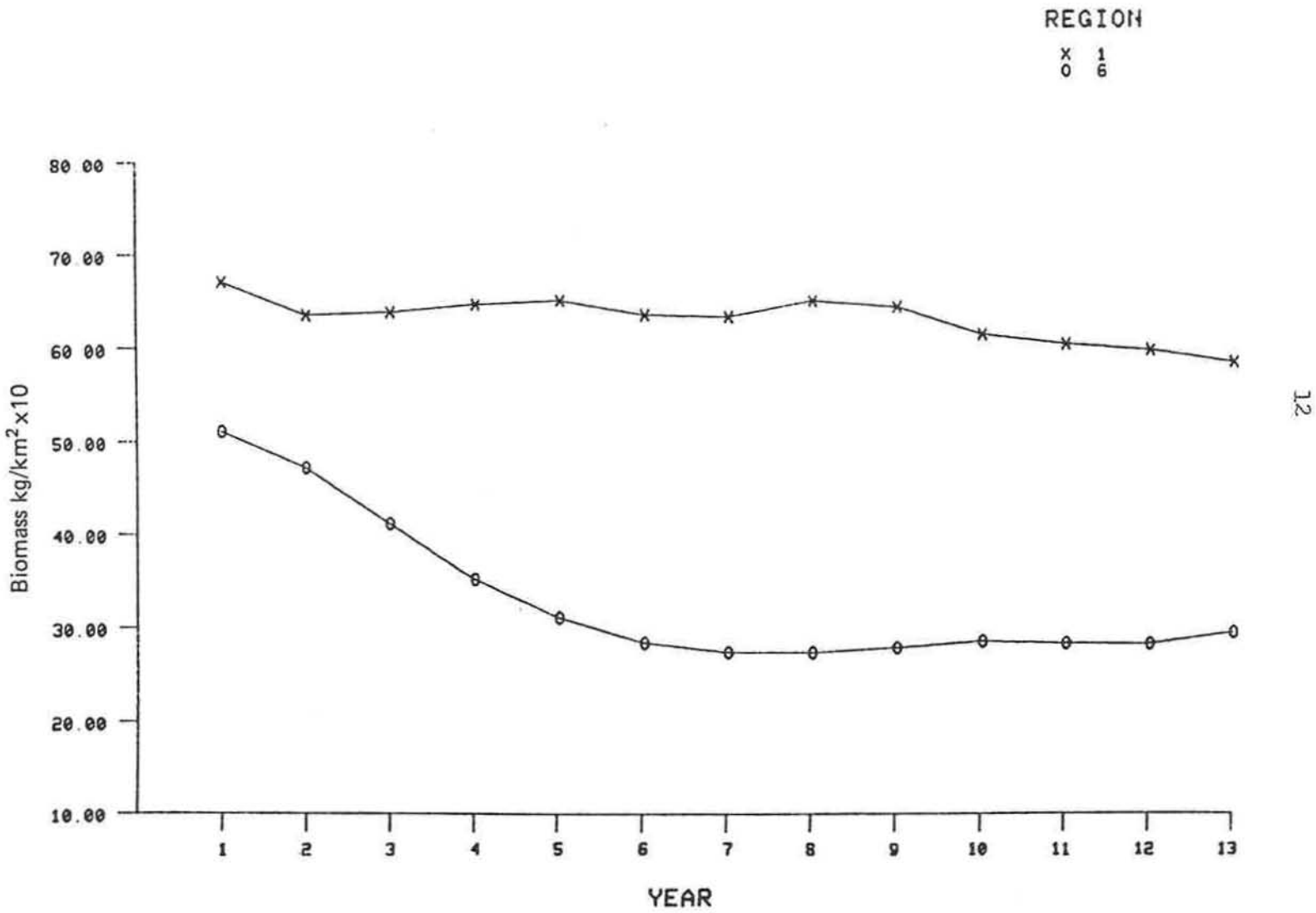

Figure 8.--Changes of cod biomasses with time in Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) (kg/km^2). (Initial catches 97K tonnes from the eastern Bering Sea and 58K tonnes from the Gulf of Alaska.)

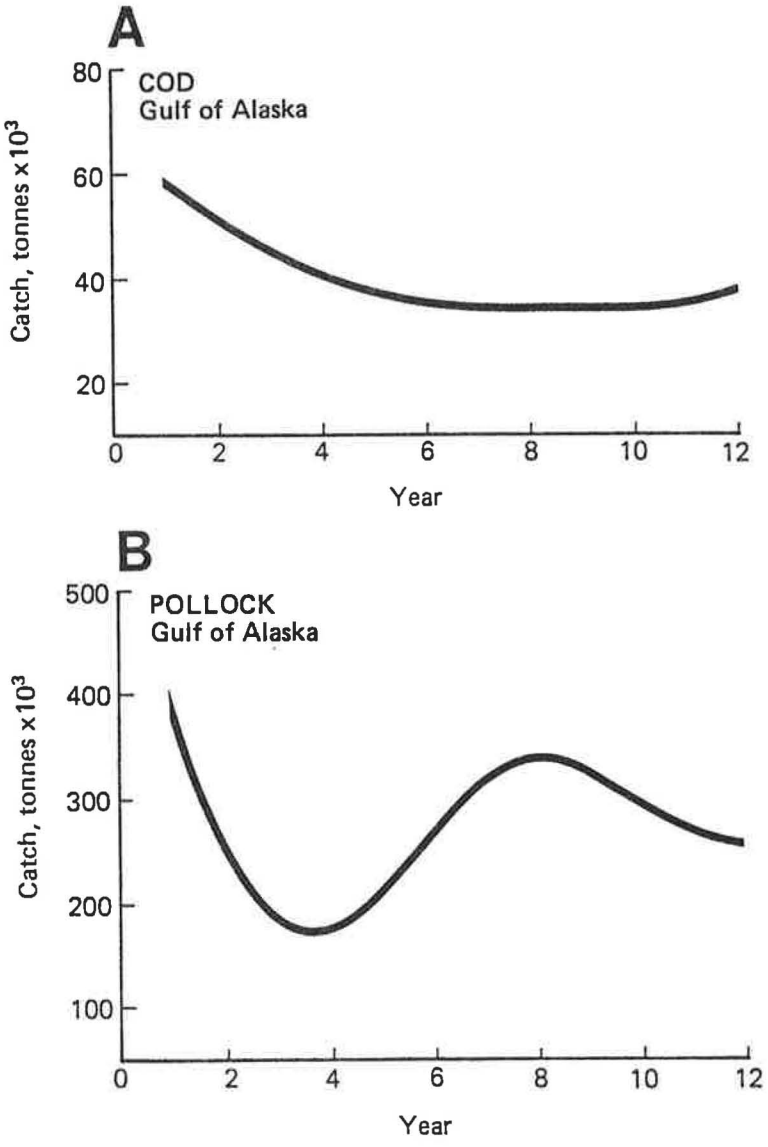

Figure 9.--Changes of catches of cod (Figure A) and pollock (Figure B) from Gulf of Alaska with a constant fishing intensity coefficient, but with changing biomasses. The catches refer to Run 8 (Figures 9 and 10).

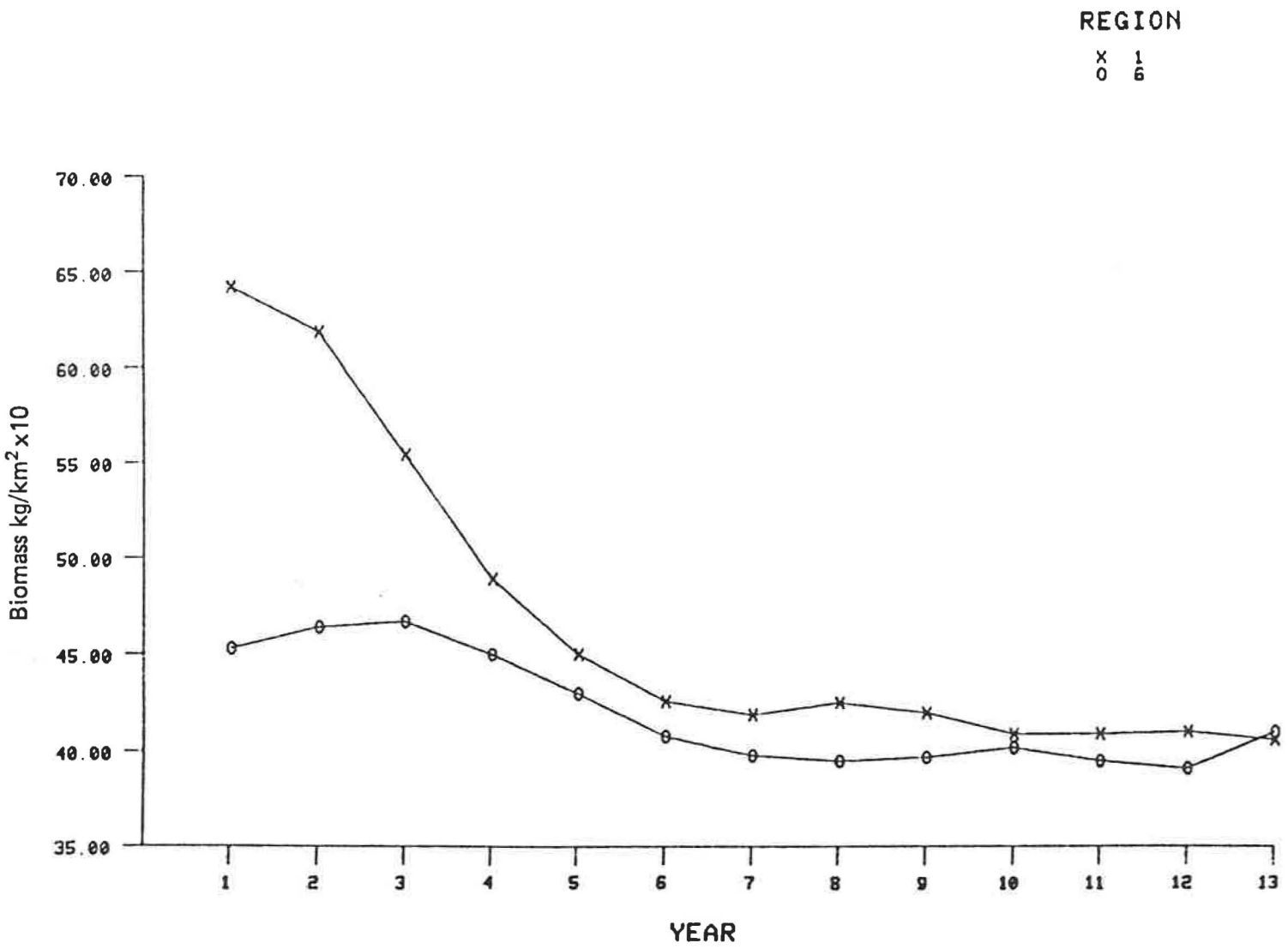

Figure 10.--Changes of yellowfin sole (including rock sole and Alaska plaice) biomasses with time in Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) (kg/km^2). (Initial catches 195K tonnes from the eastern Bering Sea and 29K tonnes from the Gulf of Alaska.)

3. Concomitant changes of biomasses of species subject to traditional U.S. fishery

The possible increase of catches of major (commercial) species from the Bering Sea and from the Gulf of Alaska will decrease (suppress) the present biomass levels of these species. Consequently, the predation by these species on other species is expected to decrease. This predation interaction is, however, relatively complex (and nonlinear), mainly due to presence of other predators besides the target species on which the fishery would increase. These complex predation interactions are computed in the ecosystem simulation.

A slight increase of halibut/turbot group biomasses in the Bristol Bay and in western Gulf of Alaska is shown in Figure 11. This increase is a consequence of increased fishery (and resulting decreased predation) on cod, yellowfin, and pollock (Experiment I, Table 1). However, no increased bycatches of halibut caused by increased trawl fishery are included in this numerical experiment.

When the increased bycatches of halibut are also accounted for (ca 6.5 percent of increased cod catches), the resulting biomass changes are shown in Figure 12. This figure leads to the simple conclusion that the possible gains due to decreased predation are approximately compensated by increased bycatches of halibut.

The bycatch of crab in trawl fishery is relatively minor. However, considerable quantities of crabs are consumed by cod, pollock, and yellowfin. Thus, crab recruitment would be expected to increase somewhat if the predator biomasses are decreased. Figure 13 shows the fluctuations of crab biomasses in the Bristol Bay and in western Gulf of Alaska with the 1980 fishing levels on pollock, cod, and yellowfin. Figure 14 shows the increase of crab biomass in the two regions as a result of increased fishing on cod, pollock, and yellowfin, which causes

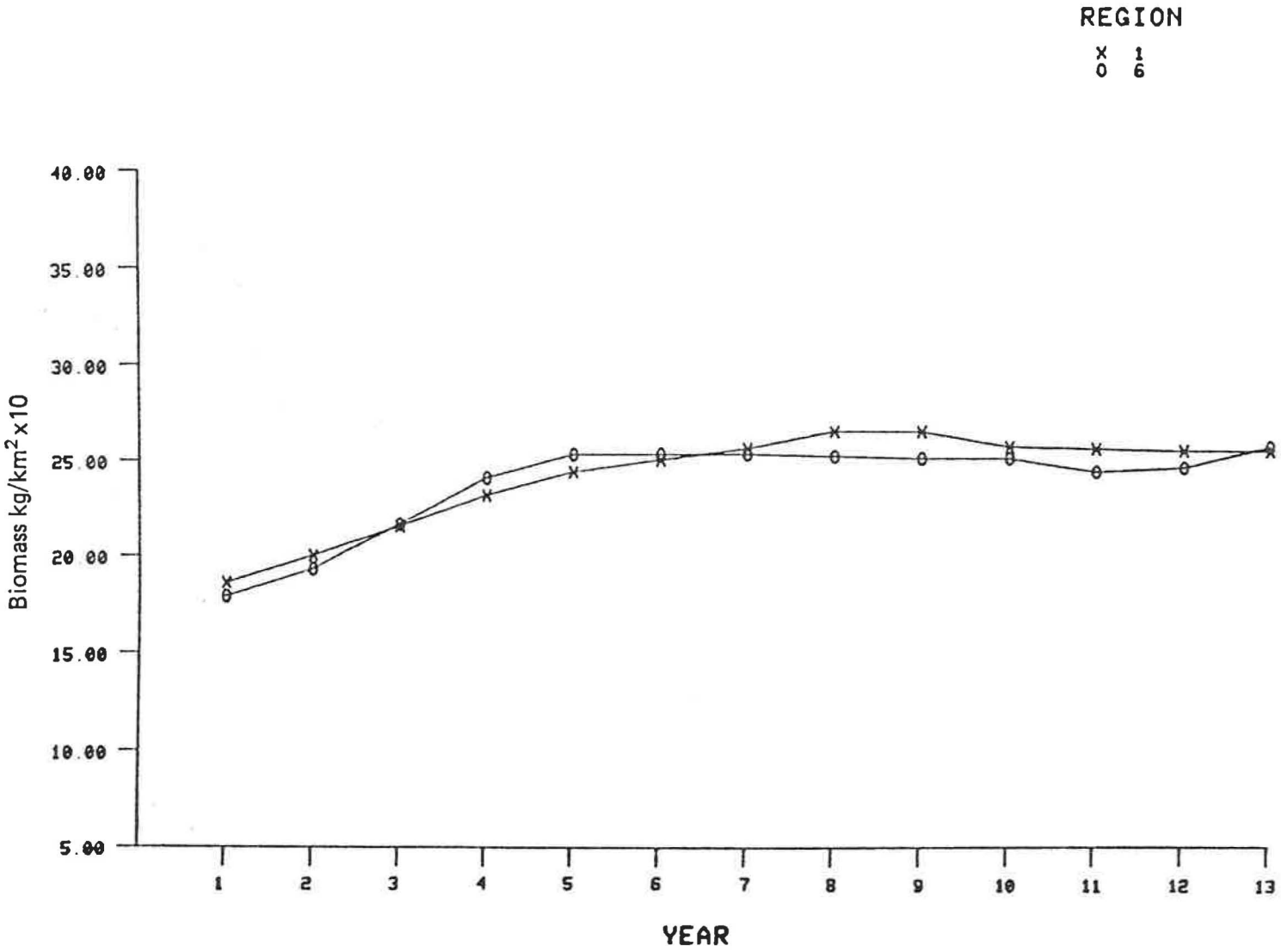

Figure 11.--Changes of halibut and turbot biomasses in the Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) corresponding to Experiment 1 (Table 1) with increased catches of cod, pollock, and yellowfin sole but no compensation for bycatches of halibut.

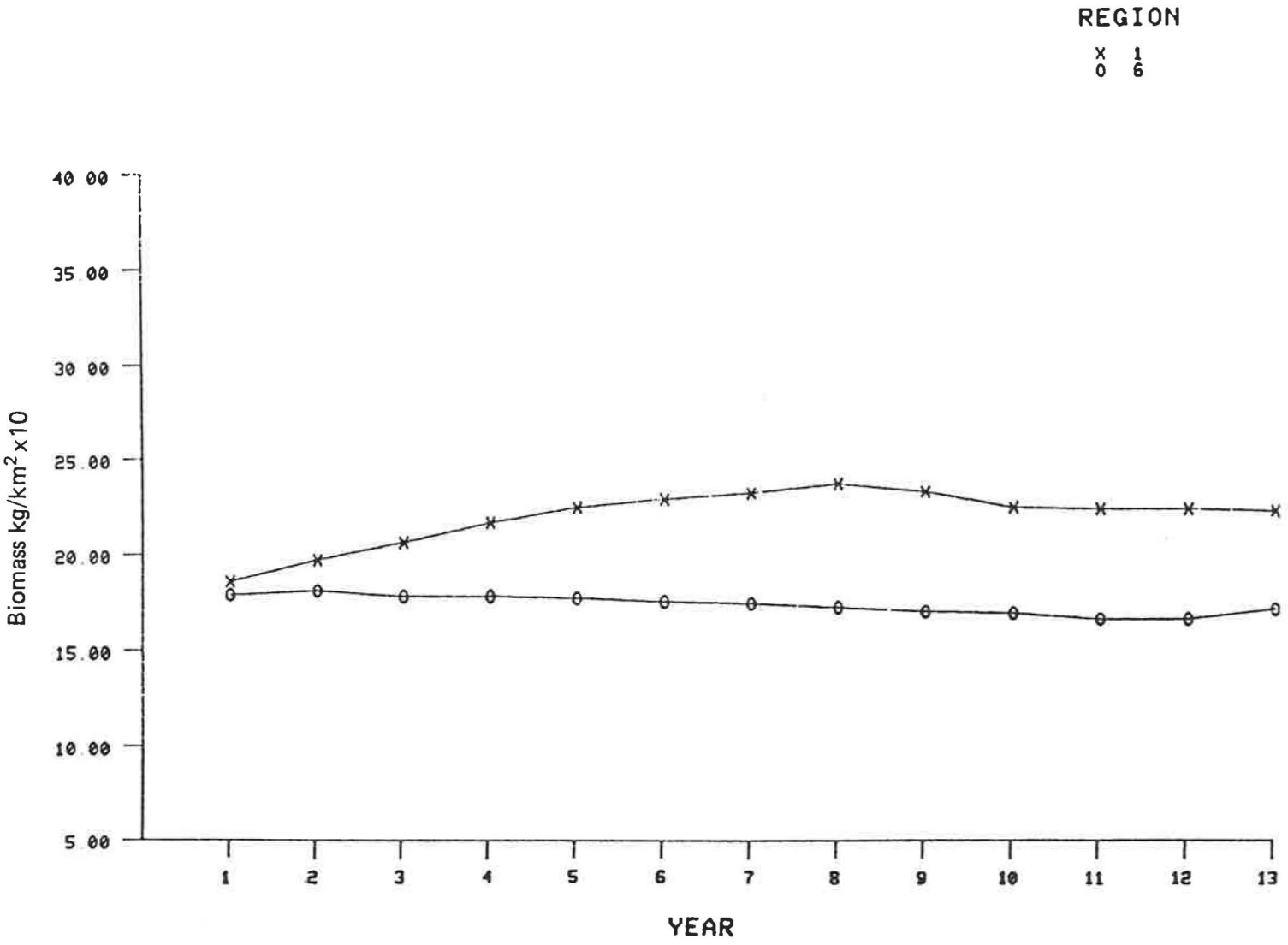

Figure 12.--Changes of halibut and turbot biomasses in the Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) corresponding to Experiment III (Figures 8, 9, and 10) with increased catches of cod, pollock, and yellowfin sole and accounting for increased bycatch of halibut (ca 6.5% of additional cod catches).

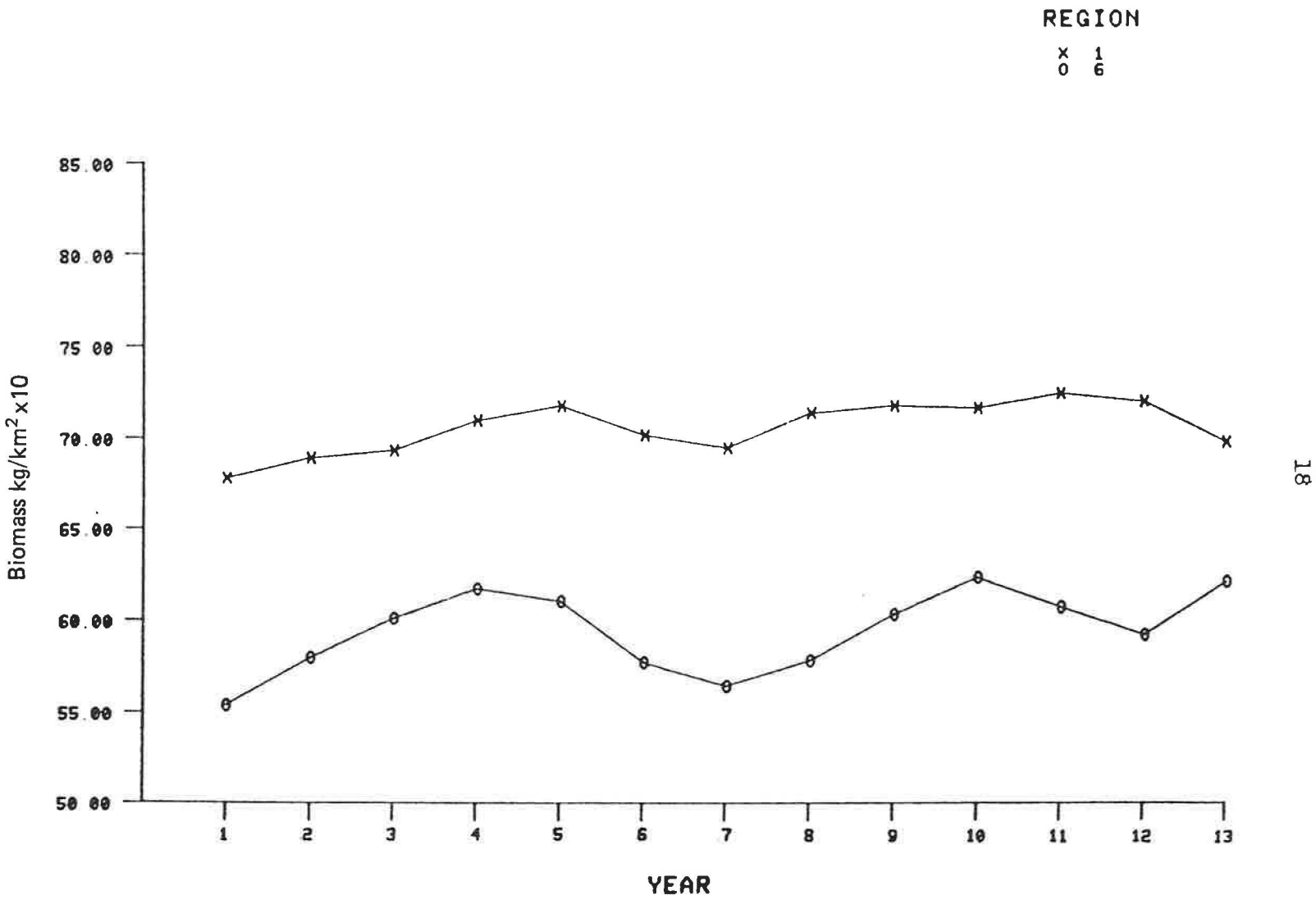

Figure 13.--Changes of crab biomasses with time in Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) (kg/km^2). (Initital catches of pollock, cod, and yellowfin sole see Table 1, column 3.)

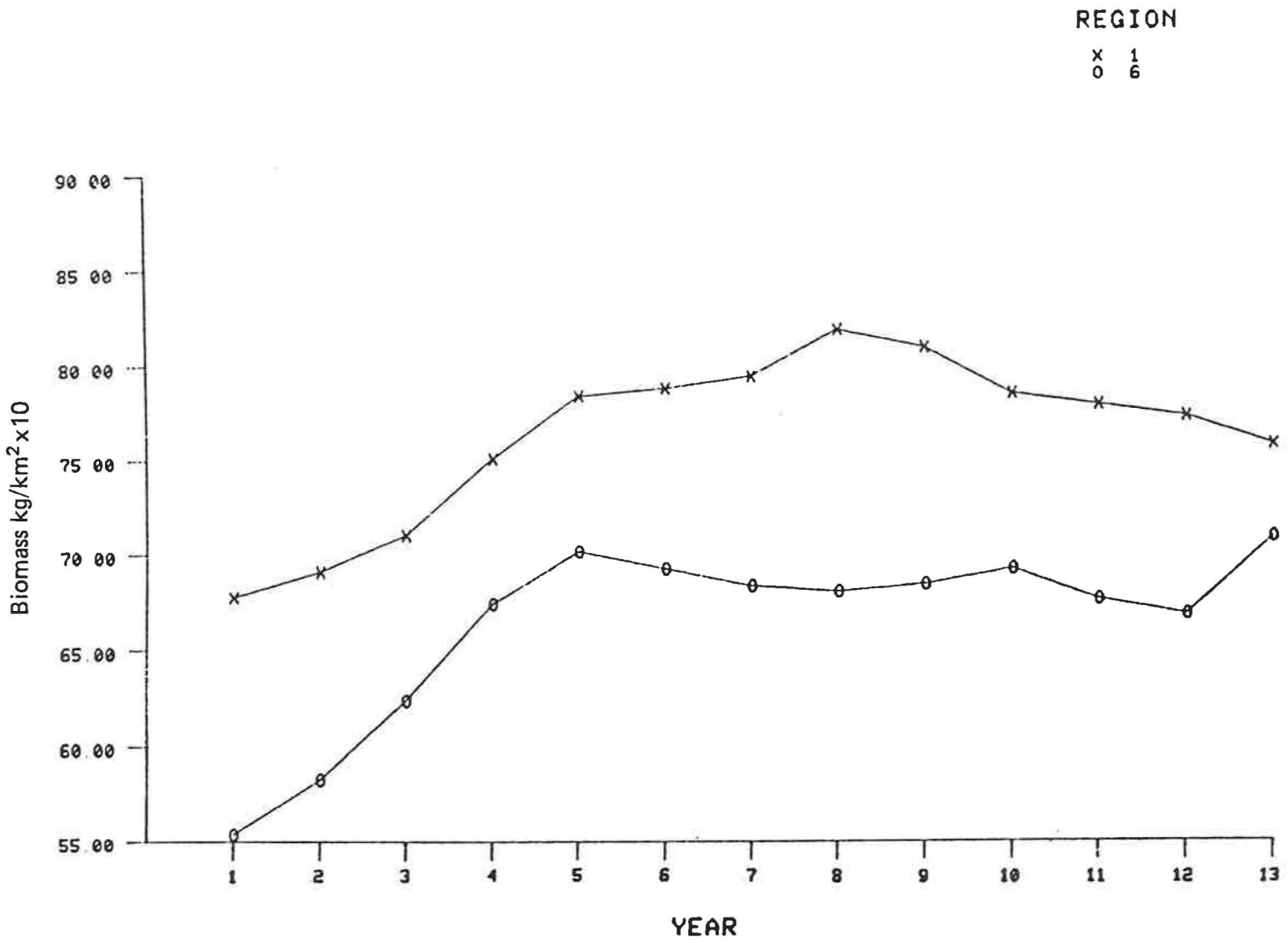

Figure 14.--Changes of crab biomasses with time in Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) (kg/km^2). The fishery on target species of cod, pollock, and yellowfin sole have been increased to: yellowfin - 195K tonnes Bering Sea, 29K tonnes Gulf of Alaska; cod - 97K tonnes Bering Sea, 58K tonnes Gulf of Alaska; pollock - 1,370K tonnes Bering Sea, 385K tonnes Gulf of Alaska.

decreased predation on crabs. The initial catches in this experiment were: cod - 97K tonnes from the Bering Sea, 58K tonnes from Gulf of Alaska; yellowfin - 195K tonnes from the Bering Sea, 29K tonnes from the Gulf of Alaska; pollock - 1,370K tonnes from the Bering Sea, 385K tonnes from the Gulf of Alaska. It should be noted, however, that the recruitment of crabs depends on several other factors, such as anomalies in transport of pelagic larvae, handling of the discards of prefishery juveniles and females for example, as much as on changes in predation.

Another change of interest is the change in the biomass of rockfishes that results from increased fishing on pollock, cod, and yellowfin. Pollock and cod prey on the pelagic larvae and juveniles of rockfishes; pollock exercising the greatest predation pressure due to its large biomass.

The fluctuations of rockfish biomasses in Bristol Bay and in western Gulf of Alaska regions with the 1980 fishery, is shown in Figure 15. Figure 16 shows the corresponding biomasses with heavy fishing on pollock, cod, and yellowfin sole populations (Experiment II, Table 1). A considerable increase of rockfish biomasses results in 6 to 7 years after increased fishing on the abovementioned species. As the rockfish biomasses in the Gulf of Alaska and Bering Sea have decreased in the last decade while the biomasses of pollock and especially cod have apparently increased, changing predation might be considered a main cause of the decline of rockfishes. The recovery of the rockfishes might, therefore, be possible only if the predatory biomasses are decreased (either with "natural fluctuations" or with heavy fishing).

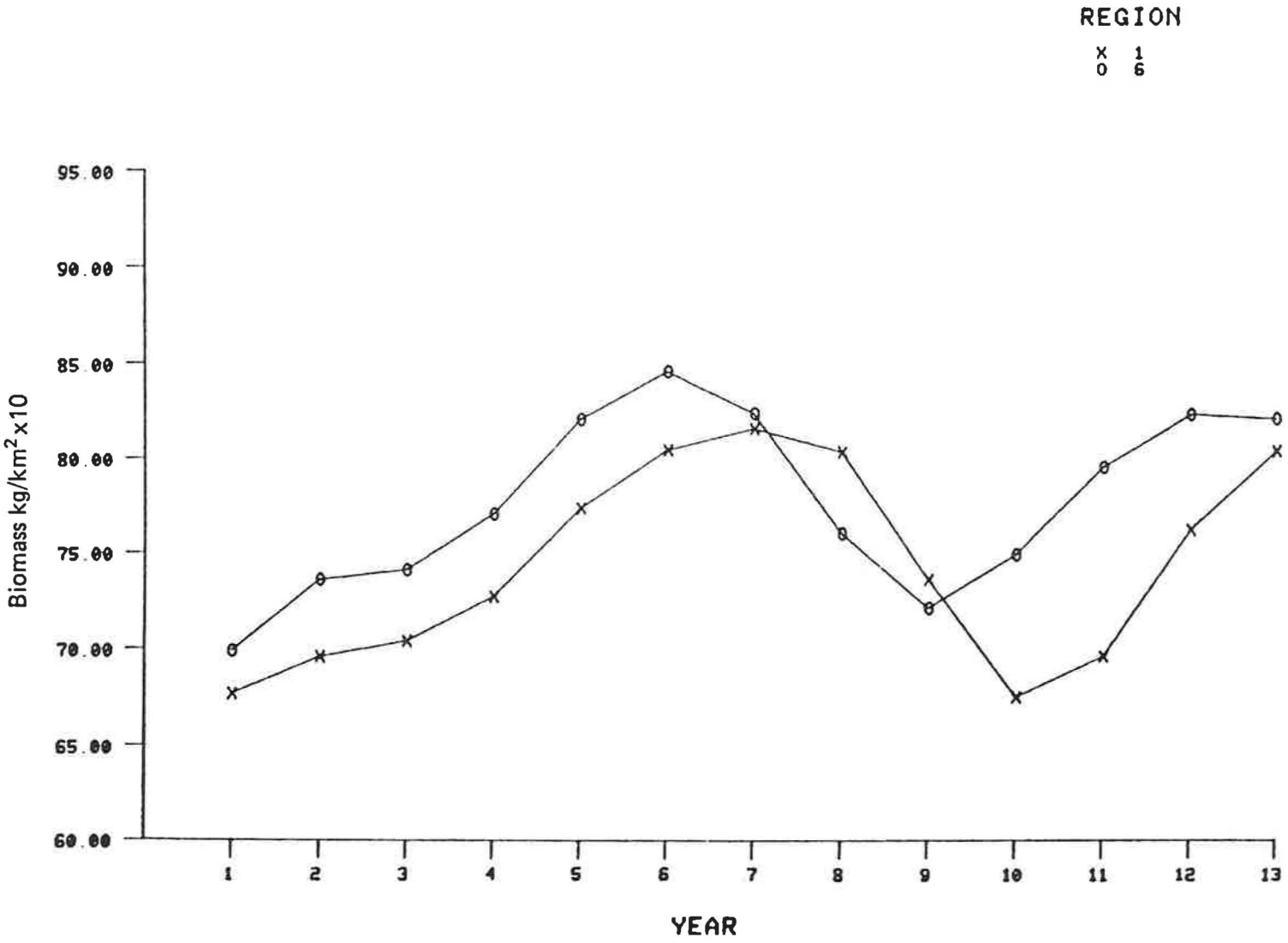

Figure 15.--Changes of rockfish biomasses with time in Bristol Bay (Region 1) and in western Gulf of Alaska (Region 6) (kg/km^2). (Initial catches of pollock see Table 1, column 3.)

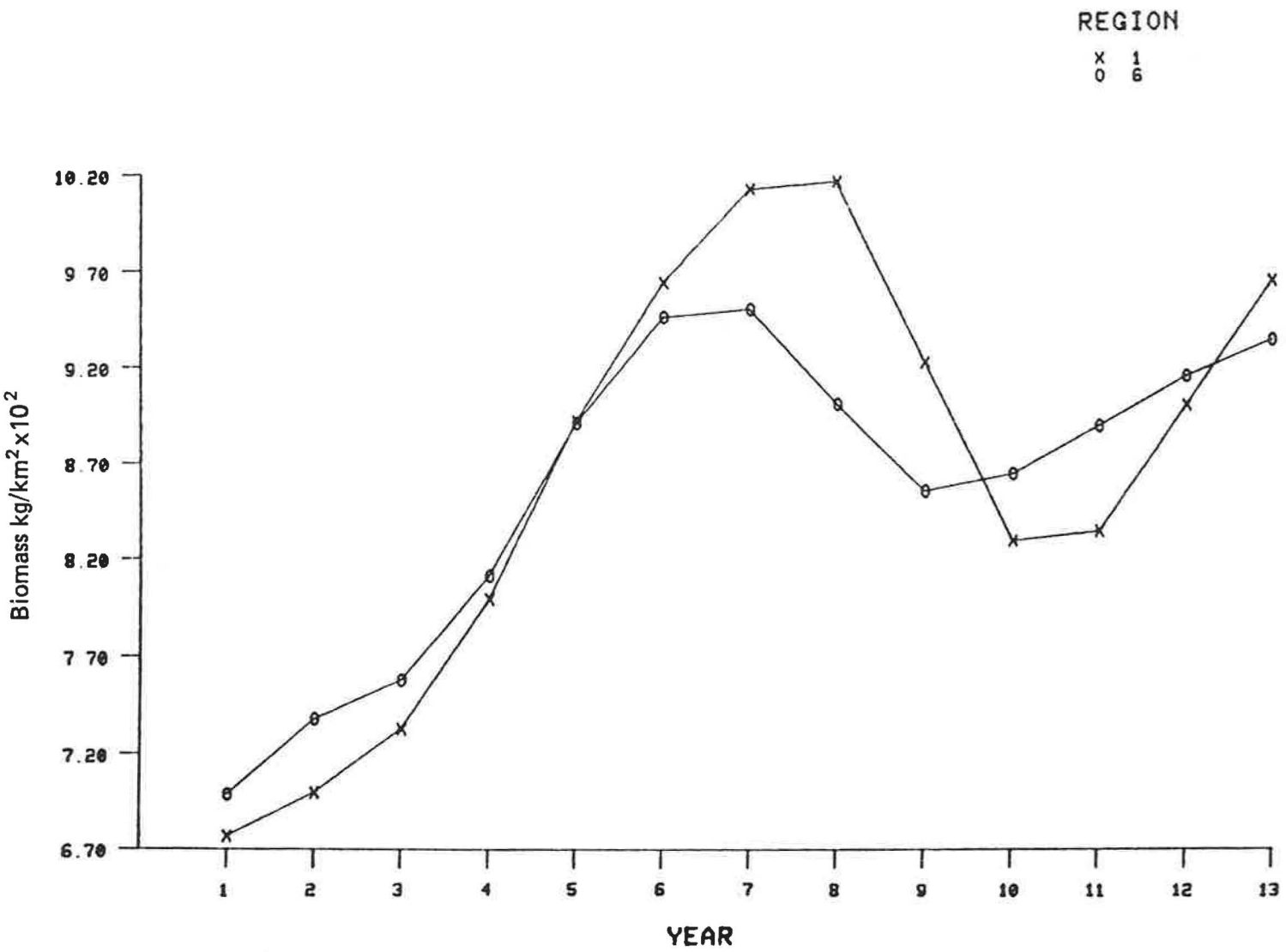

Figure 16.--Same as Figure 15 except increased catches of pollock (see Table 1, Experiment 11).

4. Effects of environmental anomalies and fishing on fish stock fluctuations

Biomass (stock) variations caused by changes in the level of fishing might be either amplified or cancelled by environmental anomalies. Ecosystem models can be used to simulate the effects of environmental anomalies. For example, the effects of temperature (anomalies) on the growth rate and on the food requirement (thus also on predation) can be examined. It is noted that temperature anomalies in high latitudes (e.g., in the Bering Sea) can be cyclic in nature (Figure 17) and are mainly caused by the surface wind anomalies (Figure 18).

In several PROBUB runs the temperature anomaly cycles were introduced whereby the annual anomalies varied between -2.5 and +2.5°C (comparable to observed magnitudes - Figure 17). In these runs, the fishing intensity was also increased. This actual increase is immaterial for the present discussions as interest was in demonstrating only the effects of temperature anomalies. Some of the results are shown in Figures 19 to 22 for yellowfin sole and pollock in Bristol Bay and in western Gulf of Alaska. These figures show the temperature anomalies, the fluctuations of biomasses without the anomalies, and the fluctuations with two sets of temperature anomalies. One set starts with the anomalous temperatures getting progressively negative and later to becoming positive. The other set is positive first and negative thereafter.

The amplitudes of yellowfin and rock sole biomass fluctuations are increased considerably by the temperature anomalies (Figures 19 and 20). The amplitudes of the fluctuations are larger in the Bristol Bay (colder area) (Figure 19) than in the western Gulf of Alaska (Figure 20) (in warmer area, temperature anomaly effects are usually smaller). In both areas, the biomass reaches a higher level when the temperature anomaly is negative first, turning positive later.

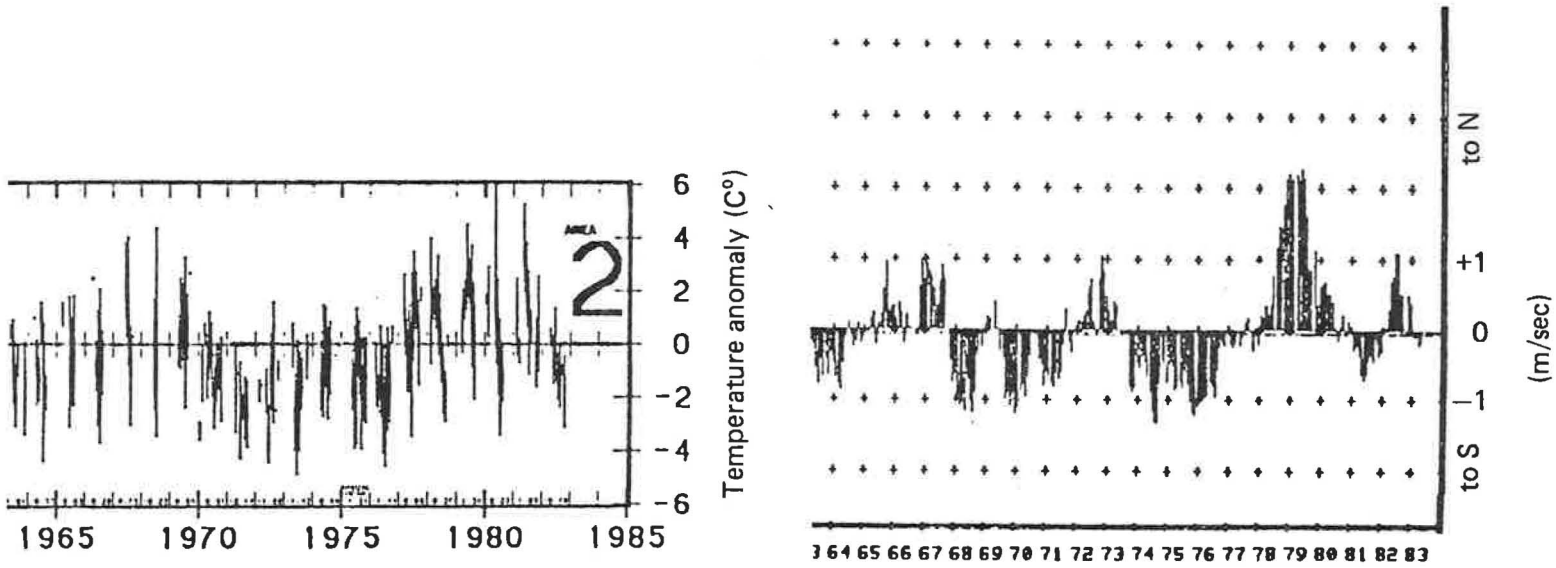

Figure 17.--Sea surface temperature anomaly in south-central Bering Sea from 1965 to 1983.

Figure 18.--Twelve-month running mean of surface wind anomaly (N-S component) in south-central Bering Sea from 1965 to 1983.

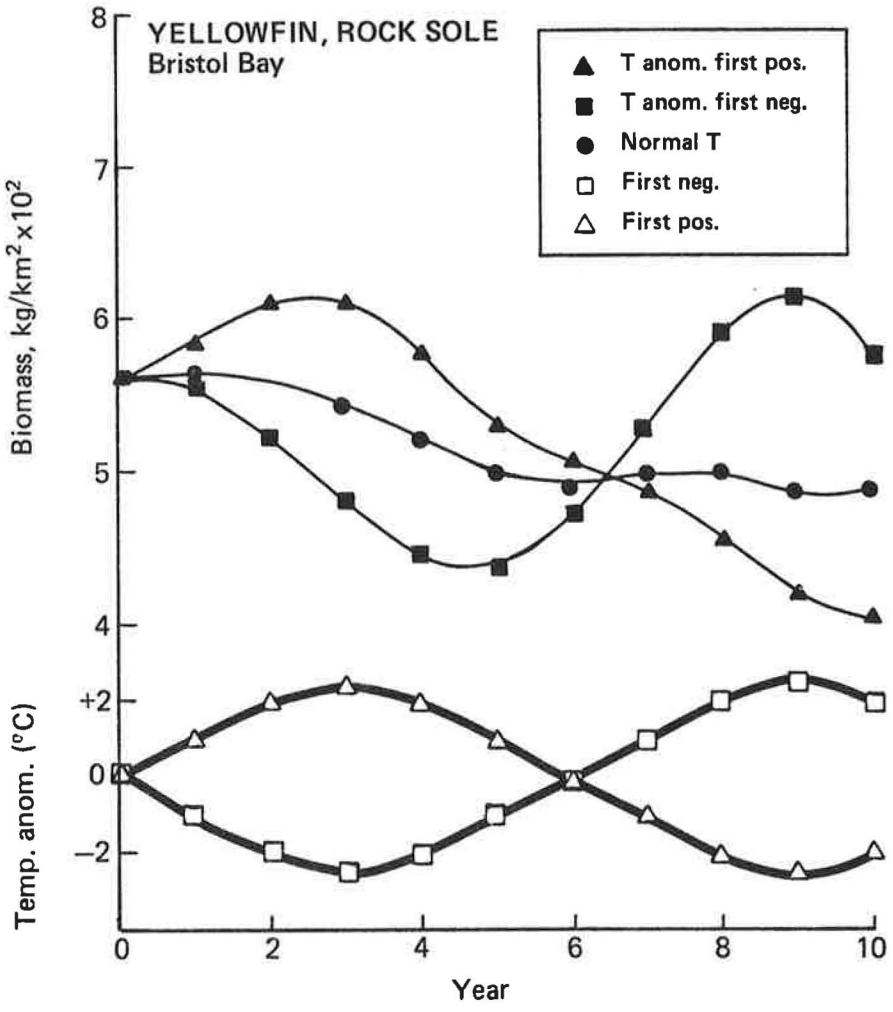

Figure 19.--Dynamics of yellowfin and rock sole biomasses in Bristol Bay with normal temperature and with temperature anomalies, starting with negative and with positive anomalies.

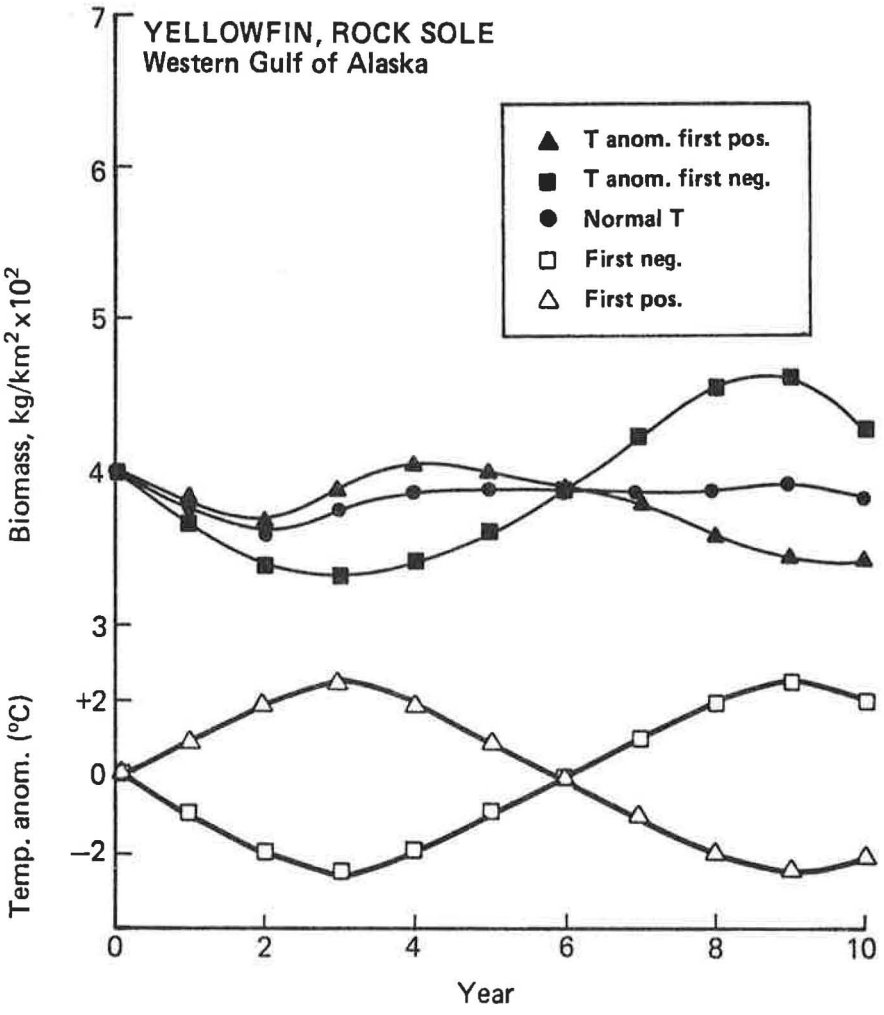

Figure 20.--Same as Figure 19 except in western Gulf of Alaska.

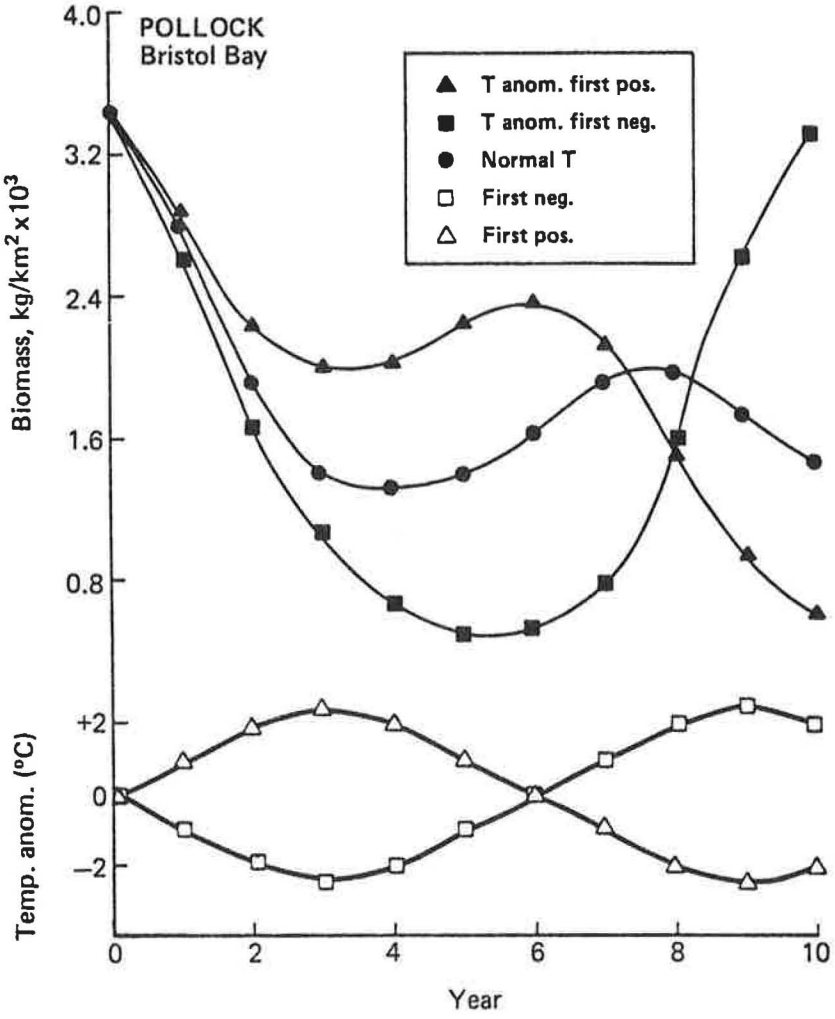

Figure 21.--Dynamics of pollock biomasses in Bristol Bay with normal temperature and with temperature anomalies, starting with negative and positive anomalies. Fishing intensity increased gradually in first three years to its threefold value as compared to year 0.

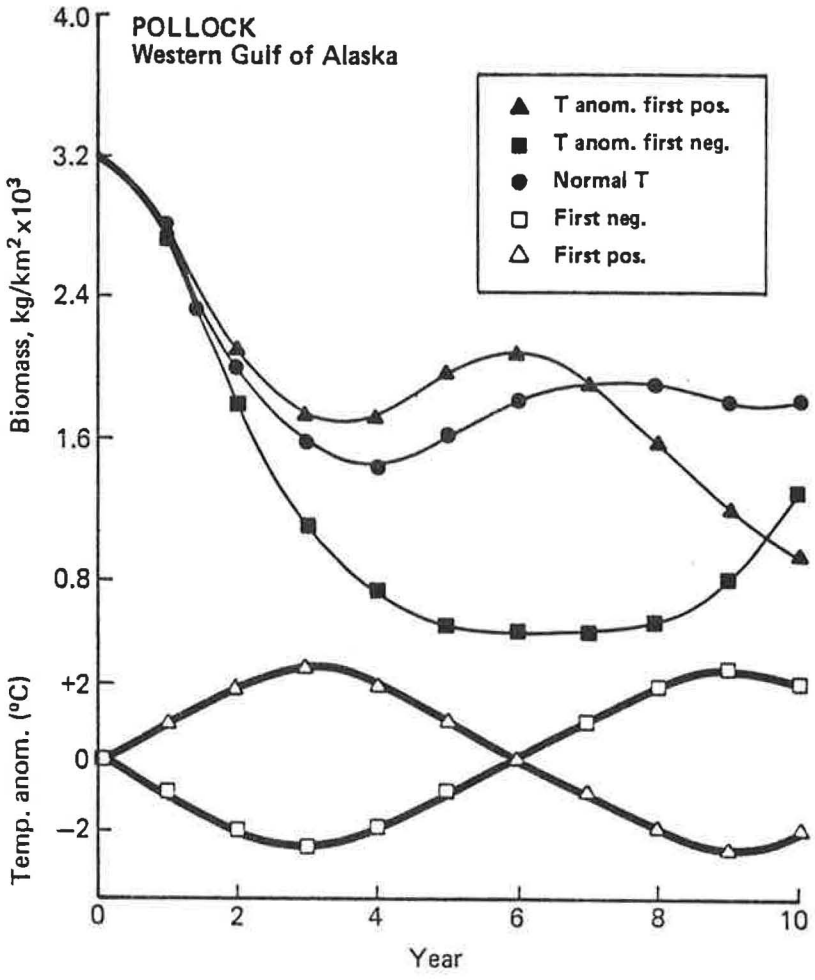

Figure 22.--Same as Figure 21 except in western Gulf of Alaska.

The fluctuations of pollock biomasses in the same regions are shown in Figures 21 and 22. Results shown in these figures indicated that the magnitudes of fluctuations are increased as they were for yellowfin sole. The fluctuations have greater magnitude in the colder area. Further, the biomass reaches a higher level if the anomaly starts negative. The latter fact was also observed in cod in the Barents Sea by Saetersdal and Loeng, 1983. The causes are found in changing predation and consequent recruitment.

5. Conclusions

1) The natural fluctuations of cod and pollock biomasses are opposite in time. Increased fishing suppresses the magnitudes of the natural fluctuations.

2) Preliminary estimates of possible increased fishing from the PROBUB runs described in this report are that cod might tolerate an annual fishing of about 120K tonnes from the Bering Sea and 60K tonnes from Gulf of Alaska. Corresponding estimates for pollock are 1250K tonnes from Bering Sea and 300K tonnes from Gulf of Alaska, and for yellowfin sole and rock sole 190K tonnes from Bering Sea and at least 40K tonnes from Gulf of Alaska.

3) There are concomitant changes in those specie biomasses which are at present subject to traditional U.S. domestic fishery, if trawl fishery on cod, pollock, and yellowfin sole is increased. These concomitant changes are caused by changing predation. The biomasses of crabs and rockfishes will increase, whereas the possible increase in halibut biomass due to decreased predation will be compensated by increased bycatch of halibut in trawl fishery.

4) Cyclic temperature anomalies, lasting a few years, can cause as large changes in the fish biomasses as do considerable changes in fishing intensity. The temperature anomaly effects are larger in colder environment (over Bering Sea shelf) than in warmer environment (Gulf of Alaska).

5) Temperature cycle, starting with cold (negative) anomaly produces larger final biomass than the cycle starting with positive anomaly. The reason for this is in changing (lowering) predation during cold anomalies, allowing higher survival of larvae and juveniles.

6. References

Laevastu, T., and H.A. Larkins.

1981. Marine fisheries ecosystem, its quantitative evaluation and management. Fishing News (Books) Ltd., Farnham, England, 162 pp.

Saetersdal, G. and H. Loeng.

1983. Ecological adaption of reproduction in Arctic cod. Contr. to PINRO/IMR Symposium on Arctic Cod, Leningrad, Sept. 1983, 23 pp.