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Eastern Bering Sea
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Aleutian Ecosystems in Equilibrium
with Present Fishery,
and These Ecosystems
in Natural State

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EASTERN BERING SEA AND ALEUTIAN ECOSYSTEMS IN EQUILIBRIUM WITH PRESENT
FISHERY, AND THESE ECOSYSTEMS IN NATURAL STATE

By

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CONTENTS

Abstract.

1. Introduction.
2. Species composition of ecological groups, definition of equilibrium biomasses and exploitable fraction of biomasses.
3. Basic simulation inputs and accuracy limits of results.
4. Total and exploitable biomasses in the eastern Bering Sea and in the Aleutian region with present fishery, and these biomasses in natural state.
5. "Natural fluctuations" of the biomasses.
6. References.

LIST OF TABLES

- Table 1.--Composition of ecological groups in the eastern Bering Sea as used in PROBUB 80-1.
- Table 2.--Average percent of exploitable biomass from total biomass.
- Table 3.--Estimated plausible maximum error limits of equilibrium biomasses in PROBUB 80-1 (preliminary) (in % of plausible mean value).
- Table 4.--Maximum equilibrium biomasses of species and ecological groups in the eastern Bering Sea (in 1,000 tons). (Estimated minimum equilibrium biomasses and mean exploitable biomasses are given for comparison.)
- Table 5.--Maximum equilibrium biomasses and ecological groups in the Aleutian subregion (in 1,000 tons).
- Table 6.--Turnover rates of biomasses in the eastern Bering Sea and in the Aleutian subregion.
- Table 7.--Maximum equilibrium biomasses in the eastern Bering Sea and in the Aleutian subregion with present fishery and in the natural state (without fishery).
- Table 8.--Maximum equilibrium biomasses in kg/km^2 in continental shelf areas (areas 1 and 4, See Figure 1), and over deep water (areas 3 and 5).
- Table 9.--Total standing stocks in the eastern Bering Sea and in the Aleutian subregion in tons/km^2 .

LIST OF FIGURES

- Figure 1.--Computation areas for PROBUB 80-1.
- Figure 2.--Schematic presentation of causal relations via processes and their feedback, which affect the error limits of the determination of equilibrium biomasses.
- Figure 3.--Equilibrium biomasses of three different regimes in the eastern Bering Sea.
- Figure 4.--Examples of monthly changes of biomasses of capelin and other pelagic fish in area 1 and squid in area 5 (tons/km²).
- Figure 5.--Examples of long-term fluctuations of biomasses of yellowfin sole and cod in the eastern Bering Sea and in the Aleutian subregion with present fishery and in natural state.
- Figure 6.--Examples of long-term fluctuations of the biomasses of capelin and other pelagic fish in the eastern Bering Sea and in the Aleutian subregion with present fishery and in natural state.

ABSTRACT

The equilibrium biomasses of species and ecological groups in the eastern Bering Sea and in the Aleutian subregion have been determined with the PROBUB 80-1 ecosystem simulation model; both with the present fishery and in the "natural state" (i.e. no fishery). The maximum and minimum biomasses (defined in the text) and the mean exploitable biomasses are given in the tables. The plausible error limit is estimated to be + 30% or less.

The biomasses of semidemersal species (especially pollock) are lower in the natural state; the total biomass of demersal species is about the same in "fished" as in the natural state, and the biomass of squids is higher in the natural state. The reasons for these changes of biomasses are complex, usually involving interspecies interactions via trophic relations. Furthermore, the biomasses of presently fished species are older in the natural state which causes the biomass growth rate to be an average 11% lower in the natural state as compared to the fished state.

The biomasses per unit area vary from one area to another. There is a considerable biomass of pollock over deep water off the continental slope in the eastern Bering Sea. Obviously this pollock biomass is pelagic and subsists mainly on euphausiids and on their own offsprings (cannibalism). The deep water biomass is also a source for the pollock biomass over the continental shelf where it is removed by the fishery and by mammal predation.

The total finfish biomass on the eastern Bering Sea shelf is 36 tons/km² and on the narrow island shelves in the Aleutian subregion the standing stock of finfish biomass is 48 tons/km². Over the deep water in the central Bering Sea the standing stock of finfish is 30 tons/km², of which 21 tons are pollock, and the standing stock over the deep water north and south of the Aleutian Island chain is 12 tons/km².

Examples of monthly and long-term fluctuations of some biomasses are given in the figures.

1. INTRODUCTION

The Prognostic Bulk Biomass (PROBUB) ecosystem simulation model permits the determination of the biomasses of species and ecological groups assuming there is an annual balance between the growth of the biomasses and their removal by predation, fishery, and other mortalities. These equilibrium biomasses are obtained as a unique solution to the set of ecosystem governing equations (see Laevastu, Favorite, and Larkins 1979, appendix). The equilibrium biomasses for the eastern Bering Sea (areas 1, 2, and 3, Figure 1) and for the Aleutian subregion (areas 4 and 5) were determined with PROBUB 80-1 and are presented in this report. The essential input data are given in other reports in this series (Laevastu and Livingston 1980; Laevastu, Livingston, and Niggol 1980, and Livingston 1980).

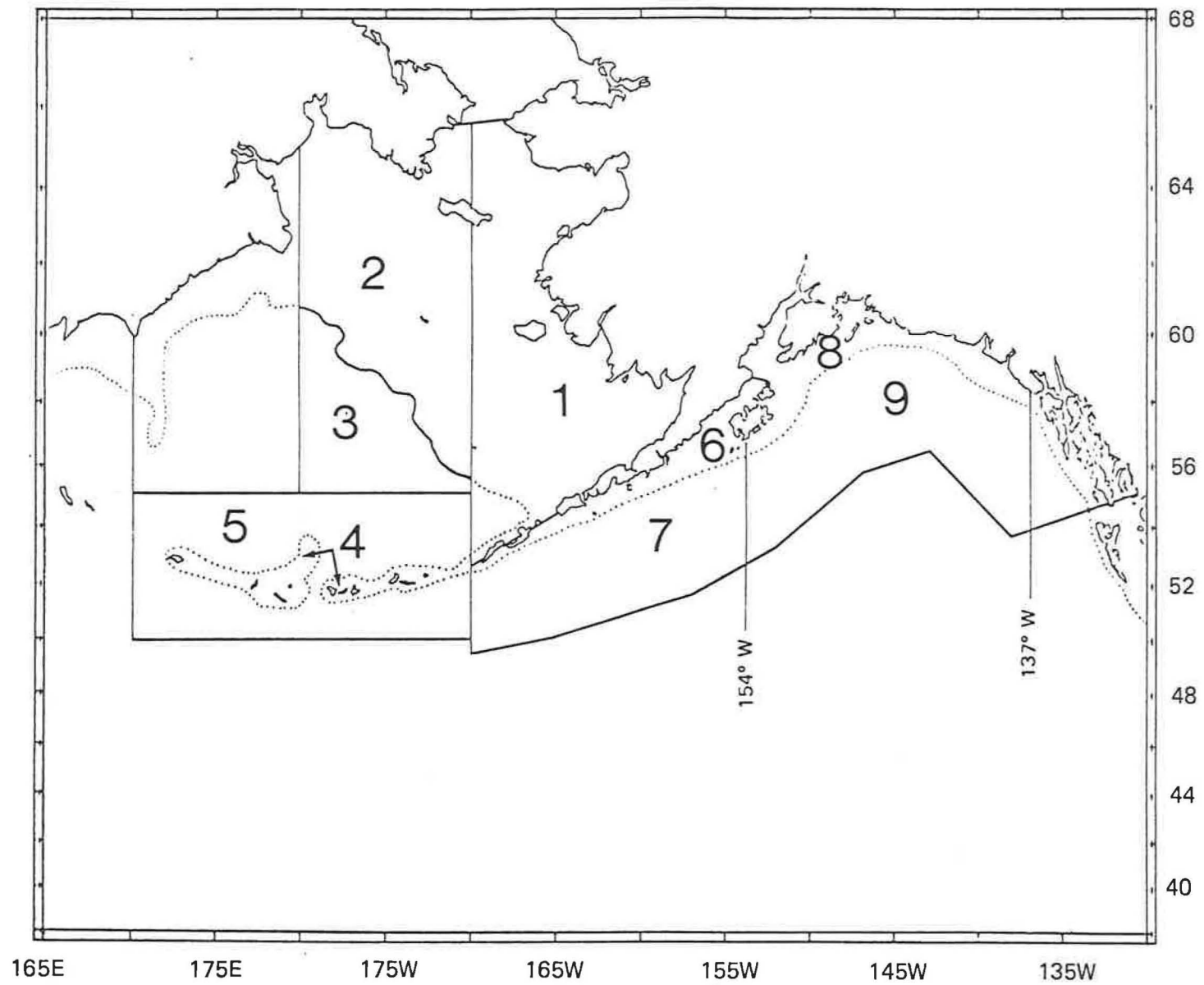


Figure 1.--Computation areas for PROBUB 80-1.

The computed values of the equilibrium biomasses are useful only if their reliability (error limits) can be ascertained. Preliminary error limits have been determined, using a variety of approaches, as customary methods in a holistic ecosystem simulation such as the determination of error limits in individual processes, error limits in input data, magnification and/or dampening of errors in a large system computation, and experiences (results) from a multitude of runs with variable inputs.

The biomasses of individual species fluctuate in time and space due to a variety of causative factors such as environmental anomalies, variations in recruitment, variations in predation, etc. These fluctuations have been termed in the past as "natural fluctuations". Before we can evaluate quantitatively the effect of fishery on the marine ecosystem we must evaluate (determine) the possible magnitudes and periods of these fluctuations. This evaluation is costly and time-consuming and requires an especially extended and tuned unstable ecosystem simulation with spatial resolution (e.g. DYNUMES model). The present PROBUB model is, however, well suited for the initial study toward this end--i.e. the determination of the equilibrium biomasses with present (combined) fishery and of the equilibrium biomasses in the "natural state" (i.e. no fishery). Preliminary results of this study are given in this report.

2. SPECIES COMPOSITION OF ECOLOGICAL GROUPS, DEFINITION OF EQUILIBRIUM BIOMASSES AND EXPLOITABLE FRACTION OF BIOMASSES.

The time-dependent ecosystem simulations require a great number of constant and variable arrays. Thus the computer core size becomes one of the limiting factors on the size of the simulations. On the other hand, an ecosystem simulation is realistic only if we consider all the biota and the total environment and all processes which contribute to the dynamics of the system. Consequently we must search for ways to reduce the core requirements. One of the ways to reduce core requirement, as well as to speed up computations, is to group several ecologically similar species into ecological groups, considering especially their living space and food composition. Furthermore, the necessary input information on individual noncommercial species is often not satisfactory for treating them as separate species.

The species and groups of species as used in PROBUB 80-1 are listed in Table 1. The relative strength of biomasses within these groups can at present be estimated only for some flatfish groups. It should also be noted that the relative species composition varies from one computation area to another (Figure 1). The corresponding ecological grouping of marine birds and mammals is given by Livingston 1980 and Laevastu, Livingston, and Niggol 1980.

No direct empirical knowledge is available on the size of marine biomasses in the NE Pacific region. Due to lack of proper data some available methods for assessment of the biomasses of exploited species (such as Virtual Population Analysis) are not applicable in this area, and extensive direct trawling surveys can indicate the exploitable biomasses of some exploited species with an accuracy of $\pm 50\%$ (Laevastu, Favorite, and Larkins 1979). Thus we need a method which can give reasonable estimates of biomasses present in different areas of the NE Pacific.

Table 1.--Composition of ecological groups in the eastern Bering Sea as used in PROBUB 80-1.

Species/ecological group designation	Major species composition of the ecological group	Estimated biomass relations
Halibut	Greenland halibut (turbot), Pacific halibut	3.5:1
Flathead	Flathead sole, arrowtooth flounder	4:1
Yellowfin	Yellowfin sole, rock sole, Alaska plaice	9:1.5:1
Other flatfishes	Longhead dab and other flatfishes not listed above	
Cottids	Cottids, elasmobranchs and other "noncommercial" demersal fish	
Cod	Pacific cod; saffron and polar cods in the northern part	
Sablefish	Sablefish or black cod (single species)	
Pollock	Walleye pollock (single species)	
Rockfish	Pacific ocean perch and other rockfishes (<u>Sebastes</u> and <u>Sebastes</u> spp.)	
Herring	Pacific herring (single species)	
Capelin	Capelin, other smelts, sand lance, and other pelagic noncommercial species	
Mackerel	Atka mackerel and other greenlings, Macrurids	
Salmon	Five species of Pacific salmon; seasonally present	
Squid	Mainly Gonatid squids, some highly migratory	
Crab	King and Tanner crabs and other noncommercial species	
Shrimp	Several commercial and noncommercial species	
Predatory benthos	Starfishes and other mobile predatory benthos	
Infauna	Annelids and other burrowing forms	
Epifauna	Bivalves, benthic crustaceans	
Zooplankton	Copepods, euphausiids, sagittas	

The PROBUB simulation model can be used to compute the equilibrium biomasses in any area by computing an unique solution to ecosystem equations set under the following conditions:

1) The growth of biomass of individual species is in equilibrium with the removal of this biomass by predation, fishing and other mortalities.

2) Immigration is in equilibrium with emigration.

3) Larval recruitment is proportional to spawning biomass present (i.e. averaging recruitment over a longer time interval).

4) Food composition of individual species reflects (to some extent) the availability (abundance) of individual food items.

Thus, for the computation of equilibrium biomasses we can assume that the biomass of a given species in one January is the same as in the previous January, and can adjust the biomass of the species at the beginning of each year's computation, using an iterative procedure (because the change of one biomass would induce changes in other biomasses via trophic relations). About 500 iterations (ca 40 years) are required to reach the unique solution. After reaching this solution, various experiments can be carried out with the PROBUB model (e.g. determination of the response of the ecosystem to changes in fisheries), but assuming that the food composition of the species varies in direct proportion to the variation of the biomass of the prey items, and that the recruitment is proportional to the square root of the variation of the spawning biomass. It could be noted that the computation of equilibrium biomasses with number based models is a quasi-impossible task.

The main input data, such as growth coefficients and food requirement coefficients, have some plausible error limits which affect the computed equilibrium biomasses. Thus we can compute some limits to the biomasses which we can term as maximum and minimum equilibrium biomasses. Maximum equilibrium biomasses are computed with plausible lowest growth coefficients and highest plausible food requirements (for growth and maintenance). Minimum equilibrium biomasses are computed with plausible highest growth coefficients and lowest plausible food requirements.

Only part of the given species biomass is of proper size for exploitation. The fraction of exploitable biomass is computed with another model (BIODIS, Granfeldt 1979b) and is given in Table 2. It should be noted that this exploitable biomass has been computed with "knife edge" recruitment and with long-term mean age composition; thus it can vary in space and time. When comparing resource survey results with computed biomasses, the former must be converted to exploitable biomasses using catchability factors (see Granfeldt 1979a and Laevastu, Favorite, and Larkins 1979).

3. BASIC SIMULATION INPUTS AND ACCURACY LIMITS OF RESULTS

The basic input data for PROBUB 80-1 run are given in other reports in this series (Laevastu and Livingston 1980; Laevastu, Livingston, and Niggol 1980; and Livingston 1980), where some of the limitations of these data are briefly discussed. Detailed discussions of the accuracy of the input data would require voluminous works, as the accuracy of individual data varies from species to species and from area to area. There are,

Table 2.--Average percent of exploitable biomass from total biomass

Species/ecological group designation	Percent of exploitable biomass	Remarks
Halibut	54	
Flathead	45	
Yellowfin	45	
Other flatfish	28	
Cottids	(50)	
Cod	72	Pacific cod
Sablefish	40	
Pollock	70	
Rockfish	30	Ocean perch
Herring	30	
Capelin	(50)	
Mackerel	45	
Salmon	(70)	Returning
Squid	-	
Crab	(35)	Commercial spp
Shrimp	(65)	Commercial spp
Predatory benthos	-	
Infauna	-	
Epifauna	-	
Zooplankton	-	

however, some basic inputs (such as growth rates and predation mortality) which affect the determination of equilibrium biomasses (which are the main subject of this report) more than some other inputs. There are also multitudes of other minor error sources which propagate through the computations (see Figure 2).

A cursory examination might indicate that error in growth coefficient might cause a linearly proportional error in equilibrium biomass. However, the equilibrium biomass level is determined by the difference between growth coefficient and predation mortality, the latter depending on food requirements and food composition of many predator species. Thus a 10% error in growth coefficient would directly cause only a 0.5% difference in the biomass within one time step. However, the error is cumulative in time and is modified by changes in predation in many species.

Possible errors in spawning stress mortality (senescent mortality) affects the equilibrium biomass relatively little, as this mortality coefficient is small.

The possible errors in food requirement coefficient are limited by food availability dependent feeding (leading to starvation) and by substitution of part of the "lacking" food by the "buffer food sources" in the ecosystem (i.e. zooplankton and benthos). Overconsumption of a species is not possible in PROBUB as the limits of consumption are prescribed, which are derived from the data on turnover rates, fecundity, and larval growth. The food item availability limit also requires changes in food composition computations and leads to an overall maximum utilization of all food resources in the ecosystem. The food composition changes are somewhat better treated in DYNUMES model with spatial resolution which allows the predator-prey "overlap distribution" consideration.

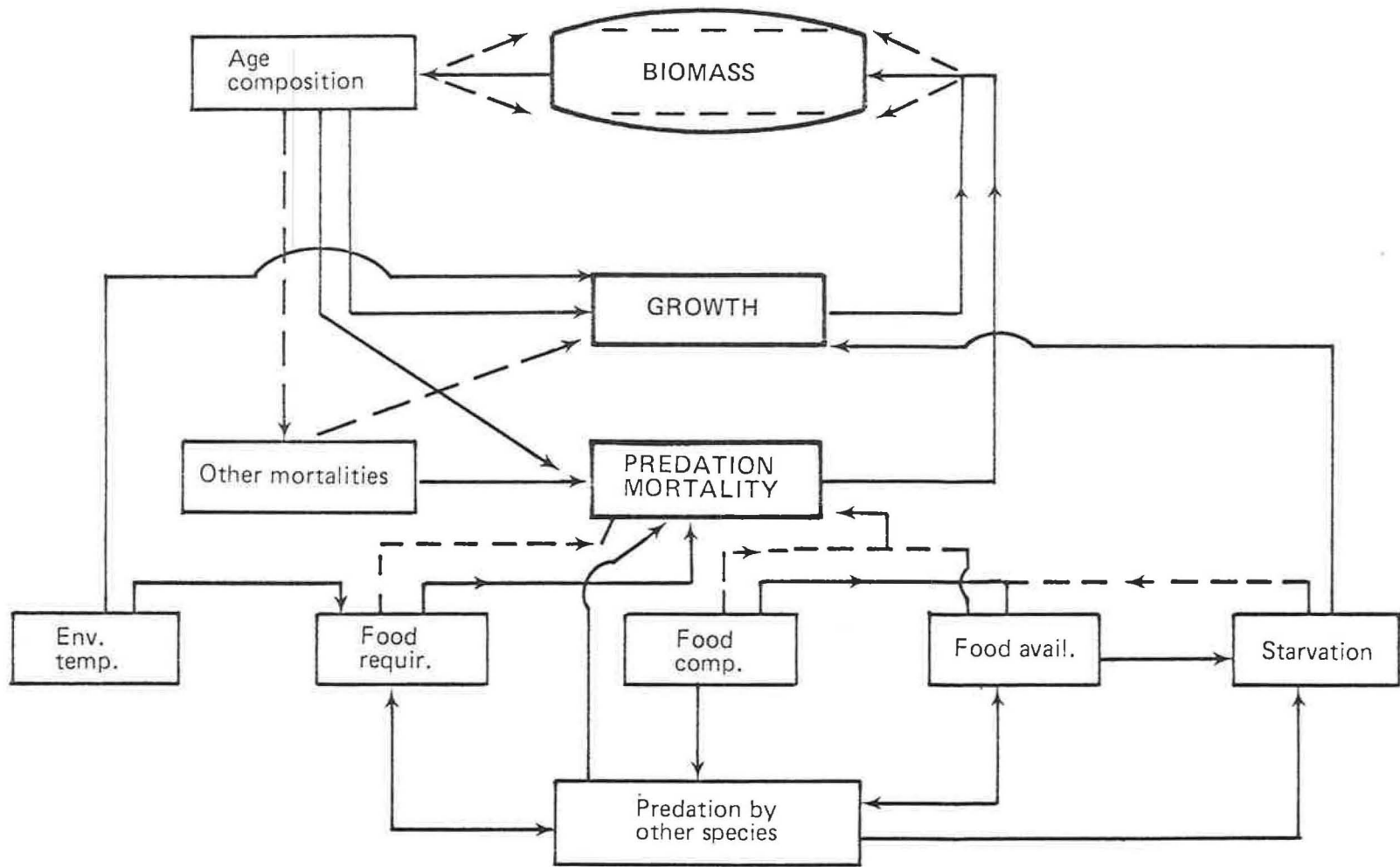


Figure 2.--Schematic presentation of causal relations via processes and their feedbacks which affect the error limits of the determination of equilibrium biomasses.

Table 3.--Estimated plausible maximum error limits of equilibrium biomasses
in PROBUB 80-1 (preliminary) (in % of plausible mean value).

Ecological group	Maximum error limits (± %)	Remarks on largest plausible source of errors
Flatfishes	18	Seasonal changes in food uptake and composition.
Pollock	18	Spatial change of growth rate and offshore distribution of biomass.
Herring	25	} Seasonal and spatial changes in the contribution of herring and rockfishes to the food of other species; seasonal migrations.
Rockfishes	30	
Cod, sablefish	20	Growth rates of juveniles, seasonal migrations.
Other noncommercial demersal	25	} Growth rates; size-age distribution; occurrence in diet of other species; age of maturity.
Other noncommercial pelagic	30	
Crabs, shrimps	25	Growth rates, distribution (spec. of juveniles).

The verification and validation of the PROBUB results have been described in earlier reports in this series (Granfeldt 1979a; Laevastu, Favorite, and Larkins 1979; and others).

4. TOTAL AND EXPLOITABLE BIOMASSES IN THE EASTERN BERING SEA AND IN THE ALEUTIAN REGION WITH PRESENT FISHERY, AND THESE BIOMASSES IN THE NATURAL STATE.

The maximum and minimum equilibrium biomasses of species and ecological groups in the eastern Bering Sea are given in Table 4. (The minimum equilibrium biomasses were estimated with an earlier version of PROBUB which differed slightly from PROBUB run 80-1 in food substitution computation.) The results are also given in Figure 3 where the biomasses are divided into three groups: pelagic, semidemersal, and demersal. The mean exploitable biomasses are also given in Table 4, subject to limitations described in Chapter 2 above.

The greatest differences between maximum and minimum biomasses occur in pelagic and semidemersal species, especially in pollock, capelin, and other noncommercial pelagic species, and in squids. Squids have a short life span and their biomass can vary considerably from year to year. Furthermore, adult squids feed predominantly on other pelagic species (including pelagic juveniles of demersal species). Thus the abundance of squids might exercise considerable influence on other biomasses.

Table 4.--Maximum equilibrium biomasses of species and ecological groups in the eastern Bering Sea (in 1,000 tons). (Estimated minimum equilibrium biomasses and mean exploitable biomasses are given for comparison.)

Species/ecological group designation	Maximum equilibrium biomass	Estimated minimum equilibrium biomass	Mean exploitable biomass
Halibut	585	400	220
Flathead sole	875	650	380
Yellowfin sole	1,660	1,100	510
Other flatfish	1,160	850	245
Cottids	4,438	4,000	-
Cod	1,468	1,000	745
Sablefish	183	120	51
Pollock	15,165	8,000	6,450
Rockfish	1,825	1,000	485
Herring	2,327	1,500	590
Capelin	5,149	3,500	(1,000)**
Mackerel	1,438	1,100	520
Salmon	(73)	(50)	-
Squid	2,310	1,200	(500)**
Crab	1,225	800	(300)**
Shrimp	1,792	900	(600)**
Predatory benthos	818	700	-
Infauna	24,219	20,000	-
Epifauna	20,947	15,000	-
Zooplankton	58,430*	35,000	-

* - 500 mg/m³; 100 m.

** - Includes species which are not exploited at present.

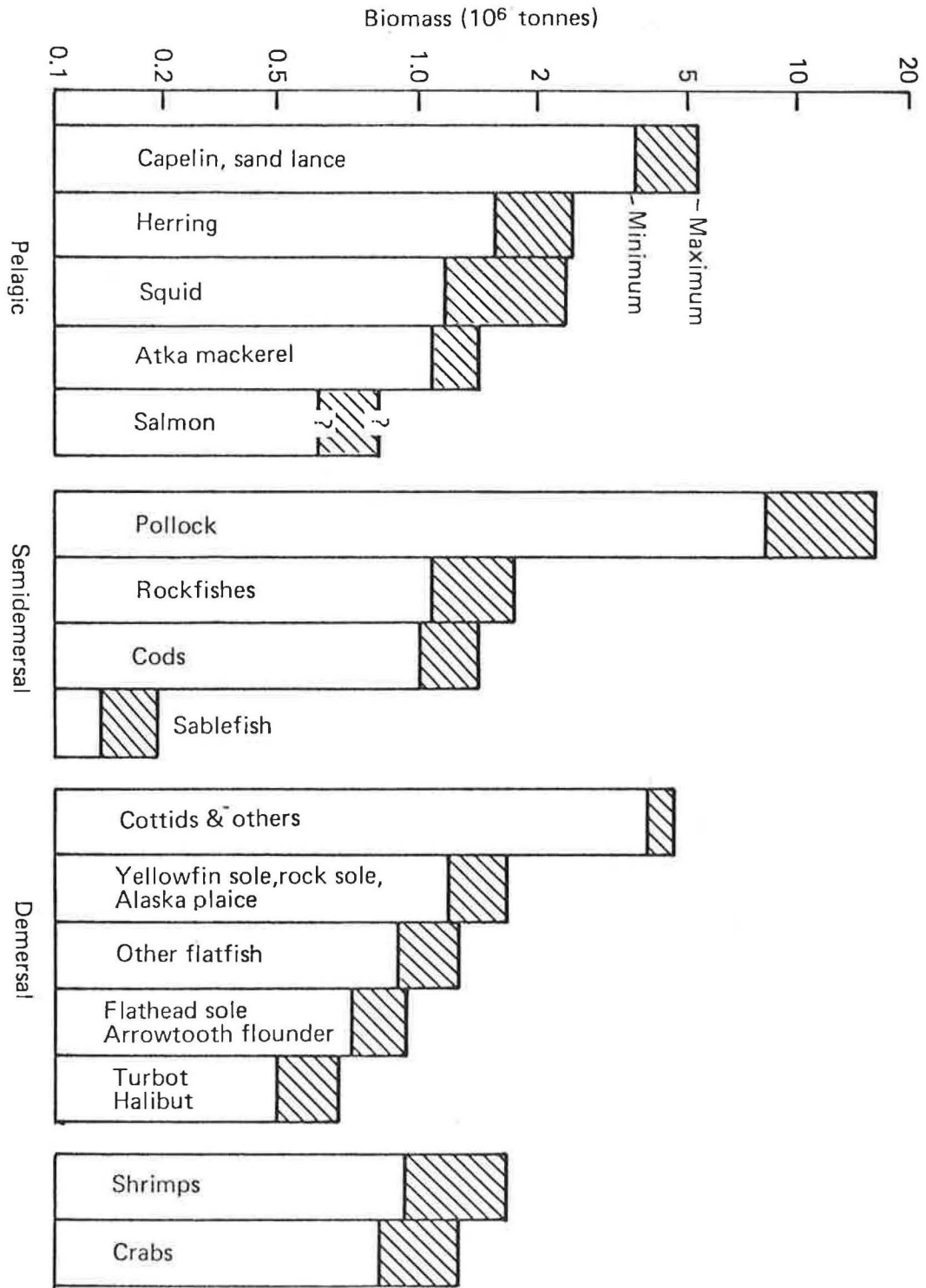


Figure 3.--Equilibrium biomasses of three different regimes in the eastern Bering Sea.

Table 5 gives the maximum equilibrium biomasses in the Aleutian subregion (areas 4 and 5 in Figure 1). The turnover rates (predation and other mortalities/mean standing stock) for biomasses in the eastern Bering Sea and in the Aleutian subregion are given in Table 6. The turnover rates in the Aleutian subregion are considerably higher than in the eastern Bering Sea. The main reason for this is higher growth rates in the warmer temperatures in the Aleutian subregion and partly due to higher utilization of food resources on the narrow shelf by migrating semidemersal and pelagic fish.

The maximum equilibrium biomasses in the eastern Bering Sea and in the Aleutian subregion were determined also in the "natural state" (i.e. without fishery) (Table 7). The predation by marine birds and mammals was assumed to be the same as at present (see Laevastu, Livingston, and Niggol 1980), and the growth rate of exploited species was 11% lower than in the exploited state (re. rejuvenation of populations due to fishery; Granfeldt 1980).

The biomass of pollock is considerably lower in the natural state. This is apparently due to the presence of a higher amount of older, more cannibalistic pollock in the natural state which suppresses the biomass of juveniles (see further Laevastu and Favorite 1976).

Yellowfin sole and other flatfish biomasses are lower in the natural state than in the present, fished state. This situation might seem to be contrary to common expectations, but corresponds well to happenings in the North Sea where groundfish biomasses increased considerably in the 1960's and 70's with the increase of exploitation. The higher biomasses of squids, cottids,

Table 5.--Maximum equilibrium biomasses of species and ecological groups in the Aleutian subregion (in 1,000 tons).

Species/ecological group designation	Maximum equilibrium biomass
Halibut	107
Flathead sole	127
Yellowfin sole	235
Other flatfish	187
Cottids	787
Cod	297
Sablefish	32
Pollock	6,234
Rockfish	768
Herring	705
Capelin	1,430
Mackerel	1,671
Salmon	(62)
Squid	2,695
Crab	190
Shrimp	241
Predatory benthos	99
Infauna	2,838
Epifauna	1,687
Zooplankton	37,230

Table 6.--Turnover ratios of biomasses in the eastern Bering Sea and in the Aleutian subregion. (Maximum equilibrium biomasses).

Species/ecological group designation	Turnover rate	
	Eastern Bering Sea	Aleutian subregion
Halibut	0.44	0.52
Flathead sole	0.46	0.55
Yellowfin sole	0.39	0.52
Other flatfish	0.57	0.64
Cottids	0.65	0.72
Cod	0.71	0.82
Sablefish	0.54	0.60
Pollock	0.64	0.77
Rockfish	0.56	0.47
Herring	0.70	0.70
Capelin	0.72	1.05
Mackerel	0.59	0.35
Salmon	(0.61)	(0.47)
Squid	1.60	1.60
Crab	0.34	0.32
Shrimp	0.77	0.85
Predatory benthos	0.63	0.79
Infauna	1.38	0.85
Epifauna	0.98	1.37
Zooplankton	(2.60)	(1.39)

Table 7.--Maximum equilibrium biomasses in the eastern Bering Sea and in the Aleutian subregion with present fishery and in the "natural state" (without fishery). (1000 tonnes)

Species/ecological group designation	Eastern Bering Sea		Aleutian subregion	
	With present fishery	No fishery	With present fishery	No fishery
Halibut	585	505	107	107
Flathead sole	875	750	127	126
Yellowfin sole	1,660	1,050	235	208
Other flatfish	1,160	1,165	187	182
Cottids	4,438	4,750	787	917
Cod	1,468	1,370	297	329
Sablefish	183	124	32	27
Pollock	15,165	11,920	6,234	5,940
Rockfish	1,825	1,660	768	790
Herring	2,327	2,215	705	775
Capelin	5,149	4,965	1,430	1,860
Mackerel	1,438	1,640	1,671	1,635
Salmon	(73)	(153)	(62)	(116)
Squid	2,310	3,030	2,695	3,610
Crab	1,225	1,105	190	165
Shrimp	1,792	1,985	241	265
Predatory benthos	818	900	99	116
Infauna	24,219	33,125	2,838	3,450
Epifauna	20,947	25,570	1,687	2,900
Zooplankton	58,430		37,230	

and elasmobranchs and older populations of semidemersal fish (pollock, cod) exercise a higher predation pressure on the juveniles (and also the adults) of flatfishes in the natural state and suppressing therewith their biomasses. The production of finfish is in general somewhat lower in the natural state than in the fished state as the biomasses are somewhat older with consequently lower growth rates in the natural state.

Table 8 gives the maximum equilibrium biomasses in kg/km^2 in two shallow (continental shelf) areas (areas 1 and 4) and in two deep areas (areas 3 and 5). The concentration of biomasses is considerably greater in the continental shelf areas than over the deep water, with the exception of squids (and pollock in area 3). There are also differences in concentrations of individual species between different shallow areas--e.g. rockfish and Atka mackerel concentrations are considerably higher in area 4 than in area 1. Table 9 gives a summary of biomasses per unit area by larger ecological groups. The total finfish biomass over the continental shelf in the eastern Bering Sea is $36 \text{ t}/\text{km}^2$ and on the Aleutian shelf it is $48 \text{ t}/\text{km}^2$. Finfish biomass over the deep water in the Aleutian subregion is $12 \text{ t}/\text{km}^2$ and in the central Bering Sea $30 \text{ t}/\text{km}^2$ of which $20 \text{ t}/\text{km}^2$ is pollock.

The small quantities of demersal fish over deep water can be considered to consist of juveniles and of a small quantity of adults in deeper parts of the continental slope.

The open, narrow continental shelf of the Aleutian Chain is visited by oceanic squids. The deep water of the central Bering Sea seems to also contain high quantities of squids, which might be considered as seasonally migrating oceanic squids aggregating near their environmental boundary of distribution.

Table 8.--Maximum equilibrium biomasses in kg/km² in continental shelf areas (areas 1 and 4, See Figure 1) and over deep water (areas 3 and 5).

Species/ecological group designation	Eastern Bering Sea		Aleutian subregion	
	Area 1 (continental shelf)	Area 3 (deep water)	Area 4 (continental shelf)	Area 5 (deep water)
Halibut	724	172	726	68
Flathead sole	1,081	125	989	65
Yellowfin sole	2,088	288	1,782	125
Other flatfish	1,232	259	1,631	71
Cottids	5,720	677	6,515	333
Cod	1,628	742	1,499	258
Sablefish	204	74	213	20
Pollock	14,001	19,619	18,874	7,177
Rockfish	1,797	1,367	3,160	691
Herring	2,118	1,263	3,483	516
Capelin	4,404	3,448	5,829	1,433
Mackerel	1,325	2,326	3,060	1,599
Salmon	(20)	(20)	(65)	(70)
Squid	695	7,851	3,251	3,381
Crab	1,305	97	1,396	70
Shrimp	2,090	303	2,005	105
Predatory benthos	926	148	925	49
Infauna	28,824	900	21,657	553
Epifauna	26,296	892	21,577	365
Zooplankton	(30,000)	(40,000)	(40,000)	(30,000)

Table 9.--Total standing stocks in the eastern Bering Sea and in the Aleutian subregion (in tons/km²).
(Maximum equilibrium biomasses.)

Ecological group	Eastern Bering Sea		Aleutian subregion	
	continental shelf	off the shelf	continental shelf	off the shelf
Demersal	10.85	1.52	11.64	0.66
Semidemersal	17.53	21.80*	23.75	8.15
Pelagic	7.87	7.06	12.44	3.62
Total finfish	36.35	30.38	47.83	12.43
Squids	0.70	7.85	3.25	3.38
Benthos	56.05	1.94	43.23	0.97
Crabs, shrimp	3.40	0.40	3.41	0.18
Zooplankton	(30.0)	(40.0)	(40.0)	(30.0)

*--19.62 t/km² pollock

5. "NATURAL FLUCTUATIONS" OF THE BIOMASSES

It is known from empirical data and historical records that the biomasses of fish vary not only from year to year (caused by variations of year-class strengths as induced by a variety of causes), but also over long periods. Whereas the year-to-year fluctuations of biomasses are buffered by the presence of many year classes, especially in longer-lived species, the long-term fluctuations can have considerable magnitudes. Thus, before we can properly and fully evaluate the effects of fishery on the biomasses, we must know the causes, magnitudes, and periods of the natural fluctuations.

The present PROBUB 80-1 simulation model is as yet not fully adapted for the quantitative study of these fluctuations, but nevertheless gives some preliminary information on this subject. The fluctuations in the present model are somewhat dampened, thus we can obtain information on minimum rate of change only.

Examples of monthly changes of the biomasses of shorter-lived species--squids and capelin, are shown in Figure 4. Figures 5 and 6 give examples of annual changes of biomasses of a few species in the eastern Bering Sea and in the Aleutian subregion over 5 years, both with present fishery and in the natural state. The changes of the biomasses can be different in different regions, as these figures indicate.

A quantitative study of the natural fluctuations of biomasses as caused by various factors, has been initiated in NWAFC and will be reported in forthcoming reports.

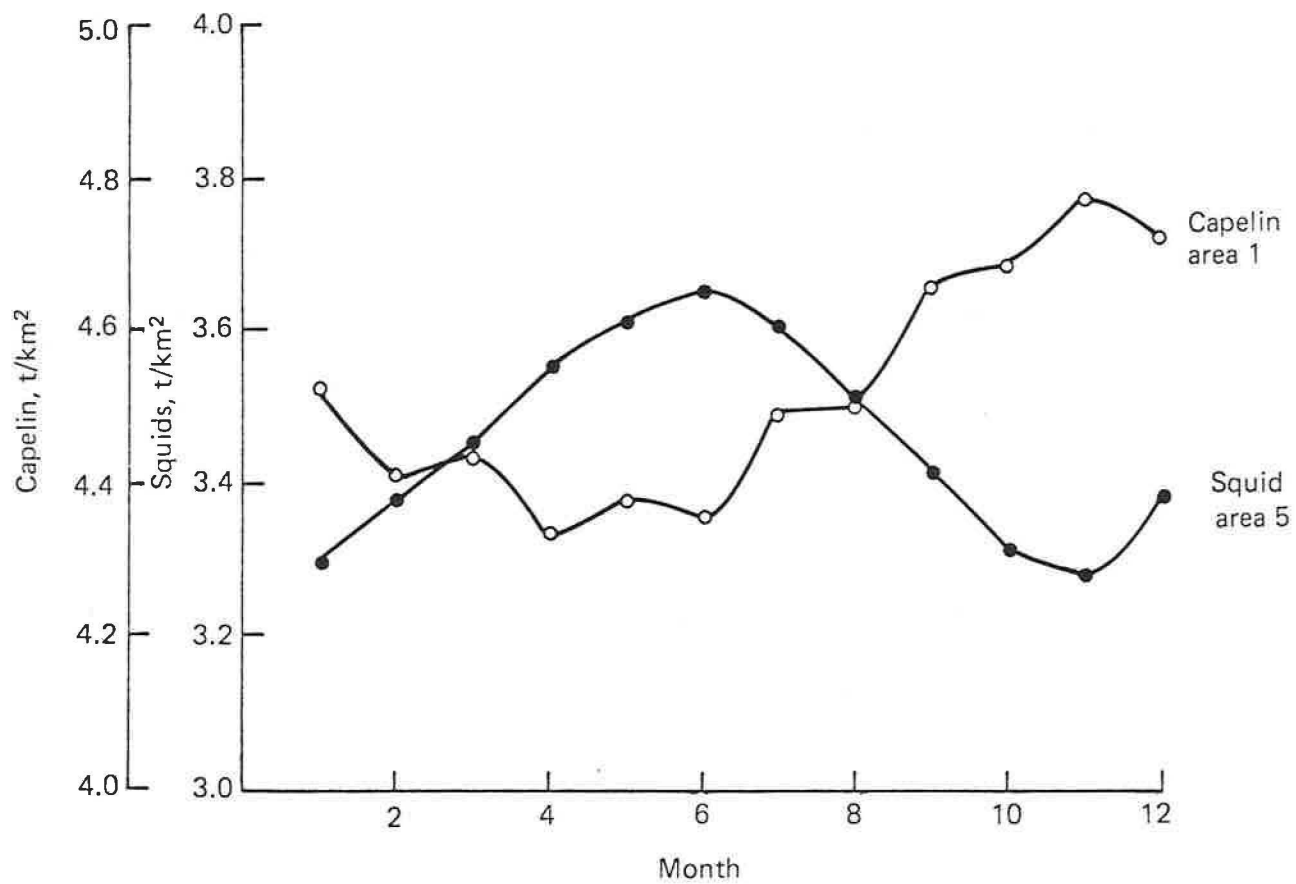


Figure 4.--Examples of monthly changes of the biomasses of capelin and other pelagic fish in area 1 and squid in area 5 (tons/km²).

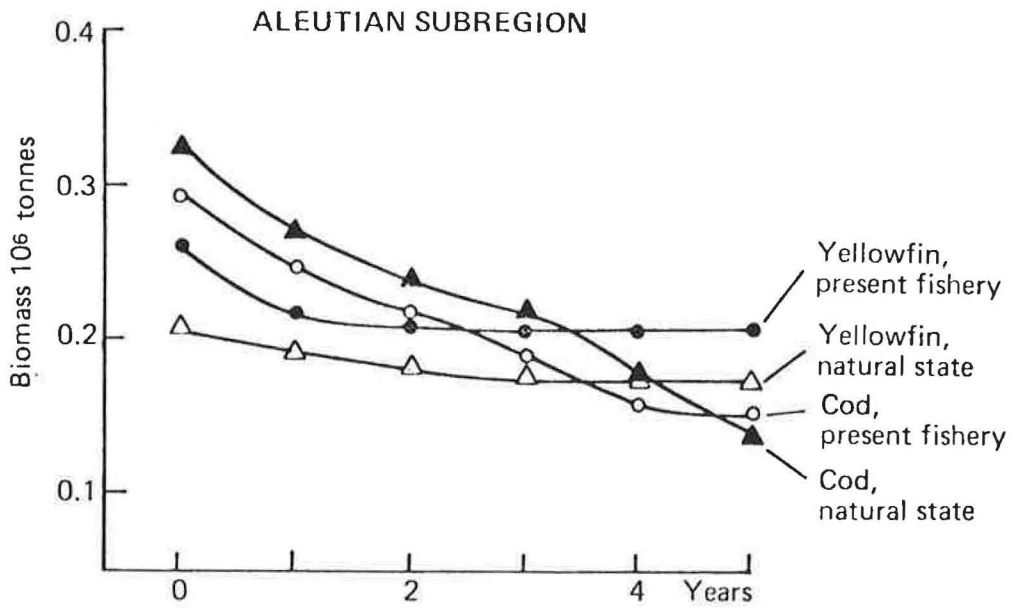
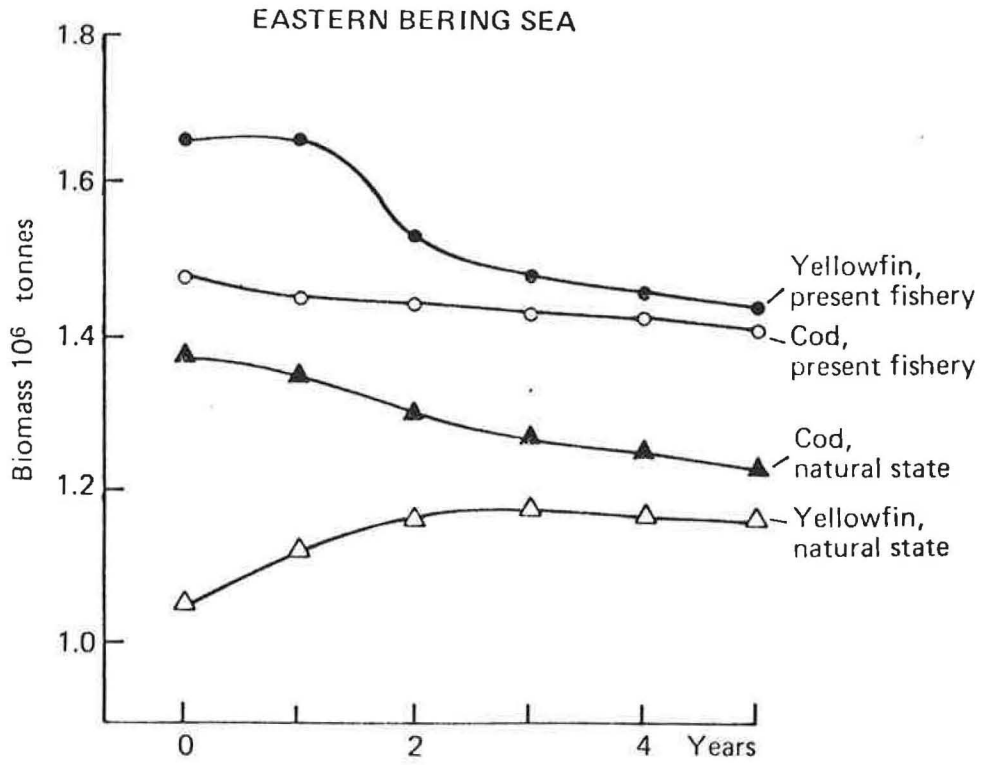


Figure 5.--Examples of long-term fluctuations of biomasses of yellowfin sole and cod in the eastern Bering Sea and in the Aleutian subregion with present fishery and in natural state.

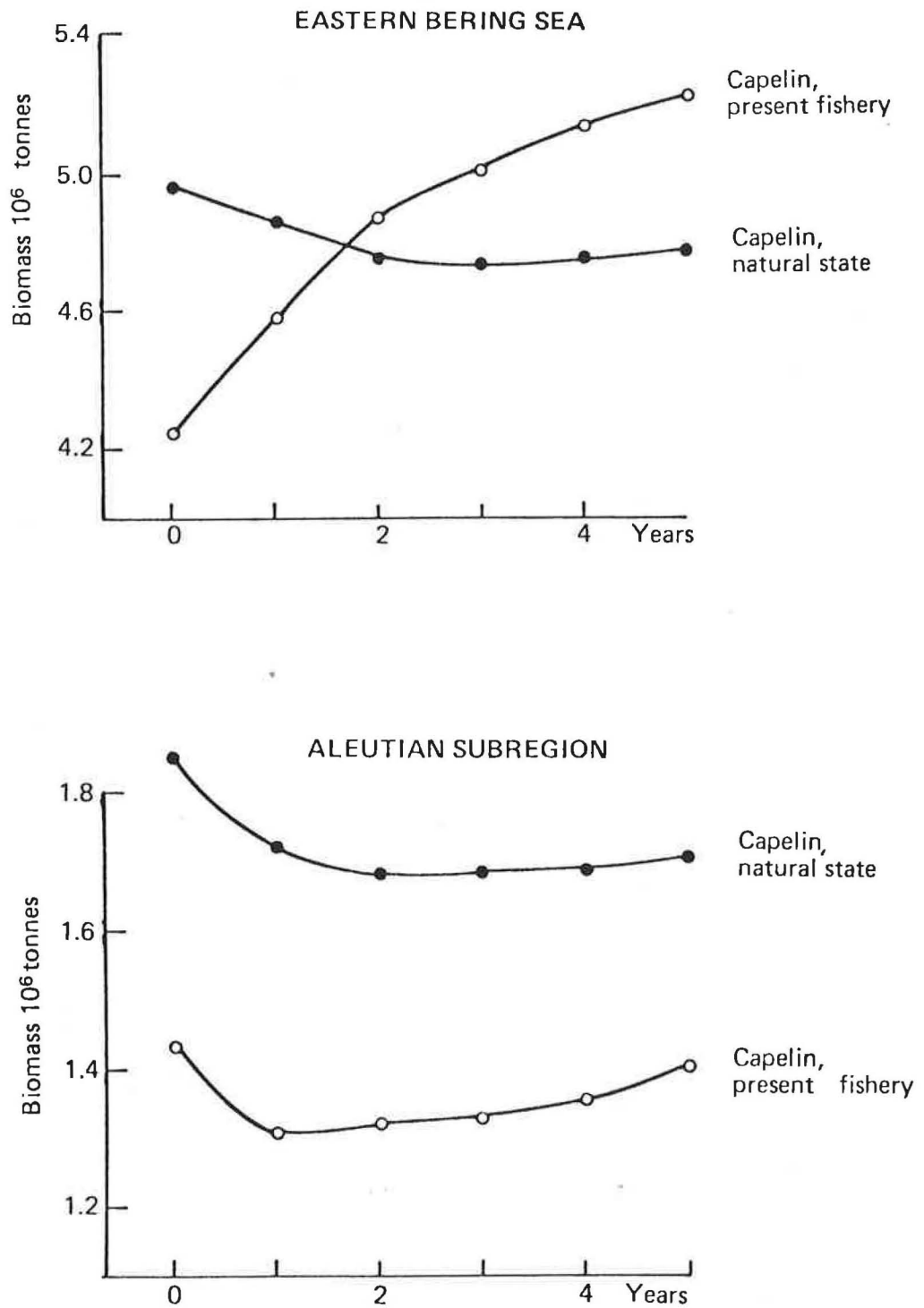


Figure 6.--Examples of long-term fluctuations of the biomasses of capelin and other pelagic fish in the eastern Bering Sea and in the Aleutian subregion with present fishery and in natural state.

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Note: NWAFC Processed Reports can be obtained from Northwest and Alaska Fisheries Center, 2725 Montlake Boulevard East, Seattle, WA 98112.

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