NORTHWEST & ALASKA FISHERIES CENTER PROCESSED REPORT

NUMERICAL EVALUATION OF MARINE BIOMASSES IN GULF OF ALASKA

(Evaluation of minimum sustainable biomasses of fisheries resources in the Gulf of Alaska using the Laevastu-Favorite Bulk Biomass Model)

by

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Resource Ecology Task
Resource Ecology and Fisheries Management Division

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ABSTRACT

The minimum sustainable biomasses of marine fisheries resources in the Gulf of Alaska are computed using a Bulk Biomass Model (BBM). The BBM method is compared to virtual population analysis and found to be more suitable for resource evaluation because it permits direct computation of the ecosystem internal consumption (grazing), which constitutes the greatest part of natural mortality. Results are presented in tabular and graphical form and compared with earlier exploratory fishery survey results. Consumption by mammals far exceeds the total commercial catch; consequently it is suggested that management of marine mammals should be an integral part of fisheries management.

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1. INTRODUCTION

The Bulk Biomass Model (BBM) devised at the Northwest and Alaska Fisheries Center (NWAFC) (Laevastu and Favorite 1977a) has been used previously to determine minimum sustainable biomasses of ecological groups off the California, Oregon, and Washington coasts and in the Bering Sea. This basically trophodynamic model has been revised and adapted to ascertain estimates of minimum standing stocks which can be sustained in the ecosystem, and turnover rates of marine ecological groups in coastal and offshore waters from British Columbia to the Alaskan Peninsula.

The classical fisheries production models are inappropriate for determining sustainable biomasses of fish because of complex trophic ecosystem interactions, and it is virtually impossible to predict production of an ecological group without knowing its relation to other organisms in the food chain. Food composition, efficiency of biomass transfer, and position of a particular fish group in the food web (if the food chain can be defined) are factors that affect not only the potential production of a particular fish group, but also the total abundance of fish in a particular area. Man's selective "cropping", which changes the relative abundance of species groups, increases the complexity of the marine ecosystem.

The BBM provides a method to quantify the basic consumption relations between fish and other animal groups in the Gulf of Alaska region and to estimate the respective, minimum, sustainable biomasses, given growth rates, fishing mortality, and mortality from diseases and old age of the various ecological groups in the system. "Minimum sustainable biomass" is defined as the biomass of a species or ecological groups which, with a given growth rate and computed ecosystem internal consumption, neither declines nor increases within a year in a defined region. As there can be a family of sustainable biomasses in an ecosystem the "minimum" level is considered directed by mammal and base species input. The effect of fish migrations on the minimum sustainable biomass computations is not included in the model, but this could be added. However, at the present time, results obtained from the BBM model are used as first-guess inputs to another larger model, DYNUMES, in which migrations are programmed.

2. METHOD

The assumption and logic of the model are basically unchanged from the previous BBM models (Laevastu and Favorite, 1976 and 1977a). The basic assumptions made in the computation of minimum sustainable biomasses for each ecological fish group are that a quasi-equilibrium biomass state is maintained throughout the year and no migration and/or advection into or out of the area occurs. Consequently it is assumed that the increase in biomass is equal to the removal. Removal is the sum of grazing, fishery, and mortality--where grazing represents the ecosystem internal consumption, fishery is the loss due to fishing removal, and mortality is merely the losses due to old age and disease (Figure 1). More explicit information on the computational formulas used in the model are given by Laevastu and Favorite (1977a).

2.1 Rationale for the method:

As catch data are most readily available to the fishery biologist these are often used to estimate population size. Gulland's (1965) method of virtual population analysis (VPA) estimates fishing mortality, F_i, and stock size, N_i, at successive ages, i, (i = 0, 1, 2,..n) using catch statistics, a previous estimate of natural mortality, M, and the fishing mortality of the oldest age group, F_n. The computational formulas for VPA are:

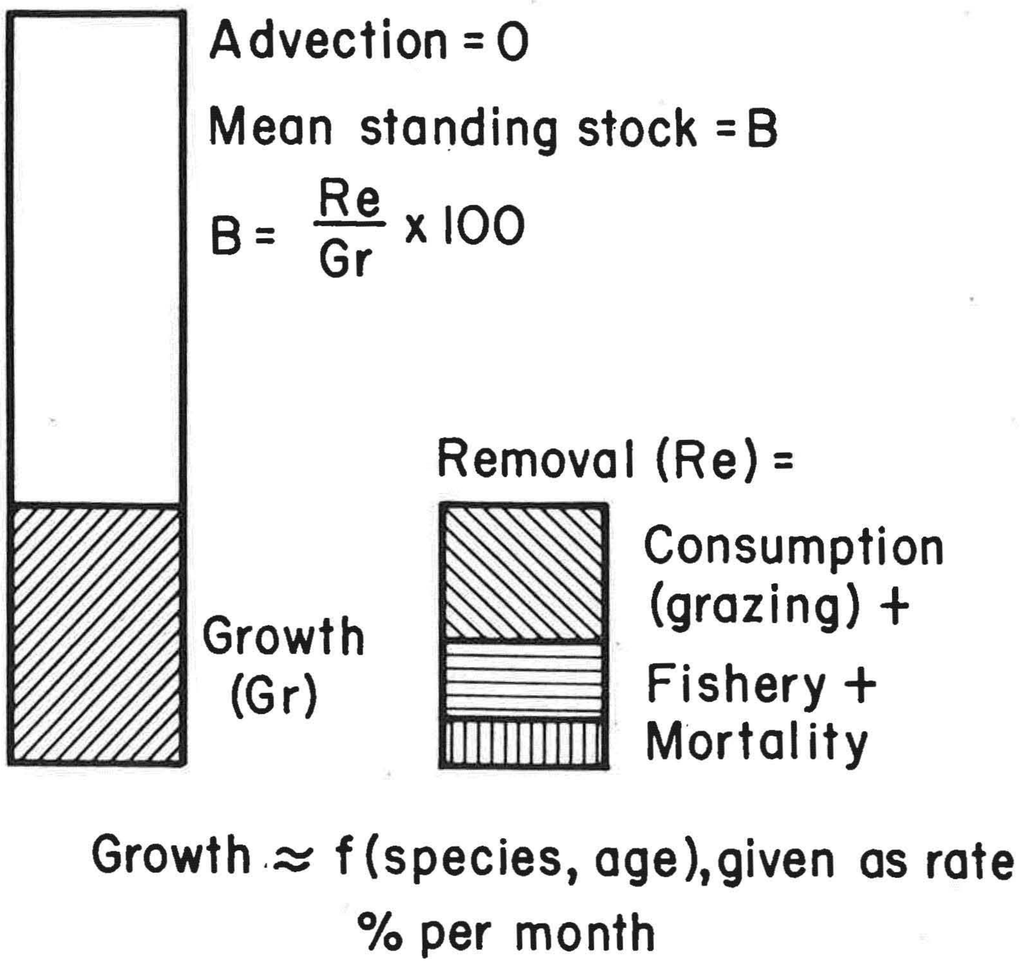

Figure 1,--Schematic presentation of quasi-equilibrium state of a standing stock as basis for computation of minimum sustainable biomass (B).

$$C_i = N_i \frac{F_i}{F_i+M} \left[1 - e^{-(F_i+M)}\right] \quad (1)$$

$$N_{i+1} = N_i\ e^{-(F_i+M)} \quad (2)$$

The process involves first obtaining N_n from (1) using the given estimates of F_n, M, and C_i (C_i is the catch of year class at the age i), and next solving (2) for N_{n-1}. Thus pairs of (F_i, N_i) are obtained from successive backcalculation through formulas (1) and (2). The cohort analysis of Pope (1971) is similar except with respect to computation.

As Beyer (1976) notes there are three serious sources of error in this method, the estimates M, F_n, and C_i: the backcalculation procedure tends to magnify further the error involved in the computation of each (F_i, N_i) especially if the "known" parameters are poorly estimated; natural mortality, M, is an estimate of many sources of mortality (i.e. predation, disease, old age); and, although the sources and magnitude of mortality may vary considerably in space and time, M is usually considered as a constant for a particular group of fish in most fisheries models.

The BBM separates natural mortality into two sources; the mortality due to old age and disease, and mortality from grazing. The mortality from old age and disease is usually quite small in an exploited population and can be estimated to be 1 to 2% per month, depending on the species. The largest component of mortality, grazing, is computed directly in the model from food composition and food requirement data, thus eliminating largely the great uncertainty in the estimation of M. The composition of food is constant in the BBM model and is ascertained as a mean composition from available literature. Food composition and food requirements are variable in space and time in the advanced DYNUMES III model (Laevastu and Favorite 1977c). Since grazing on a particular fish group is exercised by many predator species and the magnitude of grazing depends on the total biomass of these predators present and their grazing preference of the particular species, the model must consider the interactions between the consumption and growth of as many fish groups in an area as possible. Most other models do not recognize the dependence of natural mortality on interactions (i.e. through trophodynamics) with other fish groups. Consumption of fish by birds and mammals is also taken into consideration here as it is of considerable magnitude in the Gulf of Alaska area. Also included in the model are estimates of fishing mortality from catch statistics.

Model Formulation:

Monthly biomass balance formula:

$$B_{i,t} = B_{i,t-1} \, (2-e^{-g_{i,t}}) \, e^{-n} - C_{i,t-1} \qquad (3)$$

$$\text{where } g_{i,t} = g_{i,o} + g_{i,a} \cos(\alpha t - \mathcal{H}_{i,a}) \qquad (4)$$

Food requirements and food proportioning formulas:

$$F_{i,t} = B_{i,t-1} \, (2-e^{-g_t}) \, K_{i,g} + B_{i,t} \, K_{i,m} \qquad (5)$$

$$C_{i,j,t} = F_{i,t} \, \rho_{i,j}$$

$$C_{i,k,t} = F_{i,t} \, \rho_{i,k} \text{ -- etc.} \qquad (6)$$

$$C_{i,t} = C_{u,i,t} + C_{i,i,t} + \ldots C_{n,i,t} \qquad (7)$$

The symbols in the above equations are:

$B_{i,t}$ - minimum sustainable biomass (either total for the region or as kg/km^2) of ecological group i in month t.

$g_{i,t}$ - monthly bulk growth coefficient (approximately growth in % per month) (g_o is mean growth coefficient and g_a is the annual range of its change $\mathcal{H}$ is phase lag and α phase speed = 30^o per month).

$F_{i,t}$ - food requirement for growth and maintenance.

n - fishing mortality coefficient (approximate % per month).

$K_{i,g}$ - food coefficient for growth (e.g. 1:3, 3 kg of food biomass gives 1 kg of growth), for ecological group i.

$K_{i,m}$ - food coefficient for maintenance (in terms of body (biomass) weight per time step), for ecological group i.

$C_{i,t}$ - total amount of ecological group i consumed by other groups in unit time (month).

$\rho_{i,j}$ - proportion of ecological group j in the food of group i.

To initialize computations a first-guess biomass figure for each fish group in each "box" area is entered into the model; monthly amounts of mammals and birds in each computation area are also defined. All monthly biomasses and consumptions for a full year are then computed and corrections for the initial biomass estimates are made:

$$B_{i,corr} = B_{i,1} + (B_{i,1} - B_{i,12}) /12 \qquad (8)$$

where $B_{i,corr}$ is the corrected biomass of species i, $B_{i,1}$ is the initial guess for January and $B_{i,12}$ is the computed biomass for December. The iteration process is continued until the solution converges and the obtained biomasses are the computed minimum sustainable biomasses for the system. Results are only partially dependent on the initial guess input, thus, the BBM considers the growth of biomass and the multi-species interactions that may cause changes in biomass through trophodynamics. This is a definite advantage over single-species models which cannot explain or predict changes in natural mortality through time.

Although the theory behind the BBM is valid and produces reasonable results, the method does have some limitations. Although partially dependent on the initial biomass inputs, the results are even more dependent on the estimates of average food composition which have no spatial or temporal variation in this model. Such variation is, however, introduced into our more advanced DYNUMES model, as are migration and environmental influences which are not considered here. Model sensitivity studies, frequently applied to simple explicit single-species models, lose their meaning in the present model, as any study of the limits of input parameters is an extensive study of pertinent subject matter, and is better conducted with the DYNUMES model.

3. INPUT DATA

Computations have been made for the region from the northern tip of Vancouver Island to Unimak Pass, and from the coast to 200 nautical miles offshore (Figure 2). Five areas are defined within this region.

1. North of Vancouver Island to the Dixon Entrance.
2. Dixon entrance to Cape Spencer.
3. Gulf of Alaska from Cape Spencer to the tip of the Kenai Peninsula.
4. Gulf of Alaska from the Kenai Peninsula to Chirikof Island.
5. The Alaskan Peninsula from Chirikof Island to Unimak Pass.

Each area was divided into 3 subareas, from the coast to 200 m depth; from 200 m to 1000 m depth; and from 1000 m to 200 nautical miles offshore (Table 1).

The inclusion of mammals into the model is essential for the evaluation of marine resources because in some regions they can be greater consumers of fish than man (Laevastu and Favorite 1976). Most marine mammals in the Gulf of Alaska are migratory, moving to feeding grounds mainly in the summer and migrating south or offshore in other seasons. The inputs for marine mammals reflect this monthly variation in distribution except for the few species that are stationary (Tables 2-8). Estimation of mammal populations is controversial at the present time and because of this uncertainty we have tried to make conservative estimates of marine mammals. Some species of mammals have been grouped together according to feeding habits and composition of food taking into consideration mean sizes of the animals involved.

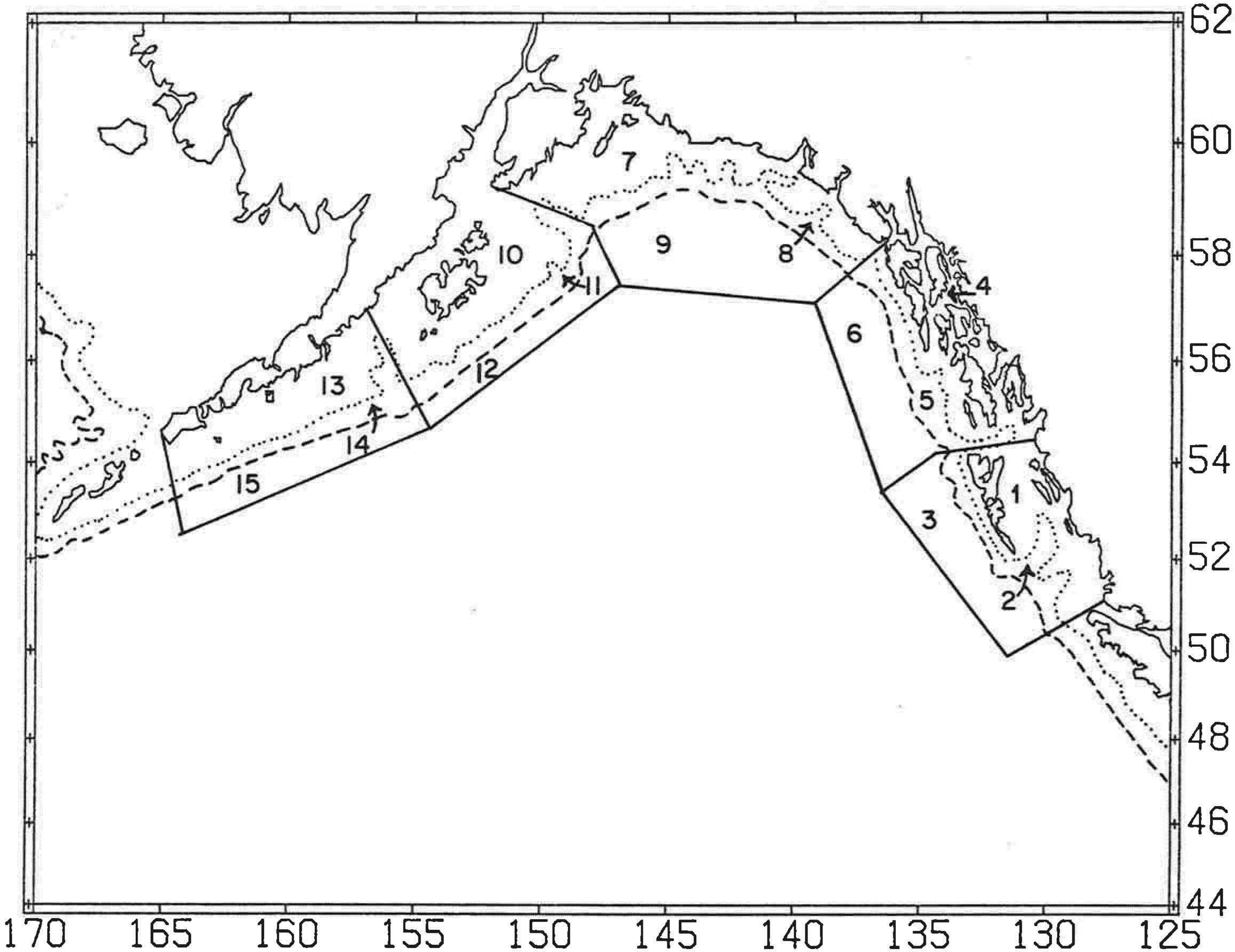

Figure 2.--The region covered by the model and the computational subareas.

Consumption by marine birds has also been included in the model. The distribution of marine birds is also of a seasonal nature and is dependent on distance from shore. The bird populations are estimated from various sources and are in numbers/km^2 (Table 9), and the mean weights of mammals and birds which allows conversion from numbers to biomass as required for trophodynamic computations is presented (Table 10).

The food composition of birds and marine mammals (Table 11) has also been extracted from various sources. There is a great variation in food composition with space and time, but it is not computationally possible to take this variation into consideration in this model as data on this subject are very fragmented and uncertain as yet.

The growth and mortality coefficients used in the model are shown in Table 12. The growth coefficient for a given biomass is very much age dependent as discussed by Laevastu and Favorite (1977b). Growth is also dependent on time of year, food availability, and temperature which, although they are not taken into consideration in this model, are considered in our DYNUMES model. To compensate for the lack of spatial and temporal variation in the growth coefficient, it has been made a sinusoidal function of time throughout the year (see Equation 4).

The customary mortality coefficient, usually denoted as Z, has been divided into three parts. The largest component, grazing, is computed directly in the model. The fishing mortality coefficient, F, is adjusted to reflect the present or potential fishery on a species. Fishing mortality can be changed in different model runs but the numbers used for the present report are indicated (Table 12). The mortality due to old age and diseases, denoted here as natural mortality, is relatively small in most species groups. Estimates for natural mortality are also given. In some cases natural and fishing mortalities have been used as a single coefficient which should not affect the results.

Table 1

Computation Areas

Area No.	Geographical limits	Depth range	Area Square Mi.	Area Square km
1	North of Vancouver	0-200m	16,939	58,100
2	Island to	200-1000m	5,889	20,200
3	Dixon Entrance	1000m-200 n. mil.	50,585	173,500
		Total	73,413	251,800
4	Dixon Entrance to	0-200m	14,986	51,400
5	Cape Spencer	200-1000m	6,677	22,900
6		1000m-200 n. mil.	40,788	139,900
		Total	62,451	214,200
7	Cape Spencer to	0-200m	25,423	87,200
8	Kenai Peninsula	200-1000m	6,618	22,700
9		1000m-200 n. mil.	37,610	129,000
		Total	69,651	238,900
10	Kenai Peninsula to	0-200m	22,799	78,200
11	Chirikof Island	200-1000m	8,397	28,800
12		1000m-200 n. mil.	21,954	75,300
		Total	53,150	182,300
13	Chirikof Island to	0-200m	20,758	71,200
14	Unimak Pass	200-1000m	6,851	23,500
15		1000m-200 n. mil.	32,333	110,900
		Total	59,942	205,600
		Total all areas	318,607	1,092,800

Table 2

Number of fur seals (in thousands) in computation subareas

MONTH	Subareas 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 - January	20	2	1	30	4	1	10	4	1	40	5	1	50	3	1
2 - February	20	2	1	30	4	1	10	4	1	40	5	1	50	3	1
3 - March	22	2.2	1.2	32	5	2.2	12	5	1	40	5	1	50	3	1
4 - April	25	3	2	39	6	3	16	6	2	45	6	1	54	4	1.3
5 - May	20	1.5	1	25	3	1.8	12	3	1.5	50	7	2	62	6	2
6 - June	8	0.7	0.3	14	2	0.9	9	2	0.7	12	3	0.8	20	3	1.2
7 - July	6	0.6	0.1	8	1.5	0.7	5	1	0.6	8	1.5	0.7	12	2	0.8
8 - August	4	0.5	0.0	6	1	0.5	3	1	0.5	4	1	0.5	8	1	0.5
9 - September	12	1	0.3	10	2	0.8	6	1	0.8	12	1.9	0.9	14	2	0.8
10 - October	16	2	0.5	15	2	1	8	1	0.9	18	2.1	0.9	18	2	1
11 - November	20	3	1	28	3	1	10	3	1.2	40	3	1	48	2	1.1
12 - December	24	3	2	32	5	1.4	12	5	1.3	44	6	1	56	4	1.3

Table 3

Number of sea lions (in thousands) in computation subareas

Subareas

MONTH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 - January	0.2	0	0	0.4	0	0	0.1	0	0	0.8	0	0	1.0	0	0
2 - February	0.2	0	0	0.4	0	0	0.1	0	0	0.8	0	0	1.0	0	0
3 - March	0.2	0	0	0.4	0	0	0.1	0	0	0.8	0	0	1.0	0	0
4 - April	0.2	0	0	0.4	0	0	0.1	0	0	0.8	0	0	1.0	0	0
5 - May	1	0.2	0.1	1	0.3	0.2	0.5	0.1	0	3	0.4	0.1	4	0.3	0.1
6 - June	5	0.5	0.2	6	1	0.5	2	0.3	0.2	11	1.2	0.4	14	1	0.4
7 - July	4	0.4	0.1	4	0.8	0.3	1.2	0.2	0.1	7	0.8	0.3	8	0.6	0.3
8 - August	0.2	0	0	0.4	0	0	0.1	0	0	0.8	0	0	1.0	0	0
9 - September	0.2	0	0	0.4	0	0	0.1	0	0	0.8	0	0	1.0	0	0
10 - October	1	0.2	0.1	1	0.3	0.2	0.5	0.1	0	3	0.4	0.1	4	0.3	0.1
11 - November	5	0.5	0.2	6	1	0.5	2	0.3	0.2	11	1.2	0.4	14	1	0.4
12 - December	4	0.4	0.1	4	0.8	0.3	1.2	0.2	0.1	7	0.8	0.3	8	0.6	0.3

Table 4

Estimated number of harbor seals and ringed/ribbon seals (in thousands) in computation subareas.

Area	Number	Area	Number
1	4	9	0
2	0.8	10	5
3	0	11	0
4	6	12	0
5	0.9	13	8
6	0	14	0
7	3	15	0
8	0.5		

Table 5

Number of sperm whales in computation subareas

Subareas

MONTH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 - January	70	20	250	60	70	250	70	30	300	80	10	10	90	5	5
2 - February	70	20	250	60	70	250	70	30	300	80	10	10	90	5	5
3 - March	70	20	250	60	70	250	70	30	300	80	10	10	90	5	5
4 - April	70	20	250	60	70	250	70	30	300	80	10	10	90	5	5
5 - May	70	25	250	60	70	250	70	30	300	80	10	10	90	5	5
6 - June	80	30	350	80	85	350	85	45	350	100	15	15	120	7	10
7 - July	120	35	400	100	110	400	110	70	420	125	18	18	160	12	15
8 - August	150	40	500	120	120	450	120	80	500	150	20	20	180	15	20
9 - September	120	35	450	100	110	375	110	70	420	135	18	18	170	12	15
10 - October	90	30	375	85	90	320	90	50	350	110	15	15	150	10	10
11 - November	80	25	300	70	80	280	80	40	320	90	12	12	110	7	7
12 - December	70	20	250	60	70	250	70	30	300	80	10	10	90	5	5

Table 6

Number of toothed whales* in computation subareas

MONTH	Subareas 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 - January	120	100	400	15	100	450	200	10	220	20	30	40	30	18	30
2 - February	120	100	400	15	100	450	200	10	220	20	30	40	30	18	30
3 - March	150	100	400	15	100	450	200	10	220	20	30	40	30	18	30
4 - April	200	120	425	20	100	450	220	15	220	20	30	40	30	18	30
5 - May	250	140	450	25	110	500	250	25	280	25	35	45	35	20	35
6 - June	300	160	475	30	110	525	300	35	320	30	40	55	40	22	40
7 - July	350	170	550	40	115	575	330	40	375	35	45	65	45	23	45
8 - August	400	180	600	50	120	600	350	50	400	40	55	70	50	25	50
9 - September	350	160	550	40	110	550	330	40	350	38	45	60	42	23	42
10 - October	300	140	500	30	100	500	300	30	300	32	39	52	38	22	37
11 - November	280	130	480	25	100	480	250	25	280	25	35	48	35	22	34
12 - December	220	120	460	20	100	450	420	20	260	22	32	45	32	20	32

* except sperm whales

Table 7

Number of baleen whales in computation subareas

Subareas

MONTH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 - January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2 - February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 - March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 - April	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 - May	10	5	15	2	4	15	8	2	12	1	2	2	2	1	2
6 - June	20	10	22	4	7	22	16	4	24	2	2	4	4	1	2
7 - July	30	14	40	6	12	40	28	6	35	4	3	7	6	1	6
8 - August	60	22	80	8	18	80	55	8	65	6	8	11	8	2	8
9 - September	80	30	120	10	25	120	70	10	100	8	12	15	10	5	10
10 - October	10	5	15	2	4	15	8	2	12	1	2	2	2	1	2
11 - November	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12 - December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 8

Estimated number of porpoises and dolphins (including beluga) in computation subareas.

Area	Number	Area	Number
1	500	9	300
2	150	10	400
3	350	11	120
4	450	12	80
5	200	13	500
6	300	14	120
7	650	15	80
8	150		

Table 9

Number of marine birds per km^2 in computation subareas

MONTH	Subareas 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 - January	10	3	0.1	10	4	0.1	8	2	0.1	10	2	0.2	10	2	0.2
2 - February	10	3	0.1	10	4	0.1	8	2	0.1	10	2	0.2	10	2	0.2
3 - March	10	3	0.1	10	4	0.1	8	2	0.1	10	2	0.2	10	2	0.2
4 - April	10	3	0.1	10	4	0.1	8	2	0.1	10	2	0.2	10	2	0.2
5 - May	22	4	0.2	20	6	0.2	14	4	0.2	20	3	0.3	12	3	0.2
6 - June	35	5	0.2	35	8	0.2	20	5	0.2	30	5	0.4	20	4	0.3
7 - July	35	5	0.3	35	9	0.3	20	6	0.3	30	6	0.5	20	5	0.6
8 - August	35	6	0.3	35	9	0.4	20	7	0.4	30	7	0.5	20	6	0.6
9 - September	35	6	0.3	35	9	0.3	20	7	0.3	30	7	0.5	20	6	0.6
10 - October	28	4	0.2	22	6	0.2	14	4	0.2	20	3	0.3	16	3	0.2
11 - November	14	3	0.1	12	4	0.1	10	2	0.1	14	2	0.2	12	2	0.2
12 - December	10	3	0.1	10	4	0.1	8	2	0.1	10	2	0.2	10	2	0.2

Table 10

Mean weights of mammals and birds

Fur seals	55 kg
Sea lions	250 kg
*Harbor seals and ringed/ribbon seals	95 kg
Baleen whales	40,000 kg
**Toothed whales	10,000 kg
Marine birds	0.4 kg
Porpoises, dolphins	100 kg

* Mean weight of the "mixture" of seals

** Except sperm = 30,000 kg (accounted separately)

Table 11

Composition of food of mammals and birds

Fur seals

40% pollock
18% rockfish
4% other pelagic fish
5% herring
11% squids
1% salmon
18% other gadids
3% others

Baleen whales

70% euphausids
14% copepods
9% squids
3% herring
4% other pelagic fish

Marine birds

35% herring
5% flatfish
5% other gadids
5% pollock
5% rockfish
10% others
20% euphausids
10% squids
5% benthos

Harbor and ringed/ribbon seals

70% benthos
10% pollock
5% flatfish
5% crustaceans
10% other demersal fish

Sea lions

60% pollock
20% rockfish
10% other pelagic fish
4% salmon
6% others

Toothed whales, porpoises, dolphins

20% squids
20% herring
24% other pelagic fish
4% salmon
22% pollock
2% other gadids
8% others

Table 12

Growth and mortality coefficients

	Growth*	Total Mortality**	Natural Mortalities**	Fishing Mortalities**
Squids	0.138 to 0.258	0.045	(0.045)	
Herring	0.115 to 0.228	0.03	0.02	0.01
Salmon	0.04 to 0.08	0.036	0.006	0.03
Other pelagic fish	0.115 to 0.288	0.035	0.02	0.015
Pollock	0.075 to 0.120	0.035	0.01	0.015
Other gadids	0.065 to 0.145	0.025	0.01	0.015
Rockfish	0.065 to 0.115	0.035	0.02	0.015
Flatfish	0.065 to 0.105	0.035	0.02	0.015
Other demersal fish	0.06 to 0.12	0.02	0.015	0.005
Benthos ("fish food" benthos)	0.10	0.035	(0.035)	
Crustaceans	0.128	0.03	(0.03)	

*Growth and mortality coefficients are in % of biomass per month. Growth coefficient was made a harmonic function of time: minimum and maximum values are given in this table.

**Total mortality is a sum of fishing mortality and natural mortality (of old age and diseases); it was used in most computations. However, in some computations the natural and fishing mortalities were computed separately.

To compute the amount of food consumed by a particular ecological group the food requirements for growth and maintenance must be known. Sometimes it is possible to separate the two but, in other cases, a single general food coefficient is used. The food requirements for ecological groups in the model are given (Table 13). Again, these are conservative values because the purpose here is to compute minimum sustainable biomasses. Composition of food for plankton and fish is also given (Table 14).

4. RESULTS

4.1 Minimum sustainable biomasses and turnover rates of marine ecological groups.

The BBM estimates for minimum sustainable biomass, ecosystem internal consumption (grazing), and the calculated turnover rates are given for each of the respective subareas (Tables 15-19) and summarized (Figures 3-11). To allow comparisons between areas of different sizes, biomass in tons/km^2 is also computed (Table 20). The biomass in terms of tons/km^2 for total finfish decreases outwards from the coast. Proceeding northward from the southernmost region, the biomass shows a slight increase up to the head of the Gulf of Alaska (subareas 7-9) and decreases thereafter to the westward (subareas 10-15).

Turnover rate trends with depth and distance from coast are compared (Table 21). For most ecological groups, turnover rate seems to increase with depth. High turnover rates may indicate that starvation may be a common occurrence especially in open waters. The total minimum sustainable biomasses and turnover rates for each ecological group (Table 22) indicate that, with the exception of herring, turnover rates in pelagic groups are generally higher than in the demersal communities. The group "other demersal fish" exhibits the highest turnover rate and an explanation for this phenomenon is not available at present. Explaining trends in turnover rates is a difficult task as the

Table 13

Food consumption (and/or requirements)

A. Fish, plankton and benthos

Squids	1:3 for growth only
Salmon	1:2 for growth + 0.9% body weight daily for maintenance
Herring and other pelagic fish	1:2 for growth + 0.9% body weight daily for maintenance
Pollock	0.9% body weight daily
Other gadids	0.9% body weight daily
Rockfish	0.7% body weight daily
Flatfish	0.7% body weight daily
Other demersal fish	0.9% body weight daily
Benthos	1% body weight daily (phytoplankton)
Crustaceans	1% body weight daily
Zooplankton	1.5% body weight daily

B. Mammals and birds

Fur seal, sea lion and harbor/ribbon seals	5% body weight daily
Baleen whales, toothed whales, porpoises, dolphins	4% body weight daily
Marine birds	12% body weight daily

Table 14

Composition of food of plankton and fish

Zooplankton

100% phytoplankton

Squids

20% copepods
30% euphausids
25% herring
25% other pelagic fish

Other pelagic fish

66% copepods
16% euphausids
10% phytoplankton
8% other pelagic fish

Pollock

6% herring
0.5% salmon
10% squids
5% other pelagic fish
50% euphausids
3% flatfish
6.5% rockfish
9% benthos
3% pollock
2% other demersal fish
3% crustaceans
2% other gadids

Flatfish

58% benthos
17% other demersal fish
4% flatfish
4% rockfish
4% pollock
9% euphausids
1.5% herring
2.5% crustaceans

Other demersal fish

37% benthos
22% euphausids
12% copepods
13% flatfish
6% other gadids
4.5% pollock
3.5% other pelagic fish
2% herring

Herring

71% copepods
12% euphausids
15% phytoplankton
2% other pelagic fish

Salmon

25% herring
35% other pelagic fish
15% squids
15% euphausids
10% pollock

Rockfish

2.5% herring
4.5% crustaceans
2% other pelagic fish
15% euphausids
9% squids
35% benthos
20% other demersal fish
3% rockfish
3% flatfish
3% pollock
3% other gadids

Crustaceans

30% benthos
5% flatfish
5% rockfish
19% euphausids
6% crustaceans
10% copepods
24% phytoplankton
1% other gadids

Other gadids

28% benthos
20% euphausids
14% copepods
10% other demersal fish
9% pollock
8% other pelagic fish
4% herring
7% flatfish

Table 15

Minimum sustainable biomass, ecosystem internal consumption, and turnover rates of ecological groups in the Gulf of Alaska, 10^3 metric tons.

N. Vancouver Island to Dixon Entrance

Ecological group	1. 0-200 m			2. 200-1000 m			3. 1000 m - 200 n. miles		
	Mean biomass	Annual consumption	Annual turnover rate	Mean biomass	Annual consumption	Annual turnover rate	Mean biomass	Annual consumption	Annual turnover rate
Squid	83.8	81.4	0.97	31.3	26.1	0.83	93.4	109.7	1.17
Herring	337.9	175.2	0.52	77.3	60.0	0.78	170.9	220.2	1.29
Other pelagic fish	224.8	315.6	1.40	70.6	104.1	1.47	311.9	402.4	1.29
Pollock	128.6	93.2	0.72	38.3	31.3	0.82	126.0	123.1	0.98
Rockfish	74.8	88.9	1.19	24.8	26.8	1.08	108.6	87.9	0.81
Flatfish	225.4	104.2	0.46	67.5	38.9	0.58	161.9	152.3	0.94
Other gadids	33.6	37.2	1.11	15.5	13.2	0.85	62.6	57.9	0.92
Other demersal fish	108.1	156.9	1.45	41.0	49.3	1.20	160.8	143.4	0.89
Crustaceans	111.4	58.8	0.53	38.9	19.8	0.51	157.5	77.2	0.49
Benthos	1,059.7	720.3	0.68	303.6	243.4	0.80	662.1	816.9	1.23
Total finfish	1,133.2	971.2	0.86	335.0	323.6	0.97	1,102.7	1,187.2	1.08

Table 16

Minimum sustainable biomass, ecosystem internal consumption, and turnover rates of ecological groups in the Gulf of Alaska, 10^3 metric tons.

Dixon Entrance to Cape Spencer

Ecological group	4. 0-200 m			5. 200-1000 m			6. 1000 m - 200 n. miles		
	Mean biomass	Annual consumption	Annual turnover rate	Mean biomass	Annual consumption	Annual turnover rate	Mean biomass	Annual consumption	Annual turnover rate
Squid	64.6	73.3	1.13	35.2	35.3	1.00	70.3	100.6	1.43
Herring	305.3	146.4	0.48	76.8	75.6	0.98	142.1	192.3	1.35
Other pelagic fish	194.5	267.3	1.37	91.8	130.1	1.42	257.3	343.6	1.34
Pollock	124.1	84.6	0.68	48.1	42.5	0.88	118.9	111.3	0.94
Rockfish	76.9	85.2	1.11	33.7	33.1	0.98	80.4	69.5	0.86
Flatfish	208.4	95.9	0.46	80.9	48.6	0.60	126.6	115.6	0.91
Other gadids	32.6	35.3	1.08	20.5	17.2	0.84	59.9	43.8	0.73
Other demersal fish	99.7	151.2	1.52	51.6	61.8	1.20	118.1	116.2	0.98
Crustaceans	99.9	55.4	0.55	48.1	24.7	0.51	110.1	57.3	0.52
Benthos	1,058.3	671.1	0.63	332.2	300.6	0.90	442.3	619.3	1.40
Total finfish	1,041.5	865.9	0.83	403.4	408.9	1.01	903.3	992.3	1.10

Table 17

Minimum sustainable biomass, ecosystem internal consumption, and turnover rates of ecological groups in the Gulf of Alaska, 10^3 metric tons.

Cape Spencer to Kenai Peninsula

Ecological group	7. 0-200 m Mean biomass	Annual consumption	Annual turnover rate	8. 200-1000 m Mean biomass	Annual consumption	Annual turnover rate	9. 1000 m - 200 n. miles Mean biomass	Annual consumption	Annual turnover rate
Squid	156.3	129.5	0.83	30.8	29.7	0.96	52.8	86.6	1.64
Herring	536.8	284.2	0.53	71.2	62.1	0.87	120.6	156.7	1.30
Other pelagic fish	304.1	477.4	1.57	80.2	108.2	1.35	222.2	284.3	1.28
Pollock	218.9	131.8	0.60	44.4	33.3	0.75	91.1	87.9	0.96
Rockfish	139.2	158.6	1.14	36.4	33.6	0.92	71.6	58.1	0.81
Flatfish	401.8	181.7	0.45	87.6	42.0	0.48	99.6	75.7	0.76
Other gadids	51.5	59.3	1.15	17.1	13.7	0.80	42.6	27.7	0.65
Other demersal fish	181.0	282.2	1.56	42.8	68.1	1.59	65.4	98.4	1.50
Crustaceans	216.5	112.2	0.52	44.6	24.7	0.55	96.2	49.5	0.51
Benthos	1,602.6	1,294.5	0.81	317.0	296.1	0.93	357.9	467.1	1.31
Total finfish	1,833.3	1,575.2	0.86	379.7	361.0	0.95	713.1	788.8	1.11

Table 18

Minimum sustainable biomass, ecosystem internal consumption, and turnover rates of ecological groups in the Gulf of Alaska, 10^3 metric tons.

Kenai Peninsula to Chirikof Island

Ecological group	10. 0-200 m			11. 200-1000 m			12. 1000 m - 200 n. miles		
	Mean biomass	Annual consumption	Annual turnover rate	Mean biomass	Annual consumption	Annual turnover rate	Mean biomass	Annual consumption	Annual turnover rate
Squid	95.1	122.1	1.28	33.6	33.2	0.99	23.7	33.4	1.41
Herring	335.3	226.5	0.68	63.0	66.0	1.05	52.9	55.7	1.05
Other pelagic fish	305.7	398.5	1.30	65.0	100.8	1.55	80.3	99.6	1.24
Pollock	212.5	123.3	0.58	52.4	34.0	0.65	44.3	27.4	0.62
Rockfish	127.8	151.5	1.18	45.5	41.1	0.90	52.0	32.4	0.62
Flatfish	291.0	157.7	0.54	100.8	47.2	0.47	54.9	39.3	0.72
Other gadids	48.8	56.9	1.17	15.2	15.7	1.03	18.0	14.5	0.81
Other demersal fish	139.9	215.4	1.54	47.4	78.7	1.66	37.5	61.8	1.65
Crustaceans	218.3	107.8	0.49	54.2	30.3	0.56	45.9	27.3	0.59
Benthos	1,466.2	1,060.2	0.73	385.8	341.5	0.89	199.9	255.9	1.28
Total finfish	1,461.0	1,329.8	0.91	389.3	383.5	0.98	339.9	330.7	0.97

Table 19

Minimum sustainable biomass, ecosystem internal consumption, and turnover rates of ecological groups in the Gulf of Alaska, 10^3 metric tons.

Chirikof Island to Unimak Pass

	13. 0-200 m			14. 200-1000 m			15. 1000 m - 200 n. miles		
Ecological group	Mean biomass	Annual consumption	Annual turnover rate	Mean biomass	Annual consumption	Annual turnover rate	Mean biomass	Annual consumption	Annual turnover rate
Squid	85.1	110.7	1.30	27.8	27.7	1.00	34.1	46.9	1.38
Herring	200.2	206.7	1.03	43.0	54.5	1.27	76.5	77.8	1.02
Other pelagic fish	286.3	352.5	1.23	54.2	82.4	1.52	116.5	141.2	1.21
Pollock	195.0	126.5	0.65	44.5	26.9	0.60	64.3	37.8	0.59
Rockfish	117.1	154.4	1.32	37.7	34.6	0.92	76.6	47.6	0.62
Flatfish	325.4	157.4	0.48	79.0	38.9	0.49	80.9	57.9	0.72
Other gadids	38.8	54.7	1.41	12.6	12.9	1.02	26.5	21.1	0.80
Other demersal fish	139.7	221.0	1.58	37.6	62.6	1.66	55.3	91.2	1.65
Crustaceans	233.2	109.7	0.47	47.6	26.0	0.55	67.7	40.3	0.60
Benthos	1,261.9	1,115.4	0.88	313.9	277.3	0.88	294.6	377.2	1.28
Total finfish	1,302.5	1,273.2	0.98	308.6	312.8	1.01	496.6	474.6	0.96

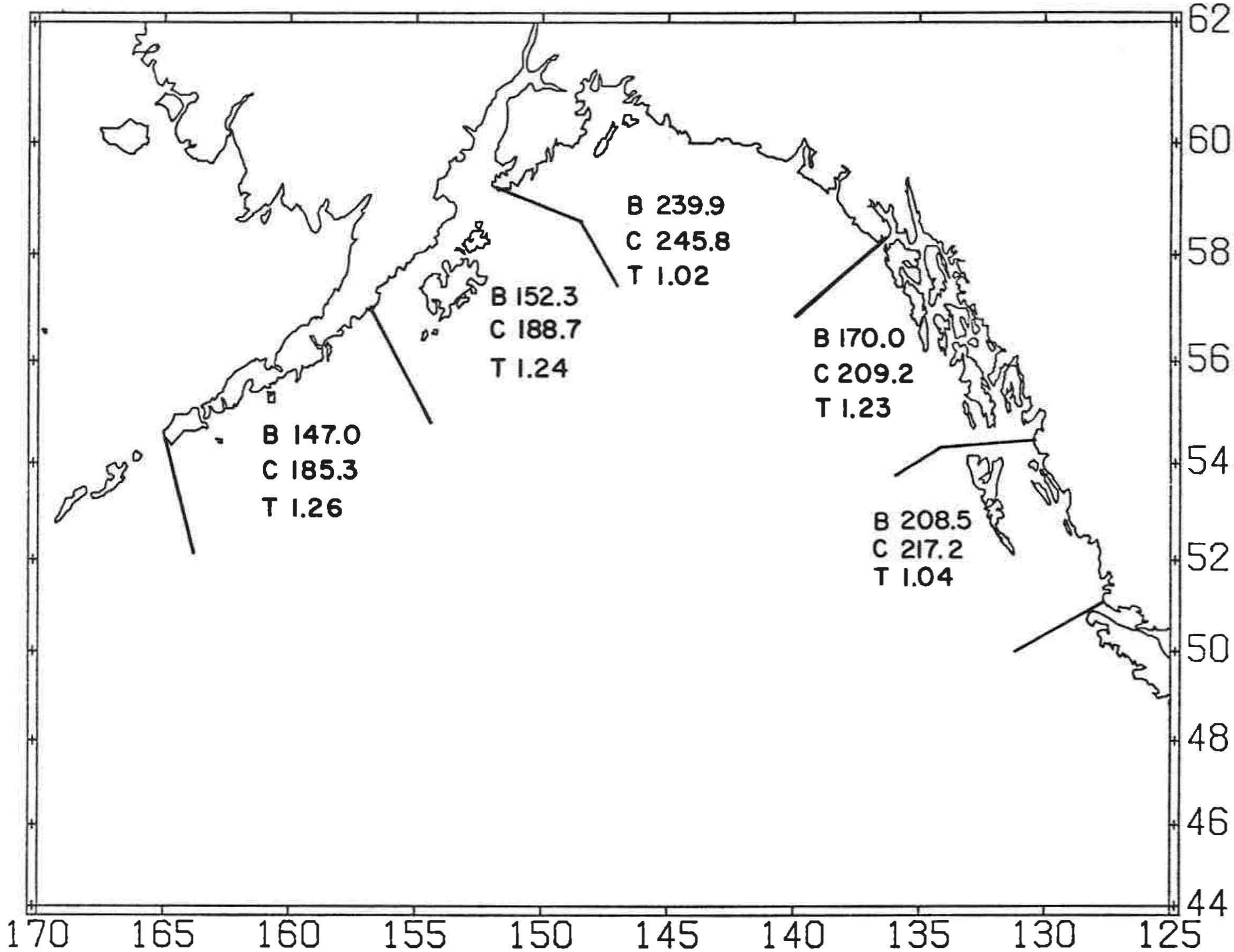

Figure 3.--Minimum sustainable biomass (B), ecosystem internal consumption (C), and annual turnover (T) of squid (10^3 metric tons).

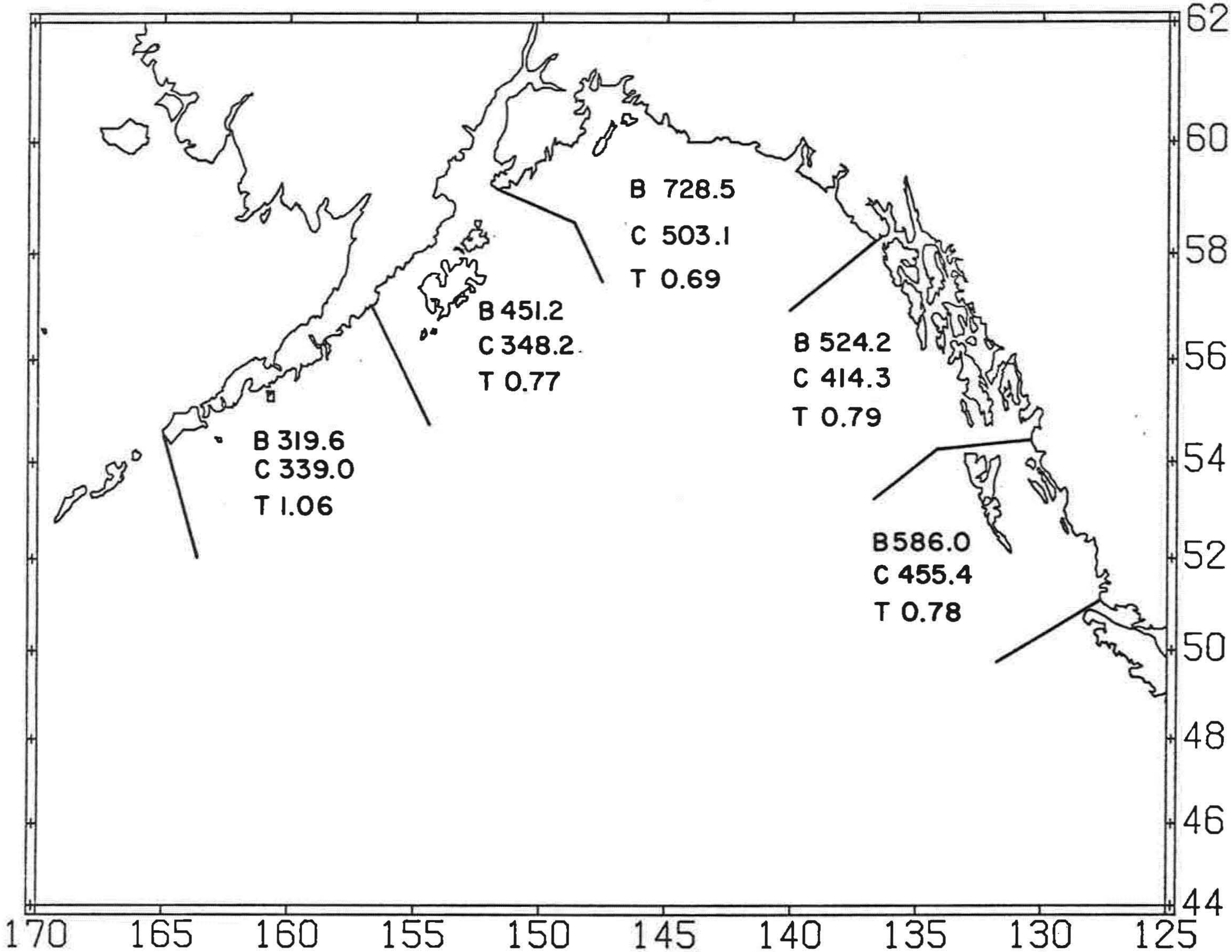

Figure 4.--Minimum sustainable biomass (B), ecosystem internal consumption (C), and annual turnover (T) of herring (10^3 metric tons).

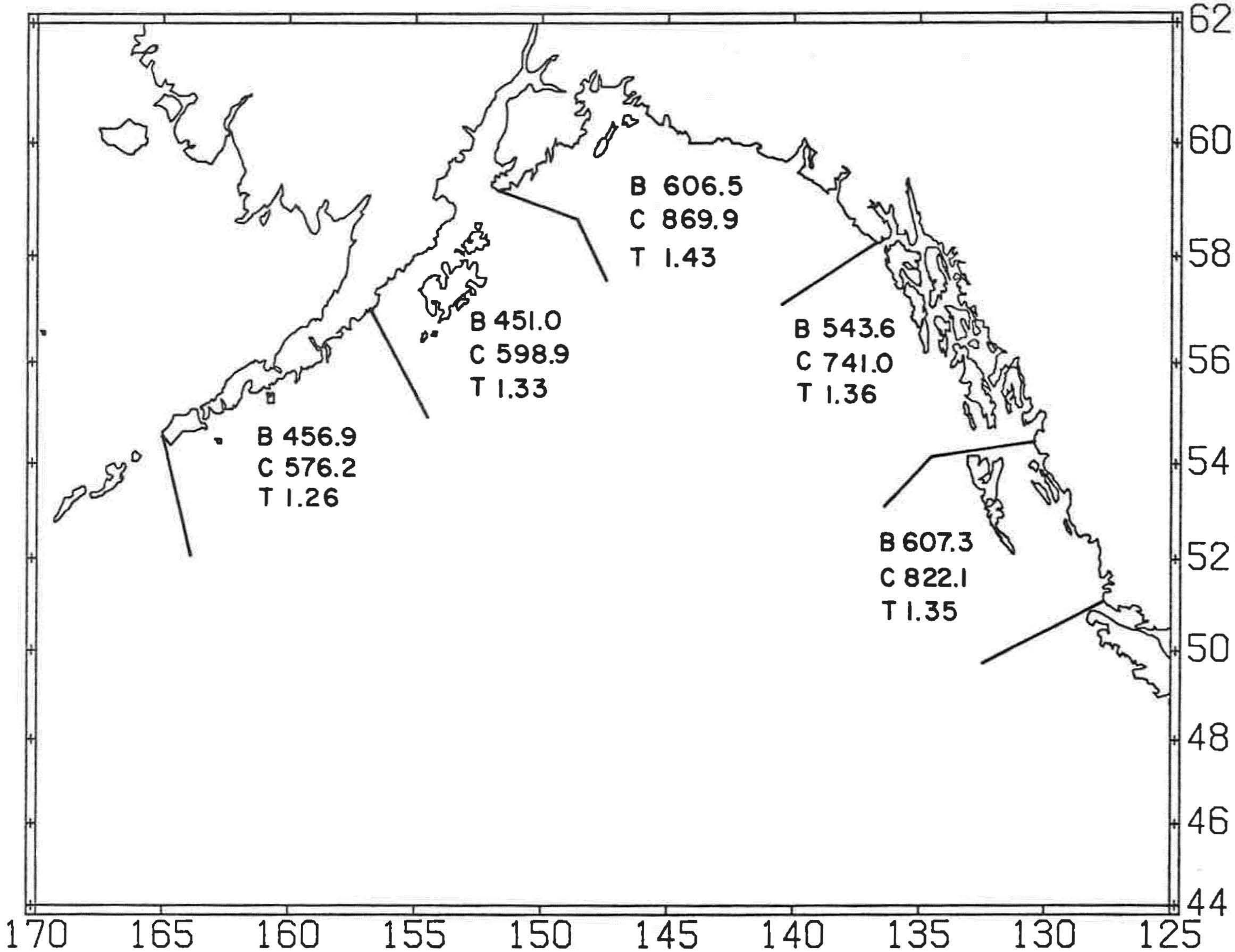

Figure 5.--Minimum sustainable biomass (B), ecosystem internal consumption (C), and annual turnover (T) of other pelagic fish (10^3 metric tons).

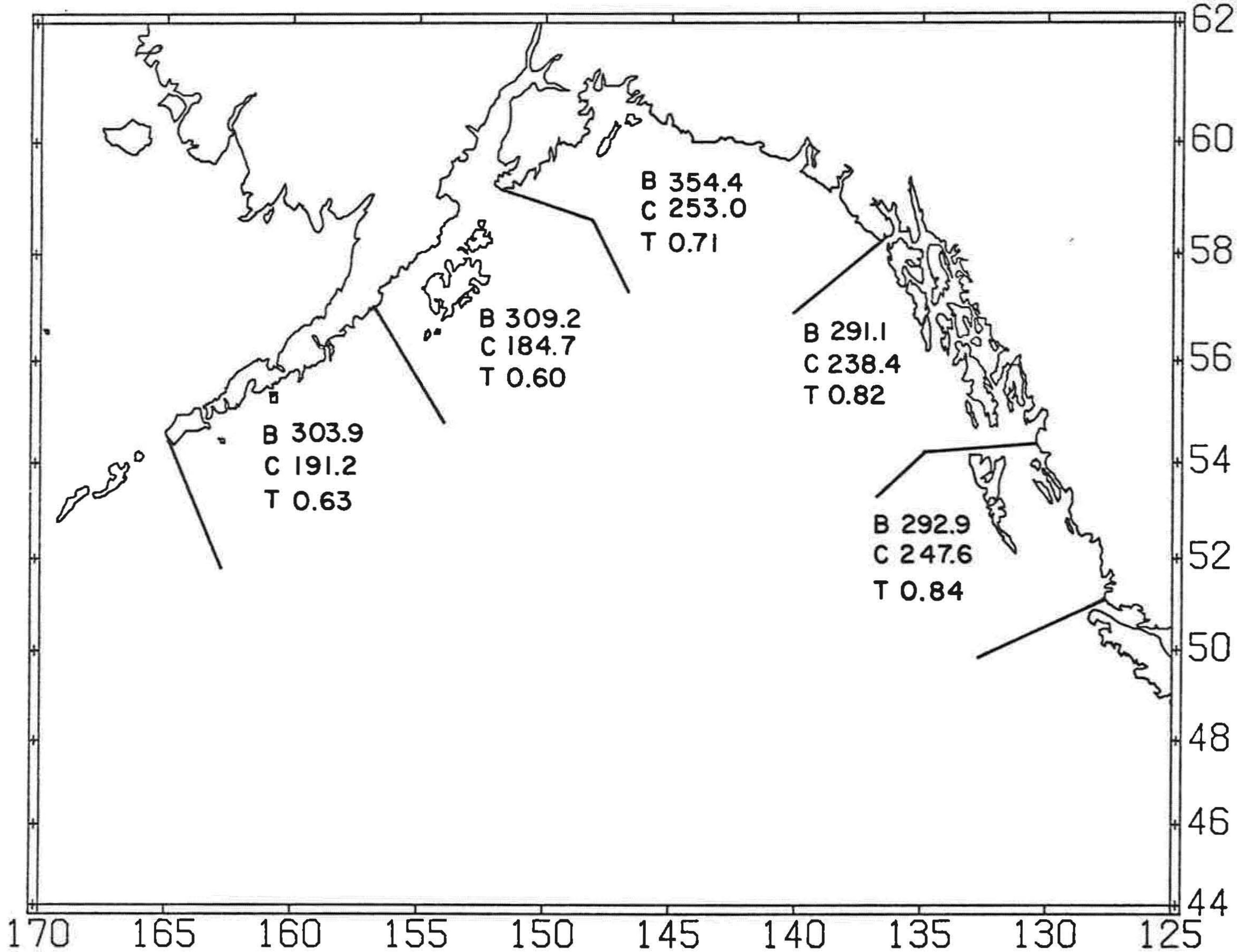

Figure 6.--Minimum sustainable biomass (B), ecosystem internal consumption (C), and annual turnover (T) of pollock (10^3 metric tons).

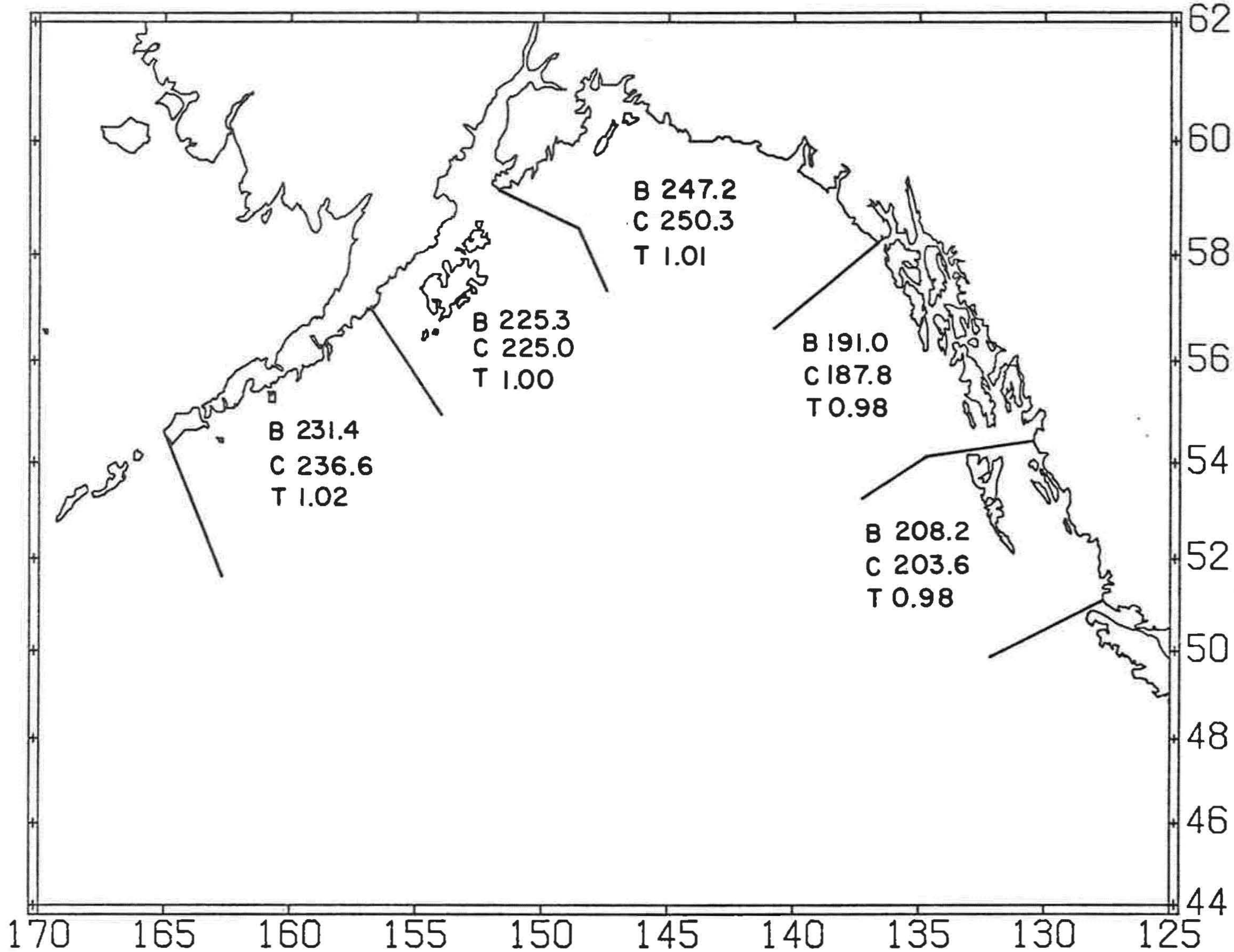

Figure 7.--Minimum sustainable biomass (B), ecosystem internal consumption (C), and annual turnover (T) of rockfish (10^3 metric tons).

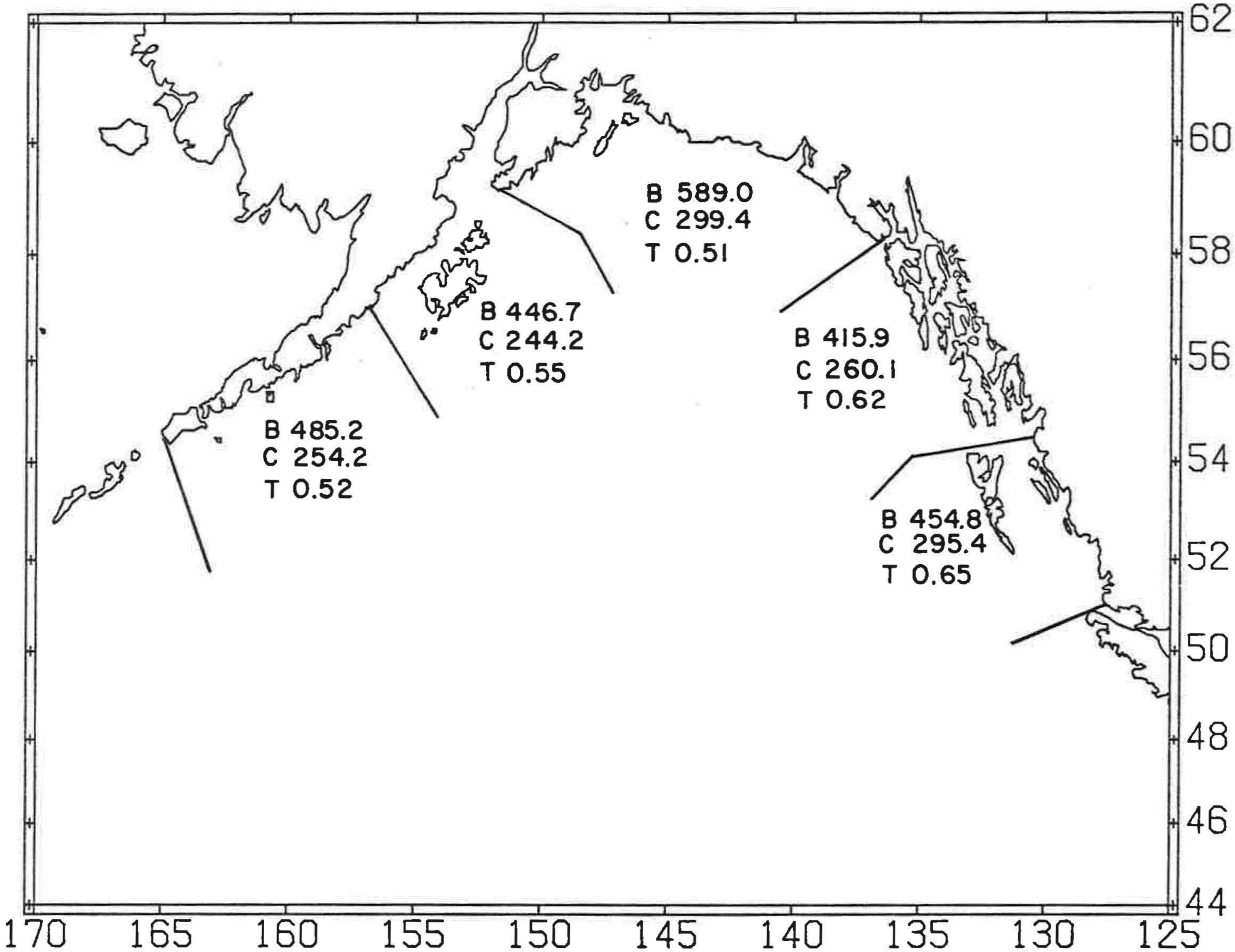

Figure 8.--Minimum sustainable biomass (B), ecosystem internal consumption (C), and annual turnover (T) of flatfish (10^3 metric tons).

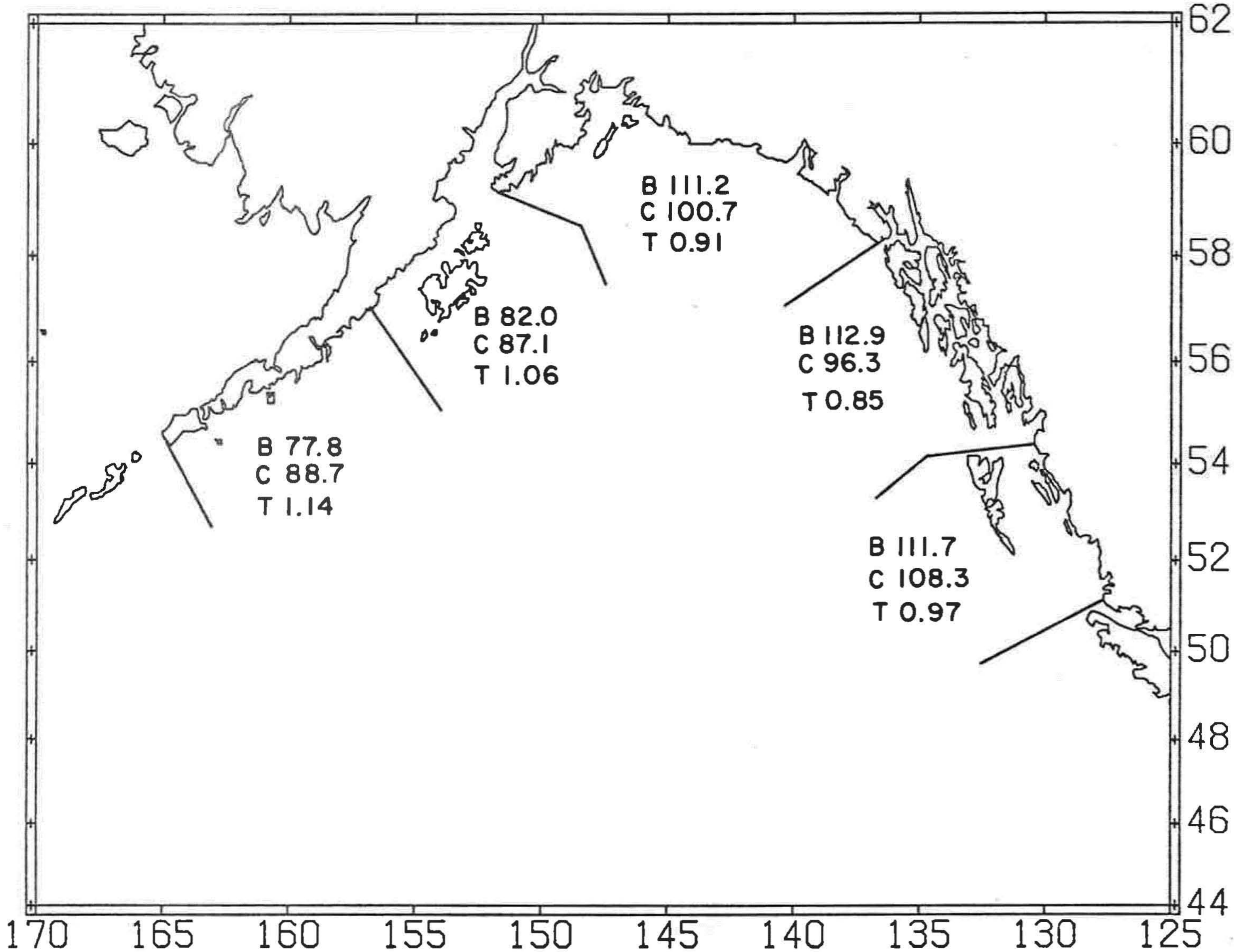

Figure 9.--Minimum sustainable biomass (B), ecosystem internal consumption (C), and annual turnover (T) of other gadids (10^3 metric tons).

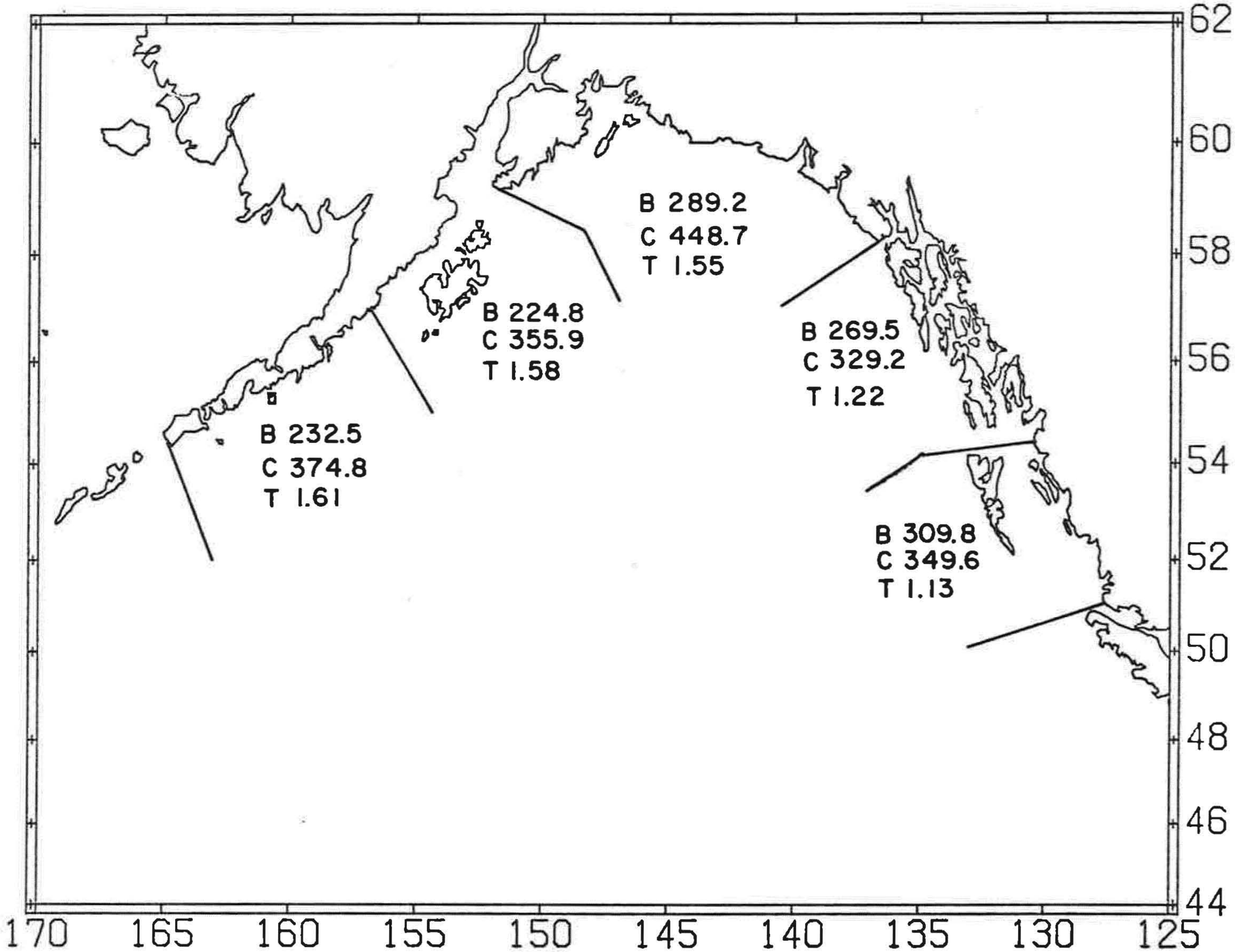

Figure 10.--Minimum sustainable biomass (B), ecosystem internal consumption (C), and annual turnover (T) of other demersal fish (10^3 metric tons).

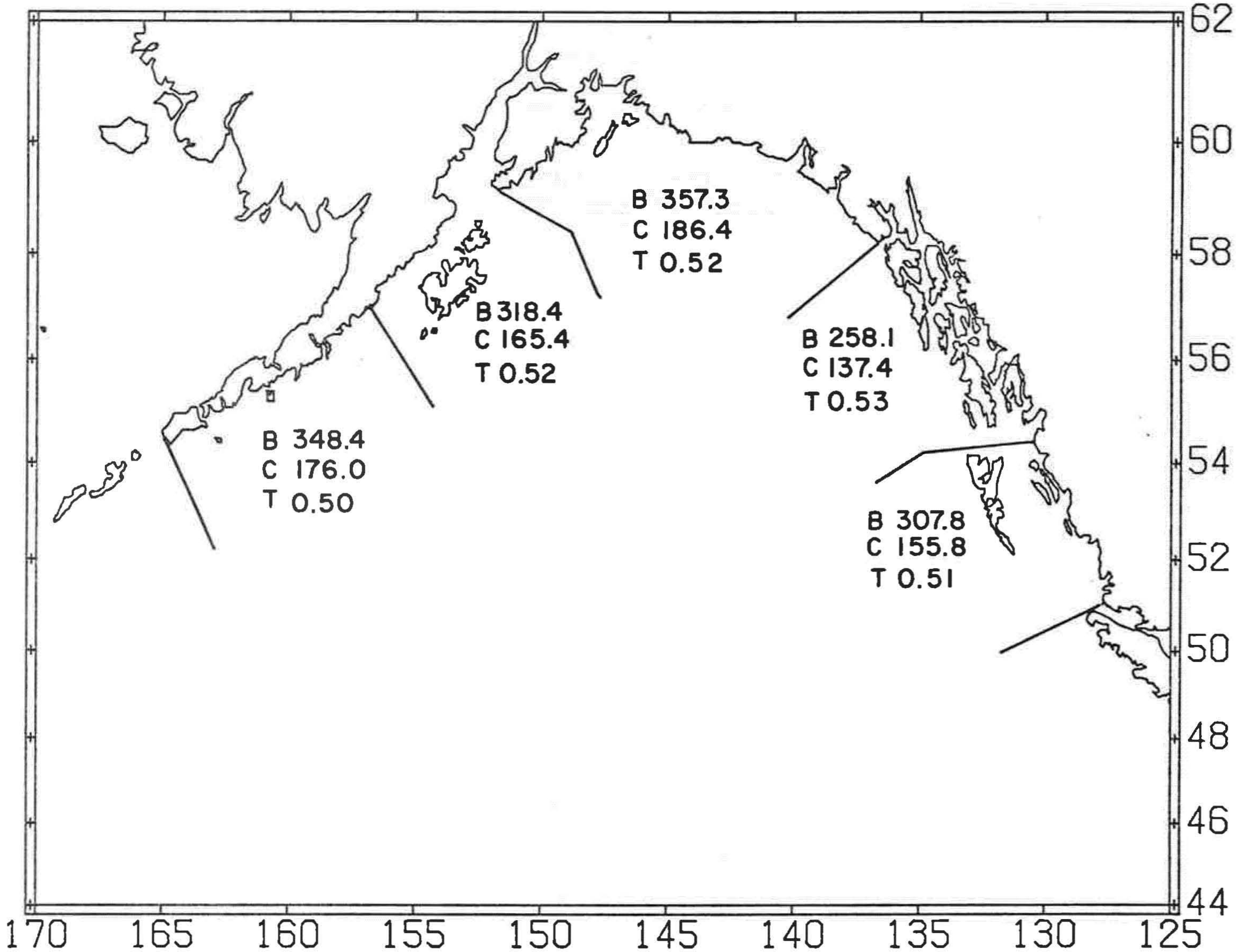

Figure 11.--Minimum sustainable biomass (B), ecosystem internal consumption (C), and annual turnover (T) of crustaceans (10^3 metric tons).

Table 20

Minimum sustainable biomass in tons/km^2 for marine ecological groups in the Gulf of Alaska

Group\Subarea	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Squid	1.44	1.55	0.54	1.26	1.54	0.50	1.79	1.36	0.41	1.22	1.17	0.31	1.20	1.18	0.31
Herring	5.82	3.83	0.99	5.94	3.35	1.02	6.16	3.14	0.94	4.29	2.19	0.70	2.81	1.83	0.69
Other pelagic fish	3.87	3.50	1.80	3.78	4.01	1.84	3.49	3.53	1.72	3.91	2.26	1.07	4.02	2.31	1.05
Pollock	1.90	0.73	2.41	2.10	0.85	2.51	1.96	0.71	2.72	1.82	0.59	2.74	1.89	0.58	0.38
Rockfish	1.29	1.23	0.63	1.50	1.47	0.57	1.60	1.60	0.56	1.64	1.58	0.69	1.64	1.60	0.69
Flatfish	3.88	3.34	0.93	4.05	3.53	0.91	4.61	3.86	0.77	3.72	3.50	0.73	4.57	3.36	0.73
Other gadids	0.58	0.77	0.36	0.63	0.89	0.43	0.59	0.75	0.33	0.62	0.53	0.24	0.55	0.54	0.24
Other demersal fish	1.86	2.03	0.93	1.94	2.25	0.84	2.08	1.88	0.51	1.79	1.65	0.50	1.96	1.60	0.50
Crustaceans	1.92	1.93	0.91	1.94	2.10	0.79	2.48	1.97	0.75	2.79	1.88	0.61	3.28	2.03	0.61
Benthos	18.24	15.03	3.82	20.59	14.51	3.16	18.38	13.97	2.77	18.75	13.40	2.66	17.72	13.36	2.66
Total finfish	19.2	15.43	8.05	19.94	16.35	8.12	20.49	15.47	7.55	17.79	12.3	6.67	17.44	11.83	4.28

Table 21

Minimum sustainable biomasses, annual consumption (10^3 tons), and turnover rates for ecological groups in the Gulf of Alaska summarized by depth.

Ecological group	Coastal Waters (areas 1, 4, 7, 10, 13)			Shelf Waters (areas 2, 5, 8, 11, 14)			Open Waters (areas 3, 6, 9, 12, 15)		
	Mean biomass	Annual consumption	Annual turnover rate	Mean biomass	Annual consumption	Annual turnover rate	Mean biomass	Annual consumption	Annual turnover rate
Squid	484.9	517.0	1.07	158.7	152.0	0.96	274.3	377.2	1.38
Herring	1,715.5	1,039.0	0.61	331.3	318.2	0.96	563.0	702.7	1.25
Other pelagic fish	1,315.4	1,811.3	1.38	361.8	525.6	1.45	988.2	1,271.1	1.29
Pollock	879.1	559.4	0.64	227.7	168.0	0.74	444.6	387.5	0.87
Rockfish	535.8	638.6	1.19	178.1	169.2	0.95	389.2	295.5	0.76
Flatfish	1,452.0	696.9	0.48	415.8	215.6	0.52	523.9	440.8	0.84
Other gadids	205.3	243.4	1.18	80.9	72.7	0.90	209.6	165.0	0.79
Other demersal fish	668.4	1,026.7	1.54	220.4	320.5	1.45	437.1	511.0	1.17
Crustaceans	879.3	443.9	0.50	233.4	125.5	0.54	477.4	251.6	0.53
Benthos	6,448.7	4,861.5	0.75	1,652.5	1,458.9	0.88	1,956.8	2,536.4	1.30
Total finfish	6,771.5	6,015.3	0.89	1,816.0	1,789.8	0.99	3,555.6	3,773.6	1.06

Table 22

Total minimum sustainable biomass, ecosystem internal consumption (10^3 tons), and turnover rates of ecological groups in the Gulf of Alaska.

Ecological group	Mean biomass	Annual consumption	Annual turnover rate
Squid	917.9	1,046.2	1.14
Herring	2,609.8	2,059.9	0.79
Other pelagic fish	2,665.4	3,608.0	1.35
Pollock	1,551.4	1,114.9	0.72
Rockfish	1,103.1	1,103.3	1.00
Flatfish	2,391.7	1,353.3	0.57
Other gadids	495.8	481.1	0.97
Other demersal fish	1,325.9	1,858.2	1.40
Crustaceans	1,590.1	821.0	0.52
Benthos	10,058.0	8,856.8	0.88
Total finfish	12,143.1	11,578.7	0.95

turnover rate for a particular group is a function of growth rate, biomass present, and consumption of the group in question.

The model results are supported by other survey results in the Gulf of Alaska (Table 23). Alverson, Pruter, and Ronholt (1964) values correspond well to the model's computed values if it is assumed that 50% of the population is exploitable (Laevastu and Favorite 1977b). The NEGOA results (Ronholt, Shippen, and Brown 1976), however, are somewhat higher than either the Alverson et al. and the model estimates if it is assumed that they present 50% of the biomass. This could be due to NEGOA's limited sampling period (May-August 1975), the uncertainty of catchability coefficient used, and the fact that values in this paper present minimum sustainable biomasses.

The North Sea has been studied intensively and estimates for the two areas (North Sea and Gulf of Alaska) are compared in Table 24. It should be kept in mind, however, that the North Sea is shallower and more enclosed than the Gulf of Alaska.

4.2 Consumption by marine birds and mammals.

The estimated consumption of marine resources by marine birds and mammals is summarized in Tables 25-30. The mammals consuming the greatest amount of marine resources in the Gulf of Alaska appear to be toothed whales, which consume large amounts of pelagic fish and pollock. The commercial catch of pollock is very small, only about 1/4 of the pollock consumption by toothed whales (Table 31). Fur seals and sea lions also prey heavily on pollock; the pollock consumption by pinnipeds is about twice the present catch of pollock. Although consumption by birds is considerably less than the consumption by mammals, birds are still important consumers of fishery resources as they feed quite heavily on herring as well as at times on young salmon. Also apparent

Table 23

Comparison of model results with survey estimates

Areas 1, 4, 7, 10, 13		
Biomass (tons)	Alverson et al. (1964)*	Model
Flatfish	7.26×10^5	1.45×10^6
Rockfish	2.73×10^5	5.36×10^5
Roundfish	4.35×10^5	1.08×10^6

Area 7		
Biomass (tons/km^2)	NEGOA (1975)*	Model
Flatfish	3.05	4.61
Rockfish	0.31	1.60
Roundfish	1.98	2.55
Invertebrates	1.91	2.48

*Survey estimates in which the coefficient of catchability assumed = 1.0

Table 24

Comparison of model results for Gulf of Alaska with estimates for the North Sea

	Gulf of Alaska	North Sea (1969-1970)*
Fish biomass (10^3 tons)	12,143.1	4,900.
Area (km^2)	1,092,988.3	500,000.
Fish biomass ($tons/km^2$)	11.11	9.8
Consumption (10^3 tons)	11,578.7	5,100.
Turnover rate	0.95	1.04

* From Andersen and Ursin (1977)

Table 25

Consumption by fur seals (10^3 metric tons/year)

Ecological Group	Subareas 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Squid	1.79	0.20	0.09	2.44	0.35	0.14	1.03	0.33	0.11	3.20	0.42	0.11	3.86	0.32	0.12	14.51
Herring	0.81	0.09	0.04	1.11	0.16	0.06	0.47	0.15	0.05	1.46	0.19	0.05	1.76	0.14	0.05	6.59
Other pelagic fish	0.65	0.07	0.03	0.89	0.13	0.05	0.37	0.12	0.04	1.16	0.15	0.04	1.41	0.12	0.04	5.27
Salmon	0.16	0.02	0.01	0.22	0.03	0.01	0.09	0.03	0.01	0.29	0.04	0.01	0.35	0.03	0.01	1.31
Pollock	6.50	0.71	0.34	8.88	1.27	0.50	3.73	1.19	0.41	11.63	1.53	0.39	14.05	1.16	0.43	52.74
Rockfish	2.93	0.32	0.15	3.99	0.57	0.23	1.68	0.53	0.19	5.24	0.69	0.18	6.32	0.52	0.19	23.73
Other gadids	2.93	0.32	0.15	3.99	0.57	0.23	1.68	0.53	0.19	5.24	0.69	0.18	6.32	0.52	0.19	23.73
Others	0.49	0.05	0.03	0.67	0.10	0.04	0.28	0.09	0.03	0.87	0.12	0.03	1.05	0.09	0.03	3.97
Total	16.26	1.78	0.84	22.19	3.18	1.26	9.33	2.97	1.03	29.11	3.83	0.99	35.12	2.90	1.06	131.85

Table 26

Consumption by harbor and ringed/ribbon seals (10^3 metric tons/year)

	Subareas															
Ecological Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Benthos	4.79	0.96	0.0	7.18	1.08	0.0	3.59	0.60	0.0	5.98	0.0	0.0	9.58	0.0	0.0	33.76
Pollock	0.68	0.14	0.0	1.03	0.15	0.0	0.51	0.09	0.0	0.86	0.0	0.0	1.37	0.0	0.0	4.83
Flatfish	0.34	0.07	0.0	0.51	0.08	0.0	0.26	0.04	0.0	0.43	0.0	0.0	0.68	0.0	0.0	2.41
Crustaceans	0.34	0.07	0.0	0.51	0.08	0.0	0.26	0.04	0.0	0.43	0.0	0.0	0.68	0.0	0.0	2.41
Other demersal fish	0.68	0.14	0.0	1.03	0.15	0.0	0.51	0.09	0.0	0.86	0.0	0.0	1.37	0.0	0.0	4.83
Total	6.83	1.38	0.0	10.26	1.54	0.0	5.13	0.86	0.0	8.56	0.0	0.0	13.68	0.0	0.0	48.24

Table 27

Consumption by sea lions (10^3 metric tons/year)

Ecological Group	Subareas 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Pollock	4.77	0.50	0.18	5.49	0.94	0.45	1.80	0.27	0.14	10.53	1.08	0.36	13.05	0.86	0.36	40.78
Rockfish	1.59	0.17	0.06	1.83	0.32	0.15	0.60	0.09	0.05	3.51	0.36	0.12	4.35	0.29	0.12	13.61
Other pelagic fish	0.79	0.08	0.03	0.91	0.16	0.07	0.30	0.05	0.02	1.76	0.18	0.06	2.18	0.14	0.06	6.79
Salmon	0.32	0.03	0.01	0.37	0.06	0.03	0.12	0.02	0.01	0.70	0.07	0.02	0.87	0.06	0.02	2.71
Others	0.48	0.05	0.02	0.55	0.09	0.05	0.18	0.03	0.01	1.05	0.11	0.04	1.31	0.09	0.04	4.10
Total	7.95	0.83	0.30	9.15	1.57	0.75	3.00	0.46	0.23	17.55	1.80	0.60	21.76	1.44	0.60	67.99

Table 28

Consumption by toothed whales (including sperm whales, porpoises and dolphins) (10^3 metric tons/year).

Subareas

Ecological Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Squid	15.07	6.23	41.66	7.50	10.41	40.90	15.06	4.63	38.31	9.47	2.24	2.60	11.49	1.30	1.83	208.70
Herring	15.07	6.23	41.66	7.50	10.41	40.90	15.06	4.63	38.31	9.47	2.24	2.60	11.49	1.30	1.83	208.70
Other pelagic fish	18.09	7.48	49.99	9.01	12.48	49.07	18.06	5.56	45.96	11.36	2.69	3.13	13.79	1.56	2.20	250.43
Salmon	3.02	1.25	8.33	1.51	2.08	5.91	3.01	0.93	7.66	1.89	0.45	0.52	2.30	0.26	0.36	39.48
Pollock	16.59	6.86	45.82	8.25	11.44	45.00	16.57	5.11	42.14	10.41	2.47	2.86	12.64	1.44	2.03	229.63
Other gadids	1.50	0.62	4.17	0.75	1.04	4.10	1.51	0.46	3.84	0.95	0.22	0.25	1.14	0.13	0.18	20.86
Others	6.03	2.50	16.66	3.00	4.15	16.35	6.01	1.86	15.32	3.74	0.90	1.05	4.60	0.53	0.74	83.44
Total	75.37	31.17	208.29	37.52	52.01	202.23	75.28	23.18	191.54	47.29	11.21	13.01	57.45	6.52	9.17	1041.24

Table 29

Consumption by baleen whales (10^3 metric tons/year).

Ecological Group	Subareas 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Euphausids	7.06	2.89	9.81	1.08	2.35	9.81	6.22	1.08	8.33	0.74	0.97	1.38	1.08	0.37	1.01	54.18
Copepods	1.41	0.58	1.96	0.22	0.47	1.96	1.24	0.22	1.67	0.15	0.19	0.28	0.22	0.07	0.20	10.84
Squid	0.91	0.37	1.26	0.14	0.30	1.26	0.80	0.14	1.07	0.10	0.13	0.18	0.14	0.05	0.13	6.98
Herring	0.30	0.12	0.42	0.05	0.10	0.42	0.27	0.05	0.36	0.03	0.04	0.06	0.05	0.02	0.04	2.33
Other pelagic fish	0.40	0.17	0.56	0.06	0.13	0.56	0.36	0.06	0.48	0.04	0.06	0.08	0.06	0.02	0.06	3.10
Total	10.08	4.13	14.01	1.55	3.35	14.01	8.89	1.55	11.91	1.06	1.39	1.98	1.55	0.53	1.44	77.43

Table 30

Consumption by marine birds (10^3 metric tons/year).

Ecological Group	Subareas 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Euphausids	4.25	0.28	0.11	3.61	0.47	0.09	3.97	0.29	0.08	5.04	0.36	0.08	3.49	0.26	0.12	22.50
Squid	2.13	0.14	0.05	1.81	0.23	0.04	1.98	0.15	0.04	2.52	0.18	0.04	1.74	0.13	0.06	11.24
Herring	7.44	0.49	0.19	6.32	0.82	0.16	6.94	0.51	0.14	8.83	0.62	0.14	6.10	0.46	0.21	39.37
Pollock	1.06	0.07	0.03	0.90	0.12	0.02	0.99	0.07	0.02	1.26	0.09	0.02	0.87	0.07	0.03	5.62
Rockfish	1.06	0.07	0.03	0.90	0.12	0.02	0.99	0.07	0.02	1.26	0.09	0.02	0.87	0.07	0.03	5.62
Flatfish	1.06	0.07	0.03	0.90	0.12	0.02	0.99	0.07	0.02	1.26	0.09	0.02	0.87	0.07	0.03	5.62
Other gadids	1.06	0.07	0.03	0.90	0.12	0.02	0.99	0.07	0.02	1.26	0.09	0.02	0.87	0.07	0.03	5.62
Benthos	1.06	0.07	0.03	0.90	0.12	0.02	0.99	0.07	0.02	1.26	0.09	0.02	0.87	0.07	0.03	5.62
Others	2.13	0.14	0.05	1.81	0.23	0.04	1.98	0.15	0.04	2.52	0.18	0.04	1.74	0.13	0.06	11.24
Total	21.25	1.40	0.55	18.05	2.35	0.43	19.82	1.45	0.40	25.21	1.79	0.40	17.42	1.33	0.60	112.45

Table 31

Comparison of consumption and fishery for marine ecological groups (10^3 metric tons)

Ecological group	Ecosystem internal consumption	Consumption by birds	Consumption by mammals	Fishery* (1975 statistics)
Squid	1,046.2	11.2	230.2	
Herring	2,059.9	39.4	217.6	
Other pelagic fish	3,608.0	-	265.6	
Pollock	1,114.9	5.6	328.0	48.0
Rockfish	1,103.3	5.6	37.3	44.0
Flatfish	1,353.3	5.6	2.4	13.0
Other gadids	481.1	5.6	44.6	5.0
Other demersal fish	1,858.2	-	4.8	56.0
Crustaceans	821.0	-	2.4	79.0
Total finfish	11,578.7	61.8	1,132.9	

* From communication Japanese Fishery Agency and Fishery Management Plan and Environmental Impact Statement for the Gulf of Alaska groundfish fishery during 1978

in Table 31 is the magnitude of the ecosystem internal consumption which is high compared to removal of resources by birds, mammals, and man.

5. CONCLUSIONS

1) The quantitative results of minimum sustainable biomasses by groups of species and subareas, consumption, and turnover rates are presented for the coastal regime in the Gulf of Alaska.

2) The model seems to produce reasonable estimates of minimum sustainable biomass as compared to estimates from survey techniques.

3) The ecosystem internal consumption is higher than customarily estimated natural mortality coefficients have indicated in the past. The present data can thus be used for revision of these natural mortality coefficients (M) for use in conventional population dynamics methods.

4) The consumption of fish by mammals in the Gulf of Alaska is considerably higher than total commercial catch. Consequently any sensible fisheries management requires the management of marine mammals as well.

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