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Estimation of Vulnerability, Availability, and Catchability Factors and Exploitable Biomasses in the Bering Sea and Western Gulf of Alaska

A comparison of exploitable biomasses as estimated in exploratory fishing, fisheries management plans, and as computed with PROBUB ecosystem model.

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ABSTRACT

Evaluation of fishery resources is enhanced by comparison of the results obtained by various independent methods. The main purpose of this paper is to compare the results of essentially annual fishery resource surveys in the eastern Bering Sea and in the western Gulf of Alaska with the exploitable biomasses of corresponding species computed with the PROBUB ecosystem model. In order to make biomass estimations by the two basically different methods comparable it is necessary to estimate vulnerability, availability, and resultant catchability factors for survey data. These preliminary factors are presented (Table 1).

The wide 95% confidence limits of survey results and the large year to year differences in individual surveys (Table 4), in some species $\pm$ 56% from the mean, cause the overall 95% confidence limits of survey data to be in excess of $\pm$ 50%. Furthermore, the low precision of any annual large-scale survey allows the detection of only very major changes in abundance over a number of years. There is a need to compliment the resource assessment surveys with other independent means of resource evaluation. One such independent means of evaluating marine resources is the use of ecosystem simulations. The results from one of the ecosystem models are compared with the survey results in this report.

The biomasses computed with PROBUB ecosystem model (Tables 6 and 7) are in reasonable agreement with the biomasses from the surveys for those species where survey results can be considered more reliable (especially in respect to species vulnerability and catchability in relation to survey gear). Furthermore, the model biomasses are proportionally in good agreement

with catches and estimates can be obtained for those species which cannot be ascertained by trawling surveys. The model results can also be verified and validated by indirect means other than trawling surveys (Granfeldt and Livingston, in prep.). In addition, the model operation costs only a very minute fraction of the survey costs.

I. THE OBJECTIVES OF RESOURCE EVALUATION BY VARIOUS MEANS AND THEIR APPLICABILITY IN THE BERING SEA AND GULF OF ALASKA.

Prior to about 1965 the fisheries research in the Gulf of Alaska and in the eastern Bering Sea was largely in an exploratory stage, the primary objective was to ascertain the abundance and distribution of commercially important resources in this relatively vast ocean area, the results of which were summarized by Alverson (1968) (see also Tables 2 and 3). The objectives of exploratory surveys are to ascertain the types of fishery resources available in an area accessible to the commercial fishery in order to determine relative abundance with reference to commercial gear and to determine their seasonal availability. The subsequent phase, that of fisheries research, which is greatly concerned with providing the bases for wise resource management, requires field surveys which might be termed resource assessment surveys. The requirements of these surveys are stringent. First, standardized gear must be used in a "standard" manner (i.e. same speed and length of tow). Furthermore, either a prescribed network of stations must be fished or certain grounds (stations) fished periodically, to obtain time-dependent (season) information. These surveys are expected to permit determination of the distribution, abundance, seasonal behavior, and especially changes in abundance and recruitment. Thus these surveys must be supplemented with additional gear and methods, such as midwater trawling and sonar surveys, especially for determination of recruitment to exploitable stock. Additional "auxiliary" information is needed for and from these surveys such as trophodynamics data, vulnerability and availability factors, etc. Unfortunately the relatively extensive and stringent requirements for these surveys can seldom be fulfilled, largely due to vastness of the area in relation to survey effort and availability of ships and personnel.

Virtual population (or cohort) analysis is another indirect method for evaluation of the abundance of exploited resources. Unfortunately this method cannot be used successfully with the Bering Sea and Gulf of Alaska resources because: first, most of the resources are highly migratory; second, all year classes are not properly sampled due to seasonal migrations and some differences in the distributions of different age groups; third, the reporting of catch statistics has not been timely; and, fourth, most species are underexploited.

There are limitations to other "auxiliary" methods of resource evaluation. The limitations of the use of catch-per-unit-effort (CPU) data from fisheries were well explored and documented in the beginning of the 1960's by ICES. The CPU does not indicate the stock abundance for schooling species. For other species it has been thought that CPU might be proportional to average stock density. However, the conversion of this relative density measure into actual abundance requires a knowledge of the total area occupied by the stocks and the elementary efficiency of the gear (Dickie 1979).

The application of single species population dynamics models in the Bering Sea-Gulf of Alaska region has been limited due to unavailability of reliable initial stock size estimates and of reliable mortality coefficient estimates. Furthermore, the limitations of single species approaches have been recently displayed in detail by several fisheries scientists (Ursin 1979).

The multispecies holistic ecosystem simulation approach has been recently explored as a quite powerful tool in resource evaluation as well as for creating a background for fisheries management. The main purpose of this paper is to compare the results of the PROBUB ecosystem model with available survey data. This task requires the estimation of catchability factors, which is also done in this paper. The PROBUB model is being documented (Granfeldt and Livingston, in prep.). It is similar to DYNUMES, except it lacks spatial resolution and works on defined regions (Figure 1).

II. ESTIMATION OF VULNERABILITY, AVAILABILITY, AND CATCHABILITY FACTORS

In order to obtain the estimate of total exploitable biomass of a given species from survey data, we must estimate the effectiveness of the gear and the bias resulting from not sampling the entire area occupied by a particular species--i.e. to estimate vulnerability and availability factors. These conversions are also necessary for comparison of the results from ecosystem models with results from surveys and to estimate allowable catches. Vulnerability refers to the success of the gear in capturing given species, i.e. the ability of the fish to escape once they come in direct contact visually or otherwise with the gear. Availability (which includes accessibility) refers to areawise availability of the species in relation to the survey network, including the effects of seasonal migration on distribution in relation to survey timing.

No direct measurement of vulnerability and availability is possible. After reviewing a considerable amount of pertinent literature (see a selected bibliography at the end of this paper), and taking the corresponding coefficients used in Northeast Fisheries Center (Edwards 1968) as a guide, estimates of the coefficients were made as presented in Table 1. It is expected that some adjustments of these coefficients will be made in the future when the seasonal migrations of species are more thoroughly investigated.

The last column in Table 1 contains the percentage of exploitable biomass from total biomass. These percentages were computed with a special model (Laevastu and Favorite 1978a) assuming a biomass turnover rate of 0.75.

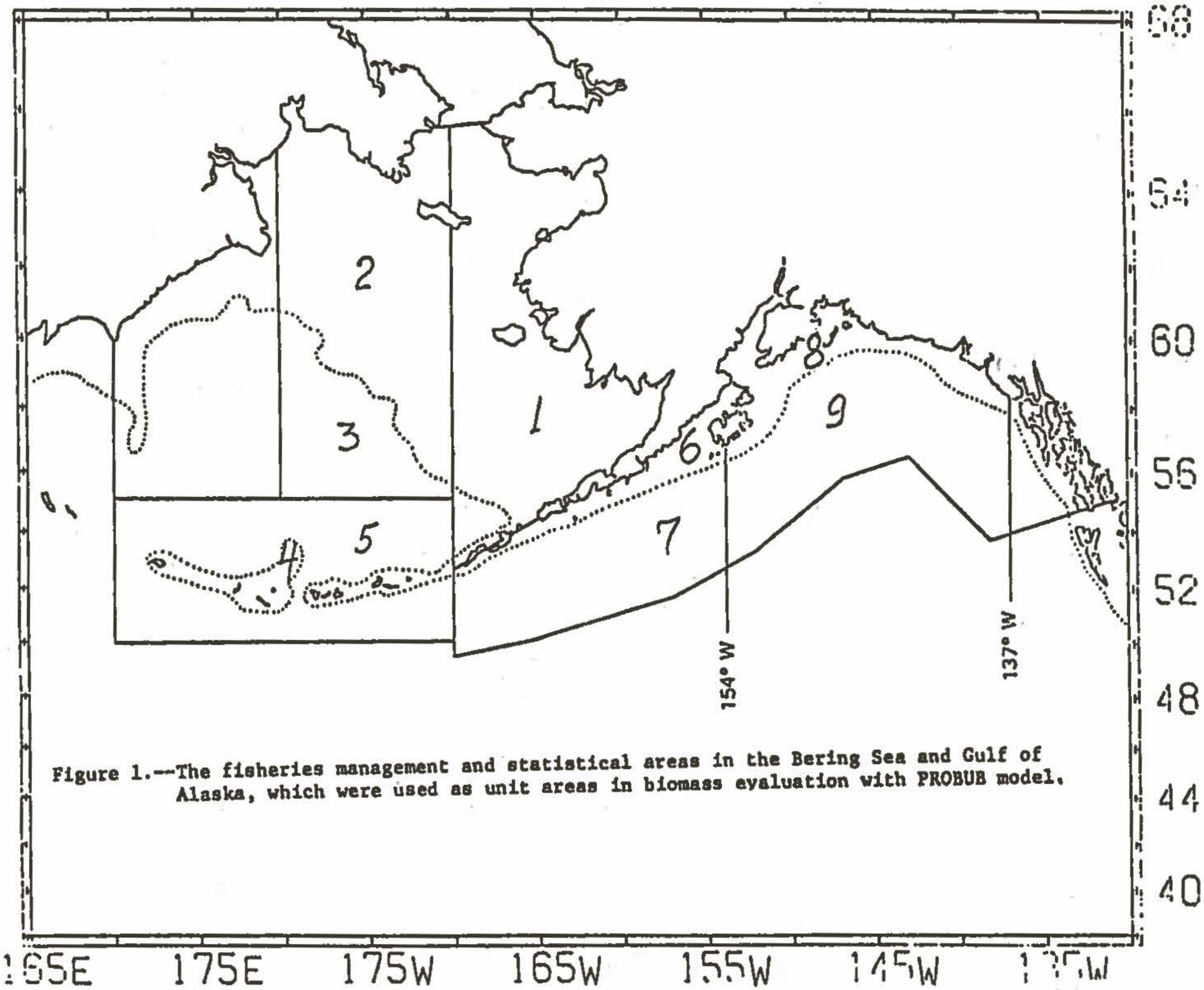

Figure 1.--The fisheries management and statistical areas in the Bering Sea and Gulf of Alaska, which were used as unit areas in biomass evaluation with PROBUB model.

Table 1.--Estimated vulnerability, availability, and catchability factors and percentage of exploitable biomass from total biomass.

Species/group of species	Vulnerability	Average seasonal/areal availability: Gulf of Alaska	Average seasonal/areal availability: Eastern Bering Sea	Resultant catchability factor: Gulf of Alaska	Resultant catchability factor: Eastern Bering Sea	Percent exploitable biomass from total biomass
Demersal						
Greenland turbot, halibut	0.8	0.8	0.85	0.64	0.68	54
Flathead sole, arrowtooth flounder	0.75	0.8	0.9	0.60	0.68	45
Yellowfin and rock sole, Alaska plaice	0.8	0.9	0.9	0.72	0.72	45
Other flatfish	0.7	0.75	0.75	0.53	0.53	28
Elasmobranches, cottids	0.7	0.5	0.4	0.35	0.28	(70)
Semi-demersal						
Pollock	0.6	0.75	0.7	0.45	0.42	70
Cod	0.6	0.7	0.6	0.42	0.36	72
Sablefish	0.5	0.3	0.3	0.15	0.15	40
Rockfish	0.5	0.55	0.40	0.28	0.20	30
Pelagic						
Herring	0.2	0.3	0.4	0.06	0.08	30
Capelin, other smelt	0.1	0.3	0.3	0.03	0.03	
Sand lance	<0.1	0.25	0.3	<0.03	<0.03	
Varia						
Atka mackerel, + macrurids	0.3	0.4	0.2	0.12	0.06	45
Squid	<0.1	0.4	0.2	<0.04	<0.02	
Crab	0.3	0.75	0.7	0.23	0.21	40
Shrimp	<0.1	0.5	0.4	<0.05	<0.04	65

III. ADJUSTED EXPLOITABLE BIOMASS ESTIMATES FROM SURVEYS AND COMPARISON TO CATCHES

This summary deals with fishery resources in the eastern Bering Sea (Areas 1, 2 and 3 in Figure 1) and in the western Gulf of Alaska (Areas 6 and 7 in Figure 1). Although the resource surveys in the 1960's in the above listed areas were still in an exploratory phase, they produced resource estimates which are not inferior to the survey results in the 1970's--compare Tables 2 and 3 with Tables 4 and 5; the estimates of Alverson (1968) (Tables 2 and 3) have not been converted with catchability factors. These early exploratory surveys were carried out in shallower water than later surveys in the 1970's and did not cover continental slope areas. Therefore, the pollock and cod, where part of the population is found on the continental slope and in deeper water, are likely underestimated in the Bering Sea in these earlier exploratory surveys. Furthermore, there has been a considerable increase in pollock biomass in the Gulf of Alaska in the 1970's.

Extensive resource assessment surveys were carried out in 1975 and 1976 in the eastern Bering Sea (Table 4). The results of these surveys are quite different in most species, except flathead sole--e.g. pollock is in 1976 nearly four-fold lower and yellowfin sole twice as high as in 1975. There is no plausible explanation for these large differences being real, but one is led to believe that these difference were caused by seasonal movements (and availability) of the species.

Comparison of the unconverted survey results (Table 4, columns two and three) with catches (column six) shows the need to convert the survey results using the catchability factor (column five). Even after conversion

Table 2.--Exploitable biomass estimates in the eastern Bering Sea, based on surveys in the 1960's (Alverson, 1968) (catchability factor 1), compared to catches in 1975.

(In 1,000 tons)

Species/group of species	Exploitable biomass Alverson, 1968 (see qualifications in text)	Catch, 1975	Percentage of catch
Demersal			
Greenland turbot, halibut			
Flathead sole, arrowtooth flounder	400	26	7
Yellowfin and rock sole, Alaska plaice	3,225	74	3
Other flatfish	(5)		
Elasmobranches, cottids			
Semi-demersal			
Pollock	1,500	1,285	86
Cod	140	57	41
Sablefish			
Rockfish	150	?	
Pelagic			
Herring			
Capelin, other smelt			
Sand lance			
Varia			
Atka mackerel, + macrurids			
Squid			
Crab			
Shrimp			

Table 3.--Exploitable biomass estimates in the Western Gulf of Alaska in 1960's as compared to catches in 1973.

(In 1,000 tons)

Species/group of species	Exploitable biomass, (one half of Alverson's 1968 estimate of whole Gulf of Alaska) catchability factor, 1	Catch 1973	Percentage of catch	Exploitable biomass from Ronholt et al 1968 adjusted with catchability coefficient, Table 1	Percentag of 1973 catc
Demersal					
Greenland turbot, halibut				239	
Flathead sole, arrowtooth flounder	290	38	11	73	26
Yellowfin and rock sole, Alaska plaice	62			74	
Other flatfish				17	
Elasmobranches, cottids	(13)			331	
Semi-demersal					
Pollock	65	(36)	(55)	44	82
Cod	40	6	15	57	26
Sablefish				60	
Rockfish	185	14	8	229	6
Pelagic					
Herring					
Capelin, other smelt					
Sand lance					
Varia					
Atka mackerel, + macrurids					
Squid					
Crab				1,330	
Shrimp					

Table 4.--1975 and 1976 survey results converted to exploitable biomass and compared to 1975 catches, Eastern Bering Sea.

(In 1,000 tons)

Species/group of species	Survey 1976	Survey 1976	Mean from '75,'76 surveys	Converted exploitable biomass, (survey mean)	Catch 1975	Percentage of catch from exploitable biomass
Demersal						
Greenland turbot, halibut	157	82	120	176	65	37
Flathead sole, arrowtooth flounder	141	140	140	206	26	13
Yellowfin and rock sole, Alaska plaice	1,336	2,575	1,956	2,716	74	3
Other flatfish						
Elasmobranches, cottids						
Semi-demersal						
Pollock	2,426	679	1,553	3,698	1,285	35
Cod	65	102	84	233	57	24
Sablefish						
Rockfish						
Pelagic						
Herring						
Capelin, other smelt						
Sand lance						
Varia						
Atka mackerel + macrurids						
Squid						
Crab						
Shrimp						

Table 5.--Survey results from 1970's, converted to exploitable biomass and compared to 1973 catches. Western Gulf of Alaska.

(In 1,000 tons)

Species/group of species	Ronholt et al. 1978 (mean, 1970's)	Mean exploitable biomass, 1970's	Catch 1973	Percentage of catch	1/2 of total catch from Gulf of Alaska 1975 (other sources than column 3)
Demersal					
Greenland turbot, halibut	88	138	24	17	4.5
Flathead sole, arrowtooth flounder	46	77			
Yellowfin and rock sole, Alaska plaice	56	78	38	21	2
Other flatfish	16	30			
Elasmobranches, cottids	30	86			
Semi-demersal					
Pollock	461	1,024	(36)	4	24
Cod	47	112	6	5	9.5
Sablefish	2	13	23	177	10.5
Rockfish	7	25	14	56	22
Pelagic					
Herring					
Capelin, other smelt					
Sand lance					
Varia					
Atka mackerel, + macrurids			11		10.5
Squid					
Crab	49	213	19	9	
Shrimp			25		

the biomasses of turbot, pollock, and cod seem too low, possibly because the catchability factors in Table 1 are conservative. The survey results from the Gulf of Alaska, converted using the catchability factor to exploitable biomasses (Table 5, column 2), show that the survey results are not realistic in this area in regard to sablefish and rockfish (i.e. annual catches 177 and 56 percent, respectively, of the exploitable stock). In general, any annual harvest in excess of 20% of the mean standing exploitable stock might be considered overfishing on most medium- and long-lived species (Edwards 1976). However, few if any signs of overfishing can be observed in most Bering Sea and Gulf of Alaska stocks.

During the search for catch data used in the tables in this paper, it became apparent that catch data vary, sometimes considerably, from one published source to another, thus indicating the need to establish an authoritative fisheries data system in the NE Pacific area.

The survey results presented in Tables 2 to 5 and a review of some "auxiliary" data available in NWAFC, such as age frequency data, indicate a need for "weighing" existing data in various ways such as through application of catchability factors and factors for known seasonal migrations to eliminate biases caused by different seasonal distributions of different age groups and changing vulnerability to gear of diffent size (age) fish. Furthermore, the effect of the regulation of fisheries via quota system must be taken into consideration in future data collection system changes.

The examination of the survey data also suggests reorientation of fisheries surveys might be called for. For example, the seasonal distribution patterns of prefishery juveniles as well as exploitable populations of commercially important species should be ascertained. One of the examples of seasonal migration pattern determination is the seasonal depth migrations as determined by Alverson (1960) for flatfishes along the west coast of the U.S. and Canada.

For cutting the costs and efforts of surveys, "defined spot sampling" techniques (especially in "time series") offer considerable possibilities and advantages over the gridded surveys. Furthermore, there is an urgent need to collect various auxiliary data, such as trophic data (stomach analysis).

IV. COMPARISON OF ESTIMATED EXPLOITABLE BIOMASSES FOR SURVEYS AND FROM MANAGEMENT PLANS WITH COMPUTED EXPLOITABLE BIOMASSES FROM PROBUB ECOSYSTEM MODEL

Tables 6 and 7 contain the mean biomasses of species/groups of species as ascertained by surveys in the 1970's and converted to exploitable biomasses, using catchability factors from Table 4. In addition, a few estimates of exploitable biomasses, which are given in recent fisheries management plans, are presented in column 2 of these Tables and MSY and ABC estimates from these plans are presented in column 4. The condensely written management plans do not describe in detail how the latter estimates have been derived (N. Pac. Fish Manag. Council 1977 and 1978).

Column 3 in Tables 6 and 7 presents the "sustainable" exploitable biomasses for different species/groups of species from a PROBUB model run. The methods used in this model have been partly described (Laevastu and Favorite 1978b) and the description of the particular model version and its results is in preparation (Granfeldt and Livingston, in prep.). The reliability of the results, as well as "natural" long-period changes of biomasses and their causes, will be described in the abovementioned report. In general, the mean sustainable biomasses are considered reliable with $\pm$ 15 to $\pm$ 30% of its mean value, depending on species, whereas the 95% confidence limits of the surveys are at best $\pm$ 50% (Grosslein 1976). Some special conditions have been imposed on the biomasses in the parenthesis in column 3 of Tables 6 and 7.

Table 6.--Comparison of exploitable biomasses as obtained by surveys, reported in management plans, and computed with PROBUB model. Eastern Bering Sea.

(In 1,000 tons)

Species/group of species	Mean, 1975, 1976 surveys (converted, see Table 4)	Groundfish management plan	Minimum sustainable exploitable biomass from PROBUB model	MSY from management plan
Demersal				
Greenland turbot, halibut	176	?	277	105
Flathead sole, arrowtooth flounder	206	94-132	310	
Yellowfin and rock sole, Alaska plaice	2,716	992 + 149	754	169-260
Other flatfish		(232-334)	319	44-77
Elasmobranches, cottids			(2,864)	
Semi-demersal				
Pollock	3,698	?	6,444	1,100-1,600
Cod	233	?	773	59
Sablefish		?	(76)	11
Rockfish		?	544	75
Pelagic				
Herring			634	
Capelin, other smelt			(1,500)	
Sand lance				
Varia				
Atka mackerel, + macrurids		?	699	33
Squid			(1,000)	
Crab			397	
Shrimp			965	

Table 7.--Comparison of exploitable biomasses as obtained by surveys, reported in management plans, and computed with PROBUB model. Western Gulf of Alaska.

Species/group of species	1970's mean from surveys (converted, see Table 5)	Groundfish management plan (half for Gulf of Alaska)	Minimum sustainable exploitable biomass from PROBUB model	ABC from management plan
Demersal				
Greenland turbot, halibut	138		52	
Flathead sole, arrowtooth flounder	77	289	50	27
Yellowfin and rock sole, Alaska plaice	78		90	
Other flatfish	30		42	
Elasmobranches, cottids	86	?	(493)	
Semi-demersal				
Pollock	1,024	697-1,393	1,228	111
Cod	112	57-112	101	14
Sablefish	13	?	(20)	4
Rockfish	25	?	134	11
Pelagic				
Herring		?	129	
Capelin, other smelt		?	(500)	
Sand lance		?		
Varia				
Atka mackerel, + macrurids		?	168	8
Squid		?	(600)	
Crab	213		58	
Shrimp			121	

A detailed comparison of the exploitable biomasses with more reliable biomass estimates for surveys and especially their comparison with catches, shows that the computed biomasses are considerably more realistic than those obtained by surveys. Only one, the yellowfin biomass in the eastern Bering Sea, seems to be somewhat low in the model computations. An explanation for this discrepancy is that the conditions imposed in the model refer to the very end of the 1960's when the biomass of yellowfin sole seemed indeed to have been lower than at present.

It might be important to point out that cost of information derived from the ecosystem model is only a very small fraction of the costs of annual surveys. Furthermore, the model allows many additional studies, such as the determination of the effects of fishing (e.g. changed quotas) directly on the target species and indirectly on other species via inter-species interactions; determination of the magnitudes and period of long term changes (including "recoveries" and "stock rebuilding") and the effects of environmental anomalies. These studies will be described in forthcoming reports (e.g. Granfeldt and Livingston, in prep.).

V. CONCLUSIONS AND RECOMMENDATIONS

Only a few preliminary conclusions and recommendations are presented as the comparison and general evaluation of the survey results and the biomass related data given in management plans seems to merit closer scrutiny of the value and validity of survey results and the need to obtain additional data of various kinds for evaluation of the resources and their dynamics by various direct and indirect methods.

The exploratory surveys in the 1950's and 1960's were an absolute necessity to ascertain the kinds, general magnitudes, and availability of commercial fisheries resources in the vast productive areas in the Bering Sea and in the northeast Pacific. However, the conditions have changed drastically in recent years, calling for some reorientation of surveys, higher accuracy in resource estimates, and especially ascertaining the dynamics of the resources in space and time.

A few general suggestions on the possible reorientation of resource assessment can be made. One of the main suggestions from the author's point of view is obviously the continuation and intensification of the use of ecosystem models. These models also indicate research priorities of various kinds, which will be described in forthcoming reports (Granfeldt and Livingston, in prep.).

It seems that one of the future fisheries survey objectives should be the study of indices of abundance in some "key" locations (fishing grounds), rather than a "gridded" survey.

The seasonal and year-to-year differences in migrations of the fishery resources in the Bering Sea and Gulf of Alaska seem to be poorly known, with the exception of the seasonal migrations of flatfish (Alverson (1960) and some Soviet studies in the mid-60's in the Bering Sea).

The surveys of prefishery juveniles (prerecruits) seems to be a necessity for modern management, using both special gear adapted to prerecruit catching and special sonar surveys with midwater sampling.

Trophic (food) studies (and data) have been badly lacking in the Bering Sea and Gulf of Alaska. These data are important in model studies, especially in ascertaining quantitatively the interspecies interactions.

Finally, more uniformity is required in the routinely observed fishery data (e.g. length-age frequency data) and continued effort seems to be needed to improve the accuracy and validity of these data.

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