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Numerical Simulations in Fisheries Oceanography (with reference to N.E. Pacific and Bering Sea)

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NOTICE

NUMERICAL SIMULATIONS IN FISHERIES OCEANOGRAPHY

(with reference to NE Pacific and Bering Sea)

By

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Abstract

Fisheries oceanography and numerical simulations are interdisciplinary subjects, the successful pursuit of which requires good familiarity with a variety of scientific subject matters. The main subject of fisheries oceanography is the study of the effects of environment on the abundance and availability of fishery resources. Numerical rendering is coherent analyses in space and time of scattered data.

In the past many simple correlation studies between single environmental variables and catches and/or landings have been attempted. Most of these studies have been crowned with failure because no causal mechanisms were considered. Recently developed holistic ecosystem simulations have enhanced the studies of the effects of the environment on fishery resources.

The sparsity of oceanographic observations from the NE Pacific and Bering Sea hinders the real-time application of fisheries oceanography in this region; however, some essential oceanographic conditions, such as surface currents and mixed layer depth could be analyzed from existing surface meteorological data.

The data on fisheries are also deficient. The best fisheries data reflecting the stock abundance come from the more extensive resource surveys conducted after 1975. Also, these data must be interpreted with regard to changes in gear and catchability. The earlier reports on foreign catches are unreliable and present catches are regulated by quotas; thus, reflecting neither abundance nor availability.

There is a need as well as possibilities for further studies of environment-fish interactions. Large holistic simulations which reproduce the ecosystem on the bases of available cause-effect knowledge can satisfy this need.

1. The Essence of Fisheries Oceanography and its Past in the NE Pacific

This brief review pertains to two interdisciplinary areas - fisheries oceanography and numerical simulation (modeling) with reference to the Bering Sea and NE Pacific. It appears that both subject matters are nebulous in many minds, as some published literature as well as numerous recent "administrative" documents pertaining to future projects indicate. According to Henry Poincaré, clarity cannot be achieved in discussions before it is introduced into definitions; thus I will briefly discuss the definitions of both subjects.

Fisheries oceanography (or fisheries hydrography, as it was called in Europe) was first defined in the first report of ICES in 1902. In fact, ICES was established mainly on the premise that the environment was in some manner responsible for the disappearance of the herring from the Bohus coast of Sweden, and the detailed causes for this disappearance could be established only through cooperative study of the ocean environment.

Fisheries oceanography proper has been mainly pursued by oceanographers working in various fisheries services. On the other hand, the biologists have been dealing with a gamut of biological problems relating to the environment, such as plankton and benthos studies. The true interdisciplinary cooperation between physical oceanographers and fisheries biologists has never been perfect, despite considerable efforts, especially by ICES, to promote this cooperation. Furthermore, progress in obtaining undisputable results in fisheries oceanography has been slow in the last 80 years. Some reasons and difficulties for this slow progress are ventilated in this report.

Fisheries oceanography includes several scientific disciplines and its successful pursuit requires that the practioners have considerable knowledge in most of these disciplines. This requirement is rarely met in present times of individual specialization. Essentials of fisheries oceanography are summarized by Laevastu and Hayes, 1981.

The other discipline of concern here - numerical simulation, is another highly diverse activity; many different approaches are called modeling - for example, the study of the behavior of a given mathematical expression which is postulated to represent the behavior of a given natural phenomenon, numerical rendering of available data sets, and numerical (quantitative) simulation of the behavior of a phenomenon, either as part of the environment alone or of an ecosystem. Consequently, many "models" are in existence; their number seemingly increasing at an exponential rate. To define numerical modeling would be futile, as few would accept any strict definition. Therefore, I will deal in a descriptive manner with the problems of numerical approaches to the study of fish-environment interactions.

The main reasons and incentives for the study of fisheries oceanography arise from the understanding that the ocean environment exercises some influence on the abundance and behavior of fish stocks. It is hoped that if this influence can be properly quantified, the fluctuations in the abundance and availability of fish stocks could be predicted from observations of the environment. I must emphasize that this was largely a pipedream, and has remained so.

Fisheries oceanography proper attempts to:

1) Find quantitative relations between the fluctuations of environment and the availability of fish (i.e., effects of environment on the "behavior" of fish stocks).

2) Find cause-effect relations between environmental changes and changes in the abundance of fish (i.e., recruitment throughout the early life history and to the exploitable stock).

3. Provided some results from 1 and 2 above are available, to apply this knowledge to predict the fish availability and abundance in space and time.

Fisheries oceanography studies require environmental studies in all space and time scales, partly because the fishery resources are mobile over large areas, and partly because the effects of the environment and its anomalies on stocks are not instantaneous, but can at times be years delayed.

Felix Favorite used to point out that scientists involved in fisheries oceanography have always encountered two dilemmas: first, other Federal agencies have always received a larger share of the oceanography funds than fisheries agencies; and, second, fisheries groups have been required to spend their limited funds on small scale, short-term, fisheries related problems.

Attempts to conduct broad spectrum fisheries oceanography studies have been made in the past in the United States. The Bureau of Commercial Fisheries TRIDENT program in the 1960's and the National Marine Fisheries Service's MARMAP program in the 1970's were attempts to focus attention on the multidisciplinary studies needed, to present the rationale for conducting such studies, and to justify the funds, vessel-time, and manpower needed.

In the late 1950's and early 1960's, the Bureau of Commercial Fisheries, Seattle Biological Laboratory, under the supervision of the American Section of the International North Pacific Fisheries Commission, was studying the oceanography of the entire Subarctic Pacific Region aboard fishing vessels 20-30 m in length. Then, the Environmental Science Services Administration (ESSA) received a mandate to conduct oceanographic studies in the Pacific Ocean; and, for several years conducted oceanographic observations along basically 2 meridians between the Hawaiian and Aleutian Island from vessels in excess of 100 m in length. These multi-million dollar studies resulted in a single research paper that was of minor relevance to INPFC studies.

Although the main thrust of oceanographic studies, especially the studies of ocean processes, has been in the universities in Northwest USA, these institutions have contributed very little to the fisheries oceanography proper. The reasons for the lack of marine fisheries oriented studies in the universities might be manifold: interdisciplinary subjects are seldom popular in universities; fisheries oceanography studies have to be conducted hand in hand with fisheries survey works, but there is often no suitable fishing gear and no perannual sampling programs in the universities; and, there is a lack of persistency for long-lasting studies in the universities and a corresponding lack of common data systems required for such studies.

2. Empirical Correlations in Past Fisheries Oceanography Studies and Need for Causal Mechanisms.

In many interdisciplinary studies it is common to attempt to find correlations between phenomena and resulting conditions in the two (or more) different disciplines. Correlation studies are especially numerous in fisheries oceanography; for example, possible relations between the surface temperature at a coastal station and landings of fish along the coast. Seldom, if ever, has thought been given to possible mechanisms of these correlations. Indeed the field of fisheries oceanography has been simplified and banalized with these such often meaningless correlation "studies".

Radovich (1982) analyzed what we have learned from the collapse of the California sardine fishery and showed that many simplified generalizations were presented, e.g., that climate (temperature) changes were responsible for the replacement of the sardine by the anchovy. In reality, the circumstances were more complex and more variable. For example, considerable north-south migrations and shifts of populations occurred which had no relation to temperature. In fact, there were population shifts between different years quite opposite of those which might have been deduced from temperature anomalies. There were variable but independent spawning successes in different areas. Furthermore, there were considerable changes in the predator populations.

Although various correlation studies in fisheries oceanography will undoubtedly continue, it seems to be necessary to emphasize the importance of selecting variables in these studies which could be meaningfully related through cause and effect. Surface temperature and demersal fish are rarely related, unless surface temperature can be considered as an index for bottom temperature or for changes in currents.

The scale of ocean variability is another factor requiring serious consideration. Little value can be given to monthly and/or seasonal anomalies if short term (days or weeks) fluctuations have considerable greater magnitude than those monthly anomalies.

Progress in fisheries oceanography studies can be made when we base these studies on known cause-effect principles and create continuity in space and time. This can be done with numerical simulation studies which consider the total environment and total biocoenosis together - i.e., total (or holistic) ecosystem simulations.

Additional reasons for the sluggish activity in the past of fisheries oceanography studies and the absence of diagnostic/prognostic services for fisheries are: First, the fisheries biologists have been mainly engaged in a descriptive phase (survey and species specific studies); and second, modeling efforts in the past have emphasized single species models, which are no longer adequate. However, these two phases (descriptive and simple modeling) must precede a complex and comprehensive ecosystem approach. A third reason is that the environment-resource interaction studies have been lagging in fisheries research; the funds for oceanographic research have been funneled to other bodies who have not cared to consider fisheries problems or needs. Fisheries oceanography has specific objectives and approaches and must be pursued concurrently with other fisheries research objectives.

In order to pursue fisheries diagnostic/prognostic service developments, the National Marine Fisheries Service needs a clear mandate for this approach. This is at present lacking. In addition, some funds, proper scientific-technical personnel, and research/survey vessel time is required. Cooperation with other organizations in the basic data gathering is imperative. Above all, fisheries oceanography must take a holistic approach in which ecosystem simulation is a central part.

Ecosystem simulations must include all pertinent environment and biological data and knowledge. Present limitations in respect to data are severe, but there are some ways to derive the necessary data indirectly (e.g., some oceanographic data are simulated from meteorological driving forces). These ecosystem simulations guide our future research and prioritize data collections. Before discussing the present state of art in numerical simulation and numerical rendering, we need to review the present situation with regard to data availability.

3. Nature and Availability of Data and Methodology of Numerical Rendering.

The physical oceanographic data collected in the past are available in NODC, provided all institutions have followed the requirements of data submission levied upon them at the time of funding. These data are inadequate for construction of any synoptic or quasi-synoptic picture, due to their sparsity and the short-term variability of the ocean. Any conclusion about the anomalies over larger areas would be uncertain, as the anomalies have relatively small space and time scales. An attempt to analyze the anomalies in two areas in the Bering Sea are shown in Figure 1 (Ingraham, pers. comm.).

The available physical oceanographic data from hydrographic casts, mechanical and expendable bathythermographs have recently been analyzed into atlases of monthly values (Robinson and Bauer 1976). The original, error-checked data and space and time averaged values are also available in numerical form.

The oceanographic data from the Bering Sea is sparse indeed and very unevenly distributed in space and time (Table 1). Surface and bottom temperatures from this area have recently been analyzed into monthly means, with the number of observations also indicated (Ingraham 1981) (Figure 2).

Sea surface temperature (SST) is the only parameter which can be analyzed in synoptic time scale (Wolff, Carstensen, and Laevastu 1967) (Figure 3). However, in some areas (e.g., in the Bering Sea and northern Gulf of Alaska) these analyses are unreliable due to lack of synoptic data. Sea surface temperature is of little use directly in fisheries oceanography, as it does not indicate conditions in the water

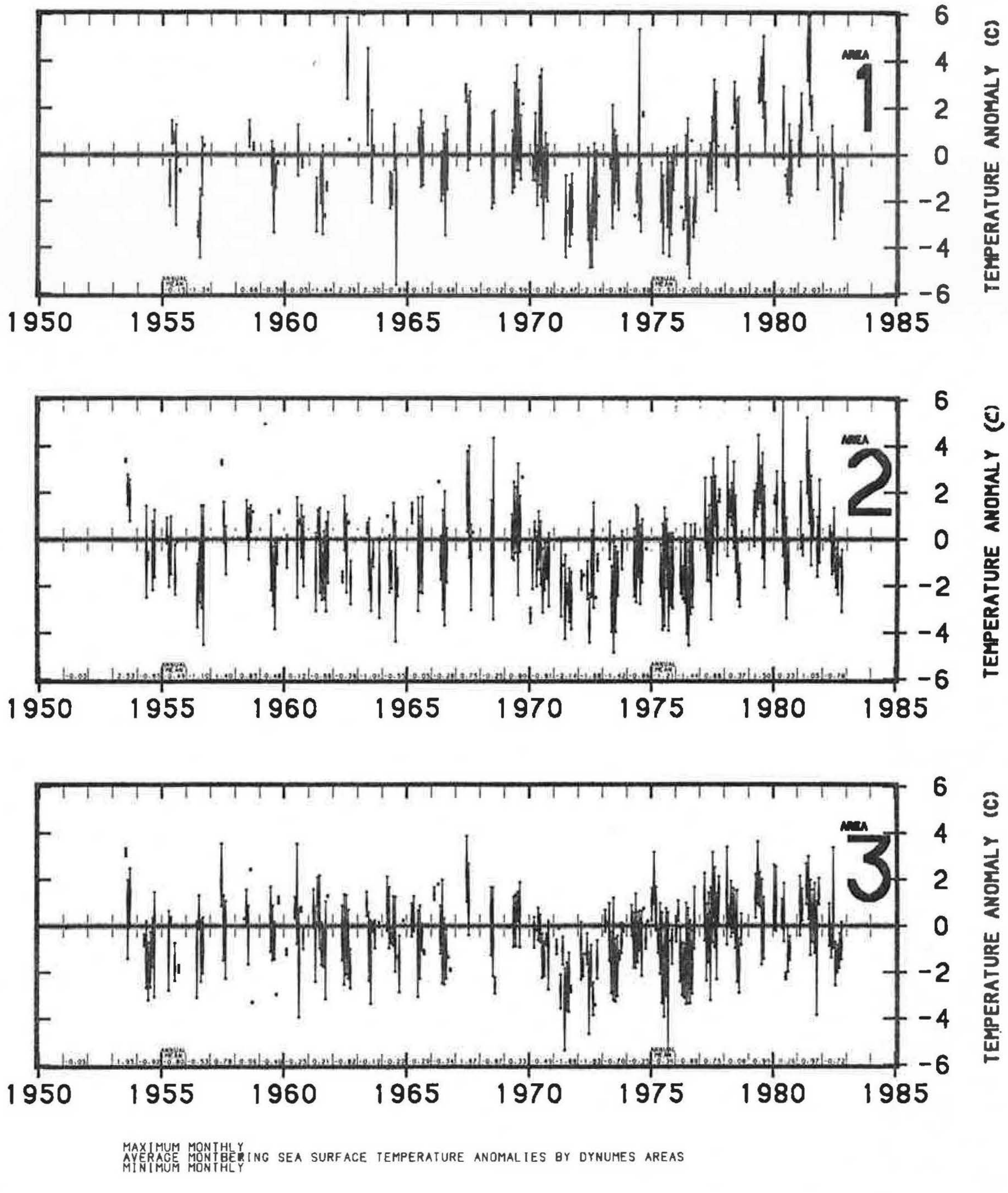

Figure 1.--Maximum, average, and minimum monthly bottom temperature anomalies in three areas in the Bering Sea from 1930 to 1982 (Area 1, eastern Bristol Bay; Area 2, south-central Bering Sea; Area 3, continental slope region) (Ingraham, pers. comm.)

Table 1.--Number of near bottom temperature values in the Bering Sea by year and month with totals (Ingraham, 1981).

YEAR \ MONTH=	1	2	3	4	5	6	7	8	9	10	11	12	TOTAL
1932	0	0	0	0	0	0	6	106	12	0	0	0	124
1933	0	0	0	0	0	0	16	78	0	0	0	0	94
1934	0	0	0	0	0	0	19	65	0	0	0	0	84
1935	0	0	0	0	0	0	0	20	0	0	0	0	20
1936	0	0	0	0	0	0	0	0	0	0	0	0	0
1937	0	0	0	0	0	74	52	12	27	0	0	0	165
1938	0	0	0	0	0	0	0	116	75	0	0	0	191
1939	0	0	0	0	14	91	134	93	6	0	0	0	338
1940	0	0	0	0	0	0	70	69	0	0	0	0	139
1941	0	0	0	0	22	11	23	0	0	0	0	0	56
1942	0	0	0	0	0	0	0	0	0	0	0	0	0
1943	0	0	0	0	0	0	0	0	0	0	0	0	0
1944	0	0	0	0	0	0	0	0	0	0	0	0	0
1945	0	0	0	0	0	0	0	0	0	0	0	0	0
1946	0	0	0	0	0	0	0	0	0	0	0	0	0
1947	0	0	0	0	0	0	9	4	0	0	0	0	13
1948	0	0	0	0	0	0	11	6	0	0	0	0	17
1949	0	0	0	0	0	0	10	70	0	0	0	0	80
1950	0	0	0	0	0	0	0	0	0	0	0	0	0
1951	4	22	0	0	0	0	0	0	0	0	0	0	26
1952	0	0	0	0	0	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	14	40	9	0	0	0	63
1954	0	0	0	0	25	2	26	9	27	0	0	0	89
1955	0	0	24	27	15	40	8	2	2	0	0	0	118
1956	0	0	0	0	0	0	4	14	8	0	0	0	26
1957	0	0	0	0	0	9	15	29	0	0	0	0	53
1958	0	0	0	0	1	13	50	16	7	0	0	0	87
1959	0	0	0	0	0	33	55	33	29	1	0	0	151
1960	3	15	0	0	0	1	150	81	14	23	0	0	287
1961	0	0	5	47	1	33	80	41	122	3	0	0	332
1962	0	0	0	0	1	20	36	3	151	21	0	0	232
1963	0	0	0	0	0	15	44	11	2	0	1	0	73
1964	0	0	9	15	6	30	41	43	1	1	1	0	147
1965	0	0	3	2	1	28	58	1	0	0	0	0	93
1966	0	3	0	0	1	100	127	31	0	0	0	0	262
1967	0	0	0	0	3	74	93	93	0	0	0	0	263
1968	0	39	0	0	0	26	228	13	0	0	0	0	306
1969	0	15	4	111	67	152	112	60	1	0	0	0	522
1970	1	12	21	35	43	61	13	95	42	11	0	0	334
1971	0	0	8	7	0	85	16	46	52	0	0	0	214
1972	0	1	3	0	24	50	103	51	12	3	0	0	247
1973	0	0	0	25	3	31	80	22	1	0	0	0	162
1974	0	0	1	13	1	9	73	27	0	4	0	0	128
1975	2	1	5	1	29	75	62	141	190	78	22	0	606
1976	0	0	47	60	135	179	39	199	236	111	0	0	1006
1977	0	26	11	48	213	73	114	150	177	10	0	0	822
1978	0	6	0	145	165	170	9	1	0	0	0	0	496
1979	0	0	0	103	139	120	0	0	0	0	0	0	362
TOTAL	10	140	141	639	909	1605	2000	1891	1203	266	24	0	8828

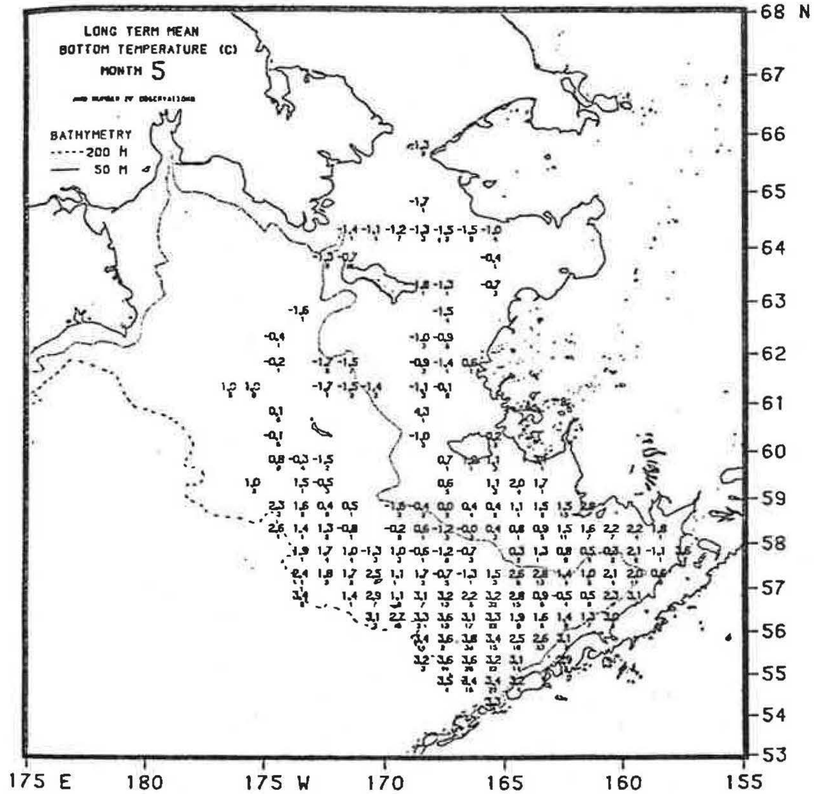

Figure 2 --Long term May near bottom temperature (°C). (Ingraham,1981)

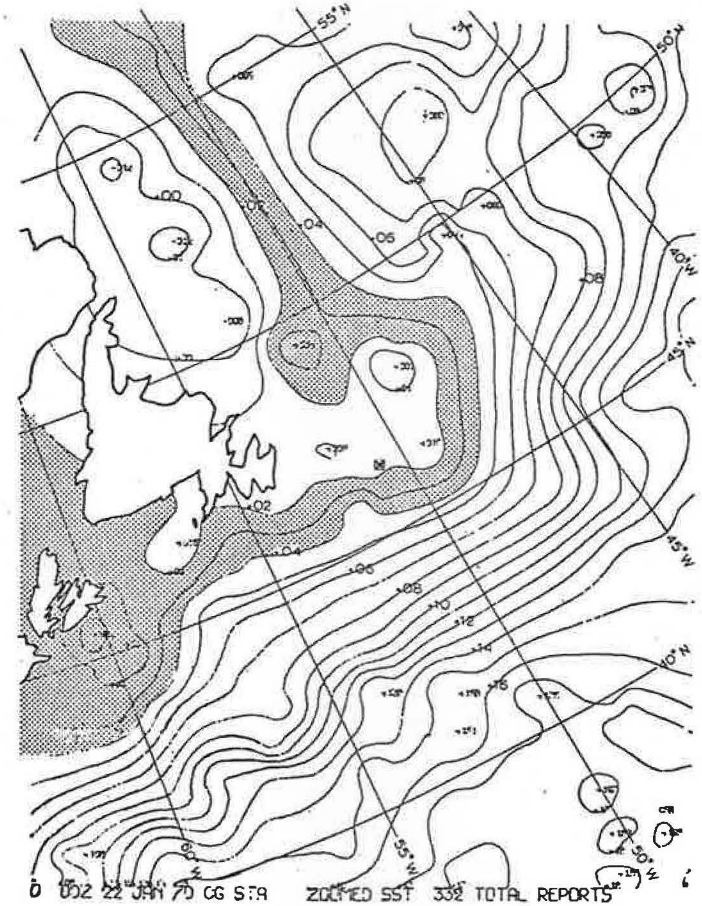

Figure 3.--Sea surface temperature analysis off Newfoundland-Grand Banks area on 22 January 1970. (The areas with temperatures from 2 to 4°C are hatched. Best cod catches during winter are made from this temperature range.) (Laevastu and Johnson, 1971.)

mass nor on the bottom (except during winter in high latitudes). Although SST anomalies have often been used in "correlation studies" in fisheries, it is very questionable that in the case of a 2°C anomaly (which is about an average anomaly) a fish would make a 200 km migration to find an optimum temperature, when it can find the same optimum temperature by moving a few meters in the vertical.

Other oceanographic parameters of possible interest to fisheries oceanography include mixed layer depth and surface currents which can be computed using data from surface meteorological analysis (mainly surface wind) (Figure 4). These ocean properties vary considerably over short periods, and meaningful values cannot be computed with monthly means of surface wind data. Twice daily analyses of these parameters must be made from which monthly means can be computed. At present this work is not done in any numerical meteorological center, mainly because little or no need has been expressed for these products.

Surface meteorological analysis (including surface wave analysis) is conducted in a few meteorological centers and the data archived. In the last fifteen years no daily surface meteorological analyses have been published in the USA. However, their publication has been taken up by the European Center for Medium Range Weather Forecasting (Figure 5). Some northern hemisphere surface wind data have been worked up by Larson (1975), but most of it is unpublished (Figure 6).

The state and availability of fisheries data for fisheries oceanography studies is as, if not more, complicated than for environmental data, especially in the Bering Sea and Gulf of Alaska. The only reasonably reliable data in respect to resource abundance are those from a few extensive resource surveys after 1975. Even these data need to be interpreted in the light of survey conditions and the gear used.

The lack of fisheries data from the NE Pacific is caused by too few research and survey vessels, dictated by the unavailability of funds. If there are about 15 to 20

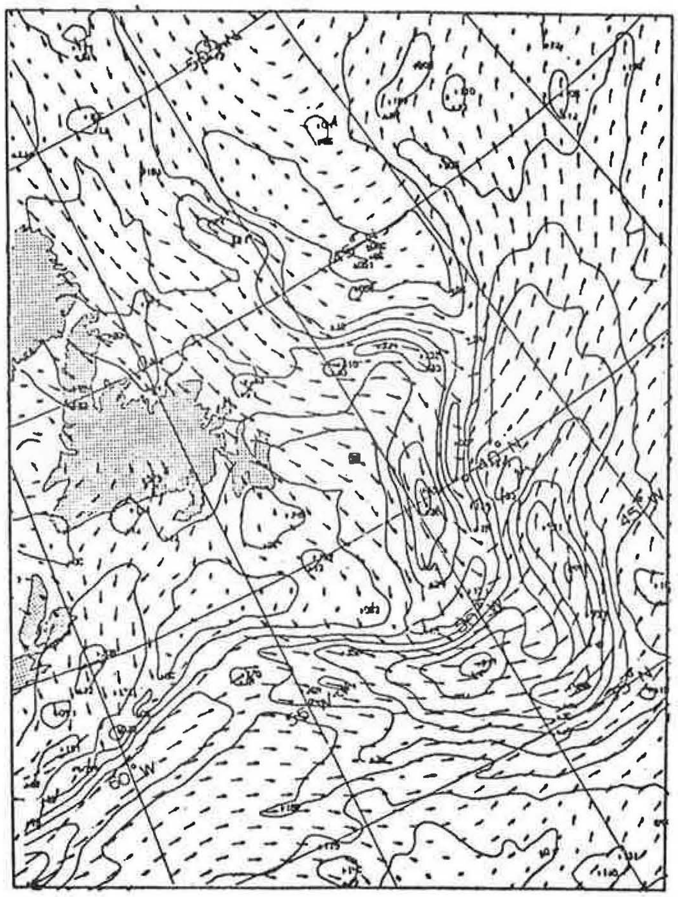

Figure 4.--Surface current analyses in the area of Grand Banks, 3 October 1970. (Isolines indicate current speeds.) (Larson and Laevastu, 1972.)

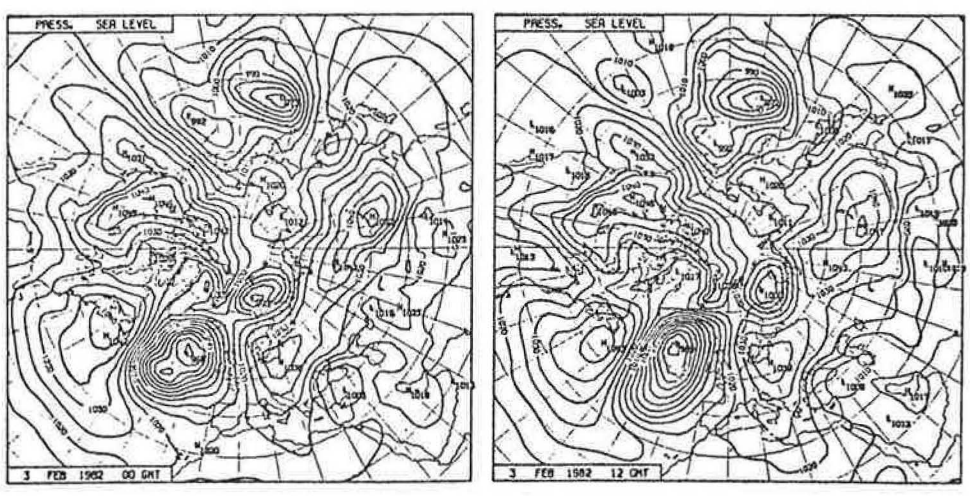

Figure 5. --Surface pressure analyses on 3 February 1982 (00 and 12 GMT) (European Centre for Medium Range Weather Forecasts, 1983.)

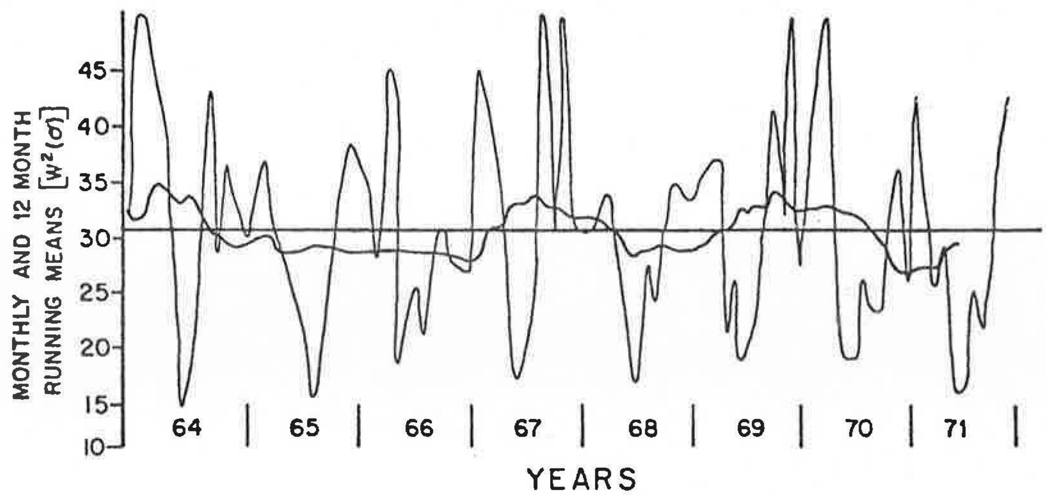

Figure 6.--Monthly mean standard deviation of surface wind speed square and 12-month running means off the Washington-Oregon coast from 1964 to 1971, indicating the variations in winter wind speeds (Larson, 1975; Favorite, Laevastu, and Straty, 1977).

REPRODUCTION, LARVAL SURVIVAL

- Reproductive potential
  - Number of spawners, maturation
    - Temperature anomalies (effect on maturation, displacement of spawning)
    - Food availability (starvation) (effect on maturation)
  - Survival of eggs, larvae
    - Predation on eggs, larvae (abundance, distribution of predators)
    - Dispersal, (transport, mixing)
    - (Availability of proper food)

PREFISHERY JUVENILES, RECRUITMENT

- Abundance, distribution, survival
  - Transport, migrations
    - Currents
  - Predation, survival (including recruitment from larvae)
    - Presence of predators
    - (Availability of other food for predators)
  - Growth
    - Temperature (especially winter season)
    - Availability of food (for larvae)

EXPLOITABLE STOCK, FISHABILITY

- Recruitment from juveniles
- Distribution, abundance
  - Predation by mammals
  - Availability to fishery
    - Environmental anomalies (affecting seasonal migration)
- Fishability of grounds
  - Type and roughness of bottom
  - Weather and sea conditions
- Behavior in respect to gear
  - Diurnal behavior
  - Visibility of gear
  - Interspecies interactions with respect to gear
  - Temperature effects on gear avoidance

Figure 7.--Processes and conditions in fish stocks potentially affected by the environment.

vessel years spent in fisheries research in the North Sea, then the corresponding number for an area of concern four times larger in the NE Pacific is about 2 vessel years.

Any fish catch and/or landing statistics which exist do not necessarily reflect the abundance and availability of most of the resources for a number of reasons: First, the changing capacities of fleets and changing market conditions affect the catches and landings. Second, catches are affected by weather conditions during the main fishing seasons. Third, the fleets frequent known fishing grounds and catch (and sample) thus only particular parts of the stocks. There have also been changes in gear. Fourth, the reports of foreign catches in earlier years are highly suspect and in recent years they have been controlled by quotas rather than by fish abundance.

4. Some Open Avenues for Numerical Simulation in Fisheries Oceanography

In the past a great number of single purpose models have been used in fisheries population studies. Although some believe that a model must be useful but not necessarily truthful, the present author does not share this view. Single purpose models ignore crucial complexes and present bogus answers. Small models do not capture the real world.

Rationalistic, holistic simulations on the other hand, should reproduce the total ecosystem realistically and the computers are used to process the complexities. Methods in these simulations are selected to fit the problems. The organism, its behavior and physiological needs prevail in the ecosystem; the most important being the interactions between organisms. The organisms are controlled by the quantity (and quality) of materials (mainly as food) present in the system - a minimum requirement applies with the recognition that most organisms are mobile and can search for food. The organisms are also controlled by their tolerance to environmental factors but limits to their tolerance are wide.

The marine ecosystem contains a complex web of interactions among species (e.g., one species preying upon the other) and between the species and the environment. As there is an intense competition for living space and food in the marine ecosystem, the removal of part of one component of this ecosystem by a fishery alters the balance (or imbalance) in the ecosystem and can result in an increase and/or decrease in other components.

The only known dynamic marine ecosystem model that includes environmental processes in it and that permits simulation of the steady state as well as the dynamics of the standing stocks of species in space and time as affected by interspecific interactions (e.g., predation), environmental factors (e.g., temperature, currents), and the activities of man (e.g., fishing), has been formulated at the NWAFC (Laevastu and Larkins 1981).

This simulation has relatively small space and time resolution and has been used for a variety of environment-fish interaction studies based on known cause-effect principles. This model can also be coupled to atmospheric models. Furthermore, meaningful short-term fisheries prognoses (which are the only meaningful prognoses - Zemskaya 1980) can be made with this simulation.

The "defined oceanographic features", such as fronts, are emphasized in fisheries oceanography, but they fail to influence effectively the aggregation, distribution, feeding differences, etc. of the species. There are no "fronts" in bottom layers, except where a thermocline intercepts the bottom. There are, however, a great number of processes on short term to interannual time scales, which can be studied with simulations. Climatological variations can explain some variations in e.g., larval recruitment; although, these climatological studies do lead to sea-air interaction problems which are at present largely excluded from ecosystem simulation.

The environment-fish interaction problems in relation to fishery research are listed in Figures 7 to 11. Figures 7 and 8 display the need for knowledge of

PAST THERMAL HISTORY (ANOMALIES)
- Time of maturation (delay of spawning)
- Growth, including effects of food availability

THERMAL ANOMALIES (PRESENT)
- Displacement of spawning
- Growth of biomass
- (Availability of food for larvae)

THERMAL STRUCTURE WITHIN DEPTH
- Availability, diurnal behavior (re. thermocline)
- Distribution and abundance of demersal fish

CURRENTS (WIND CURRENT ANOMALIES)
- Transport (eggs, larvae)
- Mixing, transport of food (e.g., plankton)
- Effects of currents on migrations
- Advection of ice

Figure 8 .--Environmental effects on fishery resources and their exploitation.

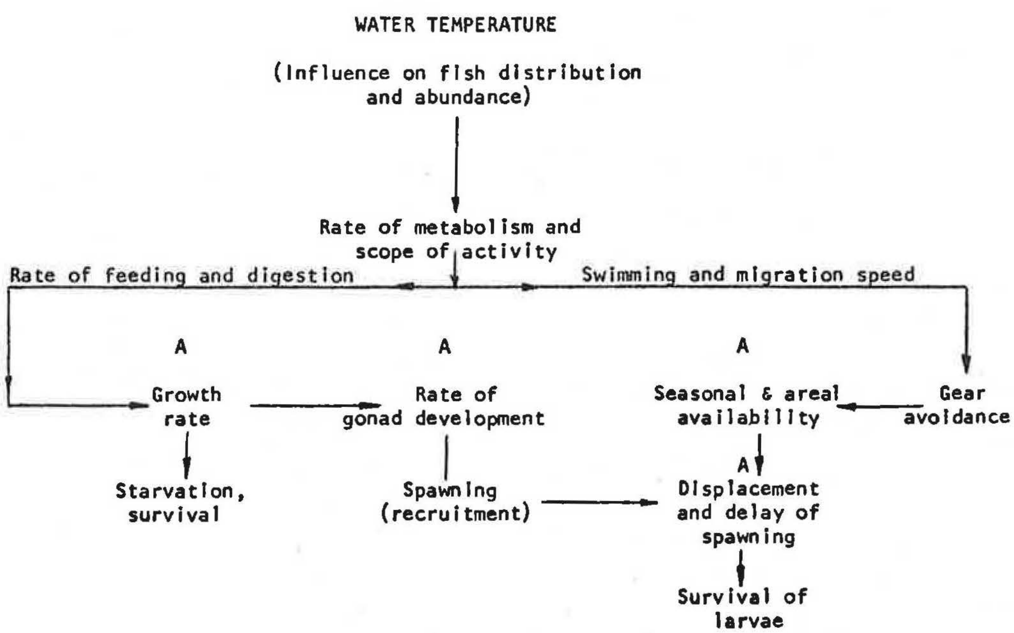

Figure 9.--Schematic presentation of the effects of water temperature on the abundance, availability, and distribution of fish. Subjects marked with A are those where year to year anomalies occur which could be monitored for fisheries prediction purposes.

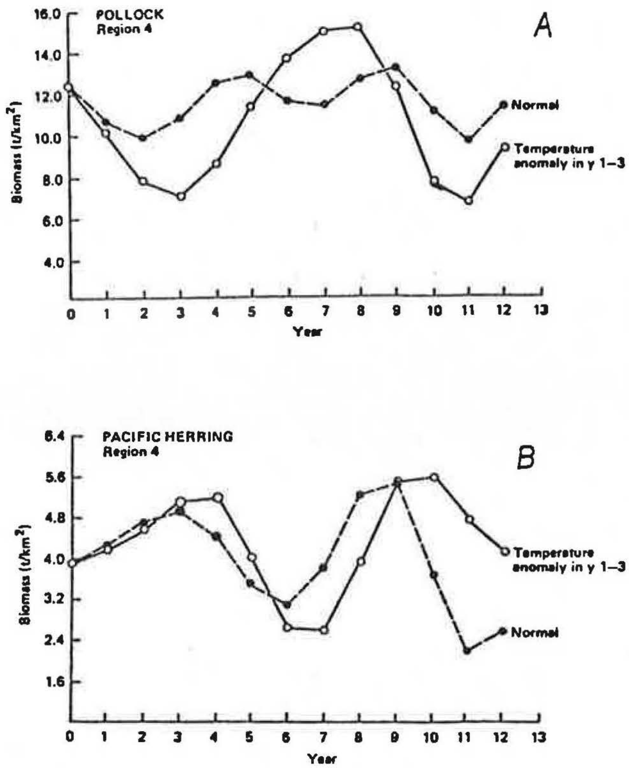

Figure 10--A-Changes of pollock biomass (in t/km^2) with time in Region 4 in normal conditions and with temperature anomaly in years 1 to 3. B-Changes of Pacific herring biomass (in t/km^2) with time in Region 4 in normal conditions and with temperature anomaly in years 1 to 3. (Temperature anomalies: -1.5; -2.5; -1.5°C, respectively.)

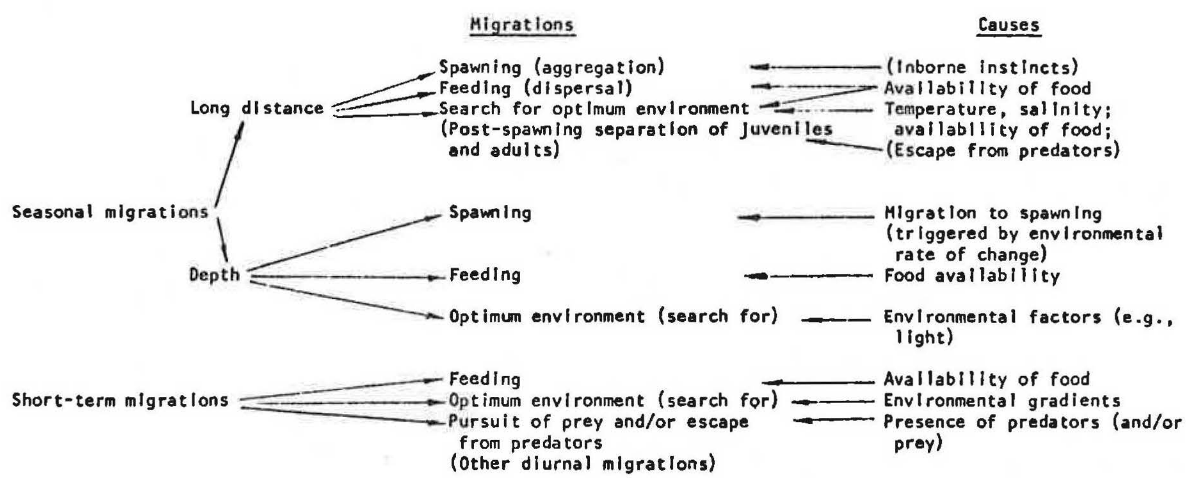

Figure 11--Scheme of environmental causes of migrations.

environment-fish relations and study by conventional subject matter of fisheries research. Figure 9 shows the possible effects of temperature on the single species as well as on stocks.

Figure 10 shows the effect of temperature anomalies on two species in the eastern Bering Sea (pollock and herring), as computed with ecosystem simulation, mediated through the well-known temperature effect on growth as the causal factor. Although temperature affects the abundance of pollock directly, its influence on herring as a forage species is mainly through changed predation pressure. Figure 11 illustrates the complexities of environment-fish interactions caused by migrations.

To summarize: Fisheries oceanography presents complex problems, the solutions of which require more data through continuous, planned monitoring and application of holistic ecosystem simulations. Simple models lead only to a "superabundance of speculative models of doubtful reliability". Holistic simulations, though using methematical statements, should not be based on assumptions that a given mathematical formula represents the behavior of nature, but rather on empirical knowledge and its quantitative reproduction - it should never enter the "dark age of barren formalism" (Skellam 1972).

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