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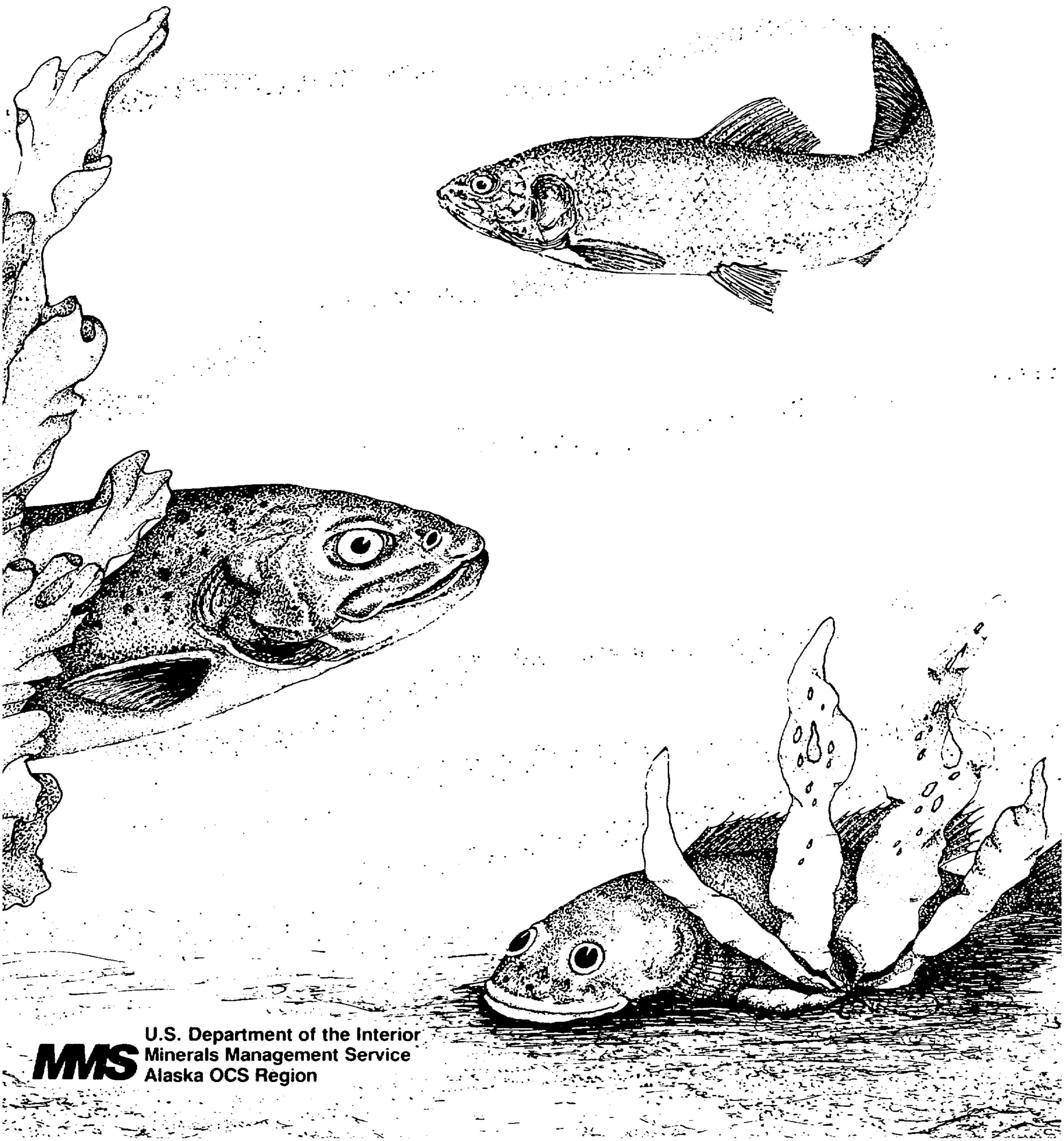
Fisheries Oceanography - A Comprehensive Formulation of Technical Objectives for Offshore Application in the Arctic

Workshop Proceedings



MMS
U.S. Department of the Interior
Minerals Management Service
Alaska OCS Region

OCS Study MMS 88-0042

Fisheries Oceanography
A Comprehensive Formulation of Technical Objectives for Offshore Application in the Arctic

WORKSHOP PROCEEDINGS

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ABSTRACT

At the time of this meeting, the Minerals Management service (MMS) was planning a multiyear study of arctic fishes. The objective of the study was to determine what fish resources are potentially at risk from oil and gas activities in the Arctic. To assist MMS personnel in identifying technical objectives for the study, MMS invited some 50 fisheries biologists and oceanographers to participate in a workshop (April 5-7, 1988) on arctic fishes. The workshop format consisted of authors presenting papers dealing with specific topics followed first by a question-and-answer period and finally by concurrent working sessions. The papers and working sessions focused on the following topics: biogeography, nearshore oceanography, species and limiting factors, habitat relationships, causes and effects, methodologies, and interagency coordination.

Participants in the workshop identified, on a regional basis, two fish-resource groups that appear to be separated on the basis of the basin configuration and terrestrial topography. In the Beaufort Sea, fish resources include Arctic char, Arctic cisco, broad whitefish, Arctic cod, least cisco, and fourhorn sculpin. In the Chukchi Sea, fish resources include Arctic char, pink and chum salmon, Arctic and saffron cod, Pacific sand lance, capelin, and Pacific herring. Species of significant value as resources for user groups (commercial and/or as monitoring species for protection agencies) that should be included in the Beaufort Sea are Pacific herring and Arctic and starry flounders.

Pacific herring are particularly sensitive because they spawn in and/or on beaches, and larvae rear in the protected embayment along the Tuktoyaktuk Peninsula.

Important needs identified were (1) population size and distribution of important species, (2) attributes that characterize each population, (3) age structures, (4) length of time they have occupied their niches in the Arctic, (5) reproductive requirements, (6) fecundity rates, (7) special habitat requirements, and (8) seasonal distribution and habitat requirements. (Because most of the information on arctic fishes has been collected during the ice-free season, little is known about what many fish species do during the winter months, when marine and fresh waters are covered with ice.)

Workshop participants also concluded that the technologies needed to collect information on arctic fish resources are available but that new methods need to be developed, e.g., active fish sampling, icebreakers, and sampling in shallow water under the ice.

In addition, interagency coordination was identified as an important need for efficient and productive research in the Arctic. Participants concluded that an organization was needed to coordinate study objectives and logistic support of fisheries research in the Arctic to minimize duplication of effort and to maximize data comparability. Following the workshop, an ad hoc committee (the Arctic Fish Technical Coordination Committee) was formed. Participating on the committee are representatives from Federal, State, and local agencies; the University of Alaska; and the oil and gas industry. The committee plans to meet quarterly to discuss the status of current research projects and to coordinate planned research projects.

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"Would you tell me, please, which way I ought to go from here?" "That depends a good deal on where you want to get to," said the cat. "I don't much care where . . ." said Alice. "Then it doesn't matter which way you go," said the Cat. " . . . so long as I get somewhere," Alice added as an explanation. "Oh, you're sure to do that," said the Cat, "if you only walk long enough."

Chapter 1

Fisheries Oceanography--A Comprehensive Formulation of Technical Objectives for Offshore Application in the Arctic

Introduction/Summary

The Minerals Management Service (MMS) of the U.S. Department of the Interior (USDOI) has a mandate to manage the leasing, exploration, and development of oil and gas resources on the Outer Continental Shelf (OCS). The MMS must oversee these resources in a manner that is consistent with the need to:

- make such resources available to meet the Nation's energy needs;
- balance orderly resource development with protection of human, marine, and coastal environments;
- ensure the public a fair and equitable return on the resources of the OCS; and
- preserve and maintain free enterprise competition.

The discovery of oil in commercial quantities at Prudhoe Bay in 1986 accelerated industrial development in the American Arctic (Tremont, 1987). By July 1988, 20 years after the initial Prudhoe Bay discovery, eight Alaskan offshore wells in the Beaufort Sea had been determined to be commercially producible. The specter of industrial activities in the Arctic has raised concerns about the potential effects that offshore oil- and gas-related activities may have on arctic ecology. In 1975, the USDOI--as part of its OCS leasing program-initiated an environmental studies program to determine what arctic resources were at risk from potential oil and gas activities and to assess the possible effects on these resources. Studies initially focused on identifying and mapping the aerial and temporal distribution of natural resources in the region that might be affected by offshore oil and gas activities. These studies evolved into more integrated ecosystem-process studies such as the Beaufort Sea barrier island-lagoon system study (Truett, 1982) and the arctic fish habitats and sensitivity study (Outer Continental Shelf Environmental Assessment Program, 1988). In addition, numerous studies recently have been conducted in the Arctic by public and private agencies to resolve site-specific issues in response to specific permit needs, i.e., the Waterflood Project and Endicott Causeway studies. These studies have resulted in large amounts of information and provide a strong base for the development of more regional or population-level studies.

The MMS initiated a fisheries oceanography study in the Arctic (Beaufort and Chukchi Seas) in 1989. To access the accumulated research experience and knowledge of fishes in the Arctic, MMS coordinated a meeting of fisheries scientists currently working on arctic problems to review the status of fish information in the Arctic and to develop objectives and methodologies for the proposed study. The initial meeting was conducted as part of the Beaufort Sea Information Update Meeting (MMS, 1988) in November 1987. Because of the amount of new information that needed to be reviewed and the amount of analysis needed to develop the guidance sought by MMS, participants recommended that MMS conduct a workshop to identify information needs and to discuss study coordination. Based on this recommendation% MMS invited Federal and State representatives as well as those of local agencies and the oil and gas industry to participate in the planning of an arctic fish workshop.

The ad hoc coordinating committee met several times, beginning in December 1987, to coordinate and facilitate development of the workshop. The first meeting set tentative dates for the workshop, developed a draft workshop schedule, and identified potential speakers and workshop participants. Subsequent meetings focused on specific details of the workshop. A post-workshop meeting was also held to critique the project and to discuss future coordination efforts.

Workshop objectives identified by the coordination committee included the following

- review and synthesize pertinent "information on fisheries resources in the Arctic;

- identify and discuss important ecological-process information needed to evaluate and predict the potential effects of oil and gas activities (e.g., potential habitat degradation and alteration) on arctic fish resources;

- identify, discuss, and recommend study objectives, data-collection methodologies, and analytical procedures pursuant to the immediately preceding objective, and

- identify other ongoing and planned fisheries-related studies in the Arctic and explore methods for coordinating logistics, sampling, and analytical activities associated with these studies to eliminate duplication of efforts.

The coordinating committee included representatives from MMS, U.S. Army Corps of Engineers, Fish and Wildlife Service, Environmental Protection Agency, National Oceanic and Atmospheric Administration (Ocean Assessment Division and National Marine Fisheries Service), Bureau of Land Management, State of Alaska Department of Environmental Conservation North Slope Borough, Atlantic Richfield Company, EXXON, and Standard Alaska Production Company. Marine Biological Consultants of Costa Mesa was retained by MMS to facilitate the workshop and to provide transcripts of workshop discussion sessions. A list of meeting participants is presented in Appendix A.

The workshop was organized around six formal presentations on four primary topics--biogeography, nearshore oceanography, species and limiting factors, and habitat relationships (see Appendix B, Workshop Agenda). Discussion sessions followed each of the primary workshop presentations. Additional sessions focused on cause-and-effect linkages, methodologies, and interagency coordination. Each session was led by a facilitator, and discussion highlights were recorded by a scribe. Following each suite of discussions, meeting participants met in plenary sessions to summarize discussion-session results and conclusions. Results of the workshop were summarized by MBC Environmental Consultants as follows:

1. Future research effort on fish in the Arctic should determine a) what resources are at risk from the potential environmental effects of oil and gas development and b) what the risks are to those resources.

2. Major fish resources in the Arctic appear to be separated geographically into those most dominant in the Chukchi Sea and those in the Beaufort Sea.

a. In the Beaufort Sea, the more dominant species are Arctic char, Arctic and least cisco, broad whitefish, Arctic cod, and fourhorn sculpin.

b. In the Chukchi Sea, the more dominant species are Arctic char, pink and chum salmon, Arctic and saffron cod, sand lance, capelin, and Pacific herring.

3. Each of these fish resources is vulnerable to some degree; each has specific life requirements, at different lifestages, and they generally share very complex life histories. Therefore, the entire life history of each species should be examined to determine the risks to that species and where the species is vulnerable at each of its lifestages. This is a large undertaking that will require additional field and laboratory work.

4. Interagency coordination is necessary if the large amount of information needed is to be collected in a reasonable, efficient, and timely manner. There was a general consensus that a coordination body is needed to coordinate the 10 to 20 fisheries-research projects and the 100 to 150 investigators working in the area. Without the coordination, the workshop participants felt that research in the area would continue as a series of site-specific studies, each making minimal contribution to the information base because of noncompatible sampling protocols or analytical methods or because the information needed to link studies was not collected.

Chapter 2

Overview of Fishes Occurring in the Alaskan Arctic

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This chapter summarizes and incorporates by reference fish-related discussions contained in the Sale 87 final environmental impact statement (EIS) (USDOI, MMS, 1984), the Beaufort Sea Sale 97 final EIS (USDOI, MMS, 1987), the Chukchi Sea Sale 109 final EIS (USDOI, MMS, 1988), and the Norton Basin Sale 100 final EIS (USDOI, MMS, 1985), augmented with additional information, as cited.

Overviews of the fish resources occurring in the Chukchi and Beaufort Seas have been provided by Craig (1984a and b), Dome Petroleum Ltd. et al. (1982), Morris (1981), Moulton and Bowden (1981), and Maynard and Partch/Woodward-Clyde Consultants (1984). Nearshore areas of the Alaskan Beaufort Sea have received more attention and appear to have a greater abundance of fishes than offshore areas, although less sampling has occurred offshore (see Craig [1984a] for references plus Craig et al. [1984]; Envirosphere [1985b]; and Moulton, Fawcett, and Carpenter [1985]. Craig and Skvorc (1982) provided an analysis of research on the fish resources in the Arctic. Studies that have been conducted in the northeastern Chukchi Sea since 1982 include Fechhelm et al., 1984, and Kinney, 1985.

Fishes occurring in coastal waters of the Beaufort Sea can be categorized as (1) freshwater species that make relatively short seaward excursions from coastal rivers, (2) anadromous species that spawn in freshwater and migrate to sea as juveniles and adults, and (3) marine species that complete their entire lifecycle in the marine environment. These fish are generally circum-polar in their distribution and range from the central Canadian Arctic through the Chukchi Sea and into Siberian coastal waters. Sixty-two fish species have been reported from the Alaskan Beaufort Sea (Craig, 1984a) and 72 from the northeastern Chukchi Sea (Craig, 1984b). By comparison, over 300 fish species occur in the Bering Sea and Gulf of Alaska. The lower level of species diversity in the Arctic has been attributed to low temperatures, low productivity, and harsh ice conditions that preclude extensive use of coastal habitats during the winter period.

Marine fishes appear to be more abundant than anadromous species in the Chukchi Sea and Beaufort Sea. In the Chukchi Sea, populations of anadromous species tend to be smaller and more widely distributed than those found in the Beaufort Sea--37 species of fish have been collected in the Beaufort Sea nearshore, whereas 43 species of fish have been collected in offshore marine waters. Some of the species were captured in both habitats. The areas of greatest species diversity tend to be the delta regions of large rivers draining into the Beaufort Sea. Recent studies indicate that there are physiological advantages and, probably, requirements for anadromous species to remain in these nearshore waters (Fechhelm arid Gallaway, 1982).

Some characteristics of the physical environment greatly influence the distribution and abundance, both spatially and temporally, of fishes found along the Beaufort Sea coast. In particular, the formation of a narrow band of warm, brackish water nearshore affects the movements and activities of anadromous fishes. The band of warm, brackish water is widest off the mouths of major rivers (Canning and Sagavanirktok Rivers), where it may extend 20 to 2.5 kilometers offshore.

The nearshore band of warm, brackish water is not as well developed along the Chukchi Sea coast. This may be due to nearshore currents, or the discharge of freshwater from streams may be inadequate to establish a narrow and significantly distinct body of warm, brackish water along the shoreline. Exceptions are enclosed areas such as Wainwright Inlet or Kasegaluk Lagoon.

A summary of the general biology of freshwater-, anadromous-, and marine-fish species occurring in the Alaskan Arctic follows.

Freshwater Species: Freshwater fishes that venture into the coastal waters are found almost exclusively in association with fresh or brackish waters extending offshore from major river deltas.

Table 2.1 Fyke-Net-Catch Summary for Fish Species Caught during Nearshore Summer Surveys in the Beaufort and Chukchi Seas'

	Beaufort sea				Chukchi Sea	
	Simpson Lagoon 1977	Simpson Lagoon 1978	Prudhoe Bay 1981	Sagavanirktok Delta 1982	Point Lay 1983	Peard Bay 1983
Arctic cod	7.6 (6.5)²	77.9 (1607.1)	49.2 (179.8)	27.9 (147.7)	39.0 (183.1)	69.5 (4135)
Fourhorn sculpin	69.6 (59.1)	17.9 (369.3)	23.7 (86.4)	2'7.7 (146.9)	19.8 (93.0)	23.7 (140.8)
Arctic cisco	14.7 (125)	0.8 (16.5)	15.0 (54.7)	29.1 (154.4)	0.0 (0.0)	0.0 (0.0)
Least cisco	2.3 (1.9)	1.2 (24.8)	6.6 (24.0)	2.3 (12.5)	0.01 (0.07)	0.15 (0.9)
Arctic char	3.8 (3.2)	0.9 (18.6)	2.3 (8.5)	5.1 (27.8)	0.01 (0.1)	0.0 (0.0)
Broad whitefish	0.1 (0.8)	0.2 (3.1)	0.9 (3.1)	5.6 (29.7)	0.0 (0.0)	0.0 (0.0)
Others	1.9	1.1	2.3	2.3	41.2	6.65

Sources: Craig and Haldorson, 1981 (Simpson Lagoon); Griffiths and Gallaway, 1982 (Prudhoe Bay); Griffiths et al., 1983 (Sagavanirktok Delta); Fechelm et al., 1984 (Point Lay); Kinney, 1985 (Peard Bay).

'Values are presented as percentage of total catch.
'Figures in parentheses present catch per unit of effort (fyke-net per day).

Their presence in the marine environment is generally sporadic and brief with a peak occurrence probably during or immediately following spring breakup. Such freshwater species include Arctic grayling, round whitefish, and burbot.

Anadromous Species: The discussion of anadromous fishes occurring in Alaskan arctic waters is divided into a discussion of fishes in the Chukchi Sea and those in the Beaufort Sea (see Table 2.1).

Chukchi Sea: Thirteen species of anadromous fishes (Morrow, 1980) can be found in offshore areas, estuaries, and freshwater systems during part of their lifecycles. Anadromous fishes of the Chukchi Sea include Pacific salmon, Arctic char (Dolly Varden), ciscoes, whitefishes, and rainbow smelt. Of the Pacific salmon species, only pink and chum salmon are found throughout the northeastern Chukchi Sea region; sockeye, coho, and chinook salmon are occasionally caught in coastal waters, but they generally reach their northern spawning boundary in the Point Hope/Point Lay coastal sector at Cape Lisburne. Arctic lamprey, the five salmon species, rainbow smelt, and Arctic char juveniles undertake extensive migrations from freshwater to mature at sea in the offshore areas; as adults, they return to freshwater to spawn. Other anadromous species such as broad whitefish seasonally enter the brackish or offshore-marine environment in the summer and spend most of their lives in freshwater lakes and rivers. During the summer open-water season, anadromous species range throughout the Chukchi Sea in offshore coastal waters; brackish estuaries and river mouths; and freshwater rivers, streams, and lakes. Most of the anadromous-fish species spawn in the fall in lakes or streams.

A study by *Craig* and Skvorc (1982) on the status of existing fisheries information for the Chukchi Sea region recognized that limited research has been conducted on the anadromous fishes that inhabit the coastal streams and estuaries north of Point Hope. The available information is the result of a few brief reconnaissance surveys, and virtually all of the data on anadromous fishes were collected during the open-water season.

Fechhelm et al. (1984) and Kinney (1985) studied fish in Kasegaluk Lagoon and Peard Bay as well as offshore during the open-water season, but few anadromous fish were caught. In March 1983, no anadromous fish were caught under the ice in Peard Bay, Wainwright Inlet, or Ledyard Bay (Fechhelm et al., 1984). Much of the knowledge regarding species occurrence has been documented from subsistence harvests by coastal inhabitants. In the southeastern Chukchi Sea south of Point Hope, the knowledge of anadromous-fish populations, life-history information, and habitat use has been augmented by studies directed at commercial fish stocks and detailed investigations conducted during the 1960's for Project Chariot in the Cape Thompson area.

Rainbow smelt appear to be the most common anadromous fish caught at Point Lay, but they were caught not far offshore. The smelt appeared to prefer the bottom of the water column, at least when traveling seaward The presence of apparently young-of-the-year fish in August, the report of a sexually ripe female in mid-June, the lack of extensive coastal migrations by rainbow smelt, and an apparent postspawning gonadal recovery make it likely that the Kokolik, Utukok, and Kukpowruk Rivers are spawning sites for smelt. The rainbow smelt and pink salmon around Point Lay consumed from 65 to 75 percent fish--mostly Arctic cod (Fechhelm et al., 1984).

Some investigators have suggested that the large rivers of the Chukchi coastline may be unsuitable for colonization by chinook, sockeye, and coho salmon because the juvenile lifestages of these species exhibit a marked intolerance of low water temperatures. Pink and chum salmon have been able to colonize streams farther north because of their relative independence from the freshwater lifestages (i.e., outmigration to marine environments shortly after emergence from the stream gravel). The principal stocks of pink salmon are found in the Kugrua, Kuk, Utukok, Kokolik, Kukporuk, Pitmegea, and Kukpuk Rivers. Although they may be small, chum salmon stocks are found in the Kugrua, Kuk, and Pitmegea Rivers. Arctic char are reported to be one of the main tish species caught along the coastal beaches by Wainwright residents (Nelson, 1982); however, few were caught by Fechhelm et al. (1984) at Point Lay, and none were caught by Kinney (1985) at Peard Bay. Studies of Arctic char populations in arctic Alaska suggest that separate spawning stocks with distinctive genetic makeups occur in different river drainages (Everett and Wilmot, 1987).

Beaufort Sea: Anadromous species found in the nearshore waters of the Beaufort Sea include Arctic char, Arctic cisco, least cisco, Bering cisco, rainbow smelt, humpback whitefish, broad whitefish, and pink and chum salmon. Other anadromous species recorded from the Alaskan Beaufort "include Arctic lamprey; chinook, sockeye, and coho salmon; inconnu; and ninespine and threespine sticklebacks.

During the open water season, many of the anadromous species appear to use the nearshore brackish-water habitats as feeding and rearing areas. Within this zone, fish tend to be concentrated along the mainland and island shorelines rather than in lagoon centers or offshore. With the spring breakup (June 5-20), adult and juvenile fishes move into and disperse through the coastal waters, where they feed primarily on epibenthic invertebrates.

During the 2.5- to 3-month open-water season, anadromous fishes accumulate energy reserves used for overwintering and spawning activities. The concentration of movement and feeding activities of anadromous fishes in the band of warm, brackish water nearshore has been postulated to be related most to (1) temperature and salinity regimes or (2) the concentration of prey in this area. Results from recent investigations and correlation analysis (Moulton, Fawcett, and Carpenter, 1985) suggest that fish distribution is most strongly correlated with temperature and/or salinity parameters. Food does not appear to be a limiting factor for the anadromous fishes studied.

The coastal distribution of some anadromous species (e.g., the broad and humpback whitefishes and Arctic char) reflect major geographical differences in the locations of anadromous fish stocks in North Slope rivers (Fig. 2.1). Details of distributions of the Alaskan Beaufort anadromous fishes are found in the Sale 87 final EIS (USDOI, MMS 1984); Morrow (1980); Craig (1984a); and Moulton, Fawcett, and Carpenter (1985). Because some fish--notably whitefishes and least ciscoes--do not disperse far from their rivers of origin, they show a somewhat disjunct pattern with greatest abundances near the Mackenzie River and west of the Sagavanirktok River. In contrast, those fishes that disperse widely from their streams of origin (Arctic ciscoes and some Arctic char) usually are common along the entire Alaskan Beaufort Sea coastline. An extreme example of a fish showing this latter pattern of dispersal is the Arctic cisco. Gallaway et al. (1983) suggest that all the Arctic cisco in the Alaskan Beaufort Sea are derived from a single stock that reproduces in the Mackenzie River system. Waves of fishes may disperse into Alaskan waters every 3 to 4 years, and juvenile fishes may use Alaskan rivers (in particular, the Colville and Adjacent environs) and their delta areas as overwintering habitat. Presumably, when they attain sexual maturity, they return to the Mackenzie River to spawn.

Most anadromous species return to North Slope rivers and lakes in late summer or fall. Some return later, in early winter, while others overwinter in brackish waters off or within the major river deltas (Mackenzie and Colville). One anadromous species, the rainbow smelt, shows a distinctly different pattern by overwintering in marine

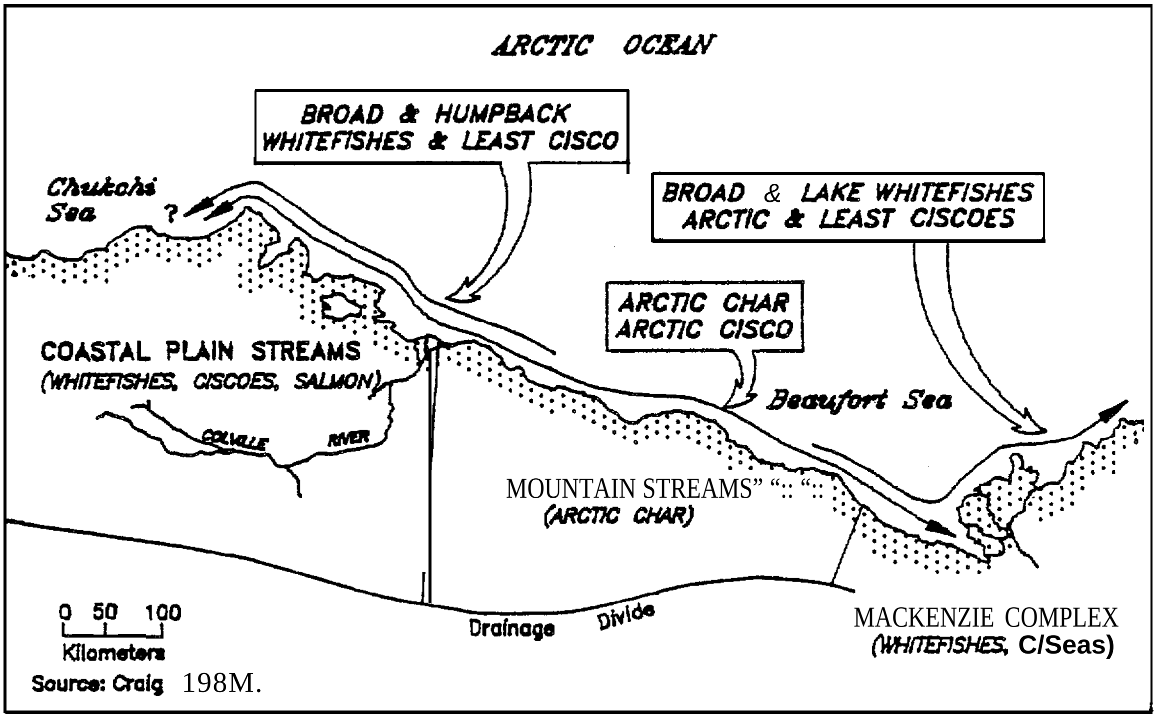

Figure 2.1 Freshwater Sources and Coastal Dispersal Patterns of the Principal Anadromous Fishes Occurring Along the Beaufort Sea Coastline

environments. Large concentrations occur off the mouths of the Mackenzie and Colville Rivers in winter. Then, in spring, the smelt migrate into the rivers to spawn.

Nearshore brackish waters, which are used by these anadromous fishes primarily as a feeding ground, contain an abundant supply of food organisms. The food habits of both anadromous and marine fishes using this zone are quite similar. Epibenthic mysids and amphipods are the primary food source of Arctic and least ciscoes, Arctic char, and Arctic cod. Other fishes may also extensively use these prey while showing preferences for other types of prey. For example, rainbow smelt and sometimes Arctic char eat fish; fourhorn sculpin and Arctic flounder eat isopods.

During the period of greatest fish abundance, in early and midsummer, there is little dietary overlap among the fish species taken in Prudhoe Bay. In late summer, as fish decline in abundance and prey increases, significant dietary overlap occurs between Arctic and least cisco, between Arctic cisco and Arctic char, and between Arctic cisco and broad whitefish. The various fish species exhibit somewhat different sets of preferences for two mysid species, amphipods, isopods, and other prey (Moulton, Fawcett, and Carpenter, 1985). Although most anadromous fishes feed in nearshore waters during the summer, both Arctic and least cisco are known to continue feeding through the winter in Colville Delta habitats.

Marine Fishes: The discussion of marine fishes occurring in Alaskan arctic waters is divided into fishes in the Chukchi Sea and those in the Beaufort Sea.

Chukchi Sea: The Chukchi Sea represents a transition zone between the fish communities of the Beaufort and Bering Seas. The fauna is basically arctic, with continual input of southern species through the Bering Strait. The marine fishes of this area include Arctic staghorn, fourhorn, shorthorn, and twohorn sculpin; Arctic cod; Canadian eelpout; Arctic flounder; and saffron cod.

The distribution of marine fish species in the Chukchi Sea appears to be influenced by temperature and salinity. Yellowfin sole and saffron cod occupy the shallower, seasonally warmer waters; Arctic cod, Arctic staghorn sculpin, and Bering flounder are usually found in deeper, colder waters. Arctic flounder, starry flounder, and fourhorn sculpin frequent the low-salinity waters near estuaries and river mouths. Fourhorn sculpin, Arctic cod, and Arctic flounder increase in abundance in nearshore coastal areas when temperature increases and salinity decreases.

Relatively few fish species have accounted for a large percentage of the fish caught during surveys conducted in this region. During otter trawl surveys conducted in the northeastern Chukchi and Beaufort Seas in early August 1977, three species (Arctic cod, Canadian eelpout,and twohorn sculpin) accounted for 65 percent of all fishes caught (Frost and Lowry, 1983). During the surveys, Arctic cod ranked fifth in biomass, although they were the dominant marine fish in numbers and in frequency of occurrence (Wolotira, Sample, and Morin, 1977). Fechhelm et al. (1984) reported that results from otter trawl and fyke and gillnet surveys conducted in the area during 1976 showed that five species (Arctic staghorn sculpin, Attic cod, shorthorn sculpin, smelt, and saffron cod) accounted for 93 percent of all fishes caught, and Arctic cod made 54 percent of the adjusted catch biomass (Fechhelm et al., 1984).

The majority of the marine fishes of the Chukchi Sea are demersal as adults; Pacific herring, capelin, and Pacific sand lance are considered to be pelagic fish as adults. It has been suggested that many of the marine fish populations are maintained by recruitment of eggs and larvae that are transported north from the Bering Sea by the Alaska Coastal Current. Fishes that probably maintain their populations by resident breeding stock include Arctic cod, saffron cod, sand lance, capelin, sculpin, and some of the flounders.

Marine fish in this region are generally smaller than those in areas farther south, and densities are much lower. Attic cod in the northern part of the area weighed significantly less per unit length than Arctic cod of the same length from the southern Chukchi Sea area (Fechhelm et al., 1984). Both the average and maximum sizes of flatfishes taken during a study of the southeastern Chukchi Sea were below the sizes accepted by U.S. commercial-fishery markets (Alverson and Wilimovsky, 1966). The same investigators also suggested that the physical climate of the Chukchi Sea may be responsible for limiting the population sizes and depressing the growth patterns of some marine fishes.

Arctic cod young-of-the-year are normally found in the upper 50 m of water, in the same zone where the greatest abundance of their food (plankton) is found. Quast (1974) estimated that more than 46 million pounds of juvenile Arctic cod were present between Cape Lisburne and Icy Cape in 1970. In many bottom trawls, adult Arctic cod are found in association with the bottom. They can also be found around ice, which may provide shelter from predators and food in the form of ice-associated invertebrates. Arctic cod are most often found around pressure ridges and rafted ice, where the undersurface of the ice is rough. The crevices, holes, caverns, and *small* ice cracks are commonly used. No large concentrations of adult Attic cod have been found in these habitats. Arctic cod spawn during winter; however, only a few of their spawning areas are known. One known Arctic cod-spawning ground is located in the nearshore waters of Stefansson Sound in the Beaufort Sea (Craig and Haldorson, 1981). It is reported that Arctic cod spawn only once (Nikolskii, 1961, as cited by Morrow, 1980).

During the summer, large schools of Pacific sand lance were reported in Ledyard Bay, north of Cape Lisburne. Marine bird-feeding studies suggest a major along-coast movement of these fish during late July and August. Sand lance spawn from November to February on sandy bottoms at depths of 50 to 75 m.

Capelin are poorly sampled by trawl surveys, and little is known of their areal abundance and distribution along the Chukchi Sea Coast. Capelin generally prefer smooth sand and gravel beaches for spawning; they have been observed spawning from early to mid-July along the sandy seaward beaches of barrier islands. During August 1 to 3, 1983,3,358 capelin caught off Point Lay apparently were part of a spawning population. Only two more capelin were caught during the rest of the study. Since no capelin were taken in Kasegaluk Lagoon, spawning may have been restricted to the seaward shoreline of the barrier islands (Fechhelm et al., 1984).

The bulk of the Pacific herring population lies south of the Bering Strait, and the density in the Chukchi Sea is currently too low to support a commercial fishery. In the spring, Pacific herring deposit eggs on vegetation or on bottom substrate that is free from silting. There was some evidence by gonadal weights and egg sizes that herring may have spawned in Kasegaluk Lagoon in the early summer of 1983; however, no trace of young-of-the-year herring was found throughout the end of the summer (Fechhelm et al., 1984). Spawning herring and young-of-the-year, however, are found in protected embayments along the Tuktoyaktuk Peninsula (Hopky, 1987, personal commun.).

Arctic flounder usually spawn in shallow coastal areas during late fall or winter. During midwinter, fourhorn sculpin spawn on the bottom in nearshore habitats. Saffron cod are marine fish that generally inhabit nearshore areas, often enter rivers, and spawn annually during the winter in nearshore waters.

Arctic cod are an important, early-season food source for the murres and kittiwakes at Capes Thompson and Lisburne, with peak numbers of cod taken by these marine seabirds during ice breakup. Swartz (1966) estimated that as many as 250 million Arctic cod are consumed annually by the Cape Thompson seabird colonies. Lowry, Frost, and

Burns (1979) identified Arctic cod as a key prey species for spotted and ringed seals and beluga whales in the Chukchi Sea. Summer distributions of Arctic cod are unknown; however, large schools reportedly form in the fall and approach the coast and warm waters near river mouths. Large numbers of this species are occasionally stranded on beaches because of storms or possibly because of attempts to escape predation by whales. Other marine fishes that are important prey of marine mammals and seabirds in the Chukchi Sea include Pacific sand lance, capelin, Pacific herring, saffron cod, sculpins, and smelt.

Capelin and Pacific herring appear to feed mostly on Mysis littoralis. During the summer, Arctic cod also eat mysids, but their diet varies from place to place and includes copepods and amphipods. During the winter in Ledyard Bay, Wainwright Inlet, and Peard Bay, copepods are the principal food item for Arctic cod. Saffron cod near Kotzebue and St. Lawrence Island appear to feed on fish (saffron cod and sculpin species) and gammarid amphipods. Fourhorn sculpin consume mostly isopods in both the lagoon and ocean environments, and Arctic flounder feed on polychaetes and unknown worms. Sand lance fed primarily on small planktonic crustaceans.

Beaufort Sea: Marine species in the Beaufort Sea have received much less attention than the region's anadromous species. In *general, they* appear to be widely distributed but in fairly low densities, with schooling species such as Arctic cod displaying a rather patchy distribution. Forty-three marine species have been reported from the Alaskan Beaufort Sea, with some found primarily in the brackish, nearshore waters and others in the marine, offshore waters. The most widespread and abundant species are Arctic and saffron Cod, twohorn and fourhorn sculpin, Canadian eelpout, and Arctic flounder.

Some marine species, for example, such as Arctic cod and capelin, sporadically enter the nearshore areas to feed on the abundant epibenthic fauna or to spawn. Others, such as fourhorn sculpin and flounder, remain in coastal waters throughout the ice-free period, then move farther offshore with the development of the shorefast ice during the winter. The Arctic cod has been described as a key species in the ecosystem of the Arctic Ocean due to its widespread distribution, abundance, and importance in the diets of marine mammals, bird, and other fishes. This species is considered to be the most important consumer of secondary production in the Alaskan Beaufort Sea and may influence the distribution and movements of marine mammals and seabirds.

Fourhorn sculpin are among the most widespread and numerous species along the Beaufort Sea coastline. This demersal fish is found in virtually all nearshore habitats, including deeper waters not frequented by anadromous fishes. Saffron cod, Arctic flounder, and starry flounder have similar distribution, however, their occurrence is sporadic and variable and in much lower numbers. Snailfish appear to be closely associated with hard, rocky substrate or kelp. Canadian eelpout are commonly found on muddy bottoms and, after Attic cod, are the most abundant species found by Frost and Lowry (1983). Twohorn sculpin are abundant but distribution is patchy. Capelin area widely distributed species that have been reported in areas west of the Mackenzie Delta; they usually are not abundant except in August when they spawn in coastal habitats.

Most other marine species spawn during the winter period. Craig and Haldorson (1981) suggest that Arctic cod spawn under the ice between November and February, and spawning areas appear to occur both in shallow coastal areas as well as in offshore waters. Fourhorn sculpin spawn on the bottom in nearshore habitats during midwinter. Snailfish are also winter spawners, attaching their adhesive eggs to rock or kelp substrate.

Feeding habits of marine species are similar to those of anadromous species in nearshore waters. Almost all of the marine species discussed rely heavily on epibenthic and planktonic crustacea such as amphipods, mysids, isopods, and copepods. Flounders also feed heavily on bivalve mollusks, while fourhorn sculpins supplement their diets with juvenile Arctic cod.

Human Use of Fish Resources:

The important fishes in nearshore waters, based on numerical abundance or use by humans, are Arctic and least cisco, Arctic char, Arctic cod, and fourhorn sculpin (the latter two are marine species). These species constitute over 90 percent of the fish caught along the Alaskan Beaufort Sea and western Yukon Territory coast. Broad and humpback whitefishes are important species in the western Beaufort Sea and near the Mackenzie River.

Chukchi Sea Subsistence fishing is an important activity at Wainwright, Point Lay, and Point Hope. During the summer, fishing occurs along the shore for salmon and varying proportions of Arctic chars, ciscoes, sculpins, flounders, saffron cods, and whitefishes. During the fall, more fishing occurs inland along the rivers for anadromous and freshwater fish. During the winter, Wainwright Inlet is often fished for smelt. For a detailed discussion of the subsistence harvest of fish, see Section III.C.2 of the Chukchi Sea Sale 109 final EIS (USDOI, MMS, 1988).

Beaufort Sea Anadromous fishes, particularly ciscoes, whitefishes, and chars, are the focal point of fisheries along the Alaskan Beaufort Sea coastline. Fish are taken principally by (1) domestic fisheries near Barrow, the Colville River Delta, Barter Island, and the Canning and Hulahula Rivers (Kaktovik Village); (2) a commercial fishery in the Colville River Delta; and (3) sport fishing at villages, on rivers during recreational rafting (float) trips, and at oil camps. Most domestic or subsistence fishing occurs in inland lakes and streams. Average annual catch statistics (1964-1984; ADF&G, 1984) for these species are shown in Table 2.2.

Table 2.2 Average Annual Catch Statistics 1964-1984 (ADF&G, 1984)

species	Number	Percent	Weight
Arctic Cisco	30,615	55	30,615
Least Cisco	21,602	3	19,441
Broad Whitefish	2,183	4	411,133
Humpback Whitefish	1,351	2	

NOTE: About 9 percent of the Arctic ciscoes and 5 percent of the least ciscoes are exploited by commercial fisheries every year. Weight is in pounds.

The only continuous commercial-fishing operation on Alaska's North Slope is operated by a single family (Helmericks) during the summer and fall months in the Colville Delta. Of the four species taken, Arctic cisco is the most important cash product. This species, along with broad and humpback whitefish, is sold for human consumption in Fairbanks and Barrow. Least cisco also are taken in large numbers and are sold for dog food.

Subsistence fishing in the Colville Delta area is conducted largely by residents of the village of Nuiqsut. Species taken are similar to those of the commercial fishery. Very little is known of the numbers of fish taken annually, but it is estimated that the subsistence harvest is roughly similar to the previously mentioned commercial catch.

In late fail and winter, Arctic cod is an important food item for residents of Barrow and Kaktovik, who traditionally fish for them through the ice. Barrow residents also harvest capelin in July and August when the fish come into shallow water to spawn.

A more detailed accounting of the human use of fish resources in the Beaufort Sea is available in a recently published paper by Peter Craig (Craig, 1989).

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Chapter 3

Overview and Descriptive Biogeography of Anadromous and Marine Fish in Arctic Alaska

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Abstract

Industrial development in the coastal region of the Beaufort and Chukchi Seas has focused the attention of the scientific, industrial, and regulatory agencies on fish communities in the Alaskan Arctic. Although the level of biological investigation that has occurred in some geographic areas of the Beaufort and Chukchi Seas has frequently been substantial major questions about the ecology and biology of anadromous and marine fish in arctic Alaska still remain. In those geographic areas that have not been intensively studied, fundamental questions remain about the taxonomy, distribution, population dynamics, and ecology of anadromous and marine fish in the Beaufort and Chukchi Seas. With the current and proposed levels of coastal development in the Beaufort and Chukchi Seas, answers to these remaining biological questions may be prerequisites for effective conservation of fishery populations along the Arctic coast.

Several anadromous- and marine-fish populations inhabiting the Beaufort and Chukchi Seas have North American distributions that complicate efforts to study their life-history phenomena. For several species, national boundaries and environmental conditions make it difficult to effectively study their ecology and biology. For other species, the limited geographic scope of scientific investigations has constrained the understanding of the ecology of fish species. In the Alaskan Beaufort Sea, fishery investigations have emphasized the coastal region between Harrison Bay and the Sagavanirktok River. In the Canadian Beaufort Sea, fishery studies have focused upon the ecology of freshwater, anadromous, and marine fish in the Mackenzie River and its delta. Fishery studies in the Chukchi Sea have been even more restricted than those in the Beaufort Sea. In the future, fishery studies should be designed to overcome data gaps resulting from the limited geographic scope of studies conducted to date.

Question-and-Answer Period

Question: You mentioned that you had a pretty good understanding of the distribution and abundance of fish in the northeast Chukchi Sea. Are the distributions and abundances somewhat similar to what we see in the Beaufort Sea? We may have a good idea of fish distribution and abundance, but in terms of stock sources or dispersal, is that still an uncertainty?

Johnson: Dispersal, yes. The summer dispersal of species in this area clearly needs to be determined. A lot of the taxonomy work, similar to that being done by the Fish and Wildlife Service for Arctic char in the Beaufort Sea, is essential to determine the vulnerability of specific stocks.

Comment: You talked about the trophic importance of Arctic cod in the north, and I think you can't talk about the southern Chukchi without also mentioning saffron cod. It's really easy to focus on the anadromous species in the Beaufort Sea because they are used in a commercial manner, but saffron cod is probably extremely important--particularly in the winter months for overwintering seals and in the early summer for beluga whales as well as seabirds.

Johnson: Yes. I didn't mean to understate their importance.

Question: You mentioned that anadromous fish aren't real abundant in the northern Chukchi Sea. Based on their biogeography, can you say something about what anadromous fish depend on? What is it about the northern Chukchi Sea habitat that keeps them from being more abundant?

Johnson: The Beaufort Sea and southern Chukchi Sea coasts are characterized by the fast-flowing rivers that flow out of the mountains. These rivers provide the spawning and overwintering habitats required by anadromous fishes. The northern Chukchi Sea coast is characterized by tundra streams and rivers. These streams and rivers provide only limited spawning and overwintering habitat.

Question: There are lagoons in Peard Bay and near Point Lay, so it's not so much the lagoons, it's the streams that are absent.

Johnson: It could be both the spawning streams, the availability of suitable spawning areas as well as availability of suitable overwintering habitat. The lagoons themselves are similar but shallower than the lagoons to the east. The lagoons are important foraging areas for many fish species. The Chukchi Sea lagoons tend to be more marine during portions of the year than Beaufort Sea lagoons. OverWintering, spawning, and foraging habitats are needed to maintain viable anadromous populations. While the three habitats are available in the northern Chukchi Sea area, they are not as abundant as they are along the Beaufort Sea coast.

Question: What about near Point Lay; aren't there a lot of mountain-fed streams flowing into Kasegaluk Lagoon?

Johnson: Yes.

Question: And yet even in the Kasegaluk Lagoon, anadromous fish aren't that abundant.

Johnson: The size of anadromous-fish populations in this area is very small compared to the southern Chukchi and Beaufort Sea areas. This maybe a result of a shortage of one of the three habitat types; the lagoon may provide suitable foraging habitat, but the streams may not provide overwintering and/or spawning habitat.

Question: Do you know of any fisheries WOrk that has been done along the north side of the Seward Peninsula? I guess that the streams are pretty small, but I have never heard of anyone working in the area.

Johnson: The only fisheries research that I'm familiar with is the herring research conducted in the lagoons behind Shishmaref (Shishmaref lies on the north side of the Seward Peninsula). The area appears to have the habitat needed to support populations of anadromous fish and, therefore, warrants further examination.

Question: Would you discuss the east and west distribution of the main fish species found along the central Beaufort Sea coast? For example, does the Arctic cod extend all the way east past the Mackenzie River and all the way west past the Bering Strait? Another example is the fourhorn sculpin.

Johnson: Arctic cod are circumarctic in their distribution. During the winter, Arctic cod are found as far south as Norton Sound where they are a local subsistence resource. The species is ice-associated and moves south as the ice advances southward in the fall. They remain ice-associated through the winter and, as the ice recedes in the summer, the cod, a lot of them at least, move northward; we don't know how many there are left in ice-free waters. They show up in trawl catches, but apparently not in the concentrations found in the wintertime.

Comment from the audience: Arctic cod appear to be in reasonably low abundance during the winter, according to Glen Hopky. For the past 3 years, he has been conducting studies under ice (winter studies) in the eastern portion of the Mackenzie Delta and along the Tuktoyaktuk Peninsula. Virtually no Arctic cod were found during these studies.

Least cisco are found in the central Beaufort area, between the Colville and Sagavaniktok (Sag) Rivers, and most may be members of the Colville River stock. This species tends to decrease in abundance east of the Sag River Delta. The western distribution of this species is, at present, unknown; however, least cisco are found in the western portion of Harrison Bay.

The Arctic cisco has received considerably more emphasis than anadromous species. Many fisheries scientists working in the Arctic hypothesize that virtually all of the Arctic cisco found in Alaskan waters are part of a Mackenzie River stock. We don't know whether they represent *just* random members of the overall population from the Mackenzie River, if they are members of a specific substock from spawning runs in the Mackenzie River itself, or whether they are some combination of the two. These fish appear to migrate between the Mackenzie and the Colville Rivers and are found throughout the region between those rivers.

Question: Is the westward migration of Arctic cisco from the Mackenzie River better understood than the eastward migration?

Johnson: Yes. We know that they migrate from the Mackenzie River to the Colville River and that they move eastward along the Tuktoyaktuk Peninsula. But we don't know how far east of the Mackenzie the population extends or if they overwinter *east* of the Mackenzie River as they do in Alaskan waters. The fish do not appear to be distributed as far east as the Copper Mine River;

however, there is a reasonably large area between those two rivers.

Regarding Arctic char--thanks to MMS, Fish and Wildlife, and the Canadian Department of Fisheries and Oceans--we have a much better understanding of the different stocks occurring along the arctic coast. According to the latest Fish and Wildlife reports, each river supporting anadromous Arctic char supports a discrete spawning population.

Broad whitefish have been emphasized in many central Beaufort Sea fish studies, and we have information on their specific life history and taxonomic status. Broad whitefish are found throughout the area in the tundra lakes and streams. To the east of the central Beaufort Sea coast, the abundance of anadromous broad whitefish decreases, then increases near the Arctic National Wildlife Refuge and again near the Mackenzie River. Movement of this species in the coastal waters is considered more limited because of their greater sensitivity to temperature and salinity than other anadromous species. Broad whitefish tend to be more freshwater oriented, but they will venture into very low-salinity coastal waters. Furnace, in 1975, suggested that broad whitefish moved between the Colville and Sag Rivers. Whether that exchange was important or not is not known.

Humpback whitefish and round whitefish were studied in the central Beaufort Sea about 4 years ago. These studies addressed specific questions related to potential industrial effects and not biological or ecological questions.

Our knowledge of fishes other than the four species discussed above--Arctic cisco, Arctic char, least cisco, and broad white fish--is very limited.

Comment from the audience Your use of the term "migration" when discussing the hypothesized movement of Arctic cisco between the Mackenzie and Colville Rivers may be misleading. The available evidence suggests that the distribution of Arctic cisco may be more a result of passive transport than a directed movement into Alaskan waters. Secondly, the fish under discussion are not anadromous fish but are amphidromous. There maybe some political and legal considerations associated with the use of those terms. These fish, with the possible exception of Arctic char, are not anadromous in the sense of Pacific and Atlantic salmon. They are found in low- to very low-salinity coastal waters, vary greatly in terms of their tolerance to salinity and temperature, and are not generally found offshore in the marine environment. Their movements into coastal waters are not necessarily summer migrations and, therefore, they aren't truly anadromous fishes.

Johnson: It depends on which author YOU are citing when defining anadromy, and that debate has been going on for quite some time. I think of differentiating amphidromous from anadromous in the sense of the fish migrating to sea--the general broader definition of anadromy--and this definition was used as recently as an article in Science magazine last week. The term anadromy is accurate but may lack the precision of amphidromy; but in the broader definition these fish are anadromous.

Regarding the migration of Arctic cisco, if the animals were passively transported, would you expect a large migration in west winds?

Question: There appears to be a mixed use of terms there; please explain.

Johnson: During periods of strong, predominantly west winds, continuing for several weeks, would you still expect large numbers of Arctic cisco to be carried from the Mackenzie River into the Central Beaufort Sea area?

Answer from the audience: Yes. Satellite imagery of the Mackenzie River Delta area reveals contiguous cores of water being transported offshore under surface waters where current reversals have occurred. This phenomenon is similar to that occurring in the North Atlantic Gulf Stream, where cold core rings spin off as patches of water in which organisms are transported out of their normal habitat into new environments. Those patches of water could be transported well offshore and moved all over the Arctic. The statistical distribution of this water is not known at this time. The process, however, de finitely provides a mechanism, purely one of physical transport, for moving fish to the east and west of the Mackenzie River. It's really difficult to imagine these very small fish (age 1) actively migrating against and/or with those currents.

Question: You mentioned that the eastward migration of Arctic cisco is not well known and stocks of Arctic cisco found in the central Beaufort may be dependent upon the Mackenzie stock. Is there any indication that westward or eastward migration is necessary to support the Mackenzie stock?

Johnson: We do know that a few fish return to the Mackenzie River from these areas, but that is all we know. The assumption is that they return to the Mackenzie to spawn. The contemporary hypothesis is that the Mackenzie is the source of Arctic cisco along the Beaufort Sea coast. Initially, the theory seemed controversial, but it is not dissimilar from the life history of Attic cisco occurring in the

Barents and Kara Seas, where fish are emerging from the Pechora River are distributed across 600 km of coastline. The fish found in the Beaufort Sea region are actually traveling less distance than upper Pechora stocks travel. Long migrations/movements appear to be something that this species is capable of doing. As a working hypothesis--and one that I am using--the migration of Arctic cisco from Alaskan waters to the Mackenzie River is important to the population, and they don't spawn in significance anywhere along the coast of Alaska.

Question: Is the Mackenzie River population of Arctic cisco stable? If none of the Arctic cisco occurring in Alaska got back *to the* Mackenzie River, would the population continue?

Johnson: Good question, but I don't have an rower. Depending on whom you ask, you may get different answers; but we (NMFS) don't have the information to answer the question.

Chapter 4

Stock Genetics in Arctic Anadromous Fish: An Organizational Basis for Biological Research

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Introduction

Prior to discussing recent genetic research on arctic anadromous fish, the relationship of various taxonomic levels to each other should be clarified for two reasons: (1) The problems presented for fisheries management by the lack of recognition of genetic stocks are equally apparent for unresolved taxonomic issues and (2) the data and methods used for resolving taxonomic issues at all levels are essentially the same, the basic difference being one of scale. Thus, data collected for issues at the lower levels of organization are applicable at the *higher levels.*

At and below the species level, a continuum of structural organization exists in which the degree of genetic exchange between coextensive units increases as the level of the unit decreases. For example, at the species level, assuming the biological-species concept applies, no genetic interchange occurs between taxa. At the level of life-history type, although biological habits and in many cases morphology may suggest otherwise, some genetic exchange is theoretically possible and likely occurs to a reasonable degree. At the level of the biological population, genetic exchange likely occurs to an even greater degree. However, in order to observe biological units definable by their divergence from each other, the absolute level of any exchange must be less than some theoretical level derived from population size, migration rates, selection, and rates of drift. If not, *then the* divergence of the units breaks down and a panmictic population ensues. Thus, we can assume that if units are identifiable and the underlying cause attributable to biological factors, then the levels of gene flow between the units are low enough to allow for genetic divergence. The emphasis of this presentation is on the latter two levels of organization. However, it is worth noting some of the potential or real problems observed in arctic taxa at the higher levels. At the species level, the incomplete formation of taxa, the lack of apparent diagnostic features for taxa, and perhaps also our inability to devise an appropriate theoretical framework lead to the formation of groups of taxa that compose species complexes. Unfortunately for arctic researchers on anadromous fish, it seems that many of the important taxa fall into this category--e.g., lake whitefish complex, Coregonus clupeaformis, and Arctic char and/or Dolly Varden complex, Salvelinus alpinus /malma. M.bough the information is sketchy, it appears that marine taxa also present problems--e. g., Arctic cod may be two cryptic species, Boreogadus saida and B. agilis.

At the next lower level, at least four arctic anadromous taxa are known to exhibit more than one life-history type. The possibilities range from purely anadromous forms to riverine forms (nonanadromous) and/or lacustrine forms. The extent of this phenomenon for wholly marine fish is unknown.

Although differences between major types of fish (freshwater, anadromous, or marine) are apparent, it appears that for all taxa examined to date, some degree of population structuring into genetic stocks or biological demes occurs. In comparing the different types of fish, it is apparent that the degree of variation is intimately related to parameters such as the environment inhabited, its heterogeneity and barriers, population size, and migratory possibilities of the taxon.

Why are such studies necessary?

At this point it is fair to ask, so what? That is, from the point of view of fisheries management or protection during industrial development, why study population structure and taxonomic problems?

First and foremost, taxa, whether they are stocks, life-history types, or species, represent individual, unique, co-adapted genetic solutions to specific environments. As such, they possess unique biological characters (or combinations thereof), many of which are relevant for effective management. These include details of biology and life history, growth rates, fecundity rates, and age and size structure, as well as abundance. Lack of appreciation of the genetic structuring inherent in the system at whatever taxonomic level will result in misestimation of such parameters and, at the very least, lead to inappropriate management decisions. In extreme cases, such mismanagement could lead to extirpation of particular taxa (species, stock, etc.) and loss of unique genetic variation, loss of unique combinations of variation, and/or narrowing of the range of genetic diversity of the parent taxon. In extreme environments such as the Arctic, in which yearly environmental variation is the rule and in which many taxa are at the extremes of their geographic ranges, such loss can have catastrophic long-term consequences for continued existence of the taxon.

Second, clear knowledge of taxonomic structuring provides many practical benefits to management. These include clear delineation of higher level taxa from all others to ensure correct assignment of contained units to the appropriate entity, assignment of information to unambiguous taxa (thereby avoiding problems such as the same name referring to different species or different names referring to the same species), and proper extrapolation and comparison of parameters between taxa. Implementation of these principles in turn allows for subsidiary questions and may elucidate new problems or questions for investigation.

Third, appropriate genetic information often provides unique biological tags peculiar to particular taxa. At the species level, such tags provide criteria for identification of taxa to species. If linked with conventional characters, this then lays the basis for adequate identification criteria for all life-history stages. At taxonomic levels below the species, such tags in turn facilitate other studies or management aims that rely on tagging. These include migration studies, determination of mixed-stock assemblages, enforcement possibilities, determination of shifts in natural variation that may reflect environmental perturbation% effects of enhancement, and so on. Clearly, should such tags be found and their distribution throughout the taxa of interest known, considerable cost savings could be realized for studies such as those noted. That is, a priori tagging of fish would not be necessary. However, this is feasible only if the population structure is adequately understood beforehand.

In short, the knowledge of taxonomic delimitation, whether at the higher level of species or *lower* levels of life-history type or genetic stocks, forms a biologically real framework for the organization of our knowledge and for the execution of research into the taxa. This aspect will be developed below, but first, some of the possibilities of organization of genetic variation will be explored using recent studies on arctic anadromous fish as the example.

Genetic Studies on Broad Whitefish--A Catalogue of Observations

Since 1983, a study of genetic structuring in broad whitefish, Coregonus nasus, an anadromous riverine fish of the western Arctic, has been under way in the lower Mackenzie River basin. The study was designed to investigate several possibilities of genetic structuring including within-river geographic or spatial grouping into stocks, temporal structuring of migratory groups within years, temporal structuring between years, and differences between river systems.

Genetic variation in fish from within the Mackenzie system revealed that considerable heterogeneity existed in allele frequencies for polymorphic enzymes (Fig. 4.1). In particular, samples of spawning whitefish obtained from the major tributaries such as the Peel, Arctic Red, and upstream mainstem Mackenzie Rivers tended to be different from each other, indicating that segregation into separate major spawning stocks occurred. Samples of migrating adults from areas in which mixing of these stocks was suspected--such as the Mackenzie Delta--also showed some differences from the spawning stocks, indicating both that genetic structuring exists and that fish sampled in the delta were most likely members of particular upstream spawning groups. In addition to these observations for samples obtained from the river systems, substantially greater differences in allele frequencies were observed for samples from extensive lake systems tributary to the Mackenzie River (e.g., Travaillant and Campbell Lakes). This, and the presence of young-of-the-year in the former system in late summer, both suggest the existence of a lacustrine form of broad whitefish. Presumably, such a form undergoes most or all of its life history within the lake systems (or at least within freshwater), and only large lake systems with suitable habitat diversity can support such types. Allele frequencies from other samples (nonspawning fish) from less extensive lake systems (e.g., Attoe Lake) were not significantly different from anadromous riverine fish. This suggests that anadromous fish also may use lacustrine environments as nursery or overwintering habitats. The degree of gene flow between life-history types, whether the third possible life-history type (nonanadromous riverine) exists for broad whitefish, and whether anadromous fish also utilize the large lacustrine environments are all unknown at present. Within-year temporal variation (Fig. 4.2) among migratory fish was not apparent for genetic data, perhaps due to small sample sizes. However, such variation was evident for phenotypic data and

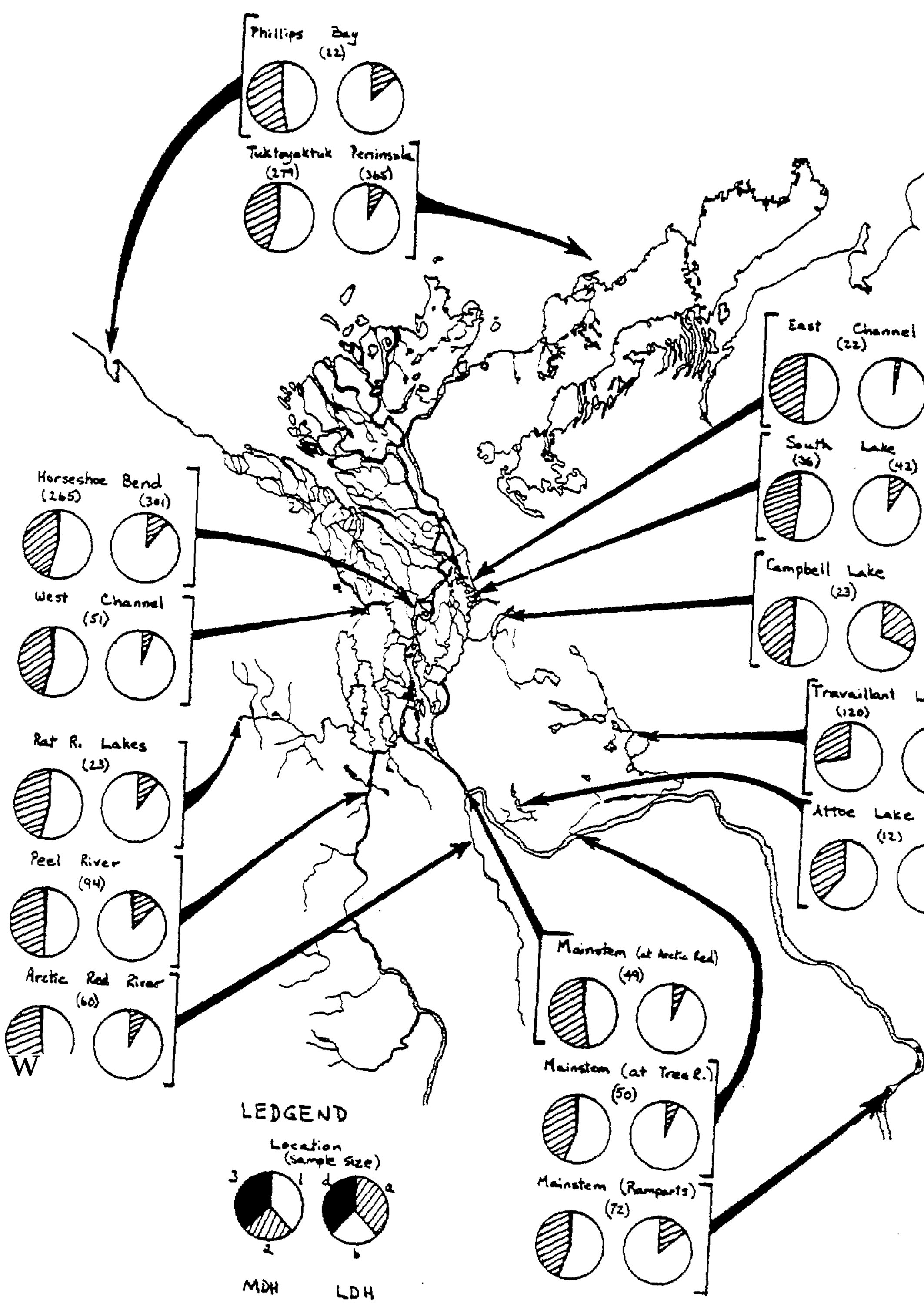

Figure 4.1 Allele Frequency Variation Within the Mackenzie River Basin for Malate Dehydrogenase (MDH) and Lactate Dehydrogenase (LDH) Enzymes

in the manner expected--samples from adjacent times were different for only a few variables, and those from more different times *were* significant for a greater number of variables. Between-year temporal variation (Fig. 4.3) among samples of spawning fish from three locations was not significantly different for any site, although in some cases sample sizes were small. However, for migratory prespawning fish, significant differences were observed for at least two enzyme loci. These observations imply that (1) fidelity of particular stocks to spawning areas exists, (2) differences between such stocks likely exist (as was discussed above), and (3) the timing of migratory events for particular stocks varies from year to year (thus, further suggesting that the lack of within-year genetic differences noted above may be artifactual).

Further to these observations, some geographic disparity among (but not within) populations from nursery systems was observed for areas on the Tuktoyaktuk Peninsula. This implies that anadromous fish may not only migrate as discrete stock units, but also that such units may utilize different areas for purposes other than spawning. In addition to all of this, geographic variation and significant genetic differences were also observed between fish from major arctic river systems (Mackenzie, Anderson, Homaday, Colville, Kobuk, and Yukon Rivers).

In short, it seems that virtually every possibility of genetic structuring below the level of species is present. That is, for broad whitefish, life-history variants, within-river basin spatially defined spawning stocks, temporally defined prespawning migratory stocks, spatially defined nursery stocks, and geographically defined riverine populations all exist. Similar possibilities and likelihoods exist for other anadromous species (e.g., Attic char from the Yukon north slope) and also are likely for marine species. However, for marine taxa, details of geographic scale, stock integrity, barriers promoting divergence and genetic structuring, and life-history interaction with stock structure are far more elusive to determine than for anadromous fish.

Summary-An Investigatory Protocol for Genetic Stocks Research

Assuming that higher order problems such as species de finition and life-history types are adequately resolved, available evidence indicates that an investigatory protocol similar to that in Figure 4.4 can be employed. Adequate information on the questions posed is necessary in order to fully understand the natural genetic variation present in fish populations. Obviously, depending upon the specific details of the taxon to be investigate some portions of this idealized protocol may not be achievable or relevant. The primary question, best asked of spawning groups initially is whether or not stocks exist and, if so, on what basis--spatial, temporal, or both? Assuming a positive answer, secondary questions are then relevant. For spatial variation, is stock integrity maintained throughout all aspects of life history or are mixed-stock assemblages formed? In the former instance, management and investigation of biological parameters are best conducted on unit stocks. In the latter instance, unit-stock questions are relevant, but mixed-stock questions are also relevant; in particular, what is the unit-stock composition of the mixed stock? A similar stream of temporal-based questions is also possible; and there is an intimate relationship between spatial variation, temporal variation, and details of life-history variation. The pertinent observations for all of these aspects directly affect decisions on how to investigate questions of biological interest as well as issues of management interest.

In short, an understanding of genetic structuring should be the guiding framework for both biological investigations and management issues. For example, the management scenario for several genetic stocks that form a mixed-stock migratory assemblage that is fished intensively and sequentially at several spatially separated locations will be quite different from that for stocks that form sequential, migratory unit-stock assemblages fished in the same way. Only by collecting data and by managing the exploitation and protection of the resource with a proper genetic-stocks framework in mind can we ensure that cumulative total impacts on the individual biological populations will be less than those sustainable by each in perpetuity.

Relevant Literature for Further Reading

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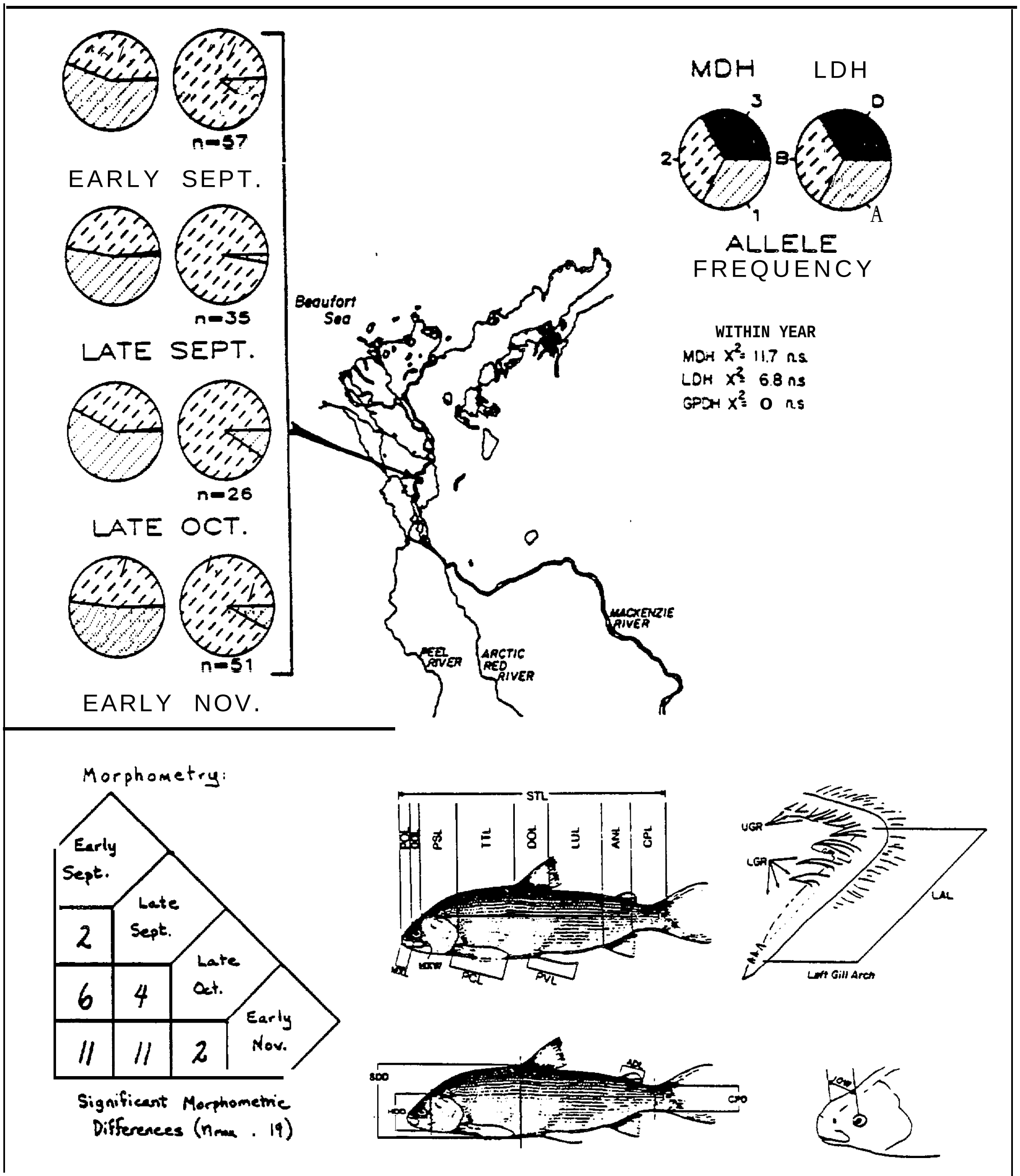

igure 4.2 Within-Year Temporal Variation in Prespawning Groups of Migratory Fish--Genetic Results Top and Morphological Results Below

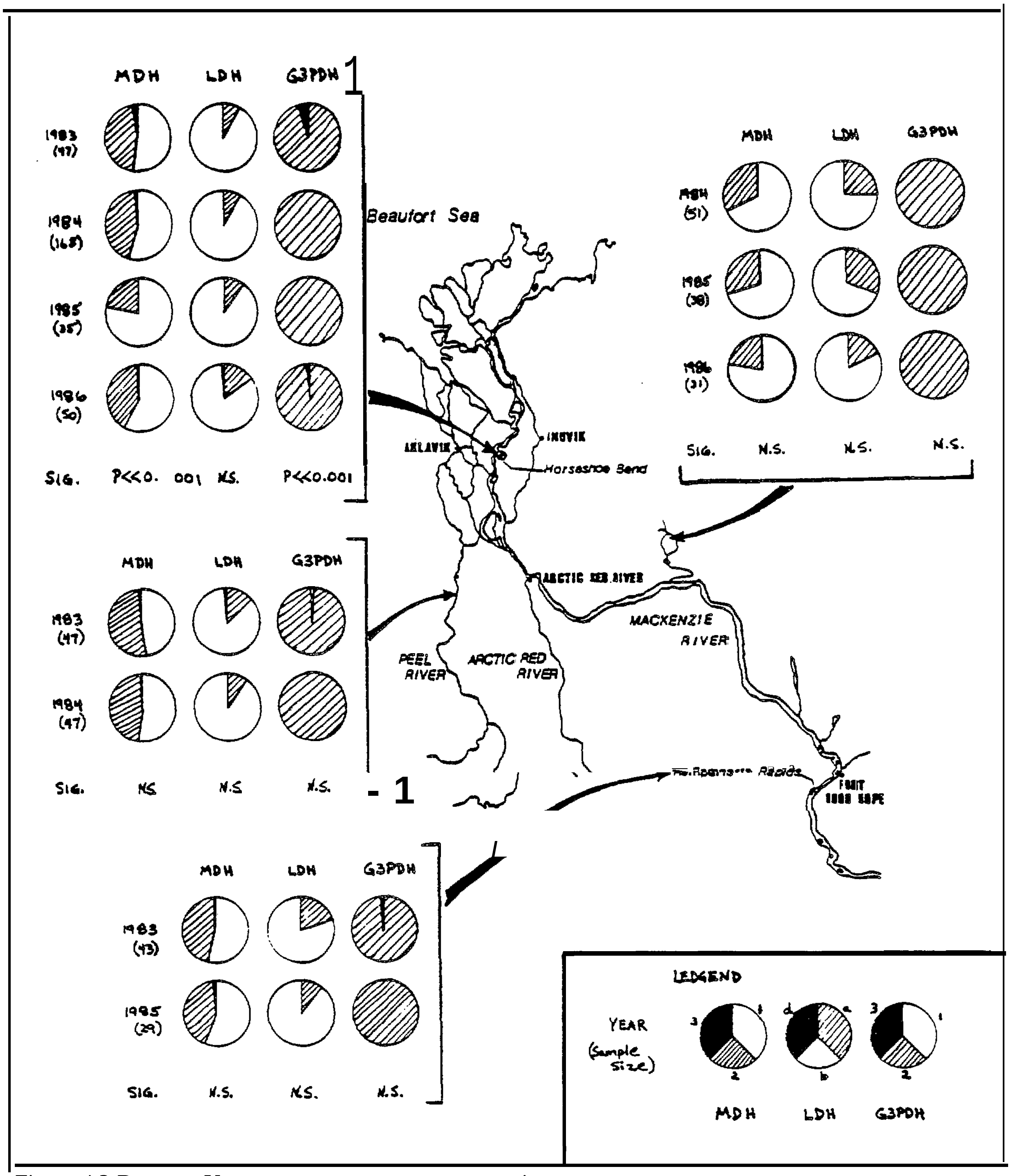

Figure 4.3 Between-Year Temporal Variation in spawning (Peel R., Ramparts Rapids, and Travaillant Lake) and Prespawning (Horseshoe Bend) Fish

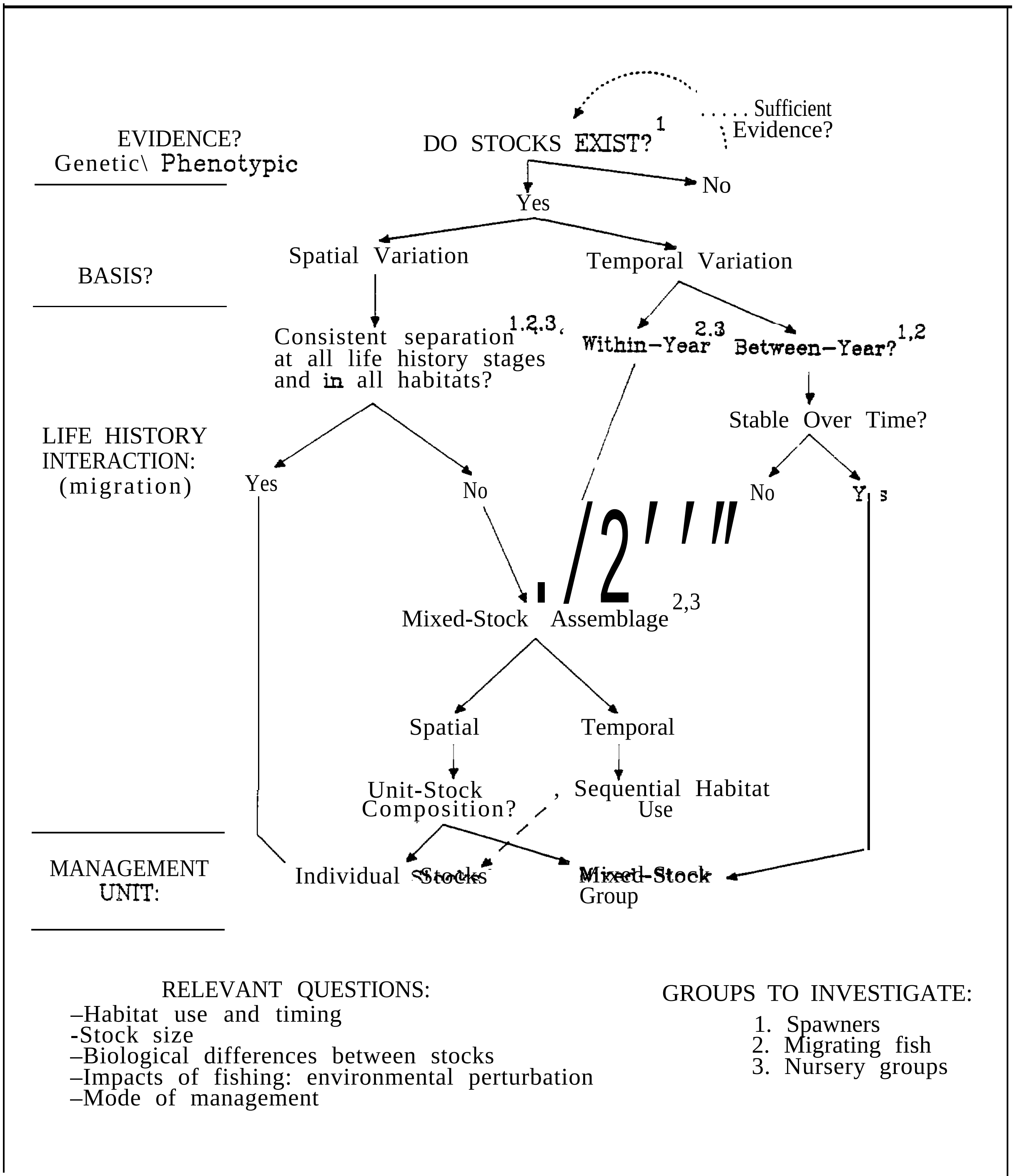

Figure 4.4 A Protocol for Investigating Genetic-Stock Structuring

Question-and-Answer Period

Question: Do you remember Muth and his Copper Mine River studies of broad whitefish mentioning the problem of differentiating between freshwater and anadromous individuals within the same riverine system--are your genetic studies capable of differentiating that?

Reist: *Not specifically so.* For these types of genetic studies, the tag is not distributed uniquely within a population. The best we can hope for is some kind of frequency difference, which is useless in identifying an individual. But what we have found is, in fact, subsidiary data help in this respect, and that is external scarring on the fish. We have recently completed a study of external scarring on coregonids, lake and broad whitefish in particular, and there is a high degree of infestation with a marine copepod. The parasitic copepod produces a round scar (about an inch in diameter) on the fish, and is sloughed off once the fish returns back into freshwater. That itself is an absolute indication that particular fish has been to sea at some point in its fife. And, of course, depending upon the recency of the healing, you can identify him from there. Of course, it doesn't help you in a negative sense; if you don't have any scars, you don't know whether that fish is a *member* of a freshwater population or not. What I hope to do, using Arctic char as the example, is to use allele frequencies from a variety of polymorphic enzymes to come up with a genetic discriminant-function that will allow us to characterize an individual. In other words, using discriminant function analysis in the same manner that you use it in characterizing individual in a morphological sense but with the basic data being allele frequencies. Whether it will work to any degree, I don't know. It seems to work reasonably well for Arctic char, but whitefish present a different story. The other option, of course, is studies with a better tag--such as mitochondrial DNA--and mit-DNA looks like it has every potential to be that better tag.

Question: You mentioned the use of genetic material for identifying variation resulting from environmental change as a possible precursor of catastrophic phenomenon. It seems as if you are already getting that kind of genetic change, that the catastrophe may have already occurred. Using that for assessment purposes might be somewhat limiting because it doesn't predict the change early enough to prevent or to take remedial action.

Reist: That's a fair statement, I suppose, if you are out there absolutely every day of the year and ensuring that you are looking for the environmental change or the catastrophe. Specifically, the examples I had in mind when I wrote that were things like hybridization--in *other* words, genetic variance showing up that was de novo--and this has been demonstrated in a variety of freshwater situations. Again, it's a matter of understanding the basic system, the unperturbed system, well enough first, I think, as to genetic structuring and population structuring. Then some hopefully low-level but continuous monitoring of genetic diversity will allow us to potentially use this technique. Obviously, if you are doing something directly, such as a causeway, there are concomitant perturbation studies directed for that purpose going on as well. It may, like you say, be supplanted by other more-directed studies.

Question: The two questions that I was asking were somewhat related since we don't really know why a lot of the anadromous fish migrate or why they are anadromous or amphidromous; why they disperse into saltwater. One of the assumptions that I have been making is that the productivity of the coastal system is higher than the productivity of the freshwater systems that would otherwise be available to them. If, as a result of development that changes, *one* of the perturbations *that might* be important is differentiating the freshwater resident fish from the anadromous fish. I was interested to know if they are distinct or is it just something that is habitual, and if through perturbation we change the relationship between oceanic and freshwater productivity, whether we would be able to detect that perturbation using some of your methodologies.

Reist: Right. Genetically, I've given you evidence that they are distinct. I can also say that morphologically they are distinct as well, although I haven't analyzed that data yet. The *lacustrine* form for broad whitefish tends to be a longer terrette sort of form, especially in the caudal region. Now why that is doesn't make any sense to me at all, but that's the way it is. So, presumably by linking the genetic studies with more conventional characters, we may be able to see something a little bit better in that sense. The other thing that I didn't mention is that we've backed up virtually all of the broad whitefish genetics works with a subproject that I talked about briefly--the habitat limnology study. We've backed it up with stable isotope work as well; and we get very different signatures from the environments, depending on the type of environment--whether it's marine, estuarine, Tuktoyaktuk Peninsula, or lake environment versus upstream-river environment versus upstream-lake environment. So, we've got a picture of that genetically, and the flesh of the fish gives us the same history or the same picture using stable isotopes. We can then determine where the immediate past 6 months or so of the fish's life history has been spent. So, we are approaching that kind of problem from a variety of perspectives.

Chapter 5

The Critical Estuarine and Marine Habitats of the Canadian Coastal Shelf Research Program--an Overview

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It is the responsibility of the Canadian Department of Fisheries and Oceans (DFO) to provide a scientifically sound basis for the management, protection, and conservation of fish and marine mammals and their habitats. During the Federal Environmental Assessment and Review Process Hearings on Beaufort Sea Hydrocarbon Production and Transportation, both proponents and interveners identified many deficiencies in the level of understanding of ecological processes and critical habitats in the Canadian Beaufort Sea (FEARO, 1984). Consequently, the Department's Central and Arctic Region has participated in the Northern Oil and Gas Action Program (NOGAP), Project B2. This, and other NO GAP projects, were implemented in 1984 specifically to advance the state of governmental preparedness to deal with the regulatory and advisory aspects of this development.

The purpose of Project B2 is to focus on critical estuarine and marine habitats of the Canadian coastal shelf. There are six subprojects comprising B2, ranging from a compilation and appraisal of all biological and oceanographic data sets from Canada's arctic waters, to a study of anadromous and marine fishes along the nearshore of the Yukon north slope, to a long-term study of the natural variability observed in benthic communities in embayments along the Beaufort Sea coast.

Subproject B2.1: Beaufort Shelf Fish-Habitat Research

The most extensive subproject, discussed for the remainder of this presentation, is B2.1--Beaufort Shelf Fish-Habitat Research. The study area extends from Herschel Island east to Amundsen Gulf and from the nearshore, including the Mackenzie River estuary, to near the edge of the continental shelf, at 100 to 200 m (Fig. 5.1).

The subproject objectives are:

1) To conduct research towards identifying, in spatial and temporal terms, habitats of significance to estuarine and marine adult and larval fish by determining their distribution, abundance, and life-history characteristics (e.g., age, maturity, etc.).

2) To characterize these habitats bv:

- measuring physical and chemical oceanographic features directly and by satellite;
- determining the importance of primary production versus all ochthonous-derived production on the Beaufort Shelf and conducting isotopic analysis to determine carbon pathways (also, by studying the regional and proximate factors affecting ice-algae biomass and production);

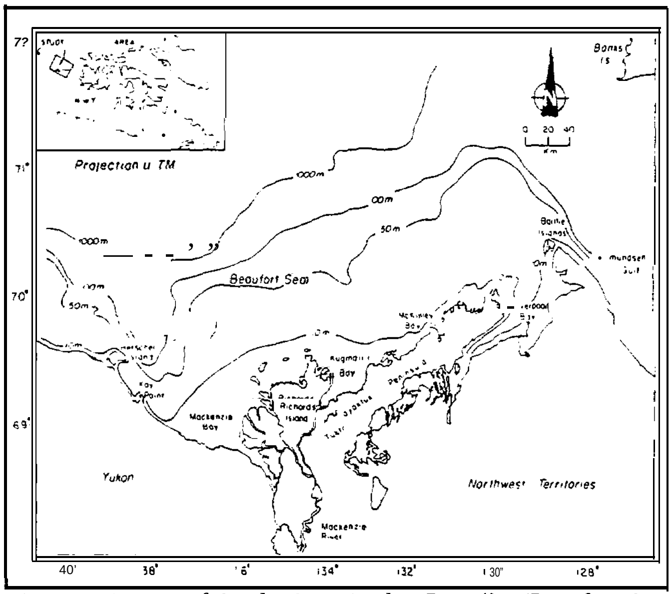

Figure 5.1 Map of Study Area in the Canadian Beaufort Sea

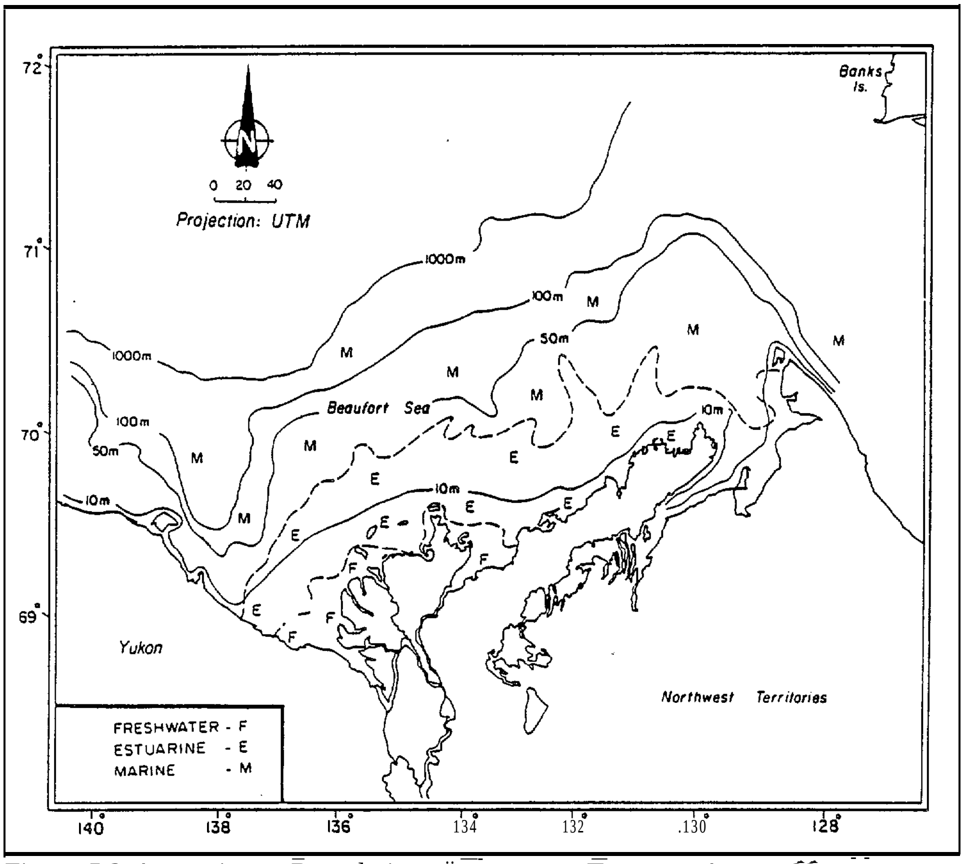

Figure 5.2 Approximate Boundaries of Watermass Types for August 22, 1984

- determining the distribution, abundance and biomass, and life-history characteristics of zooplankton on the Beaufort Shelf; and

- creating a comprehensive set of regional taxonomic keys to the major benthic and pelagic invertebrates and the ichthyoplankton.

3) To determine feeding habits, in relation to prey availability, of selected adult (e.g., Lacho, 1986) aud larval fishes and selected zooplankton groups.

Field research was conducted during the open-water (July-September) and ice-cover (March and May) periods from July 1984 to March 1988. Recognizing the need to allocate as great an effort as possible to appraising the extent of inter- and intra-annual variability, a limited effort has been allocated to data analysis and synthesis. About 5 percent of the anticipated output of this latter phase is complete. Therefore, with respect to the B2.1 subproject objectives, I will discuss selected sampling of synoptic, nonsynthesized results available to date.

Subproject B2.1: Habitat Characterization

The Canadian Beaufort Shelf can be characterized as having three oceanographic zones or habitat types: freshwater, estuarine-brackish, and coastal marine. This is based on oceanographic data collected from this subproject (Hopky et al., 1986, 1987, 1988) and others, for example, the Beaufort Sea Project (1973-1975) (MacDonald et al., 1987). The extent and stability of these somewhat arbitrary habitat types vary in response to season, wind and lunar tides, coriolis forces, presence of ice, and Mackenzie River discharges. Examples of approximate boundary lines for an open-water and ice-covered period are depicted in Figures 5.2 and 5.3, respectively. Freshwater habitat is found primarily near the mouths of major channels of the Mackenzie River. In summer; large volumes of fresh (salinity < 0.1), warm (UP to 16-18 ‘C) and turbid (50-100 mg solids/l) water inundate the nearshore and delta out to depths of 3 to 4 m, up to distances of 20 km offshore. Winds can compress this water along the shoreline, flooding bays and inlets, or blow it offshore, resulting in jets and subsequent upwelling of cold, saline water. During winter, as a result of protection provided by landfast ice cover, the freshwater mass stabilizes in the nearshore area, extending around the delta out to the 4- to 5-m isobath (Fig. 5.3).

The estuarine-brackish zone typically extends out to the 15- to 25-m isobath along the coastal plain. This is the most dynamic and unstable zone, where Mackenzie River waters mix with marine offshore waters. During summer, in the top 6 to 7 m, salinities range from 2 to 28, compared with 15 to 31 below the pycnocline. Temperatures are inversely correlated with salinity, ranging from 1 to 12 ‘C. During winter, this zone forms a more stable salt-wedge estuary (Fig. 5.3). By May, the increased Mackenzie River flows result in a

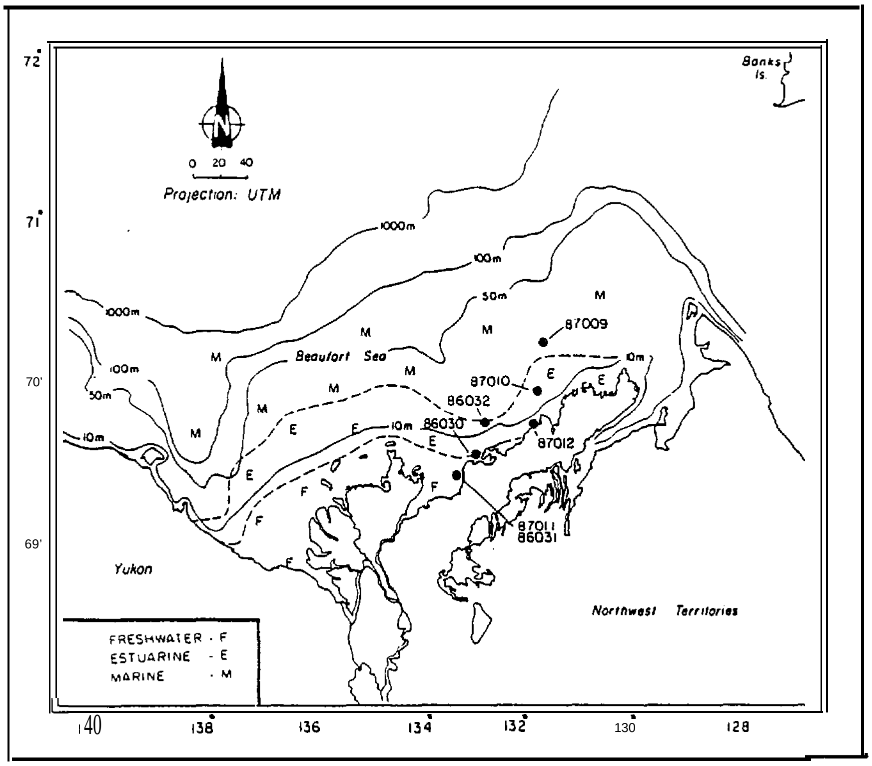

Figure 5.3 Approximate Boundaries of Watermass Types for 17-19 May, 1985; Location of Fishing Stations as Indicated

Production studies were conducted during the open-water periods of 1986 and 1987, from the inner estuary of the Mackenzie River to beyond the shelf break (Parsons et al., 1988; Parsons, pers. commun.). Typical of production in subarctic estuaries, two plankton communities were identified. One, located near the river mouth, was characterized by high, dissolved organic carbon; high bacterial activity; and amphipods. The second community was associated with higher phytoplankton production offshore and marine zooplankters. In 1986, bacterial production was much less than phytoplankton production (5 versus 220 mg Cm-3/day). In 1987, however, bacterial production was much higher than phytoplankton production (Parsons, 1987, pers. commun.) and was likely related to wind responses and temperature differences (Table 5.1).

decreased salinity and increased temperature in the upper layer, and in the opposite in the lower layer. The coastal marine zone occurs over a broad, marginally sloped shelf extending offshore about 100 km to the 100-m isobath, where the shelf break is very steep (Fig. 5.1). The exception to this is off the Yukon coast, where--in addition, in proximity to the Mackenzie Canyon--upwellings are observed (Macdonald et al., 1987). Summer salinities range from 28 to 33 and temperatures from -1.70 to 8 °C in the coastal marine zone. Relative to the mixed estuarine-brackish zone, the marine zone is considerably more stable.

An approximation of the extent of interannual variation in water salinity and temperature is indicated in Table 5.1. Values are not corrected for annual differences in the extent of aerial coverage (Hopky et al., 1986,1987, 1988). However, two strong results are clear: 1) reduced salinities in 1985 correspond to a year when the ice pack remained very near to shore, "trapping" fresher ice melt and Mackenzie River waters; and 2) the much higher upper layer temperatures in 1987, which probably are related to meteorological conditions that favored an early breakup and retreat of the ice pack. Interannual differences have also been observed during the ice-cover period.

Table 5.1 Average (±1 S.D.) August Salinity and Temperature (°C) Values for the Top 5 m, All Stations Combined

Year	198.5	1986	1987
Salinity	6.4 (4.9)	22.9 (7.8)	24.6 (5.9)
Temp.	4.2 (2.1)	4.7 (1.9)	8.5 (1.7)

Zooplankton communities were extensively sampled (n = 1,220 samples) during the open-water and, to a much lesser extent, ice-cover periods from 1984 to 1988, utilizing primarily bongo and neuston gear with mesh sizes of 500 or 83. While no analyses have been made, two generalizations are warranted. First, in the context of proceeding from the very nearshore (2 m) to the shelf edge, zooplankton abundance declines while community diversity increases. Second, the copepod Limnolcalanus macrurus, an important prey item (e.g., Bradstreet et al., 1987), found only in the freshwater and nearshore estuarine zones, shows marked annual variation in abundance.

Table 5.2 Summary of Gillnet Catches for Each of Four Habitat Types Along the Tuktoyaktuk Peninsula, May 1986 and 1987

Habitat Type	Station	No. of 24 hr Sets	Mean Catch Per Set	Percent Species Composition of Catch: PCHR[1]	SFCD	ARFL	RNSM	FHSC	ARCS	LSCS	LKWF	INCO	BRBT
Freshwater - Shallow (<5 m)	86030	7	21.7	3.9	7.9	0.7	6.6	63.1	13.2	0.7	-	3.9	-
	86031	6	11.2	1.5	-	-	56.7	4.5	16.4	3.0	-	11.9	6.0
	87011	5	15.4	-	-	-	53.2	7.8	15.6	3.9	3.9	11.7	3.9
Estuarine - Shallow (<5 m)	87012	3	0.0										
Estuarine - Deep (<10 m)	87010	6[2]	0.0										
Marine - Deep (< 10 m)	86032	2	0.0										
	87009	6	0.0										

[1]PCHR = Pacific herring; SFCD = saffron cod; ARFL = Arctic flounder; RNSM = rainbow smelt; FHSC = fourhorn sculpin; ARCS = Arctic cisco; LSCS = least cisco; LKWF = lake whitefish; INCO = inconnu; BRBT = burbot.
[2]3 sets on bottom and 3 sets 2 m below bottom of ice.

Subproject B2.1: Fish-Spatial and **Temporal** Utilization of Shelf Habitat

The winter under-ice distribution and abundance of anadromous and marine fishes along the Canadian Beaufort Shelf are poorly understood (see review in Lawrence et al., 1984). Variable-mesh gillnets and acoustic gear were used in May of 1986 and 1987 (Fig. 5.3) to sample four habitat types (Table 5.2). Fish were caught only in the freshwater (salinity <0.1; temperature: 0.1-0.5 "C), shallow habitats. Anadromous rainbow smelt and euryhaline fourhorn sculpin dominated the catch. However, the anadromous Arctic cisco was also abundant, and the piscivorous freshwater species of inconnu and burbot were frequently caught.

Midwater trawl (cod end 1.5 cm bar) and acoustic studies conducted in August 1987 demonstrated regional differences in species composition and relative abundance of both fish and invertebrates (Table 5.3). Station samples ranged in depth from 30 to 60 m with tows made throughout the water column. Watermasses off the Yukon coast were stratified with strong pycnoclines, while the sampling stations north of Kugmallit Bay were only weakly stratified (Table 5.3).

The family Gadidae, virtually all Arctic cod, was the overwhelmingly dominant fish in all catches. Each of the other fish families demonstrated regional differences in relative abundance. Significantly, and without exception, no fishes larger than 100 mm (total length [TL]) were caught (size range: 25 to 100 mm TL). Also, there were marked differences in the distribution and estimated abundance of the major invertebrate groups captured (Table 5.3). The extent to which these differences relate to salinity, temperature, or other oceanographic features (e.g., upwelling off the Yukon coast) is currently unknown.

Ichthyoplankton were collected during the open-water seasons of 1985 to 1987 in 500-u-plankton gear. The gadoids, stichaeids, and cottids predominated but also showed the most significant interannual fluctuations (Table 5.4). These families *were* most abundant in the estuarine-brackish habitat zone irrespective of year, season, and ice-pack location (e.g., 1985 vs. 1986 and 1987 and Table 5.1). Coregonids and osmerids were most frequently captured in the freshwater habitat zone. The marine habitat zone was where all species were least likely to be caught. Factors contributing to these patterns of abundance and distribution are being investigated.

Summary

In response to impending oil and gas development in the Canadian Beaufort Sea, DFO has conducted a suite of research projects designed to provide

Table 5.3 Summary of Midwater Trawl Net Catches for Two Regions on the Beaufort Sea Shelf, 10-18 August; Catch Percentages Are Estimated Separately for Fish and Invertebrates

Region	Number of Trawls	Mean Satinity Surface (± SD)	Mean Satinity Bottom (± SD)	Mean Temperature Surface (± SD)	Mean Temperature Bottom (± SD)	Fish: Gad[1]	Fish: Stich	Fish: Cot	Fish: Cycl	Fish: Agon	Invertebrates: Amph	Invertebrates: Mysid/Euph[2]
Kugmallit Bay - North	3	293 (0.23)	320 (0.06)	8.9 (0.20)	-1.3 (0.00)	92.3 (20956)[3]	- -	6.0 (1343)	1.6 (363)	0.1 (19)	90.6 (706)	9.1 (71)
Yukon Coast - North	5	20.1 (2.57)	32.4 (0.36)	9.6 (0.72)	-0.5 (0.70)	93.2 (15963)	0.1 (23)	1.2 (210)	5.5 (955)	- -	4.0 (5099)	96.0 (123550)

Column group heading: Percent Competition of Catch - Taxon Group

[1]Gad = Gadidae; Stich = Stichaeidae; Cot = Cottidae; Cycl = Cyclpteridae; Agon = Agonidae; Amph = Amphipoda; Mysid = Mysidacea; and Euph = Euphausiacea.
[2]Identification in progress - estimate 90-95% euphausids
[3]Number caught

Table 5.4 Percent Composition of Fish, by Family, to the Total Catch in Plankton Gear for 1985-1987

Family	Year: 198s	1986	1987
Gadidae	52.6	51.1	21.5
Stichaeidae	6.3	28.0	45.7
Cyclopteridae	3.s	5.	2.4
Agonidae	<0.1	0.3	-
Cludeidae		0.4	1.5
Pleuronectidae	-	0.1	3.1
Cottidae	33.0	12.4	17.7
Osmeridae	1.6	1.3	2.9
Coregonidae	29	0.3	1.8

sufficient background data such that development-related impacts-can be adequately assessed. Many of these projects are currently ongoing. The Beaufort Shelf Fish Habitat Research Subproject will contribute significantly to the identification and delineation of habitat important to fishes and related biological and physical processes. In practical terms, research from this project will be completely documented in DFO data reports and peer-review publications.

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Chapter 6

Biogeography

Introduction

The Biogeography Workshop consisted of three concurrent working sessions. Each working session was charged with reviewing papers presented by Johnson, Reist, and Hopky; identifying information needs; and listing research needed to better understand the biology and distribution of fishes in the Arctic.

A facilitator led the discussions, and a scribe took notes and helped the facilitator prepare summaries (oral) of each session's progress. Summaries were presented by the facilitator at a plenary session immediately following the working sessions.

Working Session 1

Facilitator: Bill Wilson
Scribe: Chuck Mitchell

Sampling Methods

Fish-sampling methods and gear for marine arctic environments need to be carefully examined. For example, certain species are not readily caught by gillnets because of fish-body shape. New gear types or new approaches may be needed in order to effectively sample certain fishes, especially in under-ice environments. Bottom trawling has been effective in sampling demersal marine fishes, yet trawling hasn't been conducted in the Beaufort or Chukchi Seas since the late 1970's. Industry has been very innovative in exploring for and producing oil under arctic conditions. Scientists should be similarly innovative in developing sampling methodologies and gear designs appropriate for arctic conditions and for target species.

Species Emphasis

Information on Arctic cod biology is limited. Some very fundamental information on the basic life history of Arctic cod is missing, e.g., location of spawning areas. Future studies should focus on the life history of Arctic cod in the Beaufort Sea followed by Arctic cod, saffron cod, and perhaps sand lance and capelin in the Chukchi Sea.

Growth rates of arctic marine fishes including Arctic cod are poorly understood, and studies of growth rates should be correlated with oceanographic/ seasonal processes.

What may happen to Arctic cod as a result of human-related effects or natural phenomena will likely be felt by many species of seals and birds. Therefore, investigations should focus on the trophic importance of Arctic cod in Beaufort and Chukchi Sea ecosystems, especially as they relate to marine mammal and bird populations.

There is some evidence that both cod and whales consume the same species, which might indicate competition. Since cod feed on smaller individuals, however, zooplankton size maybe the determining factor influencing predation. Therefore, predation by Arctic cod and bowhead whales on zooplankton should be investigated.

Basic Studies

Because many marine and coastal fish studies have been mission-oriented (driven by a regulatory need), the "picture" of arctic fish life history is incomplete; and, consequently, more broad-based (regional) studies of arctic marine-fish life history are needed, to include studies on where and when fish spawn, spatial and temporal distribution and abundance of ichthyoplankton, larval dispersal patterns and mechanisms, information on stock structures, etc. This work will be complicated by logistic and sampling problems.

Available Data

An arctic fish-study program should include, in its initial stages, a review and a workup of existing biological samples and unanalyzed data. Also, emphasis should be placed on publication of these data. The level of knowledge for certain species and trophic dynamics may be greatly advanced by simply working up data already in hand. Therefore, new study programs should include funds and investigator time for working up all data and getting results published in peer-reviewed literature. Perhaps a series of papers should be published annually in an appropriate journal or in a special publication devoted to arctic fish-research programs.

Additionally, because the existing database is largely on the open-water season, more effort should be (proportionally) expended in the longer winter season.

In summary, the working group focused on the following study needs:

- Develop appropriate sampling methodologies and necessary logistical support.
- Consider hypothesis testing as a means for determining the specific elements of a study program.
- Conduct more marine-fish and -habitat sampling in the winter season.
- Attempt to maintain continuity in any long-term study effort; strive to keep a core group of investigators together.
- Give more emphasis to marine-fish species.
- Consider making an effort to gather and publish what we know about Arctic cod to date; use this base of knowledge to refine a long-term cod-research program.
- Expend efforts in both nearshore and offshore marine zones; the arctic environment from the *coast* to the offshore zone is a continuum and should be sampled accordingly.
- Focus on stock identification *of* key marine and coastal species; important questions include what stocks are involved, how many, and their spatial/temporal separation.
- Evaluate interannual variability in physical processes in order to further refine hypotheses and to establish the content of the future study program.
- Publish results of past, and any future, studies in open literature.

Working Session 2

Facilitator Pamela Pope
Scribe: Lyman Thorsteinson

Introduction and General Comments

Discussions were organized by region--Chukchi and Beaufort Seas--and nearshore and marine habitats. These discussions revealed the existence of many databases (Table 6.1), most of which have been developed from a "project-specific" approach to environmental assessments.

These databases contain only limited information on the biology of important marine species, which were identified as saffron and Arctic cod in the Chukchi Sea, Arctic cod in the Beaufort Sea, and fourhorn sculpin in the coastal waters of the Beaufort Sea.

Table 6.1 Arctic Environmental Databases

- Chukchi Sea
  - Project Chariot
  - Red Dog Mine
  - National Petroleum Reserve in Alaska
- Beaufort Sea
  - National Petroleum Reserve in Alaska
  - ADF&G Indices
  - Arctic Gas Pipeline Project
  - Prudhoe Bay Waterflood
  - Endicott Monitoring Program

Overwintering habitat may limit the population size and range of anadromous species in the Arctic; therefore, the importance of identifying and characterizing overwintering habitat for anadromous species in both the Chukchi and Beaufort Seas was stressed. Where appropriate, stock-identification research was also identified as an important ingredient in assessing the risk to anadromous fish populations in the Arctic.

Chukchi Sea--Anadromous Fish

Studies of anadromous-fish productivity, seasonal migrations, and coastal use in the Chukchi Sea were recommended. The southeastern Chukchi Sea was considered to be biologically more important to fishes, and anadromous fish in particular, than its northeastern counterpart (northeast of Cape Lisburne). The rivers in the southeast tend to be larger perennial systems that offer more suitable habitat to anadromous fish for overwintering, whereas rivers along the northern Chukchi Sea coast tend to be slow-flowing tundra streams, many of which freeze to the bottom and, therefore, offer little overwintering habitat.

The southeast Chukchi Sea is an important area for subsistence and commercial fisheries harvesting chum and pink salmon, Arctic char, and several whitefish species.

Chukchi Sea-Marine Fish

Basic life-history, population and ecological information is needed for saffron and Arctic cod because of their trophic importance in regional food webs; and similar information needs were identified for sand lance and boreal smelt. The seasonal use of the southeast Chukchi Sea by Pacific herring and possible interchange with the Bering Strait is unknown; however, large stocks of Pacific herring have been observed between the Bering Strait and Point Hope. In terms of sheer biomass, the fourhorn sculpin is an important species. Although it may be an apex predator, its ecological role is unknown.

Beaufort Sea-Marine Fish

Information on the distribution relative abundance, and life history of marine fish in the Beaufort Sea is limited. From the standpoint that additional information may be needed for OCS-related environmental assessments, the focus of any marine-fish study should include areas where offshore development is likely, or where a species is thought to be especially vulnerable. Population assessments were considered a high priority.

Arctic cod was considered to be the key ecological species. Questions concerning spawning times and areas, such as this species' apparent fidelity to areas in Simpson Lagoon, need further investigation. In addition to abundance surveys, plankton surveys and " investigations of early lifestage remitment were recommended.

Beaufort Sea--Anadromous Fish

Primary species of concern included the Arctic cisco, broad whitefish, Arctic char, and least cisco. Possible research topics included the need for additional information on population size and on the proportion of population at risk from OCS activities or other projects. By species, research needs were indicated as follows:

Arctic Cisco: A high priority was given to determining if stocks of the Mackenzie River drainages are unique. To obtain this information% fish must be collected from their known spawning sites. A second need identified was the requirement to obtain data on the east-west dispersal of Arctic cisco from the Mackenzie River in relation to dominant oceanographic and meteorological events.

Broad Whitefish This species is limited by the availability of freshwater along low-salinity coastal habitat--broad whitefish are restricted to larger river drainages in the Arctic; and information on relative abundance, particularly on spawning grounds, is needed. The broad whitefish may be a good indicator species because of its limited *range* in coastal waters and its population dynamics.

Arctic Char: Increasing harvest pressure on these stocks appears to be of growing concern, and information is needed on population sizes and stock productivity. Because stocks appear to be discrete, yet some exchange at overwintering sites is known, information also is needed on the rate of this interchange. This was considered the easiest anadromous fish on which to collect population-size data. It was noted that aerial assessment surveys should be resumed.

Least Cisco: Little is known about coastal use west of the Colville River. Stock-identification research appears to be a necessary component of any vulnerability or risk assessment. High priority was given to obtaining distribution and abundance information for all anadromous species west of the Colville River to Barrow. Identification and characterization of over-wintering habitats was noted as another special research need.

Working Session 3

Facilitator: Rosalind Cohen
Scribe: Laurie Jarvela

Chukchi Sea-Study Needs

There are notable differences in the physical and biological features of the northern and southern portions of the Chukchi Sea; therefore, studies should be designed to reflect these differences.

European and Soviet investigators are currently working on fishery problems in their portions of the Arctic, and efforts should be made to obtain recent and current research results from these investigations. This information would be very useful in synthesizing information on Beaufort and Chukchi fishes and would aid research planning. Ongoing international cooperative programs might prove useful for contacting the appropriate investigators and establishing lines of communication for data exchanges. One potential use of European and Soviet data might be to test hypotheses about factors limiting fish use of marine habitats that have been generated using U.S.-Canadian data.

During 1977-1978, the National Marine Fisheries Service, under contract to MMS, conducted the first marine-fish resource-assessment surveys in the Chukchi Sea; and this work should be repeated. Results from the initial survey and results from more contemporary oceanographic studies in the region could be used to refine the earlier survey design. It was recommended that otter trawls and gillnets be used to sample both pelagic and demersal species.

Use of the eastern Chukchi Sea coast as a migration corridor for fishes should be examined. Because of the apparent negligible use of the northeastern Chukchi Sea by anadromous species, it is important to examine why fish are not present in this area.

Coastal lagoon habitats should be classified in terms of their biophysical attributes and processes and compared with Beaufort Sea lagoon habitats to determine if models of Beaufort Sea lagoons are applicable to lagoons along the Chukchi Sea coast.

Beaufort Sea--Study Needs

The alongshore movements of Arctic cisco should be clarified. The ecological implications of active movement vs. passive transport influences the perceived risk to this species from either natural or anthropogenic perturbations, e.g., if Arctic cisco young-of-the-year are transported west from the Mackenzie River rather than actively migrating west, their distribution and probability of reaching suitable overwintering habitat may not be greatly affected by causeways or other manmade structures.

Consistency and uniformity in the identification of certain taxa (e.g., char) are important if the exchange of data between U.S., Canadian, Soviet, and European scientists is to be facilitated and confidence in the data is to be maintained.

Information on specie occurrences, movements, and stock discreetness is needed for the nearshore waters west of the Colville River. If industrial development is to proceed in a timely manner, more information on fish use of this area is needed.

Additional information on the onshore-offshore distribution and habitat associations of Arctic cod is necessary to allow more refined assessment of risk to this and other marine fishes from offshore petroleum exploration and development.

Additional information on the physiological factors limiting habitat use is needed to understand the habitat requirements of anadromous fishes. This information can also be used to determine the potential effects that habitat changes may have on anadromous species.

Studies of fish in the Arctic should be coordinated to reduce duplications of effort and to ensure that the maximum amount of information (e.g., electrophoretic, morphometric, age, etc.) is gathered from each fish specimen collected. Considering the high cost of conducting research in the Arctic and that intensive and extensive sampling efforts may adversely affect small fish populations, coordination of sampling efforts should be given high priority.

Chapter 7

Nearshore Oceanographic Processes of Potential Importance to to Marine and Anadromous Fishes

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Since 1981, substantial efforts have been undertaken to document and understand the Beaufort Sea conditions that affect summer movements of marine and anadromous fishes along the coast. Oceanographic processes and conditions that are presumed important to marine and anadromous fishes are those that govern nearshore water movements (hydrodynamic) and water properties (hydrographic). Water movements (i.e., currents) are believed to be the primary transport agent for *small* fishes along the Beaufort coast, while water properties (specifically, temperature and salinity). are considered to be fundamental indicators of “habitat preference for anadromous fishes of all sizes (Moulton et al., 1985).

The hydrodynamics and hydrography of coastal waters suggest that the nearshore zone be interpreted as a fluid-dynamics boundary-layer problem, which can be quite complex because of the potentially simultaneous occurrence and interaction of several wavelike phenomena and frictional dissipation processes. Recognition of the spatial and temporal scales at which important processes and conditions are of measurable significance is essential to reaching conclusions about their effects.

Circulation Features of the Coastal Ocean

The geographic region of concern is generally within 5 to 15 km of the shore and is thus largely within the “coastal boundary layer” (CBL), which is so named because of the profound influence of the shoreline on watermass dynamics. Several characteristic cross-shelf-length scales can be used to define the distances over which the set up and set down of the coastal water level and similar distortions of the pycnocline occur. The most useful cross-shelf scale is the baroclinic Rossby radius, which is a measure of the relative importance of buoyant and Coriolis forces. For conditions typical of the nearshore Beaufort Sea, this parameter is only about 3 to 4 km due to the usually strong density stratification and the high latitude. Within this distance of the shoreline, usually between the depths of 2 and 7 m, the effects of friction become dominant over geostrophic (i.e., Coriolis) effects. An important result of this is that surface transports are aligned with the wind-stress direction in this zone.

Farther seaward, geostrophic effects become more important in determining the response of watermasses to wind stress and horizontal pressure gradients. The demarcation between the inner, "friction-dominated," and the outer, "geostrophic," subregions of the CBL is actually an indistinct transition in which the divergence (convergence) of shore-normal surface transports produces local upwelling (downwelling) under easterly (westerly) winds. These processes occur on a regional scale and have important implications in the general circulation and distribution of watermasses in the coastal Beaufort Sea.

Three forcing factors drive the circulation of the coastal ocean: wind stress, horizontal pressure gradients, and tides. Because wind stress is proportional to the square of wind speed, periods of high winds (storms) tend to dominate the circulation scenarios in shallow coastal waters. Since there is (generally) no regular periodicity in either frequency or duration of the winds, the intermittent forcing prompts several wavelike responses in the waterrnass(es), as would be expected on general dynamical principles. Horizontal pressure gradients are the result of water-density differences that arise from solar heating, especially in early summer, and from the influx of freshwater at the shore (river discharge) or, to a lesser extent, from ice melt offshore. Freshwater influx is more important than solar heating by a factor of three or more in altering the density of coastal waters. Although there is also seasonal variability in freshwater inflow, thermohaline forcing is much less variable than wind forcing. Tidal waves, propagating toward shore from the deep ocean with their well-defined periodicities, can be important but are not considered here.

Wind-driven coastal currents are the most evident of the responses to any of the forcing factors. In waters as shallow as the nearshore Beaufort Sea, current speeds can be estimated as 2 to 3 percent of the wind speed; however, the fictional drag of the seafloor inhibits water movement sufficiently such that current speeds >50 cm/sec are rare. Because of surface-level variations, the force of gravity exerts an important influence. For example, when the wind blows perpendicular to the coast, the water surface rises or falls to a level sufficient to balance the wind stress because the water cannot accelerate in a direction normal to the shore. An alongshore wind would not produce an alongshore surface distortion on a long and straight coastline but, on a typically irregular coastline, there will always be some degree of "piling-up" or depletion of water.

The clearest situation is that of an enclosed basin where, between the upwind and downwind shores, a marked elevation in water level is established and known as the "setup." Where the depth is greater than average, the (horizontal) pressure gradient more than balances the wind, while in shallow water the wind stress dominates (Csanady, 1982). The circulation is then characterized by at least two closed gyres that are related to the depth distribution; that is, the downwind legs coincide with shallow water, while the return flow occurs in the deepest portion of the basin.

Application of such models to coastal seas is a problem because it is difficult to predict the alongshore pressure gradient along an irregular shoreline; nevertheless, the same principles apply on an open coast. Downwind streaming characterizes the inner, friction-dominated subregion of the CBL. Along an irregular shoreline, such as the Beaufort Sea coast, this results in nonuniform coastal currents with strong down-coast flows in shallower sections and either flow expansion or recirculating gyres where nearshore depths locally increase. This condition has been called an "arrested topographic wave" (Pettigrew and Murray, 1986).

When the nearshore watermass is unstratified and a shore-parallel wind blows with the coast on its right, a setup (elevation) of the water surface occurs at the shoreline. This in turn results in an offshore pressure gradient and a strong jet-like current alongshore. If the coastal ocean is stratified, the setup of the surface layer is related to a much larger setdown (depression) of the pycnocline. A shore-parallel flow opposite the surface current then develops in the bottom layer, and friction reduces the speed of the surface jet. When the density difference between two layers is sufficiently large and abrupt, the layers are uncoupled dynamically such that momentum transferred to the upper layer by wind is essentially confined there. The speed of the upper layer is then substantially higher than if the momentum had been distributed throughout the water column. If the wind blows with the shore on its left, the Coriolis force will cause the upper layer to move freely offshore (to the right of the wind) over the frictionless pycnocline. Drogue studies in the Sagavanirktok River plume have demonstrated such coastal jet behavior as a northward veering of the low-salinity upper layer under east winds (Colonell and Weingartner, 1982; Envirosphere, 1988). The characteristic width of coastal jets is given by the ratio of internal wave velocity to Coriolis parameter and is typically a few kilometers.

Two long-wave phenomena that may accompany wind-driven circulation are worthy of mention here: topographic waves and Kelvin waves. The former are free modes of motion generated by wind-stress impulses, with variable winds producing complex patterns of waves. Depth variations are essential for the existence of topographic waves, which are manifest as alongshore surface currents that occur with no obvious driving force. Kelvin waves travel alongshore on the interface between watermass layers. The passage of Kelvin waves is evident as (possibly large) movements of the pycnocline, with an alongshore velocity difference between top and bottom layers. Both topographic and Kelvin waves are "coastally trapped waves and are thus confined within a few to several kilometers of the shore. The theory of such waves is "still under vigorous development" (Csanady, 1982), so further insight into their importance remains to be developed. These waves are potentially important to fish movements because currents induced by their passage are comparable to those produced directly by the wind (i.e., 10-20 cm/see).

The four physical factors discussed above affect the CBL, and their combined effect is to generate an oceanographic "climate" within this zone that is markedly different from the climate farther offshore. All of these factors are associated with the presence of the boundary, in close analogy with well-known boundary layers that occur in other fluid dynamical situations. The width of the CBL maybe determined empirically as the extent of the region within which shore-parallel flow dominates.

Another flow phenomenon that serves to mark the seaward extent of the CBL is associated with horizontal density gradients, which arise from the freshening or heating of nearshore waters. When the horizontal density gradient is very intense, a "front" is said to exist and is manifest as a steeply inclined (sometimes nearly vertical) pycnocline.

AlongShore currents will erode the front gradually however, occasional storms produce more intense currents that mix the water column vertically and restore the front nearly to its original condition. Winds acting in the alongshore direction will impart momentum to the lighter water, which occupies more of the surface. If those winds blow such that the shore is on the right, this effect enhances the velocity contrast between light and heavy fluid and steepens the density gradient. However, when the wind is in the opposite direction (shore on left), an offshore displacement of the light fluid takes place. A sufficiently strong wind of the latter direction can cause a bolus of lighter fluid to separate completely from the shore. Eventually, these processes serve to obliterate the front, a process known as "frontal adjustment."

The rapid deterioration of the pycnocline along the Beaufort coast, which typically occurs in late July or early August, is an example of frontal adjustment that serves as a demarcation between the two distinct oceanographic regimes that prevail each summer. Frontal adjustment in the Great Lakes occurs 6 to 8 weeks after the initial formation (Csanady, 1982); the Beaufort coastal front appears to have a similar time scale.

Open-Water-Season Evolution of the Beaufort Sea Coastal Ocean

A series of six schematic diagrams (Figs. 7.1-7.6) is used to illustrate the evolution of conditions in the Beaufort Sea CBL at a location that is dominated by a river. The source of freshwater serves to freshen the nearshore watermass such that stratified conditions occur for much of the open-water season. The series starts with spring breakup, when the above-mentioned strong frontal zone is established. The often-observed "step intrusion" of marine water into the coastal region marks the end of Phase One of the open-water season with an obliteration, or "frontal adjustment" of the strong-density front that was established early in the summer. Phase Two comprises the remainder of the open-water season, with the nearshore waters becoming almost totally marine in character due to reduced river discharge and progressively greater mixing with offshore waters.

Oceanographic Effects of Coastal Structures

At the opposite end of the spatial scale from regional oceanographic processes are those that may be attributed to large coastal structures, such as causeways. The oceanographic effects of causeways can be categorized as either "dynamic," which refers to alterations of water motions such as waves, currents, or surges, or "hydrographic," which refers to alterations of watermass distributions as reflected by patterns of temperature and salinity. Dynamic effects are generally limited to the immediate vicinity of the structure, within a distance equal to at most a few times the largest dimension of the structure. Occasionally, hydrographic effects can be observed at substantially greater distances, since altered watermasses can be advected away from the structure. Elongated topographic features such as causeways, promontories, and barrier islands are capable of altering local circulation in ways that also affect local hydrography. When coastal flows are transverse to such features, a rotating watermass, or "eddy," forms on the lee side (Wolanski et al., 1984).

A vertical (secondary-flow) circulation soon develops within the eddy (Wolanski, 1986; Scorer, 1958; Prandtl, 1952), which then serves to mix the water column by bringing bottom water to the surface. This phenomenon has been observed near the Prudhoe Bay Causeway, or "West Dock."

Under easterly winds, the causeway is a barrier to the brackish alongshore flow and, by deflecting this flow, creates an offshore-directed low-salinity plume (Mangarella et al., 1982; Savoie and Wilson, 1983, 1986). Simultaneously, an eddy forms on the west (lee) side and, meanwhile, regional oceanographic processes that are driven by easterly winds are effective in displacing higher salinity bottom water shoreward, a phenomenon known as "upwelling." Under these conditions, it is not unusual for upwelled bottom water to appear as a distinct bottom layer in depths as shallow as 3 to 4 m. Because the causeway terminus is at a 4.3-m depth, the eddy on its lee side intercepts the layer of marine water and mixes it upward into the water column to form a "pool" of higher salinity water on that (west) side of the causeway. When the water column is stratified prior to the onset of westerly winds, a less extreme but similar condition prevails on the east (lee) side of the causeway. The occurrence of this phenomenon at the Prudhoe Bay Causeway (Fig. 7.7) has occasionally been held to be evidence of "upwelling enhancement" by the causeway. It is important to recognize that the structure itself does not induce the coastal upwelling process, which is a regional phenomenon. However, it is appropriate to assign responsibility to the structure for the local phenomenon by which the high-salinity pools are formed on its lee side. It is similarly important to understand that the high-salinity pools will occur only if the marine bottom water has penetrated sufficiently shoreward to allow its interception by the structure-induced eddy.

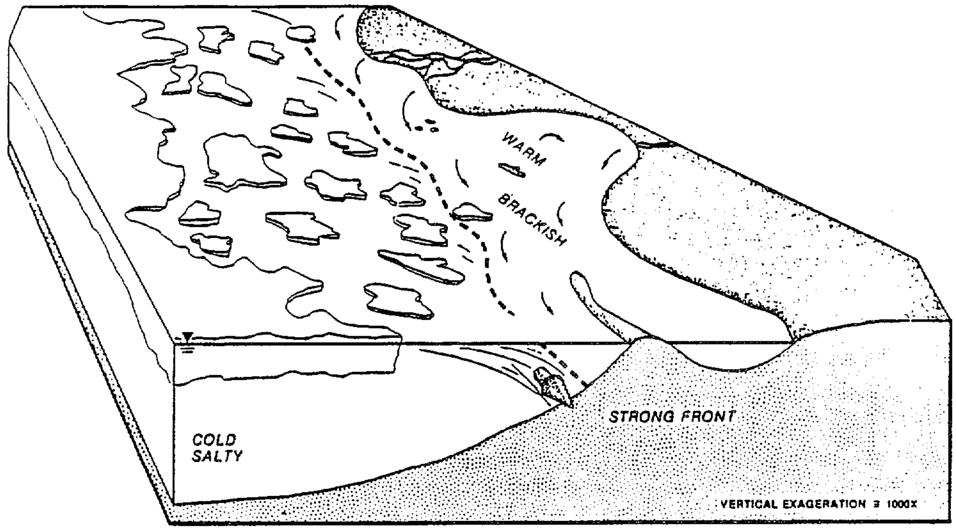
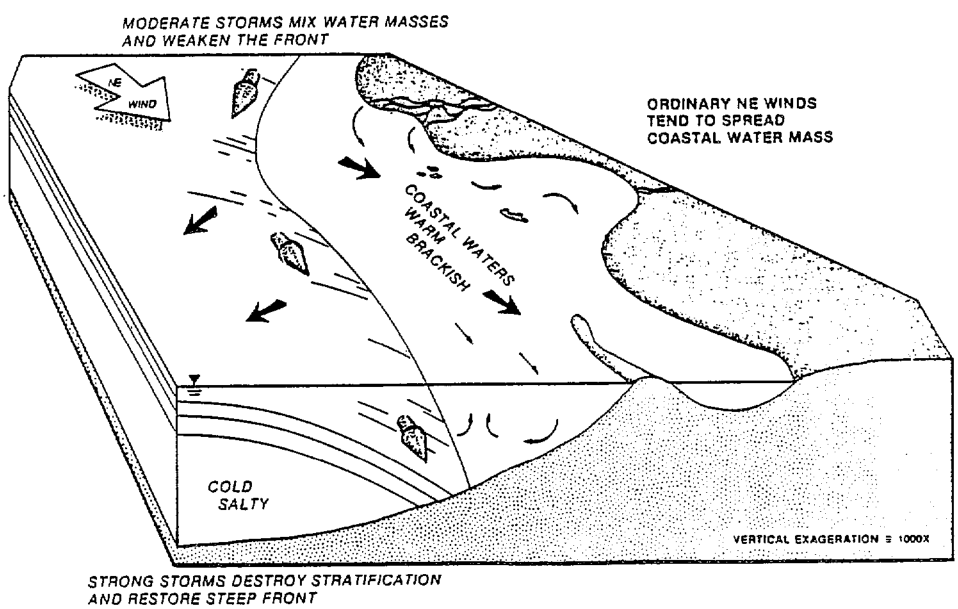


Figure **7.1** Breakup



igure 7.2 Early Phase-One Open-Water Season

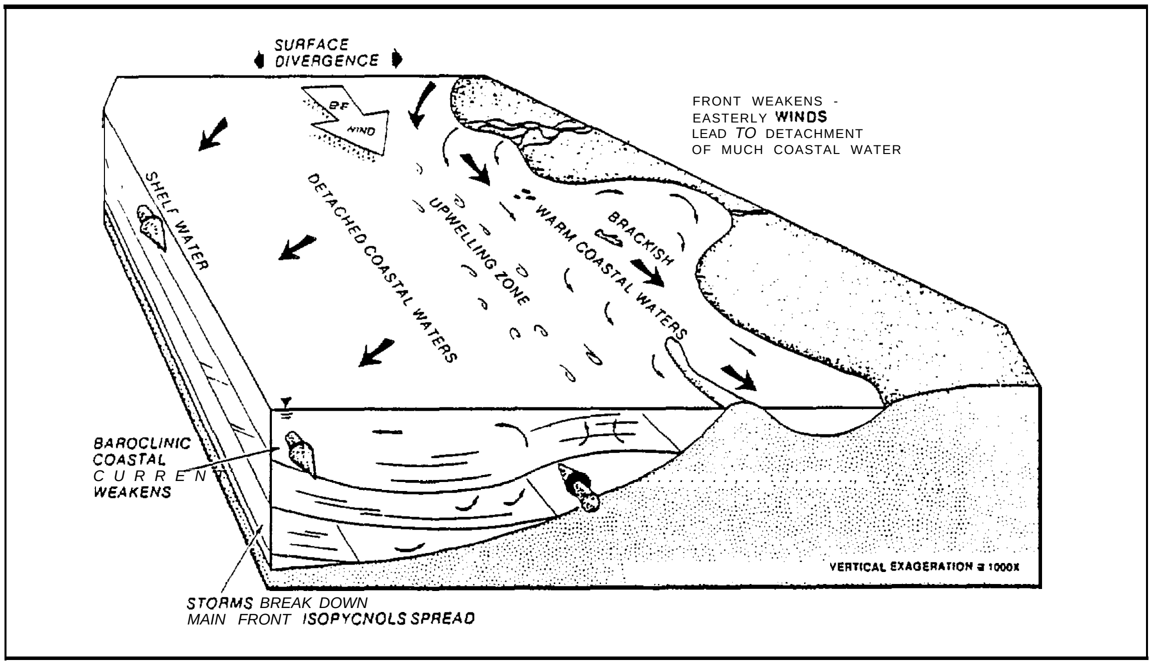
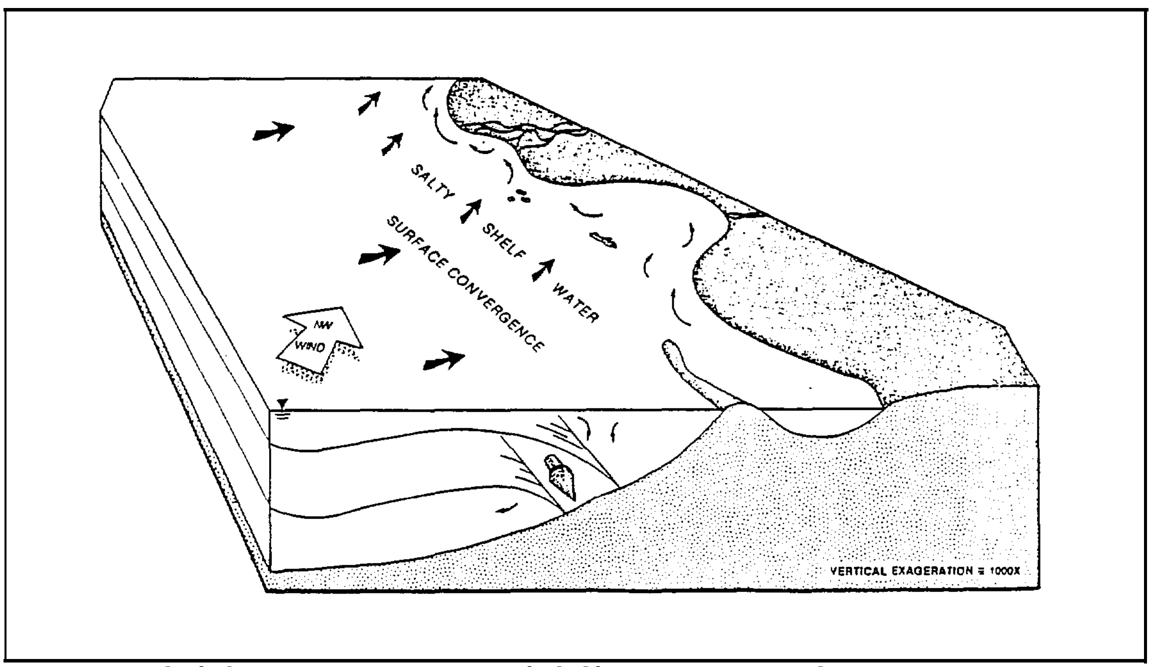


Figure 7.3 Open-Water Late Phase One



igure 7.4 End of Phase-One Step intrusion of Shelf Water Into Coastal Region

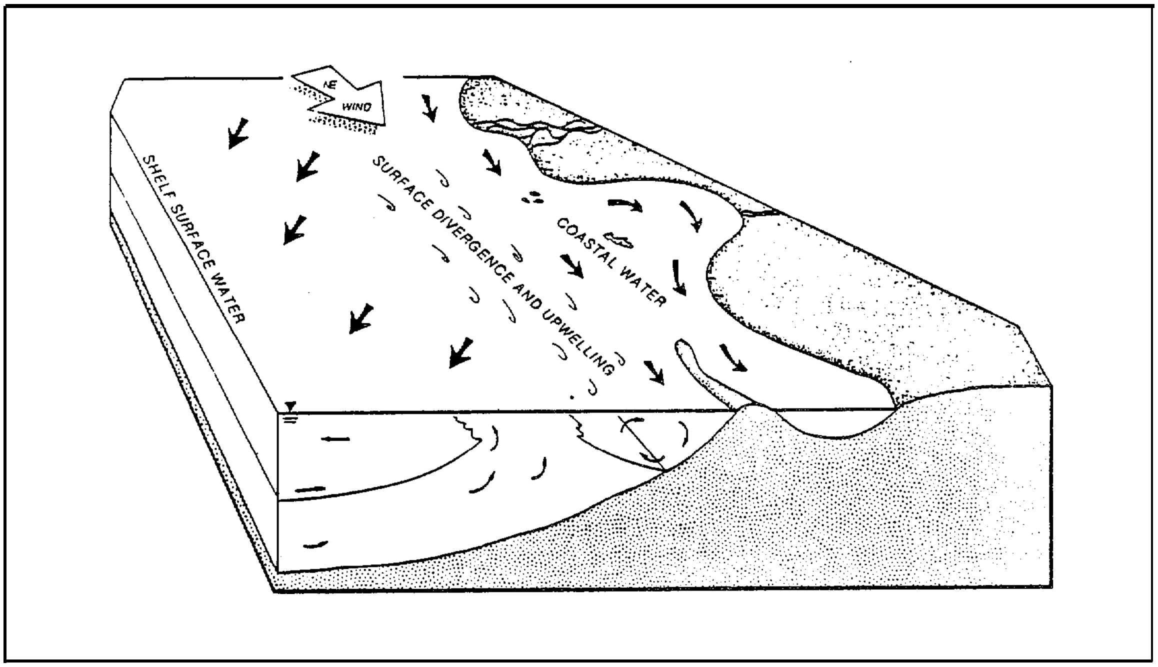


Figure 7.5 Open-Water Phase Two--NE. Wind

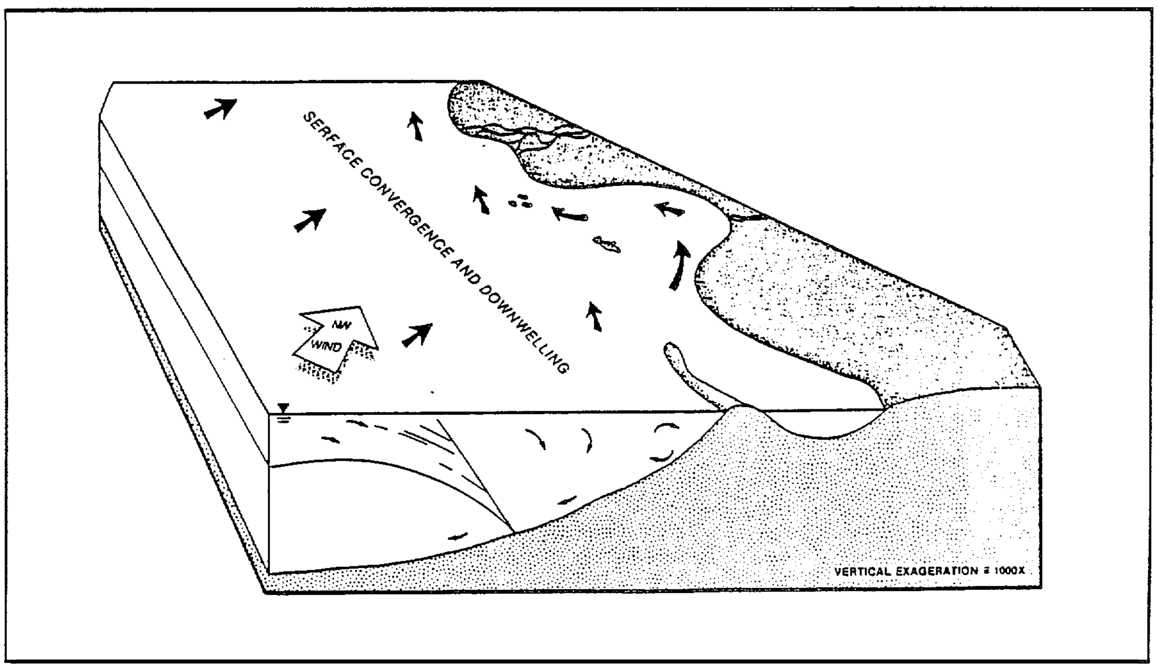


Figure 7.6 Open-Water Phase Two--NW. Wind

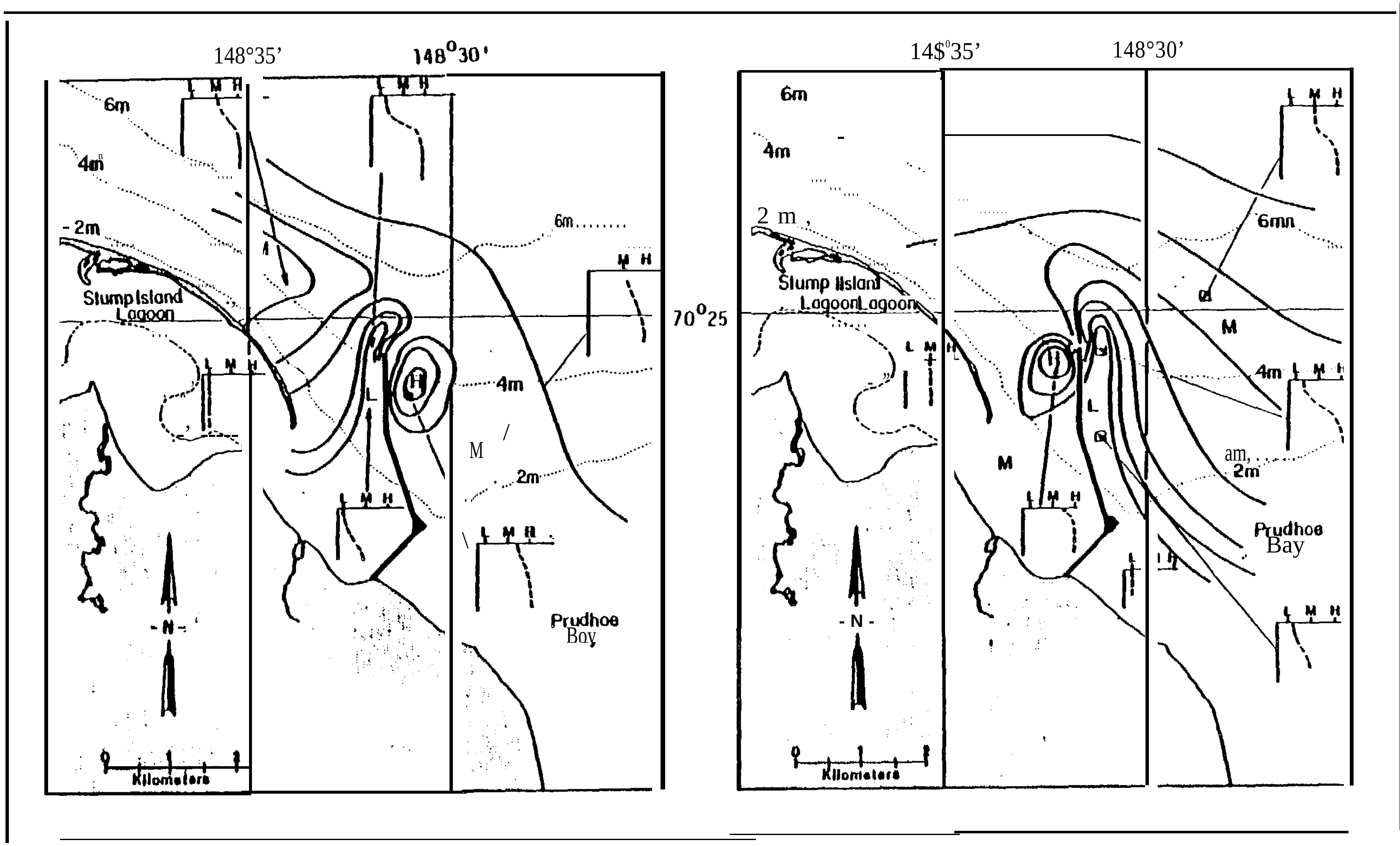


Figure 7.7 Generalized Salinity Distributions-Surface Maps and Selected Vertical Profiles for Prevailing Easterly Winds (Right) **and Westerlies** (Left)

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Chapter 8

Nearshore Oceanography

Introduction

The Nearshore Oceanography Workshop consisted of three concurrent working sessions. Each working session was charged with reviewing the paper presented by Colonell and Niedoroda, identifying information needs, and listing research needed to better understand nearshore oceanographic processes in the Arctic.

A facilitator led the discussions, and a scribe took notes and helped the facilitator prepare summaries (oral) of each session's progress. Summaries were presented by the facilitator at a plenary session immediately following the working sessions.

Working Session 4

Facilitator: Mike Wheeler
Scribe: Chuck Mitchell

Oceanographic data (temperature, salinity, turbidity, and currents) from shoreline to offshore as far as coastal waters extend is needed to locate and identify coastal marine habitats.

This work will be facilitated if ongoing and planned fisheries-related studies, including MMS efforts (i.e., coordinating logistics, sampling, and analytical activities), are coordinated. Ongoing and future coastal oceanographic studies include the oceanographic studies being conducted by the Fish and Wildlife Service (FWS), who will be collecting salinity, temperature, and depth (CTD) profiles in Camden Bay and will establish in-situ current meters offshore of Pokok Bluff; the Canadian Department of Fisheries and Oceans, who will be measuring water temperatures and salinities along the eastern side of the Tuktoyaktuk Peninsula as part of their coregonid studies; and the oil and gas industry, who will be continuing the Endicott monitoring project. Additional data also may be gathered using ships of opportunity; and MMS should consider making current meters, equipment, etc., available for use by scientists on ships of opportunity.

Region-Specific, Nearshore Oceanographic Information Needs

Hydrographic and meteorologic data should be collected in coastal lagoons so that dynamics of physical properties within the lagoon can be described. This information is needed to help understand temporal and spatial changes in the use of coastal habitats by larval, juvenile, and adult fishes.

Oceanographers need to know the scale of information desired by fisheries biologists because study-design criteria to resolve oceanographic processes on a 10- to 20-km scale are different than design considerations to resolve processes on a 100-km scale. If oceanographic information on a 10-to 20-km scale is needed, the interpretation of satellite-imagery--which generally has a l-km-scale pixel size--may be applicable for determining regional processes. However, on-ground data will be needed to support satellite-data interpretation of temperature and salinity by depth profiles in key areas.

Modeling

The regional model of offshore oceanography in the Arctic developed by MMS needs to be refined to provide a better understanding of macroscale circulation. Improvements in the model are possible, but additional information e.g., boundary information is needed.

In general, models are good for comparing variables (processes) versus attempting to reproduce conditions. The primary use of models is to predict trends rather than to predict absolute changes in specific parameters. Absolute values are better obtained by physical measurement.

To determine the scale and accuracy needed in a model of coastal oceanography, additional information on the tolerances and habitat preferences of fish is needed. Because information on fish physiological limits is not well known, the utility of high-resolution modeling is reduced.

Additional information on local oceanographic factors is needed to better predict local current patterns and thereby improve trajectory analyses.

Ice covers the Chukchi and Beaufort Seas for about three quarters of the year, but most of the information on oceanographic parameters in these areas has been collected during the brief ice-free period. Therefore, additional information on oceanographic parameters and processes during the ice-covered period is needed to provide a more balanced understanding of oceanographic properties and processes. Examples of the types of oceanographic information needed include (1) determining what controls formation of the saltwater wedge that moves into river delta areas during winter and how this affects available fish habitat and, conversely, (2) more knowledge about freshwater intrusion onto the shelf and how it affects primary and secondary productivity and how turbid ice affects under-ice algal productivity is needed.

Summary

- Primary interest is in nearshore fish habitat.
- Additional oceanographic data is needed to:
  - Define coastal waters from the coast to the seaward boundary.
  - Understand macroscale regional-circulation patterns, particularly in Harrison Bay and off the Mackenzie *River.*
  - Characterize Chukchi Sea lagoons to determine the significance of rearing areas for marine species.
  - Refine the oil-spill-trajectory analysis.
  - Determine winter oceanographic processes.

Working Session 5

Facilitator: Scott Robertson
Scribe: Lyman Thorsteinson

Each of the Biogeography Workshop sessions noted regional differences in patterns of fish distribution and abundance in the Chukchi and Beaufort Seas. The Chukchi Sea represents, for example, a transition area between the fish communities of the Beaufort and Bering Seas. It contains many Arctic species at their southern distribution limits and Pacific (Bering) species at their northern limits. With reference to the southern Chukchi Sea, there appears to be distinctive zoogeographic boundaries between fish communities south of the Bering Strait and north of Point Hope. This information underscores the realization that regional differences are indicative of differing oceanographic requirements of the fish. Future fisheries-oceanography research should be driven, in large part, by what species are present in the proposed study area and any pertinent life-history information regarding specific habitat requirements. With respect to offshore oil and gas development, species and areas of concern should be given highest priority in locations where development is likely or effects on fish populations can be expected.

Arctic oceanographic information needs were considered from a regional perspective and from offshore and nearshore perspectives. Prior to any new research, especially if winter data are to be obtained, historical databases should be reviewed to determine the exact nature of existing information. By region, the workshop reached the following conclusions regarding the status of existing information and recommendations for future research

Offshore Chukchi Sea

OCSEAP and other research such as the NSF-funded ISHTAR investigation% have provided reasonably good information on regional circulation and transport processes. In terms of fisheries oceanography, more information is needed on the interactions and influences of shelf waters on coastal waters. How do these interactions affect temperature and salinity distributions and fish occurring in coastal habitats? Polynyas are known to provide biologically important winter habitats for bird and mammal populations, and possibly for fish. such as char and Arctic cod. Polynya and other ice-related studies (e.g., ice-edge productivity) were identified as potential topics where additional physical data will be needed in possible ecological studies.

Offshore Beaufort Sea

The dominant physical processes are known, although higher temporal and spatial resolutions in shelf data may be required in certain kinds of fish research. This would include an examination of the temporal variability in shelf waters during the open-water season for both within- and between-yearn comparisons. A specific open-water requirement for additional winter data was not immediately known; however, this need could depend on critical questions that may arise concerning fish and hydrographic influences on their environment (e.g., transport and development of eggs and larvae). A major need to better understand the fate and effect of Colville and Mackenzie River outflows in shelf waters was expressed. What is the signature of these plumes in shelf habitats? Examples were provided of how freshwater inputs into coastal environments during spring breakup affected the distribution of least and Arctic ciscoes in the Colville River Delta. Satellite imagery was recommended as being a particularly useful tool for acquiring location data to study plume dynamics.

Nearshore Chukchi Sea

General nearshore physical-oceanographic processes in the area are well known. Reasonably well-informed predictions of nearshore water transport can be made' even though there is a general lack of data, with exceptions, on nearshore (inside the 10-m isobath) circulation and hydrographic processes for the Chukchi Sea. Local influences, such as winds, can influence distributions of fish and warrant further investigations.

The southeastern Chukchi Sea is much different than the northeastern Chukchi Sea, and these regions are separated by a zone of marine waters intruding inshore in the Cape Lisburne area. Fish use of the nearshore environment is poorly known, although the southern Chukchi and Kotzebue Sound are of much greater importance to anadromous species. In the case of coregonids, this maybe related to availability of overwintering habitat among other possible factors (e.g., spawning habitat, width of coastal brackish waters). Again, the species and its relative importance in coastal habitats will determine what physical processes and variables need to be studied. The influence of Bering Sea water, including nutrients and organic matter, on usage patterns in the coastal Chukchi Sea is not known.

Nearshore Beaufort Sea

The coastal oceanography of the Beaufort Sea, inside the 10-m contour between the Colville and Sagavanirktok Rivers, has been studied extensively (a limited amount of data also are available from Beaufort Lagoon and FWS coastal investigations). Information on the nearshore environment to the east and west of this central portion of the Beaufort Sea is limited, and more data is needed. Especially noteworthy are the coastal areas to the west of Harrison Bay and to the east of Barter Island. Some CTD data will be collected in the eastern Beaufort Sea in 19S8 by NOAA and the FWS in coastal char studies. The influence of Colville and Mackenzie River plumes on nearshore environments needs to be more fully described. Special emphasis is needed on the MacKenzie River plumes' influences on east-west dispersals of migratory fish (with emphasis on the Arctic and least ciscoes). Regarding the Mackenzie River plume, an interesting question was raised concerning the roles of freshwater outflows of the Malcolm, Babbage, and Firth Rivers on the establishment and maintenance of the coastal band of brackish water and its importance in the transport of young-of-the-year Arctic cisco. Questions were also voiced regarding the naturally occurring levels of temporal and spatial variability in temperature and salinity changes that fish might experience from shifting winds and coastal landforms. This information is needed in order to accurately assess possible habitat-related changes in fish distribution and abundance that may result from causeway developments. Finally, a general need for more detailed physical characterizations of overwintering habitats for the major anadromous species was identified.

Working Session 6

Facilitator: Mark Savoie
Scribe: Laurie Jarvela

Summary of Data Needs

- The need for further definition and characterization of coastal plumes and river discharges along the Beaufort and Chukchi coasts was identified. The use of satellite , imagery was suggested as a potential tool.
- Information on early breakup work.
- Information on&h usage of the ice edge during offshore breakup.
- Information to define boundary-layer-front dynamics and use of these fronts by feeding fish.
- Information to determine the year-to-year differences in the breakup of the Mackenzie River and how much and how often the river plume is transported to the west.
- Information on region wide wind data to improve understanding of local current and fish movements.
- Information to develop better hydrodynamic model for predicting impacts from coastal developments.
- Information to further define variability in coastal circulation.
- Information to better understand oceanographic processes during the ice-covered period.
- Information to better understand the oceanographic processes in the nearshore, hipboot zone.
- Information to better coordinate the collection of physical oceanographic information with the collection of fish information.
- Information on oceanographic properties and processes in the southern Chukchi Sea and Kotzebue Sound to support fish studies.

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Chapter 9

Assessment of the Colville River Fall Fishery, 1985-1987

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Introduction

The Colville River on the Alaskan Arctic Coastal Plain supports substantial populations of Arctic cisco (Coregonus autumnalis), least cisco (C. sardinella), broad whitefish (C. nasus), humpback whitefish (C. pidschian), and Dolly Varden char (Salvelinus malma) that have historically been harvested by Native people (Murdoch, 1884; Steffanson, 1913). In contrast to the commercial fishery, for which there is an abundance of data, there is scant information on harvest levels for subsistence fisheries in the remainder of the Colville drainage (Craig and Haldorson, 1981; George and Kovalsky, 1986; George and Nageak, 1986). The harvest from the village fishery is retained for food, trade, or other subsistence uses.

The primary objectives of this study were to (1) obtain estimates of the total effort and catch for the fall fishery in the delta, including harvests of both the village of Nuiqsut and the commercial fishery, and (2) evaluate the effects of these harvest levels on the stocks. The lack of information on harvest levels, coupled with concern for possible effects on the fish stocks from coastal developments around the Prudhoe Bay oilfields, prompted this effort to evaluate current harvest levels and develop recommendations for future management strategies.

Methods

The study area included the Colville River from the Itkillik River downstream to Harrison Bay and was subdivided into four areas based on known areas of concentrated fishing effort: (1) the Outer Colville Delta, (2) the Upper Nigliq Channel near Nuiqsut, (3) the Nanuk area of the Nigliq Channel, and (4) the Nigliq Delta. Monitoring of the fall under-ice gillnet fishery began in early October and continued through mid-November from 1985 to 1987. Within these areas, each net was identified and tracked throughout the entire time the net was fishing. This method chronicled the start and end dates of fishing for each net, net locations, net lengths, and mesh sizes; thus, there was virtually a complete census of fishing effort.

During the main fishing season, village and commercial catches were sampled daily for species composition, number of fish caught, and fork length to the nearest mm. Fish were also examined for tags, fin clips, and dye marks. Whenever catch data were collected, set duration, net length, and mesh-size data *were also* recorded so that catch rates could be calculated for the net set. In 1986 and 1987, otoliths were obtained from Arctic cisco captured in 76-mm (3.0-inch) stretched-mesh nets to evaluate the age composition of the Arctic cisco catch. In 1987, otoliths were also collected from least cisco caught in 76-mm mesh. Aging was completed by the cross-sectional burn technique. Fish used for aging were selected from 76-mm mesh nets, the most common mesh size used in the fishery.

Effort was calculated in net-days by using the start and end dates for each individually tracked net. The catch rate was estimated by treating each individual sample (usually the catch from one net on a given day) as an independent sample. The total effort expended by each mesh size in each area and the associated estimated catch rates *were* calculated for each 10-day interval during the fishing season, starting on October 1. Estimated catches for each mesh size by 10-day intervals were *then* Calculated and summed to provide the estimates of total catch. In many cases in the Outer Colville Delta, especially in 1986 and 1987, complete counts of total catch *were* obtained from individual fishermen.

In 1984 and 1985, the release and subsequent recapture of a substantial number of tagged cisco by studies near Prudhoe Bay (Moulton et al., 1986; Envirosphere, 1987) allowed an estimate of the total number of fish available to the fishery. Tagging was suspended following 1985, so subsequent evaluation of population size was based on changes in catch rate in the fishery.

Results

Distribution of Fishing Effort: The number of Nuiqsut fishing groups (a family or group of families fishing cooperatively) participating in the under-ice fishery decreased from 30 in 1985 to 25 in 1986 and increased to 34 in 1987. Fishing effort was concentrated on the Upper Nigliq area because of its proximity to town. Fishing on the Nigliq Channel began at Nuiqsut when the ice became safe enough to set nets, usually in early October; effort was greatest in mid-October to early November, then decreased by mid-November. By mid-November, daylight is reduced, and the thickness of the ice interferes with operation of the nets.

The 49-percent decrease in effort from 1985 to 1986 in the Outer Colville Delta was caused by reduced commercial and Nuiqsut subsistence fishing effort in the East Channel. The 32-percent increase from 1986 to 1987 waa primarily caused by increased commercial fishing, since the village effort decreased markedly. The commercial fishery accounted for 34,23, and 39 percent of the total effort expended in the fall fishery from 1985 to 1987.

Arctic cisco, the target species, dominated the catch, comprising about 75 percent of the total catch over the survey period. Least cisco was the dominant incidental species, with small broad whitefish caught in the Nigliq Channel and humpback whitefish caught in both the Nigliq Channel and Outer Colville Delta. Fourhorn sculpin was the only other species taken consistently, but it is rarely utilized.

Comparative Catch Rates: The mean catch rates of both Arctic cisco and least cisco are higher in the Outer Colville Delta than in the Upper Nigliq area (Fig. 9.1). Within the Nigliq Channel, mean-catch rates of Arctic cisco were highest near the Nigliq Delta and declined upstream near the village.

Least cisco mean-catch rates showed the opposite trend, being highest near the village and decreasing downstream.

The highest catch rates for Attic cisco during the 3-year-survey period were recorded in 1986 in the Outer Colville Delta and the Nigliq Delta. These catch-rate patterns were interpreted as indicating that Arctic cisco abundance was highest in 1986 compared to the other 2 years.

Estimated Total Catch: The total catch of Arctic cisco *in the* Colville region has declined during the survey period (Table 9.1). While the catch decreased approximately 10 percent from 1985 to 1986, it was accompanied by a 38-percent reduction in total effort. The 23-percent reduction in catch from 1986 to 1987 was accompanied by a 61-percent increase in total effort, reflecting the overall reduced-catch rate. Conversely, the least cisco total catches have followed the direction of the effort, although not the same magnitude of change, decreasing by 53 percent from 1985 to 1986 and increasing 12 percent from 1986 to 1987 (Table 9.1).

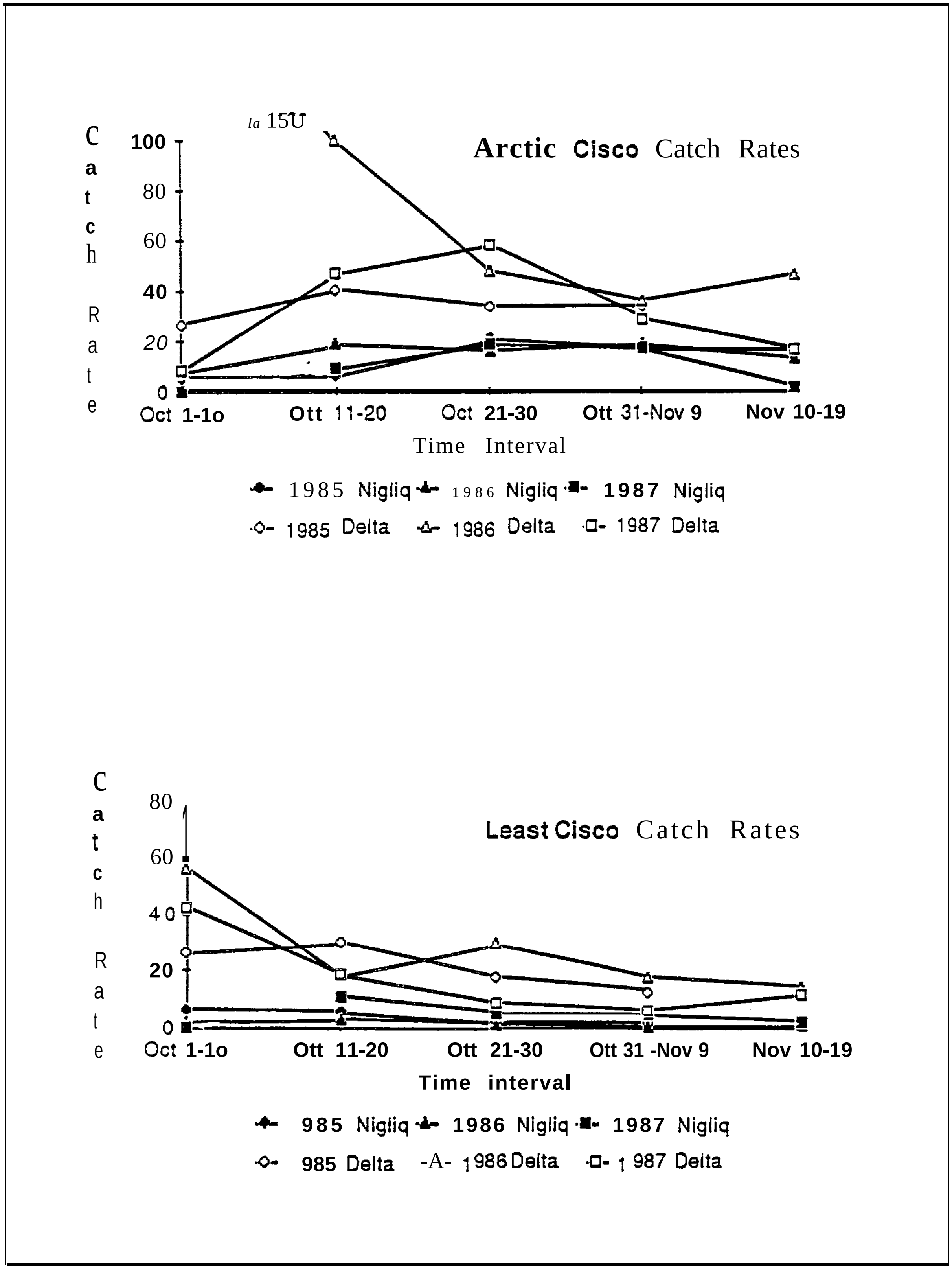
Age Composition: The age composition of Arctic cisco caught in 76-mm mesh was dominated by ages 6 and 7 in 1986 and ages 7 and 8 in 1987, reflecting the strength of the 1979 and 1980 year-classes in the fishery. In 3 previous years for which age data from the fishery are available (1976-1978), age 5 or 6 has dominated, although other ages often comprised major portions of the catch. The 1976 to 1978 data also show changes in age structure likely resulting from strong and weak year-classes moving through the fishery. Since Arctic cisco mature at age 8 or older, the fishery harvests immature fish.

In 1987, least cisco captured in 76-mm mesh were dominated by ages 9 to 12, with ages 8 and 13 to 15 also common. Full recruitment occurred at age 9, at a mean fork length of 308 mm. No single age group was dominant after full recruitment. Because anadromous least cisco mature at age 7 or 8 (Craig and Haldorson, 1981) and fishing occurs after the spawning season, the fishery harvests least cisco that have spawned at least once.

Tag Returns: During the 3-year survey, over 2,870 tags were returned from fish tagged in various studies in the Beaufort Sea coastal region since 1976, with over 65 percent of these tags returned by the commercial fishery. The rate of tag recapture for Arctic cisco and least cisco from the various release years was calculated to evaluate the persistence of tags in the population. For least cisco, the tags decreased at a mean rate of 28 percent per year (SD = 20.7), whale Arctic cisco tags decreased by nearly 70 percent per year (SD = 15.0) for the first 3 years, then were absent from the population. The rate of decline for tagged least cisco is considered to be an indication of total mortality, plus tag shedding; but for Arctic cisco there is support for the Mackenzie-origin hypothesis of Arctic cisco inhabiting the Colville River.

In all 3 years, Arctic cisco tagged in the Arctic National Wildlife Refuge were recaptured during the fall fishery. In 1987, a least cisco tagged in the 1987 Camden Bay study was recaptured in the East Channel. The recoveries of Arctic cisco released in the eastern Beaufort Sea may represent the extent of eastward movement by Colville-area fish during the summer-feeding period and/or movement of adult fish from the Mackenzie region to the Colville region.

Population Estimates and Trends: There was au estimated 16.5-percent increase in the number of catchable Arctic cisco between 1984 and 1985. Concurrently, the estimated number of Arctic cisco



igure 9.1 Comparative Catch Rates (Fish Per 24-Hr 18-m Net Set) of Arctic Cisco and Least Cisco in the Outer Colville Delta and Nigliq Channel by Time Interval, 1985-1987

Table 9.1 Total Estimated Catch of Arctic Cisco and Least Cisco in the Colville Delta Fall Fishery, 1985-1987

Area	Arctic Cisco 1985	1986	1987	Least Cisco 1985	1986	1987
Niglia Channel (all-village catch)						
Upper Nigliq	17,878	8,238	10,331	1,871	1,329	4,483
Nanuk	·-	4,636	3,310	·-	440	124
Nigliq Delta	8,500	5,924	2,635	0	38	74
Outer Colville Delta						
Main Channel						
Village	12,397	14,724*	4,571*	8,698	4,998*	1,433*
Commercial	10,321*	1,839*	0	8,657*	578*	0
East Channel						
Village	7,906	0	0	5,245	0	0
Commercial	13,357*	27,617*	27,494*	8,939*	8,422*	11,939*
Total	**70,359**	**62,978**	**48,341**	**33,410**	**1.5,805**	**18,053**

*Entire catch counted.

greater than 250 mm increased by only 9.9 percent because in 1984 there was a much larger pool of unmatchable (but greater than 250 mm) Arctic cisco, which, by 1985, had grown large enough to be captured by the mesh sizes used in the fishery (Fig. 9.2).

The two size modes apparent in the 1984 and 1985 released fish-length frequency (Fig. 9.2) correspond to the 1978 year-class (320-340 mm in 1985) and 1979 to 1980 year-classes (a single mode at 270-310 mm in 1985), as described from otolith analysis (Moulton et al., 1986). In 1986, the 1979 to 1980 year-classes were almost fully recruited into the fishery, and by 1987 the catches were dominated by the 1980 year-class.

The catch rates in the commercial fishery, which have been used as Arctic cisco-abundance indices for the Colville region (Gallaway et al., 1983), indicate the relative strength of these year-classes. Contrary to the population estimates, the Arctic cisco-catch rate decreased almost 13 percent between 1984 and 1985, although the catch rates were high compared to the historical average. In both years, the fishery was dominated by the 1978 year-class with larger members of the 1979 year-class available in 1985. In 1986, when the 1979 and 1980 year-classes entered the fishery, the catch rates were the highest in the 21-year record. There was a 58-percent decrease from 1986 to 1987 as the 1979 year-class and larger members of the 1980 year-class moved out of the fishery.

The least cisco catch rates in the commercial fishery have fluctuated less dramatically than the Arctic cisco catch rates because the population has a greater range of ages in the harvestable stock and the catches are less influenced by individual year-classes. The basic pattern has been a gradual, but significant (r = 0.49, sig. at a = 0.05), increase in catch rate over the last 21 years.

Historical Catch Levels: Catch data are available from the commercial fishery for the last 21 years, while the village of Nuiqsut was founded at its present site in the early 1970's. It is likely that the current levels of effort were reached begirming in the mid-to-late 1970's as the village stabilized and fishing patterns became established. Over the last 10 years, the mean, annual commercial catch has been 22,300 Arctic cisco (SD = 8,587) and 21,500 least cisco (SD = 9,252). If it is assumed that the ratio of village to commercial catch observed from

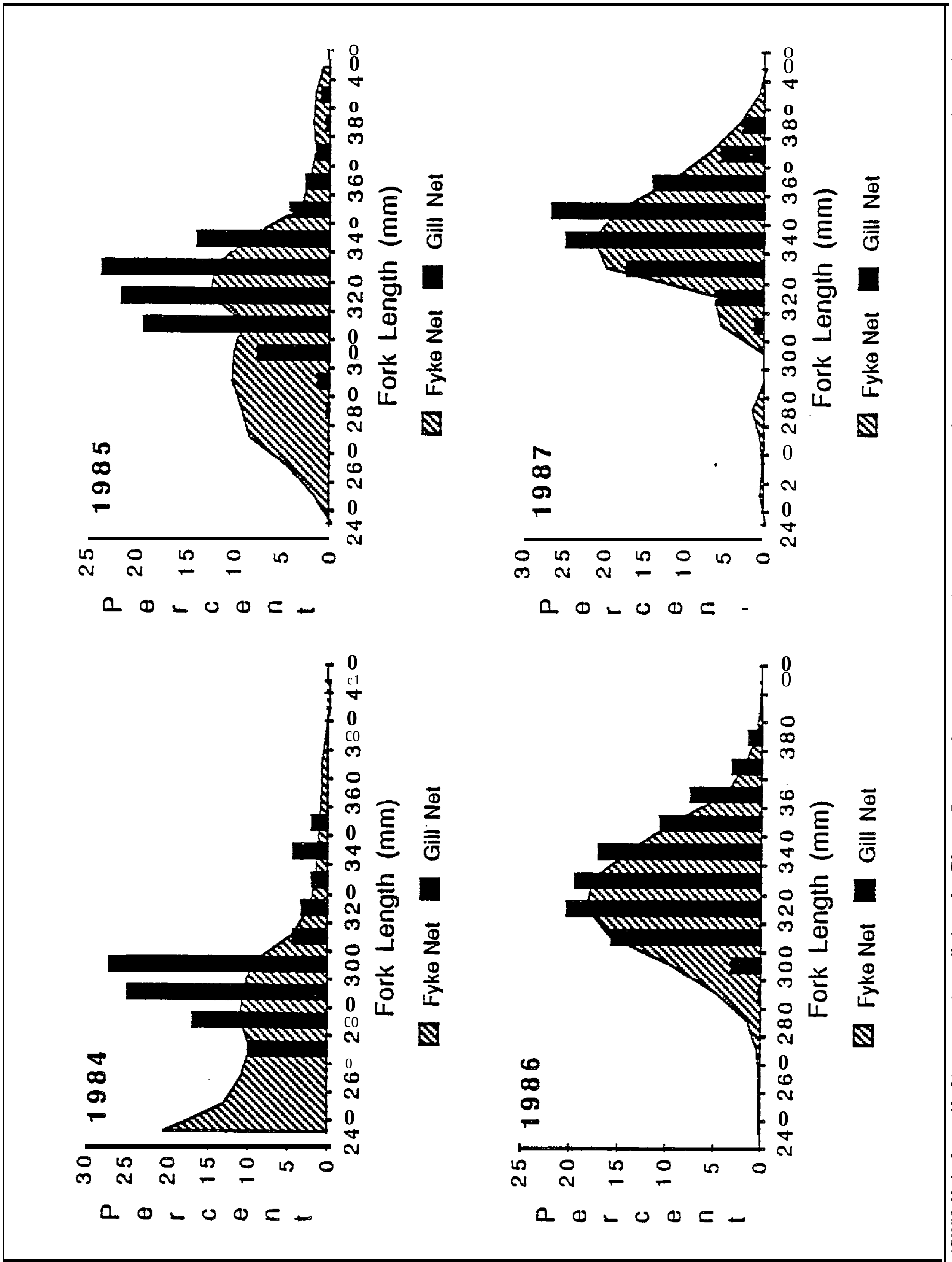


Figure 9.2 Length Frequencies of Arctic Cisco Caught in Fyke Nets Near Prudhoe Bay Compared to Those Caught by Gillnet in the Colville Delta Commercial Fishery, 1984-1987

1985 to 1987 represented an average condition, then the commercial harvest has averaged 46 percent of the Arctic cisco catch and 59 percent of the least cisco catch; and the mean, annual catches for the village and commercial fisheries for the last 10 years were 48,500 Arctic cisco and 36,400 least cisco. As evident from the 1985 to 1987 estimates and historical pattern of catch rates, there is substantial variation between years.

Discussion

Variability in Effort and Catch: During the 3 years of survey, both village and commercial fishing effort fluctuated drastically. Village effort fluctuated primarily because of competing requirements for time, including employment or lack of employment, and pursuit of other resources. The early fishing period coincides with the whaling season, and hunting and processing of whales in 1986 and 1987 likely reduced the early and mid-October effort in those 2 years. The commercial effort responded to both catch rate and market conditions. The fisherman sets a desired catch level based on anticipated markets (within a maximum harvest quota) and adjusts effort based on the observed catch rate. The high catch rate in 1986 allowed reaching a desired harvest with minimal effort.

The increase in Arctic cisco catch rate from 1985 to 1986, resulting in the highest catch rate seen in the commercial fishery in 21 years of record, was caused by the full recruitment of the 1979 and 1980 year-classes into the fishery. There was a pool of Arctic cisco that were inaccessible to 76-mm mesh nets in 1985, but these grew to a harvestable size in 1986. This group of fish dominated fish samples in Beaufort Sea coastal studies between 1982 and 1985 (Griffiths et al., 1983; Woodward-Clyde Consultants, 1983; Moulton and Fawcett, 1984; Moulton et al., 1986). The data also indicate that few young fish entered the region from 1981 to 1984; thus, few are available to recruit into the fishery. The 1987 catch continued to be composed of 1980 and 1979 year-class fish that remained in the Colville region prior to maturation these will likely be gone in 1988. The catch rate of Arctic cisco in the commercial fishery declined 58 percent between 1986 and 1987 and will likely decline further in 1988.

Impact of Fishery on Stocks: The exploitation rate on Arctic cisco cannot yet be accurately estimated. The estimated harvest of Arctic cisco in 1985--70,400 fish --represented approximately 6 percent of the harvestable Arctic cisco, assuming that all of the released tagged Arctic cisco in the Prudhoe Bay area moved to the Colville region in late summer and were vulnerable to the fall fishery. If substantial numbers of tagged Arctic cisco moved *elsewhere*, such as remaining in the Sagavanirktok Delta (adjacent to Prudhoe Bay) or moving eastward to the Mackenzie River, then the proportion of the population in the Colville would decrease and the harvest rate on those fish utilizing the Colville Delta would increase.

Evidence of substantial eastward movement by Arctic cisco is beginning to emerge as sampling effort increases in the eastern Beaufort Sea. In 1986 and 1987, 12 Arctic cisco tagged in the Prudhoe Bay region were recovered in Canada after being at large 1 to 6 years. There is also westward movement of large Arctic cisco from the Mackenzie region into the Colville region during the summer, as evidenced by the recapture of Arctic cisco tagged east of Kaktovik.

For least cisco, the pattern is more clear. Virtually all least cisco tagged near Prudhoe Bay entered the Colville Delta in late summer and were vulnerable to the fishery (Moulton et al., 1986). There are resident populations of least cisco in lakes and streams connected to the Colville system, but these appear to occupy different habitats than the anadromous least cisco that winter in the delta and do not contribute significantly to the harvest. The estimated harvest of 33,400 anadromous least cisco in 1985 represented approximately 10 percent of the harvestable fish. The catch rates of least cisco in the 1986 commercial fishery increased slightly over those in 1985, indicating that the harvestable population was of similar size in both years. The total catch, however, decreased over 50 percent because of the reduced effort; thus, the 1986 exploitation rate may have been around 5 percent. Using the same reasoning for 1987 (commercial fishery catch rates approximately 18 percent less than 1985 levels while total catch was 46 percent less), the exploitation rate likely was between 5 and 10 percent.

Summary and Recommendations

The 3 years of investigation on the Colville River cisco fishery reveals that the present harvest levels are within an acceptable range. The stocks do not exhibit characteristics often seen in overfished populations, and the catch rates of both Arctic cisco and least cisco are high compared to the previous 20 years of record. As discussed, the recent high catch rates for Arctic cisco were a result of a high recruitment of young in 1980; since this group of fish has grown out of the fishery, catches are predicted to decline in 1988 and remain low until the 1985 to 1987 year-classes reach harvestable size.

Because the present harvest levels appear to be within an acceptable range, i.e., are not adversely affecting stock levels, it is recommended that no changes be made in the management of the fishery at this time. Monitoring of the fishery should focus on estimating effort, catch rates, and age structure so that the effects of increased fishing effort or harvest level will not go undetected. Monitoring of juvenile abundance and age or size structure also would allow predicting the future direction of catch rates based on abundant or weak year-classes.

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Question-and-Answer Period

<u>Question:</u> How are fish used in the village?

<u>Larry Moulton</u>: The villagers who are fishing in the Nigliq Channel, the channel near town, mostly use everything they catch. Some of the villagers are a bit selective in what fish they take home. The small, broad whitefish, which show up as an incidental catch, often are not used. But the least cisco, the Arctic cisco, larger broad whitefish, and burbot are all used in the homes. They use some of the fish for dogfood, but that's not a major factor in the village. The people who fish the outer delta catch a lot more fish. They will give a large share of these fish to relatives--and they may sell a portion of the catch. Some of the catch is given to relatives in Barrow and Kaktovik. The commercial fishermen may sell their catch to other villages and to Fairbanks for dogfood.

<u>Question:</u> Is similar information available for villages on the Chukchi Sea coast west of Barrow and south to Kotzebue Sound, i.e., Kivalina and Deering?

<u>Moulton</u>: Some information is available for Point Lay and Kivalina. Information on the subsistence harvest of fish at Kivalina was studied quite thoroughly back in 1968 by Window, for the Department of Fish and Game. Subsequently, Steve Braund did a similar study in 1982 or 1983.

<u>Question:</u> Have you been actually doing any late fall measurements of juvenile Arctic cisco

recruitment into the Colville River, or have you been relying on the work done to the east?

Moulton: In 1985, we did our own. We had nets in there and watched the recruitment of the 1985 group come in. So, we had data on that, but nothing has been done since then in the Colville River. We are relying on the information from the Endicott studies.

Question: In talk about human use Of these species, you have covered subsistence and commercial fish. I thought maybe we should talk briefly about sportfish.

Moulton: Sportfishing occurs throughout the area. Flight services fly clients into remote airstrips in the Echooka Springs and Ivishak region to sportfish. In addition, local helicopter services fly sportfishermen into some well-known lagoons along the coast.

Comment: There's virtually no information on the sportfishing harvest or documentation of sportfishing effort in the Prudhoe Bay area or the Ivishak River or Sagavanirktok River systems. However, the Alaska Department of Fish and Game, Sportfishing Division, has proposed to collect this information next year (FY 1989).

Comment: If Division personnel want to estimate past sportfishing effort in the area, they might consider contacting local North Slope air service operators and requesting to review their flight records. The flight records can provide an estimate of the number of anglers transported to specific areas and the amount of time between pickup and delivery.

Question: How much information is available on predation by piscivores on anadromous fishes in the Mackenzie River?

Moulton: Burbot in the Mackenzie River feed extensively on younger stages when they are available.

Comment: The Simpson Lagoon study and work conducted by Kathy Frost provide information on the consumption of anadromous fish by birds, by other fish, and by seals.

Question: Larry, the Simpson Lagoon data show a logical progression from 1977 to 1978 on the relative abundance of year-classes. These data suggest peaks of abundance at yearn 5 and then at 6; however, for year-classes 1 through 4, that logical flow wasn't/isn't apparent. Do you think that this is an artifact of sampling?

Moulton: Some of it's just the strength of the year-class involved. What doesn't show on this graph is the sampling CPUE's; the catch rates were very low, while the age-class distribution was quite high. The sample size of the *younger year-classes* during the initial years might have been extremely low so that by the following year, its length frequency could be masked by that of younger year-class(es). The apparent under-sampling of the *younger* year-classes maybe a result of sampling-gear bias. With the older year-classes, you can see the logical progression of length frequencies as the fish grow and leave the system. The age-6 fish turn into 7's and decrease. By the time the fish reach age 8, they begin leaving the river system as they mature. By the time they reach age 9, most have left the river.

Question: I remember reading in one of the reports a while back that there was some indication that the number of nets set downstream of the commercial fishery had increased and that they *were* intercepting fish that traditionally had been harvested in the commercial fishery. In addition, subsistence-catch rates during the late 1960's and early 1970's, downstream of the commercial fishery, were higher than the commercial-catch rates. Do you think that the time-series data presented here are comparable year to year because of the potential interception of fish downstream from the commercial fishery?

Answer: No, that's not true, but that is a good point that I haven't included here. Both the commercial and the village fishing efforts have varied substantially over the years. Until about 1980, the commercial fishing effort was much higher than it is now. Currently, commercial fishing rates are about 400 to 500 net days per season. Typically, that's about half of what Helmericks used to fish in the 1970's and 1960's. So, we have seen a real decrease in this effort. Concurrent with that, there are variations in the village fishery. There are some traditional fishermen who have fished adjacent to Helmericks' fishing site for at least a century. We've got good records of that, the Tukle family. They've occupied the same net site, but now Helmericks fish adjacent to them. But, in 1985, we did see tremendous effort in the outer delta; it did affect Helmericks' catch rates. We documented that those adjacent nets did affect his catch rates. That could be some of the viability we have seen in here. That probably also caused some of the problems with evaluating this data in the historical sense, too. In 1986 and 1987, the village effort was steadily declining in that outer delta region so that in 1987, there was very little competing effort. In fact, he did very little fishing himself. Again, catch rates were high enough where he could get the harvest he needed without a lot of effort. So, there's a lot of variability built into this that we don't account for by just raw CPUE. I did a little analysis on the effort curve and what I want to do is go back and clean up some of that by looking at comparable time periods and try to reduce some of the bias that this effort data is giving us. We are aware of these problems, and they cause *some* of the fluctuations.

Question: Does the database contain information on fish-condition factors? Is information on relative K factors available for an extended time period (several years), and can you give us a general feeling for the economic value of the commercial fishery?

Moulton: Regarding condition factors, little or no information is available. Several years ago, circa 1985, some villagers and commercial fishermen complained that the fish were leaner than normal, but there is nothing beyond hearsay.

In regard to the other question about dollar value, if you go to Barrow and buy Arctic cisco, you are probably paying $1.50 to $2.00 per lb. or is it up higher than that? $3.00? Anyway, we are looking at a harvest of about 100,000 fish or less.

Question: Have YOU done a sensitivity analysis, using your mortality data, to estimate the effect that fluctuations in natural mortality may have on the Colville River fishery?

Moulton: Yes. If the natural mortality rate decreases, the fishing mortality increases quite a bit; however, I don't recall the relative magnitude of the changes.

Question: Are there resident spawning populations of least cisco in the Colville River?

Moulton: Yes. There are at least two spawning stocks of least cisco in the Colville River: an anadromous stock upon which the fishery is dependent and a lacustrine stock, which resides in the main stem of the river. Few of the lacustrine stock are taken in the fishery; although in Nigliq (Nechelik) Channel, near town, fish with typical lacustrine characteristics are harvested.

Question: Are anadromous forms mixed in with the lacustrine stock on spawning runs?

Moulton: The two stocks do not appear to be mixed on their spawning runs; however, when spawning is completed, they are found in the delta region and are distributed pretty much from about up from the Itkillik River and throughout the delta region. The abundance of' lacustrine fish decreases in the outer delta as salinities increase.

Comment: One of the things we found along the Tuktoyaktuk Peninsula in the peninsula lakes and *river* systems is that there are basically two populations of least cisco. One is an anadromous form out of the main stem of the Mackenzie River, and the other is a lake-dwelling form (lacustrine). Morphologically, virtually all the other life-history aspects appear quite different than the anadromous form.

Comment: There appears to be a third form in the Colville River that matures at about age 3 and doesn't ever reach the size of the fish are harvested in the fishery.

Question: One other question I had was on your estimate of natural mortality rates on the anadromous commercially-tished populations. You were estimating it around 25 percent. I was wondering about your catch curve there--the commercial or resident catch of anadromous fishes --where it showed from the age-class structure starting at about 8 ranging out to 17 years. Just curious--there seems to be some discrepancy there between an estimated 25-percent natural mortality rate and the decline of just the year-classes based on those catches.

Moulton: That particular age frequency was based on a 3-inch gillnet. So, it's not a representation of relative year-class strength for the older fish but reflects gear selectivity.

Question: So, the fish are not fully recruited to the fishery by age 8?

Moulton: It seems that by age 9, the fish are fully recruited and that for the size of gillnets employed in the fishery, the fish are equally within these size ranges.

Question: On that basis, is the 25-percent mortality-rate estimate realistic based on catch curve?

Moulton: The 25-percent-mortality estimate appears high because it is based on tag recoveries and does not account for tag-induced mortality and tag shedding which would inflate the natural mortality estimate.

Question: DO YOU have estimates of tag losses in the anadromous least cisco populations associated with the fish moving to other spawning streams, either through outmigration or the loss of these anadromous fishes to other populations along the coast?

Moulton: We haven't received least cisco tags from any other *river system in* the area, so we think there is little tag loss associated with moving to other river systems.

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Chapter 10

Factors Limiting the Growth of Arctic Anadromous-Fish Populations

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Introduction

Factors limiting the growth of arctic anadromous-fish populations are poorly known as is true overall in terms of fact as opposed to theory. Although in some studies it has been possible to determine causal relationships between particular factors in the environment and changes in populations, it is more often the case that changes in birth and death rates have been vaguely related to population densities and groups of factors supposed to vary with these. The complexity of natural systems usually precludes clear definition of causal relationships. These thoughts notwithstanding my personal excitement about studies of arctic anadromous-fish populations stems from my belief that this system is not hopelessly complex and that clear causal relationships can be, and are being, established.

To achieve this goal will require judicious focus and integration of existing and planned programs, new approaches, and cooperative efforts--not only among scientific disciplines but also among institutions involved in such studies. This meeting appears to be a positive step in the right direction toward contributing to integrated, focused, and cooperative efforts.

The Problem and Overall Strategy

The success of any population depends first on survival, then on the ability to grow and develop to maturity, then on successful reproduction. The Arctic environment of western North America imposes a set of harsh physical and biological constraints on the anadromous-fish populations of interest.

AS Craig (1988) has noted, these conditions are not unique to the Arctic, but here their severity is extreme:

- Arctic aquatic habitats are very cold, with annual averages of only 1 °C in coastal waters and 2.5 °C in large rivers;
- Winter freezing reduces low-salinity, nearshore-coastal habitat to nil and stream habitat by 95 percent (these are the habitats required to survive the long winter);
- The fish must accumulate their year's food reserves during the brief 3-month summer period; and
- During the summer period, fish must move from the freshwater or low-salinity river-delta habitats (where food is scarce) into the coastal zone where, although food is more abundant, temperature/salinity/current environment is fickle depending upon the vagaries of weather.

Despite these constraints, the species upon which this workshop is focused are surprisingly well-adapted, for several reasons, again as outlined by Craig (1988):

- The fish involved have had 200,000 years (since Pleistocene glaciation) at their present location to adjust genetically to temporal and spatial variations in temperature and salinity.
- Some (not all) key environmental variables fluctuate predictably on an annual cycle, thereby facilitating adaptation to them;
- As K-strategists, the populations are resilient to short-term adversity resulting from unpredictable environmental fluctuations. While each of the species reflects a high degree of similarity to the others in terms of behavioral adaptations and life-history strategies used to cope with overall arctic conditions, they occupy somewhat different temperature/salinity niches--which has a great bearing upon which factors are most important in limiting population growth.

Temperature/Salinity Niches

Regardless of season, temperature and salinity will appear as key factors. As poikilotherms, fish are "conformers" with regards to temperature--body temperature closely follows the temperature of the environment. The only means of thermoregulation they have available is behavioral in nature, that is by moving to the most favorable place in the environment within a given season.

Arctic anadromous fish seem to possess varying degrees of ability to cope with salinity--some appear to mainly conform, whereas others seem to be able to regulate salt balance. Broad whitefish, at one end of the spectrum, do not appear to possess significant osmoregulatory capabilities, at least at younger ages, and are thus mainly restricted to fresh- or very low-salinity water.

Least and Arctic cisco appear to have progressively better osmoregulatory capabilities as compared with broad whitefish, but the mechanisms of their osmoregulatory capabilities are not well known--if at all. Whatever it is (increase in salt-secretion cells, hormonal and enzymatic activity, and/or changes in membrane permeability), it is not without metabolic cost.

Older age Arctic char appear to have better osmoregulatory capabilities than the other mentioned species, perhaps due to an ability to regulate salt ions in their blood plasma and muscle tissue. Despite this, they do not appear to tolerate marine salinities, and they spend more time in freshwater than either of the ciscoes.

Overwintering Habitat

A part of the overall behavioral strategy common to ail species is to retire during winter to a habitat that permits existence and requires the least metabolic cost. For anadromous Arctic char and broad whitefish, a freshwater habitat appears to be required, and the availability of such habitat is extremely limited on a relative basis.

At freezeup, the water levels in North Slope streams are at their lowest, and up to 2 m of ice will form by late winter. These factors result in the absence of water at most locations (some 95-9770 of summer stream channel habitat is lost during winter (Craig, 1989)--even the two largest rivers on the Alaskan North Slope (the Colville and the Sagavanirktok) cease to flow by late winter and freeze to the bottom over long stretches of their courses.

Anadromous Arctic char are unique among the species of interest in that they primarily use the spring-fed areas of North Slope streams for overwintering, spawning, and even early-age rearing. Given the great spatial limitation of such areas, overwintering habitat is undoubtedly the overall limiting factor for char populations.

Density-dependent recruitment patterns also would be expected for Arctic char due to competition for space and, for early-age cohorts, food resources. The key environmental factor that might limit the population during winter is dissolved oxygen; but yea-round flow occurs in the spring areas, and oxygen levels are typically high.

Broad whitefish also are restricted to freshwater overwintering habitats. In the Mackenzie River Delta, where populations are large, the life-history strategy involves the use of deep lakes connected to the rivers for both overwintering and summer-feeding habitat by the younger year-classes. Older year-classes apparently use the river for spawning and overwintering and the freshwater coastal zone for summer feeding. Such lake habitat is greatly restricted or absent along the eastern Alaskan coast but is present in limited amounts along the western Alaskan Beaufort Sea coast. The scarcity of this habitat undoubtedly sets the population limits for broad whitefish. This overwintering and rearing-habitat limitation appears especially evident for rivers such as the Sagavanirktok and Canning in which the availability of alternative freshwater-overwintering sites (deep pools in the river) are restricted mainly to delta areas and are subject to oxygen failure and salinity intrusion.

In these delta habitats, competition for space and dissolved oxygen could result in density-dependent recruitment patterns--unexplained forays of small, broad whitefish from the Sagavanirktok River into the cold, saline coastal zone during fall may reflect the results of such competition.

Delta-channel overwintering habitats in rivers like the Sagavanirktok and Canning also are subject to failure if high densities of fish become restricted to small pools when an increase in ice thickness precludes movement out of these areas. Under such conditions, adequate oxygen may not be available to support the fish over the winter period; or, if in the lowermost part of the delta, salinity levels may increase to lethal levels.

The anadromous ciscoes, especially the Arctic cisco, utilize brackish-water areas of river deltas for overwintering. Arctic cisco, and perhaps even the anadromous least cisco to some extent, may represent obligatory anadromous species based upon the proportion of their life spent in brackish waters.

Brackish-water delta habitat along the North Slope of Alaska is mainly represented in the Colville River (with channel depths of 2 to 10 m and a composite channel length of over 70 km, the Colville Delta is second only to the Mackenzie Delta in the amount of potential overwintering habitat), but other rivers such as the Sagavanirktok offer limited amounts of this habitat.

Unlike the Mackenzie, the Colville ceases to flow in winter, thereby allowing brackish or marine water to penetrate as far as 60 km into the delta. Winter salinities of 11 to 40 ppt and even higher have been recorded in the delta; and, based on the studies of Moulton and Field (19S8), the ciscoes appear to move in response to salinity surges and desert areas in which high salinity becomes predominant. Both movement and osmoregulation have a metabolic cost, which is especially significant during winter when ability to feed and assimilate food is greatly restricted by temperature.

Despite its apparent size, suitable areas of overwintering habitat in the Colville River may be limiting to the cisco populations residing there, primarily as a function of the salinity increases that occur over the winter.

Other river deltas along the western North Slope of Alaska provide only limited areas of brackish-water delta habitat and thereby can support only limited numbers of ciscoes--and those that are there are in a precarious situation.

In summary, I strongly believe that the availability and size of overwintering habitat are the major limiting factors for Arctic char and Alaskan broad whitefish populations, and probably for ciscoes as well.

Significant areas of suitable cisco overwintering habitat are located only in the Colville, although other river deltas can be and are utilized by Arctic cisco under some conditions, probably dependent upon how recruitment occurred, which will be discussed later. Despite the attention now being paid to the carrying capacity of summer-feeding habitat, the concept that overwintering habitat is a scarce and critically important commodity that almost certainly limits population sizes should not be discarded or down played.

Historical Levels of Cisco Populations

Before proceeding, an examination of estimated population fluctuations of the ciscoes based upon historical CPUE values from the Colville River Delta fisheries is in order. This database covers 21 years and is unique in that meticulous records have been kept and the fishery has been largely operated by the same people using the same methods year after year. Changes and expansions in the fishery in recent years have been subject to scientific study and monitoring, including population estimates, enabling an assessment of the reliability of using the CPUE fluctuations as population-level indices. Although not without problems, the database represents an invaluable assessment resource.

From Figure 10.1, it can be seen that the population levels have varied markedly over the years. There appear to be some recurring cycles; and for each species, the highest catches for the period of record have occurred in recent years.

I became interested in this database during the late 1970's and early 1980's because of the decline in the Arctic cisco population that occurred during these years, which corresponded to the 1976 extension of West Dock. With the *historical* data covering 1%7-1981, several colleagues and I subjected the data to a population-dynamics model, attempting to define the mortality, growth, and recruitment parameters that might account for the observed fluctuations.

The model that was developed was able to mimic the historical record rather well, and the parameters made sense if:

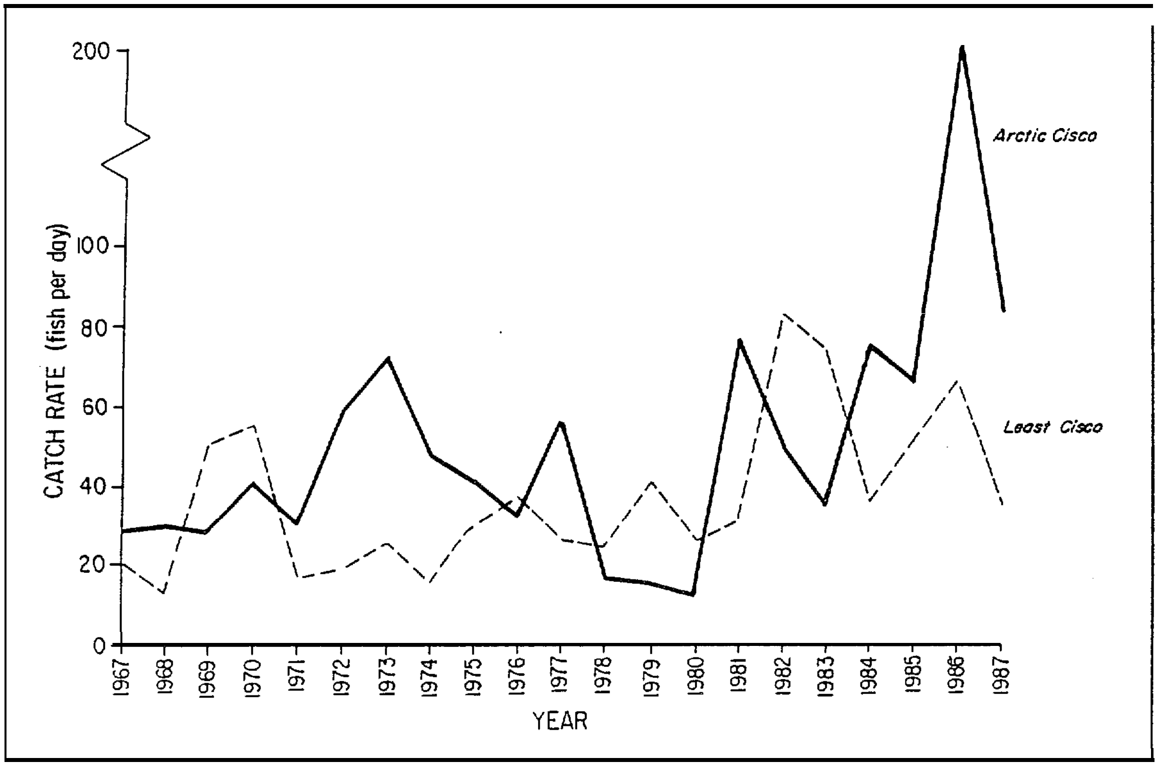
- A large fraction of the population was invulnerable to the fishery;
- The high mortality represented fish leaving the system; and
- The overall population was characterized by a strong, density-dependent stock-recruitment relationship.

These and other observations led us to hypothesize that the "population" in the Colville River Delta fishery were, in fact, migrants from Canada that were transported into Alaska as age-O/l fish, but then returned to the Mackenzie River for spawning.

The size of the Alaska "population" would thus initially be determined by the factors controlling the recruitment of age-O/l fish from Canada and their ultimate success in reaching the Colville River.

Recruitment Patterns of Arctic Cisco As a Limiting Factor

As stated, one hypothesis that would explain much of the historically observed abundance patterns of Arctic cisco in Alaska is that the *overall* population has a strongly density-dependent stock-recruitment function, and (on the whole) a constant proportion (about 30%) is recruited to Alaskan habitats.



'igure 10.1 Catch-Per-Unit Effort for Arctic and Least Cisco in the Helmericks' Commercial Fishery, 1967-1987

A case can be made for this argument based upon relative Mackenzie River discharge from various channels across the delta, nearshore current patterns west of the delta, and the long-term average proportion of time that wind direction would favor westward transport.

However, meteorological conditions at a given time and place are seldom average, and variation among and within seasons and years is the rule. Several lines of evidence suggest that the migration is, at the minimum, current-aided or that the event may even be controlled by currents.

In 1985, the migration of age-O Arctic cisco from Canada to the Colville River was documented by synoptic sampling conducted from Phillips Bay on Canada's Yukon Coast to the Colville River of Alaska. The observed migration rate corresponded to predicted rates based upon mean wind speed and resulting current speeds. The fish moved past the causeways in Prudhoe Bay in a pattern much as would be expected if currents were the major factor responsible for movements, and large numbers of these fish arrived at the Colville River.

The observed pattern of movement in the vicinity of the Endicott Causeway was much as had been predicted based upon a biased-random walk-movement model under conditions where current strength overrides the ability of the fish to behaviorally thermoregulate, which is especially apparent at lower temperatures.

Also, a most convincing case for the importance of currents is being published by Fechhelm and Fissel (1988). In this paper, they show a highly significant correlation between percent of time meteorological conditions in the eastern Beaufort favor westward transport and the Colville River fishery catches 5 years later when these fish enter the fishery. Exceptions to the observed pattern correspond to bad ice years. Whatever the mechanism, it appears certain that, for Arctic cisco, the strength of the recruitment event sets the initial limits for the size of the Alaskan "population." Understanding of this event, especially knowledge of what proportion and stocks of the overall population are represented and the factors that control the movements of these small fish to the Colville River Delta, is especially important.

Summer-Feeding Habitat

Until recent years, the spatial extent of summer-feeding habitat was considered extensive, extending across the entire coast as an uninterrupted band of wren, brackish waters through which the fish foraged at will during summer. Tag returns for large fish supported this view of the world. However, as studies have progressed, it has become apparent that the habitat varies considerably over time and space in terms of temperature and salinity, factors that affect the habitat-utilization patterns of the fish.

Early in the season, the old concept may be true (or nearly true) but, by about the middle to the end of July, low-temperature/high-salinity waters regularly impinge against the coast in some areas to divide the overall coastal area into three general habitat units.

These areas may, in fact, constitute the extent of feeding habitat available for the fish associated with each of the overwintering rivers within a habitat unit --with all the exceptions, of course (large fish of most of the species, small Arctic cisco, Arctic char in the eastern Beaufort drainages).

The fish move out of the rivers during or shortly after breakup. While, due to ice, the habitat area available at this time may be small, prey appears to be concentrated and feeding conditions may be good. As the ice retreats and/or melts, the area of habitat increases, but prey levels may not be as dense, except at brackish-marine-water interfaces. The fish exploit these areas to the extent that they are capable depending upon their temperature/salinity restrictions.

AS the season progresses, the fish forage even farther, probably in association with the watermass from the river, or with the direction of flow, foraging all the while. This movement is not without energetic cost associated with the increased activity. Energetically, the shorter the migration required, the better. There is considerable evidence that at least small fish travel in the direction of drift, and this makes sense from a bioenergetics point of view. No fish can afford to spend as much or more energy in finding or capturing prey than the prey contributes to the fish's metabolic requirements.

Maintaining an association with the watermass may also be a mechanism ensuring that young fishes are able to relocate the overwintering area, but this location is likely learned early in life, enabling the fishes to be more free in their movements with age.

The fishes have great similarity in their diets, feeding mainly on mysids and arnphipods of marine origin, but access to these prey is limited by temperature and salinity constraints that vary by size class within species, and among species. Broad whitefish have the most disparate diet due to their restriction to fresh- or nearly freshwater, followed by large Arctic char. Large char, along with large Arctic cisco, can utilize more saline habitats and can therefore move closer to the source of the prey.

Char also have the additional advantage of attaining a size and having the morphology to be able to feed on Arctic cod, which can be exceedingly abundant. Arctic char thus pass through an ecological threshold, i.e., they attain a size that enables a shift in food from *small* crustaceans to Attic cod.

The daily ration required by arctic anadromous fish is poorly known, but has been estimated at 5 to 6 percent of body weight based upon stomach evacuation studies of Arctic cod. There is a wealth of stomach content data and gross measures of percent fullness data; but in the absence of bioenergetics information and biomass growth information% these shed little light on the rations required to support growth.

On a mass-balance basis, most habitats would seem to normally have prey biomass levels more than adequate to support all consumers, but this is not always so. The fish may be more restricted in distribution than previously believed, and the period during which the energetic cost of obtaining this food is favorable may be more limited than generally believed.

As I have noted, by the middle to the end of July, the system naturally undergoes a step-increase in salinity (and decrease in temperature), which fragments the overall range. Within each habitat unit, there is also an increase in salinity, and temperatures are becoming progressively cooler. The metabolic cost of osmoregulation increases, and the ability to capture and assimilate food decreases with temperature. Conversely, prey densities undergo a corresponding increase.

So far, all of this sounds fairly hopeless. However, let me also note that fish, in general, are fairly efficient at obtaining a full ration, even at low prey densities. Beyond a certain level, additional prey do not increase the ability of the fish to obtain a maximum ration; i.e., a maximum ration can be obtained at considerably lower prey densities than might be expected. Determining this level should be a key research priority.

I personally still suspect that the extent of summer-feeding habitat and prey availability are generally not limiting to most anadromous-fish populations, except under unusual circumstances--particularly large year-class strength, unusually low prey levels, etc. However, growth data for the 1979 year-class of Arctic cisco and their period of residence in Alaska suggest that the system can be stressed. The strength of this year-class in the fishery has been almost three times the historical maximum that has been observed.

To my knowledge, the reduced growth of this year-class has not been reflected by the other species, nor by subsequent year-classes of Arctic cisco. This, if true, I find of particular interest. Also, that the growth rates of this year-class appear parallel to historical rates, only size at age is different, I find of particular interest.

Food availability and extent of summer-feeding habitat may limit arctic anadromous-fish populations. Environmental factors of key concern include temperature and salinity levels as well as prey abundance levels. A key objective of future research should be the determination of the rations required to permit maximum growth and how feeding success relates to prey abundance or density levels.

Studies of the Future

To explain changes in numbers of fish, we must understand how individual fish respond to their environment in terms of survival, reproduction, growth, and movement. A great deal of the fundamental biological research necessary for this understanding has not been conducted. *Although this* research may seem of remote value to those whose interest is simply determining causeway effects and abatement, population responses to development effects cannot be reliably predicted without such information.

Research and monitoring studies of the future also must rely more heavily on mechanistic models of the physical system, fish movements within this system, and the growth and bioenergetics of the individual species as a function of these movements. These results will need to be incorporated into an overall population-dynamics model.

To date, programs have been long on data and short on models. Not enough attention has been paid to interpreting the information available. Note that I did not recommend a reanalysis of the existing data, or that no more field data are required. What I am recommending is that a greater effort be placed upon describing the mechanisms that might account for our observations and subjecting these hypotheses to quantitative testing.

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Question-and-Answer Period

Question: Benny, you did a good job in pointing out the density-dependent factors that are at work in natural mortality and growth. What, would you venture, are the factors that affect initial year-class strength? This seems to be a density-independent factor, if environmental conditions are the cause. It also could have been the result of growth or energy assimilation the previous year.

Gallaway: There are so many density-dependent phenomena that I could bring up as examples to illustrate how those kinds of things could occur. Likewise, it is almost unequivocal, I think, that, initially, we are talking about a density-independent phenomenon of getting the young fish over here from the Mackenzie River. On the other hand, how many young fish that are in the coastal zone of the Mackenzie River may be attributable to water levels that occurred in the river and how many got trapped in flood-plain lakes? The Russians have made a pretty convincing case that this all relates to sunspots or something like that, and you can predict it. So, it's a "dog's breakfast," as Peter Craig used to say. We need to sort through these in a quantitative fashion. That gets me back to my modeling approach. That's why I think we should define a testable hypothesis, disprove that or not, and move on to the next area of concern.

Question: You discussed some difficulties with correcting the data used by Larry Moulton for effort. Could you clarify how that was corrected for effort?

Gallaway: The catch data reported here is based on the catch-per-net day, which has mainly been by the same size net, etc. Larry (Moulton) has standardized other nets and data utilized in the fishery and is presently completely standardizing the data. Larry, can you provide additional information?

Moulton: Well, the problem is that the indices I used include the entire commercial fishing season for the years in which the fisheries were conducted. The issue is confused because the timing and duration of the fisheries have changed through time. Historically, Helmericks used to fish into mid-December; then his harvest data (indices) include the entire period. Catch levels tend to drop off later in the season so we decided to use the entire period of fishing as 1 year of effort, but some years the fishing period is shorter than other years. Right now, the commercial fishery operates from about early October until mid-November. He quits when catch levels drop. Also, he's using a smaller number of nets, 8 to 10, whereas in some years, he used to use up to 50 nets. I would like to standardize the harvest data so that in all years, we are looking at the same period of fishing effort. Basically, cut out anything past mid-November; the catches are quite low anyway, and it would artificially reduce the CPUE's.

Question: But those catch numbers are adjusted for the number of nets that are in the water on any given day.

Gallaway: Yes.

Question: Did YOU examine a model correlating the frequency of west winds in a given year, with the catches at the Colville River 5 years later?

Gallaway: Age at recruitment. Those were not model data, those were the catch data correlated to the observed percent of time wind was from the east. Tom has a manuscript, or actually the galley proofs of a publication% that shows this relationship.

Question: Okay, so what I am curious about is, are you correlating it with the abundance of 5-year-old fish in the catch or with the abundance of the catch?

Gallaway: We are correlating it with the catch some 5 years later, which would correspond to the age-O fish that were being transported during the wind event.

Question: My point here is that the majority of the catch is not 5 years old but is indeed 6 to 8 years old; so, you are actually correlating with a wind event a couple of years earlier. Your 5-year-old fish are just stinting to recruit into the fishery at that time.

Gallaway: Correct. There is always going to be that kind of variance; and talking with Larry about CPUE, I'm not so much interested in the problems of accurately predicting changes. What I am most interested in is whether or not I can capture the trend with the model. And when you capture the trends, given the imprecision of the data that we have, I think that's reasonably significant.

Comment: The point I wanted to make here was that we've been conducting our own analysis but we haven't published it yet, nor have we completed the analysis. Going through the records and looking at the fyke-net data, including all the ages where we can, and length-frequency distributions, there is a very strong correlation between the abundance of 7- and 8-year-old fish in one year and recruitment the following year. The majority of the variance in the recruitment levels can be explained just by that spawn-and-recruit relationship.

Comment: I'm surprised that there is a sufficient age database.

Comment: There is. You know as well as I do that the age database is spotty. But the length and age are fairly consistent, and you can tell whether or not you've got a large cohort of spawners available and whether or not you have a large level of recruitment. Also, it is a very tight correlation. We've also been playing with a few other things on the westerly wind thing. We do have some other difficulties in that we did observe some westerly moving fish against some pretty strong currents in 1987, moving particularly between the Sag and the Oliktok Rivers, which was entirely under a west-wind period. I want to point out that there does seem to be a good correlation between spawners and recruitment without considering the winds. I'm sure the winds affect the amount of recruitment, but the majority of it seems to be directly related to the number of spawners available.

Question: I recognize that, and I think it is generally accepted that carrying capacity of overwintering habitat in the Arctic sets the critical upper limit for population growth. Could you address some of the questions about spawning habitat? That seems to have been something all of us have overlooked, and spawning habitat would be as affected by changes in water levels, bad winters, etc., as any of the other habitats up there.

Gallaway: Exactly. In our area, given that we lose 95 to 97 percent of the estimated habitat each winter, spawning habitats either must correspond or have quite similar distributions. I'm not sure that spawning habitats have been accepted as a major limiting factor, with the exception of perhaps Arctic char; there are some areas that are known to be spawning habitats, but I'm not sure that encapsulates all of them.

Question: In trying to develop study recommendations, we know little, if anything, about spawning habitats for a lot of these species--the distribution, the abundance, population dynamics, etc. --we might want to concentrate on this aspect since a lot of the discussion was focused on recruitment as an important parameter in some of the coastal dynamics.

Gallaway: I agree; and let me make the distinction however, that I don't know a lot about where the spawning habitats are located. I suspect that there are other people in the room, particularly Fish and Game personnel, who would probably have a better concept than I do.

Question: I've got just a few questions in the context of the O+ age Arctic cisco. First, how are they aged, and secondly, what are their sizes? Or, what sizes have been documented as they move along the North Slope?

Gallaway: In my off-the-top-of-my-head response, I would say that we are probably talking about a range of 40 mm to 100 mm progressing through the season.

Question: So, you are picking them UP as small as 40 mm; is that on the Colville River?

Gallaway: Yes.

Question: From our studies in Kumalit Bay, and also in Tuktoyaktuk Harbor, typically in mid-July or early August, we pick up Arctic cisco just on the low side of that, say 25 to 35 mm. So, you are getting, say, 100-mm-size fishes arriving at what time of the year then?

Gallaway: In the Colville River in August.

Comment: So, presumably they are growing significantly as they are moving down along the coast towards the Colville River.

Comment: It's amazing, the conditions that they must pass through on that trip.

Question: Well, I'm just thinking in the context of ration requirements and energetics envelopes as to whether it's a passive drift or an active migration, and in the context of feeding while they are moving several hundred kilometers along the coast, if there is significant growth, essentially a doubling of body length and tripling or quadrupling of body weight.

Gallaway: They are feeding; they do have things in their stomachs. They may be feeding rather well. But, if you have ever seen fish of this size acclimated at 5 'C, which is what the temperature is going to be by the time they get here, they don't perform very well in their movements.

Question: They are still feeding actively at these temperatures'?

Gallaway: From the reports that I've read, they do have food in their stomachs.

Comment: To *answer your* question--based on stomach-contents data we have for the last few years-they are feeding pretty heavily on copepods.

Question: Larry Moulton indicated the commercial and apparently the subsistence fishery on the Colville River essentially declines about mid-November; is that right?

Gallaway: Yes.

Question: You had said that the ice was becoming so thick that it was less efficient to continue working through the ice. Jim Helmericks has reported that the reason the fishery tends to stop around mid-November is that the fish have been running for several days downchannel, and their numbers have now declined. Based on data that Larry has published from the Colville River studies, conversations with Helmericks, and so forth, I have gotten a very strong impression that since the catches have declined markedly past mid-November, that realistically there aren't a lot of Arctic cisco overwintering in those lower channels. So, where are they overwintering? Maybe they are overwintering along the coast somewhere; for those species, perhaps habitat or overwintering habitat isn't quite so restrictive.

Gallaway: The way I interpret the evidence is that the fish are certainly moving and that the environment is changing. There are shifts in distribution. I'm not sure whether they are going upchannel or downchannel or whatever. This is the case where I think we need some basic laboratory bench mark data. What can they do with regard to cold temperatures and high salinities? If the fish have access to high-salinity water (26-28 ppt) and can tolerate these conditions and get outside the landfast ice, then they would have a pretty large area for overwintering.

Comment: We do have information that shows how they are moving--what happens to Attic cisco when they are moving through the fishery in the early period just after ice-up. AS the saltwater penetrates into the channel, the fish move upriver. And this is when the fishery is intercepting them. As the salinity increases and ice thickens, the fish move farther upstream. The fish move downriver in mid-November. We also see this pattern in the channel near town; right after ice-up, there are very few Arctic cisco in the area. But as the season progresses, the fish move in. You can see pulses of fish move through the channel as the season progresses. So that by the time the fishing stops, you are actually getting some of your higher catch rates in this region. By that time, the sun has gone down and it's getting very dark, and people just do not fish. In this region, the nets are fixed, and the same geographic location is fished each year. So, if there are changes and shifts of distribution% you will see it at these sites.

Chapter 11

Species and Limiting Factors

Introduction

The Species and Limiting Factors Workshop consisted of three concurrent working sessions. Each working session was charged with reviewing the papers presented by Moulton and Gallaway, identifying information needs, and listing research needed to better understand the factors that control the distribution and abundance of fishes in the Arctic.

Workshop facilitators led the discussions, and scribes took notes and helped the facilitators prepare summaries (oral) of each session's progress. Summaries were presented by the facilitators at a plenary session immediately following the working sessions.

Working Session 7

Facilitator: Lon Hachmeister
Scribe: Chuck Mitchell

The following list of limiting factors is not intended to be inclusive; it focuses on the Beaufort Sea with less emphasis on the Chukchi Sea.

Limiting Factors

Arctic Cisco

° Availability of parents and spawning habitat in the Mackenzie River
° Recruitment to Sagavanirktok/Colville River population of 0/1 fish
° Overwintering habitat (probably not limiting in the Colville River)
° Prey, utilization of food (probably are not generally limiting--perhaps at some places/times)
° Habitat parameters (probably are not generally limiting--perhaps at some places/times)

Least Cisco

° OverWintering habitat (probably is not limiting in the Colville River)
° Spawning habitat
° Utilization of prey
° Habitat parameters (probably are not generally limiting--perhaps at some places/times)
° Distributions of temperature and salinity properties in summer.

Broad Whitefish

° Overwintering habitat
° Spawning habitat
° Localized temperature and salinity properties
° Prey availability and competition for prey in "bad years" with displaced species

Arctic Char

° Overwintering habitat is very important but is not considered critical unless modified (this is not considered to be quite as critical as for the other species because overwintering-habitat requirements are fairly well understood)

Arctic Cod

° Spawning-habitat requirements are unknown
° Competition for prey

Recommended studies can be combined into three specific types:

Basic Stock-Identification Studies (Arctic cisco, least cisco, broad whitefish, Arctic cod)

° Continue work on Arctic char
° Conduct specific studies of Bering and Attic cisco to determine if they are separate species

Laboratory Studies--Basic Bioenergetics (Arctic cisco, least cisco, broad whitefish, Arctic char, cod species)

° Determine temperature and salinity tolerances
° Determine conversion-efficiency-evacuation dependence on temperature
° Study the effects of size and temperature on determining swimming speed

Habitat (Overwintering and Spawning-Site) Studies

° Target Colville/Sagavanirktok River Delta areas for overwintering and spawning studies (How does overwintering habitat become limiting?)
° Continue past work begun on Arctic char-population indexes

° Begin basic biological studies of Arctic cod and saffron cod in the Chukchi Sea.

In the Beaufort Sea, overwintering and spawning studies for Arctic and least cisco and broad whitefish should focus on the Colville River, because this area is likely to be developed in the near future. These studies also should be coordinated with similar studies being conducted in Canadian waters.

In the Chukchi Sea, work should focus on locating and defining overwintering and spawning habitats of Arctic and saffron cod.

Additional studies discussed but not necessarily recommended for immediate action included determining the Arctic cisco migration--is it directed, is it random, or is it assisted? How sensitive is the Arctic cisco population to changes in temperature and salinity properties along the route and to the current direction? Is the population more sensitive to changes in the migration during various Arctic cisco lifestages; are the fish growing during their migration; is *there an increase in* their tolerance to changing environmental conditions as migration progresses. (For example, an eastern Beaufort causeway could have a greater effect on the migration of age "O Arctic cisco than a causeway constructed on the central Beaufort *Sea* coast if the fish became more tolerant to environmental changes as the migration progressed along the coast from east to west. Likewise, there might be similar effects on 7- to 8-year-old fish when they are migrating eastward toward the Mackenzie River.)

The recommended studies should attempt to answer the following questions about Arctic cisco migration and migration sensitivity

<u>Is the Arctic cisco migration</u>

° Directed?
° Dependent on currents?
° Assisted by oceanographic/meteorological events (i.e., storms or prevailing winds)?

<u>Is the Arctic cisco-westward-migration sensitive to changes in</u>:

° the migration route?
° temperature and salinity properties?
° current direction?
° the developmental stage of the young?
° the swimming speed of young fish?
° the rate of development during the migration?
° the success rate of the eastward spawning migration?

Working Session 8

Facilitator: Al Maki
Scribe: Lyman Thorsteinson

Anadromous-fish species in the nearshore Beaufort Sea feed primarily on mysids, copepods, and amphipods, which are present in high abundance throughout the summer-feeding period. As prey species for marine mammals, the anadromous-fish species may be important, in the nearshore environment under some conditions. It is well known that marine fish species such as Arctic cod do serve as a significant prey source in the marine environment.

The Colville River fishery has both commercial and subsistence applications. It is a fall, under-ice, gillnet fishery for Arctic cisco. In addition, development and access along the North Slope is increasing and bringing with it increased harvest pressure on these resources from recreational fishermen. This increased harvest pressure may have adverse effects on the populations. Therefore, the effect that sport fishing may have on arctic fish populations was identified as an important information need.

Changes in the Colville fishery can be described using the available database, which spans more than 20 years. This database provides information on year-class recruitment and year-class strength and can be used to predict changes in future harvests. Based on the database, it appears that recruitment into the Colville River fisheries in 1988 and 1989 will be reduced.

° Historical catch records show a high degree of interyear variability in recruitment, and relative year-class strengths of young-of-the-year (YOY) fish will define the success of future Ming efforts.

° Recruitment of the 1983 to 1984 year-classes into the Colville was low, which correlates with the abundance of YOY years previous.

° The total subsistence and commercial take for the Colville fishery is approximately 100,000 fish annually.

From a standpoint of fishing mortality, no change in management strategy is obvious. However, the need to continue monitoring the fishing efforts and gathering information on age structure and recruitment of successive year-classes, i.e., monitoring juvenile abundance to provide information on the emigration of young fish from the Mackenzie Delta, continues.

Better regional integration of information particularly in the area of Harrison Bay in the west is needed. For example, this area is very lightly sampled and, therefore, little area-specific information is available.

A question still exists regarding the validation of aging techniques for coregonids. The age of scales and/or otoliths should be validated and accepted techniques established. This is an important issue, and additional work is needed to develop an acceptable method to age fish.

Factors limiting the growth of fish populations in the Arctic include availability of suitable overwintering habitat, which is considered the factor limiting the existing population; summer-feeding habitat is not considered to be limiting except in specific locations or specific spots; recruitment of young Arctic cisco from the Mackenzie River controls initial population size of this species along the Alaskan coast (annual recruitment appears to be wind and current dependent); and availability of spawning habitat may be limiting for some of the anadromous species in some areas. Information on the availability of spawning habitat in the Mackenzie River area will become available as the Canadian Mackenzie River fisheries research program evolves.

The parallel fisheries research being conducted on the Mackenzie Delta and in the Canadian Beaufort were discussed, and the need for better coordination with Canadian researchers was evident. Similarly, Soviet and Scandinavian scientists are addressing a lot of the bioenergetics, food-diversions *efficiency*, and similar issues. Therefore, access to their information is considered an important goal.

A better understanding of the importance of the distant offshore/deeper marine environment should be developed. The distribution of fish and fish-food organisms can be significantly affected by conditions in the marine system. Oceanographic differences between the Beaufort and Chukchi Seas suggest that there may be a significantly different trophic regime in the Chukchi Sea. Therefore, summer-feeding habitat may be a limiting factor in the Chukchi Sea and should be evaluated.

Information on the subsistence use of fishes and marine mammals exists for the Chukchi Sea; however, it has not been consolidated and analyzed.

Benny Gallaway's modeling framework was considered to be a productive way to focus research efforts. It can provide a framework to aid in the design of future studies, in future field-sampling efforts, and to facilitate hypothesis testing. General areas for future modeling efforts and research include bioenergetics, condition-factor analysis, temperature-salinity-preference values, feeding efficiencies, etc. Modeling also could be used to help integrate and coordinated arctic fish studies field programs.

The following is an outline of topics discussed and conclusions reached during the review of Benny Gallaway's paper.

<u>Beaufort Sea</u>

- Availability of suitable overwintering habitat likely is the limiting factor controlling the size and distribution of anadromous fish in the central Beaufort region.
- Initial population size of Arctic cisco is controlled by recruitment from the Mackenzie River which, in turn, is wind and current dependent.
- Summer-feeding habitat is probably not limiting these species. Summer-food availability may be limiting in specific high-density areas.
- The Colville River may provide an excellent site for better refining overwintering-habitat-preference profiles.
- A modeling framework can serve to aid in the design of future field and laboratory studies as well as a basis for hypothesis testing. Specific issues such as energetic, K-factor, salinity and temperature preference, and feeding-e fficiency data can be prioritized under a modeling decision framework.
- Better international coordination with Soviet and Scandinavian researchers is needed.
- Spawning habitat may be a limiting factor for some species in some areas; however, the requirements for and availability of adequate spawning habitat for anadromous fish are virtually unknown. Therefore, a better understanding of this issue is needed.
- Fundamental fishery-population and food-availability and -distribution studies are needed to predict effects of development.

Chukchi Sea

- This area is characterized by a lack of data.
- The coastal environment may be quite different from the Beaufort Sea system. Higher frequency of storm events, more onshore winds, and faster currents may result in a much smaller distribution of preferred low-salinity, warm-temperature waters. Thus, offshore-feeding habitat may be limiting fish populations in these areas.
- A relatively large amount of subsistence-use information and marine mammal-predation data exists in diverse sources; however, it needs to be collated, reviewed, and analyzed.

Working Session 9

Facilitator: Bill Wilson
Scribe: Laurie Jarvela

Data Availability

Data are available on human use of fish in most villages of the Beaufort and Chukchi Sea coasts. However, a regional analysis of the importance of arctic fishes to human residents of the Chukchi and Beaufort Sea areas is lacking and is needed.

Data on arctic fish predator-prey relationships, especially regarding marine mammal utilization of fish, are also available and indicate, among other relationships, that Arctic cod and certain anadromous fishes are important to seals (e.g., for spotted seals). Trophic dynamics of the Chukchi Sea marine ecosystem are more complicated than in the Beaufort Sea because of the larger numbers of fish species involved, and fish use by some consumer groups (e.g., seabirds) is better understood in the southeastern Chukchi Sea than elsewhere. However, the overall ecological importance of marine and nearshore fishes in both areas (Beaufort and Chukchi) is not well understood. For example, the reason why spotted seals and beluga whales are seasonally abundant in certain coastal areas of the Chukchi Sea is unknown.

Information Needs

The degree to which Arctic cod utilize plankton is unknown. Cod are omnivorous (and cannibalistic) but may exert some influence on the plankton food base which, in turn, is also important to other organisms. Information on marine food-chain dynamics involving plankton and marine fishes is a study need.

Overwintering is an important factor influencing fish-population dynamics. Information on the overwintering habitat is available for certain fishes (e.g., for Arctic char) but poorly understood for others (e.g., for coregonids). Information is needed to understand the physiological and bioenergetic preparations certain fish make during the summer-feeding period for the overwintering phase; fish feed not only to grow but also to store energy for a rigorous and long winter phase. How does fish condition relate to overwintering success, mortality, etc?

Limiting-factors research, per se, may not be fruitful; rather, the approach to understanding factors limiting fish populations should be broad and cautious, because these factors are very much interrelated, and these interrelationships maybe so subtle that research may overlook important criteria.

There appears to be wide interannual variability in the significance of some factors. Physical-habitat conditions may be of key importance in constraining fish populations in one year, while another factor may take on primary importance in another year. Studies of limiting factors, therefore, should be broad and long term so that non-time-continuous factors are not missed.

Locations and conditions of spawning habitat, especially for certain marine fishes, are unknown. Even in freshwater, exact spawning locations and spawning-habitat conditions for certain fish, like the whitefishes, are not well documented.

Dynamics of the nearshore invertebrate-forage species are in question. Some invertebrate populations may be recruited from offshore marine habitats, but through what mechanisms and which species? What are the fluctuations in the forage-species biomass?

Bioenergetics and population dynamics of young-of-the-year Arctic cisco are unknown. What prey items are important as young-of-the-year Arctic cisco move from the Mackenzie River Delta to the Alaskan coast? What predators are significant (Arctic. cod)? Early life-history factors are critical to establishing year-class strength in any species--Arctic cisco is mentioned here as an example.

Major study emphasis is needed on the general subject of bioenergetics and growth of all key marine and nearshore fish species. This is considered a key information need for understanding how various habitat factors may limit population size.

Basic information on stock structure of various fish species is needed to design appropriate study approaches and to permit informed management of those stocks exploited by humans.
Information on the habitat factors in the zone between the nearshore estuarine fringe and the offshore marine zone (roughly that area between hip boot depth and the 10-m contour) is not available.

The early life history of juvenile salmon moving through the southeastern Chukchi Sea/Kotzebue Sound environment is essentially unknown (information needed includes feeding relationships, predator influence, movement rates, and movement patterns),

Dynamics of herring stocks in the southeastern Chukchi Sea are not understood; information is needed on herring-stock structure and the locations and habitat conditions of overwintering areas.

Chapter 12

Habitat Relationships of Beaufort Sea Anadromous Fish: Integration of Oceanographic Information and Fish-Catch Data

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Introduction

Potential effects of causeways on anadromous-fish habitat have been identified as major concerns for both past and proposed developments in the Alaska Beaufort Sea coastal zone. Four anadromous species have been routinely identified as of primary importance in terms of numbers and role in subsistence and commercial fisheries in the central Alaska Beaufort Sea: Arctic cisco (Coregonus autumnalis), least cisco (C. sardinella), broad whitefish (C. nasus), and Attic char (Salvelinus alpinus). These species all spawn in freshwater and rear there for periods varying from a few weeks to several years, depending on the species. Each spring, these fish migrate out of overwintering and/or spawning areas in freshwater to feed in the nearshore waters of the Beaufort Sea. There, during the brief arctic summer, they acquire the necessary food-energy resources to sustain them through the subsequent winter (Schell et al., 1982). During the period from late August to October, they reenter the rivers or delta areas seeking channels with sufficient depth to provide overwintering habitat under the 6 to 8 feet of ice that forms. There they remain, moving little and consuming little, until spring breakup allows return to the summer-feeding areas.

The large body of oceanographic information gathered in the nearshore Beaufort Sea over the last decade (e.g., Mangarella et al., 1982; Savoie and Wilson, 1986; Hachmeister et al., 1987) clearly documents that the ecosystem is typically estuarine and subject to wide variations in temperature and salinity distributions throughout the open-water period. These variations are largely determined by changes in wind speed and direction, with recorded temperature ranges from -15 “C to > 12 “C and salinity ranges from essentially freshwater (O ppt) to near open-sea salinity (> 30 ppt).

Concerns have been expressed that oceanographic and water-quality conditions may be altered by causeways to the point where food-intake efficiency is significantly reduced. Numerous studies have identified temperature and/or salinity as the environmental parameters that have the most profound effect on the distribution of anadromous fish in the nearshore Beaufort Sea (e.g., Fechhelm et al., 1983; Craig, 1984; Moulton et al., 1986). Despite the inherent variability of these parameters in space and time and despite the often nonlinear relationships that occur, temperature and salinity have generally correlated well with catches of anadromous fish in 24-hour fyke-net sets. Other habitat descriptors (e.g., prey density, depth, current, wind) have shown much weaker, or no, correlation with catch. Furthermore, temperature and salinity stand out as the nearshore-habitat descriptors most likely to be predictably altered by construction of causeways in the Beaufort Sea coastal zone.

The objective of this analysis was to evaluate anadromous-fish-habitat usage and response to changing oceanographic conditions in the central Alaska Beaufort Sea area using available field data. The data analysis was designed to test the hypothesis that habitat utilization is correlated with the widely varying temperature and salinity conditions that are part of the nearshore Beaufort Sea ecosystem. If habitat utilization is characterized by adaptation to a high degree of natural background variability, then localized effects of offshore causeways that are within the range of natural variation in these temperature and salinity distributions can be expected to have a minimal influence on these fish.

Methods

Data from the 1983 (Critchlow, 1983) and 1984 (Moulton et al., 1986) Lisburne Development Project environmental studies and the 1985 (Cannon et al., 1987) and 1986 (Glass et al., 1987) Endicott Environmental Monitoring Program were used. To create the data files used in this analysis, the catches of anadromous fish were aggregated by species and cohort, and the effort (net days) for each date and station was summarized. For each date, station, species, and cohort combination% the record was checked to ensure that all required data, including temperature and salinity, were included. All data were checked for errors and outliers, and the catch per day (catch/fishing time) was computed for each net direction.

Habitat-utilization relationships were developed as follows The catch per day of a particular species/cohort was summed within each habitat category. The total catch (sum of the catch per days within each habitat category) was then normalized to a maximum value of 1. The following species/cohorts were selected for the analysis:

° Arctic cisco	cohort 1- < 100 mm, cohort 2-100 to 200 mm, cohort 3- >200 mm;
° least cisco	cohort 1- < 200 mm, cohort 2-200 to 400 mm;
° broad whitefish	cohort 1-<75 mm, cohort 2-75 to 200 mm, cohort 3- > 200;
° Arctic char	cohort 1-100 to 350 mm, cohort 2- >350 mm.

The uncertainty regarding the exact environmental conditions at the time of fish entry into the net was minimized by eliminating sets significantly longer than 1 day. Geographic differences were evaluated by developing a separate set of curves for stations within Prudhoe Bay (1983 through 1986 data), and over the entire 1985 and 1986 Endicott study area (eastern Foggy Island Bay to Oliktok Point, less selected stations adjacent to causeways). The time period of the analysis of habitat utilization was restricted to 1 July through 15 August on the assumption that, during this time period, the species/cohorts present were on their summer-feeding grounds; movements can, therefore, be assumed to be in response to the suitability of conditions for feeding rather than dictated by migrational stimuli.

Effects of periods of oceanographic change on fish movement were examined by regression of total net-catch rate (both directions) for each cohort versus degree of change in temperature and salinity (independently) from set to retrieve. To examine the effects of changing oceanographic conditions on the direction of movement, a new variable was calculated as the maximum ratio of the catch in either side of the net to the total catch for each cohort. This maximum ratio, which ranged from 0.5 (equal catch in each side) to 1.0 (entire catch in one side), was then regressed against the degree of change in temperature and salinity (independently) from set to retrieve.

In addition, frequency distributions of this maximum ratio were developed for periods of less environmental variability (salinity change less than 4 ppt and temperature change less than 2 °C) and for periods of more environmental variability (salinity change more than 4 ppt or temperature change more than 2 "C). A Kolmogorov-Smirnov goodness-of-fit test was used to test for differences between the two frequency distributions. Obviously, when only one fish was taken in a set, the ratio was necessarily at its maximum: all fish were from one side of the net, none from the other. To reduce this artifact, analyses using this ratio were run at several minimum levels of total catch (3, 5, 10,20, and 50).

Results and Discussion

General

A common criticism of fyke-net data is that passive sampling of this nature does not yield an accurate assessment of actual temperature and salinity at the exact time of capture. Since the net is typically retrieved at approximately 24-hour intervals, it is difficult to state precisely the habitat conditions under which fish entered the net. Our analysis of habitat utilization assumed that the capture conditions were adequately represented by the retrieve temperature and salinity. To test this assumption, differences in temperature and salinity between set and retrieve were examined. In the 1985 and 1986 database, 81 percent of the sets had less than a 2 "C differential between set and retrieve and 60 percent had less than a 4-ppt change in salinity. Of the sets when change was less than these values (defined as conditions of "lesser" variability), 62 and 65 percent of the sets had less than 2-ppt and 1 "C change, respectively. Thus, under these conditions of minimal change, there is a high expectation that retrieve conditions measured are closely representative of conditions used by the fish at the time of capture.

In the context of this discussion, habituation is the relationship between the number of fish captured in 24-hour fyke-net sets and the prevailing environmental conditions. It could be argued that these relationships do not necessarily reflect the fish's true "habitat preference" if the range of environmental conditions sampled is not representative of the range of available conditions in the Prudhoe Bay area. A preference curve can be developed from field data by weighing the utilization (in this case, CPUE) in each habitat category by the availability of that habitat category (Bovee and Cochnauer, 1977). If the reasonable assumption is made that the fyke nets are randomly placed within the nearshore habitats that are available to fish, then fyke-net effort can be used as an estimate of availability. Since the utilization curves in these analyses use CPUE, which is effort weighted, the utilization curves may then be considered to represent preference curves under the above assumption. The effort curves for the sampling used in these analyses for 4 years of data are shown in Figure 12.1.

Habitat Utilization (Conditions of Lesser Variability)

The approaches taken to screen the data used in this analysis intentionally emphasized habitat utilization during the early to mid-open-water period under relatively less-variable meteorological conditions. As a result, this portion of our analysis does not address fish response to stimuli that have been hypothesized to drive a significant part of the major movement of fish in the area, i.e., behavior during periods when fronts are moving through. It has been pointed out (Johnson, 1987) that, despite data-screening techniques used in this analysis, relatively high CPUE's at the extremes of high salinity and low temperature seen in *several* of the graphs (especially for individual years) may not reflect any preferential use of these habitat conditions; rather, they maybe a reflection of large numbers of fish moving to avoid unfavorable conditions. The potential bias of isolated large catches in "unfavorable" habitats was a primary reason for pooling several years of data. In this way, anomalies in individual data sets are effectively given reduced emphasis in the very large sample size considered, and underlying patterns of habitat utilization are separated from peculiarities of use in any one year.

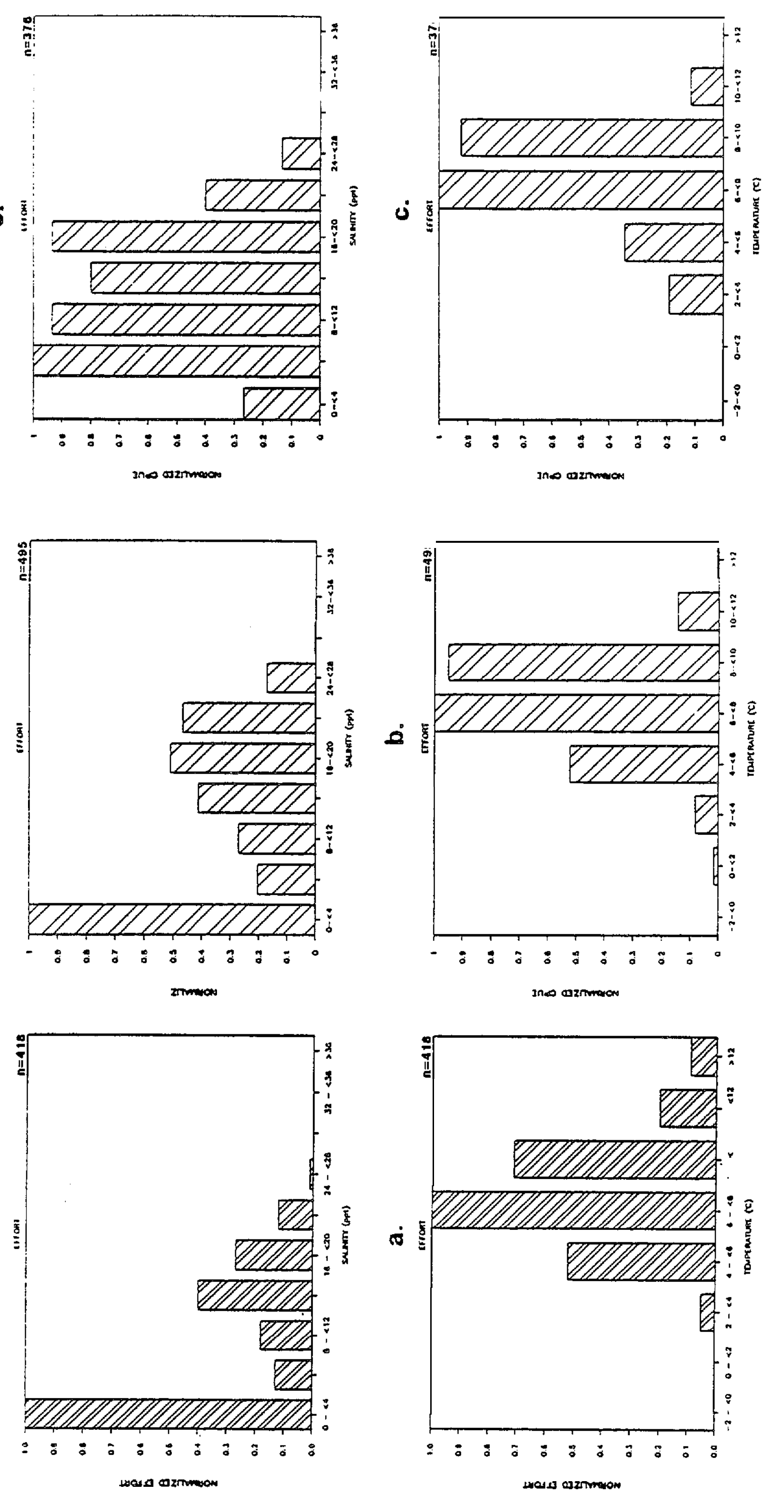
It was anticipated that these analyses would have a range of possible outcomes, i.e., from no apparent relationship of catch to environmental parameters to strong associations. Since the histograms produced were effort weighted, any positive relationship with an environmental parameter is depicted on the histograms as a distinct peak in utilization. Conversely, utilization histograms that have approximately the same normalized CPUE value for each parameter category are indicative of no relationship.

The habitat-utilization patterns described below, except as noted, are in general agreement with those reported by the original authors in describing the results of individual sampling years. However, the statistical power of the combined 4 years of data is evident from examination of the interyear variability in temperature utilization for broad whitefish cohort 3 (Fig. 12.2). If one were to base conclusions on individual years (e.g., 1984 and 1985), entirely different and incorrect habitat/temperature profiles could result. Combining data from the 4 yearn clearly shows that broad whitefish are distributed widely in waters from 4 to 12 'C.

Arctic cisco: The salinity- and temperature-utilization histograms and bivariate-surface plots for Arctic cisco cohort 2 in Prudhoe Bay (Figs. 123a and 12.4) show an association with low to intermediate salinities under conditions of lesser environmental variability. There are two major peaks in the utilization histogram; one is at O to 4 ppt, and a lower peak is at 12 to 16 ppt. This cohort was distributed across the entire temperature range with peak utilization at moderate to warm temperatures (8-12 'C). Over the geographically broader Endicott study area, this cohort had very similar habitat-utilization patterns, except that they were more selective of both temperature and salinity (Fig. 12.3b).

Cohort 3 Arctic cisco in Prudhoe Bay (Figs. 4 and 5b) were generally associated with lower salinities (peak utilization at < 8 ppt); however, there was a secondary peak at 20 to 24 ppt. There was extensive use of temperatures above 6 "C with peak utilization at > 12 'C. Fish from the Endicott study area, as with cohort 2, appeared to be more selective of temperature and salinity than those from Prudhoe Bay.

Least Cisco: There was little apparent relationship between cohort 1 least cisco catch and salinity treated as an independent variable, i.e., salinity alone was not an important factor in determining cohort 1 distributions within Prudhoe Bay (Fig. 12.6a), although it was more important in the broader Endicott study area (strong peak at 12-16 ppt). On the other hand, there was a pronounced association with warm water (> 10 'C in Prudhoe Bay and 8 to 10 'C in the Endicott study area) considered independently. The three-dimensional surface plot (Fig. 12.6b) shows strong selective utilization of habitat, with both warm temperatures and low salinities within Prudhoe Bay demonstrating the need to consider the two variables as dependent. Least cisco cohort 2 were about equally distributed across the entire available salinity and temperature range in Prudhoe Bay (Fig. 12.7a), indicating an apparent lack of a relationship between catch and salinity or temperature. This apparent lack of a relationship between least cisco cohort 2 catch and both salinity and temperature (above 4 'C) treated independently may indicate



a. Prudhoe Bay, 1983-1986, Low Variability
b. Endicott Stations, 1985-1986, Low Variability
c. Endicott Stations, 1985-1986, High Variability

Figure 12.1 Normalized Effort (Relative Number of Sets) by Salinity and Temperature

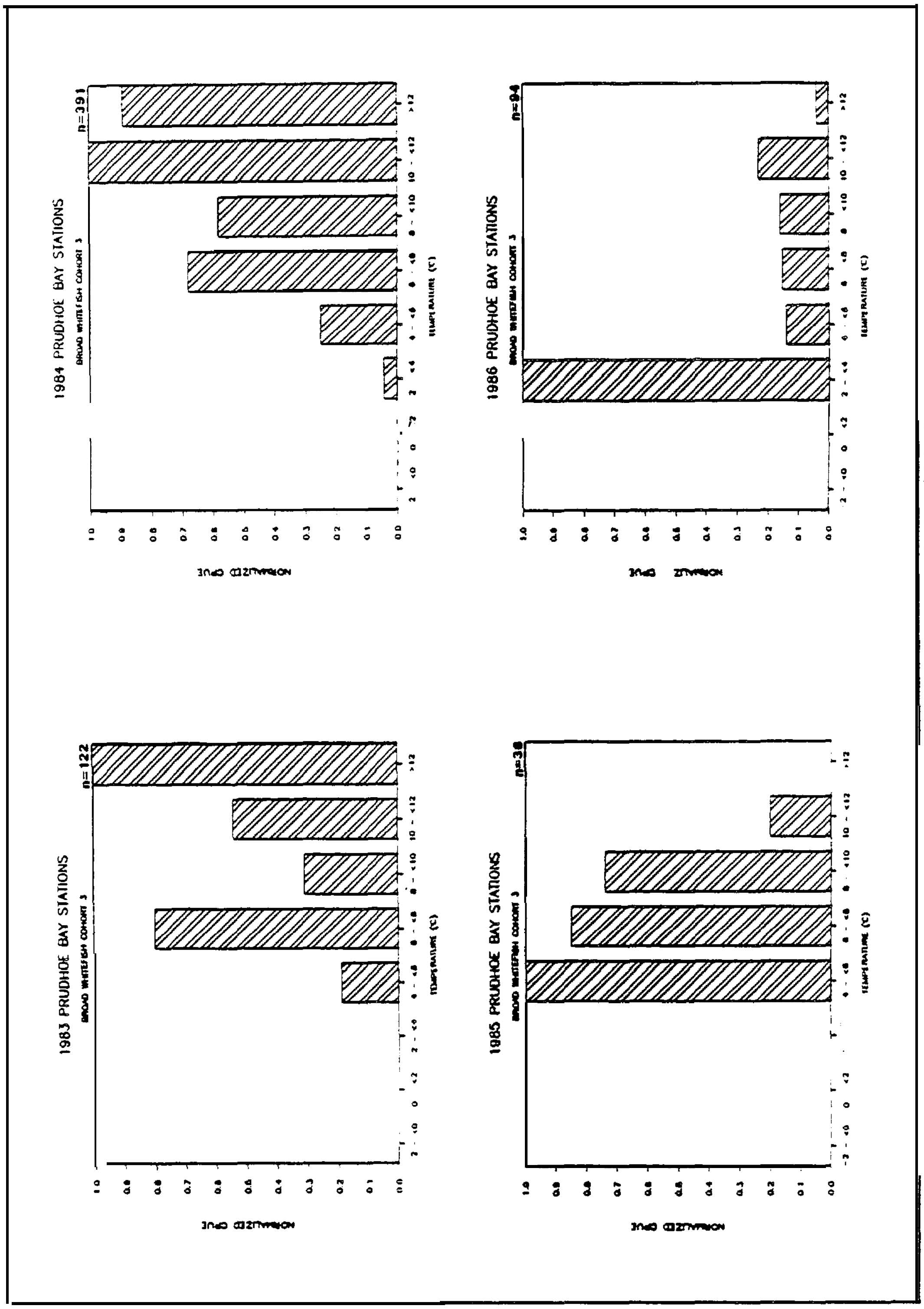
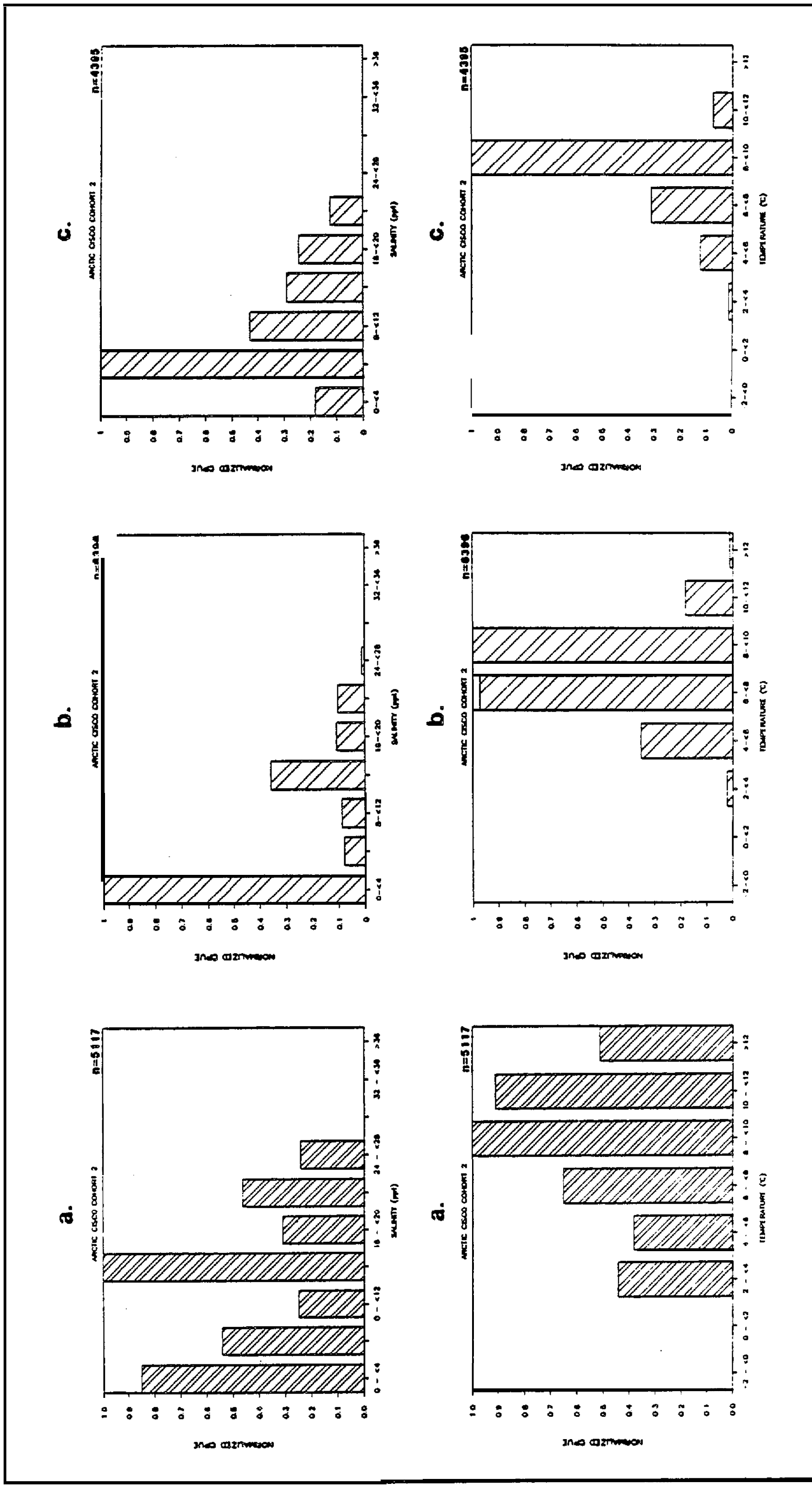


Figure 12.2 Normalized CPUE Versus Temperature in Prudhoe Bay 1983, 1984, 1985, and 986, for Broad Whitefish Cohort 3



a. Prudhoe Bay, 1983-1986, Low Variability
b. Endicott Stations, 1985-1986, Low Variability
c. Endicott Stations, 1985-1986, High Variability
Figure 12.3 Normalized CPUE of Arctic Cisco Cohort 2 by Salinity and Temperature Category

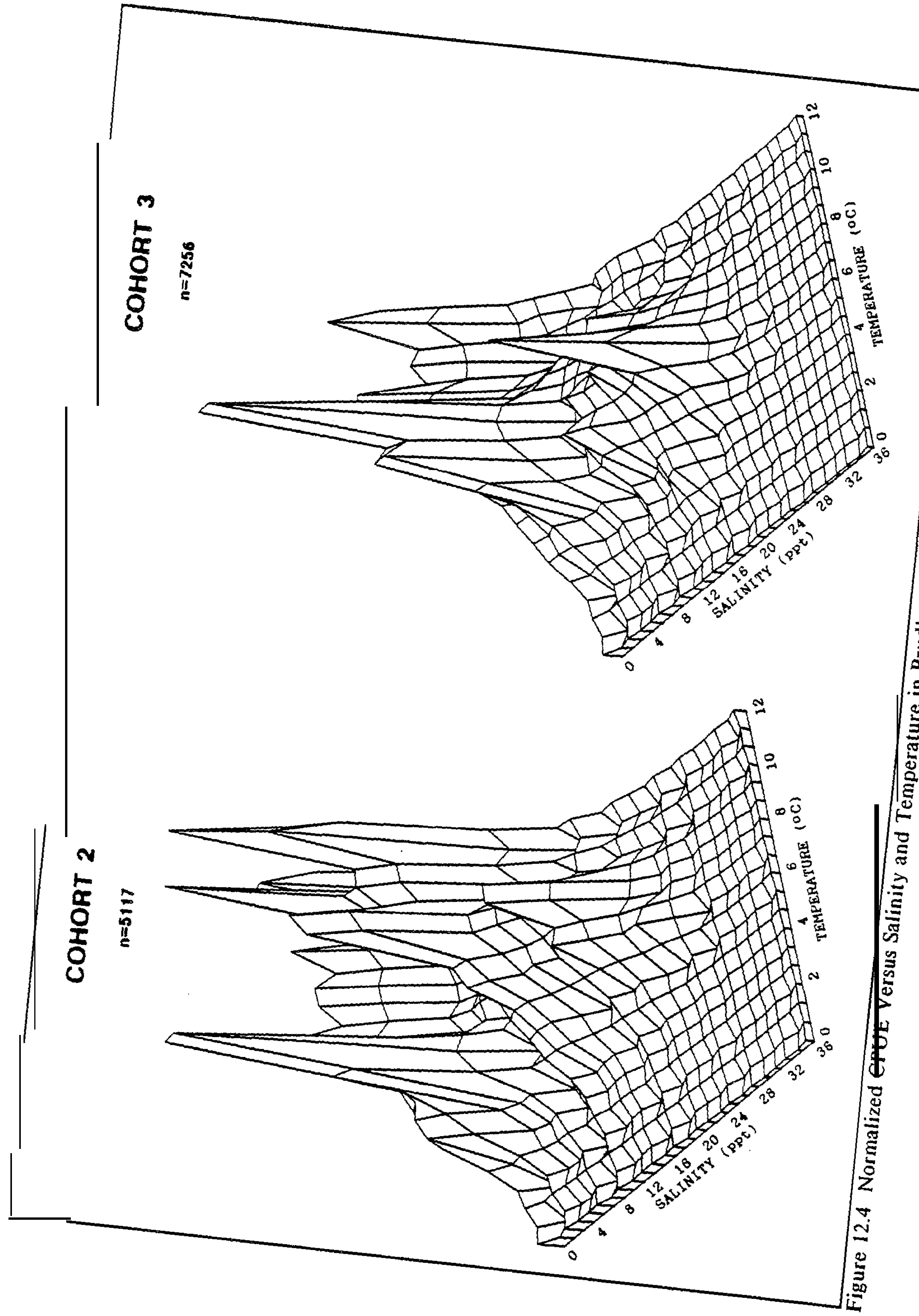
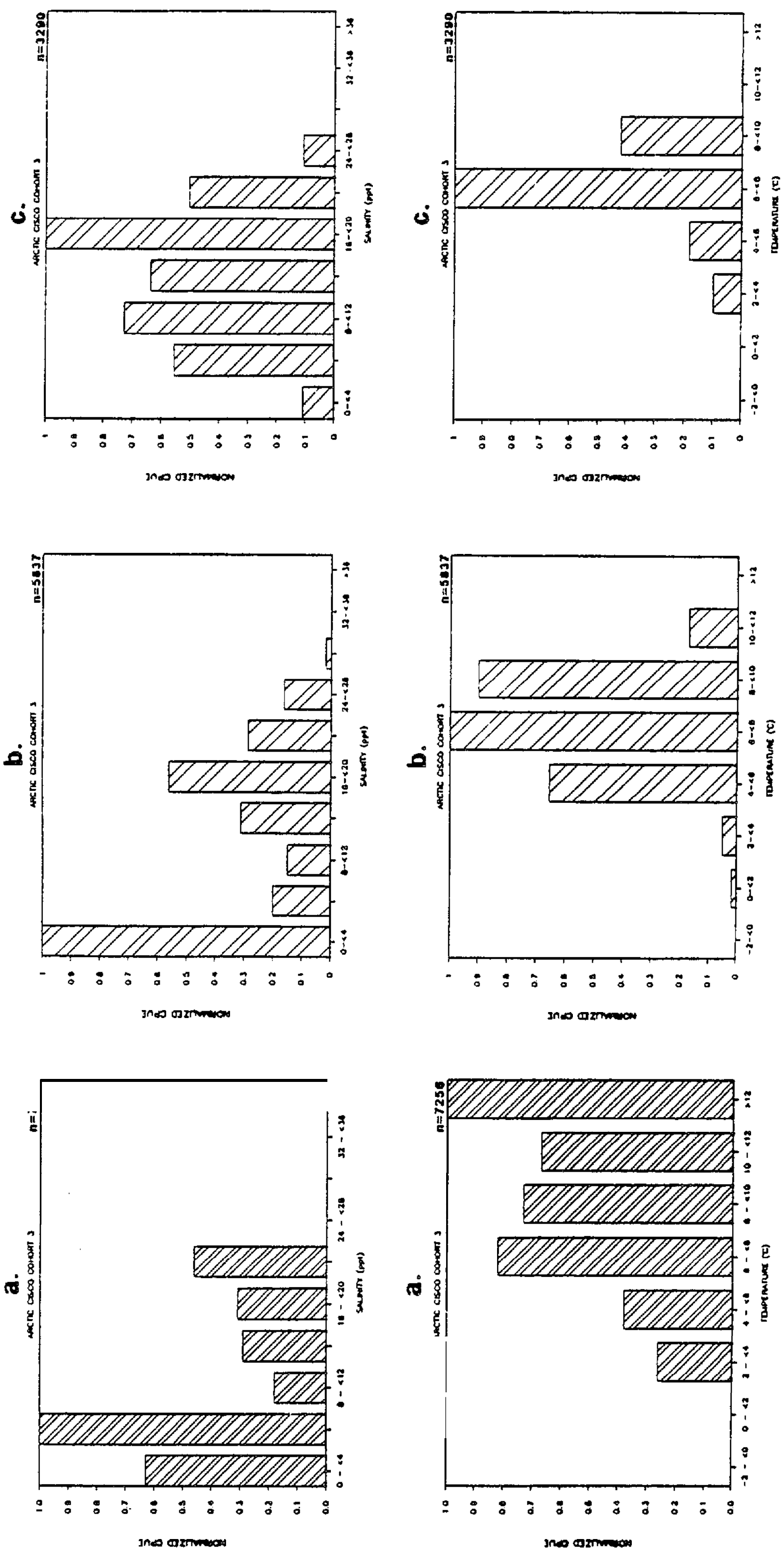
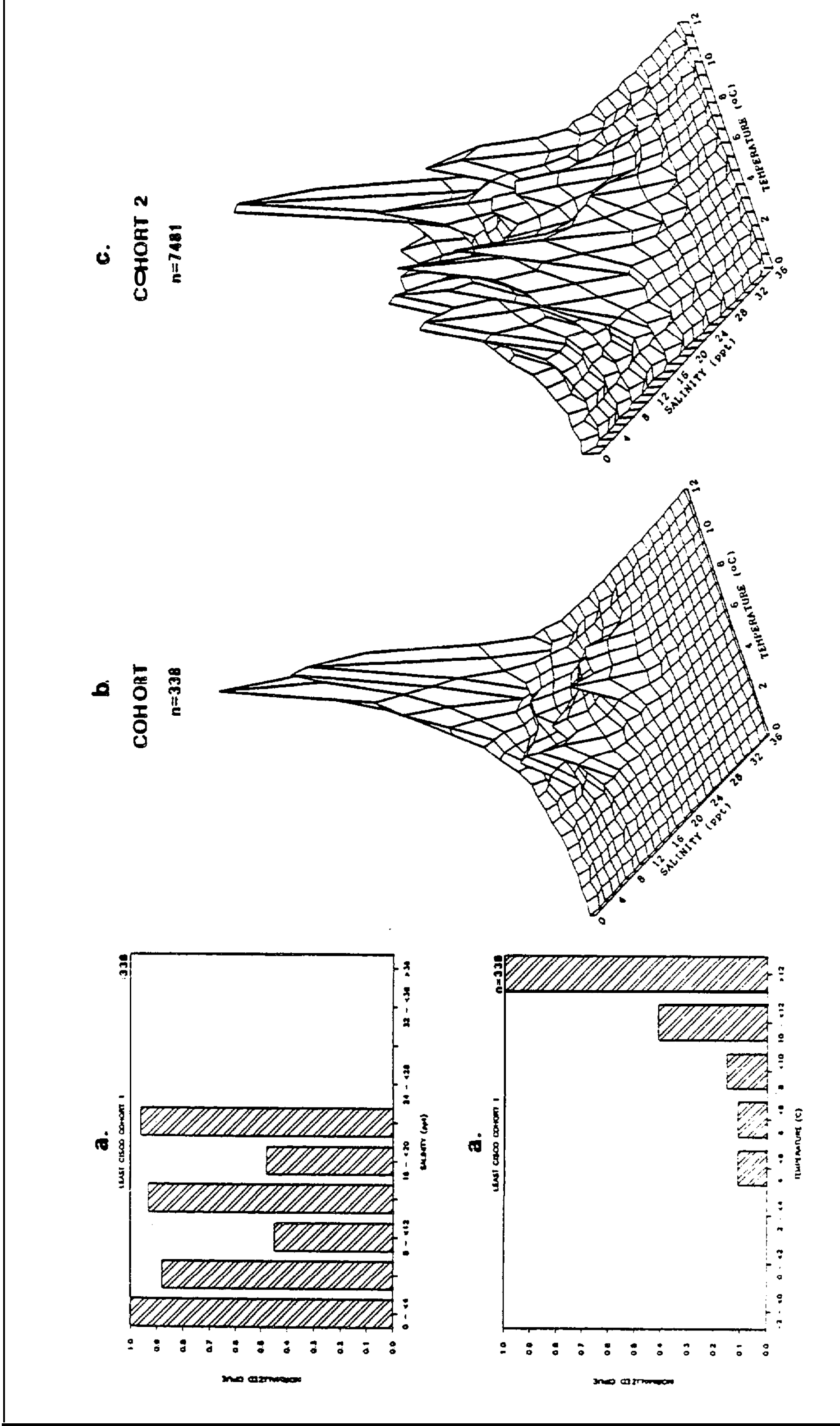


Figure 12.4 Normalized CPUE Versus Salinity and Temperature in Prudhoe Bay 1983–1986 Combined for Broad Whitefish



a. Prudhoe Bay, 1983-1986, Low Variability
b. Endicott Stations, 1985-1986, Low Variability
c. Endicott Stations, 1985-1986, High Variability

Figure 12.3 Normalized CPUE of Least Cisco Cohort 2 by Salinity and Temperature Category



a. Cohort 1 by Salinity and Temperature Independently
b. Cohort 1 by Salinity and Temperature Combined
c. Cohort 2 by Salinity and Temperature Combined

Figure 12.6 Normalized CPUE of Least Cisco in Prudhoe Bay 1983-1986 that some environmental parameter other than salinity or temperature drives cohort 2 least cisco distribution. A minor peak of utilization was seen (Fig. 12.6c) in some waters with both low salinity and warm temperatures. As with Attic cisco, least cisco from the broader Endicott study area utilized a much narrower portion of the available temperature range (Fig. 12.7b).

Broad Whitefish Cohort 1 broad whitefish (Fig. 12.8a-c) were distributed across the entire salinity range (O-24 ppt), with peak utilization at 4 to 8 ppt. This may result from the poor swimming abilities of these small fish or from the general absence of low-salinity waters late in the study period when they reach the area. Temperature was the major factor influencing cohort 1 distribution with warm water (> 12 "C) being the most extensively utilized. Warm water (> 12 °C) treated independently may indicate that some environmental parameter, other than salinity or temperature, drives cohort 2 least cisco distribution.

A minor peak of utilization was seen (Fig. 12.6c) in some waters with both low salinity and warm temperatures. As with Arctic cisco, least cisco from the broader Endicott study area utilized a much narrower portion of the available temperature range (Fig. 12.7b).

Cohort 2 broad whitefish in both Prudhoe Bay and throughout the Endicott study area were associated with salinities < 8 ppt; however, there was a secondary peak at 16 to 20 ppt in both areas (Fig. 12.9a, 12.9b). Peak temperature utilization in Prudhoe Bay occurred at > 12 "C, with a secondary peak at 4 to 8 "C (Fig. 12.9a). In the Endicott area, the peak temperature utilization was at 8 to 10 'C (Fig. 12.9b). The habitat relationships for broad whitefish cohort 3 show a pronounced association with salinities c 8 ppt, with little utilization above 8 ppt. The utilization was evenly distributed between 2 and > 12 "C, with a peak at > 12 'C. The relationship with salinity developed for cohort 3 in this study is stronger than the temperature relationship, indicating that salinity is the more important parameter in determining cohort 3 distribution.

Arctic Char: Habitat-utilization relationships developed for cohort 1 Arctic char in Prudhoe Bay indicate that char are strongly associated with low salinities (<S ppt) and moderate temperatures (4-10 °C; Fig. K2.1O). This likely reflects the char's abundance in the Sagavanirktok Delta area in the early open-water season and their general absence for the remainder of the period of interest (through August 15). Cohort 2 Arctic char in Prudhoe Bay showed little association with temperature, but they were associated with low salinities (4-8 ppt). The entire temperature (2-12" 'C) and salinity (0-28 ppt) ranges were utilized.

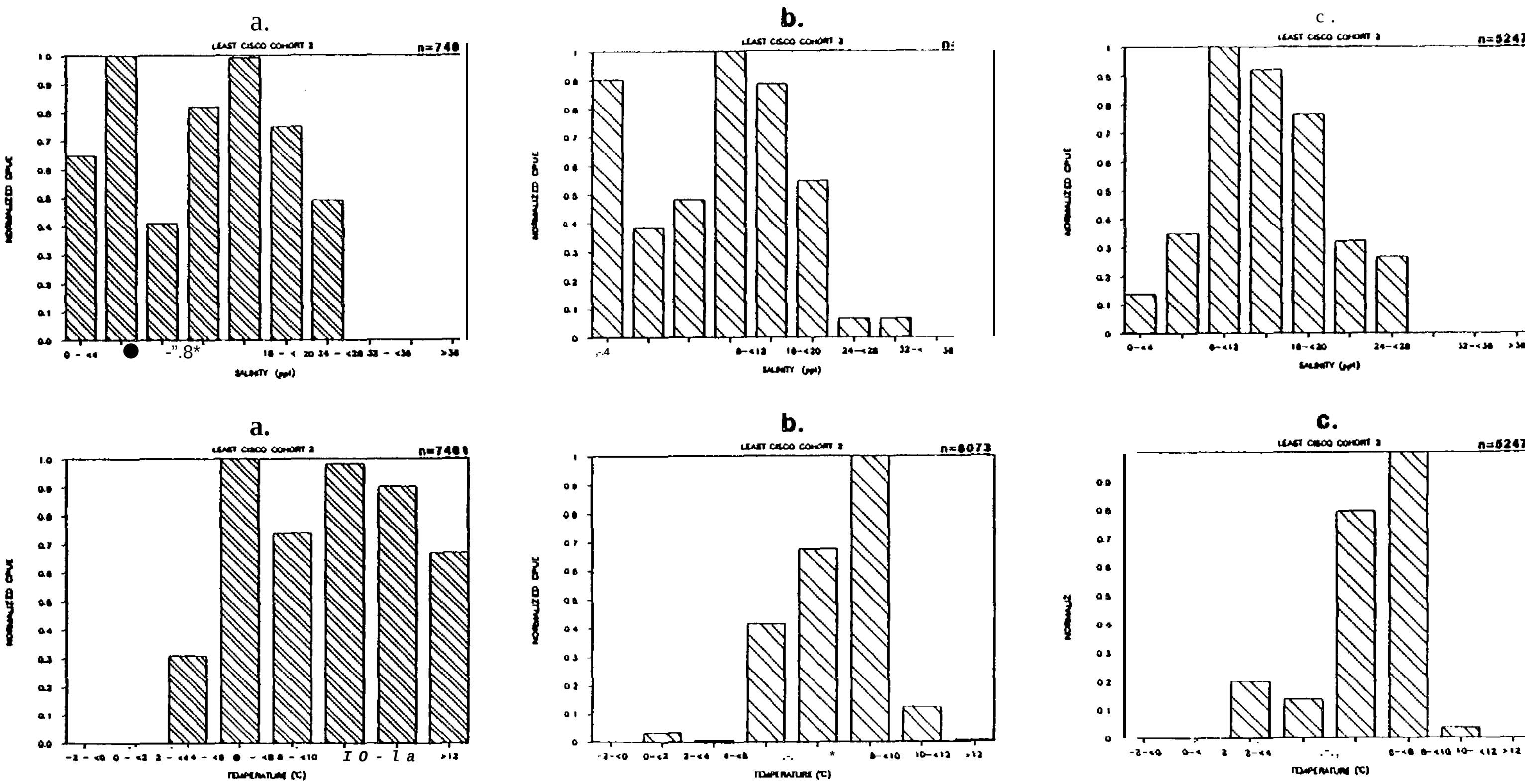
Conditions of Greater Environmental Variability

It has been suggested that major movements of anadromous fish in Prudhoe Bay may be in response to large changes in oceanographic conditions (Moulton et al., 1986; Cannon and Hachmeister, 1987). Large catches in the fyke nets have been noted during transitional periods when fronts are moving past the fyke-net locations. Effort curves developed from the 1985 and 1986 data under conditions of lesser and greater environmental variability were remarkably simiiar except for the artificial reduction of effort in the 0- to 4-ppt-salinity category under conditions of greater variability (Fig. 12.1c). Since most sets under these conditions had a salinity change of greater than 4 ppt, and since there are no salinities less than O ppt, there was a much reduced chance of a set having a mean set-to-retrieve salinity change less than 4 ppt.

Habitat-utilization curves for the various specie cohorts were likewise generally similar under conditions of lesser and greater environmental stability. However, in the O- to 4-ppt-salinity category, there was a reduced CPUE for all species/cohorts under more variable conditions. Since salinity is much more likely to be rising under these conditions (salinity cannot drop 4 ppt from a set salinity less than 4 ppt), this consistent pattern indicates a reduced catch when salinity is low and rising for most species/cohorts (e.g., Fig. 12.3c, 12.5c, 12.7c, 12.9c).

Separate regressions of total net catch (both sides of the net; each species/cohort separately) against the degree of change in temperature and salinity from set to retrieve showed no significant relationship (all r^2 less than 0.10). This result could be compatible with the idea that anadromous fish undertake major directed movements in reaction to the movement of *fronts if, under conditions* of relatively little environmental change, catch is roughly equal between sides of the net while, when conditions are changing, there is increasing directionality (greater proportion of the catch in one side or the other).

This was tested first by regressing the maximum degree of imbalance in catch from one side of the net to the other against the degree of change in temperature and salinity (independently); no significant relationship was found (ail r^2 less than 0.10). Next, we compared frequency distributions of the degree of imbalance in the catch for conditions of greater and lesser variability in temperature or salinity during the set. It was expected that there would be an increasing imbalance in catch from one



a. Prudhoe Bay, 1983-1986, Low Variability
b. Endicott Stations, 1985-1986., Low Variability
c. Endicott Stations; 1985- 1986, High Variability

igure 12.7 Normalized CPUE of Arctic Cisco Cohort 3 by Salinity and Temperature Category

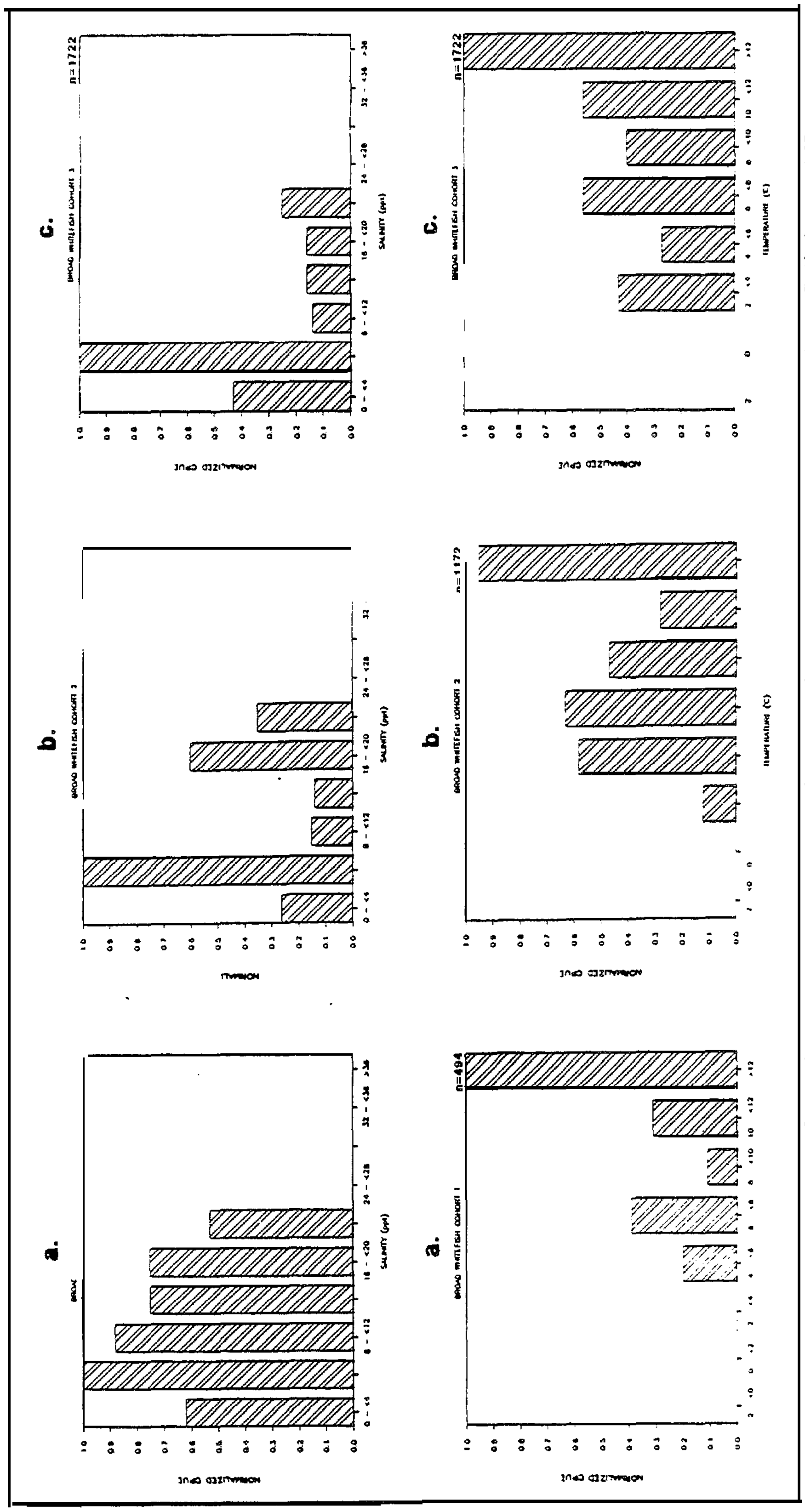
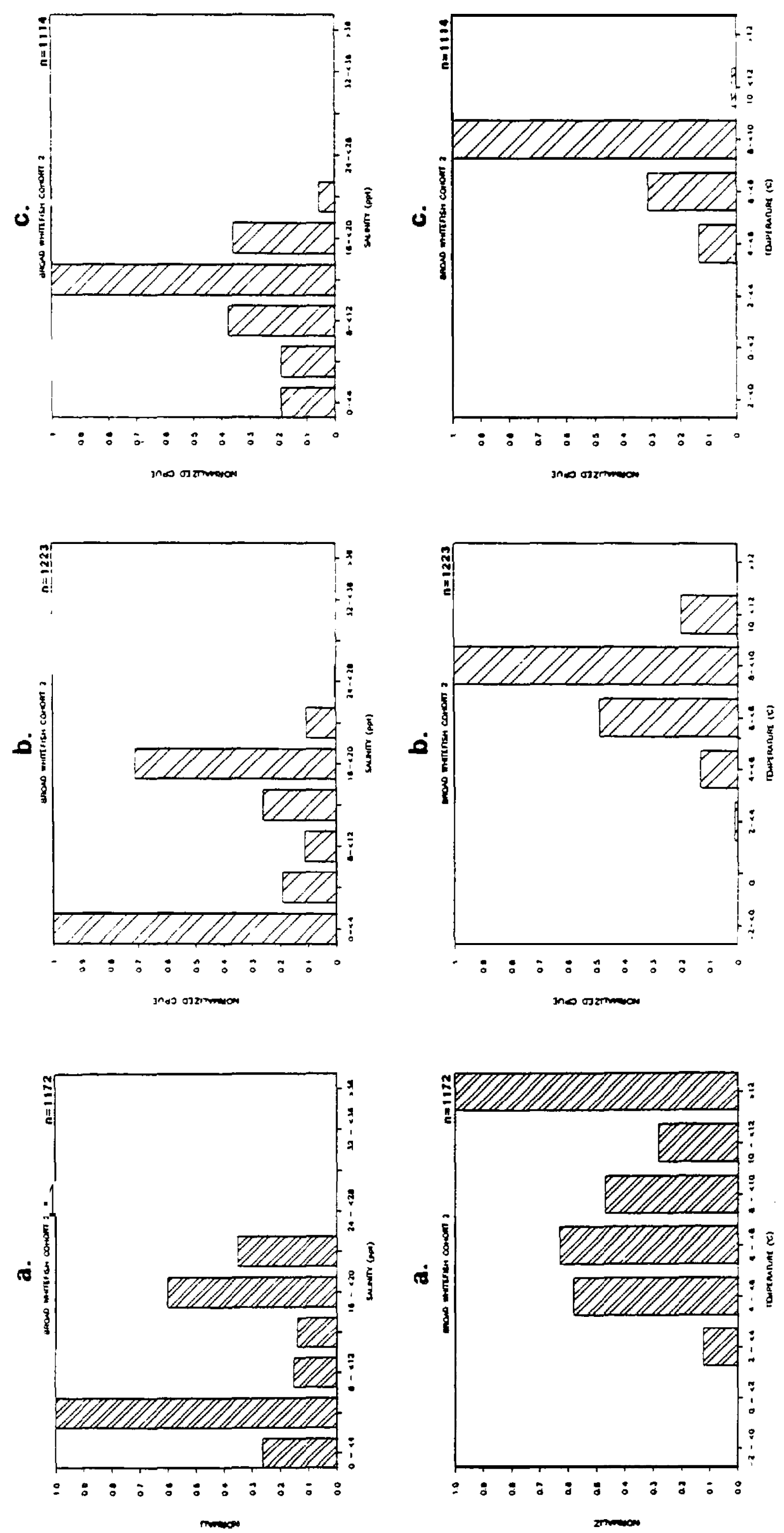


Figure 12.8 Normalized CPUE of Arctic Cisco Cohort 2 and 3 Captured in Prudhoe Bay, 983 to 1986, by Salinity and Temperature



a. Prudhoe Bay, 1983-1986, Low Variability
b. Endicott Stations, 1985-1986, Low Variability
c. Endicott Stations, 1985-1986, High Variability

Figure 12.9 Normalized CPUE of Broad Whitefish Cohort 2 by Salinity and Temperature Category

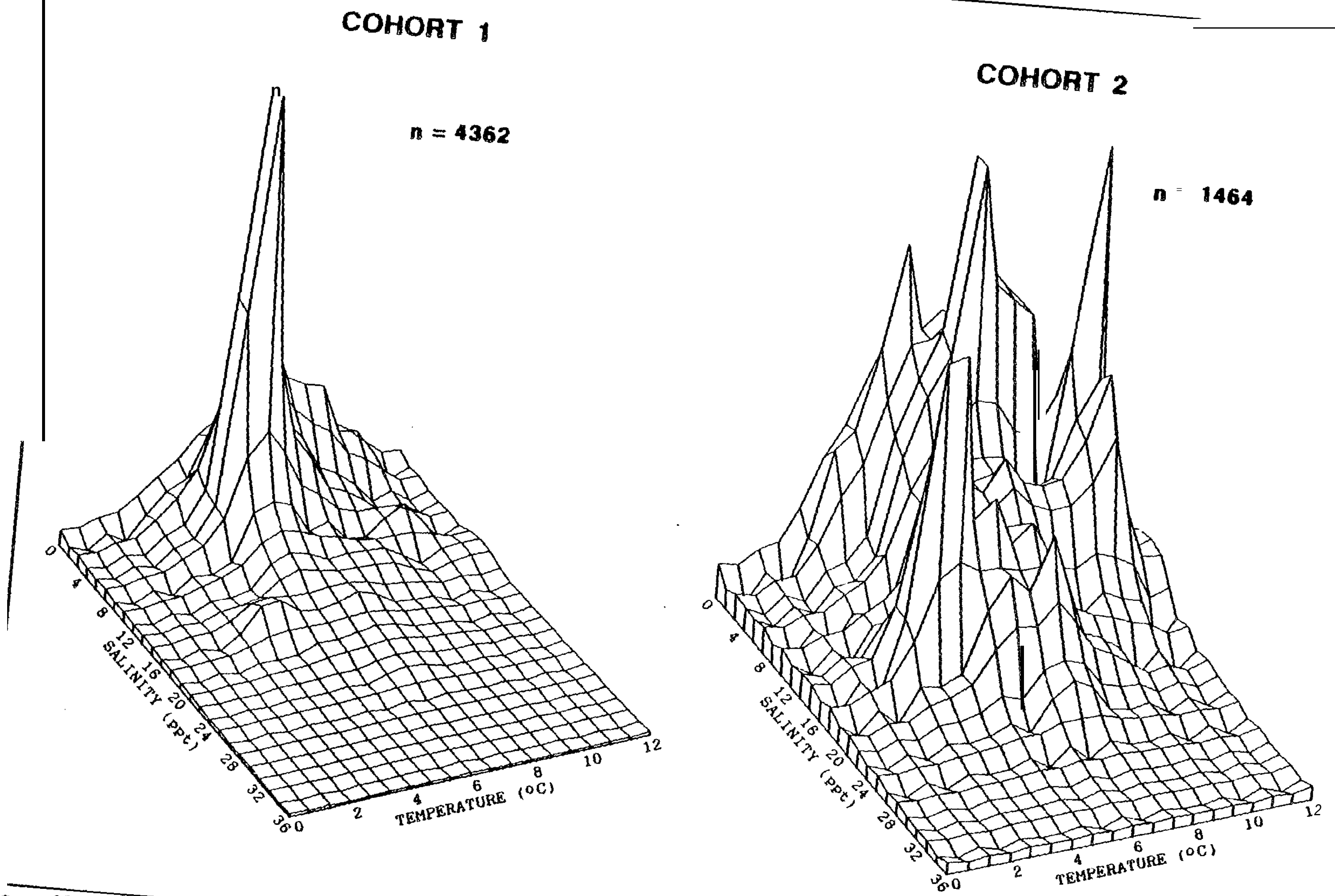


Figure 12.10 Normalized CPUE of Arctic Char Cohorts 1 and 2 Captured in Prudhoe Bay, 1983 to 1986, by Salinity and Temperature

side or the other, with increasing change in either of the environmental parameters between set and retrieve. However, in all of the tests run for the species/cohorts in question, *there* were only a few instances of a significant difference in the catch-ratio-frequency distributions between sets under lesser and greater environmental variability. The instances of a significant difference showed no consistent pattern of direction and occurred at a rate indicating a random process.

Summary and Conclusions

The analyses presented in this paper are based on screening of a 4-year database containing some 180,000 records. The distribution of fyke-net fishing effort in the database used correlates well within the range and abundance of available habitat measured in other programs (e.g., Glass et al., 1987). Also, the temperature and salinity variations over the 24-hour fyke-net periods were moderate. Median changes in the combined 1985 and 1986 databases (excluding stations where catch is influenced by causeways) were 1 "C arid <3 ppt. Thus, we can conclude with a high degree of confidence that fishing effort was indeed representative of available habitat and that our analyses do indeed reflect true habitat-utilization relationships. It is not surprising that responses of fish to environmental stimuli experienced in the natural environment (e.g., temperature) differs somewhat from that which would be predicted based on laboratory analyses of fish in a medium designed to minimize other variables (e.g., Fechhelm et al., 1983).

Sensitivity of fyke-net catch data to environmental variability was explored by constructing habitat-utilization curves for periods of greater environmental variability and by the analysis of effect of degree of environmental change on CPUE and catch directionality. The similarity of the habitat-utilization curves under conditions of lesser and greater environmental variability demonstrates the strength and applicability of the approach used. The lack of significant effects of degree of environmental change on CPUE and catch directionality was somewhat unexpected based on the observations of specific instances of apparent effect reported by various investigators. The lack of a consistent relationship may indicate that these instances are relatively rare and masked by the size of the database, or that the specific reactions of fish to most periods of environmental change are more random than had been thought.

The general trend evident from our analyses is that all four species of anadromous fish show a greater utilization of waters with low to moderate salinities ranging from O to about 20 ppt, and also a trend for greater utilization of waters with temperatures between 4 "C and 12 "C. Curves for Prudhoe Bay stations only are very similar to those for the entire Endicott study region but typically show utilization of a broader portion of the temperature and salinity range present despite the narrower range available. This utilization pattern suggests that for fish within Prudhoe Bay, responses to other stimuli, e.g., food, may be masking somewhat the stronger temperature and salinity responses seen in the broader Endicott study area. Although the true cause of this pattern is unclear, it indicates flexibility in utilization patterns.

Clearly, the survival strategy of these tish is well adapted to the widely variable temperature and salinity conditions characteristic of this nearshore environment. The habitat-utilization relationships developed in this analysis underscore the conclusion that these fish have evolved a summer-feeding strategy well suited to their highly variable environment. The localized effects of existing causeways on temperature and salinity (e.g., Cannon and Hachmeister, 1987) are generally within the natural background range of variability encountered and utilized by these species during their summer-feeding movements. Therefore, it appears unlikely that the localized changes in habitat conditions induced by the effects of causeways on nearshore circulation would be significantly detrimental to anadromous-fish populations.

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Question-and-Answer Period

Question: One of the things that you appear to have been doing through your analysis is to address the question of sensitivity. However, particularly for a forum like this, you only addressed a portion of the sensitivity--the sensitivity of the animals to actual changes to the distribution of physical properties in the coastal environment. On the broader scale, though, in terms of vulnerability and sensitivity, I listed Arctic char as being both vulnerable and sensitive throughout the Attic. The vulnerability was based upon their distribution in coastal waters and distribution of overwintering and spawning habitat. The distribution of those properties makes them vulnerable to disturbances such as oil spills, disruption of oceanographic properties, conflicting water uses (particularly in terms of overwintering and spawning), and harvest by humans. I list them as being sensitive because the data we have from Canadian studies suggest that their populations are sensitive to overexploitation. The availability of food for postspawning adults will affect their ability to spawn repeatedly. They are clearly sensitive to conflicting water uses. For example, in the Arctic National Wildlife Refuge, each stream supports a discrete stock, some of them very small. I listed Arctic cisco as being vulnerable because of their apparent distribution. They are exposed to just about anything we do on the Beaufort Sea coast, both in Canadian and U.S. waters. Despite your analyses, I would still say that the sensitivity of these species is still unknown.

The vulnerability and sensitivity of least cisco appear to be unknown. Broad whitefish in a fashion similar to what Benny proposed in the baseline studies for the Endicott Project were both vulnerable and sensitive; they enter the coastal waters and are subsequently exposed to a lot of the activity along the coast. And they are sensitive because their distribution is limited, particularly in the central Beaufort Sea. Any alteration of that habitat, given the limitations of the habitat, could have a profound effect upon the animals utilizing the coastal system.

Given that lengthy treatise, I was wondering if you could address some of the Chukchi Sea questions, the vulnerability and sensitivity of anadromous-fish stocks--for example, the salmon. Char, 1 presume, are probably as sensitive in the Chukchi Sea as they are along the Beaufort Sea coast. Regarding marine species, we know so little about them that it's hard to say what their vulnerability and sensitivities are. In the southern Chukchi where we encounter a greater variety of marine fish (Pacific herring for example, which utilize very specific spawning habitats, and some of the smelt, which also have specific spawning requirements), we haven't identified their overwintering requirements. I wonder if you could address some of the marine species.

Houghton: In the southeastern Chukchi, char are vulnerable and sensitive in the same way as char along the Beaufort coast. They spawn in extremely specific areas; they have limited overwintering habitat. The questions of gravel availability, disturbance of spawning areas, and water deprivation are applicable in both areas. Once char leave those rivers, they may be somewhat less vulnerable than they are in the Beaufort Sea simply because there's less of a constraint of proximity of ice edge; they've got a little bit more room to work with in their marine-feeding migrations. Our sampling along the shoreline right at breakup failed to detect any movements along the shore, although some of the Cape Thompson work did catch fish in gillnets set offshore. This suggests that they seem to be a little less dependent on the nearshore zone along the Chukchi Sea.

Regarding salmon in the southeast Chukchi, I really don't know a lot about the Noatak and Kobuk salmon. In the Wulik, there are populations of pinks and chums. They appear to be limited by the amount of spawning habitat. Rearing and overwintering habitats are not a problem, but spawning habitat is limited. There may be a problem of overspawning by char that spawn after the pink and chum salmon. Early marine life history of salmon can only be guessed at. My guess would be that considering the major runs that come out of the Noatak and the Kobuk Rivers, that broad, flat area around Kotzebue--up in the Hotham Inlet and so on--provides ample early marine habitat. Certainly it could be very vulnerable because of its shallow nature and prevailing weather. If there were a large oil spill in this area, environmental effects could approach a fairly worst-case condition, through vertical mixing of the oil by wave agitation in the shallow waters.

Regarding herring--I don't think anyone has documented herring-spawning locations in the Chukchi Sea. Our beach-seining crews, however, saw large schools of herring offshore but no eggs were taken during the beach-seining operations. There is a lot of gravelly beach in the area between Kivalina and Cape Thompson, and that's quite possibly where they spawn.

We caught a few rainbow smelt in the lagoons. Cisco and whitefish are apparently much less important there than they are in the Beaufort Sea. Kivalina villagers fish in Kivalina Lagoon, which is a relatively deep, brackish lagoon, for whitefish or cisco throughout the winter.

Question: That helps, that addresses some of the questions that I had. Mostly I wanted to bring that up so when we get to the working sessions, we don't begin an argument about the sensitivity of whitefish in the Prudhoe Bay region. That argument has been ongoing for at least 4 years, if not longer. One question I did have about the sensitivity analysis: in the graphs that you presented, you coupled temperature and salinity, whereas from the perspective of physiology, the response of the animal will differ; they are actually decoupled (temperature will affect the rate of metabolic processes and the salinity will affect the distribution of energy within the animal). Did you examine treating the two properties as separate variables in a broader bioenergetics context? Given these variables, where would you expect the animals to locate themselves, within the coastal habitat. Were they going out to feed? Were they satiated, etc.? And, depending upon the actual state of the animal, you are going to get different responses to the two properties of temperature and salinity. Did you look at your data in that sense?

Houghton: We really didn't. We did, of course, look independently at temperature and salinity. We literally just finished these analyses yesterday. We haven't really gotten much beyond what I presented in terms of trying to figure out the grander meaning of it all. One thing that intrigues me is this significant or apparently significant difference in utilization within Prudhoe Bay versus the broader area. I don't know if it means when the fish are in Prudhoe Bay they're "where they are going." At least in this timeframe, they are there primarily to feed, and they are moving within the bay more in response to food availability or abundance than they are to temperature and salinity. Whereas when they are observed along the coast out of Prudhoe Bay early in the season, they have just come out of the rivers, they appear to be moving in a more directed manner. This is not what I expected, I expected just the opposite.

Question: Considering the sampling effort in Prudhoe Bay compared to the amount of sampling effort in other areas, is it possible that in your scheme for eliminating rapid changes if the change occurred over a 2-day period rather than a l-day period, that it would not be eliminated? In other words, is there more variability in temperature and salinity in Prudhoe Bay than *there is in other* regions but maybe not necessarily occurring at such a random pace?

Houghton: The data were partitioned to reduce that type of effect. We looked at each data set individually to see if it had more or less met the criteria. The data sets analyzed here are those that had a less than 4-ppt change in salinity and a less than 2 "C change in temperature. The level of sampling effort was weighted. Catches that occurred only under a narrow set of circumstances *were* used and then weighted to a standard level of effort.

Question: If a salinity occurred only once and a lot of fish were collected, does the catch get weighted up?

Houghton: Yes, it could. And that's why, when We look at individual years, you have some anomalous catches. An individual year, for example, may show little sampling effort but yield a bunch of fish; and it could be the highest effort or CPUE of any category or any habitat category. But by combining the 4 years, I think we largely eliminated that kind of error.

Comment: Prudhoe Bay tends to have a lot of variability in hydrographic conditions (salinity, temp., etc.) during the open-water period. That's why I asked about the availability catch statistics from a broader spectrum of hydrographic conditions.

Houghton: In Prudhoe Bay you have a narrow range of salinity and temperature values in this 4-year database; the maximum salinity range was 24 to 28 ppt; whereas in the Endicott monitoring database, we had quite a few sets in that salinity range and a few in the next highest salinity range.

Question: So, it doesn't look that anomalous relative to what's going on at Endicott?

Houghton: No. The shape of the curve kind of surprised me, too. But it was consistent here and in Prewitt's effort curve.

Question: You mentioned prey availability being perhaps an overriding consideration of where fish are. And I assume you didn't do any prey availability with your studies and wonder if you had to do it over again, if you would take that into consideration?

Houghton: We certainly would. In fact, we had hoped to; but time and money didn't allow us to. But it would be very interesting to do so. I think Envirosphere has.

We did collect samples using drop nets and fyke nets. The data are there. It is just a matter of coupling them with the tish catch. In the active sampling program, Prewitt was doing drop-net samples at each set. His intent, had he caught enough fish, was to construct a similar curve using prey availability as a variable.

Question: I am glad to see that YOU addressed the question of passive gear-measuring movement; not necessarily abundance. I was surprised not to see a correlation.

Houghton: With all the problems of passive gear, you would think that there would be a correlation between abundance and movement; however, we didn't see one.

Question: Was there a lag time following a change in environmental parameters and an increase or decrease in the catch rate?

Houghton: We thought about that a little bit and decided to look at the data without a time lag. You could easily postulate a condition where, if a front were approaching, fish might sense the front ahead of the 4-ppt salinity change and move ahead of it. They also might be on the leading edge of the front where you have only a 1-ppt change. If that is happening and a front goes by, you might get a huge catch of fish in the first half hour of sampling. But, if that front is of sufficient magnitude in the subsequent time period, you might violate the data-set criteria. There might be some instances where the front moves through just before you pull the net and you wouldn't catch the subsequent pulse of fish; the big change, however, would be in the next day's catch.

Question: I have a question for Larry Moulton concerning his sampling on the Colville River. You mentioned that there was a relative measure of an influx of isolated waters moving upriver and an increase in the catch rate. When and where did you measure the change?

Moulton: Salinity and catch were measured prior to freezeup. These measurements indicated that as the higher salinity water moved upstream, catches decreased at the sets where salinity increases occurred and catches upstream from the front increased dramatically. You can see the fish moving in front of that saltwater. Similarly, these events are pretty well documented in the summer studies. It would be fairly simple to go back and read the descriptions and see how they fit into Houghton's data set.

Comment: Well, Eke I said, they certainly have occurred and they certainly have been documented. It is curious, I guess, that in this broader database, they don't show up at least in the ways we've tried to twist the data.

Comment: I wanted to point out that in your talk, you used the words preference and utilization. The title of your talk, which you apologized for, uses the words sensitivity and vulnerability. I felt that that's partly what Craig was bringing out. You used the word sensitivity continually. At the beginning of the conference, Gail Irvine put together a description of effects and made a distinction between death, factors that influence survival, and growth. Well, that word preference to me implies what they select. Sensitivity to me implies tolerance or death. And, I think we shouldn't use those words interchangeably. One implies that something is not tolerated, it blocks, whereas the other implies it's going to affect perhaps growth rates, ecological importance, that sort of thing. I think we should not confuse those two. One of your conclusions was the animals seemed well adapted to the conditions that they are exposed to. When we convince ourselves that the fish aren't going to be able to tolerate early spring temperatures or the effects of a storm or a cold year, I think that we have gone too far. It might not be what they prefer, but they are not sensitive to it in the sense that they can't tolerate it.

Comment: I agree. I didn't use the word sensitivity, although I may have implied it a time or two. Also, just to clarify that point, I wasn't using them interchangeably either. I felt what Jon (Houghton) was presenting was in many ways a sensitivity analysis in the sense of, are these animals capable of tolerating the magnitude of change, in water properties that they are exposed to.

Question: Then let Jon (Houghton) answer that. What was your conclusion?

Houghton: Well, I think my conclusion was that they appear to use a broad range of the available habitat. Really, I don't think I went beyond that other than to say that their feeding strategy is adapted to widely varying conditions that occur. You can see by the breadth of a number of the tunes. The fact that the curves look different within Prudhoe Bay and without Prudhoe Bay indicates to me that they have some flexibility, even in that range. they can expand it when something else is driving their behavior; be it "throw cares to the wind and feed like mad or whatever. Given the breadth of those utilization curves, I think you can look at temperature and salinity changes that are induced by causeways and compare these with conditions that the fish appear to be using elsewhere. If you find that the fish appear to be utilizing a broad area or are found in a specific area, under a wide range of conditions, then you might suspect that under some conditions the fish may be under stress. Bioenergetics studies, e.g., are they getting enough food in these areas to compensate for the stress and growth, will provide insight into these effects.

Comment: I've frequently hounded Jon on the difference between preference and utilization. Since we don't know the full range of physical properties over which the animals are distributed, we can only address the question of utilization. When we get considerably more data than we presently have, then we can deal with preference.

Comment: We may have enough oceanographic data, but we haven't analyzed it in a manner that will allow us to integrate the data with the fish data.

Question: Jon, I admire the effort, but I have significant problems with some of the criteria you utilized to subset the database. Could you repeat for me why you did not use that portion of the data set collected post-August L5?

Houghton: We were trying to focus on the hydrographic conditions in the summer-feeding habitat. We felt that after August 1.5, you start to experience much colder temperatures and much higher salinities. We were trying to determine the choices that fish would make when they have the broadest range of choice. I think that if you look at the effort curve after August 15, I suspect it would be radically different from the effort curve that we presented here. Seldom do temperatures reach 12 °C or 10 °C, maybe even 8 °C very much of the time that late in the year. So that's why we focused in on that early open-water period.

Question: I think, as far as I'm concerned, you make my point, in that somewhere in the neighborhood of August 15, you get this step function of salinity. Salinities are up, temperatures are down for the rest of the summer. A lot of the adult fish, char, virtually all of them, leave.

Houghton: Yes, that's another reason. We didn't want the catch that we were looking at to reflect the fact that, "Hey, I'm over here and I've got to get there before winter sets in; so I don't give a damn what's in the way, I'm going." We wanted the analysis to reflect a movement pattern that we hoped would reflect a preferential utilization under conditions where there weren't other strong stimuli moving the fish.

Question: Then it's an unfortunate circumstance, because you were also constrained by the nature of the database available and the biases associated with the database. But by virtue of assuming beforehand, when you *screen* the database, that things of importance in defining "summer-feeding period weren't really occurring past August 15, I think something is terribly wrong. Because you have artificially constrained your relationships. Juvenile fish (nonSpawning fish) are, generally, trickling back into wherever they overwinter, but they are still out there, they are still feeding, they are still putting on a fair bit of growth--albeit at a slower rate. So they are exposed to generally lower temperatures, generally higher salinities than are portrayed here. In your efforts to remain sort of pristine and pure in your academic approach to the subject, because of the bias recognized in the sampling itself, you have thrown out a whole lot of information that truly reflects what they are utilizing.

Houghton: It certainly reflects their tolerance and their utilization in that later period. I'm not sure that it's likely to reflect their habitat preference, because they don't have as broad a range to choose *from.* The other reason that we focused on the pre-August 15 period was that we were concerned, in the impact evaluation for the Lisburne Causeway, with early- to mid-open-water-season feeding habitat that has been identified as an issue of concern. This is also the time of year when you can get the largest change in conditions induced by a structure such as a causeway, because you have more widely varying source in terms to input. The point was well taken that in any one year you might have what looks very clear but is totally wrong because it happened to represent a single data point. Many times we see so many different examples that one could pick and choose and prove almost anything you wanted to by selecting isolated incidents. You need to have enough data, temporally and spatially, to get a generalized picture of average conditions.

Comment: Should we be surprised since these fish we've heard about today have been here for 200,000 years, and during the period of time that we've really looked at it we've heard "for the last 10 years every year has been anomalous"? It's incredibly variable and yet they are still here. So they must be doing something right.

Chapter 13

Habitat Relationships

Introduction

The Habitat Relationships Workshop consisted of three concurrent working sessions. Each working session was charged with reviewing the paper presented by Houghton, Whitmus, and Maki; identifying information needa; and listing research needed to better understand the factors that control habitat relationships of fishes in the Arctic.

A workshop facilitator led the discussions, and a scribe took notes and helped the facilitator prepare summaries (oral) of each session's progress. Summaries were presented by the facilitator at a plenary session immediately following the working sessions.

Working Session 10

Facilitator: Dick Marshall
Scribe: Chuck Mitchell

The 1986 Endicott sampling program and Soviet and Scandinavian literature were identified as sources of additional information for broad whitefish.

Reasons for focusing on habitat relationships include the observation that annual variation in population parameters is so great that if there are development-related effects, it will be very difficult to attribute population changes to a specific development causative agent and that by comparison, it's much easier to measure habitat changes. Therefore, once an important habitat or habitat attribute has been identifies activities that may adversely affect that habitat may be restricted or prohibited.

Metricizes can be used as a strategy for identifying specific study-objectives metricizes including species, habitats, and measurable parameters. Important habitats including spawning, rearing, feeding, overwintering, and (perhaps) migratory corridors were identified as being important to four anadromous-fish species and three marine-fish species considered important in the Beaufort and Chukchi Seas. Important parameters included, in the case of spawning habitat--gavel or the type of substrate necessary for spawning and in the case of overwintering habitat--dissolved oxygen. The working group was unable to reach a consensus on the vulnerability of the various habitat types to development, there was consensus that on a per species basis, the relative vulnerability of the habitats should be determined and that the vulnerability index be used as an aid in prioritizing the inventorying of habitat types.

Important "constraints" to be considered when designing studies and developing specific study objectives include: habitat variability (use of the habitat varies with time), prey patchiness and predator patchiness. In addition, the environment is dynamic; salinity, temperature, turbidity, and the other environmental parameters change with -time. A fish's behavior at the time of capture must also be considered What were the fish doing when captured? Were they feeding? Were they feeding cold in marine waters, or were they inshore metabolizing that food, or were they moving between? Are they escaping very unfavorable conditions and not in their preferred habitat at ail? Is the feeding habitat too plastic to describe in terms of the physical and chemical parameters? Are oceanographers being asked to answer what are really biological problems, i.e., prey availability may override all the physical and chemical parameters being measured (in other words, the fish are where the prey is).

Additionally, a study should be designed to provide a snapshot in time; studies should use active sampling gear versus passive sampling gear, so that habitat characteristics at the time of sampling are known and that the sample is an indicator of activity, not an indicator of abundance; habitat studies should be conducted in an area where fish have free access to a variety of different habitat types; and there should be enough fish to capture.

The following is an outline of topics discussed during this working session:

<u>Additional Kev Information</u>

- 1986 Endicott Active Sampling Program
- Russian literature
- Scandinavian literature, especially on broad whitefish
- Fechhelm's work

<u>Purposes of Developing Habitat Relationship</u>

- Predevelopment: <u>avoid</u> impacts to critical habitat
- Postdevelopment: establish biological significance to habitat changes that might occur

Strategies

- develop matrix to describe
  - habitat categories (spawning, rearing, feeding, overwintering, migratory corridors)
  - species (Beaufort, Chukchi, marine, anadromous)
  - important parameters (e.g., spawning--gravel, overwintering--dissolved oxygen)
  - vulnerability
  - limited--unlimited
- inventory habitat, priority to Vulnerable/limited
- conduct laboratory studies to establish tolerances and bioenergetics
- address data gaps in the matrix

Constraints to Studies Designed to Address Data Needs, Particularly Feeding Habitats

- patchiness — fish [schooling behavior]; prey; nature, e.g., temperature/salinity of the water column
- background noise--what *were the* fish doing when caught? Feeding? Metabolizing? Moving between? Escaping unfavorable conditions?
- prey availability might override all other factors
- conceptual problem as well as methodology problem
- study design should provide a snapshot in time (active gear); measure abundance, not activity (active gear again); and be conducted in areas where fish have a variety of habitats from which to choose

Working Session 11

Facilitator: Scott Robertson
Scribe: Lyman Thorsteinson

Research Review

Most habitat-utilization studies. conducted in the Beaufort and Chukchi Seas have been of a short-term and mission-oriented nature. The most extensive studies have been conducted in the central Beaufort Sea, including Prudhoe Bay and Simpson Lagoon. In this area, the availability of nearshore habitat for use by anadromous cisco, char, and broad whitefish has been intensively studied. Most of the work has been conducted inside 10-m depths and shoreward of the barrier islands. Other research has been conducted in Beaufort Lagoon in the eastern Beaufort Sea and in Peard Bay in the northeastern Chukchi Sea. These efforts have been sufficient to provide general habitat descriptions and use patterns by fish in open and "pulsing" arctic lagoons. The data have demonstrated considerable annual variations in the standing-stock estimates of macroplankton and near-bottom crustaceans within the lagoons. A fish database developed by British Petroleum includes most of the data collected in the nearshore region from Point Hope to Cape Dalhousie (up to 1984-85).

Ongoing studies by the Fish and Wildlife Service (FWS) in the eastern Beaufort Sea are expected to provide additional information on fish abundance in areas of potential port development (i.e., Camden Bay and Poykok Bay) and in association with NOAA (Attic char study) at other coastal sites between Harrison Bay and Barter Island. All catch data will be analyzed in conjunction with CTD data collected at the time of catch. Canadian investigators have recently completed fieldwork on a 3-year interdisciplinary study of the Mackenzie River estuary. Other studies supported by the oil and gas industry and involving Arctic cisco, char, and broad whitefish will be ongoing along the Beaufort coast.

Few studies have been conducted in the offshore Beaufort Sea (greater than 10-m depths) and fewer still in the Chukchi Sea. Because data is lacking on the distribution and abundance of most marine fish, little can be said about their specific habitat requirements. Similarly, in the nearshore Chukchi Sea, many marine and anadromous fishes are seasonal residents, and the specific aspects of this use (e.g., timing and habits) are poorly known. However, because these species also occur in the Bering Sea and elsewhere, a major literature review (including international sources) of the Chukchi Sea, examining all fish groups (demersal, pelagic, commercial, and forage fishes) in relation, where possible, to major features of the environment--such as the origin of various watermasses, temperature and salinity patterns, major river inputs, other nearshore and offshore characteristics, and food-web relationships--may reveal that more is known, or is available, than currently thought. A similar synthesis of fisheries information is currently being prepared by FWS for the eastern Beaufort Sea, including its major freshwater drainages.

Study Needs

Important attributes for future habitat characterizations include:

Temperature and Salinity Distributions: Available data indicate that, with the exception of broad whitefish, anadromous species utilize coastal waters of widely ranging temperature and salinity combinations reflecting tolerance limits and optimum ranges. How do these variables affect metabolic expenditures for growth and survival? Once preferences have been determined in the laboratory, field data can be more fully evaluated. A shortcoming of extrapolating laboratory results to predict or explain the field observations is that they do not account for environmental variables (i.e., prey availability) that may have an equal or greater influence on patterns of habitat use.

Availability of Food Determinations of habitat suitability should include food habits, prey availability (including size of prey), and "scope-for-growth" studies. What is the role of Pacific sand lance as a prominent forage species?

Presence of Predators and Competitors: The presence of predators and competitors will have a great bearing on habitat partitioning. Specific age-related (e.g., cannibalism) and inter-specific relationships need investigation% i.e., bird and mammal predation on fish and fish and whale competition for crustacean food resources in the Cape Lisburne area. In the southern Chukchi Sea (and other places), jellyfish are thought to feed extensively on ichthyoplankton. This predation may be a major source of mortality.

Degree of Physical Energy: Most aquatic environments are mobile and influenced to varying degrees by wind, tides, ice, etc. The dynamic nature of the location of brackish- and marine-water interfaces has a great influence on the distribution of fish. These factors influence local productivity within an area and its habitat role in providing food and refuge to fish.

Location of Foraging and Spawning Habitat: Information is needed on foraging and spawning areas and times of many marine and coastal fish species. In the northeastern Chukchi Sea, coregonids may be greatly restricted in numbers by the extent of summer-foraging habitat. Clues to the location of important feeding grounds may be associated with areas of upwelling, waters in vicinity of seabird colonies, or congregations of marine mammals.

Species that migrate into nearshore environments to reproduce are thought to be especially vulnerable to development activities, i.e., in the Chukchi Sea, species such as the boreal smelt, Pacific herring, and capelin. Information is available on the timing of herring, smelt and capelin spawning and their substrate requirements. However, information on the residence and migration of salmon and other species in the southern Chukchi Sea are not known. In some sahnon-producing rivers, nutrients from decaying, spawned-out carcasses may play an important role in the productivity of juvenile rearing areas. Does this kind of relationship exist for other fish in the Arctic? Information also is needed on the locations and times of spawning for saffron and Attic cod. What effect does regional circulation have on the transport and development of egg and larval stages and, ultimately, on the formulation of year-class strength? Are there important rearing areas for juvenile cod located inshore? Ichthyoplankton surveys were recommended as a possible way in which to address some of these questions.

The Simpson Lagoon research demonstrated how important coastal transport processes were in the functioning of coastal waters and open lagoons. It was estimated that during the summer, it would be possible for Arctic cod to deplete the entire crustacean food base (mysids, amphipods, isopods, and copepods) within 2 to 5 days if immigration of prey were not possible.

AS an example of a species' vulnerability to potential oil spills, saffron cod in the Mackenzie River estuary are winter spawners with spawning occurring in several embayments. Spawning occurs in waters of about 10-m depths. Results from plankton surveys indicate that eggs and larva of the saffron cod are contained inside the 30-m contour. Older-aged juveniles (ages 1 and 2) were reported in slightly deeper waters than younger cod. The distribution of eggs, larvae, and juveniles is in a relatively small area in waters overlaying potential drilling sites. From the habitat standpoint, the apparent distribution of juveniles offers the young fish the greatest opportunity to feed on planktonic foods. It was suspected that the juveniles may be competing with large zooplankton and Arctic cod for small zooplankton prey.

Working Session 12

Facilitator: Brian Ross
Scribe: Laurie Jarvela

Laboratory studies--development of basic biological information--are needed for each of the important arctic anadromous- and marine-fish species. Laboratory studies should focus on determining physiological tolerances, bioenergetics, and using biological markers such as enzyme activity or stable isotopes to study feeding preferences.

Field studies also are needed to relate results from laboratory studies to conditions observed in the field and because all ecological relationships do not lend themselves to laboratory analysis.

The importance of selecting appropriate methodology when designing habitat studies was stressed. The present practice of gathering anecdotal habitat-relationship information using methodologies designed for other non-habitat-relationship studies is not totally satisfactory. The use of active sampling gear as opposed to passive sampling gear or shorter sampling periods when using passive sampling gear (fyke-net), is recommended if an objective of non-habitat-relationship "studies is to gather habitat-relationship information.

Canadian fisheries scientists working in the Arctic use an indicator-system habitat-study approach when designing their fisheries studies. Canadian scientists studying habitat relationships in the Arctic are intensively studying specific river systems and the species utilizing the systems and applying their results to other systems by analogy. Benefits of this approach include reduced logistics costs, more focused studies, and the opportunity to improve integration between studies. In addition, the understanding of habitat relationships in one system can be used to develop more focused working hypotheses for designing monitoring or habitat studies for other specific areas.

Overwintering habitat for many fishes in the Arctic is considered limiting; and the Alaska Department of Fish and Game has determined that some gravel barrow pits can contain more overwintering habitat, by volume, than adjacent rivers. They are in the process of determining the long-term effects of using the barrow pits to enhance local fish stocks.

Future fisheries research in the Arctic should emphasize basic science and move away from the project-specific types of studies conducted in the past. Basic information developed through these studies will be applicable in assessing the potential effects from future development projects in the Arctic. Past experience indicates that the process doesn't necessarily work the other way around. Future studies should also make use of modeling as away of focusing study efforts. The indicator-system concept used by the Canadians lends itself to modeling applications.

Chapter 14

Cause and Effects

Introduction

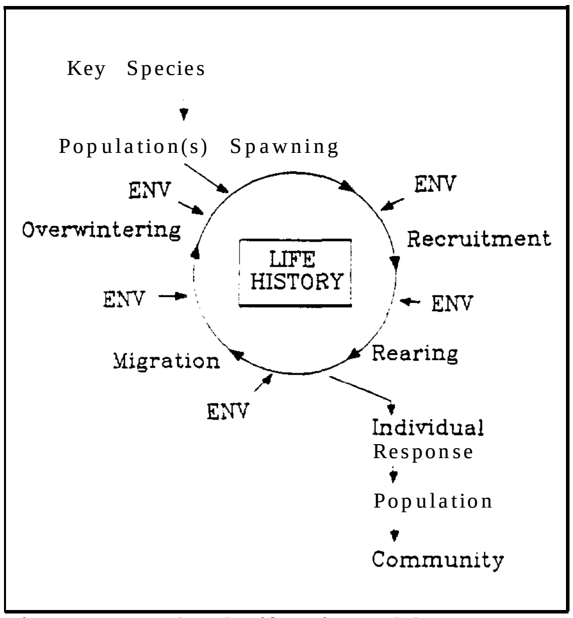
The Cause and Effects Workshop consisted of three concurrent working sessions. Each working session was charged with reviewing results from preceding working sessions, identifying information needs, and listing research needed to better understand the linkages between causes (petroleum development in the Arctic) and effects (arctic fish-population changes).

A facilitator led the discussions, and a scribe took notes and helped the facilitator prepare a summary (oral) of the session's progress. Summaries were presented by the facilitator at a plenary session immediately following the working sessions.

Working Session 13

Facilitator: Jon Houghton
Scribe: Chuck Mitchell

A stylized lifecycle representation (Figure 14.1) was presented to aid in the process of determining a species' vulnerability or sensitivity to effects from OCS oil and gas development. The arrows labeled "ENV" represent the influences of environmental conditions including potential perturbations at each of the major lifestages.



igure 14.1 Stylized Lifecycle Model

The model, on a species-by-species basis, was used as a guide for evaluating the level of knowledge of the life history, limiting factors, and stock structure. Since each species' population may include one or more stocks, stock discreteness may relate to the potential vulnerability of that species. For example, recently gathered information indicates that there are relatively discrete stocks of Arctic char in each of the major rivers along the Beaufort and Chukchi Sea coasts. Based on the current understanding of the char's lifecycle, spawning habitat is a limiting factor; recruitment and freshwater-rearing habitats do not appear to be limiting, primarily because of other limiting factors; and overwintering habitat also is considered limiting. Additional MMS-supported studies of species were considered out of MMS'S area of concern relative to many other species, because spawning and overwintering areas are inland, well away from the coast and from areas where OCS-related infrastructure would have a major impact.

The use of the lifecycle model was recommended to identify regional basic biological questions for the key species that are unlikely to be answered by project-specific studies. Examples include the dynamics of the Arctic cisco's westward movement from the Mackenzie River. What segments of the population, or stocks in the Mackenzie River move into Alaskan waters? How do the fish behave on that movement pathway? Can they actively migrate? Is their swimming ability sufficient to overcome adverse current patterns?

Questions concerning least cisco in the Colville River were considered analogous to the Arctic cisco questions: How many discrete stocks are there and which way do they go when they leave the river? What proportion goes east? What proportion goes west?

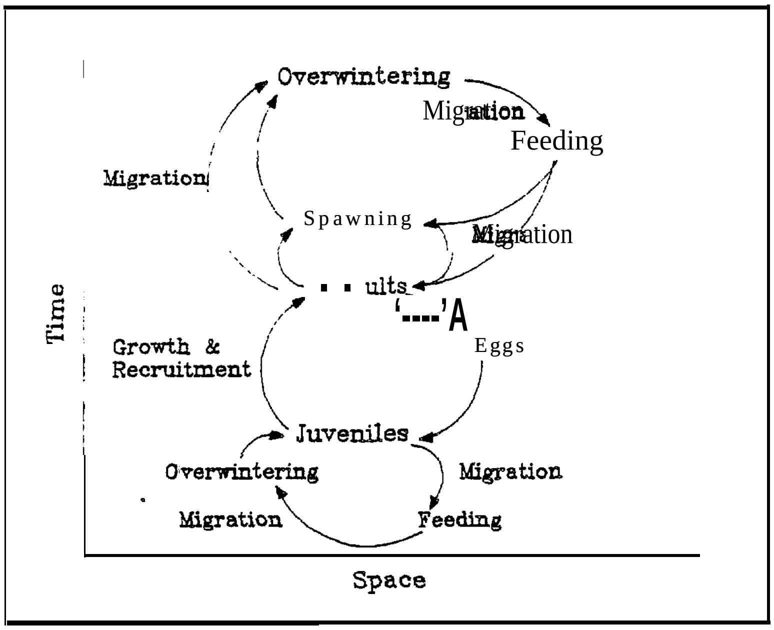
Broad whitefish were considered an important species, but because of this species' relatively limited annual coastal migration, no regional studies were recommended. However, because of its limited life history, this species may provide a better opportunity to understand the factors influencing it as apposed to the broader ranging species with more complex life histories.

Working Session 14

Facilitator: Craig Johnson
Scribe: Lyman Thorsteinson

This session also developed a lifecycle model (Fig. 14.2) for use in focusing discussions and study planning. The basic pattern of the model is similar to that developed during working session 13; however, it has more distinctions between the cycles of adults and juveniles and shows that the cycle occurs within time and space.

An example of how the lifecycle model can be used



'igure 14.2 Stylized Lifecycle Model

to focus studies is comparing portions of the Arctic char lifecycle with portions of the whitefish lifecycle. The lifecycle and important linkages, i.e., limiting factors, between lifestages of Arctic char are" known, and the lifecycles of Arctic char and whitefish appear similar. Therefore, inferences about important whitefish lifestages and linkages between the life stages can be drawn from information on Arctic char. Future studies, consequently, need only concentrate on validating the similarities and identifying and resolving differences between the two species to develop an understanding of the linkages between the whitefish liie stages. This improved model would then lead to a better understanding of the vulnerability and sensitivity of whitefish. For example, populations or stocks with limited distribution and low abundance in areas potentially affected by OCS activities may be more of a concern than pandemic populations. Results from recent Arctic char population studies indicate that some of the genetically distinct Arctic char stocks are very small--200 or so. Therefore, these stocks may be considerably more sensitive to disturbance than stocks numbering in the hundreds of thousands.

The lifecycle model also can be used to evaluate the importance of bioenergetics (energy is required if fish are to move through their lifecycle). The vulnerability of these species in terms of bioenergetics may be based on the loss of or alteration to foraging habitat sufficient to affect a species' bioenergetics. If adults accumulate only the energy necessary for survival but not the surplus. necessary to formulate gonads, they would be unable complete the reproduction portion of the cycle. In the Arctic, where the conditions promoting feeding, growth, and reproduction are limited, foraging habitat (conditions) may be liiting.

A synthesis of existing data can be used to fill in the life-history models regardless of the origin of the data. For example, information on Arctic char from Scandinavia or Canada can be used to complete this species' lifecycle model. In those cases where absolutely no information is available, this becomes a data need. Another example is the availability of information on capelin, Arctic cod, and Pacific herring from the Bering Sea, that can be used to complete the lifecycle models for these species in the Chukchi Sea. If there are readily apparent and significant differences between the Bering Sea and Chukchi Sea portions of the population, then future studies can focus on other topics rather than replicating studies that have already been done on these target species in other areas.

Other refinements to the model included considering habitats, i.e., coastal regions, that are important during specific life-history stages. In this context, the question of sensitivity and vulnerability becomes a question of distribution. For example, if the entire coastal area provides suitable foraging habitat for a species, a disturbance that affects only one minor fraction of that habitat is of less concern than if the distribution of foraging habitat were limited. Another example discussed was the importance of overwintering habitat. If overwintering habitat for a species is limiting, then the abundance and location of this habitat becomes important.

Table 14.1 Fish Species of Primary Interest in the Beaufort and Chukchi Seas"

Beaufort Sea	Chukchi Sea
Arctic char	Arctic char
Arctic cisco	Pink salmon
Broad whitefish	Chum salmon
Least cisco	Arctic and saffron cod
Arctic cod	Sand lance }may not
Fourhorn sculpin	Capelin }need new
	Herring }data

Several species (Table 14.1) of importance were identified 'during development of the model. For the Beaufort Sea, the anadromous species are Arctic char, Arctic cisco, broad whitefish, least cisco, the marine species are Arctic cod and fourhorn sculpin. Not everyone agrees with the priority placed on least cisco. Fourhorn sculpin were identified as an important consumer, at least in the coastal system, and Arctic cod is tropically important offshore and is important in the lifecycle of several marine mammal species. For the Chukchi Sea, the anadromous species are Arctic char and chum and pink salmon, and the marine species are Arctic and saffron cod because of their ecological importance. Other marine species found in the Chukchi Sea--sand lance, capelin, and herring--were identified as being" ecologically important, but the need for new data was questioned because of the existing database from the Bering Sea.

The following is an outline of topics discussed during working session 14

Tasks

- Examine and synthesize existing data to try to fill in "model" for important species.

  - This will identify data needs.

- If knowledge/data to fill in "model" comes from other areas, then check its application to Beaufort and Chukchi.

- Generalize "model" tits, then test the sensitivity of linkages by:

  - Developing taxonomic distinctions used to define "model" boundaries.
  - Determine distribution of habitats necessary to support "cycle."
  - Determine abundance and distribution of animals in specific habitats.

- Conduct vulnerability analysis:

  could be bioenergetic
  could be taxonomic (e.g., Arctic char)
  might begin developing "model" by grouping first, then splitting as needed

Working Session 15

Facilitator: Ken Critchlow
Scribe: Laurie Jarvela

A lifecycle model (Fig. 143) was used as a structure for hypotheses development and testing.

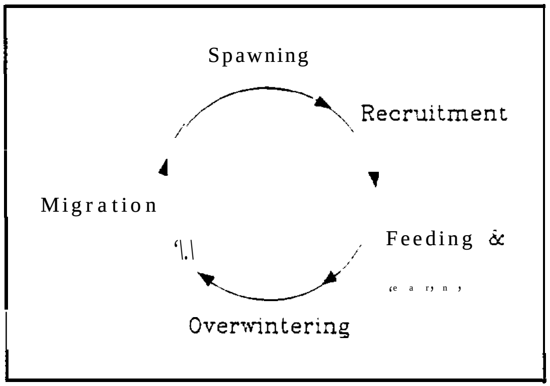


Figure 14.3 Lifecycle Framework for Hypothesis Statement and Testing

The first order questions identified were: "What are the resources at risk? What are the risks to these resources"? A second-order question discussed was the hypothesis that local changes in species or stocks will not adversely impact species or stock populations.

The first-order questions embodied: What occurs when initiating a biological study, i.e., what's there? Where are they? What do they use? Which of these resources are at risk? In addition, two following alternative hypotheses were developed . (Table 14.2).

°If the first hypothesis (species "x" is a single genetic stock throughout its relevant range) is true, the risk is presumably low. This is similar to arguments posed by Dunbar about the risks to arctic species and the concept that they are fragile. His argument, in large part, was drawn from offsh°re elements in which those populations are truly very large and the risks are far lower than they are closer to shore.

Table **14.2 Working Hypotheses**

What Are the Resources at Risk?

Step 1

H^1_o: **Local** changes in species stocks (habitats) will not adversely affect populations.

H^2_o: Local changes in species stocks **will** adversely affect fish species stock populations.

Conclusion: If H^1_o: is true, then risk is LOW.
If H^2_o: is true, then risk is HIGH.

Step 2

H^1_o: Species "x" is a single genetic stock throughout its relevant range.

H^2_o: Species "x" is comprised of discrete genetic stocks within its relevant range.

Define "relevant range."

Conclusion: If H'$_o$: is true, then risk is LOW.
If H^2_o: is true, then risk is HIGH.

Other Risks

Risks to **Populations**	Risks to Habitat
Mediated through access to habitat	Habitat modification
Mediated through energetic	Habitat loss
Habitat value	Habitat character
Habitat use	Likelihood of habitat 1OSS
Energy availability	
Energy conversion	
Fish production	

[0] **If** hypothesis **2** (species "x." is composed of discrete genetic stocks within the relevant range) is true, then the risks are potentially high. These hypotheses **also can** be framed in terms of limited habitats for **field** and laboratory testing.

The **first-order** hypothesis **reads:** "What are the risks to habitat." Habitat risks can be identified as habitat **modification** due to man-induced changes or absolute habitat loss and the determination of the likelihood of change or loss occurring. In parallel, the question of the **fish** having access to habitat, i.e., will a causeway **eliminate** access to a limiting **habitat,** can also be flamed. To address habitat questions, it is important to characterize habitat use and then define what energy levels are available to species, how effective the species are at converting energy to tissue, and how that relates to **fish** production.

Chapter 15

Methodologies

Facilitator Mike Philo
Scribe: Lyman Thorsteinson

Introduction

The Methodologies Workshop consisted of a single working session that was held concurrently with the Interagency Coordination Workshop. The working group was charged with reviewing methodologies commonly used in fisheries research and evaluating their potential use under arctic conditions.

A facilitator led the discussions, and a scribe took notes and helped the facilitator prepare a summary (oral) of the session's progress. A summary was presented by the facilitator at a plenary session immediately following the working session.

Summary

In most cases, there are enough technologies and research tools available to answer arctic fisheries questions, if the questions are properly formulated and the study design carefully planned. Technical fisheries questions tended to fall into general categories, such as those associated with fish locations and those involving coastal use in general, i.e., migrations and daily excursions.

One of the tools that has recently become available for use is the sonic tag. The tag is about the size of a pan cap and can be used in adult fish. Other available technologies include: echo location with appropriate verification to locate fish shoals and estimate biomass, video cameras used in overwintering studies, radar to identify potential overwintering locations, surface drifters to find where the watermasses would carry something that wasn't moving under its own speed, enzyme analyses, directed gillnets, satellite imagery to identify and measure coastal plumes, and laboratory studies to determine the Arctic cisco-larvae swimming speeds and stamina.

Technologies available for use in stock-identification studies include electrophoresis, scale-pattern analysis, morphometrics, and life history information. Because some of these are new, they have been applied to only a few species; additional workup may be required for their use on new species--for example, the application of electrophoresis techniques to species where genetic standards have not yet been developed.

The technical problems of trying to conduct research during early breakup, when the ice is too dangerous to work on and displaces fixed sampling gear, presents an interesting challenge. Sonic tags and use of industrial structures that are already in place, i.e., concrete pads and causeways as sampling or staging areas, may have application during this period. Hovercraft or helicopters using suspended hydrophores, and other equipment are also possible solutions to sampling during early breakup.

New technologies are not needed if appropriate attention is given to asking the questions properly, designing the study to answer those questions, and using the technologies that are available.

It also appears that during hypotheses testing, the problem of type I and type II errors can be reduced if attention is paid to study design, reanalysis of the hypotheses over time, and analysis of the causes of variability.

Highlights from working sessions discussions

Technical Questions:	Available Technologies:
° Fish locations: coastal use in general, migrations, and daily excursions	Sonic tags Hydroacoustics Radio tagging Directed gillnets Satellite imagery
° Overwintering studies	Cameras Radar
° Lab studies	Use of industrial structures
° Early breakup	Suspended platforms studies
° Stock id.	Enzyme analyses Morphometrics Life-history information

No need for new technologies but must pay attention to:

° Hypotheses testing and type I and II errors
- attention to design
- reanalysis of hypotheses over time
- analysis of causes for observed variability

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Chapter 16

Interagency Coordination

Facilitator Cleve Cowles
Scribe: Lauri Jarvela

Introduction

The Interagency Coordination Workshop consisted of a single working session held concurrently with the Methodologies Workshop. The working group was charged with reviewing interagency coordination practices commonly used in fisheries research and evaluating their potential use under arctic conditions.

A facilitator led the discussions, and a scribe took notes and helped the facilitator prepare a summary (oral) of the session's progress. A summary was presented by the facilitator at a plenary session immediately following the working session.

Summary

Dr. Cowles reported that his group proposed an interagency arctic fish steering group as a method of coordinating fisheries research activities in the Arctic. However, the interagency group should have bounds on its goals, and its composition should be manageable and effective. The term "interagency" was used in a general sense and referred to research-funding organizations rather than governmental agencies exclusively. The definition was not intended to exclude the scientist as opposed to the funding organization but the orientation of the coordination group, at a minimum, would focus on funding organizations.

It was suggested that the interagency group meet regularly (schedule based in part on the Arctic field season) to discuss a variety of topics relating to fisheries research in the Arctic. Possible discussion topics included coordinating logistics or achieving compatibility in sampling methods. For example, topics on sampling techniques within a species or at a point in time, or coordination on research permits and how permits may relate to the access and the availability of data.

The interagency steering group also could enhance the movement of field results, i.e., project reports, into the published literature and into planning for future research. Another role of the group would be to serve as a forum for discussing interproject competition and minimizing scientifically counterproductive effects. Perhaps there is a way that a steering group could balance out the interproject competitiveness of scientists to orient toward common goals.

Another suggested discussion topic for the steering group was establishing guidelines for determining what basic information should be collected on every record, i.e. time, date, location, capture method, water temperature, species, sex, length, weight, etc. --whatever the project objectives are for collecting the samples.

The following are summary highlights from the Interagency Coordination Workshop.

Composition/Structuring of the Coordination Committee

° Interagency in the general sense, e.g., all funding organizations
° Held regular meetings, possibly before planning for prime field season, if this is definable
° Focus on existing interproject linkage in the short term to set the stage for developing long-term- planning linkage
° Establish manageable organizational and geographic bounds

Objectives of Longer Term Interagency Coordination

° Logistics/sampling
° Research permits
° Data retention/loss
° InterProject competition versus common good; resolve conflicts
° Project-specific vs. general
° Data standards/disseminate record needs
° Enhance publication of results

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Chapter 17

Cause-and-Effects Linkages

Introduction

Table 17.1 Working Group Facilitators and Discussion Topics

Maki	Life-History Framework for Hypothesis Statement and Testing
Johnson	Bioenergetics--Fitness, Survival
Wilson	Biological Requirements
Reist	Stock Identification
Houghton	Ecological Concerns
Hachmeister	Physical Environment
Robertson	Local Changes Versus Population Impacts

The Cause-and-Effects Linkages Workshop consisted of seven concurrent working groups, each with an assigned discussion topic and a facilitator. Table 17.1 lists the facilitators and working group discussion topics. Each working group was asked to identify, discuss, and order hypotheses that MMS could test through the proposed study project. Following the working sessions, each working group facilitator presented a synthesis of working session discussions.

Life-History Framework for Hypothesis Statement and Testing

Al Maki

A strategy was presented using information developed during previous sessions to develop and use a life-history model as a framework or forum for developing and testing hypotheses. Key pieces of the lifecycle, such as habitat use/dependence, population behavior, and population dynamics, were discussed in terms of identifying limiting factors. For example, is spawning habitat limiting? This hypothesis could lead to a study to determine the availability of spawning habitat in the Colville River for the species that are known to spawn in the system. The study could be coordinated with similar studies being conducted in the Mackenzie River. The lifecycle model also could be used to define the environmental parameters that determine egg hatching, etc.

Recruitment is considered a priority topic. Genetic stock identification is considered the fist task in addressing the Mackenzie River origin of Arctic cisco theory Are there distinct Arctic cisco stocks? Are they intermixed; and what kind of a stock identification criteria would be identified? Questions concerning physical oceanography also are considered part of the question, i.e., is a transport mechanism really important in the recruitment of this species into the Colville River? Oceanographic observations such as those made using satellite imagery were suggested as a way to test the hypothesis, i.e., satellite imagery was used in a similar oceanographic study during the “East Coast Warm Core Ring Program," to track specific pockets of Atlantic along the east coast of the United States.

Tagging also can be used to study recruitment. Is tagging an appropriate technology? Would an enhancement of ongoing mark-and-release efforts improve the recapture program? What are the young-of-the-year swimming capabilities? what relative proportion of the population is migrating? Do Arctic cisco return to the Mackenzie River? If so, how fast and at what rates? Where do some of the other coregonid species migrate to spawn?

Questions concerning feeding and rearing habitats included temperature, salinity, and prey selection. Other examples include: anadromous-fish will or will not exhibit statistically significant mortality when they are exposed to the full gambit of temperature and salinity ranges in the Beaufort Sea coastal waters, and growth will or will not be affected by primary prey distributions in the nearshore feeding habitat. Where do marine species go for spawning activities?

In summary, the lifecycle model provides a framework for identifying potential hypotheses and for relating the hypotheses to the fundamental biological information needs relative to a species.

Bioenergetics

Craig Johnson

Bioenergetics - as it relates to fitness is a common thread running through behavioral strategies, habitat relationships, and population dynamics (dispersal, production, survivorship, etc.) and maybe a single unifying theory for arctic ecology, biology, etc.

This is based on the theory that the ability of an animal to assimilate sufficient energy during the open-water season determines the continuous success of the population. Population dynamics included dispersal; production in the sense of survival of the young-of-the-year, just after they emerge from the egg stage, perhaps being tied to the availability of food immediately within the system, the productivity of the number of eggs being tied to the specific fitness of the females; survivorship; availability of overwintering habitats; and general fitness of the animals, i.e., if they don't have sufficient energy reserves to survive the overwintering period, they fall out of the population.

Biological Requirements

Bill Wilson

The observation that fish are always moving may be a way to conceptualize how the system functions and how a research program maybe ordered; fish must be moving for feeding; they move to reproductive areas. This also can be viewed as the dynamics of a species' spatial/temporal distribution, and it relates to human use *or* human development, human-related impacts, and how the fish might be affected.

The second hypothesis is that there will be no effect from oil and gas development on the maximum sustained yield of arctic fish populations. The types of information needed to test this hypothesis include: information on different stocks, what stocks of fish are there in the Arctic, what are the dynamics of those stocks, what is the annual production of each stock, how and where are they reproducing and what are the quantitative relationships needed to understand stock dynamics?

Another hypothesis is that warm, brackish water is required by anadromous fish during summer for reproductive maturation. Based on this hypothesis, reproduction may be a limiting factor in arctic fish populations. Growth is very rapid until fishes in the Arctic reach a mature size, and then growth decreases significantly. The observation was made that a great deal of effort, particularly for repeat spawners, is directed toward elaborating body tissue and building up reproductive products in these fish. To accomplish this, there must be sufficient food at the right temperatures, and the fish must have access to this foraging habitat.

Many of the hypotheses lend themselves to laboratory testing, i.e., determining growth rates for certain species with different food rations under different temperature requiems, possibly under different salinity/temperature combinations, etc.

Water must be available there must be space or fish will not survive. Therefore, overwintering habitat, particularly where freezing concentrates available habitat down to a small percentage of the available summer habitat is considered another principal limiting factor.

Hypotheses discussed by this working group included

H^1: Fish are always moving
- feeding, reproduction
- spatial/temporal aspects
- human use/impacts

H*: There will be no effect from oil and gas development on the maximum sustained yield of arctic fish populations
- stock id.
- stock dynamics--production, reproduction
- habitat

H^3: Warm, brackish water is required by anadromous fish during summer for reproductive maturation
- reproduction is where it's at
- fish grow rapidly to mature size
- between spawnings, fish activity is directed toward gamete maturation
- fish must find warm water to feed and elaborate body tissue and mature gametes
- fish must have sufficient food, "right" temperatures, access (migration), etc.
- space/water must be available; overwintering is a key to the production of arctic anadromous fish stocks

Subhypothesis:

- Cooler, food-rich water provides improved conditions for fish growth and reproductive maturation
- Laboratory testing is required

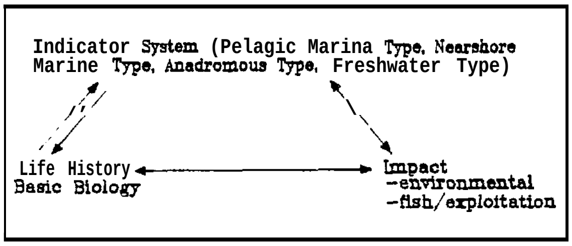
Stock Identification

Jim Reist

Impacts, including environmental changes and fishing exploitation, interact with genetic structuring. How and to what degree they affect the populations needs to be determined.

There are two genetics-related null hypotheses. Hypothesis I is that species "x" is a single genetic stock throughout the relevant parts of its range and that relevancy is defined by the study objectives, the study location, the scope of the study, etc., and decreases from world to regional to local concerns.

Hypothesis II is that species "x" is not genetically structured with respect to major parameters of its environment. The null hypothesis I was reformulated such that the answer to the second hypothesis, or the findings for it, can be used as an analogous argument to extend our information in a manageable fashion from a well-studied situation and indicator system to situations that are not so well known (Fig. 17.1). By



17.1 Assessment Model Using an Indicator System

cuing on major pasameters--environmental parameters that *seem* to be causing, or allowing for, the genetic structuring, such as habitat type, perhaps river systems, spawning locations, etc.--an understanding of the system is developed. These things, however, depend on the species being studied. As a basic premise, the study should focus on a major tish species in each of the primary habitats (for example, an open pelagic marine species such as Arctic cod, a nearshore marine species such as fourhorn sculpin, an anadromous species such as broad whitefish within the Colville River, or Arctic cisco in the Colville and Mackenzie Rivers, etc., and probably a freshwater type such as grayling). Genetic studies should be started with known spawning stocks because that's the time most likely to measure genetic structuring if it exists.

Whether null-hypothesis I is really the first and null-hypothesis II the second, or vice versa, may be debated. To understand the system on a local basis, the logical approach is to start with the. hypothesis of larger scope because that is where the diversity is most likely to exist. Then, address the hypothesis of smaller scope; in other words, address hypothesis I and then hypothesis II. If a difference is observed, this approach will improve confidence in the results.

A hypothesis cannot be proven; a null hypotheses can only be rejected. Therefore, it is only possible to conclude that two populations of fish are definitely different but not that they are identical, because 100 characters can be measured without noting a difference but character 101 may, in fact, be the critical character.

A basic understanding of a species stock structure does not negate the need to gather additional data on a site-specific basis. Site-specific studies can be focused on a specific issue and limited in geographic scope using the database previously established. For example, regional studies on Arctic cod suggest that there is no apparent genetic structuring, but the hypothesis can't be accepted absolutely. However, the results imply that Arctic cod is one panmictic population throughout the Beaufort Sea. Therefore, a site-specific development project that may impinge on a portion of that population is relatively insignificant to the Attic cod population.

Genetic studies are interconnected with life history and basic biology studies, and these can be conducted concomitantly with the genetic studies. An integrated sample-processing protocol can provide for the collection of genetics data, life-history data, basic fisheries kinds of data, and the recent history of the fish itself. Using available technologies, it is now possible to collect information on the previous 6 months to a year and perhaps even the entire life history of a sample through stable isotope studies.

Likewise, during aging (annulus) studies using otolith and/or bones, available technologies can be used to determine environmental conditions when the fish put on each annulus. In addition, other things, like hydrocarbon and heavy metal loads, etc., can be determined using the same tissues collected for electrophoretic work. Procedures other than electrophoretic analysis also can be used for determining genetic-stock structure. These include morphological data, growth rates, and fisheries kind of data.

Once the hypothesis that a population is not genetically homogeneous (in other words, it is apparent that there is genetic structure) has been rejected, a series of subsidiary hypotheses can be tested. These may include Is genetic structuring maintained throughout the life history; in other words, do the genetic stocks do things as units throughout all of their life history? Is the genetic structuring observed maintained throughout time, that is, from one year to the next? If the hypotheses is rejected, then the issue becomes much more complex because it is then necessary to know how the structuring is maintained each year in order to be able to predict potential development impacts. Fortunately, the available evidence *indicates* that genetic structuring is maintained with time. However, this hypothesis must be tested for each of the indicator species for a 3- to 5-year period.
The newer, more technical procedures may require some preparatory work. For example, the long

history of enzyme studies on anadromous and freshwater fishes provides an extensive database. Fewer enzyme studies have been conducted on marine fish; therefore, the database is limited. An example of the problems encountered during enzyme studies is the difficulties encountered when doing electrophoretic gels on Arctic cod--Arctic cod is an oily fish, and the oil confuses electrophoretic patterns for enzymes. This is not considered an insurmountable problem, but it takes time to develop a method for processing the tissues to eliminate the oil so that nice, clean gels can be produced.

In addition to technical problems with enzyme electrophoresis, theoretical models of the genetic variation are needed to determine whether the observed bands are real or artificially caused by sample processing.

The following is an outline of workshop discussions

H^1_o: Species "x" is a single genetic stock throughout its relevant range (world, regional, local).

H^2_o: Species "x" is not genetically structured with respect to major parameters of its environment (e.g., habitat type, river system, spawning location). (Indicator system = open (pelagic) marine type, nearshore marine type, anadromous type, freshwater type.)

H^3_o: Genetic structuring is maintained throughout life history (unit stocks vs. mixed stocks).

H^4_o: Genetic structuring is maintained throughout time (annual).

Subsidiary Questions/Thoughts

- Species = just fish - fish prey
  - fish predators also

- Genetic studies go hand in hand with other biological studies. The same specimen can be processed appropriately to yield genetics data, life-history data including recent history (stable isotopes)..., hydrocarbon loads, heavy metals . . . .

- Genetic studies start with spawning fish, since this is when they are most likely "structured."

- Some preparatory work is necessary, e.g., which types of data are best, ensuring that we can believe the results etc., physical details of methodology.

Ecological Concerns

Jon Houghton

Working hypotheses that frost, fish are more vulnerable to impacts of OCS oil and gas activities in nearshore rather than offshore waters and, second, that the nature of the nearshore fish communities' vulnerability differed significantly between the Chukchi and Beaufort Seas. These two hypotheses may be tested using existing knowledge as has been done in some of the existing environmental impact statements (EIS's).

Basic studies of biogeography, populations, *stocks*, distribution of fish, and life history of fish are the primary areas of future studies. However, information also is needed on ichthyoplankton and, to perhaps a lesser degree, a knowledge of benthic communities where they are an important prey base for fish. Second-order information needs include environmental tolerances, bioenergetics, and habitat delineation. What do the fish need to live, what can they tolerate, and what are the environmental parameters (oceanographic conditions)?

The following are highlights from the preceding discussion:

- Emphasize basics
- Geographic dichotomy

H^o: Fish are more vulnerable to impacts of OCS oil and gas activities in the nearshore (vs. offshore).

H^o: Nature of fish communities vulnerable in the nearshore Chukchi Sea differs fundamentally from that in the Beaufort Sea.

These hypotheses can be tested using existing knowledge (as done in MMS EIS's).

Information needs:

Level 1: Biogeography
Populations, stock distributions, life histories
Ichthyoplankton
Benthos
Oceanographic information to understand environment, dynamics, and transport

Level 2: Tolerances
Bioenergetics
Habitats

Level 3 Limiting factors

Physical Environment

Lon Hachmeister

A first-order hypothesis is that large-scale regional processes govern the small-scale or more localized oceanographic processes and distributions of properties that can be altered by oil and gas development activities. On a regional basis, the meteorology, the river input, and the large-scale meteorological and oceanographic processes govern smaller scale processes and, in effect, the smaller scale environment that can be locally affected by oil and gas development activities.

A second-order hypothesis is that *small-scale,* localized perturbations to the oceanographic processes do not alter the large-scale processes or property distributions.

These two hypotheses can be tested using available "formation.

The following are highlights from working session discussions.

H[1]: Large-scale (i.e., regional) physical processes govern the small-scale (i.e., local) oceanographic processes and property distributions that can be altered by oil and gas development activities.

° Regional meteorological, oceanographic, and river-discharge characteristics control local water characteristics

° Regional interannual variability determines localized degree of impact of oil and gas development

* 2: Small-scale (i.e., localized) perturbations to oceanographic processes do not alter large-scale processes or property distributions

° Local perturbations by oil and gas development will not affect regional distributions of properties

° Need exists to define what a localized perturbation may be

Local Changes vs. Population Impacts

Scott Robertson

The various hypotheses presented above appear to be subsets of one overriding, basic hypothesis; and the tools are available to test the null hypothesis

HO: Local changes in fish distribution will not detrimentally impact the populations of those species.

There are important nuances to this general statement that require precise definition before the question of whether this hypothesis should be rejected. A starting point is defining the geographic limits of the population, i.e., the Beaufort and Chukchi Seas, or a specific spawning area? The degree of local changes maybe obvious, depending on the population. For example, a coastal causeway is unlikely to affect Arctic cod in the Beaufort Sea, whereas stream diversion may be devastating to a stock of char denied access to their specific overwintering area.

Changes observed at the local level may generate concerns that are very species-specific. These concerns can have a variety of attributes: What is the location of the change? What is the areal extent of the change? What is the magnitude of the change? How much variability exists within these attributes? What is the timing of the change in relation with the lifecycle and seasonal cycle of the species of concern? These local changes may involve one or more of the attributes and hypotheses presented in the previous summaries of the working sessions:

Maki	Spawning habitat--limits, access Recruitment-stock id., transport, tagging Overwintering habitat--limits
Johnson	Bioenergetics-- fitness, survival
Wilson	Movement--feedmg, reproduction Maximum sustainable yield--stock id., dynamics Summer habitat--growth, reproduction
Reist	Stock i.d.--genetic structuring, habitat
Houghton	Vulnerability--location, nature
Hachmeister	Physical processes--scale

These are the tools that provide the pathway in determining if *there is* a link between local changes and population effects.

In evaluating the utility of pursuing these questions, it is important that the sublevel hypotheses do not become ends unto themselves. They are the means to the end; and unless a study clearly fits into a coordinated plan designed to address the general null hypothesis given above, it should be discarded.

It was suggested that MMS should be concerned about the population aspects of change. Local changes are essentially invisible to the population *(even if* visible to some individuals in the population) if there is no change in the ability of the population to reproduce itself. Historically, the focus of industry-funded studies has been on investigations of local changes caused by specific projects. This difference in approach is reflected in the impact of our ability to analyze biological and physical processes along the central Beaufort Sea coast with regard to causeways. Millions of dollars have been spent measuring the local changes, but information is not available to determine what local changes mean in a regional context. The proposed MMS studies can provide the context of a regional perspective that will allow determination of the significance of the local changes that are observed.

In some cases, it may not be necessary to address the larger population question. This can occur when the local changes are *small* enough that all parties, industry and regulatory agencies, can agree that the changes are insignificant. It appears that when there is lack of agreement between the parties regarding the impact of changes, it is usually because there is insufficient background data to. put the local change into context. It is hoped that the fish studies being planned by MMS will provide that background.

"Are we nearly there?" Alice managed to pant at last. "Nearly there!" the Queen repeated. "Why, we passed it ten minutes ago!"

Chapter 18

WORKSHOP SUMMARY

Chuck Mitchell
MBC Applied Environmental Sciences
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At the start of this workshop, it was stated that over the last 10 years or so, $40 million had been spent examining the arctic fisheries; and the result of that expenditure was a marginal database for anadromous fishes and practically no information on marine species. This was the general consensus at the start of this meeting, but as we have worked together over the last few days and picked one another's brains, a different picture has emerged. To reiterate what was stated earlier, "we suddenly found that perhaps we know a little more than we thought we did." Collectively, as we picked one another's brains, patterns of knowledge began to appear. It's only with the help of all of you that we began to really see the big picture, and that was the goal of this workshop.

Your participation in this workshop was by invitation only, you were hand selected. That was because you folks hold the core knowledge. Maybe it's still in bits and pieces, but you're the ones that have the firsthand experience and are most familiar with the fishes and the rather unique environment of the Arctic.

If we go back just for a second and look at the objectives that MMS has given us, let me read the very first one because it addresses the essence of this meeting 'The results of these studies [that MMS is proposing] are to be used to refine the agency's ability to predict and evaluate potential environmental effects caused by offshore oil and gas exploration and development activities." That's the tool, the database, that MMS is looking for. We are providing the yardstick by which these things can be measured. Granted, we don't have ail the answers--we don't have all the information--and, in some cases, perhaps the yardstick doesn't have any units on it; but we are working at that.

Basically, what I've heard over the last few days was best summarized by Ken Critchlow. We have two problems: 1) we have to determine what resources are at risk and 2) we have to determine what the risks are to those resources.

Those are the two major elements that we have to deal with. If we first examine what resources are at risk, we have made significant progress at this meeting by defining those resources. When we came into this meeting 3 days ago, a consensus about what resources were present in the Arctic seemed very removed. We were hearing stories like "We don't even know where arctic cod go"; "We don't *even know if* they are there, but sometimes they are over here"; and "I've seen them over here, but we don't know what happens in between." This still may be the case, but we have made progress in defining what resources are "present and have identified some of the data needs.

On a regional basis, we have two main resource groups that appear to be separated on the basis of the basin configurations and terrestrial topography. If we look at the Beaufort Sea, we come up with a resource list that contains Arctic char, Arctic cisco, broad whitefish, Arctic cod, least cisco, and fourhorn sculpin. In the Chukchi Sea, we have identified Arctic char, pink and chum salmon, Arctic and saffron cod, sand lance, capelin, and herring as the major resources.

In the case of the last three species, we do have some biological information from other more-temperate areas. For the other species, we have bits and pieces of information, and we need to fill in the missing data. What do we need to know about them? The answer is "a lot," and the opinions as to specific needs have ranged from basic biology to lifestage-specific information on physiological tolerances and preferences.

We need something to determine the population size and distribution of these species. We need to know something about the characteristics of each population. What does the age structure look like? How long have they been there? We need to know something about the reproductive status and requirements. What is their fecundity rate? Do they have any special habitat requirements?

We need to really enlarge the window of our knowledge. We have been looking at these fishes in little tiny snapshots during the ice-free season, when it is easiest for the investigators to get there. We are looking at databases that are generally only 3 or 4 months long at best. The rest of the year is a complete blank--we don't know very much about what they do during the winter months when everything is covered with ice. Granted, it's a tough time of the year to work, but there are some big data gaps there, and they have to be filled before we can reasonably assess what resources are at risk.

Now, the other part of the question. What is the risk to the resources?

If we look at all of these resources, these fishes, they all have a degree of vulnerability; they all have different life requirements, at different stages in their lives, and we all know that the life histories of these animals is extremely complex, probably some of the most complex life histories of any of the fishes in the world. We're talking about fishes going from upstream into the ocean, coming back, and vice versa. Incredibly complex. At each stage of their life history, their life requirements are different and their vulnerabilities are different, so it behooves us to look at the whole life cycle of each one of these species to determine what their risks are and where they are vulnerable at each one of these lifestages. Otherwise, we are just doing the same "cookbook" biology we did in the past. Recognizably, these are hard data to gather, but they are needed to make these final determinations of the risk to the resource. This element requires a lot more fieldwork. It requires laboratory work. It may be approached from an energetic standpoint or from a strictly ecological standpoint. There's a variety of ways we can approach the answers to the questions of risk to the resource. This is personal bias, but I still think the energetic approach is probably the one that answers most of the questions. Whether it be habitat, food habits, or activity pattern, it is probably related to, or the result of, some kind of energy requirement that is working in the most energy-efficient manner.

As far as sampling methodologies are concerned, it appears that we have the necessary methodologies available. We are not going to have to invent new methods. The equipment and materials are there, and all we have to do is get the money to use them since many are very expensive. But we need to utilize these methodologies if we are going to expand that window of our knowledge. It's going to take some imaginative use. It's going to take some real critical thought about how these studies are designed. It's going to take coordination between everybody involved, I think, in terms of what kind of information we are going to be collecting. We have seen over the last 3 days where people have collected bits and pieces of information in relationship to other studies that were ongoing. Maybe someone was doing a tagging study, for instance, but they were collecting information on salinity and temperature. We need to pull all that data together. We need to know what everybody is sampling, whether it be a standardized datasheet with a list of the parameters that are available, if somebody is collecting salmon, if somebody is collecting Attic cod for some kind of meristic study or something like that. Why can't we have them pulling the gonads out for somebody that may be doing histological studies someplace else? It's so expensive to work in this environment that I think it is absolutely imperative that we share that database, and we can spread that cost for accumulating some of this basic biological knowledge over a wide base.

To facilitate interagency coordination% we need a group to oversee these diverse research efforts. We are talking about fielding maybe 100 to 150 people during the course of this study over maybe 10 or 20 different kinds of programs, and unless we get our act together and keep track of what we are all doing and how that affects the objectives at the end, we're all going to end up dispersing our efforts and going off into little blind ends; and we'll end up with a whole series of the little tiny site-specific kinds of studies and information sources that we have had in the past, with no coordination and collective results. This is something that we can't afford. Whoever serves on that committee, I think it's going to be a tough job. It's going to be a really tough job. I know that there's going to be a lot of agencies involved, and each one has their own thing going, but we need them to really all pull together if we are going to pull this thing off.

I'd like to take this opportunity to thank you all on behalf of MMS and MBC.

It's been a pleasure working with all of you.

Thank you.

APPENDICES

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APPENDIX A

Workshop Objectives

Results of studies supported by the Minerals Management Service (MMS) are used to refine the agency's ability to predict and evaluate potential environmental effects caused by offshore oil and gas exploration and development activities. A multiyear arctic fisheries study is being developed to improve environmental assessments in the area of fisheries oceanography.

Specific objectives of the workshop are to

1. Synthesize and critically evaluate pertinent information on fisheries resources in the Arctic;

2. Identify and discuss relevant ecological information needed to evaluate and predict the potential effects of oil and gas activities (i.e., limiting factors controlling fish population growth and potential habitat alteration) on arctic fisheries resources;

3. Identify, discuss, and recommend study objectives, study design, data-collection methodologies, and analytical procedures pursuant to objective 2 above;

4. Identify other ongoing and planned fisheries-related studies in the Arctic and explore methods for coordinating logistics, sampling, and analytical activities associated with these studies to eliminate duplication, and

5. Enhance communication among concerned scientists and managers through open discussion and publication of findings.

APPENDIX B

Guidelines for Working Sessions

There will be three concurrent working sessions on each of the six discussion topics identified in the agenda. Each working session will *consist* of about 15 participants, including a Facilitator, a Note Taker, and a Meeting Coordinator. Note that participation in these working sessions has been assigned in advance, in order to balance representation. For easy identification% sessions are numbered consecutively from 1 to **18.** Please attend your assigned working session. If you have any problem with your assignment, will not be present for a particular session, or cannot fulfill your responsibility as a Facilitator, please see one of the Meeting Coordinators immediately. Meeting Coordinators are:

Gail **Irvine** - MMS
Toni Johnson - MMS
Robert Meyer - MMS
Kathy Mitchell - MBC

As a participant in the working sessions, you are asked to keep the following guidelines in mind:

1. Be objective. Although we each have our own special interests, due to the organizations we represent and our particular expertise, please try to focus your input as much as possible on the stated workshop objectives (see pink sheet).

2. Be prepared. An Interagency Coordinating Committee has spent a great deal of time assisting MMS staff in preparation for this workshop. Please take the time to read the material in your information kit as soon as possible. The kit includes
   - Guidelines for working sessions
   - Working session assignments (yellow sheets)
   - Workshop objectives (pink sheet)
   - Workshop topics
   - Information for consideration (environmental concerns)
   - Speaker abstracts
   - Agenda (green sheets)
   - List of participants

3. Participate. Participants have been invited because of their expertise and interest in arctic fish research and planning. The working sessions will be most useful if we each contribute our knowledge and perspective to the discussions.

4. Record key information. Although each working session has an assigned Note Taker, this is a big job. If you hear a key point that you feel should be brought forward to meet workshop objectives, be sure to jot it down and turn it into the session Facilitator or Note Taker. They will need assistance in preparing verbal and written summaries for the plenary sessions and workshop report. Your support will be welcome.

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APPENDIX C

Information for Consideration

Fisheries-related environmental concerns have been identified through the National Environmental Policy Act (NEPA) process by MMS and the U.S. Army corps of Engineers while preparing Environmental Impact Statements (EIS's) for arctic projects. These concerns will provide a context to help guide workshop discussions.

A. Chukchi and Beaufort Sea Ecosystems (current level of knowledge)

1. Populations and Distribution

   a. historical abundance
   b. relative year-class strength
   c. recruitment and mortality

2. Habitat Requirements (define and quantify)

   a. summer-feeding habitat
   b. overwintering habitat
   c. spawning-habitat access

3. Limiting Factors Controlling Fish Populations

B. Potential Effects on Chukchi and Beaufort Sea Ecosystems

1. Habitat Modification (including loss)

   a. gravel deposition and extraction
   b. restricting access to habitat for
      1) feeding
      2) overwintering
      3) spawning
   c. temperature and salinity distribution
   d. prey density
   e. potential for increased stress
   f. potential for decreased recruitment

2. Effects on Subsistence Harvests

3. Cumulative Effects

C. Potential Effect-Causing Agents or Activities

1. oil spills

2. Construction Activities

   a. dredging
   b. causeways
   c. gravel islands

3. Drilling-Mud Discharge

APPENDIX D

Workshop Agenda

Arctic Fish Workshop
Fisheries Oceanography A Comprehensive Formulation of Technical
Objectives for Offshore Application in the Arctic

Kuskokwim Room[1]
Sheraton Anchorage Hotel
April 5-7, 1988

<u>April *5.1988*</u>

800 a.m.	Registration--Kuskokwim Room $35.00/person by advance reservation only
8:30	Opening remarks, Robert Meyer--MMS Statement of workshop objectives, Jerry Imm--MMS
9:00	Overview and descriptive biogeography of anadromous and marine arctic fishes. Keynote speaker Craig Johnson, NMFS
9:30	Question-and-Answer Period
9:45	Summary of Canadian fisheries research in the western Arctic. Keynote speakers: Glen Hopky and Jim Reist, Canada Department of Fisheries & Oceans
10:30	Question-and-Answer Period
10:45	Break
11:00	Biogeography working sessions 1, 2, and 3
12:30	LUNCH BREAK--Yukon Room
1:45 p.m.	Plenary Session--Kuskokwim Room
2:30	Nearshore oceanographic conditions in the Arctic that may affect fishes. Keynote speaker: Jack Colonell, ESE
300	Questiori-and-Answer Period
3:15	Break
3:30	Nearshore Oceanography Working Sessions 4, 5, and 6
5:00	REFRESHMENT BREAK
6:00	Plenary Session--Kuskokwim Room
6:30-8:00	Working Sessions, continued

[1] All plenary sessions and presentations will be in the Kuskokwim Room on the mezzanine level. Meals will be seined in the Yukon Room, next door. Working sessions will use the Kuskokwim Room and third-floor conference room 305. Room 301 will be available for typing handouts, previewing slides, and for further discussions.

April 6.1988

8:30 a.m.	Opening Remarks--Kuskokwim Room Statement of day 2 objectives
845	Plenary Session, MMS
9:15	Consideration of the social and ecological importance of fish species. Keynote speaker: Larry Moulton, ESE
9:45	Question-and-Answer Period
10:00	Factors limiting arctic fish population growth. Keynote speaker: Benny Gallaway, LGL, Inc.
10:30	Question-and-Answer Period
10:45	Break
11:00	Species and Limiting Factors Working Sessions 7, 8, 9
1230	LUNCH BREAK--Yukon Room
1:45 p.m.	Plenary Session--Kuskokwirn Room
230	Integration of oceanographic information with fisheries data, combined with discussion of the sensitivity and vulnerability of various species. Keynote Speakers: Al Maki, Exxon; and Jon Houghton, Dames and Moore
3:00	Question-and-Answer Period
3:15	Break
3:30	Habitat Relationships Working Sessions 10, 11, 1.2
5:00	DINNER BREAK--on your own
630-800	Working Sessions, continued

April 7.1988

8:30 a.m.	Opening remarks--Kuskokwim Room, MMS Statement of day 3 objectives
8:45	Plenary session, MMS
915	Panel discussion directed to defining linkages between the potential causes and effects of offshore OCS development-related activities on arctic fish.
10:15	Break
10:30	Cause-and-Effects Linkages Working Sessions 13, 14, 15
12:00	LUNCH BREAK--Yukon Room
1:15 pm	Plenary Session--Kuskokwim Room
200	Methodologies and Interagency Coordination Working Sessions 16, 17, 18
3:30	Break
3:45	Plenary Session--Kuskokwim Room
415	Summary of information needs (study objectives and study methods suggested for inclusion in the proposed MMS arctic fisheries study program)
5:00	End Workshop

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Appendix E

Fishes of the Alaskan Arctic

Species are arranged according to principal life-history patterns; x indicates presence, xx indicates species is widespread and abundant (where data are available).

		Occurrence	
		Brackish Nearshore	Marine Offshore
Anadromous			
Lampreys			
Lampetra Japonica	Arctic lamprey	x	
Salmonids			
Coregonus autumnalis	Arctic cisco	xx	
Coregonus sardinella	least cisco	xx	
Coregonus laurettae	Bering cisco	x	
Coregonus clupeaformis	lake (humpback) whitefish	xx	
Coregonus nasus	broad whitefish	xx	
Oncorhynchus gorbuscha	pink salmon	x	
Oncorhynchus keta	churn salmon	x	
Oncorhynchus tshawytscha	chinook salmon		x
Oncorhynchus nerka	sockeye salmon		x
Oncorhynchus kisutch	coho salmon	x	
Salvelinus alpinus	Arctic char	xx	
Stenodus leucichthys	inconnu		x
Smelts			
Osmerus mordox	boreal (rainbow) smelt		xx
Sticklebacks			
Pungitius	ninespine sticklebacks	x	
Gasterosteus aculeatus	threespine sticklebacks	x	
Freshwater			
Salmonids			
Prosopiurn cylindraceum	round whitefish	x	
Thymallus arcticus	grayling	x	
cods			
Lota	burbot	x	
Marine			
Herring			
Clupea harengus pallasi	Pacific herring	x	
Smelts			
Mallotus villosus	capelin	x	x
Lanternfishes			
Benthosema glaciale	glacial lanternfish	x	
cods			
Arctogadus glacialis	polar cod		x
Arctogadus borisovi	Siberian cod		x
Boreogadus saida	Arctic cod	xx	xx
Eleginus gracilis	saffron cod	xx	x
Gadus morhua ogac	ogac	x	

		Occurrence	
		Brackish Nearshore	Marine Offshore
	Anadromous		
Sculpins			
Artediellus scaber	rough hookear sculpin	x	x
Artediellus uncinatus	smooth hookear sculpin	x	
Gymnocanthus tricuspis	Arctic staghorn sculpin	x	x
Icelus bicornis	twohorn sculpin	x	
Icelus spatula	spatulate sculpin		x
Myoxocephalus quadricornis	fourhom sculpin	xx	
Myoxocephalus scorpius	sea scorpion		x
Myoxocephalus scorpioides	Arctic sculpin	x	
Triglops pingeli	ribbed sculpin		x
Algonus acipenserinus	sturgeon seapoacher		x
Alligator Fishes			
Asidophoroides olriki	Arctic alligatorfish	x	
Lumpfishes and Snailfishes			
Eumicrotremus derjugini	leatherfin lumpsucker		x
Liparis tunicatus	kelp snailfish	x	x
Liparis fabricii	gelatinous snailfish	x	x
Liparis gibbus	dusky snailfish	x	
Sand Lance			
Ammodytes hexapterus	Pacific sand lance	x	
Pricklebacks			
Eumesogrammus praeciscus	fourline snakeblenny		
Lumpenus fabricii	splender eelblenny	x	
Lumpenus macultus	shanny	x	
Lumpenus medius	stout eelblenny		
Eelpouts			
Gymnelis viridis	fish doctor		
Lycodes mucosus	saddled eelpout		
Lycodes palaris	Canadian eelpout	x	
Lycodes turneri	polar eelpout		
Lycodes rossi	threespot eelpout	x	
Lycodes endipleurostictus	doubleline eelpout		
Lycodes squamiventer	scalebelly eelpout		
Lycodes jugoricus	shulupoaluk		
Lycodes Sagittarius	archer eelpout		
Lycodes seminudus	longear eelpout		
Lycodes raridens	eelpout		
Lycodes pallidus	pale eelpout	x	
Flatfishes			
Liopsetta glacialis	Arctic flounder	xx	
Platichthys stellatus	starry flounder		
Limanda aspera	yellowfin sole		

Sources: From the Sale 97 EIS--Walters, 1955; McAllister, 1962; Griffiths et al., 1975, 1977, 1982; Carey, 1977; Able and McAllister, 1980; *Craig* and Haldorson, 1981; McAllister et al., 1981; Dunton et al., 1982; Griffiths and Gallaway, 1982; Frost and Lowry, 1983; Schmidt et al., 1983; Griffiths et al., 1977; Bendock, 1979; and Griffiths et al., 1983.

APPENDIX F

Selected Reference Material

Arctic Fish Workshop

Synthesis and Related Reports Supported by the Minerals Management Service

Barnes, P.W., D.M. Schell, and E. Reimnitz, eds. 1984. The Alaskan Beaufort Sea Ecosystems and Environments. Orlando, FL: Academic Press, 466 pp.

Becker, P.R., ed. 1987. Outer Continental Shelf Environmental Assessment Program. Proceedings of a Synthesis Meeting The Diaper Field Environment and Possible Consequences of Planned Offshore Oil and Gas Development, 25-28 January 1983. Chena Hot Springs, AK. Anchorage, AK: USDOC, NOAA, and USDOI, MMS. OCS Study, MMS 85-0082, May 1987,285 pp.

Becker, P.R., ed. 1988. Outer Continental Shelf Environmental Assessment Program. Beaufort Sea Information Update. Based on the Beaufort Sea (Sale 97) Information Update Meeting, March 6-7, 1985. Anchorage, AK Anchorage, AK: USDOC, NOAA, and USDOI, MMS. OCS Study, MMS 86-0047, April 1988,81 pp.

Hale, D.R., ed. 1987. Outer Continental Shelf Environmental Assessment Program. Chukchi Sea Information Update. Based on the Chukchi Sea (Sale 109) Information Update Meeting, March 27, 1986, Anchorage, AK. Anchorage, AK: USDOC, NOAA, and USDOI, MMS. OCS Study, MMS 86-0097, June 1987, 106 pp.

Norton, D.W. and W.M. Sackinger, eds. 1981. Outer Continental Shelf Environmental Assessment Program Beaufort Sea (Sale 71) Synthesis Report Proceedings of a Synthesis Meeting Chena Hot Springs, AK, April 21-23, 1981. Juneau, AK: USDOC, NOAA, and USDOI, BLM, December 1981, 178 pp. plus appendices.

Schell, D.M., ed. 1980. Beaufort Sea Winter Watch: Ecological Processes in the Nearshore Environment and Sediment-Laden Sea Ice: Concepts, Problems and Approaches. Arctic Project Bulletin, Special Bulletin #129, May 1, 1980, for USDOC, NOAA, OCSEAP, by Arctic Project Office, Geophysical Institute, University of Alaska, Fairbanks, AK. 74 pp.

Truett, J.C., ed. 1984. Outer Continental Shelf Environmental Assessment Program. Proceedings of a Synthesis Meeting The Barrow Arch Environment and Possible Consequences of Planned Offshore Oil and Gas Development Girdwood, AK, October 30-November 1,1983. Anchorage, AK: USDOC, NOAA, and USDOI, MMS, August 1984,229 pp.

USDOI MMS, 1988. Arctic Information Transfer Meeting: Conference Proceedings. Anchorage, AK: USDOI MMS OCS Study MMS 88-0040

Weller, G., D. Norton, and T. Johnson, eds. 1978. Environmental Assessment of the Alaska Continental Shelf: Interim Synthesis: Beaufort/Chukchi. Boulder, CO: USDOC, NOAA, and USDOI, BLM, August 1978, 362 pp.

Weller, G., D. Norton, and T. Johnson, eds. 1977. Beaufort Sea Synthesis Report Environmental Impacts of OCS Development in Northern Alaska Proceedings of a "Synthesis Meeting" of OCSEAP and other investigators working in Northern Alaska, Barrow, AK, February 7-11, 1977. Arctic Project Bulletin, Special Bulletin #15, June 1, 1977, for USDOC, NOAA, OCSEAP by Arctic Project Office, Geophysical Institute, University of Alaska, Fairbanks, @ 219 pp.

APPENDIX G

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APPENDIX H

List of Participants

Arctic Fish Workshop
April 5-7, 1988

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F = Facilitator
M = Meeting Coordinators .
N = Note Taker
s = Speaker

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources. protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interest of all our people. The Department also has a major, responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.