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**A OCEAN CARRYING CAPACITY (OCC) STRATEGIC PLAN FOR
EASTERN BERING SEA (BRISTOL BAY) COASTAL RESEARCH ON
BRISTOL BAY SALMON**

by the

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Introduction

In 1997 and 1998, lower than expected returns of sockeye salmon to Bristol Bay prompted the State of Alaska and the U. S. Department of Commerce to declare the Bristol Bay region an economic disaster area. The cause of the disastrous returns of sockeye salmon to Bristol Bay is not fully understood, but may be related to changes in the marine environment. Fishery scientists generally agree that conditions in the ocean, particularly in the first few months after leaving freshwater, strongly influence interannual variability in salmon survival and growth (Parker 1962; Pearcy 1992). The assumption is that growth rates of juvenile salmon in the estuarine and nearshore marine environments are directly linked to their survival. Thus, years with favorable environmental conditions and increased growth rates of juvenile salmon may result in improving their early marine survival, ultimately affecting total returns of salmon in the following years.

The following plan highlights a new research program intended to improve our understanding of the linkages between the environment, growth rates, and early marine survivals of juvenile salmon. The plan begins by outlining a conceptual model of sockeye salmon survival based on historical work done in the 1960s and early 1970s. An implementation plan then follows, laying out program goals, objectives, research elements, and specific study plans.

Historical Studies of Juvenile Bristol Bay Sockeye Salmon

Past studies of Bristol Bay sockeye salmon have given us a good description of the habitat and migration characteristics of juvenile sockeye salmon as they leave Bristol Bay, moving along the north shore of the Alaska Peninsula (classified as inner and outer Bristol Bay; Figure 1; Straty 1974; Straty and Jaenicke 1980; Straty 1981). These studies have also shown how juvenile salmon respond to environmental conditions along their migration path, suggesting the following conceptual model on the possible affects of marine environment on distribution, migration, and growth of juvenile Bristol Bay sockeye salmon in the eastern Bering Sea.

1. The distribution of juvenile sockeye salmon in the coastal waters of Bristol Bay is influenced by environmental conditions such as temperature and salinity;
2. Migration rates vary as a function of temperature, food density, juvenile salmon body size, and stock origin; and
3. Growth rates are related to migration rates, coastal distribution patterns, and food production in Bristol Bay.

Distribution

The width and extent of the seaward migration route of juvenile Bristol Bay sockeye salmon across the shelf are related to annual sea temperature differences in the coastal waters of the eastern Bering Sea (Straty 1974). Juvenile sockeye salmon migrating seaward are generally observed in a narrow band which extends from near shore to as far as 50 km offshore (Straty 1974; Hart and Dell 1986). Coastal waters on the southeastern side of Bristol Bay are generally a few degrees warmer than adjacent waters offshore (i.e., isotherms parallel the coast), which may explain why juvenile sockeye salmon avoid the colder offshore waters during seaward migration, particularly when anomalously cold sea temperatures prevail (Straty 1974).

Salinity may also influence the distribution of juvenile Bristol Bay sockeye salmon during seaward migration. Straty and Jaenicke (1980) observed juvenile Bristol Bay sockeye salmon using salinity gradients as one of the directive cues in their seaward migration. If salinity gradients are the principle environmental condition directing seaward migration of juvenile salmon after they enter the coastal waters, then environmental events such as prolonged periods of high wind, which cause shifts in the position of river outflows, may produce short-term changes in distribution (Straty 1981).

Migration

The seaward migration rate of juvenile sockeye salmon through inner Bristol Bay is rapid but can be influenced by changes in the environment. In 1971, a year characterized by anomalously cold sea temperatures from spring through fall, juvenile sockeye salmon were virtually absent in outer Bristol Bay in early July; whereas, they were abundant in this area in 1967, a year with warm spring through fall sea temperatures (Straty and Jaenicke 1980). The reduced migration rate of juvenile sockeye salmon during 1971 can be attributed to a reduction in swimming speed as a result of the unusually low sea temperatures and later than usual outmigration of smolts from some major river systems.

The seaward migration rate and timing of juvenile Bristol Bay sockeye salmon are also a function of stock, body size, and food density. At first, juvenile sockeye salmon migrate in fairly distinct stock groups through inner Bristol Bay. Factors contributing to stock separation include smolt outmigration timing from various river systems (Table 1), distances between river systems, and age (and therefore size) of sockeye salmon smolts when they enter Bristol Bay. Although major stocks of Bristol Bay sockeye salmon may be segregated during the initial period of seaward migration, they mix after the fish have been at sea a few months (Straty 1974). This mixing likely stems from a decrease in the seaward migration rate once fish enter outer Bristol Bay waters where they encounter more abundant and larger food items.

Growth

Warmer sea temperatures along the migratory paths of juvenile Bristol Bay sockeye salmon lead to higher growth rates, which, in turn, lead to increased early marine survival of juvenile Bristol Bay sockeye salmon. Straty and Jaenicke (1980) found that warmer sea temperatures near Port Moller in Bristol Bay resulted in greater scale growth of juvenile sockeye salmon. Faster growing individuals may have a survival advantage over slower growing individuals since the survival rate of juvenile salmon apparently increases with increased size (Foerster 1954, Ricker 1962, Manzer 1972, Pella and Jaenicke 1978, Holtby et al. 1990).

Growth of juvenile salmon is also a function of the amount and type of food consumed. For juvenile Bristol Bay sockeye salmon, changes in stomach fullness correspond to changes in food availability along the migration corridor (Straty 1981). Zooplankton are far more abundant in offshore, deeper, waters of outer Bristol Bay than within inner Bristol Bay. The response of juvenile sockeye salmon to greater food abundance in outer Bristol Bay was clearly evident in the size and growth patterns of the fish. Straty (1974) found that marine growth on scales of juvenile sockeye salmon did not occur or accelerate until the juvenile sockeye salmon had entered the outer Bristol Bay area. Zooplankton in outer Bristol Bay are also larger, which may contribute to the increased growth rate of juvenile sockeye salmon as they migrate from inner to outer Bristol Bay (Straty and Jaenicke, 1980).

Large populations of early-migrating stocks of juvenile Bristol Bay sockeye salmon can impact growth potential of late-migrating stocks. As mentioned earlier, juvenile sockeye salmon migrate in fairly distinct stock groups through inner Bristol Bay. Early-migrating stocks of juvenile sockeye salmon reach the more productive waters of outer Bristol Bay before late-migrating stocks. Large populations of early-migrating juvenile sockeye salmon stocks may crop-down zooplankton populations thus effecting the available food supply and growth of late-migrating stocks of juvenile sockeye salmon (Straty 1981).

Additional Research

Additional research will focus on substantiating the conceptual model with the primary goal of establishing and verifying the linkages between adult sockeye salmon survival and annual variations in biological characteristics (growth, migration, and distribution) of juvenile sockeye salmon. The following implementation plan provides a framework for analyzing the effects of annual variations in the marine environment along the coastal waters of the eastern Bering Sea on the biological characteristics of juvenile Bristol Bay sockeye salmon. The plan is designed to first fill gaps in our understanding of stock-specific biological characteristics of juvenile Bristol Bay sockeye salmon, which may help explain stock-specific annual variations in returning adults. It then looks towards developing a sampling plan for annual assessments of variations in the biological

characteristics of juvenile sockeye salmon to provide a basis for assessing changes in early ocean survival and ultimate productivity of Bristol Bay sockeye salmon stocks.

Eastern Bering Sea (Bristol Bay) OCC Program Implementation

Program Goal

To understand the relationship between adult Bristol Bay sockeye salmon survival and annual variations in the biological characteristics (growth, migration, and distribution) of juvenile Bristol Bay sockeye salmon.

Program Objectives

Our working hypothesis is that growth, migration characteristics, and environmental conditions encountered by juvenile sockeye salmon emigrating from Bristol Bay are all functionally linked to survival and that between-stock differences in these variables will correspond to between-stock differences in survival.

- 1) Identify environmental and biological factors related to the migration and distribution of juvenile Bristol Bay sockeye salmon in the coastal waters of the eastern Bering Sea.
- 2) Measure the affects of temperature, migration pathways, juvenile salmonid density, and predator/prey densities on growth of juvenile Bristol Bay sockeye salmon.
- 3) Compare distribution, migration, and growth of individual Bristol Bay sockeye salmon stocks during early marine residence and relate these variables to ocean survival rates.
- 4) Develop a sampling design for annual assessments of juvenile salmon growth, migration, and early marine habitat characteristics.

Program Elements

- 1) **Migration and distribution** studies of the distribution and abundance of juvenile Bristol Bay salmon in the coastal waters of the eastern Bering Sea.
- 2) **Early marine growth** studies of Bristol Bay juvenile salmon based on biological characteristics determined from juvenile salmon scales, stomach fullness, diet analyses, and juvenile salmon density.
- 3) **Stock identification** studies assessing the extent to which we can identify the stock origin of individual fish.
- 4) **Oceanographic observations** to quantify habitat (temperature, salinity, prey densities) in the coastal waters of the eastern Bering Sea.

Migration and Distribution of Juvenile Salmonids

Objective

Identify the spatial distribution and migration characteristics of juvenile salmon inhabiting the coastal waters of the eastern Bering Sea using ship surveys.

Strategy

Shipboard surveys of the coastal waters of the eastern Bering Sea are needed to collect data on the spatial distribution of juvenile salmonids and ecologically related species (prey, competitors, and predators), and to collect specimens for laboratory studies. We will sample in different months to identify seasonal changes in distribution and growth patterns. The survey will begin in late July or early August focusing on waters inhabited by juvenile salmonids immediately after they leave inner Bristol Bay. Subsequent sampling will occur in September and October, a period when juvenile salmonids may begin moving into offshore waters.

We plan to sample along a series of transects, each starting near shore and extending perpendicular to shore to at least 111 km. Transects will be separated by 55 - 111 km to maximize spatial coverage of the survey area (see Figure 2 for the 1999 survey area). Along each transect, fish samples will be collected using a midwater rope trawl, which is 198 m long, has hexagonal mesh in wings and body, and has a 1.2-cm mesh liner in the codend. The rope trawl is towed at 5 kts, at or near surface, and has a typical spread of 52 m horizontally and 18 m vertically. Salmon and other fishes will be sorted by species and counted. Standard biological measurements including fork length, body weight, and sex as well as scale samples from the preferred area will be taken from subsamples (approximately 50 per trawl haul, or, if appropriate, 300 per transect) of all salmon species. All other fish species will be counted and subsamples (approximately 10 per trawl haul) will be frozen for later laboratory analyses.

Early Marine Growth of Juvenile Salmonids

Objective

Examine early marine growth of juvenile salmonids by analyzing marine scale growth increments, stomach fullness, diet, and juvenile salmon density.

Strategy

Scale Collection and Processing

All juvenile salmon with scales will be processed during the survey. The juvenile salmon will be measured for length and weight, assigned a control id number, and individually packaged and frozen for further laboratory analysis.

All scales will be digitized using standard image analysis software such as OPTIMAS. Although several different digitizing procedures are currently in practice, we will select a procedure that provides the best fit between the software program and scale characteristics. Sockeye salmon generally spend one or more years in freshwater then migrate to sea and spend one or more years in the ocean until returning to spawn. Therefore, circuli growth will be measured for both freshwater and marine residence. An image of each scale measured for growth will also be cataloged in an image database to allow for future inspection. These images will be used in this study to repeat growth measurements on a subset of scales to assure consistent measurement procedures and to provide access to the scale images for future investigation.

Stomach analyses

Stomachs from up to 10 juvenile salmon from each trawl haul will be retained for laboratory analysis. In the laboratory, stomachs will be blotted dry and weighed to the nearest mg. Stomach fullness will be measured and stomach contents will be identified, measured, and enumerated to the lowest practical taxonomic level. The results of the stomach analyses will be related to migration pathways, prey availability, juvenile salmon density, and oceanographic features.

Stock Identification

Objective

Develop and implement methods of identifying the river system of origin for individual fish captured during the survey.

Strategy

In order to understand how stock-specific biological characteristics of juvenile Bristol Bay sockeye salmon effect stock-specific annual variations in returning adults, we will need to be able to identify stock-origin of individual salmon in our catch. We will work cooperatively with other agencies (e.g., Fisheries Research Institute (FRI); University of Alaska) researching methods of identifying river system of origin for Bristol Bay sockeye salmon. In the interim, we will work cooperatively with the Auke Bay Laboratory genetics group doing electrophoretic analyses on juvenile sockeye salmon captured during the surveys. A sample size of 300 juvenile sockeye salmon will be collected from transects where sufficient numbers of juvenile sockeye salmon are present. Electrophoretic analyses cannot identify stock-origin of individual fish, but will provide stock distribution characteristics over the survey area.

Oceanographic Observations of the Coastal Waters of the Eastern Bering Sea

Objective

Describe habitat (currents, temperature, salinity, and prey densities) occupied by juvenile salmon as they migrate along the coastal waters of the eastern Bering Sea. Collection and analysis of oceanographic data will be done in cooperation with the Fisheries-Oceanography Coordinated Investigations (FOCI) of the Alaska Fisheries Science Center.

Strategy

Biological and physical oceanographic data will be collected in conjunction with trawl operations. Sampling operations will typically consist of: 1) CTD casts made before each trawl station, 2) operation of a multi-beam hydroacoustic system (cast mode) to provide biomass estimates of zooplankton by size category made before each trawl station, and 3) oblique Tucker trawls or bongo hauls made before each trawl station to determine species composition and to identify hydroacoustic targets.

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Table 1. Average dates by which 50 percent of sockeye smolts leave major Bristol Bay river systems (Hartman et al. 1967).

River system	Date	Number of years of observation
Ugashik	May 30	6
Egegik	June 1	3
Kvichak	June 2	9
Naknek	June 16	7
Wood	June 22	7

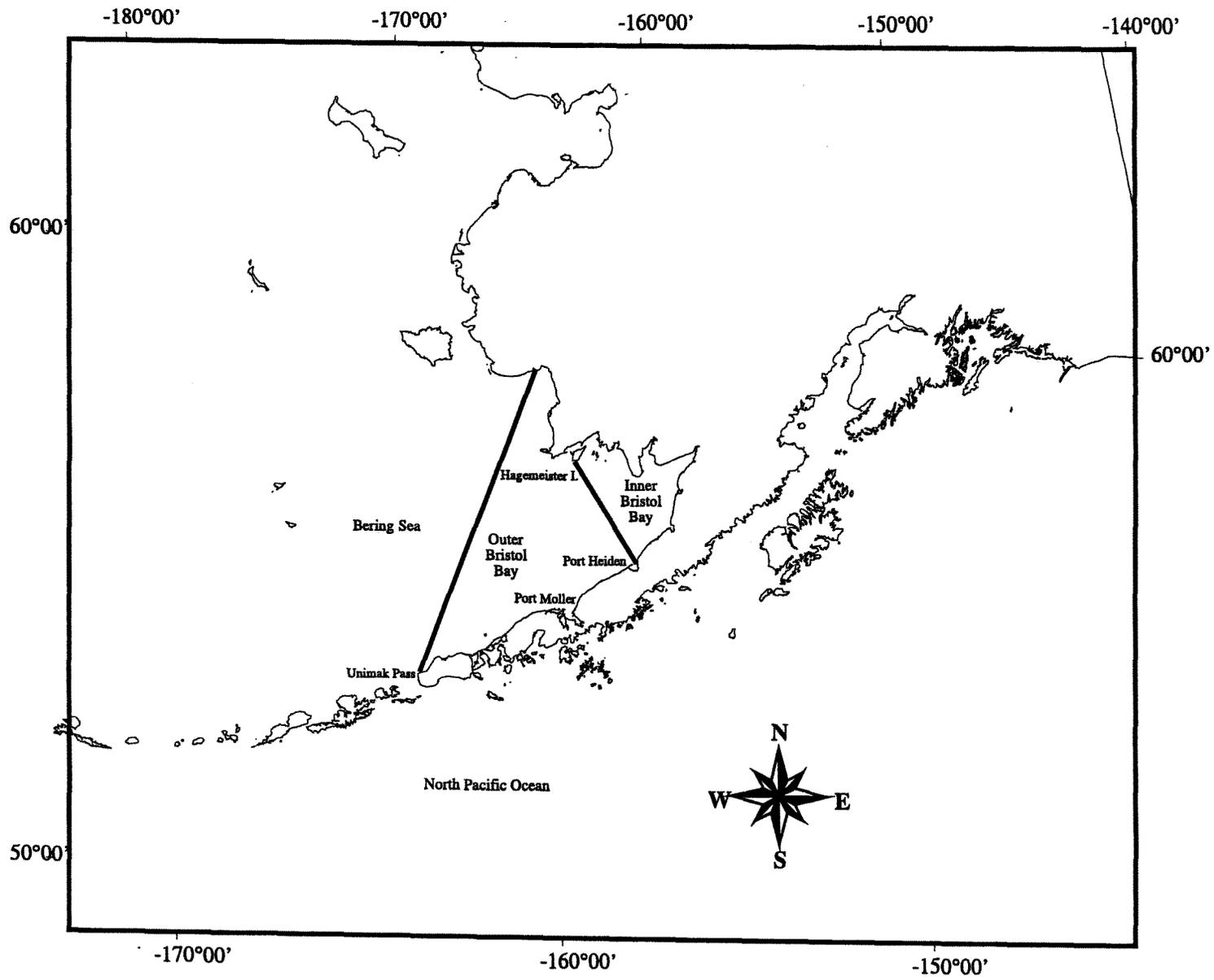
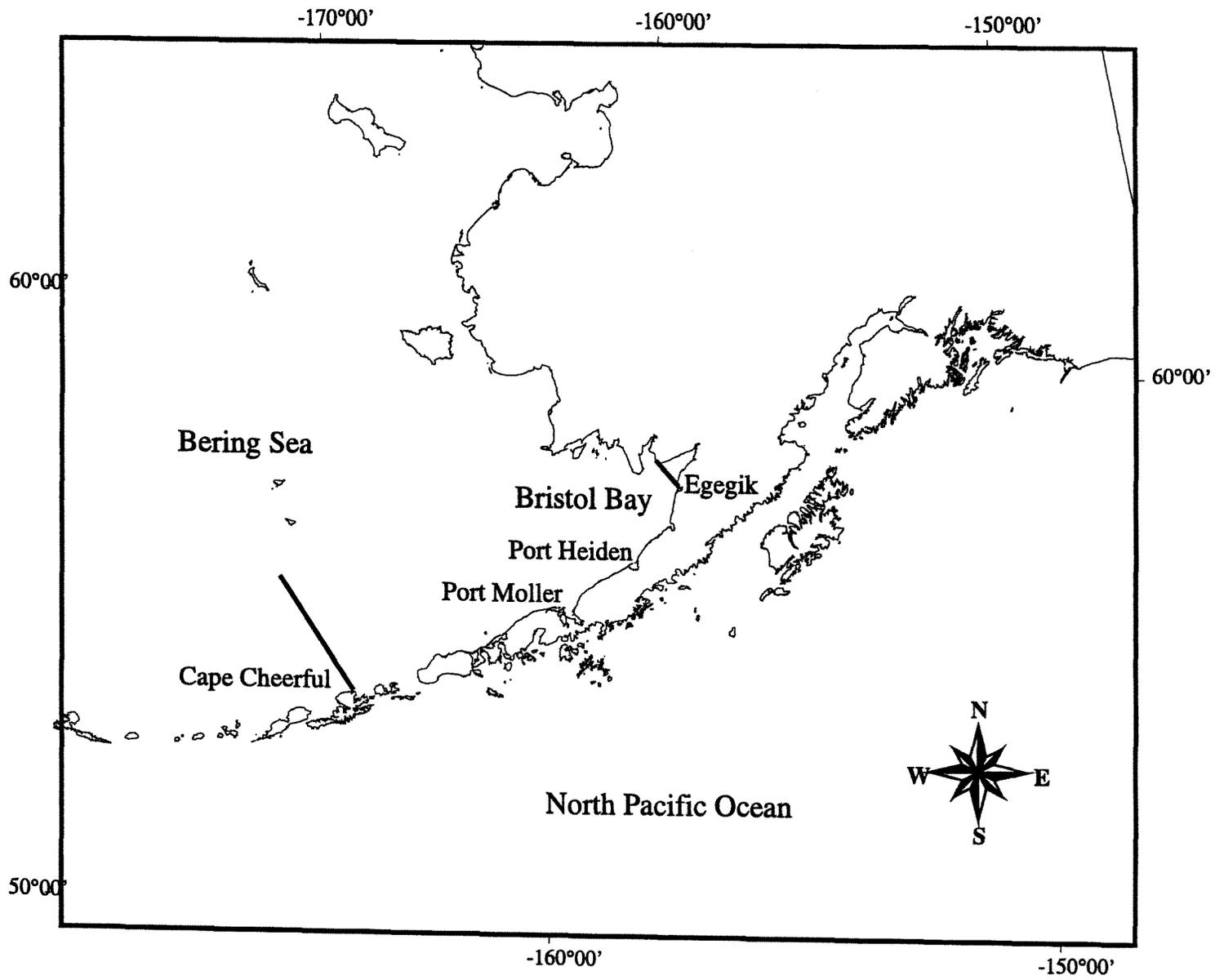


Figure 1. Bristol Bay, showing inner and outer bays (from Straty and Jaenicke 1980).



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Figure 2. Survey area (Cape Cheerful - Egegik) for the Ocean Carrying Capacity Bristol Bay juvenile sockeye salmon program.