Table of Contents

Chapter 3c Alaska Arctic Marine Fish Species

Chapter 3. Alaska Arctic Marine Fish Species Accounts

By Milton S. Love[1], Nancy Elder[2], Catherine W. Mecklenburg[3], Lyman K. Thorsteinson[2], and T. Anthony Mecklenburg[4]

Abstract

Species accounts provide brief, but thorough descriptions about what is known, and not known, about the natural life histories and functional roles of marine fishes in the Arctic marine ecosystem. Information about human influences on traditional names and resource use and availability is limited, but what information is available provides important insights about marine ecosystem status and condition, seasonal patterns of fish habitat use, and community resilience. This linkage has received limited scientific attention and information is best for marine species occupying inshore and freshwater habitats. Some species, especially the salmonids and coregonids, are important in subsistence fisheries and have traditional values related to sustenance, kinship, and barter. Each account is an autonomous document providing concise information about a species zoogeography, western and Alaska Native taxonomy, life history, niches, and life requirements. Each account is fully referenced with the identification of the most critical literature for Alaska and a more comprehensive listing of referencing from which biological and ecological information was drawn. New-to-science narratives, distributional maps, and vertical profiles, provide quick, reliable sources of information about fish life history and habitat requirements for this segment of the Arctic fauna.

Purpose and Design of Species Accounts

Individual species accounts were prepared for 104 of the 109 confirmed marine fishes for which adequate biological information was available from the U.S. Chukchi and Beaufort Seas. These descriptions are an important source of documentation about Arctic Alaska's marine fish fauna. Although tailored to address the specific needs of BOEM Alaska OCS Region NEPA analysts, the information presented in each species account also is meant to be useful to other users including state and Federal fisheries managers and scientists, commercial and subsistence resource communities, and Arctic residents. Readers interested in obtaining additional information about the taxonomy and identification of marine Arctic fishes are encouraged to consult the *Fishes of Alaska* (Mecklenburg and others, 2002) and *Pacific Arctic Marine Fishes* (Mecklenburg and others, 2016). By design, the species accounts enhance and complement information presented in the *Fishes of Alaska* with more detailed attention to biological and ecological aspects of each species' natural history and, as necessary, updated information on taxonomy and geographic distribution.

Each species account includes a concise summary of the natural history, population dynamics, functional roles, and traditional and economic values of the marine fish found off Alaska. An initial organizational task was to create a standard format for effective information delivery. The species descriptions by Ehrlich and others (1988) were provided to the USGS by BOEM as an example of a creative template for information transfer. Four pilot species accounts, representing well known to poorly known species, were developed, reviewed, and repeatedly revised for improvements, interagency approval, and selection of the final layout and design. Final decisions about content represented the priority needs of BOEM.

More than 1,200 individual scientific publications relevant to Arctic marine fishes were reviewed in preparation of the species accounts. In each species account, the most relevant literature for each species is cited. A shorter list (about 5–10 articles) identifies key Alaskan information sources that, in our opinion, have had the greatest scientific effect on understanding the species of the Arctic area of the United States.

[1]University of California, Santa Barbara.

[2]U.S. Geological Survey.

[3]California Academy of Sciences, San Francisco, and Point Stephens Research, Auke Bay, Alaska.

[4]Point Stephens Research, Auke Bay, Alaska.

Limitations of Data

The species accounts reveal many gaps in the biological information needed to conduct vulnerability assessments of the marine fishes of the Beaufort and Chukchi Seas to human interventions. Part of this problem relates to the geographic coverage of existing research and surveys in Alaska as, in many instances, we were required to incorporate the results of investigations conducted outside the region. This raises an important caution because, even though the best available information was used in preparing the species accounts, our reliance on data and information from outside Alaska will introduce uncertainty to EIS expectations. Ideally, and with respect to oil and gas activities, baseline information for fishery resources should be collected from the potentially affected environment to appropriately evaluate the potential effects of oil spills or other possible industrial-related disturbances. However, as has been widely noted (for example, Bluhm and others, 2011), systematic and methodologically comparable data typically are not available from Arctic Alaska marine ecosystems. Evaluating change in populations and communities from natural and anthropogenic stressors is limited by the variable quality and lack of quantitative reports on abundance, distribution, community structure, and demographics for Arctic marine fishes.

In each species account, an attempt was made to incorporate the most reliable baseline information available and offer impressions of information needs. Important ongoing studies sponsored by BOEM, and others, may be addressing some of these needs. The needs assessments for this study considered these efforts to the extent that oral and (or) written communications and preliminary results allowed. The focus of this study was on impressions of the population parameters (Williams and others, 2002) and environmental measurements needed to detect changes in marine fish populations (Reist and others, 2006; Wassmann and others, 2011) and their resilience to a variable and rapidly changing environment (Holland-Bartels and Pierce, 2011). For key marine fish species, examples might include changes in range, community structure, abundance, phenology, behavior, and population growth and survival.

Each species account is designed as a self-contained article; therefore, no references to other accounts are included. Additionally, to reduce complexity in the presentations, only common names were used to identify the major predator and prey species for the marine fish described. Because this document was meant to be a companion document to the *Fishes of Alaska* (Mecklenburg and others, 2002), interested readers are encouraged to consult this book or Page and others (2013) and Mecklenburg and others (2016) for more complete information about the scientific authorities and literature citations associated with the original descriptions of each species. Readers are directed to the references cited in each species account for additional information on the species.

Operational Definitions

In chapter 1, several concepts about the temporal and spatial habitat requirements for Arctic marine fish were introduced. More information is presented in this chapter to explain the vertical distribution and the location of shelf break, as used in this report.

Vertical Distribution

The conceptual design of the species depth profiles (vertical structure by life history stage) was patterned after the "coastal marine life zones" of Allen and Smith (1988). The goal of the profiles is to visualize what is known about a species occurrence and reproductive ecology by depth and location. An idealized characterization of Arctic shelves was designed to visualize these relationships. Additional detail about origins of data was included in the depth profiles to reflect Alaskan records or collections from other Arctic regions. This is important because actual field collections and observations are limited from this region. In many instances, the actual presence of a life stage remains unverified by field sampling. Thus, for many of species, the depth of a fish's life cycle should be considered untested hypotheses in need of additional testing.

Location of Shelf Break

Early versions of the depth profiles were modified at the request of BOEM with respect to the depiction of the continental shelf break. As a special effect for the Arctic, the species depth profiles were redrawn to depict the change in bathymetry that typically occurs at depths of about 75 m throughout the Chukchi and western Beaufort Seas. This depiction is not an attempt to redefine the oceanographic definition of shelf break. Instead, it highlights the relatively sharp gradient in depths that often occurs near 70- to 80-m contours over much of the region. Although species depth profiles in this report depict an apparent "break" at 75-m, three factors were considered: (1) this is a generalization and the actual shelf break may be geographically close but at a slightly greater depth; (2) shelf edge effects on fish distribution at depths occurring between 75-, 150-, or 200-m are likely negligible due to the gradient and area involved; and (3) the conceptual depictions of depth distributions by life history stage are consistent with accepted oceanographic conventions for continental shelf and slope (despite the magnified view at 75-m) and thus are compatible to the import of biological data obtained elsewhere.

Keystone Species

The concept of keystone species describes the critical role certain organisms are perceived to have in maintaining the structure of biological communities and resilience of ecosystem dynamics (Paine, 1966). Arctic Cod (*Boreogadus saida*) are widely distributed in the Arctic Ocean and by virtue of their abundance and intermediate trophic position between invertebrates and higher-level predators are integral to the movement of nutrients in marine food webs. For this reason, Arctic Cod are considered a keystone species in the Arctic marine (Bradstreet and others, 1986; Walkusz and others, 2011). Arctic Cod are common in United States waters of the Beaufort and Chukchi Seas being considered for energy exploration and development and are an ecological focus of BOEM fishery studies to understand potential effects on the species (Maule and Thorsteinson, 2012).

Outline of Species Accounts

The species accounts are scientifically accurate descriptions of the life histories, populations, habitats, and community values of individual species in the Arctic marine ecosystem. The mix of quantitative and qualitative information presented reflects state-of-the-art knowledge, a faunal assessment of information gaps, and prioritization of priority needs for population and process understanding. Limited information for many Alaskan species required that relevant observations from other geographic locales be included. Each species account attempts to be clear about the geographic origins of data and information, through scientific referencing or special notations in graphics. As an example, *italics* are used in the species accounts to highlight data collections from the Alaska study area. In several instances, species information was so lacking that inferences from a closely related species were required.

The generic species account includes a comprehensive accounting of scientific and cultural information in a standard format. The scientific information addresses multiple disciplinary areas including taxonomy, life history and habitats, ecological relationships including predator-prey interactions and environmental preferences, and population ecology. The population information is critical to evaluations of population status and health, resilience, and vulnerability to natural and anthropogenic changes in the marine environment. Each species account includes a photograph of an adult specimen (or line drawing if an image was not available); distribution maps (horizontal and vertical); and concise descriptions of abundance, life history, and ecology (11 life history categories); major stressors; research needs; and key references. To assist users, a suite of easily recognized icons was developed to provide quick access to specific life history information. In addition, some species attributes regarding life history, population dynamics, and biological interactions are defined in the Glossary (chapter 7).

Information presented in each species account is outlined and described as:

Taxonomic—Scientific and Common Names

The format of the species accounts was, by design, intended to link the biologic and ecologic information presented in this document directly to the species identification guides contained in the "*Fishes of Alaska*." This connection was established by adherence to naming conventions as described by Mecklenburg and others, 2002 (p. 25 and 26). The common names of each marine fish are presented first, followed by scientific and family names. Each scientific name includes a reference to the name of the person (author) who formally described and named the species in the ichthyological literature. The bibliographic data for the authors and dates of publication of scientific names can be found in Eschmeyer's Catalog of Fishes online (http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp) and are not reported here. In some instances, a *Note* (italicized) has been included to describe exceptional details about existing biological data, morphology, nomenclature, taxonomic status, life history strategy, or occurrence of a species in the United States Chukchi and Beaufort Seas.

Iñupiat Name

The existence of colloquial Iñupiat (Iñupiaq) names for the Arctic's marine fish fauna by indigenous peoples is an important component of traditional ecological knowledge. Relatively few marine fish species are abundant or susceptible enough to subsistence fisheries to have received special names. For those species having Iñupiat names, this information is reported to assure that a common vocabulary can facilitate future exchanges of ideas and knowledge across disciplinary boundaries. In this manner, colloquial names can provide a cultural link between local marine resources and science supporting sustainability of Arctic communities and ecosystems.

Ecological Role

Fishes play a pivotal role in marine ecosystems as secondary and higher-level consumers in many marine food webs. In many instances, information about predator-prey relationships is so limited that only preliminary, qualitative assessments of the relative role of each species are possible. The ecological niche describes how an organism or population responds to resources and competitors. Importance or significance descriptors do not diminish the fact that all organisms contribute in ways large or small to the provision of ecosystem goods and services. These descriptors however, may provide useful information about the relative importance of a particular species as an indicator of ecosystem condition and trajectories of change associated with climate change, habitat fragmentation, ecosystem stress, effect of pollutants, or other anthropogenic effects.

Physical Description/Attributes

A brief physical description of the species is summarized from information presented by Mecklenburg and others, (2002) in the *Fishes of Alaska*; the relevant page number is included for quick referral to more comprehensive morphological information. An image of the adult form of each fish is presented with appropriate attribution. High-quality images were selected to highlight the key identifying features of a particular species.

Information about the presence of a swim bladder and antifreeze glycoproteins is included because of its relevance to geo-seismic oil and gas exploration, climate change issues, and evolutionary life history.

Range

The geographic occupancy of the species in United States sectors of Chukchi and Beaufort Seas and adjacent waters is presented in brief narratives and depicted on maps. Known occurrence in the Arctic OCS Planning Areas is highlighted by symbols indicating locations of valid species identifications from properly archived voucher specimens on each map. Although the symbols on the maps may suggest that some of the species are rare in the region, the study of historical collections from the United States and Canadian sectors of the Beaufort Sea, as well as the collections from BOEM surveys in the Beaufort in 2011 and 2012, is still in progress and may reveal that these species are more abundant in deep sectors of the study area than the maps suggest. Definitions of zoogeographic pattern are from the Online Resource 1 (electronic supplemental to Mecklenburg and others, 2011), Mecklenburg and Steinke (2015), and Mecklenburg and others (2016) and relate to ranges of population viability (see chapter 2).

Depth profiles in each species account graphically summarize existing information about the benthic and reproductive distributions of each marine fish. In both depth profiles, the width of areas depicted confers species information about horizontal (onshore-offshore) patterns of distribution. The italicized captions in the depth profiles highlight species information germane to the study area. Areas in the graphs denoted by the orange coloration represent understanding from data collection within the United States Chukchi and Beaufort Seas; olive colors represent data collection outside the study area. For benthic distributions, solid lines in the depth profiles represent species for which no specific information is available about its preferred depth range. Solid lines represent a synthesis of understanding that includes information not necessarily specific to the study area. In some instances, only one record of a species occurrence by depth was available and coding in orange was not meaningful. In these cases, an explanatory comment, in italicized font, with a line pointing to the appropriate depth was included in the graph (for example, see the species account for *Megalocottus platycephalus*). Highlighted depths as indicated through “bolded” (dark black) and dashed segments, represent most common depths where the species has been detected, and depth distribution as has been reported throughout the species range, respectively. Areas denoted with diagonal cross-hatching represents depth distribution of juveniles (immature); adult distributions are not cross-hatched and age-related habitat overlaps, are informed by captioning in the figures.

For reproductive distribution, eggs and larvae (pre-juvenile life stages) of marine fishes are represented with respect to depth and distance from the coast. Orange areas in the reproductive distribution profiles represent data collection in the study area. In many instances, information about spawning habitats and egg and larval distributions is summarized from information reported from throughout a species range. In these cases, dark blue represents species distributions in spawning habitats; light blue represents the geographic distributions of eggs and larvae; and light green is used to highlight areas of substantial habitat overlap (for example, see the species account for *Hippoglossus stenolepsis*). Distribution patterns of eggs and larvae are symbolized by “dots” and “horizontal dashes,” respectively, in the graphs. As for benthic distribution, solid lines represent species-specific information from data collections from throughout the species entire range. Highlighted (dark black lines) segments of solid lines indicate the most common depths where egg and larvae samples have been collected. Dashed lines represent areas of hypothesized distributions for species for which no information is available about egg or larval occurrence. In these instances the hypothesized distributions are based on known patterns for closely related species; the lack of data is stated in captions above the graph.

Relative Abundance

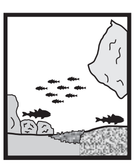
Relative abundance refers to the contribution a species makes to the total abundance of the fishery community. It is a measure that provides an index of the number of individuals present, but not the actual numbers. Relative abundance terms, such as “common,” “uncommon,” or “rare” often are used to express the general population status of a given species, but are most useful when they are defined by something that is measured or estimated in a manner that makes comparison meaningful.

Depth Range

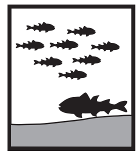
Benthic distribution refers to the spatial arrangement of a particular species at different depths over continental shelf and slope waters. The life cycle of fishes occurs in multiple dimensions in time and space and generally reflects genetically determined life history or behavior that has evolved to maximize fitness (life time reproductive success, see Gross [1987]). Benthic distribution profiles for each species represent the location of important habitats as they are presently known for juvenile and marine fishes. Reproductive distributions depict important habitats for spawning and early life history development.

Life History, Population Dynamics, and Biological Interactions

Life history theory holds that the schedule and duration of key events in a species' lifetime are shaped by natural selection to produce the largest possible number of surviving offspring. These events, notably juvenile development, age of sexual maturity, first reproduction, number of offspring and level of parental investment, senescence, and death, depend on the abiotic and biotic environment of the organism. Specific information about these traits informs understanding of a species' adaptive capacity including major influences on population abundance. A number of fisheries models use basic length-weight and age-at-size relationships to describe the growth and dynamics of fishery populations (for example, von Bertalanffy and Gompertz, growth models and derivatives [Ricker, 1975]). Ecological models estimate transfer of energy or matter along the trophic chain (Gamito, 1998). The parameters that are estimated in these models are individually important indicators of population condition and may be used with other indicators to derive quantitative information about compensatory responses and resilience. Much of this information, including population parameters, has been compiled in FishBase for the Arctic marine fish (Froese and Pauly, 2012).



Habitats and Life History—Basic information about the life history (for example, body size, reproductive ecology, growth) and ecology (for example, mobility, growth, habitat) of a species and the environmental area inhabited by that species is foundational to effective resource management. Habitat is the natural environment that influences and is used by a species population. Information about abiotic (that is, temperature, salinity, other physiochemical factors, depth, and substrate types) and biotic (that is, type and abundance of food, presence of other biota) often are used to describe fish habitats and provide insights about a species environmental preferences and habitat associations (for example, water masses). Maximum body size often is reported and can be an important surrogate of different life history traits (for example, age at maturity, growth, and reproductive output). In population dynamics studies, the relationships between length and weight and size and age form the basis for population growth and production models and quantitative analysis of environmental effects. Length measurements are reported as standard length (SL), total length (TL), and fork length (FL) in fisheries studies.



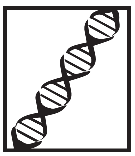
Behavior (see also Glossary [chapter 7]).—Behavior is the manner in which a fish operates or functions within its environment (that is, home range, territoriality, and many others) to procure food, orient to specific locations, or relate to other organisms. Knowing how individuals respond to the environment (physical, chemical, and biological cues) is critical to understanding population processes such as distribution, survival, and reproduction and recruitment and for managing fisheries. Many behaviors are evolutionary adaptations to the physiological and reproductive requirements for a species' survival. For example, migration involves the regular movement of animals between different geographic locations. Migrations can be extensive in terms of time and distance involved (anadromous model) or seasonal (amphidromous and marine models). Each of these models reflects a life strategy adapted for age and growth at sea. Diel relates to daily changes in water column position due to changes in light, temperature, and food supply.

Migratory behaviors are rooted in physiological requirements for food, growth, reproductive, and survival ("scope for growth"). Movement behaviors are more tactical responses to local environmental conditions (for example, variable hydrographic conditions in the nearshore Beaufort Sea). Fish movement can be active or passive and involve large distances in search of suitable habitats and foods. The seasonal nature of migration and movement behaviors are typically related to life history stage, predator-prey distributions, or energetic requirements for growth.

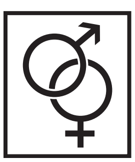
Schooling (that is, social structure of fish of the same species moving in more or less harmonious patterns in the sea) often is related to survival and reproduction. Schooling confers physical benefits to fish movement, safety against predators, search behaviors (for example, foods), population immunology, and reproduction.

The functional feeding morphology of a fish relates to its anatomical adaptations (for example, body size, gape sizes, shape, and body form) to environmental conditions especially food preferences. The adage "function determines morphology and morphology determines way of life" is an important evolutionary concept as it applies to fish feeding behavior, dietary preferences, habitat selection, and trophic stature. Trophic position (within categories of trophic levels) expresses the "tendency of larger (less abundant) fishes feeding on smaller (more abundant) fishes, which themselves feed on zooplankton and all these animals resting upon primary producers" (from Pauly and Watson, 2005). Categories of trophic levels are:

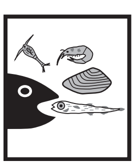
- Trophic level 1 (T1), plants and animals make their own food and are called primary producers;
- Trophic level 2 (T2), herbivores eat plants and are called primary consumers;
- Trophic level 3 (T3), carnivores eat herbivores and are called secondary consumers;
- Trophic level 4 (T4), carnivores eat other carnivores and are called tertiary consumers; and
- Trophic level 5 (T5), apex consumers, which have no predators, are at the top of the food chain.



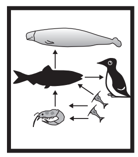
Populations or Stocks—A population often is defined as a group of organisms of the same species occupying a particular space at a particular time with the potential to breed with each other (Williams and others, 2002). Stocks are subpopulations of a particular species of fish that result from reproductive isolation and subdivisions within the biological range. The current state of knowledge about local stocks and their genetic population structure is reported. Grossberg and Cunningham (2001) described the combined effects of demographic, behavioral, genetic, oceanographic, climate, and tectonic processes as major determinants of population structure. These mechanisms act across a range of temporal and spatial scales to determine the rates and patterns of dispersal of different life stages of marine fishes. Dispersal, combined with the successful reproduction and survival of immigrants, control the scale and rate of processes that build or erode structure within and among groups of individuals.



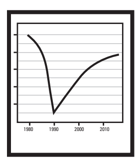
Reproduction Mode—Little information is available about the spawning times and locations, mating behaviors (breeders or nonbreeders), and genetic diversity of Arctic marine fishes. What is known is drawn largely from observations from populations studied outside the United States. For most Arctic marine fish species, there is no information about population or stock structure (for example, age structure, reproductive behavior, sex ratios, age-at-maturity, fecundity, and genetic). These are key population parameters needed for understanding reproductive ecology, population dynamics (for example, growth, survival, and mortality), and assessments of resiliency (response to disturbance).



Food and Feeding—Dietary information is summarized from literature and, unless in italics, is reported from other regions. Fish communities can affect the ecological characteristics of marine ecosystems in response to productivity and abundance patterns, the mobility and migratory behavior of species, and through food influences in different habitats (for example, Grebmeier and others, 2006b). Trophic Index (T) values are reported from FishBase (Froese and Pauly, 2012). The T values for Arctic marine fishes are largely derived from stomach contents analyses, which have correlated well with stable isotopes of nitrogen in tissues. The fractional values (between 1 and 5) realistically address complexities of consumer feeding behaviors (omnivory and feeding across multiple trophic levels) and predator-prey relationships. For example, the mean T value for Blackline Prickleback (*Acantholumpenus mackayi*) is 3.1 (±0.31). This mid food web value is indicative of a primary carnivore that feeds across trophic levels, in this case on lower level herbivores.



Biological Interactions.—The effects organisms in a community have on one another. Competition and consumption (predation, herbivory, or cannibalism) are the best known of the major ecological processes affecting resource abundance, community composition, and ecosystem function. Competition involves interactions between individuals of the same species (intraspecific) or different species (interspecific) in which the fitness of one is lowered by the presence of another. Competition often is related to food and habitat requirements and reproductive behavior. Interspecific competition for foods is greatest for species occupying similar trophic positions in relatively short food chains and for animals living in regions of low biological productivity.

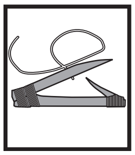


Resilience—In ecology, resilience traditionally refers to the ability of a population or biotic community to sustain or return to its former state after a disturbance. The rate of recovery is a measure of resilience determined by the population processes involved in restoring abundance to healthy, sustainable, or pre-disturbance levels. Four categories of productivity (high, medium, low, and very low) are used to classify reliance in marine fish populations (Musick, 1999). These categories are based on a combination of population parameters for intrinsic rate of growth, growth coefficient, fecundity, age at maturity, and maximum age. Because population parameters were unavailable, resiliency is defined here based on estimated population doubling time where high = <15 months, medium = 1.4–4.4 years, and low = 4.5–14 years.

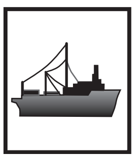
Traditional, Cultural, and Economic Values

In August 2009, the U.S. Secretary of Commerce approved a Fishery Management Plan for the Arctic Management Area. The plan covers U.S. Arctic waters in the

Chukchi and Beaufort Seas, and acknowledges that changing climate may potentially favor the development of commercial fisheries. However, until adequate fisheries resource assessments are completed, the region remains closed to commercial fishing in federal waters. A small salmon fishery exists in Kotzebue Sound; in 2010, a small commercial fishery for Arctic Ciscoes in the Colville River was terminated.



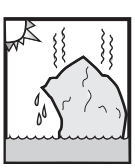
Traditional and Cultural Importance.—Several species of nearshore marine fishes are important in subsistence fisheries. The protection of traditional lifestyles and economies, including these subsistence fisheries, is a responsibility of the Federal government. Subsistence relates to resource use patterns (for example, seasonal round) and values (that is, sustenance, kinship, and barter) in coastal communities of northern Alaska.



Commercial Fisheries.—Currently (2016) there are no offshore marine fisheries in the U.S. Chukchi and Beaufort seas. Changing Arctic environmental conditions and shifting distributions of species in response to warming suggest that there may be fisheries in the future. A precautionary approach by fishery managers has been adopted that requires the collection of reliable baseline information for decision-making and ecosystem management (North Pacific Fishery Management Council [North Pacific Fishery Management Council, 2009; Wilson and Ormseth, 2009]).

Climate Change

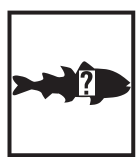
Alaska's climate is changing at more than twice the rate of the rest of the United States (Mellilo and others, 2014). Year-to-year and regional variability in air temperatures are evident and the warming trend currently is being moderated by large-scale cooling associated with the Pacific Decadal Oscillation. Even so, climate effects are pronounced and are being seen in changes in sea ice, timing of snowmelt, widespread glacier retreat, and changes in hydrology (runoff) and coastal processes, such as erosion (Markon and others, 2012). The effects of rising ocean temperatures and ocean acidification on marine food webs are of growing regional concern with respect to the condition and trends in marine ecosystems and human community resilience are of concern. Climate changes potentially can affect marine fish in numerous ways, leading to distributional changes, increased or decreased mortality rates, changes in growth rates, and by altering the timing in reproduction (Clow and others, 2011).



Potential Effects of Climate Change.—A pole-ward shift of many fish distributions is possible as is a reduction or extinction of species that are narrowly adapted to Arctic environments. Generally, the species are expected to increase in abundance if they are currently present in the Bering Sea and decrease if they have very low tolerance for temperatures greater than 1.5–2.0 °C. However, it is hypothesized in current climate projections that temperatures near the ocean floor in the northern Bering Sea will remain cold (<2 °C) due to persistence of winter sea ice (Sigler and others, 2011). Cold-water conditions and other marine ecosystem effects related to seasonal sea ice extent and timing of retreat may effectively block northward migrations and production of exploitable quantities of species, such as pollock and cod, for several decades. Shifts in range and other possible climate-related effects, such as increased predation or competition for food, are identified in the species accounts. Only "loose qualitative generalizations" are presently possible (Reist and others, 2006).

Research Needs

The compilation and review of species information for species in U.S. Arctic waters revealed many gaps in life history understanding and environmental relations. These are evaluated on the basis of a species current fishery and community values and ecological significance in marine ecosystem structure and function. The needs reflect the researcher's perceptions and their understanding that new fishery information is becoming available for the Arctic region and that, although Arctic research is currently a national priority, some aspects of population ecology will take many years of data collection to accurately assess.



Areas for Future Research.—The preparation of individual accounts led to the identification of many information gaps in knowledge about the biology and ecology of marine species including life history, population dynamics, and community associations. Generally, species life history and ecology gaps are most pronounced with respect to: (1) depth and location of pelagic larvae; (2) depth, location, and timing of young-of-the-year habitats; (3) preferred depth ranges for juveniles and adults; (4) spawning seasons; (5) seasonal and ontogenetic movements; (6) population genetics and dynamics; (7) prey–predator relationships and food web relationships; and (8) environmental health (multiple stressor effects on fitness). Behavioral studies for all life stages are virtually non-existent. New information is being developed and, for the lesser-known species, gaps may be slowly addressed over time. Priority needs, for species having special significance in subsistence fisheries and marine food webs or that may be indicator species are emphasized in the species accounts. One of two categories of identified research need is identified for each species. The meaning of the categories **[A]** and **[B]** is as follows:

- **[A]** Many gaps in our understanding of the species life history and ecology remain in Alaska (for example, research areas 1 through 8). These are high profile species in terms of ecological, subsistence, or potential fisheries values. Specific research priorities are briefly discussed.
- **[B]** Most aspects of the species life history and ecology are unknown for Alaska (for example, research areas 1 through 8). Species information will likely accumulate over time and focused studies are not warranted at this time.

References Cited and Bibliography

A thorough review of scientific literature was done in the preparation of the species account. A list of references (References Cited [chapter 8]) is provided for each species for readers seeking additional information. This list identifies key sources of information that make the greatest contributions to current knowledge (2014) and understanding. The Bibliography section provides a full accounting of all scientific literature cited in each species account. For a small number of species from the family Cottidae, only a Bibliography was possible to provide and this is indicative of the lack of information available. Citations are not always in numerical order in species accounts because new information became available during the production phase of this publication and were incorporated into the species accounts as appropriate.

Inconnu and Glacier Lanternfish

Inconnu (*Stenodus leucichthys*)
(Güldenstadt, 1772)

Family Salmonidae

Inconnu (*Stenodus leucichthys*). Photograph by R.J. Brown, U.S. Fish and Wildlife Service.

Colloquial Name: Iñupiat—*Siiġruaq* [1]. Most often called sheefish in Alaska.

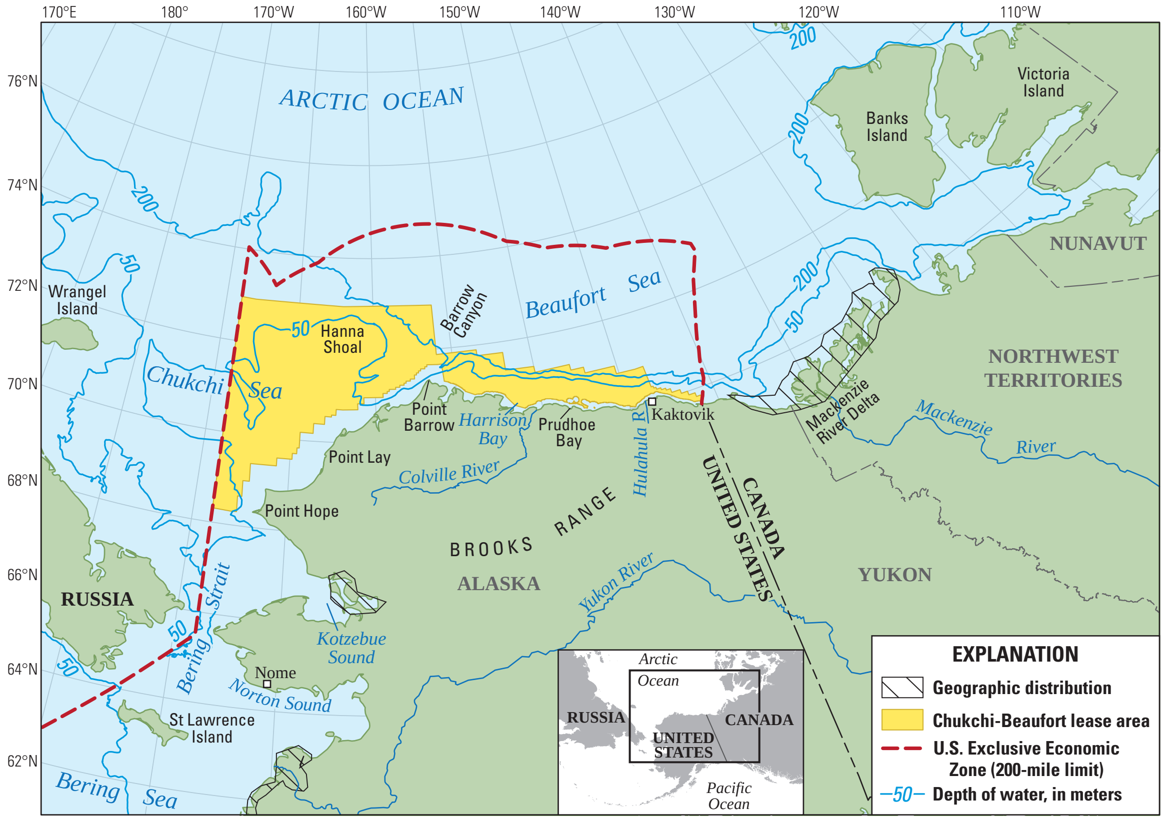
Ecological Role: Rarely enters marine waters and thus is not of ecological importance in the U.S. Chukchi and Beaufort Seas. Common in coastal lagoons in Kotzebue Sound, this fish is a major predator of pelagic species, such as Pacific Herring and possibly juvenile salmon. Inconnu is an important subsistence species in western Alaska including the southeastern Chukchi Sea.

Physical Description/Attributes: Body not much compressed; and colored green, blue, or brown dorsally and silvery white ventrally. For specific diagnostic characteristics, see *Fishes of Alaska* (Mecklenburg and others, 2002, p. 181) [2]. Swim bladder: Present [3]. Antifreeze glycoproteins in blood serum: Unknown.

Range: *Northward to Kobuk River* [2] *and probably Noatak River drainages of U.S. Chukchi Sea* [4]. Elsewhere in Alaska, this fish has been found as far south as Kuskokwim River [2]. Worldwide, Inconnu are found from Firth to Anderson Rivers, Canada [5], and in Caspian, Siberian, and White Sea drainages, south to Kamchatka, Russia [2]. Reported in nearshore semi-saline waters of Canadian Beaufort Sea to at least as far west as Herschel Island and Nunaluk Lagoon, Yukon Territory; most numerous just west of Mackenzie River, Northwest Territory [6].

Relative Abundance: *Common in the Kobuk River. Despite earlier reports of scattered fish in the Meade and Colville Rivers, there have been no recent reports of fish from any North Slope drainage* [2].

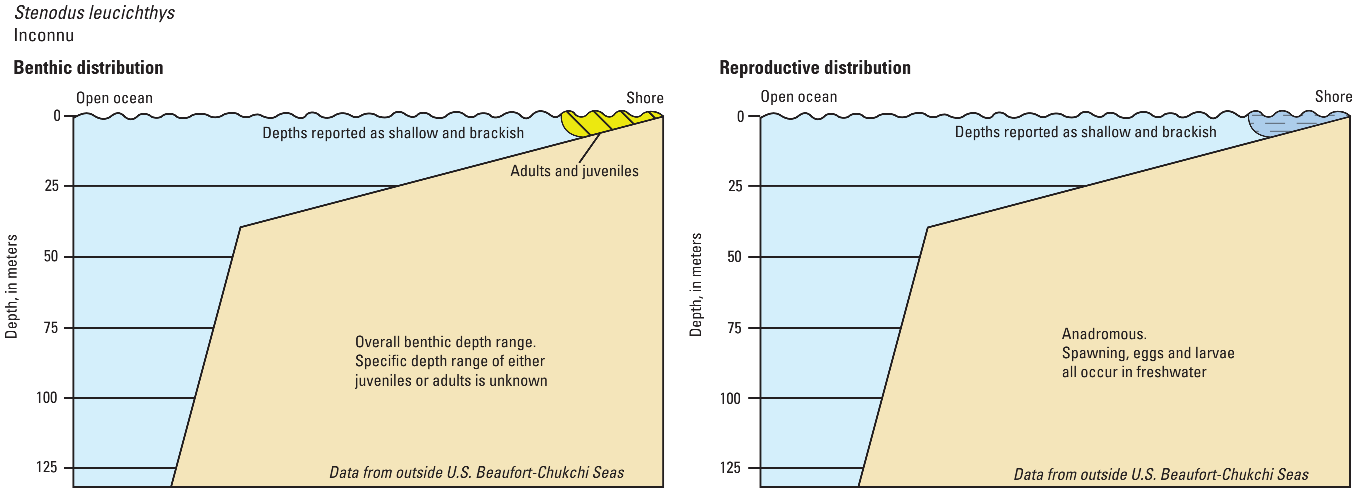
Inconnu
Stenodus leucichthys



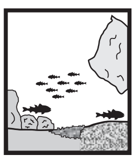
Base modified from USGS and other digital data. U.S.-Russia Maritime Boundary follows the EEZ/200-mile limit line, western edge. Coordinate reference system: projection, Lambert Azimuthal Equal Area; latitude of origin, 75.0°; horizontal datum, North American Datum of 1983.

Geographic distribution of Inconnu (*Stenodus leucichthys*), in brackish nearshore and delta waters within Arctic Outer Continental Shelf planning areas [7] based on review of published literature and specimens from historical and recent collections [2, 8].

Depth Range: Shallow waters in rivers and brackish, near-shore coastal systems [9].



Benthic and reproductive distribution of Inconnu (*Stenodus leucichthys*).



Habitats and Life History

Amphidromous.

Eggs—Size: 2.5–2.7 mm [5, 10–13]. Time to hatching: 6–9 months. Habitat: Benthic, buried in gravel in freshwater rivers [5, 10, 14].

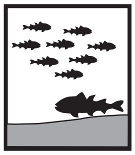
Larvae—Size at hatching: 11.0–11.3 mm [15]. Size at juvenile transformation: 7.0 cm [15]. Days to juvenile transformation: Unknown. Habitat: Newly hatched larvae are carried down river to nursery and overwintering areas in river deltas, estuaries, or lower reaches of watersheds [11].

Juveniles—Age and size: 0–7 years and about 70 cm average [5, 10, 14]. Habitat: Fresh and brackish water [5, 10, 14].

Adults—Age and size at first maturity: Males mature at 4–11 years (70–85 cm) [10, 11, 14] and females at 6–14 years (75–90 cm) [10, 14]; most fish mature at 8–12 years [16]. On average, males mature when younger and smaller than females [5]. Maximum age: At least 41 years [17]. Older studies using scales to age fish rather than otoliths underestimated fish ages beginning at about 10 years [18]. Females grow larger than males, live longer, and tend to reach maturity later [9–11, 14]. Growth rates, life spans, and size and age at maturity vary between watersheds and between populations within watersheds [11, 19]. For instance, fish in Kobuk and Selawik Rivers live longer and grow larger than those in Yukon and Kuskokwim systems; however, Kobuk and Selawik fish grow slower [14]. Maximum size: 140 cm [2]. Habitat: Large and slow moving rivers and estuaries. Entire life is spent within or adjacent to their home rivers [5, 11, 16].

Substrate—Coarse gravel and cobble mixed with sand for spawning [10, 11, 16].

Physical/chemical—Temperature: Spawning occurs at least between 0–7 °C [5, 13]. Salinity: Primarily freshwater, but some in brackish waters to about 20 parts per thousand [5, 20].



Behavior

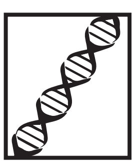
Diel—Unknown.

Seasonal—Many watersheds contain a relatively small resident freshwater population that migrate within a river system and a larger amphidromous population that may or may not enter estuarine waters in a given year [5, 10]. For example, Mackenzie River sea-going inconnu spend their first 1–2 years in freshwater and then tend to move annually into brackish and more marine coastal waters. Among these stocks, some regularly migrated to sea throughout their lives, whereas others made only occasional estuarine migrations or sea migrations followed by extended periods in freshwater or in estuaries [9]. In some rivers, resident and amphidromous forms do not share feeding, overwintering, or spawning grounds [20, 21]. Overwintering areas vary with watershed. Fish in Kobuk and Selawik Rivers overwinter in brackish waters of Hotham Inlet and Selawik Lake. Fish in the lower Yukon and Kuskokwim Rivers spend winter in those rivers' deltas [11], whereas Mackenzie River fish winter both in the delta and nearshore coastal waters of Canadian Beaufort Sea [9]. Slightly before or at about ice break-up time, adults and some juveniles begin to leave overwintering grounds [14, 22], although in some areas (for example, Selawik Lake) juveniles remain on nursery grounds throughout the year [10]. Individuals that will spawn in autumn migrate with other fish to feeding grounds during summer, but do not feed, instead they continue on to spawning grounds [5, 14]. Feeding (non-spawning) fish migrate back to overwintering grounds during August and September [5, 10, 16].

Reproductive—Spawn in their natal rivers. Spawning migrations may be long; as much as 1,800 km on the Mackenzie River [23], 1,500 km on the Yukon River [4], and 2,400 km on Siberian rivers [5]. Arrive on spawning grounds as early as 1–2 months before spawning in early autumn [5, 14, 24]. In the Selawik and Kobuk Rivers, spawning occurs in late afternoon and evening between at least 1500 and 1800 hours (local), perhaps peaking between 1545 and 2200 hours (local) [5, 10, 14]. Spawning sites are in relatively small and restricted areas, although these may change with time [5]. Inconnu are broadcast spawners in shallow and fast moving waters over coarse gravel and cobble mixed with sand [10, 11, 16]. Females release eggs at the surface and males release sperm just below the surface and rarely come to the surface [5, 11]. A female emits eggs in a series of discrete spawning spurts, returning to the bottom between each episode [5]. Eggs fall to the riverbed and are slightly adhesive to gravel and cobble [11]. Eggs are deposited in autumn and reportedly hatch around time of ice break-up in early spring [12, 16]. Some populations spawn annually [17]. However, in other populations, most individuals do not spawn annually; however, males are more likely to spawn in sequential years [16, 25, 26]. Although many migrate downstream immediately after spawning (arriving in October), others remain on spawning grounds for some length of time (as late as January) [5, 10, 16].

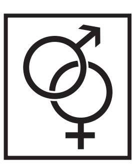
Schooling—Forms schools [5, 10, 14].

Feeding—Migrating juveniles and non-spawning adults travel to feeding areas. In western Alaska, foraging areas tend to be in lower reaches of rivers, upstream of overwintering grounds [22], but also include the brackish waters of Kotzebue Sound (for Kobuk and Selawik River fish) [5] and the Beaufort Sea (for Mackenzie River fish) [20]. Does not feed during spawning migrations (about 1–4 months) [14].



Populations or Stocks

Two distinct spawning locations have been identified, one in the upper Kobuk River and one on the refuge in the upper Selawik River. In cooperation with the Native Village of Kotzebue and Alaska Department of Fish and Game, genetic mixed stock analysis is ongoing to understand the proportion of the winter inconnu harvest that comes from each of the two spawning populations.



Reproduction

Mode—Gonochoristic, oviparous, iteroparous with external fertilization [5, 10, 11].

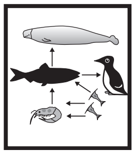
Spawning season—Autumn, primarily September and October [9, 16, 27].

Fecundity—26,000–455,000 eggs [5, 10–12, 17].

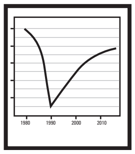
Food and Feeding

Food items—Plankton and insects for juveniles. For fish 2 years and older, food is primarily fishes (for example, whitefishes, Arctic Lamprey, Pacific Herring, and salmon) and secondarily on small invertebrates such as isopods, mysids, and insects [5, 6, 11].

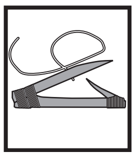
Trophic level—4.15 (standard error 0.75) [28].



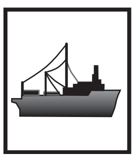
Biological Interactions
Predators—Unknown, although grayling, whitefish, and char consume newly spawned eggs [10].
Competitors—Likely omnivores such as various whitefish species, char, and grayling.



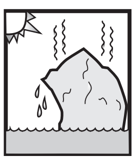
Resilience
Low, minimum population doubling time: 4.5–14 years (K=0.05–0.10; t_m=9–12; t_{max}=22; Fecundity=80,000) [28].



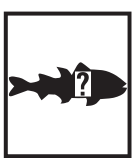
Traditional and Cultural Importance
Inconnu are an important subsistence species for humans and dogs. In many watersheds, they are usually taken around the time of spawning, but in the Selawik-Kobuk river system a large fishery operates during winter in the Hotham Inlet area [4, 9, 10]. Many fish are taken by gill nets; however, seines and hook and line also account for large numbers. The fish are eaten fresh, dried, or aged and frozen, and the fat-riddled large intestines are boiled for the oil [27].



Commercial Fisheries
Currently, inconnu are not commercially harvested. A small barter and trade fishery exists in the Kotzebue area and in Great Slave Lake [9, 25] and Inconnu are popular with recreational anglers, particularly on the Kobuk River [5].



Potential Effects of Climate Change
Unknown. Generally, Durand and others (2011) [60] predict that, at least for anadromous fishes in subarctic rivers, shifts in biology will be effected by spring ice break-up and resultant peak flows and surrounding permafrost processes: both of which affect the supply of nutrients and (or) sediment to the watershed of climate change on spring break-up intensity. Climate change and its effects on the spawning recruitment of inconnu in the Selawik River are being studied in cooperative research between U.S. Fish and Wildlife Service and U.S. Geological Survey.



Areas for Future Research [A]
Research needs include: movements and migrations, behavior of larval and juveniles in response to environmental variables, and enumeration of predator-prey relationships in coastal waters. Catch and subsistence use patterns should continue to be monitored.

References Cited

Alt, K.T., 1969, Taxonomy and ecology of the inconnu, *Stenodus leucichthys nelma*, in Alaska: Anchorage, University of Alaska, Biological Papers of the University of Alaska, no. 12, 63 p. [10]

Alt, K.T., 1987, Review of sheefish (*Stenodus leucichthys*) studies in Alaska: Juneau, Alaska Department of Fish and Game, Division of Sport Fish, Fishery Manuscript no. 3., 69 p. [5]

Alt, K.T., 1988, Biology and management of inconnu (*Stenodus leucichthys*) in Alaska: Finnish Fisheries Research, v. 9, p. 127–132. [14]

Alt, K.T., 2008, Alaska wildlife notebook series—Sheefish: Alaska Department of Fish and Game. [11]

Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p. [2]

Bibliography

1. George, C., Moulton, L.L., and Johnson, M., 2007, A field guide to the common fishes of the North Slope of Alaska: Alaska Department of Wildlife Management, North Slope Borough, 93 p.

2. Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p.

3. Moyle, P.B., and Cech, J.J., Jr., 1996, Fishes—An introduction to ichthyology: Upper Saddle River, New Jersey, Prentice-Hall, 590 p.

4. Savereide, J.W., 2002, Under-ice gillnet harvest of sheefish in Hotham Inlet in 2000–2001—Fisheries data series: U.S. Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program, Final Report (Study No. 00-020), and Alaska Department of Fish and Game, Division of Sport Fish, Fairbanks, Alaska, No. 02-04, 22 p.

5. Alt, K.T., 1987, Review of sheefish (*Stenodus leucichthys*) studies in Alaska: Juneau, Alaska Department of Fish and Game, Division of Sport Fish, Fishery Manuscript no. 3., 69 p.

6. Kendel, R.E., Johnston, R.A.C., Lobsiger, U., and Kozak, M.D., 1975, Fishes of the Yukon coast: Victoria, British Columbia, Department of the Environment (Canada), Beaufort Sea Project, Technical Report 6, 114 p.

7. Minerals Management Service, 2008, Beaufort Sea and Chukchi Sea planning areas—Oil and Gas Lease Sales 209, 212, 217, and 221: U.S. Department of the Interior, Minerals Management Service Alaska OCS Region, OCS EIS/EA, MMS 2008-0055, 538 p.

8. Mecklenburg, C.W., and Mecklenburg, T.A., 2009, Arctic marine fish museum specimens, 2nd ed., Metadata report and database submitted to ArcOD, Institute of Marine Science: University of Alaska, Fairbanks, by Point Stephens Research, metadata report accessed August 8, 2012, at http://www.arcodiv.org/Database/Fish_datasets.html.

9. Howland, K.L., Tonn, W.M., Babaluk, J.A., and Tallman, R.F., 2001, Identification of freshwater and anadromous inconnu in the Mackenzie River system by analysis of otolith strontium: Transactions of the American Fisheries Society, v. 130, no. 5, p. 725–741.

10. Alt, K.T., 1969, Taxonomy and ecology of the inconnu, *Stenodus leucichthys nelma*, in Alaska: Anchorage, University of Alaska, Biological Papers of the University of Alaska, no. 12, 63 p.

11. Alt, K.T., 2008, Alaska wildlife notebook series—Sheefish: Alaska Department of Fish and Game.

12. Chereshnev, I., Shestakov, A.V., Yusupov, R.R., Shtundyuk, Y.V., and Slugin, I.V., 2000, Biology of nelma *Stenodus leucichthys nelma* (Coregonidae) from the Anadyr basin (the northeast of Russia): Journal of Ichthyology, v. 40, no. 6, p. 457–470.

13. Howland, K.L., Tonn, W.M., and Tallman, R.F., 2002, The influence of genetic and environmental factors on egg development and juvenile growth in two life history forms of inconnu (*Stenodus leucichthys*), *in* Todd, T., and Fleischer, G., eds., Biology and management of coregonid fishes, 1999—Proceedings of the seventh international symposium on the biology and management of coregonid fishes held in Ann Arbor, Michigan, U.S.A.: Schweizerbart, Stuttgart, Germany, p. 253–264.

14. Alt, K.T., 1988, Biology and management of inconnu (*Stenodus leucichthys*) in Alaska: Finnish Fisheries Research, v. 9, p. 127–132.

15. Sturm, E.A., 1994, Description and identification of larval and juvenile *Stenodus leucichthys nelma* (Güldenstadt) from central Alaska: Copeia, v. 1994, no. 2, p. 472–484.

16. Hander, R.F., Brown, R.J., and Underwood, T.J., 2008, Comparison of inconnu spawning abundance estimates in the Selawik River, 1995, 2004, and 2005, Selawik National Wildlife Refuge: U.S. Fish and Wildlife Service, Alaska Fisheries Technical Report No. 99.

17. Brown, R.J., Brown, C., Braem, N.M., Carter, W.K., III, Legere, N., and Slayton, L., 2012, Whitefish biology, distribution, and fisheries in the Yukon and Kuskokwim river drainages in Alaska—A synthesis of available information: U.S. Fish and Wildlife Service, Alaska Fisheries Data Series Number 2012-4, 316 p.

18. Howland, K.L., Gendron, M., Tonn, W.M., and Tallman, R.F., 2004, Age determination of a long-lived coregonids from the Canadian North—Comparison of otoliths, fin rays and scales in inconnu (*Stenodus leucichthys*): Annales Zoologici Fennici, v. 41, p. 205–214.

19. Alt, K.T., 1973b, Age and growth of the inconnu (*Stenodus leucichthys*) in Alaska: Journal of the Fisheries Research Board of Canada, v. 30, no. 1, p. 457–459.

20. Howland, K.L., Tonn, W.M., and Goss, G., 2001, Contrasts in the hypo-osmoregulatory abilities of a freshwater and an anadromous population of inconnu: Journal of Fish Biology, v. 59, no. 4, p. 916–927.

21. Howland, K.L., Tallman, R.F., and Tonn, W.M., 2000, Migration patterns of freshwater and anadromous inconnu in the Mackenzie River system: Transactions of the American Fisheries Society, v. 129, no. 1, p. 41–59.

22. Alt, K.T., 1977, Inconnu, *Stenodus leucichthys*, migration studies in Alaska 1961–74: Journal of the Fisheries Research Board of Canada, v. 34, no. 1, p. 129–133.

23. Stephenson, S.A., Burrows, J.A., and Babaluk, J.A., 2005, Long-distance migrations by inconnu (*Stenodus leucichthys*) in the Mackenzie River system: Arctic, v. 58, no. 1, p. 21–25.

24. Underwood, T.J., 2000, Abundance, length composition, and migration of spawning inconnu in the Selawik River, Alaska: North American Journal of Fisheries Management, v. 20, no. 2, p. 386–393.

25. Alt, K.T., and Taube, T.T., 2002, Abundance and composition of inconnu spawners from the Kobuk River, Alaska: Archiv für Hydrobiologie, Special Issues Advances in Limnology, v. 57, p. 639–645.

26. Taube, T.T., 1997, Abundance and composition of sheefish in the Kobuk River, 1996: Anchorage, Alaska Department of Fish and Game, Fishery Manuscript No. 97-1, 38 p.

27. Georgette, S., and Loon, H., 1990, Subsistence and sport fishing of sheefish on the upper Kobuk River, Alaska: Kotzebue, Alaska Department of Fish and Game, Division of Subsistence, Technical Paper No. 175.

28. Froese, R., and Pauly, D., eds., 2012, FishBase—Global information system on fishes: FishBase database, accessed July 8, 2012, at http://www.fishbase.org.

29. Durand, J.R., Lusardi, R.A., Nover, D.M., Suddeth, R.J., Carmona-Catot, G., Connell-Buck, C.R., and others, 2011, Environmental heterogeneity and community structure of the Kobuk River, Alaska, in response to climate change: Ecosphere, v. 2, no. 4.

Glacier Lanternfish (*Benthosema glaciale*)

(Reinhardt, 1837)

Family Myctophidae

Glacier Lanternfish (*Benthosema glaciale*). Photograph by Rudolf Svensen, http://www.uwp.no.

Note: *Except for geographic range data, all information is from areas outside of the study area.*

Colloquial Name: *None within U.S. Chukchi and Beaufort Seas.*

Ecological Role: Rarely observed in the U.S. Chukchi Sea. The role of the species in regional food webs is minimal.

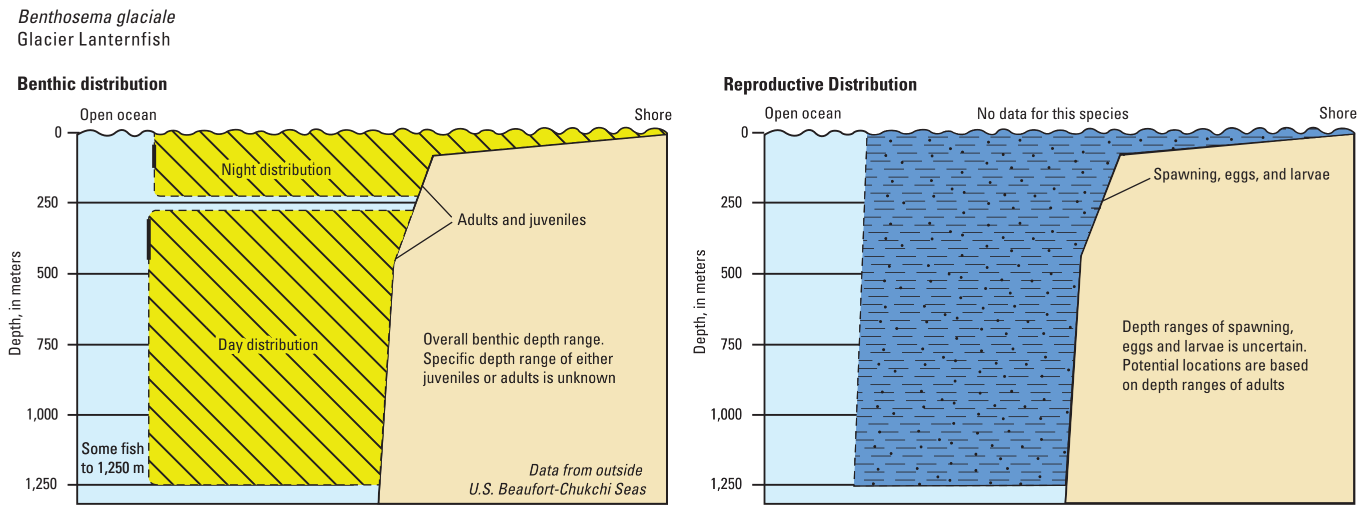
Physical Description/Attributes: Small, silvery fish with compressed body, blunt head, large eyes, and numerous round photophores in a specific pattern. For specific diagnostic characteristics, see *Fishes of Alaska* (Mecklenburg and others, 2002, p. 249) [1]. Swim bladder: Present [2]. Antifreeze glycoproteins in blood serum: Unknown.

Range: *U.S. Chukchi Sea* [1, 3]. Elsewhere, from Baffin Bay and northwest Greenland, east to Svalbard Islands, Norway; Barents Sea; and Kara Sea [3].

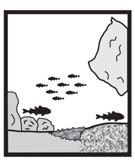
Relative Abundance: *Rare, one record from U.S. Chukchi Sea near Point Barrow, Alaska* [1, 3]. Elsewhere, common in Barents Sea [6].

Geographic distribution of Glacier Lanternfish (*Benthosema glaciale*), within Arctic Outer Continental Shelf planning areas [4] based on review of published literature and specimens from historical and recent collections [1, 3, 5].

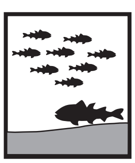
Depth Range: Near surface to 225 m at night [1], mainly 30–90 m [7]; descending to 275–1,456 m during day [1, 5], mainly 350–450 m [7].



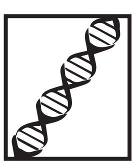
Benthic and reproductive distribution of Glacier Lanternfish (*Benthosema glaciale*).



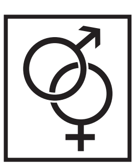
Habitats and Life History
Eggs—Size: 0.75–0.80 mm [8].Time to hatching: Unknown. Habitat: Pelagic [9].
Larvae—Size at hatching: *Unknown*. 5 mm or less [8]. Size at juvenile transformation: 11–15 mm [8]. Days to juvenile transformation: Unknown. Habitat: Pelagic [9].
Juveniles—Age and size: Age unknown. 1.1–5.0 cm [6, 8]. Habitat: Epipelagic to mesopelagic [1].
Adults—Age and size at first maturity: 2–3 years and 4.5–5.0 cm [6]. Maximum age: 8 years in Barents Sea [6]. Maximum size: As long as 10.3 cm (reported as both TL and SL) [10], usually less than 7.0 cm [1]. Habitat: Epipelagic to mesopelagic, typically offshore [1].
Substrate—Unknown.
Physical/chemical—Temperature: Common between 4 and 16 °C in northwest Atlantic Ocean. Has been captured at temperatures of -0.1–21 °C [5]. Salinity: Marine [9].



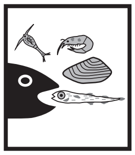
Behavior
Diel—Mesopelagic by day, epipelagic by night [1].
Seasonal—Unknown.
Reproductive—Spawns pelagically [6].
Schooling—Forms schools [6].
Feeding—Filter feeder [6]. Feeds year-round, but activity is most intensive in spring and summer [11].



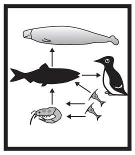
Populations or Stocks
There have been no studies.



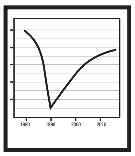
Reproduction
Mode—Oviparous, separate sexes [9].
Spawning season—June–July in Barents Sea [6]. Early spring off Nova Scotia, Canada [8].
Fecundity—750–800 eggs [6].



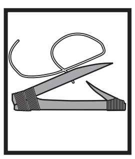
Food and Feeding
Food items—Mainly copepods and euphausiids [6, 7, 11].
Trophic level—2.99 (standard error 0.29) [12].



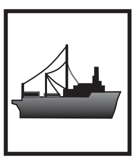
Biological Interactions
Predators—Leach's Storm-Petrels off Newfoundland, Canada [13]. For lanternfish in general, predators are squids, larger fishes, and marine mammals [1].
Competitors—As one of the few mesopelagic species in the U.S. Chukchi Sea, Glacier Lanternfish probably have few fish competitors, especially at depth. Arctic Cod and Ice Cod co-occur with Glacier Lanternfish and may compete for zooplankton prey.



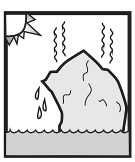
Resilience
Medium, minimum population doubling time: 1.4–4.4 years (K=0.20–0.45; t_m=2–3; t_{max}=8; fecundity=700) [12].



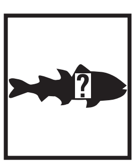
Traditional and Cultural Importance
None reported.



Commercial Fisheries
Glacier Lanternfish are not currently harvested commercially.



Potential Effects of Climate Change
Unknown.



Areas for Future Research [B]
Little is known about the ecology and life history of this species. Research needs include: (1) depth and location of pelagic larvae, (2) depth, location, and timing of young-of-the-year benthic recruitment, (3) preferred depth ranges for juveniles and adults, (4) spawning season, (5) seasonal and ontogenetic movements, (6) population studies, (7) prey, and (8) predators.

References Cited

Gjøsaeter, J., 1981, Growth, production and reproduction of the Myctophid fish *Benthosema glaciale* from western Norway and adjacent seas: Fiskeridirektoratets skrifter, Serie Havundersøkelse, v. 17, no. 3, p. 79–108. [8]

Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p. [1]

Mecklenburg, C.W., Møller, P.R., and Steinke, D., 2011, Biodiversity of Arctic marine fishes—Taxonomy and zoogeography: Marine Biodiversity, v. 41, no. 1, p. 109–140, Online Resource 1. [3]

Sameoto, D.D., 1988, Feeding of lantern fish *Benthosema glaciale* off the Nova Scotia shelf: Marine Ecology Progress Series, v. 44, p. 113–129. [7]

Wienerroither, R., Johannesen, E., Langøy, H., Børve Eriksen, K., de Lange Wenneck, T., Høines, Å., Bjelland, O., Aglen, A., Prokhorova, T., Murashko, P., Prozorkevich, D., Konstantin, Byrkjedal, I., Langhelle Drevetnyak, and G., Smirnov, O., 2011, Atlas of the Barents Sea fishes: IMR/PINRO Joint Report Series 1-2011, ISSN 1502-8828, 274 p. [6]

Bibliography

1. Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p.

2. Salvanes, A.G.V., and Kristoffersen, J.B., 2001, Mesopelagic fishes, *in* Steels, J., and others, eds., Encyclopedia of ocean sciences: Academic Press, p. 1,711–1,717.

3. Mecklenburg, C.W., Møller, P.R., and Steinke, D., 2011, Biodiversity of Arctic marine fishes—Taxonomy and zoogeography: Marine Biodiversity, v. 41, no. 1, p. 109–140, Online Resource 1.

4. Minerals Management Service, 2008, Beaufort Sea and Chukchi Sea planning areas—Oil and Gas Lease Sales 209, 212, 217, and 221: U.S. Department of the Interior, Minerals Management Service Alaska OCS Region, OCS EIS/EA, MMS 2008-0055, 538 p.

5. Mecklenburg, C.W., Mecklenburg, T.A., Sheiko, B.A., and Steinke, D., 2016, Pacific Arctic marine fishes: Akureyri, Iceland, Conservation of Arctic Flora and Fauna, Monitoring Series Report No. 23, 406 p., accessed May 10, 2016, at http://caff.is/monitoring-series/370-pacific-arcticmarine-fishes.

6. Wienerroither, R., Johannesen, E., Langøy, H., Børve Eriksen, K., de Lange Wenneck, T., Høines, Å., Bjelland, O., Aglen, A., Prokhorova, T., Murashko, P., Prozorkevich, D., Konstantin, Byrkjedal, I., Langhelle Drevetnyak, and G., Smirnov, O., 2011, Atlas of the Barents Sea fishes: IMR/PINRO Joint Report Series 1-2011, ISSN 1502-8828, 274 p.

7. Sameoto, D.D., 1988, Feeding of lantern fish *Benthosema glaciale* off the Nova Scotia shelf: Marine Ecology Progress Series, v. 44, p. 113–129.

8. Gjøsaeter, J., 1981, Growth, production and reproduction of the Myctophid fish *Benthosema glaciale* from western Norway and adjacent seas: Fiskeridirektoratets skrifter, Serie Havundersøkelse, v. 17, no. 3, p. 79–108.

9. Love, M.S., 2011, Certainly more than you wanted to know about the fishes of the Pacific Coast: Santa Barbara, California, Really Big Press, 649 p.

10. Love, M.S., Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2005, Resource inventory of marine and estuarine fishes of the West Coast and Alaska—A checklist of North Pacific and Arctic Ocean species from Baja California to the Alaska-Yukon border: Seattle, Washington, U.S. Department of the Interior, U.S. Geological Survey, Biological Resources Division, OCS Study MMS 2005-030 and USGS/NBII 2005-001, 276 p.

11. Gjøsaeter, J., 1973, The food of the myctophid fish, *Benthosema glaciale* (Reinhardt), from western Norway: Sarsia, v. 52, no. 1, p. 53–58.

12. Froese, R., and Pauly, D., eds., 2012, FishBase—Global information system on fishes: FishBase database, accessed July 8, 2012, at http://www.fishbase.org.

13. Hedd, A., and Montevecchi, W.A., 2006, Diet and trophic position of Leach's storm-petrel *Oceanodroma leucorhoa* during breeding and moult, inferred from stable isotope analysis of feathers: Marine Ecology Progress Series, v. 322, p. 291–301.

Ice Cod to Pacific Cod

Ice Cod (*Arctogadus glacialis*)
(Peters, 1872)

Family Gadidae

Ice Cod (*Arctogadus glacialis*) 221 mm, Chukchi Borderland, 2009. Photograph by C.W. Mecklenburg, Point Stephens Research.

Note on taxonomy: *Evidence from morphology and molecular genetics demonstrates that* Arctogadus borisovi *(Dryagin, 1932) is a junior synonym of* A. glacialis [1]. *Data on fish originally identified as* A. borisovi *are included here*. Commmonly referred to as Polar Cod in North America.

Colloquial Name: *None within U.S. Chukchi and Beaufort Seas*.

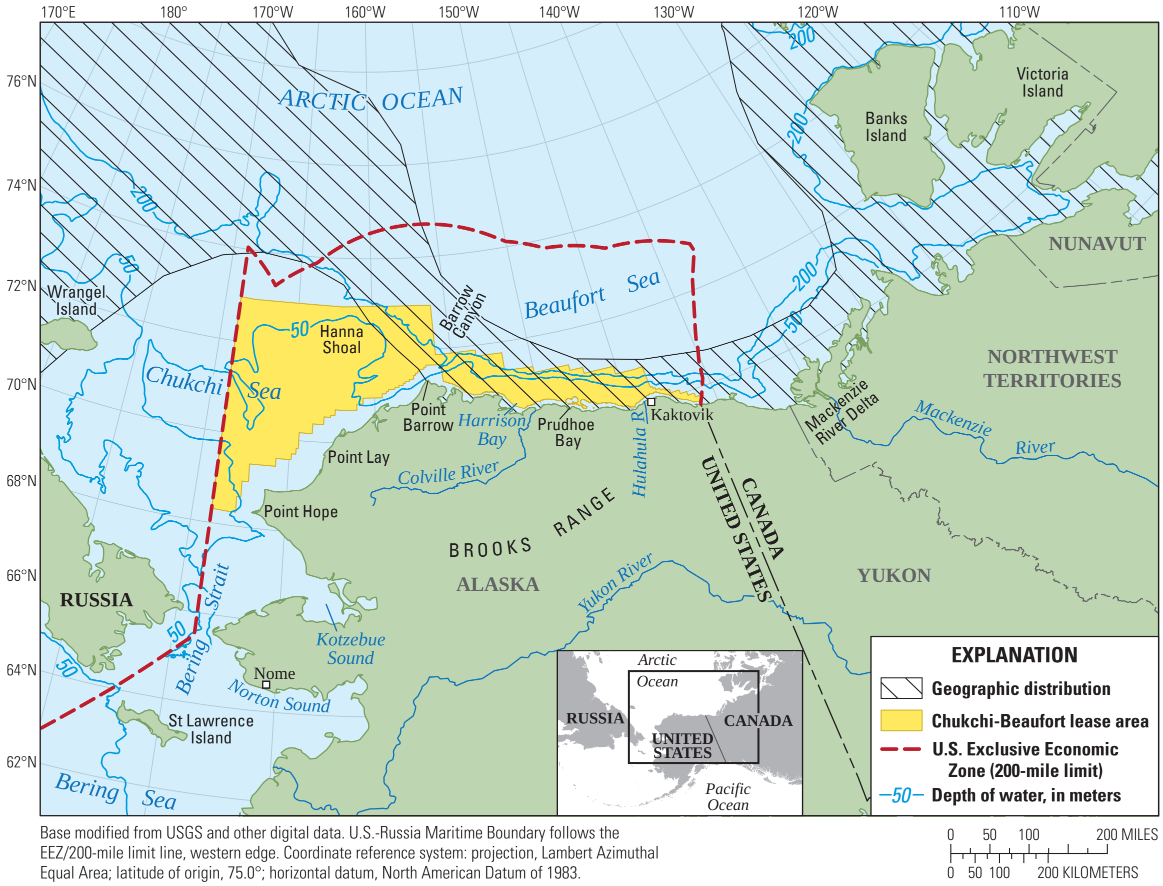
Ecological Role: The ecological role of the species in marine ecosystems of the U.S. Chukchi and Beaufort Seas is not as significant as Polar and Saffron Cod.

Physical Description/Attributes: An olive brown to bluish gray cod with darker fins and head. For specific diagnostic characteristics, see *Fishes of Alaska* (Mecklenburg and others, 2002, p. 291–292) [2]. Swim bladder: Present; no otophysic connection [2]. Antifreeze glycoproteins in blood serum: Unknown.

Range: *U.S. Beaufort* [2] *and Chukchi Sea* [3, 4]. Worldwide, circumpolar, northward to at least 81°41’N; Arctic Canada south to southern tip of Greenland, east through Barents Sea to East Siberian Sea and Chukchi Sea [2–4].

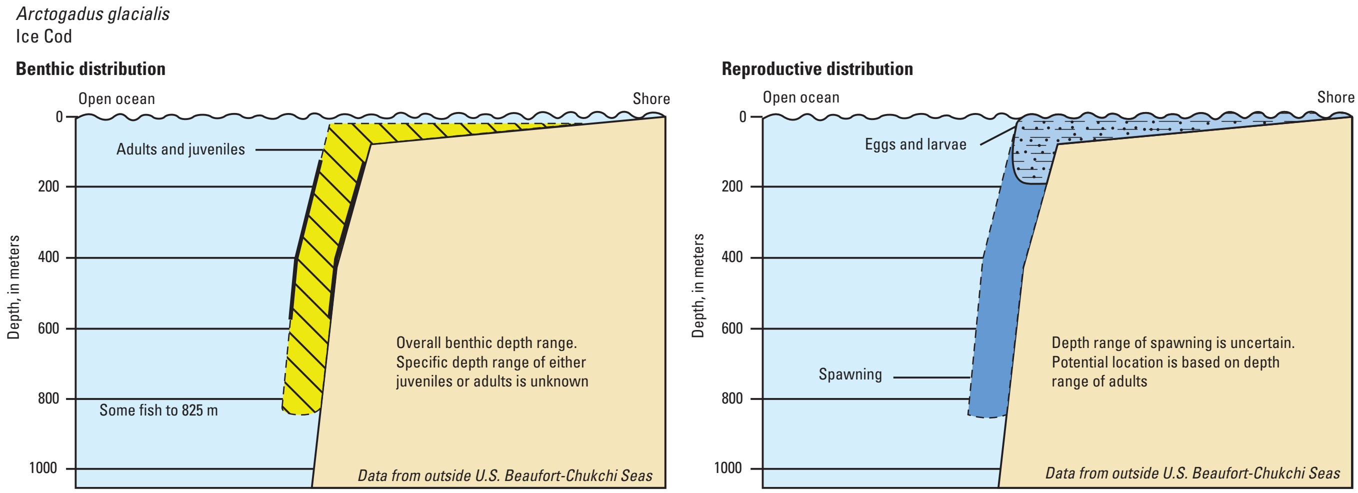
Relative Abundance: *Rare in U.S. Beaufort Sea (two specimens captured north of Point Barrow)* [2] *and Chukchi Sea (one specimen found on beach at Wainwright)* [4].Abundant to at least as far eastward to deep waters off Tuktoyaktuk Peninsula and off Capes Bathurst and Parry, Canada [6–8].

Ice Cod
Arctogadus glacialis

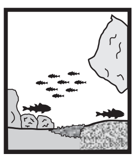


Geographic distribution within Arctic Outer Continental Shelf planning areas [5] of Ice Cod (*Arctogadus glacialis*) based on review of published literature and specimens from historical and recent collections [3, 4].

Depth Range: 5–930 m, on continental shelf and upper slope [1, 2]. Highest abundance is found off Europe at 300–400 m [9]. In northeast Greenland fjords, abundant at 120–575 m [10]. Eggs and larvae are pelagic [11] but specific depths unknown.

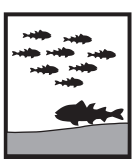


Benthic and reproductive distribution of Ice Cod (*Arctogadus glacialis*).



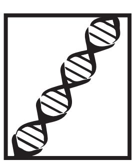
Habitats and Life History

Eggs—Size: Unknown. Time to hatching: Unknown. Size: Unknown. Habitat: Pelagic [11].
Larvae—Size at hatching: Unknown. Size at juvenile transformation: Unknown. Days to juvenile transformation: Unknown. Habitat: Pelagic [11].
Juveniles—Age and size: Unknown. Habitat: Cryopelagic and benthic [9].
Adults—Age and size at first maturity: Unknown. Females 25–26 cm long (TL) have been found with ripening gonads [12]. Maximum age: At least 11 years [13]. Maximum size: 60 cm TL [2] and 1.2 kg [12]. Habitat: Nearshore to well offshore [4, 8, 14]. Cryopelagic and benthic [5], throughout the water column (including near the seafloor) as well as under ice and within ice cracks [10, 15, 16].
Substrate—Unknown.
Physical/chemical—Temperature: -1.7 to about 4 °C [10], may prefer temperatures of about 1 °C or less [1, 10]. Salinity: Marine, estuarine, and occasionally fresh waters from near the coast to well offshore [8, 14].
Ice dependence—Although characterized as an ice-associate, also found well away from ice, sometimes in large numbers [10, 17].



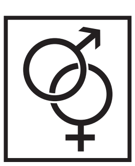
Behavior

Diel—Unknown.
Seasonal—Unknown.
Reproductive—Unknown.
Schooling—Forms schools [2].
Feeding—Opportunistic pelagic feeder [9].



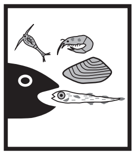
Populations or Stocks

There have been no studies.



Reproduction mode

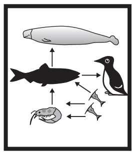
Mode—Oviparous [11].
Spawning season—Ripe fish were observed in October and during the summer in the European Arctic [9, 10].
Fecundity—Unknown.



Food and Feeding

Food items—Crustaceans (for example, mysids, copepods, and amphipods), fishes, and polychaetes comprise much of the diet of this species. Fishes assume a greater part of the diet in larger cod [15, 18, 19].

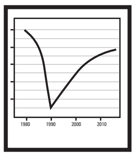
Trophic level—3.82 (standard error 0.61) [20].



Biological Interactions

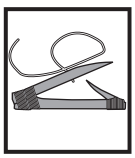
Predators—Commonly, bearded seals and narwhals in the Canadian Arctic [21, 22].

Competitors—Unknown.



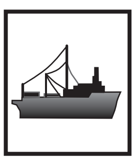
Resilience

Medium, minimum population doubling time: 1.4–4.4 years (Preliminary *K* or Fecundity) [20].



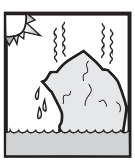
Traditional and Cultural Importance

None reported. Form only a small part of the subsistence fisheries in the Canadian Arctic [8]. Commercially fished for fishmeal and oil in Norway, Greenland and northern Siberia [23].



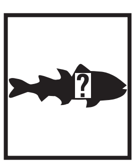
Commercial Fisheries

Currently, Ice Cod are not commercially harvested.



Potential Effects of Climate Change

Unknown.



Areas for Future Research [B]

Little is known about the ecology and life history of this species. Although information should improve with increased sampling, the role of this species in the gadid assemblage and how this might change with global warming is of research interest. Spawning areas and other important habitats remain to be described.

References Cited

Aschan, M., Karamushko, O.V., Byrkjedal, I., Wienerroither, R., Borkin, I.V., and Christiansen, J.S., 2009, Records of the gadoid fish *Arctogadus glacialis* (Peters, 1874) in the European Arctic: Polar Biology, v. 32, no. 7, p. 963–970. [9]

Christiansen, J.S., ed., 2003, TUNU-1 Expedition—The fish fauna of the NE Greenland fjord systems—Technical report: Tromsø, Norway, University of Tromsø, Norwegian College of Fishery Science, Institute of Aquatic Resources, 33 p. [10]

Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p. [2]

Mecklenburg, C.W., Møller, P.R., and Steinke, D., 2011, Biodiversity of Arctic marine fishes—Taxonomy and zoogeography: Marine Biodiversity, v. 41, no. 1, p. 109–140, Online Resource 1. [3]

Stewart, D.B., Ratynski, R.A., Bernier, L.M.J., and Ramsey, D.J., 1993, A fishery development strategy for the Canadian Beaufort Sea-Amundsen Gulf area: Canadian Technical Report Fisheries and Aquatic Sciences 1910, 135 p. [8]

Bibliography

1. Jordan, A.D., Møller, P.R., and Nielsen, J.G., 2003, Revision of the Arctic cod genus *Arctogadus*: Journal of Fish Biology, v. 62, no. 6, p. 1,339–1,352.
2. Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p.
3. Mecklenburg, C.W., Møller, P.R., and Steinke, D., 2011, Biodiversity of Arctic marine fishes—Taxonomy and zoogeography: Marine Biodiversity, v. 41, no. 1, p. 109–140, Online Resource 1.
4. Mecklenburg, C.W., Mecklenburg, T.A., Sheiko, B.A., and Steinke, D., 2016, Pacific Arctic marine fishes: Akureyri, Iceland, Conservation of Arctic Flora and Fauna, Monitoring Series Report No. 23, 406 p., accessed May 10, 2016, at http://caff.is/monitoring-series/370-pacific-arcticmarine-fishes.
5. Minerals Management Service, 2008, Beaufort Sea and Chukchi Sea planning areas—Oil and Gas Lease Sales 209, 212, 217, and 221: U.S. Department of the Interior, Minerals Management Service Alaska OCS Region, OCS EIS/EA, MMS 2008-0055, 538 p.
6. Byers, S.C., and Kashino, R.K., 1980, Survey of fish populations in Kugmallit Bay and Tuktoyaktuk Harbour, Northwest Territories: Dobrocky Seatech Limited Ocean Services for Dome Petroleum Limited, Calgary, Alberta, 20 p.
7. Arctic Laboratories Limited, 1987, Beaufort Ocean dumpsite characterization: Prepared for Environment Protection, Conservation and Protection, Environment Canada, Yellowknife, Northwest Territories, by Arctic Laboratories Limited and LGL Limited, 135 p.
8. Stewart, D.B., Ratynski, R.A., Bernier, L.M.J., and Ramsey, D.J., 1993, A fishery development strategy for the Canadian Beaufort Sea-Amundsen Gulf area: Canadian Technical Report Fisheries and Aquatic Sciences 1910, 135 p.
9. Aschan, M., Karamushko, O.V., Byrkjedal, I., Wienerroither, R., Borkin, I.V., and Christiansen, J.S., 2009, Records of the gadoid fish *Arctogadus glacialis* (Peters, 1874) in the European Arctic: Polar Biology, v. 32, no. 7, p. 963–970.
10. Christiansen, J.S., ed., 2003, TUNU-1 Expedition—The fish fauna of the NE Greenland fjord systems—Technical report: Tromsø, Norway, University of Tromsø, Norwegian College of Fishery Science, Institute of Aquatic Resources, 33 p.
11. Love, M.S., 2011, Certainly more than you wanted to know about the fishes of the Pacific Coast: Santa Barbara, California, Really Big Press, 649 p.
12. Wienerroither, R., Johannesen, E., Langøy, H., Børve Eriksen, K., de Lange Wenneck, T., Høines, Å., Bjelland, O., Aglen, A., Prokhorova, T., Murashko, P., Prozorkevich, D., Konstantin, Byrkjedal, I., Langhelle Drevetnyak, and G., Smirnov, O., 2011, Atlas of the Barents Sea fishes: IMR/PINRO Joint Report Series 1-2011, ISSN 1502-8828, 274 p.

13. Boulva, J., 1979, Comparison of the Arctic cod (*Boreogadus saida*), the polar cod (*Arctogadus glacialis*), and the toothed cod (*A. borisovi*): Quebec City, Quebec, Government of Canada, Fisheries and Oceans, Fisheries Sciences Division, CAFSAC Research Document 79/50, 12 p.

14. Berg, L.S., 1949, Freshwater fishes of the U.S.S.R. and adjacent countries, volume 3 (4th ed.): Moscow, Academy of Sciences of the U.S.S.R. Zoological Institute, 250 p. [Translated from Russian by Israel Program for Scientific Translations, Jerusalem, IPST Catalog No. 743.]

15. Walters, V., 1961, Winter abundance of *Arctogadus glacialis* in the polar basin: Copeia, no. 2, p. 236–237.

16. McAllister, D.E., 1975, Ecology of the marine fishes of Arctic Canada, *in* Proceedings of the Circumpolar Conference on Northern Ecology, September 15–18, 1975: Ottawa, National Research Council of Canada, p. II-49–II-65.

17. Borkin, I.V., and Mel'yantsev, R.V., 1984, New data on the distribution of polar cod, *Arctogadus glacialis* (Gadidae), in the Arctic region: Journal of Ichthyology, v. 24, no. 1, p. 101–103.

18. Andriashev, A.P., 1954, Fishes of the northern seas of the U.S.S.R.—Keys to the fauna of the U.S.S.R.: Academy of Sciences of the U.S.S.R., Zoological Institute, no. 53, 566 p. [Russian, translation by Israel Program for Scientific Translation, Jerusalem, 1964, 617 p., available from U.S. Department of Commerce, Springfield, Virginia.]

19. Joensen, J., 2008, Comparative feeding ecology of the sympatric cod fishes *Arctogadus glacialis* and *Boreogadus saida* in north-east Greenland evaluated from diet and stable isotope analyses: Tromsø, Norway, University of Tromsø, Master's thesis. 54 p.

20. Froese, R., and Pauly, D., eds., 2012, FishBase—Global information system on fishes: FishBase database, accessed July 8, 2012, at http://www.fishbase.org.

21. Finley, K.J., and Gibb, E.J., 1982, Summer diet of the narwhal (*Monodon monoceros*) in Pond Inlet, northern Baffin Island: Canadian Journal of Zoology, v. 60, no. 12, p. 3,353–3,363.

22. Finley, K.J., and Evans, C.R., 1983, Summer diet of the bearded seal (*Erignathus barbatus*) in the Canadian High Arctic: Arctic, v. 36, no. 1, p. 82–89.

23. Cohen, D.M., Inada, T., Iwamoto, T., and Scialabba, N., 1990, FAO species catalogue, volume 10—Gadiform fishes of the world (Order Gadiformes)—An annotated and illustrated catalogue of cods, hakes, grenadiers and other gadiform fishes known to date: Rome, Food and Agriculture Organization of the United Nations, FAO Fisheries Synopsis, no. 125, v. 10, 442 p.

Arctic Cod (*Boreogadus saida*)
(Lepechin, 1774)

Family Gadidae

Arctic Cod (*Boreogadus saida*) 174 mm TL, Chukchi Sea, 2004. Photograph by B.A. Sheiko and C.W. Mecklenburg, Russian Academy of Sciences and Point Stephens Research.

Colloquial Name: Iñupiat: *Iqalugaq*, *Uugaq* [1]. *Tomcod* [2].

Notes on Taxonomy: *Boreogadus saida is referred to as both "Arctic Cod" and "Polar Cod" in North American scientific literature. The American Fisheries Society and Society of Ichthyologists and Herpetologists recommend using "Polar Cod" for Boreogadus saida to bring consistency with European conventions and this recommendation is gaining in acceptance in contemporary reporting and publications. We chose to use "Arctic Cod" for Boreogadus saida in this report to ensure consistency with the vast majority of Alaskan literature and to avoid confusion with Ice Cod, which has been referred to as Polar Cod by North American researchers. Anyone using literature that does not specify the scientific name must read carefully to decide which species is meant. However*, A. glacialis *is rare in Arctic Alaska waters, and most references to Polar Cod from that region that do not provide the scientific name will refer to* B. saida.

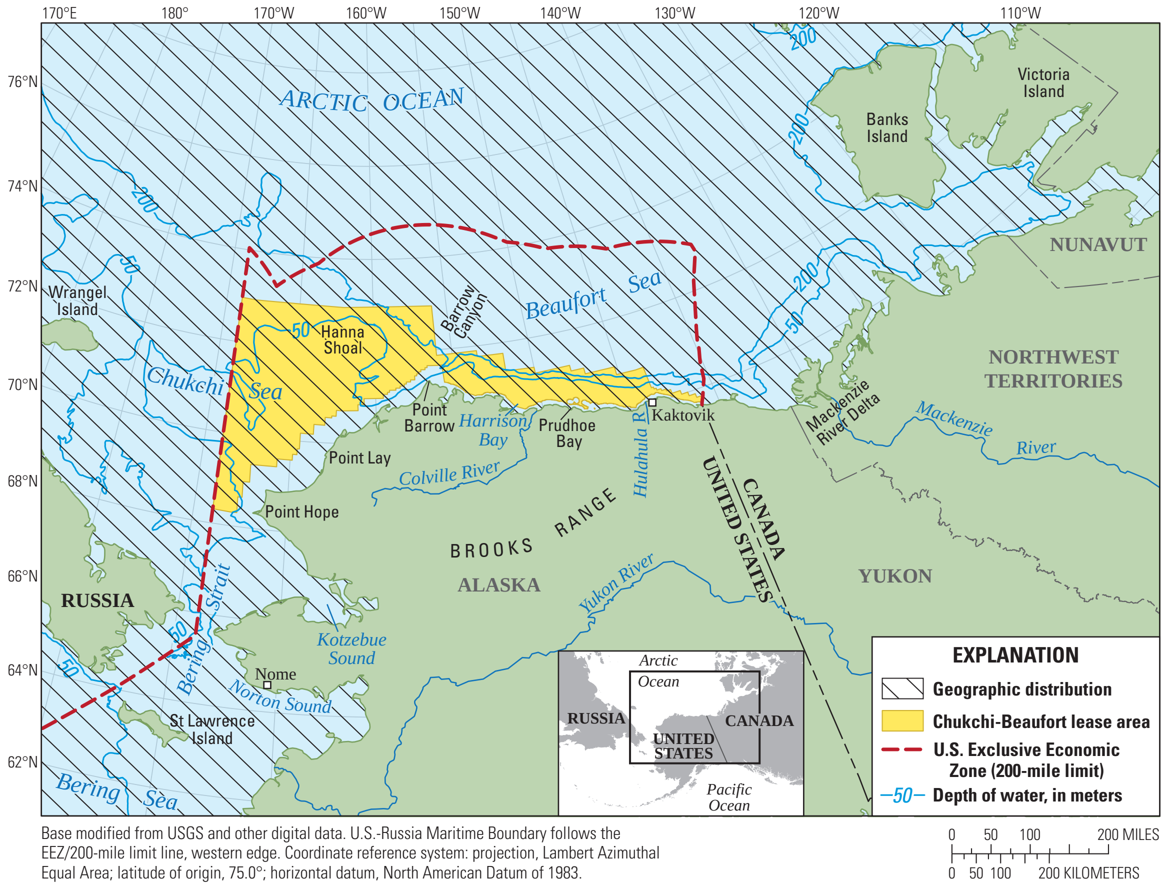
Ecological Role: Arctic Cod play a vital role in anchoring Arctic food webs in the U.S. Chukchi and Beaufort Seas. The small fish is one of the main consumers of plankton that flourish around sea ice. Arctic Cod compose 92 percent of all fish in numbers and 80 percent in weight in a 2008 western Beaufort Sea fish survey [3], and this species comprises the forage base for a wide range of marine mammals and birds. A recent model predicted a mass loss of most Arctic Cod within 30 years because of rising temperatures and receding ice pack. Key interactions between sea ice, Arctic Cod biology, and marine ecosystem function must be better understood to identify possible effects of climate change and cumulative effects of human activities.

Physical Description and Attributes: Brownish back and sides with violet or yellowish sheen covered with tiny black dots, and silvery white lower sides and belly. Fins are dusky yellow or gray, and dorsal and caudal fins are edged in white. For specific diagnostic characteristics, see *Fishes of Alaska* (Mecklenburg and others, 2002, p. 290) [4]. Swim bladder: present. Antifreeze glycoproteins in blood serum: Present [5].

Range: *Throughout U.S. Chukchi and Beaufort Seas from very shallow, neritic waters to well offshore (although abundance hundreds of kilometers offshore is poorly known)* [6–9]. A circumpolar species, documented in Chukchi Sea northward nearly to the North Pole at 88°26′N, 126°26′E. In continental shelf waters, west and south of U.S. Chukchi Sea from Siberian Arctic to Olyutorskiy Bay in western Bering Sea and to Bristol Bay in eastern Bering Sea; and east of U.S. Beaufort Sea continuous throughout the Canadian Beaufort Sea [10, 11].

Relative Abundance: *Very abundant in U.S. Chukchi and Beaufort Seas* [9, 12–15].

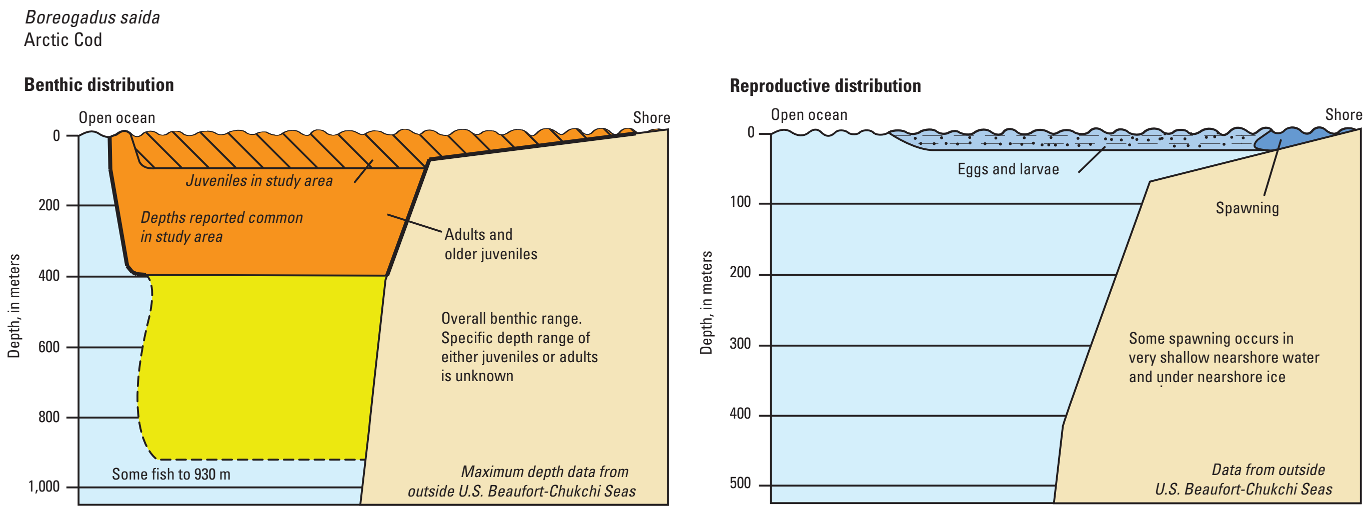
Arctic Cod
Boreogadus saida



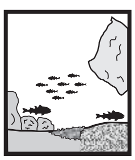
Base modified from USGS and other digital data. U.S.-Russia Maritime Boundary follows the EEZ/200-mile limit line, western edge. Coordinate reference system: projection, Lambert Azimuthal Equal Area; latitude of origin, 75.0°; horizontal datum, North American Datum of 1983.

Geographic distribution within Arctic Outer Continental Shelf Planning Areas [16] of Arctic Cod (*Boreogadus saida*) based on review of published literature and specimens from historical and recent collections [11, 17].

Depth Range: Larvae: *Maximum depth unknown. Surface to at least 20 m* [12]. Juveniles: *Maximum depth unknown. Near surface to 75 m* [9, 18]. Older juveniles and adults: *Maximum depth could be 930 m (the species' maximum recorded depth) but such depths have not been sampled in the U.S. Chukchi and Beaufort Seas. Found throughout the water column, abundant from surface waters to at least 400 m* [9, 12, 19] and deeper (500 to 1,000 m in the United States Beaufort Sea, Kathleen Wedemeryer, Bureau of Ocean Energy Management, Alaska OCS Region, oral commun., October 13, 2015). Elsewhere, Arctic Cod are found from barely subtidal waters to depths of 930 m [20]. Spawning: Shallow nearshore waters and under nearshore ice [21, 22].



Benthic and reproductive distribution of Arctic Cod (*Boreogadus saida*).



Habitats and Life History

Although Arctic Cod are assumed to both spawn and live *under* ice in Arctic Alaskan waters, virtually no surveys have been conducted to determine the importance of this habitat to Arctic Cod in the Alaskan Arctic. Throughout its range, Arctic Cod occupy a remarkably wide breadth of habitats. They occupy all parts of the water column in estuaries and off river mouths and in shallow subtidal waters, and are found many hundreds of kilometers off the coast [6, 21, 23, 24]. *These fish are often associated with ice* although they have been captured during spring and summer in the northern Bering Sea at least 300 km (186 mi) away from the nearest floe or pack ice *and are abundant along the U.S. Chukchi and Beaufort Seas in seasonally ice-free areas* [6, 25]. However, they can be found in very large numbers under ice and are often seen in cracks, crevices, and in melt-water ponds on the ice [20, 26, 27].

Eggs—Size: 1.5–1.9 mm [28, 29]. Time to hatching: *Unknown.* Elsewhere, between 26–90 days; highly variable, apparently dependent on water temperature [30, 31]. Habitat: *Planktonic. Location unknown.*

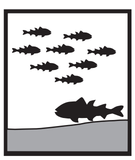
Larvae—Size at hatching: *6 mm* [32] Size at juvenile transformation: 27–50 mm [30, 33]. Days to juvenile transformation: *Unknown.* In the Russian Arctic, the larval stage lasts about 2 months [30]. Habitat: *Pelagic. Location poorly understood.* Elsewhere, found under ice [34].

Juveniles—Habitat: *Poorly known. Some pelagic juveniles are found in near-surface waters away from ice* [18, 35]. *Some young-of-the-year recruit from the plankton directly into inshore habitat, but it is likely that others remain well offshore (to at least 175 km off Prudhoe Bay)* [6, 18] *in near-surface waters* [6, 32]. *Large numbers of juveniles were found in shallow U.S. Beaufort Sea lagoons* [36]. Elsewhere, juveniles are common under ice [20, 26, 27, 37]. *However, in the Alaskan Arctic, they also are very abundant in the summer well away from ice* [6, 8, 38]. In other areas, in offshore waters and in the absence of ice, smaller fish tend to inhabit shallower depths in the water column than do larger individuals [32, 39, 40].

Adults—Age and size at first maturity: *A few fish, possibly only males, are mature at 1year and around 100 mm FL. Most fish mature at –3 years (120 mm FL and larger) and males may mature about 1 year earlier than females* [6, 19]. Maximum age: *In study area, 7–8 years* [15]. Maximum size: 46 cm TL [41]. Habitat: Adults are common under ice [20, 26, 27, 37]. *However, in the Alaskan Arctic, they also are very abundant in the summer well away from ice* [6, 8, 38].

Physical/Chemical—Temperature: *Preferred temperatures poorly known, but probably about –1.5–5 °C* [12, 13, 42], *although sometimes they are abundant in waters as warm as 10 °C* [8, 43]. *Documented between -2.0 and 13.5 °C* [43, 44]. Elsewhere, to -2.1 °C [45]. In Bering Sea, mainly -2.0 to -0.7 °C [45]. In the Canadian High Arctic, larvae are reported to develop only at temperatures less than 3.0 °C [46] and in the Russian Arctic, less than 5 °C [30]. Juveniles may favor warmer waters than adults [8, 39]. Salinity: *Documented from 0 to 32.6 practical salinity units (psu)* [10, 43, 44] and elsewhere to 34.9 psu [17]. All life stages live in marine waters. Although occasionally abundant in brackish waters [43], low abundance in such areas as the Mackenzie River estuary may reflect general avoidance of very low salinity waters [47].
Ice Dependence—Although it is clear that many Arctic Cod live under ice, it is unclear whether these fish are ice *associated or ice dependent* [27, 48]. The hypothesis that Arctic Cod are ice dependent is derived from a number of inconclusive observations. Examples include:

4. Known to spawn along the ice edge [49] and under ice [23, 50]. However, whether spawning is limited to ice or a near-ice area is unknown. For instance, Arctic Cod eggs have been taken in May around the ice-free Pribilof Islands, Alaska [51]. In addition, surveys of possible spawning in ice-free areas have not been conducted during the overwinter, for instance, the Bering Sea.
5. *Juveniles and adults are very abundant under ice* [52], *but can be extremely abundant during summer in relatively warm water and ice-free conditions* [9, 12, 32, 44].
6. The relationship between ice densities, water temperatures, and fish growth and survival is uncertain. In the Greenland Sea, larvae living in low-ice, relatively warm waters survived better than those in thicker ice and colder (<0 °C) temperatures, implying that the lengthening of the ice-free season may result in improved recruitment and larger populations in Arctic Cod in the short term [50]. This has also been noted among polynyas in Arctic Canada [48]). In addition, juvenile and adult Arctic Cod in the northeast Chukchi Sea grew fastest in a warmer-water year [15]. However, this position has been challenged by some authors based on the hypothesis that Arctic sea warming will reduce sea ice habitat and allow sub-Arctic or temperate taxa to replace this species [50].



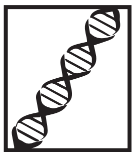
Behavior
Diel—*Unknown.* Elsewhere, from January to April, post-spawning adults in the eastern Beaufort Sea rise in the water column at night [52].
Seasonal—*Poorly understood* [6]. *Current information suggests that throughout their range, fish move into nearshore waters in the summer. Precise time and intensity varies between locations and between years at the same location* [6, 13, 53, 54]. *In the U.S. Beaufort Sea, relatively scarce in shallow waters immediately after ice-out, but move into shallow waters as the season progresses* [6, 7, 53]. *However, ringed seal diet studies in the nearshore of Arctic Alaska* [55], *and other fish surveys* [44, 56], *imply that at least some Arctic Cod overwinter in nearshore waters under ice. In nearshore waters, schools can move quickly through an area* [44, 57] or reside in the same location for weeks [58]. *Proportion of population migrating into shallow waters is unknown; many fish might not migrate into the shallowest waters* [19, 38]. *In summer, Arctic Cod are by far the most abundant fish in Alaska Arctic nearshore waters* [14, 15]. *For example, estimates of summer cod abundances in Simpson Lagoon have been as high as 12–27 million fish* [44].

Data regarding the environmental parameters driving inshore migrations are often contradictory. *For instance, in the U.S. Chukchi Sea, catches increased when water temperatures rose and salinities decreased* [38], *but was the opposite in the Sagavanirktok River Delta of the U.S. Beaufort Sea* [59]. *In Prudhoe Bay of the U.S. Beaufort Sea, highest densities were noted in frontal areas bordering low salinity and high temperature surface waters, and high salinity and low temperature bottom waters, perhaps an area of high productivity* [60]. *Another U.S. Chukchi Sea study found no environmental-parameter-associated abundance; authors hypothesized that food availability might underlay fish movements* [15].

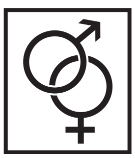
Thus far, the most complete study of winter behavior was in Franklin Bay, eastern Canadian Beaufort Sea. It was documented that after spawning during the early winter (perhaps over deep waters in the Amundsen Gulf; (D. Benoit, Université Laval, 2010), very large numbers of fish either migrated, or were passively carried, into 180 m or deeper depths and did not feed during this time. Migration out of these waters began with an abrupt upward migration and coincided with phytoplankton blooms and the onset of feeding [52]. Similar work in the nearby Amundsen Gulf demonstrates a similar pattern [61].

Reproductive—*Poorly known.* In the Arctic in general, spawning occurs near the bottom along the ice edge [49] and under ice [23], whether limited to under-ice areas is unknown. For instance, eggs have been found in

May around the ice-free Pribilof Islands [51]. The winter (spawning-season) behavior throughout the Arctic is very poorly known. *In the U.S. Chukchi and Beaufort Seas, at least some fish spend winters under nearshore ice (presumably spawning)* [38, 44, 56, 62]. *However, whether the bulk of the population overwinters and spawns in shallow waters is unknown. For instance, spawned-out cod were reported both near the coast and 175 km off Prudhoe Bay* [6]. In the autumn and winter, large, spawning-oriented migrations occurred in the Russian Arctic and spawning in the Barents Sea may have occurred from near shore to hundreds of kilometers off the coast [49].
Schooling—*Schooling behavior under ice has not been studied. In ice-free areas, very large schools are formed, often millions of individuals* [6, 44]. *This species often schools by size class* [8]. *The amount of cohesion of fish schools in Arctic Alaska is unknown*, although in the Canadian Arctic some schools stay together for at least 1–2 months in summer [24, 58].
Feeding—*Prior to spawning, a few nearly ripe fish in Simpson Lagoon were still feeding* [44], whereas in the Canadian Arctic, feeding ceases for several months beforehand [52].

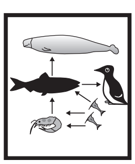


Population or Stocks
Initial research underway in U.S. Chukchi and Beaufort Seas and Arctic Ocean. Microsatellite markers imply some population structure among Chukchi Sea, Canadian and Siberian Arctic Cod, and potentially low differentiation between those from Hudson Bay and the eastern Beaufort Sea [63]. The genetics research indicates very little structuring across the United States Beaufort Sea with respect to the three dichotomies of east/west; coastal/slope; and riverine/marine water influence (Kathleen Wedemeyer, Bureau of Ocean Energy Management, oral commun,, October 13, 2015). A single circum-artctic population with only minor differences is currently hypothesized.



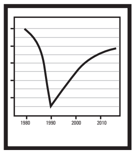
Reproduction
Mode—Separate sexes, oviparous. Fertilization is external.
Spawning season— *Poorly understood*. Over the species' entire geographic range, spawning occurs under ice floes from November to at least April, perhaps peaking in January and February in the Beaufort Sea [6, 15, 31, 49]. *The capture of spawned-out adults in May, 175 km off Prudhoe Bay, implies that some spawning may continue well into the spring* [6]. *The capture of newly hatched larvae in July in the northeastern Chukchi Sea* [33] and as late as July and August in Tuktoyaktuk Harbor, Northwest Territories, and near Baffin Bay [64, 65], also may imply late spawning. However, eggs fertilized in February will often remain as larvae into July [30].
Fecundity—*Unknown.* Elsewhere, 9,000–33,251 eggs, apparently in one batch [28, 29]. Females may not spawn every year [6]. However, in a laboratory study, several females spawned in two successive years, implying that some fish are capable of spawning more than once in their lives and in sequential years [46].

Food
Food items—Larvae: *Unknown.* In Hudson Bay, pelagic larvae under ice feed on nauplii and eggs of those copepods feeding on under-ice phytoplankton [34]. Juveniles and Adults: *Diets vary with fish size and location, although epibenthic or pelagic crustaceans (for example, mysids, isopods, copepods, gammarid and hyperiid amphipods, and shrimps), as well as larval fish, polychaetes, chaetognaths, and small fishes (such as other Arctic Cod), are important. Fish living under ice often target ice-associated crustaceans such as amphipods* [6, 57, 66-68]. Feed primarily on copepods and amphipods in northern Bering Sea [69]. *Diets also may vary with season. In Simpson Lagoon of the Alaskan Beaufort Sea, mysids, amphipods, isopods were most important during the summer and mysids dominated during the winter* [44].
Trophic level—3.6 [70].



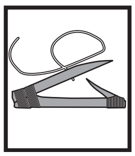
Biological Interactions
Predators—Arctic Cod are an extremely important prey for a wide range of predators and are possibly the most important forage fish in the U.S. Chukchi and Beaufort seas. *They are consumed by at least 8 fish species, 17 bird species, and 3 marine mammal species* [19, 38, 67, 71–75]. *The major predators of Arctic Cod in the Alaska Beaufort Sea are considered to be, in order of importance, Arctic Cod (cannibalism), ringed seals, Beluga whales, and seabirds (particularly Black-legged Kittiwake, Thick-billed Murre, Ivory Gull, Black Guillemot, Glaucous Gull, loons, Ross' Gull, Arctic Tern, and Sabine's Gull)* [67]. *Almost all studies were conducted during summer months, although it has been shown that in the Alaskan High Arctic they form a major part of the diet of ringed seals (particularly important to pups) throughout the year* [55, 67] *and bearded seals in the U.S. Chukchi Sea from at least November through June* [71]. Arctic Cod appear to be particularly susceptible to beach strandings, caused by predators or storms [6, 58].

Competitors—*Likely competitors are other schooling midwater feeders, particularly Walleye Pollock, but also Dolly Varden, whitefish species, Capelin, and Pacific Sand Lance*.



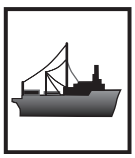
Resilience

Medium, minimum population doubling time: 1.4–4.4 years (K=0.22; t_m=2-5; Fecundity =30,000) [76].



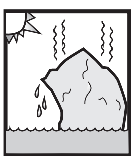
Traditional and Cultural Importance

In the past, this was a fairly important human subsistence species in the Alaskan High Arctic. For instance, it was reported that Arctic Cod were heavily fished through the ice off Barrow in the winter [77]. *Over time and today, Arctic Cod are of only limited importance as food fish* [1, 78–80]. Arctic Cod appear to be of more importance in Canadian subsistence fisheries of the Barrow Strait and Hudson Bay where they are widely caught and consumed [58, 81].



Commercial Fisheries

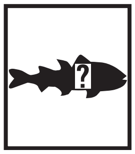
Arctic Cod are not commercially harvested in the U.S. Chukchi and Beaufort Seas. The commercial fishery for Arctic Cod is small and limited to Russian vessels fishing primarily in the northwest Russian Arctic [82].



Potential Effects of Climate Change

Climate change may influence the numbers of Arctic Cod through a number of mechanisms. (1) Assuming that this species is in some way ice-dependent, a poleward shift in distribution would be expected with retreating ice. (2) There is some evidence that survivorship of Arctic Cod larvae increases with earlier ice break-up, more frequent winter polynyas, a warmer (ocean) surface layer, and increased river discharge [83], all possible effects of warming conditions. (3) Arctic Cod coming under increased competition for resources from some northward-migrating species would be expected, particularly from Saffron Cod and possibly Walleye Pollock. (4) Greater periods of ice-free conditions likely will alter predation patterns, but in ways that are not yet predictable. Receding ice may increase predation. In Resolute Bay, North West Territories, fish under heavy ice cover were less aggregated than when the bay was relatively ice-free. When ice drifted into the bay, fish would move under it [84]. In Hudson Bay, a sharp decrease in the abundance of Arctic Cod coincided with an approximately 50 percent decrease in summer ice cover [85]. However, the millions of Arctic Cod inhabiting the ice-free Simpson Lagoon in the summer do not appear to suffer heavy predation [44]. Reduced ice pack can be argued to cause an increase or decrease predation depending on predator. For instance, reduced ice pack would decrease resting habitat for seals, while making Arctic Cod perhaps more available to cetaceans or seabirds [48]. (5) Food availability and growth rates will change, although the direction and intensity of this change are unknown. As an example, fish in the northeast Chukchi Sea grew fastest in warmer water years [15] and larvae residing in the low-ice, relatively warm waters in Greenland survived better than those under thicker ice [50]. (6) Effects on Arctic Cod predators are unknown, but may be substantial. For instance, retreating pack ice near Point Barrow led to reduced Arctic Cod availability for Black Guillemots and subsequent reductions in nestling growth and brood size [86]. (7) Effects of predation by Arctic Cod on prey are unknown but the species mid-level role in transferring energy from low to high trophic levels is hypothesized to be significant. Local effects of Arctic Cod predation on prey concentrations also may be significant. For instance, feeding by large schools of adult Arctic Cod in the Canadian Arctic may be sufficiently intense as to cause localized depletion of zooplankton [24]. The effects of possible changes in Arctic Cod distribution and abundance, in association with climate warming, may have profound, cascading effects on the Arctic marine ecosystems. The effects of increasing ocean acidification on Arctic Cod food webs dynamics and developmental biology are of concern. The protocols for capturing, transporting, breeding, and rearing larvae through adult stages in the laboratory have been tested and described [87, 88] making empirical studies of thermal sensitivity to warming using an Arctic Cod model possible. New information is available describing the thermal limits of cardiac function on Arctic Cod [89, 90], effects of warming and ocean acidification on metabolism and performance on Arctic Cod and Atlantic Cod (*Gadus morhua*) [91], and temperature-dependent growth and swimming behaviors of Arctic Cod, Saffron Cod, Walleye Pollock, and Pacific Cod [92]. In general, the results suggest optimal food conversion for juvenile Arctic

Cod in Cold waters (0 °C), near optimal growth at 5 °C, and diminished growth and condition with increasing temperatures above this (detrimental effects above 16 °C). Differential acute effects of warming on larvae and adults further suggest the potential role thermal limitations of younger-aged cod may have on the Arctic Cod distribution in coastal waters.



Areas for Future Research [A]

Considering the species central role in Arctic marine ecosystems dynamics, relatively little focused research attention has been given to Arctic Cod in Arctic Alaska. In particular, the role of sea ice in the species' life cycle, though speculated, is not well understood. The location and timing of spawning locations and presence of stock structures are unknown. Information is needed regarding population movements and behaviors, particularly during winter months, and with respect to the relative important habitats in slope, shelf, and nearshore, and deeper areas of the Canada Basin. The latter need is of particular importance because a recent model predicted a mass extinction of most Arctic Cod within 30 years [93]. However, the model appears to be at least partially based on the assumption that there are no Arctic Cod well offshore of northern Alaska, although no surveys have been conducted there. The use of Autonomous Underwater Vehicles to investigate Arctic Cod ecology should be explored. There needs to be new and continued empirical research to determine the seasonal effects of changing temperatures, ocean acidification, and ice coverage on the reproduction ecology and population growth and condition of Arctic Cod. An additional experimental priority is for toxicological research on the potential effects of spilled, dispersed, and weathered oil on Arctic Cod under Arctic conditions. Accurate assessments of species interactions and effects of human developments and climate changes will require that the population dynamics of the species are understood and that abundance patterns and population parameters are monitored over time.

References Cited

Benoit, D., Simard, Y., and Fortier, L., 2008, Hydroacoustic detection of large winter aggregations or Arctic cod (*Boreogadus saida*) at depth in ice-covered Franklin Bay (Beaufort Sea): Journal of Geophysical Research, v. 113, no. CO6S90, 9 p. [52]

Craig, P.C., Griffiths, W.B., Haldorson, L., and McElderry, H., 1982, Ecological studies of Arctic cod (*Boreogadus saida*) in Beaufort Sea coastal waters—Alaska: Canadian Journal of Fisheries and Aquatic Sciences, v. 39, no. 3, p. 395–406. [6]

Craig, P.C., and Haldorson, L.J., 1981, Beaufort Sea Barrier Island Lagoon ecological process studies—Final report, Simpson Lagoon—Fish: U.S. Department of Commerce, Biological Studies, p. 384–649. [44]

Fechhelm, R.G., Griffiths, W.B., Wilson, W.J., Trimm, B.A., and Colonell, J.M., 1996, The 1995 fish and oceanography study in Mikkelsen Bay, Alaska: Anchorage, Alaska, Prepared by LGL Alaska Research Associates and Woodward-Clyde Consultant for BP Exploration (Alaska) Inc., 102 p. plus apps. [14]

Fortier, L., Sirois, P., Michaud, J., and Barber, D., 2006, Survival of Arctic cod larvae (*Boreogadus saida*) in relation to sea ice and temperature in the Northeast Water Polynya (*Greenland Sea*): Canadian Journal of Fisheries and Aquatic Sciences, v. 63, no. 7, p. 1,608–1,616. [50]

Frost, K.J., and Lowry, L.F., 1984, Trophic relationships of vertebrate consumers in the Alaskan Beaufort Sea, *in* Barnes, P.W., Schell, D.M., and Reimnitz, E., eds., The Alaska Beaufort Sea—Ecosystems and environments: San Diego, Academic Press, p. 382–401. [67]

Gillispie, J.G., Smith, R.L., Barbour, E., and Barber, W.E., 1997, Distribution, abundance, and growth of Arctic cod in the Northeastern Chukchi Sea, *in* Reynolds, J.B., ed., Symposium 19, Proceedings of the Fish Ecology in Arctic North America Symposium, Fairbanks, Alaska, May 19–21, 1992: Fairbanks, Alaska, American Fisheries Society, p. 81–89. [15]

Jarvela, L.E., and Thorsteinson, L.K., 1999, The epipelagic fish community of Beaufort Sea coastal waters, Alaska: Arctic, v. 52, no. 1, p. 80–94. [8]

Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p. [4]

Quast, J.C., 1974, Density distribution of juvenile Arctic cod, *Boreogadus saida*, in the eastern Chukchi Sea in the fall of 1970: Fishery Bulletin, v. 72, no. 4, p. 1,094–1,105. [32]

Bibliography

1. Craig, P.C., 1989b, Subsistence fisheries at coastal villages in the Alaskan Arctic, 1970–1986: Biological Papers University of Alaska, no. 24, p. 131–152.

2. George, C., Moulton, L.L., and Johnson, M., 2007, A field guide to the common fishes of the North Slope of Alaska: Alaska Department of Wildlife Management, North Slope Borough, 93 p.

3. Logerwell, E.A., and Rand, K.M., 2010, Beaufort Sea marine fish monitoring 2008—Pilot survey and test of hypotheses: Seattle, Washington, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Alaska Fisheries Science Center, Final Report, BOEMRE 2010-048, 262 p.

4. Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p.

5. Power, G., 1997, A review of fish ecology in Arctic North America: American Fisheries Society Symposium, no. 19, p. 13–39.

6. Craig, P.C., Griffiths, W.B., Haldorson, L., and McElderry, H., 1982, Ecological studies of Arctic cod (*Boreogadus saida*) in Beaufort Sea coastal waters—Alaska: Canadian Journal of Fisheries and Aquatic Sciences, v. 39, no. 3, p. 395–406.

7. Wiswar, D.W., West, R.L., and Winkleman, W.N., 1995, Fisheries investigation in Oruktalik Lagoon, Arctic National Wildlife Refuge, Alaska, 1986: U.S. Fish and Wildlife Service, Alaska Fisheries Technical Report, no. 30, 38 p.

8. Jarvela, L.E., and Thorsteinson, L.K., 1999, The epipelagic fish community of Beaufort Sea coastal waters, Alaska: Arctic, v. 52, no. 1, p. 80–94.

9. Parker-Stetter, S., Horne, J., Logerwell, L., Rand, K., and Weingartner, T. 2010, Assessment of Arctic cod and young-of-the-year fish distributions in the Beaufort Sea [abs.]: Alaska Marine Science Symposium, Book of Abstracts, p. 24.

10. Mecklenburg, C.W., Stein, D.L., Sheiko, B.A., Chernova, N.V., Mecklenburg, T.A., and Holladay, B.A., 2007, Russian–American long-term census of the Arctic—Benthic fishes trawled in the Chukchi Sea and Bering Strait, August 2004: Northwestern Naturalist, v. 88, no. 3, p. 168–187.

11. Mecklenburg, C.W., Møller, P.R., and Steinke, D., 2011, Biodiversity of Arctic marine fishes—Taxonomy and zoogeography: Marine Biodiversity, v. 41, no. 1, p. 109–140, Online Resource 1.

12. Crawford, R.E., 2010, Occurrence of Arctic cod shoals along the Chukchi and Beaufort continental slope regions [abs.]: Alaska Marine Science Symposium, Book of Abstracts, p. 23.

13. Thedinga, J.F., Johnson, S.W., and Neff, A.D., 2010, Nearshore fish assemblages in the Chukchi Sea near Barrow, Alaska [abs.]: Alaska Marine Science Symposium, Book of Abstracts, p. 24.

14. Fechhelm, R.G., Griffiths, W.B., Wilson, W.J., Trimm, B.A., and Colonell, J.M., 1996, The 1995 fish and oceanography study in Mikkelsen Bay, Alaska: Anchorage, Alaska, Prepared by LGL Alaska Research Associates and Woodward-Clyde Consultant for BP Exploration (Alaska) Inc., 102 p. plus apps.

15. Gillispie, J.G., Smith, R.L., Barbour, E., and Barber, W.E., 1997, Distribution, abundance, and growth of Arctic cod in the northeastern Chukchi Sea, *in* Reynolds, J.B., ed., Symposium 19, Proceedings of the Fish Ecology in Arctic North America Symposium, Fairbanks, Alaska, May 19–21, 1992: Fairbanks, Alaska, American Fisheries Society, p. 81–89.

16. Minerals Management Service, 2008, Beaufort Sea and Chukchi Sea planning areas—Oil and Gas Lease Sales 209, 212, 217, and 221: U.S. Department of the Interior, Minerals Management Service Alaska OCS Region, OCS EIS/EA, MMS 2008-0055, 538 p.

17. Mecklenburg, C.W., Mecklenburg, T.A., Sheiko, B.A., and Steinke, D., 2016, Pacific Arctic marine fishes: Akureyri, Iceland, Conservation of Arctic Flora and Fauna, Monitoring Series Report No. 23, 406 p., accessed May 10, 2016, at http://caff.is/monitoring-series/370-pacific-arcticmarine-fishes.

18. Parker-Stetter, S.L., Horne, J.K., and Weingartner, T.J., 2011, Distribution of polar cod and age-0 fish in the U.S. Beaufort Sea: Polar Biology, v. 34, no. 10, p. 1,543–1,557.

19. Frost, K.J., and Lowry, L.F., 1983, Demersal fishes and invertebrates trawled in the northeastern Chukchi and western Beaufort seas 1976–1977: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, AA Technical Report NMFS-SSRF-764, 22 p.

20. Jensen, A.S., 1948, A contribution to the ichthyofauna of Greenland: Spoila Zoologica Musei Hauniensis, v. 9, p. 27–57.

21. Musienko, L.N., 1970, Reproduction and development of Bering Sea fishes, *in* Moiseev, P.A., ed., Soviet fisheries investigations in the northeastern Pacific—part V: Jerusalem, Israel Program for Scientific Translations (1972), p. 161–224.

22. Cohen, D.M., Inada, T., Iwamoto, T., and Scialabba, N., 1990, FAO species catalogue, volume 10—Gadiform fishes of the world (Order Gadiformes)—An annotated and illustrated catalogue of cods, hakes, grenadiers and other gadiform fishes known to date: Rome, Food and Agriculture Organization of the United Nations, FAO Fisheries Synopsis, no. 125, v. 10, 442 p.

23. Andriashev, A.P., 1954, Fishes of the northern seas of the U.S.S.R.—Keys to the fauna of the U.S.S.R.: Academy of Sciences of the U.S.S.R., Zoological Institute, no. 53, 566 p. [Russian, translation by Israel Program for Scientific Translation, Jerusalem, 1964, 617 p., available from U.S. Department of Commerce, Springfield, Virginia.]

24. Hop, H., Welch, H.E., and Crawford, R.E., 1997, Population structure and feeding ecology of Arctic cod schools in the Canadian High Arctic: American Fisheries Society Symposium 19, p. 13–39.

25. Lowry, L.F., and Frost, K.J., 1981, Distribution, growth, and foods of Arctic cod (*Boreogadus saida*) in the Bering, Chukchi, and Beaufort Seas: The Canadian Field-Naturalist, v. 92, p. 186–191.

26. Bradstreet, M.S.W., 1980, Thick-billed murres and black guillemots in the Barrow Strait area, N.W.T., during spring—Diets and food availability along ice edges: Journal of Zoology, v. 58, no. 11, p. 2,120–2,140.

27. Gradinger, R.R., and Bluhm, B.A., 2004, In-situ observations on the distribution and behavior of amphipods and Arctic cod (*Boreogadus saida*) under the sea ice of the High Arctic Canada Basin: Polar Biology, v. 27, no. 10, p. 595–603.

28. Dunn, J.R., and Matarese, A.C., 1987, A review of the early life history of northeast Pacific gadoid fishes: Fisheries Research, v. 5, nos. 2–3, p. 163–184.

29. Hop, H., Graham, M., and Treadeau, V.L., 1995, Spawning energetics of Arctic cod (*Boreogadus saida*) in relation to seasonal development of the ovary and plasma sex steroid levels: Canadian Journal of Fisheries and Aquatic Sciences, v. 52, no. 3, p. 541–550.

30. Rass, T.S., 1968, Spawning and development of polar cod: Rapports et Procčs-Verbeaux des Réunions du Conseil International pour l’Exploration de la Mer, v. 158, p. 135–137.

31. Aronovich, T.M., Doroshev, S.I., Spectorova, L.V., and Makhotin, V.M., 1975, Egg incubation and larval rearing of navaga (*Eleginus navaga* Pall.), Arctic Cod (*Boreogadus saida* lepechin) and Arctic flounder (*Liopsetta glacialis* Pall.) in the laboratory: Aquaculture, v. 6, no. 3, p. 233–242.

32. Quast, J.C., 1974, Density distribution of juvenile Arctic cod, *Boreogadus saida*, in the eastern Chukchi Sea in the fall of 1970: Fishery Bulletin, v. 72, no. 4, p. 1,094–1,105.

33. Wyllie-Echeverria, T., Barber, W.E., and Wyllie-Echeverria, S., 1997, Waters masses and transport of age-0 Arctic cod and age-0 Bering flounder into the northeastern Chukchi Sea, *in* Reynolds, J.B., ed., Symposium 19, Proceedings of the “Fish Ecology in Arctic North America Symposium,” held at Fairbanks, Alaska, May 19–21, 1992: American Fisheries Society, p. 60–67.

34. Ponton, D., and Fortier, L., 1992, Vertical distribution and foraging of marine fish larvae under the ice cover of southeastern Hudson Bay: Marine Ecology Progress Series, v. 81, p. 215–227.

35. Norcross, B.L., Holladay, B.A., Busby, M.S., and Mier, K.L., 2009, Demersal and larval fish assemblages in the Chukchi Sea: Deep-Sea Research II, v. 57, nos. 1–2, p. 57–70.

36. Dunton, K.H., Schonberg, S.V., and Cooper, L.W., 2012, Food web structure of the Alaskan nearshore shelf and estuarine lagoons of the Beaufort Sea: Estuaries and Coasts, v. 35, no. 2, p. 416–435.

37. Bradstreet, M.S.W., 1980, Thick-billed murres and black guillemots in the Barrow Strait area, N.W.T., during spring—Diets and food availability along ice edges: Journal of Zoology, v. 58, no. 11, p. 2,120–2,140.

38. Fechhelm, R.G., Craig, P.C., Baker, J.S., and Gallaway, B.J., 1984, Fish distribution and use of nearshore waters in the northeastern Chukchi Sea: LGL Ecological Research Associates Inc., Outer Continental Shelf Environmental Assessment Program, National Oceanic and Atmospheric Administration, OMPA/OCSEAP, Final Report, 190 p.

39. Hognestad, P.T., 1968, Observations on polar cod in the Barents Sea: Rapports et procès-verbaux des reunions, Conseil permanent international pour l'exploration de la mer., v. 158, p. 126–130.

40. Falk-Petersen, I.-B., Frivoll, V., Gulliksen, B., and Haug, T., 1986, Occurrence and size/age relations of polar cod, *Boreogadus saida* (Lepechin), in Spitsbergen coastal waters: Sarsia, v. 71, no. 3–4, p. 235–245.

41. Wienerroither, R., Johannesen, E., Langøy, H., Børve Eriksen, K., de Lange Wenneck, T., Høines, Å., Bjelland, O., Aglen, A., Prokhorova, T., Murashko, P., Prozorkevich, D., Konstantin, Byrkjedal, I., Langhelle Drevetnyak, and G., Smirnov, O., 2011, Atlas of the Barents Sea fishes: IMR/PINRO Joint Report Series 1-2011, ISSN 1502-8828, 274 p.

42. Logerwell, E., Rand, K., and Weingartner, T.J., 2011, Oceanographic characteristics of the habitat of benthic fish and invertebrates in the Beaufort Sea: Polar Biology, v. 34, p. 1,783–1,796.

43. Cannon, T.C., Glass, D.R., and Prewitt, C.M., 1991, Habitat use patterns of juvenile Arctic cod in the coastal Beaufort Sea near Prudhoe Bay, Alaska, *in* Benner, C.S., and Middleton, R.W., eds., Symposium 11, Proceedings from the 119th Annual Meeting of the American Fisheries Society, Anchorage, Alaska, 1989: American Fisheries Society, p. 157–162.

44. Craig, P.C., and Haldorson, L.J., 1981, Beaufort Sea Barrier Island Lagoon ecological process studies—Final report, Simpson Lagoon—Fish: U.S. Department of Commerce, Biological Studies, p. 384–649.

45. Mueter, F.J., University of Alaska-Fairbanks, written commun., 2010.

46. Graham, M., and Hop, H., 1995, Aspects of reproduction and larval biology of Arctic cod (*Boreogadus saida*): Arctic, v. 48, no. 2, p. 130–135.

47. Bradstreet, M.S.W., Sekerak, A.D., Finley, K.J., Griffiths, W.B., Evans, C.R., Fabijan, M.F., and Stallard, H.E., 1986, Aspects of the biology of Arctic cod (*Boreogadus saida*) and its importance in Arctic marine food chains: Canada Department of Fisheries and Oceans, Canadian Technical Report of Fisheries and Aquatic Sciences, iss. 1491, 193 p.

48. Thanassekos, S., Virginia Institute of Marine Science, written commun., 2010.

49. Ponomarenko, V.P., 1968, Some data on the distribution and migrations of polar cod in the seas of the Soviet Arctic: Rapports et Procès-Verbeaux des Réunions du Conseil International pour l'Exploration de la Mer, v. 158, p. 131–135.

50. Fortier, L., Sirois, P., Michaud, J., and Barber, D., 2006, Survival of Arctic cod larvae (*Boreogadus saida*) in relation to sea ice and temperature in the Northeast Water Polynya (*Greenland Sea*): Canadian Journal of Fisheries and Aquatic Sciences, v. 63, no. 7, p. 1,608–1,616.

51. Doyle, M.J., University of Washington, written commun., 2010.

52. Benoit, D., Simard, Y., and Fortier, L., 2008, Hydroacoustic detection of large winter aggregations or Arctic cod (*Boreogadus saida*) at depth in ice-covered Franklin Bay (Beaufort Sea): Journal of Geophysical Research, v. 113, no. CO6S90, 9 p.

53. Palmer, D.E., and Dugan, L.J., 1990, Fish population characteristics of Arctic National Wildlife Refuge coastal waters, summer 1989: Fairbanks, Alaska, U.S. Fish and Wildlife Service, Progress Report, 83 p.

54. Wiswar, D.W., and Frugé, D.J., 2006, Fisheries investigations in western Camden Bay, Arctic National Wildlife Refuge, Alaska, 1987: Alaska Fisheries Data Series, U.S. Fish and Wildlife Service, 2006-10, 49 p.

55. Lowry, L.F., Frost, K.J., and Burns, J.J., 1980, Variability in the diet of ringed seals, *Phoca hispida*, in Alaska: Canadian Journal of Fisheries and Aquatic Sciences, v. 37, no. 12, p. 2,254–2,261.

56. Schmidt, D.R., Griffiths, W.B., and Martin, L.R., 1987, Importance of anadromous fish overwintering habitat in the Sagavanirktok River Delta, Alaska: Anchorage, Alaska, Report by Ecological Research Associates for Standard Alaska Production Company and North Slope Borough, 71 p.

57. Craig, P.C., and Schmidt, D.R., 1985, Fish resources at Point Lay, Alaska: Barrow, Alaska, LGL Alaska Research Associates, Inc., North Slope Borough, Materials Source Division, 105 p.

58. Welch, H.E., Crawford, R.E., and Hop, H., 1993, Occurrence of Arctic cod (*Boreogadus saida*) schools and their vulnerability to predation in the Canadian High Arctic: Arctic, v. 46, no. 4, p. 331–339.

59. Griffiths, W.B., 1983, Fish, *in* Truett, J.C., ed, Final reports of principal investigators—Volume 24—Environmental characterization and biological use of lagoons in the eastern Beaufort Sea: Anchorage, Alaska, National Oceanic and Atmospheric Administration, Office of Oceanography and Marine Assessment, Ocean Assessments Division, p. 325–366.

60. Moulton, L.L., and Tarbox, K.E., 1987, Analysis of Arctic cod movements in the Beaufort Sea nearshore region, 1978–79: Arctic, v. 40, no. 1, p. 43–49.

61. Geoffroy, M., Robert, D., Darnis, G., and Fortier, L., 2011, The aggregation of polar cod (*Boreogadus saida*) in the deep Atlantic layer of ice-covered Amundsen Gulf (Beaufort Sea) in winter: Polar Biology, v. 34, no. 12, p. 1,959–1,971.

62. Thorsteinson, L.K., Jarvela, L.E., and Hale, D.A., 1990, Arctic fish habitat use investigations—Nearshore studies in the Alaskan Beaufort Sea, summer 1988: Final Report, Alaska Office, Ocean Assessments Division, National Oceanic and Atmospheric Administration, Research Unit 682, 125 p.

63. Bouchard, C., Madsen, M.L., Fevolden, S.-E., and L. Fortier, 2008, Population structure in polar cod (*Boreogadus saida)*—First results from a circumpolar study using microsatellites: Quebec City, Quebec, Arctic Change 2008, Conference Programme and Abstracts, p. 187–188.

64. Sekerak, A.D., Stallard, N., and Griffiths, W.B., 1992, Distribution of fish and fish harvests in the nearshore Beaufort Sea and Mackenzie Delta during ice-covered periods, October–June: Environmental Studies Research Funds Report, LGS Ltd. No. 117, 524 p.

65. Ratynski, R.A., 1983, Mid-summer ichthyoplankton populations of Tuktoyaktuk Harbour, N.W.T.: Canadian Technical Report of Fisheries and Aquatic Sciences, no. 1218, 21 p.

66. Frost, K.J., and Lowry, L.F., 1981, Foods and trophic relationships of cetaceans in the Bering Sea, *in* Hood, D.W., and Calder, J.A., eds., The Eastern Bering Sea Shelf—Oceanography and Resources: National Oceanic and Atmospheric Administration, p. 825–836.

67. Frost, K.J., and Lowry, L.F., 1984, Trophic relationships of vertebrate consumers in the Alaskan Beaufort Sea, *in* Barnes, P.W., Schell, D.M., and Reimnitz, E., eds., The Alaska Beaufort Sea—Ecosystems and environments: San Diego, Academic Press, p. 382–401.

68. Coyle, K.O., Gillispie, J.A., Smith, R.L., and Barber, W.E. 1997, Food habits of four demersal Chukchi Sea fishes, *in* Reynolds, J.B., ed., Symposium 19, Proceedings of the Fish Ecology in Arctic North America Symposium: American Fisheries Society, Fairbanks, Alaska, May 19–21, 1992, p. 310–318.

69. Cui, X., Grebmeier, J.M., and Cooper, L.W., 2012, Feeding ecology of dominant groundfish in the northern Bering Sea: Polar Biology, v. 35, no. 9, p. 1,407–1,419.

70. Mueter, F.J., and Litzow, M.A., 2008, Sea ice retreat alters the biogeography of the Bering Sea continental shelf: Ecological Applications, v. 18, no. 2, p. 309–320.

71. Johnson, M.L., Fiscus, C.H., Ostenson, B.T., and Barbour, M.L., 1966, Marine mammals, *in* Wilimovsky, N.J., and Wolfe, J.N., eds., Environment of the Cape Thompson Region, Alaska: Oak Ridge, Tennesee, United States Atomic Energy Commission, Division of Technical Information, p. 877–924.

72. Jones, M.L., and Den Beste, J., 1977, Tuft Point and adjacent coastal areas fisheries projects: Calgary, Alberta, Canada, Aquatic Environments, Ltd., 152 p.

73. Frost, K.J., and Lowry, L.F., 1981, Trophic importance of some marine gadids in northern Alaska and their body-otolith size relationships: Fishery Bulletin, v. 79, no. 1, p. 187–192.

74. Lowry, L.F., Frost, K.J., and Seaman, G.A., 1986, Investigations of belukha whales in coastal waters of western and northern Alaska: Outer Continental Shelf Environmental Program Unit 612, Final Report, p. 359–392.

75. Bond, W.A., and Erickson, R.N., 1989, Summer studies of the nearshore fish community at Phillips Bay, Beaufort Sea coast, Yukon: Winnepeg, Manitoba, Canadian Technical Report of Fisheries and Aquatic Sciences, Central and Arctic Region, Department of Fisheries and Oceans, no. 1676, 102 p.

76. Froese, R., and Pauly, D., eds., 2012, FishBase—Global information system on fishes: FishBase database, accessed July 8, 2012, at http://www.fishbase.org.

77. Murdoch, J., 1884, Fish and fishing at Point Barrow, Arctic Alaska: Transactions of the American Fisheries Society, v. 13, no. 1, p. 111–115.

78. Saario, D.J., and Kessel, B., 1966, Human ecological investigations at Kivalina, *in* Wilimovsky, N.J., and Wolfe, J.N., eds., Environment of the Cape Thompson region, Alaska: Oak Ridge, Tennessee, U.S. Atomic Energy Commission, Division of Technical Information, p. 969–1,039.

79. Nelson, R.K., 1969, Hunters of the Northern Ice: Chicago, University of Chicago Press, 429 p.

80. Bendock, T.N., 1977, Beaufort Sea estuarine fishery study: Alaska Department of Fish and Game Annual Report, Contract #03-5-022-69, p. 670–729.

81. Wein, E.E., Freeman, M.M.R., and Makus, J.C., 1996, Use of and preference for traditional foods among the Belcher Island Inuit: Arctic, v. 49, no. 3, p. 256–264.

82. Food and Agriculture Organization of the United Nations, 2011, *Boreogadus saida* (Lepechin, 1774): Fisheries and Aquaculture Department, Food and Agriculture Organization of the United Nations, Species Fact Sheet, Web site, accessed May 18, 2014, at http://www.fao.org/fishery/species/2233/en.

83. Bouchard, C., and Fortier, L., 2011, Circum-Arctic comparison of the hatching season of polar cod *Boreogadus saida*—A test of the freshwater winter refuge hypothesis: Progress in Oceanography, v. 90, nos. 1–4, p. 105–116.

84. Crawford, R.E., and Jorgenson, J.K., 1993, Schooling behaviour of Arctic cod, *Boreogadus saida*, in relation to drifting pack ice: Environmental Biology of Fishes, v. 36, no. 4, p. 345–357.

85. Gaston, A.J., Woo, K., and Hipfner, J.M., 2003, Trends in forage fish populations in northern Hudson Bay since 1981, as determined from the diet of nestling thick-billed murres *Uria lomvia*: Arctic, v. 56, no. 3, p. 227–233.

86. Divoky, G., 2008, Annual and seasonal variation in nearshore fish availability associated with the record Arctic pack ice minimum of 2007: Quebec City, Quebec, Arctic Change 2008, Conference Programme and Abstracts, p. 69–70.

87. Kunz, K.L., Frickenhaus, S., Hardenberg, S., Johansen, T., Leo, E., Pörtner, H.O., Schmidt, M., Windisch, H.S., Knust, R., and Mark, F.C., 2016, New encounters in Arctic waters—A comparison of metabolism and performance of polar cod (*Boreogadus saida*) and Atlantic cod (*Gadus morhua*) under ocean acidification and warming: Polar Biology, no. 39, p. 1,137–1,153.

88. Kent, D., Drost, H.E., Fisher, J., Oyama, T., and Farrell, A.P., 2015, Laboratory rearing of wild Arctic cod *Boreogadus saida* from egg to adulthood: Journal of Fish Biology, doi:10.1111/jfb.12893.

89. Drost, H.E., Carmack, E.C., and Farrell, A.P., 2014, Upper thermal limits of cardiac function for Arctic cod *Boreogadus saida*, a key food web fish species in the Arctic Ocean: Journal of Fish Biology, doi:10.1111/jfb.12397.

90. Drost, H.E., Fisher, J., Randall, F., Kent, D., Carmack, E.C., and Farrell, A.P., 2015, Upper thermal limits of the hearts of Arctic cod *Boreogadus saida*: Journal of Fish Biology, doi:10.1111/jfb.12807.

91. Drost, H.E., Lo, M., Carmack, E., and Farrell, A.P., 2016, Acclimation potential of Arctic Cod (*Boreogadus saida* Lepechin) in the rapidly warming Arctic Ocean—Advanced publication: Journal of Experimental Biology, doi:10.1242/jeb.140194.

92. Laurel, B.J., Spencer, M., Iseri, P., and Copeman, L.A., 2015, Temperature-dependent growth and behavior of juvenile Arctic cod (*Boreogadus saida*) and co-occurring North Pacific gadids: Polar Biology, no. 39, p. 1,127–1,135.

93. Cheung, W.W.L., Lam, V.W.Y., and Pauly, D., 2008, Dynamic bioclimate envelope model to predict climate-induced changes in distribution of marine fishes and invertebrates, *in* Cheung, W.W.L., Lam, V.W.Y., and Pauly, D., eds., Modeling present and climate-shifted distribution of marine fishes and invertebrates: Vancouver, University of British Columbia, Fisheries Centre Research Reports, v. 16, no. 3, p. 5–50.

Saffron Cod (*Eleginus gracilis*)
(Tilesius, 1810)

Family Gadidae

Saffron Cod (*Eleginus gracilis*), 233 mm, Chukchi Sea, 2007. Photograph by C.W. Mecklenburg, Point Stephens Research.

Colloquial Name: Iñupiat: *Uugak* [1]. This species and the Arctic Cod are called Tomcod (not to be confused with *Microgadus proximus*).

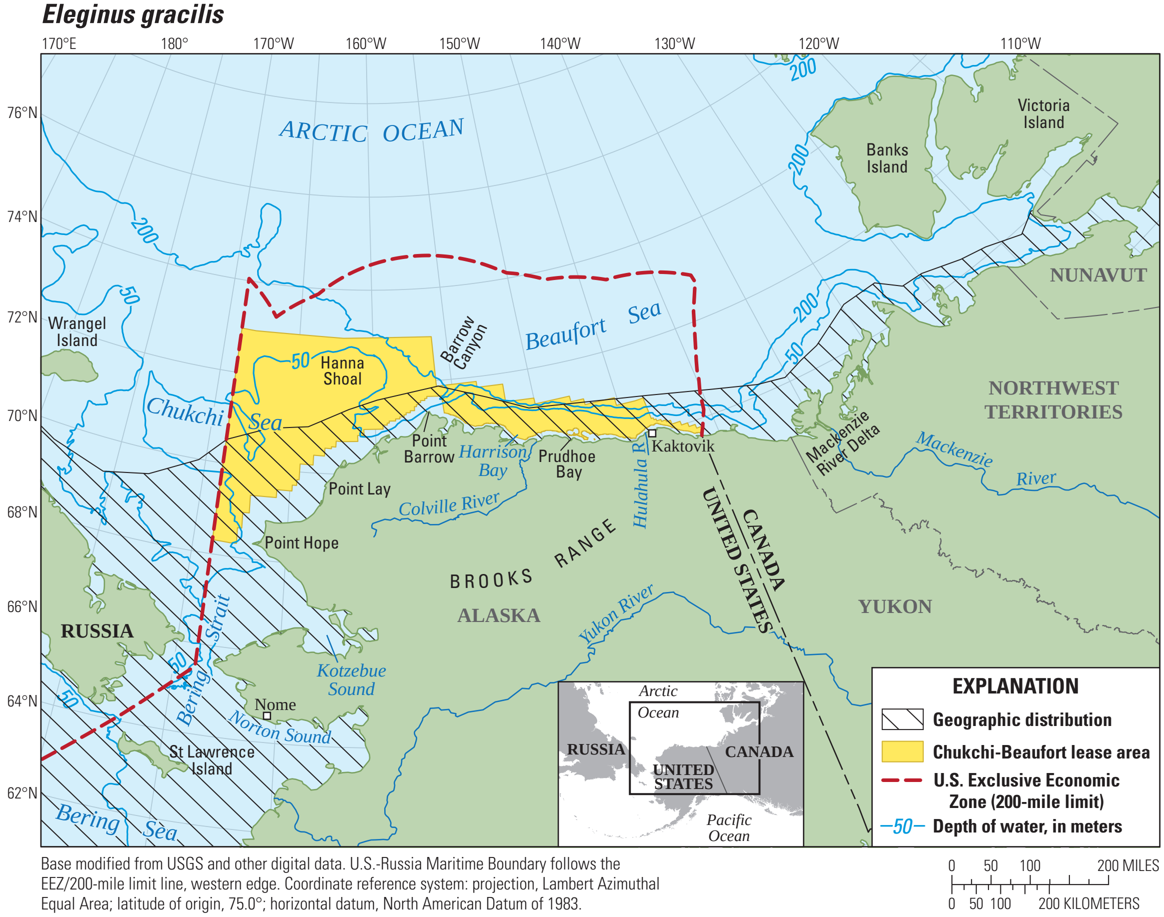
Ecological Role: This is a species of major ecological importance, particularly in the Chukchi Sea. Saffron Cod are believed to be a major competitor of Arctic Cod and changes in sea ice associated with warming may give the species a competitive advantage.

Physical Description/Attributes: Mottled brown to gray-green body washed with yellow. Ventral areas are white to yellow, pectoral fins are yellow, and margins of dorsal and anal fins are white. For specific diagnostic characteristics, see *Fishes of Alaska* (Mecklenburg and others, 2002, p. 293) [2]. Swim bladder: Present [2]. Antifreeze glycoproteins in blood serum: Present [3].

Range: *U.S. Chukchi and Beaufort Seas* [4]. Elsewhere in Alaska, from Bering Sea and Gulf of Alaska to Sitka, southeastern Alaska. Worldwide, from Sea of Japan and Sea of Okhotsk to East Siberian Sea and eastward in Arctic to Melville Sound, Bathurst Inlet, Nunavut [4].

Relative Abundance: *Patchily abundant in U.S. Chukchi and Beaufort Seas* [7–10] eastward to Cambridge Bay, Nunavut [6]. Most abundant species during summer in northern Bering and southern U.S. Chukchi Seas [12]. Abundant from Sea of Japan and Sea of Okhotsk to eastern Bering Sea [13–15] and central Gulf of Alaska [16]. Appears to be increasing in abundance in Prince William Sound [17].

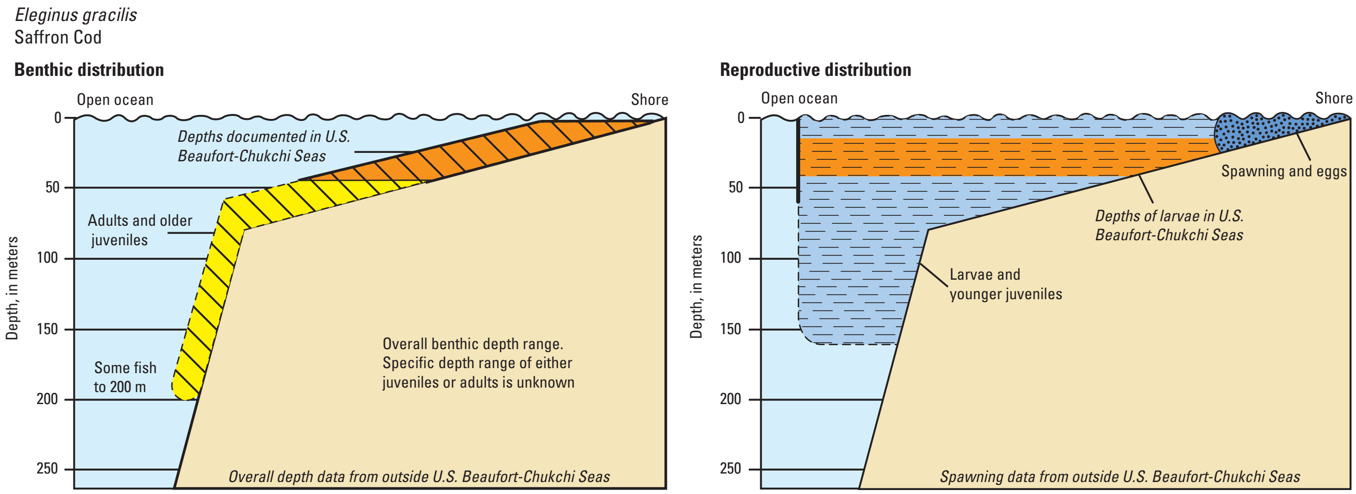
Saffron Cod
Eleginus gracilis



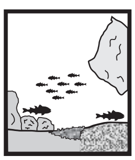
Base modified from USGS and other digital data. U.S.-Russia Maritime Boundary follows the EEZ/200-mile limit line, western edge. Coordinate reference system: projection, Lambert Azimuthal Equal Area; latitude of origin, 75.0°; horizontal datum, North American Datum of 1983.

Geographic distribution of Saffron Cod (*Eleginus gracilis*) within Arctic Outer Continental Shelf Planning Areas [5] based on review of published literature and specimens from historical and recent collections [2, 4, 6].

Depth Range: Shallow, nearshore to 200 m, typically less than 50 m [18–20]. *Four pelagic larvae taken in U.S. Chukchi Sea between 18 and 36 m* and in Bering Sea from 0–162 m. Largest catches were in less than 60 m [21]. *One pelagic juvenile was taken in U.S. Chukchi Sea in midwaters between 45 m and surface* [22]. Older juveniles recruit to very shallow near-shore waters [23–26]. However, off Hokkaido, Japan, and the Kuril Islands, Russia, juveniles are abundant to depths of at least 200 m [27]. Spawning occurs in shallow waters [23, 28, 29] to at least 32 m in the western Pacific Ocean [27].



Benthic and reproductive distribution of Saffron Cod (*Eleginus gracilis*).



Habitats and Life History

Eggs—Size: 0.8–1.7 mm [27, 30]. Time to hatching: 28–49 days [30]. Habitat: Demersal, non-adhesive [27, 30–32].

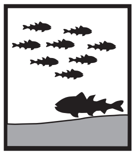
Larvae—Size at hatching: *3.5–3.9 mm SL* [31]. Size at juvenile transformation: 24–27 mm SL [21]. Days to juvenile transformation: Unknown. Habitat: Pelagic [17, 21].

Juveniles—Age and size: 21–35 cm FL [21, 31]. Habitat: Early juveniles are pelagic, becoming more benthic as fish mature [21]. In Gulf of Alaska, closely associated with nearshore eelgrass beds [16, 17].

Adults—Age and size at first maturity: *Very little research has been conducted*. Generally, maximum age, growth rates, and age at first maturity vary with location. Off Hokkaido, Japan, few mature as early as one year and all are mature by 2 years [33]. In Siberian Chukchi Sea, fish mature at 4–5 years. Overall, fish mature at 21.0–35.0 cm FL [31]. Maximum age: 19 years in Canadian Beaufort Sea, [34]. Maximum ages are highly variable among geographic locations [7, 27, 35]. In Siberian Chukchi Sea, fish live to 15 years. Maximum life spans steeply decline to the south. Fish living in Peter the Great Bay, in Sea of Japan, only reach about 8 years of age [27]. Maximum size: 55 cm TL [2] and possibly to 63 cm TL [6]. Females are slightly heavier at length than males. Habitat: Benthic and midwater [2, 36–39]. Shallow, nearshore and, at least around Kodiak Island and Sea of Japan, often associated with eelgrass [16, 40].

Substrate—Soft and hard sea floors [41]. Sandy-stone or gravel bottoms for spawning [32].

Physical/chemical—Temperature: *Unknown.* Elsewhere, between -1.7 and 11.7 °C in southeastern Bering Sea [42]. In Amundsen Gulf, a large mortality event occurred when fish encountered 18.0 °C waters flowing out of Coppermine River [11]. Spawn between -1.8 and 1.8 °C [27, 32, 34, 43]. Eggs remain viable at water temperatures of somewhat greater than -3.8–8.0 °C [43]. Salinity: Primarily marine and brackish waters [36–39], although described as entering both rivers and lakes [43], and not ascending upstream of river mouths [32]. In Russia, spawning occurred only at 27 parts per thousand or more [32]. Temperatures higher than 1.2 °C and salinities less than 21 parts per thousand are reportedly unfavorable for egg and larval survival [27, 32, 44].



Behavior

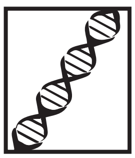
Diel—Unknown.

Seasonal—*Juveniles recruit to very shallow near-shore waters in summer* [23–26]. *Movements of juvenile and adults are not well known.* Generally, Saffron Cod have relatively circumscribed movements, with a limited winter inshore and summer offshore migration [29]. However, large numbers move into shallow waters of the Yukon Territory, Canada and southeastern Beaufort Sea in early summer [28] and *fish in northern Bering Sea may move northwards into U.S. Chukchi Sea in summer* [45]. *Alongshore movements may be quite limited. One fish tagged in the Arctic National Wildlife Refuge only moved 30 km in 3 years* [46]. *Locations of overwintering grounds are not well known. Some fish overwinter in nearshore estuarine and marine waters and these aggregations may be limited to specific geographic areas* [34, 47–49].

Reproductive—*Spawning behavior and locations are poorly understood.* Throughout their geographic range, some spawning occurs in shallow waters [23, 28, 29]. In Russia, fish spawned in areas with strong tidal currents and sandy-stone or gravel bottoms [32].

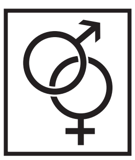
Schooling—Schools, sometimes in high densities [40].

Feeding—*Feed throughout the year at least in U.S. Chukchi Sea and* northern Bering Sea [23]. Juveniles in White Sea feed during day and night. Fish fed among rockweed patches during day and over sand at night. They also fed in the water column on the flood tide [50].



Populations or Stocks

Initial investigations on genetic diversity and stock structure are underway at the University of Alaska Fairbanks.



Reproduction

Mode—Separate sexes, oviparous. Fertilization is external.

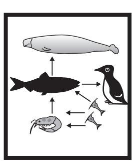
Spawning season—*Winter in U.S. Chukchi Sea* [23]. Mainly, December–February throughout Alaska [31]. Elsewhere, from December to at least May [29, 37] and off Kamchatka Peninsula, Russia, perhaps as late as June [43].

Fecundity—4,900–690,000 eggs, varies with location [27].

Food and Feeding

Food items—*Fishes (for example, Arctic Cod, Capelin, Fourhorn Sculpin, and Saffron Cod) and crustaceans (for example, amphipods, isopods, mysids, and shrimps) often are very important, and priapulids, polychaetes, clams, insects, pteropods, and plant material also are consumed* [11, 23, 35, 36, 51–53]. Juveniles prey on zooplankton [35]. Larger fish prey on a wide range of benthic and epibenthic organisms. During spawning season, adults reportedly feed heavily on Saffron Cod eggs [19].

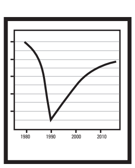
Trophic level—4.1 [54].



Biological Interactions

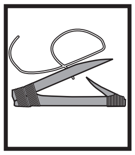
Predators: *Very important prey for ringed seals from at least Nome, Alaska (during at least mid-summer to December) to the U.S. Chukchi Sea (throughout the year)* [55, 56]. *Important summer food for belugas to at least as far north as Wainwright* [57, 58]. *Other predators include Arctic Lamprey and Fourhorn Sculpin* [20, 23]. Additional predators that have been reported include Great, Plain, and Thorny Sculpins, Pacific Cod, Pacific Halibut, Arctic Smelt, Saffron Cod, Black-legged Kittiwake, Common and Thick-billed Murres, bearded and ribbon seals, Steller sea lion, harbor porpoise, Beluga, Fin, Humpback, Ninke, and Sperm whales [59–67].

Competitors: *Likely co-occurring gadids including Arctic Cod, Ice Cod, Pacific Cod (including ogac), and Walleye Pollock* [7, 21, 68].



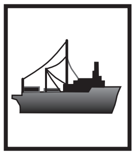
Resilience

Medium, minimum population doubling time: 1.4–4.4 years (t_m=2–3; Fecundity=4,900) [69].



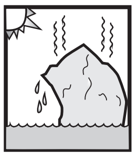
Traditional and Cultural Importance

Commonly taken in subsistence fisheries in both the U.S. Chukchi and Beaufort Seas and in the Bering Sea, usually through the ice by both hook and line and gill nets [1, 24, 37, 70]. Historically, this was an extremely important species to the Inuits residing along the Bering Sea of Alaska where fish were commonly taken during spring as soon as the ice melted from the nearshore, but were particularly important in November, when the pack ice returned. Large numbers of Saffron Cod were utilized by the inhabitants of Norton Sound. They are used as food for both man and dog [71].



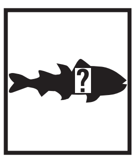
Commercial Fisheries

Currently, Saffron Cod are not commercially harvested.



Potential Effects of Climate Change

Uncertain. Reproducing in Arctic as well as Boreal waters [4], this is a somewhat eurythermic species, apparently able to function within a relatively wide temperature range. Assuming that such coldwater-adapted competitors as Arctic Cod are negatively effected, the reduced competition could be beneficial to the Saffron Cod population. This is supported by new experimental studies that indicate juvenile Saffron Cod growth rate responded positively to increasing temperatures ranging from 0 to 16 °C and above [72].



Areas for Future Research [A]

Little is known about the ecology of this species. It is an important forage fish, subsistence resource, and competitor of Arctic Cod. Information about seasonal habitats and life history and stocks structure of the populations is needed. Initial laboratory and modeling studies suggest the competitive capacity of Saffron Cod with respect to Arctic Cod and other gadids. Additional studies are needed to evaluate the effects of temperature and other population limiting factors, including competition, on this species.

References Cited

Dunn, J.R., and Matarese, A.C., 1987, A review of the early life history of northeast Pacific gadoid fishes: Fisheries Research, v. 5, nos. 2–3, p. 163–184. [31]

Dunn, J.R., and Vinter, B.M., 1984, Development of larvae of the saffron cod, *Eleginus gracilis*, with comments on the identification of gadid larvae in Pacific and Arctic waters contiguous to Canada and Alaska: Canadian Journal of Fisheries and Aquatic Sciences, v. 41, no. 2, p. 304–318. [21]

Fechhelm, R.G., Craig, P.C., Baker, J.S., and Gallaway, B.J., 1984, Fish distribution and use of nearshore waters in the northeastern Chukchi Sea: LGL Ecological Research Associates Inc., Outer Continental Shelf Environmental Assessment Program, National Oceanic and Atmospheric Administration, OMPA/OCSEAP, Final Report, 190 p. [23]

Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p. [2]

Safronov, S.N., 1986, Peculiarities of reproduction and principles of change in the fecundity of Pacific navaga, *Eleginus gracilis* (Gadidae): Journal of Ichthyology, v. 26, no. 5, p. 59–68. [27]

Bibliography

1. George, C., Moulton, L.L., and Johnson, M., 2007, A field guide to the common fishes of the North Slope of Alaska: Alaska Department of Wildlife Management, North Slope Borough, 93 p.

2. Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p.

3. Power, G., 1997, A review of fish ecology in Arctic North America: American Fisheries Society Symposium, no. 19, p. 13–39.

4. Mecklenburg, C.W., Møller, P.R., and Steinke, D., 2011, Biodiversity of Arctic marine fishes—Taxonomy and zoogeography: Marine Biodiversity, v. 41, no. 1, p. 109–140, Online Resource 1.

5. Minerals Management Service, 2008, Beaufort Sea and Chukchi Sea planning areas—Oil and Gas Lease Sales 209, 212, 217, and 221: U.S. Department of the Interior, Minerals Management Service Alaska OCS Region, OCS EIS/EA, MMS 2008-0055, 538 p.

6. Mecklenburg, C.W., Mecklenburg, T.A., Sheiko, B.A., and Steinke, D., 2016, Pacific Arctic marine fishes: Akureyri, Iceland, Conservation of Arctic Flora and Fauna, Monitoring Series Report No. 23, 406 p., accessed May 10, 2016, at http://caff.is/monitoring-series/370-pacific-arctic-marine-fishes.

7. Wolotira, R.J., Jr., Sample, T.M., and Morin, M., Jr., 1977, Demersal fish and shellfish resources of Norton Sound, the southeastern Chukchi Sea, and adjacent waters in the baseline year 1976: Seattle, Washington, Northwest and Alaska Fisheries Center, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Processed Report, 69 p.

8. Fruge, D.J., Wiswar, D.W., Dugan, L.J., and Palmer, D.E., 1989, Fish population characteristics of Arctic National Wildlife Refuge coastal waters, summer 1988: Fairbanks, Alaska, U.S. Fish and Wildlife Service, Fishery Assistance office, Progress Report, 73 p.

9. Bond, W.A., and Erickson, R.N., 1993, Fisheries investigations in coastal waters of Liverpool Bay, Northwest Territories: Winnipeg, Manitoba, Canada Department of Fisheries and Oceans, Central and Arctic Region, Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2204, 59 p.

10. Fechhelm, R.G., Griffiths, W.B., Wilson, W.J., Trimm, B.A., and Colonell, J.M., 1996, The 1995 fish and oceanography study in Mikkelsen Bay, Alaska: Anchorage, Alaska, Prepared by LGL Alaska Research Associates and Woodward-Clyde Consultant for BP Exploration (Alaska) Inc., 102 p. plus apps.

11. Ellis, D.V., 1962, Observations on the distribution and ecology of some Arctic fish: Arctic, v. 15, no. 3, p. 179–189.

12. Lowry, L.F., and Frost, K.J., 1981, Distribution, growth, and foods of Arctic cod (*Boreogadus saida*) in the Bering, Chukchi, and Beaufort Seas: The Canadian Field-Naturalist, v. 92, p. 186–191.

13. Chereshnev, I., Nazarkin, M.V., Skopets, M.B., Pitruk, D., Shestakov, A.V., Yabe, M., and others, 2001, Annotated list of fish-like vertebrates and fish in Tauisk Bay (northern part of the Sea of Okhotsk), *in* Andreev, A.V., and Bergmann, H.H., eds., Biodiversity and ecological status along the northern coast of the Sea of Okhotsk—A collection of study reports: Dalnauka Vladivostok, Russia, Institute of Biological Problems of the North, p. 64–86.

14. Kolpakov, N.V., 2005, Diversity and seasonal dynamics of ichthyocenosis of the Circumlittoral of Russkaya Bight (Northern Primor's): Journal of Ichthyology, v. 45, no. 9, p. 744–753.

15. Hoff, G.R., 2006, Biodiversity as an index of regime shift in the eastern Bering Sea: Fishery Bulletin, v. 104, no. 2, p. 226–237.

16. Laurel, B.J., Stoner, A.W., Ryer, C.H., Hurst, T.P., and Abookire, A.A., 2007, Comparative habitat associations in juvenile Pacific cod and other gadids using seines, baited cameras and laboratory techniques: Journal of Experimental Marine Biology and Ecology, v. 351, nos. 1–2, p. 42–55.

17. Johnson, S.W., Thedinga, J.F., and Neff, A.D., 2009, Invasion by saffron cod *Eleginus gracilis* into nearshore habitats of Prince William Sound, Alaska, USA: Marine Ecology Progress Series, v. 389, p. 203–212.

18. Allen, M.J., and Smith, G.B., 1988, Atlas and zoogeography of common fishes in the Bering Sea and northeastern Pacific: National Oceanic and Atmospheric Administration Technical Report NMFS 66, 151 p.

19. Chuchukalo, V.I., Radchenko, V.I., Nadtochii, V.A., Koblikov, V.N. and Slabinskii, A.M., 1999, Feeding and some features of ecology of Gadidae of the western Kamchatka shelf in summer 1996: Journal of Ichthyology, v. 39, no. 4, p. 309–321.

20. Majewski, A.R., Sareault, J.E., and Reist, J., 2006, Fish catch data from offshore sites in the Mackenzie River estuary and Beaufort Sea during the open water season, August 2004 aboard the CCGS Nahidik: Winnipeg, Manitoba, Fisheries and Oceans Canada, no. 2771, 42 p.

21. Dunn, J.R., and Vinter, B.M., 1984, Development of larvae of the saffron cod, *Eleginus gracilis*, with comments on the identification of gadid larvae in Pacific and Arctic waters contiguous to Canada and Alaska: Canadian Journal of Fisheries and Aquatic Sciences, v. 41, no. 2, p. 304–318.

22. Norcross, B.L., Holladay, B.A., Busby, M.S., and Mier, K.L., 2009, Demersal and larval fish assemblages in the Chukchi Sea: Deep-Sea Research II, v. 57, nos. 1–2, p. 57–70.

23. Fechhelm, R.G., Craig, P.C., Baker, J.S., and Gallaway, B.J., 1984, Fish distribution and use of nearshore waters in the northeastern Chukchi Sea: LGL Ecological Research Associates Inc., Outer Continental Shelf Environmental Assessment Program, National Oceanic and Atmospheric Administration, OMPA/OCSEAP, Final Report, 190 p.

24. Barton, L.H., 1978, Finfish resource surveys in Norton Sound and Kotzebue Sound: Alaska Department of Fish and Game, Commercial Fisheries Division, p. 75–313.

25. Wiswar, D.W., and Frugé, D.J., 2006, Fisheries investigations in western Camden Bay, Arctic National Wildlife Refuge, Alaska, 1987: Alaska Fisheries Data Series, U.S. Fish and Wildlife Service, 2006-10, 49 p.

26. Laurel, B.J., Ryer, C.H., Knoth, B., and Stoner, A.W., 2008, Temporal and ontogenetic shifts in habitat use by juvenile Pacific cod (*Gadus macrocephalus*): Journal of Experimental Marine Biology and Ecology, v. 377, no. 1, p. 28–35.

27. Safronov, S.N., 1986, Peculiarities of reproduction and principles of change in the fecundity of Pacific navaga, *Eleginus gracilis* (Gadidae): Journal of Ichthyology, v. 26, no. 5, p. 59–68.

28. Bond, W.A., and Erickson, R.N., 1989, Summer studies of the nearshore fish community at Phillips Bay, Beaufort Sea coast, Yukon: Winnepeg, Manitoba, Canadian Technical Report of Fisheries and Aquatic Sciences, Central and Arctic Region, Department of Fisheries and Oceans, no. 1676, 102 p.

29. Andriashev, A.P., 1964, Fishes of the northern seas of the U.S.S.R.: Jerusalem, Israel Program for Scientific Translations, 617 p.

30. Aronovich, T.M., Doroshev, S.I., Spectorova, L.V., and Makhotin, V.M., 1975, Egg incubation and larval rearing of navaga (*Eleginus navaga* Pall.), Arctic Cod (*Boreogadus saida* lepechin) and Arctic flounder (*Liopsetta glacialis* Pall.) in the laboratory: Aquaculture, v. 6, no. 3, p. 233–242.

31. Dunn, J.R., and Matarese, A.C., 1987, A review of the early life history of northeast Pacific gadoid fishes: Fisheries Research, v. 5, nos. 2–3, p. 163–184.

32. Berg, L.S., 1949, Freshwater fishes of the U.S.S.R. and adjacent countries, volume 3 (4th ed.): Moscow, Academy of Sciences of the U.S.S.R. Zoological Institute, 250 p. [Translated from Russian by Israel Program for Scientific Translations, Jerusalem, IPST Catalog No. 743.]

33. Chen, A.-L., and Sakurai, Y., 1993, Age and growth of saffron cod (*Eleginus gracilis*): Scientific Reports of Hokkaido Fisheries Experimental Station, v. 42, p. 251–264.

34. Lawrence, M.J., Lacho, G., and Davies, S., 1984, A survey of the coastal fishes of the southeastern Beaufort Sea: Canadian Technical Report of Fisheries and Aquatic Sciences, no. 1220, 178 p.

35. Anukhina, A.M., 1968, Population dynamics of White Sea navaga: Rapports et Procčs-Verbeaux des Réunions du Conseil International pour l'Exploration de la Mer, v. 158, p. 138–142.

36. Bond, W.A., and Erickson, R.N., 1987, Fishery data from Phillips Bay, Yukon, 1985: Winnipeg, Manitoba, Canadian Data Report of Fisheries and Aquatic Sciences, Central and Artic Region, Department of Fisheries and Oceans, no. 635, 47 p.

37. Stewart, D.B., Ratynski, R.A., Bernier, L.M.J., and Ramsey, D.J., 1993, A fishery development strategy for the Canadian Beaufort Sea-Amundsen Gulf area: Canadian Technical Report Fisheries and Aquatic Sciences 1910, 135 p.

38. Dragoo, D.E., 2006, Seabird, fish, marine mammals and oceanography coordinated investigations (SMMOCI) near Bluff, Norton Sound, Alaska, July 2002: U.S. Fish and Wildlife Service Report AMNWR 06/03, 35 p.

39. Walters, V., 1955, Fishes of western Arctic America and eastern Arctic Siberia: Bulletin of the American Museum of Natural History, v. 106, p. 259–368.

40. Gomelyuk, V.E., and Shchetkov, S.Y., 1992, Distribution of fish in coastal biotopes of Peter the Great Bay, Sea of Japan, in the summer period: Biologiya Morya, nos. 3–4, p. 26–32.

41. Mecklenburg, C.W., Stein, D.L., Sheiko, B.A., Chernova, N.V., Mecklenburg, T.A., and Holladay, B.A., 2007, Russian–American long-term census of the Arctic—Benthic fishes trawled in the Chukchi Sea and Bering Strait, August 2004: Northwestern Naturalist, v. 88, no. 3, p. 168–187.

42. Mueter, F.J., University of Alaska-Fairbanks, written commun., 2010.

43. Musienko, L.N., 1970, Reproduction and development of Bering Sea fishes, *in* Moiseev, P.A., ed., Soviet fisheries investigations in the northeastern Pacific, Part V: Soviet Fisheries Investigation in the Northeastern Pacific, p. 161–224. [Russian translation by Israel Program for Scientific Translations, Jerusalem (1972).]

44. Ratynski, R.A., 1983, Mid-summer ichthyoplankton populations of Tuktoyaktuk Harbour, N.W.T.: Canadian Technical Report of Fisheries and Aquatic Sciences, no. 1218, 21 p.

45. Lowry, L.F., Frost, K.J., and Burns, J.J., 1980, Variability in the diet of ringed seals, *Phoca hispida*, in Alaska: Canadian Journal of Fisheries and Aquatic Sciences, v. 37, no. 12, p. 2,254–2,261.

46. Palmer, D.E., and Dugan, L.J., 1990, Fish population characteristics of Arctic National Wildlife Refuge coastal waters, summer 1989: Fairbanks, Alaska, U.S. Fish and Wildlife Service, Progress Report, 83 p.

47. Percy, R., 1975, Fishes of the outer Mackenzie Delta: Victoria, British Columbia, Beaufort Sea Project, Beaufort Sea Technical Report, no. 8, 114 p.

48. Craig, P.C., 1989a, An introduction to anadromous fishes in the Alaskan Arctic: Biological Papers of the University of Alaska, v. 24, p. 27–54.

49. Sekerak, A.D., Stallard, N., and Griffiths, W.B., 1992, Distribution of fish and fish harvests in the nearshore Beaufort Sea and Mackenzie Delta during ice-covered periods, October–June: Environmental Studies Research Funds Report, LGS Ltd. No. 117, 524 p.

50. Girsa, I.I., 1986, Effect of ecological conditions on changes in the behavior of yearling navaga, *Eleginus navaga* (Gadidae) during summer in the coastal waters of the White Sea: Journal of Ichthyology, v. 26, no. 2, p. 140–143.

51. Jones, M.L., and Den Beste, J., 1977, Tuft Point and adjacent coastal areas fisheries projects: Calgary, Alberta, Canada, Aquatic Environments, Ltd., 152 p.

52. Lacho, G., 1991, Stomach content analyses of fishes from Tuktoyaktuk Harbour, N.W.T., 1981: Winnipeg, Manitoba, Canadian Data Report of Fisheries and Aquatic Sciences, Central and Arctic Region, Department of Fisheries and Oceans, no. 853, 15 p.

53. Coyle, K.O., Gillispie, J.A., Smith, R.L., and Barber, W.E. 1997, Food habits of four demersal Chukchi Sea fishes, *in* Reynolds, J.B., ed., Symposium 19, Proceedings of the Fish Ecology in Arctic North America Symposium: American Fisheries Society, Fairbanks, Alaska, May 19–21, 1992, p. 310–318.

54. Mueter, F.J., and Litzow, M.A., 2008, Sea ice retreat alters the biogeography of the Bering Sea continental shelf: Ecological Applications, v. 18, no. 2, p. 309–320.

55. Johnson, M.L., Fiscus, C.H., Ostenson, B.T., and Barbour, M.L., 1966, Marine mammals, *in* Wilimovsky, N.J., and Wolfe, J.N., eds., Environment of the Cape Thompson Region, Alaska: Oak Ridge, Tennesee, United States Atomic Energy Commission, Division of Technical Information, p. 877–924.

56. Frost, K.J., and Lowry, L.F., 1981, Foods and trophic relationships of cetaceans in the Bering Sea, *in* Hood, D.W., and Calder, J.A., eds., The Eastern Bering Sea Shelf—Oceanography and Resources: National Oceanic and Atmospheric Administration, p. 825–836.

57. Craig, P.C., and Haldorson, L.J., 1981, Beaufort Sea Barrier Island Lagoon ecological process studies—Final report, Simpson Lagoon—Fish: U.S. Department of Commerce, Biological Studies, p. 384–649.

58. Lowry, L.F., Frost, K.J., and Seaman, G.A., 1986, Investigations of belukha whales in coastal waters of western and northern Alaska: Outer Continental Shelf Environmental Program Unit 612, Final Report, p. 359–392.

59. Kawakami, T., 1980, A review of sperm whale food: Scientific reports of the Whales Research Institute, no. 32, p. 199–218.

60. Kawamura, A., 1980, A review of food of balaenopterid whales: Scientific Reports of the Whales Research Institute, v. 32, p. 115–197.

61. Pitcher, K.W., 1981, Prey of the Steller sea lion, *Eumetopias jubatus*, in the Gulf of Alaska: Fishery Bulletin, v. 79, no. 3, p. 467–472.

62. Kajimura, H., and Loughlin, T.R., 1988, Marine mammals in the oceanic food web of the eastern subarctic Pacific: University of Tokyo, Bulletin of the Ocean Research Institute, v. 26, no. 2, p. 187–233.

63. Lowry, L.F., and Frost, K.J., 1981, Feeding and trophic relationships of phocid seals and walruses in the eastern Bering Sea, *in* Hood, D.W., and Calder, J.A., eds., The Eastern Bering Sea Shelf—Oceanography and resources: National Oceanic and Atmospheric Administration, p. 813–824.

64. Tokranov, A.M., 1981, Distribution of sculpins (Pisces, Cottidae) on the west Kamchatka shelf in summer: Zoologicheskii Zhurnal, v. 60, no. 2, p. 229–237.

65. Tokranov, A.M., and Vinnikov, A.B., 1991, Diet of the Pacific cod, *Gadus morhua macrocephalus*, and its position in the food chain in Kamchatkan coastal waters: Journal of Ichthyology, v. 31, no. 5, p. 84–98.

66. Karpenko, V.I., and Vasilets, P.M., 1996, Biology of smelt (Osmeridae) in the Korf-Karagin coastal area of the southwestern Bering Sea, *in* Mathisen, O.A., and Coyle, K.O., eds., Ecology of the Bering Sea—A review of Russian literature: Fairbanks, Alaska, University of Alaska, Alaska Sea Grant Program, AK-SG-96-01, p. 217–235.

67. Lang, G.M., Livingston, P.A., and Dodd, K., 2005, Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1997 through 2001: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Technical Memorandum NMFS-AFSC-158, 249 p.

68. Quast, J.C., 1974, Density distribution of juvenile Arctic cod, *Boreogadus saida*, in the eastern Chukchi Sea in the fall of 1970: Fishery Bulletin, v. 72, no. 4, p. 1,094–1,105.

69. Froese, R., and Pauly, D., eds., 2012, FishBase—Global information system on fishes: FishBase database, accessed July 8, 2012, at http://www.fishbase.org.

70. Moulton, L.L., Field, L.J., and Kovalsky, R., 1991, Predictability in the catch of Arctic cisco in the Colville River, Alaska: American Fisheries Society Symposium no. 11, p. 145–156.

71. Turner, L.M., 1886, Contributions to the natural history of Alaska—Arctic series of publications, no. 2, Washington: Washington D.C., U.S. Government Printing Office, 226 p.

72. Laurel, B.J., Spencer, M., Iseri, P., and Copeman, L.A., 2015, Temperature-dependent growth and behavior of juvenile Arctic cod (*Boreogadus saida*) and co-occurring North Pacific gadids: Polar Biology, no. 39, p. 1,127–1,135.

Walleye Pollock (*Gadus chalcogrammus*)
Pallas, 1814

Family Gadidae

Walleye Pollock (*Gadus chalcogrammus*) juvenile, 141 mm, Bering Strait, 2007. Photograph by C.W. Mecklenburg, Point Stephens Research.

Scientific name: Previously called *Theragra chalcogramma* (Pallas, 1814), this species was recently returned to its original genus *Gadus* on the basis of morphological and molecular evidence [1].

Colloquial Name: *None within U.S. Chukchi and Beaufort Seas*.

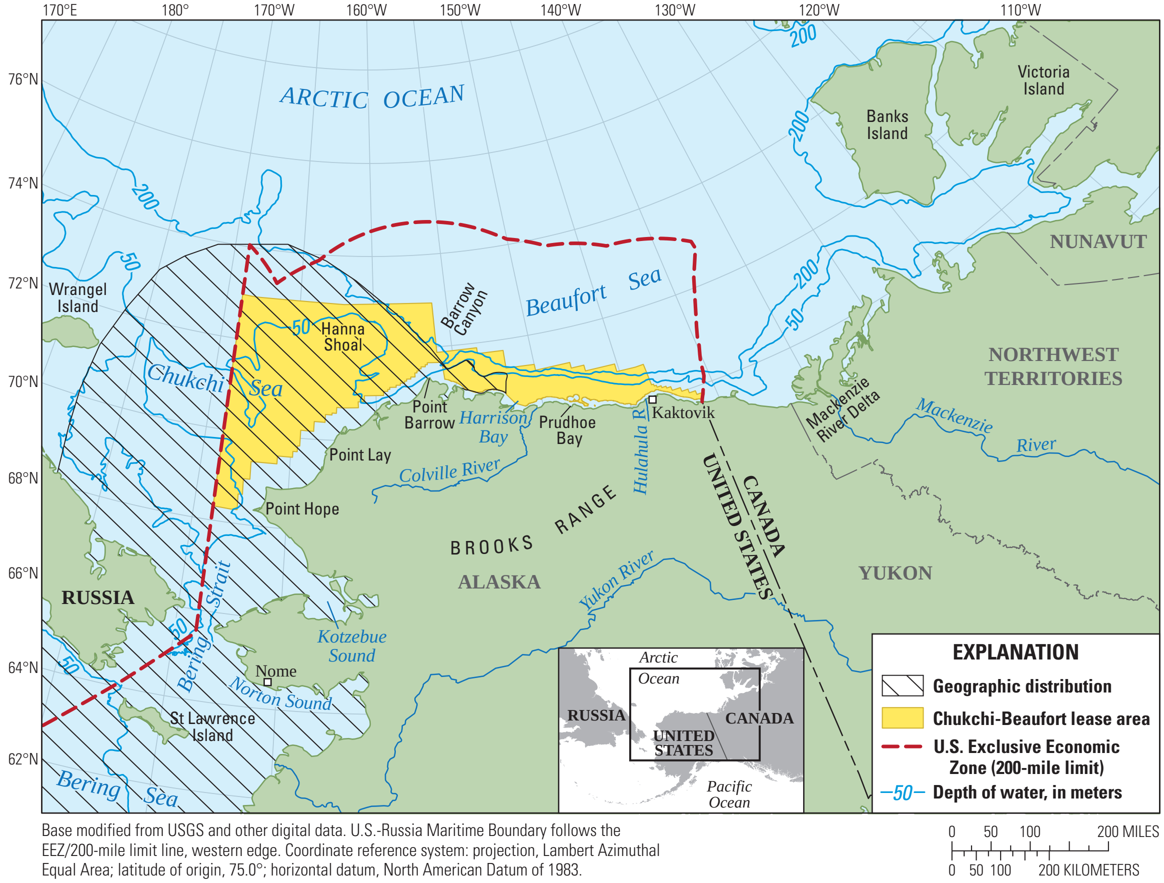
Ecological Role: Current information on the distribution and abundance of this species suggests it could be of low to moderate ecological importance in some parts of the Chukchi Sea and offshore waters north of Barrow, Alaska. This is a key species in ecosystem dynamics of the Gulf of Alaska, Prince William Sound, and Bering Sea [2].

Physical Description/Attributes: Olive green to brown with dark mottling and blotches on back, and interrupted dark brassy olive stripes on upper sides. Fins are brown, dusky gray, or black. For specific diagnostic characteristics, see *Fishes of Alaska* (Mecklenburg and others, 2002, p. 295) [3]. Swim bladder: Present; no otophysic connection [3]. Antifreeze glycoproteins in blood serum: Unknown.

Range: *U.S. Chukchi and Beaufort Seas* [4–6]. Elsewhere, through Bering Sea, Aleutian Islands and Gulf of Alaska south to Carmel, central California and west to Seas of Okhotsk and Japan [3]. Also found in Barents Sea off Norway, where it used to be called *Theragra finnmarchica* [1].

Relative Abundance: *Common in U.S. Chukchi and rare in U.S. Beaufort Sea* [1, 4, 5, 8, 9]. Elsewhere, abundant in Sea of Japan, northern Kuril Islands, Kamchatka Peninsula, Russia, and throughout Bering Sea southward to southeastern Alaska and Puget Sound [10–15].

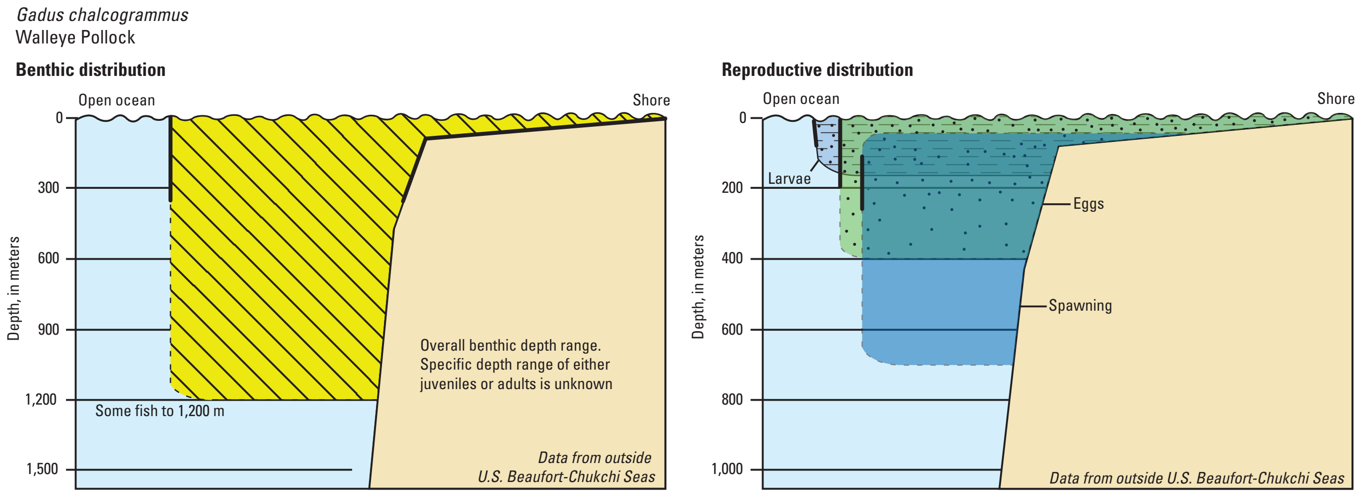
Walleye Pollock
Gadus chalcogrammus



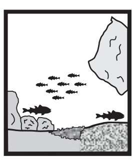
Base modified from USGS and other digital data. U.S.-Russia Maritime Boundary follows the EEZ/200-mile limit line, western edge. Coordinate reference system: projection, Lambert Azimuthal Equal Area; latitude of origin, 75.0°; horizontal datum, North American Datum of 1983.

Geographic distribution of Walleye Pollock (*Gadus chalcogrammus*) within Arctic Outer Continental Shelf Planning Areas [7] based on review of published literature and specimens from historical and recent collections [1, 3, 8].

Depth Range: Entire water column, from surf zone to 1,200 m, commonly at 400 m or less, though large numbers have been taken at 800–1,000 m in Bering Sea [13, 16, 17]. Spawning occurs from 46 to 700 m, most commonly between 100 and 250 m on deeper continental shelf and upper continental slope [18–20]. Pelagic eggs are from 0 to 400 m, typically less than 200 m in Gulf of Alaska and eastern Bering Sea [21–23]. Pelagic larvae are from 0 to 153 m, typically 60 m or less in Gulf of Alaska and eastern Bering Sea [22, 24–26].



Benthic and reproductive distribution Walleye Pollock (*Gadus chalcogrammus*).



Habitats and Life History

Eggs—Size: 1.2–1.8 mm [27, 28]. Time to hatching: 25.5 days at 2 °C and 14 days at 5 °C [29]. Habitat: Pelagic, in deep water, rising to shallower water as they develop [3, 22, 30].

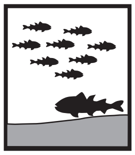
Larvae—Size at hatching: 3.0–4.0 mm SL [28]. Size at juvenile transformation: About 2.5–4.0 cm SL [20, 29]. Days to juvenile transformation: 60 days [29]. Habitat: Epipelagic, over continental shelf and slope [3, 27, 28, 31].

Juveniles—Age and size: 2 months to 2–7 years [29] and 2.5 cm SL to 20–48 cm FL [32, 33]. Habitat: Semi-benthic, in nearshore waters [3, 34, 35] and then migrate somewhat deeper as they mature [34–36]. Taken among eelgrass and kelp [37].

Adults—Age and size at first maturity: In eastern Bering Sea, a few males matured at 20 cm FL (2 years), 50 percent were mature at 31 cm (3 years), and 100 percent were mature at 48 cm (about 7 years) [32]. For females, size and age at maturity varied somewhat with location and year. On average, a few matured at 25 cm FL, 50 percent at 37.4 cm (4 years), and virtually all by 56 cm [33]. In the Gulf of Alaska, 50 percent of females matured at 42 cm FL and 5 years [38]. Older females are perhaps somewhat larger at age than are males. Maximum age: 33 years [20]. Maximum size: 91 cm TL [3]. Habitat: Semi-demersal to pelagic [3]; commonly associated with outer shelf and slope but also uses a wide variety of habitats including nearshore eelgrass and kelp beds, large estuaries (such as the Puget Sound), coastal embayments, and open ocean basins (such as the Aleutian Basin of Bering Sea) [30, 37].

Substrate—Sand, gravel, mud, silt, and bedrock [20, 37].

Physical/chemical—Temperature: -*1.8*–12 °C; rare in waters less than 0 °C [6, 30, 39, 40]. Salinity: Marine [20]. *Found at 31.3–33.5 ppt in U.S. Chukchi Sea* [6].



Behavior

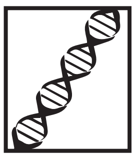
Diel—They make limited day-night vertical migrations, moving into shallow waters at dusk and night, then deeper during day [25, 41, 42]. Juveniles aggregate near sea floor during day then disperse and move shallower at night [30, 35, 43]. Juveniles often associated with tentacles of medusae during day [43, 44]. Some adults migrate into near-surface waters at night [42].

Seasonal—Young-of-the-year recruit to nearshore waters from early summer through autumn [34, 35]. Make seasonal inshore-offshore migrations, overwintering in deep part of their depth range [45]. Strong year classes have been linked to warm water years when juveniles are transported offshore and away from cannibalistic adults [46].

Reproductive—Spawning occurs in a number of discrete locations in Strait of Georgia, Gulf of Alaska, Bering Sea, and in western Pacific Ocean off Asia [30]. Fish may return to their natal sites to spawn. Females are batch spawners [27, 47], spawning at least 14 times in a season [20]. Spawning of an individual female probably takes less than 1 month [18].

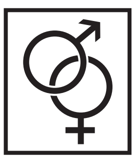
Schooling—Forms large schools [34–36].

Feeding—Juveniles and adults are mainly nocturnal feeders [48] whereas most feeding of larvae occurs during the day [25].



Populations or Stocks

There is evidence for semi-discrete populations in the Gulf of Alaska and Bering Sea, although the degree of genetic isolation of these stocks is unclear. As many as 12 stocks in waters between Japan and southeastern Alaska have been postulated [30, 38, 49, 50].



Reproduction

Mode—Oviparous [20].

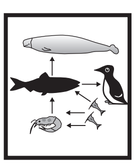
Spawning season—Over all their range, some spawning may occur throughout the year [51]. However, most spawning takes place in winter and spring, varying somewhat with location. For instance, in Gulf of Alaska, fish spawn around Shumagin Island, Alaska from about 15 February to 1 March, 15 March to 1 April in Shelikov Strait [38] and mostly April to Mid-May in southeastern Bering Sea [30].

Fecundity—58,000–1,400,000 non-adhesive eggs per season, in batches [27, 47, 52].

Food and Feeding

Food items—Larvae: Copepod naupli, larval copepods and small euphausiids [29]. Juveniles: Mainly euphausiids [48] as well as copepods and other planktonic crustaceans [29]. Adults: A wide array of midwater and benthic organisms. Smaller pollock feed primarily on zooplankton (for example, euphausiids, copepods, and gammarid amphipods). Among larger fish, copepods and euphausiids are often very important, as are a number of fish species (for example, capelin, eulachon, and lanternfishes) and shrimps. Other frequently eaten organisms include mysids, crabs, polychaetes, and cephalopods and crustacean larvae [53–56].

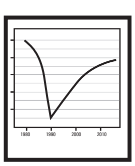
Trophic level—3.7 [57]



Biological Interactions

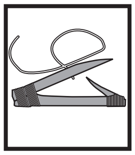
Predators—Walleye Pollock are extremely important prey for many fishes, seabirds, and mammals. A literature search discloses that at least 42 species of fishes, 18 species of seabirds, 7 species of pinnipeds, 9 species of cetaceans, and river otters prey on pollock. In Gulf of Alaska, pollock are very important prey to Arrowtooth Flounder, Pacific Cod, Pacific Halibut, and Steller sea lion [38]. In some years, juvenile pollock are a major part of the diet of older pollock [30].

Competitors—Walleye Pollock, an ecologically generalist species, compete with a very wide range of other fish species [30].



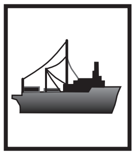
Resilience

Low, minimum population doubling time: 4.5–14 years [58].



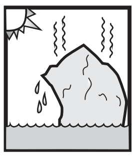
Traditional and Cultural Importance

None in study area.



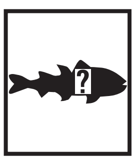
Commercial Fisheries

In the United States, Walleye Pollock are not commercially harvested north of the Bering Sea. Walleye Pollock was a major food fish in southeastern Alaska and the Gulf of Alaska [59]. Commercial catches by foreign fleets began in the early 1950s and increased substantially with the advent of at-sea processing of fish for surimi. Currently, the average Alaskan harvest of pollock is 1.1 million metric tons with processed catches destined for U.S. and export markets [30, 38, 60].



Potential Effects of Climate Change

It is hypothesized that this species will become more abundant in the U.S. Chukchi and Beaufort Seas marine ecosystem changes resulting from climate change. Increased abundance will result in changes in food web dynamics such as competition with other gadid species, especially in the Chukchi Sea if benthic-pelagic energy flows become decoupled. New experimental results indicate that Walleye Pollock and Pacific Cod grow at 2–3 times the rate of other Arctic gadids when exposed to increasing temperature regimes in the laboratory that are similar to field conditions in summer in the coastal Chukchi and Beaufort Seas. This suggests a potential competitive advantage for Walleye Pollock under warming conditions [61].



Areas for Future Research [A]

Field identifications of young pollock may be confused with other gadid species, especially Arctic Cod. A rapid diagnostic (genetic) identification tool is needed for field applications as these cods may occur in mixed assemblages. Pollock are not well adapted to cold-water environments and, as temperatures warm, monitoring programs should be sufficient to detect abrupt changes in abundance. Predator-prey relationships should be established to investigate competition with other gadid species. Important spawning and overwintering habitats require delineation. Improved information about the species physiological tolerances and growth rate in Arctic waters is needed to evaluate potential climate change effects.

References Cited

Bailey, K.M., Powers, D.M., Quattro, J.M., Villa, G., Nishimura, A., Traynor, J.J., and Walters, G., 1999, Population ecology and structural dynamics of Walleye Pollock (*Theragra chalcogramma*), *in* Loughlin, T.R., and Ohtani, K., eds., Dynamics of the Bering Sea: Fairbanks, University of Alaska Sea Grant, AK-SG-99-03, p. 581–613. [30]

Carlson, H.R., 1995, Consistent yearly appearance of age-0 Walleye Pollock, *Theragra chalcogramma,* at a coastal site in southeastern Alaska, 1973–1994: Fishery Bulletin, v. 93, no. 2, p. 386–390. [35]

Dorn, M., Aydin, K., Barbeaux, S., Guttormsen, M., Megrey, B., Spalinger, K., and others, 2007, Gulf of Alaska walleye pollock, *in* The Plan Team for the Groundfish Fisheries of the Gulf of Alaska, compilers, Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska: Anchorage, Alaska, North Pacific Fishery Management Council, p. 51–168. [38]

Love, M.S., 2011, Certainly more than you wanted to know about the fishes of the Pacific Coast: Santa Barbara, California, Really Big Press, 649 p. [20]

Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p. [3]

North Pacific Fishery Management Council, 2010, Fishery management plan for groundfish of the Bering Sea and Aleutian Islands management area—Appendices—Fishery management plan for groundfish of the BSAI Management Area: North Pacific Fisheries Management Council, 233 p. [29]

Bibliography

1. Mecklenburg, C.W., Møller, P.R., and Steinke, D., 2011, Biodiversity of Arctic marine fishes—Taxonomy and zoogeography: Marine Biodiversity, v. 41, no. 1, p. 109–140, Online Resource 1.

2. Bailey, K.M., and Ciannelli, L., 2007, Walleye pollock, *in* Spies, R.B., ed., Long-term ecological change in the northern Gulf of Alaska: Amsterdam, Elsevier, , p. 85–93.

3. Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p.

4. Fechhelm, R.G., Craig, P.C., Baker, J.S., and Gallaway, B.J., 1984, Fish distribution and use of nearshore waters in the northeastern Chukchi Sea: LGL Ecological Research Associates Inc., Outer Continental Shelf Environmental Assessment Program, National Oceanic and Atmospheric Administration, OMPA/OCSEAP, Final Report, 190 p.

5. Barber, W.E., Smith, R.L., Vallarino, M., and Meyer, R.M., 1997, Demersal fish assemblages of the northeastern Chukchi Sea, Alaska: Fishery Bulletin, v. 95, no. 2, p. 195–209.

6. Mecklenburg, C.W., Stein, D.L., Sheiko, B.A., Chernova, N.V., Mecklenburg, T.A., and Holladay, B.A., 2007, Russian–American long-term census of the Arctic—Benthic fishes trawled in the Chukchi Sea and Bering Strait, August 2004: Northwestern Naturalist, v. 88, no. 3, p. 168–187.

7. Minerals Management Service, 2008, Beaufort Sea and Chukchi Sea planning areas—Oil and Gas Lease Sales 209, 212, 217, and 221: U.S. Department of the Interior, Minerals Management Service Alaska OCS Region, OCS EIS/EA, MMS 2008-0055, 538 p.

8. Mecklenburg, C.W., Mecklenburg, T.A., Sheiko, B.A., and Steinke, D., 2016, Pacific Arctic marine fishes: Akureyri, Iceland, Conservation of Arctic Flora and Fauna, Monitoring Series Report No. 23, 406 p., accessed May 10, 2016, at http://caff.is/monitoring-series/370-pacific-arcticmarine-fishes.

9. Logerwell, E.A., and Rand, K.M., 2010, Beaufort Sea marine fish monitoring 2008—Pilot survey and test of hypotheses: Seattle, Washington, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Alaska Fisheries Science Center, Final Report, BOEMRE 2010-048, 262 p.

10. Balykin, P.A., 1996, Dynamics and abundance of western Bering Sea walleye pollock, *in* Mathisen, O.A., and Coyle, K.O., eds., Ecology of the Bering Sea: Fairbanks, University of Alaska, Alaska Sea Grant College Program, p. 177–182.

11. Sokolovskaya, T.G., Sokolovskii, A.S., and Sobolevskii, E.I., 1998, A list of fishes of Peter the Great Bay (the Sea of Japan): Journal of Ichthyology, v. 38, no. 1, p. 1–11.

12. Gustafson, R.G., Lenarz, W.H., McCain, B.B., Schmitt, C.C., Grant, W.S., Builder, T.L., and Methot, R.D., 2000, Status review of Pacific hake, Pacific cod, and walleye pollock from Puget Sound, Washington: Seattle, Washington, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Technical Memorandum NMFS-NWFSC-44.

13. Orlov, A.M., 2005, Bottom trawl-caught fishes and some features of their vertical distribution in the Pacific waters off the north Kuril Islands and south-east Kamchatka, 1993–1999: Aqua, Journal of Ichthyology and Aquatic Biology of Fishes, v. 9, no. 4, p. 139–160.

14. Martin, M.H., and Clausen, D.M., 1995, Data report—1993 Gulf of Alaska Bottom Trawl Survey: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Technical Memorandum, NMFS-AFSC-59, 217 p.

15. Zenger, H.H., Jr., 2004, Data report—2002 Aleutian Islands bottom trawl survey: U.S. Department of Commerce, National Oceanic and Atmospheric Administration Technical Memorandum NMFS-AFSC-143, 247 p.

16. Hoff, G.R., and Britt, L.L., 2003, The 2002 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources: National Oceanic and Atmospheric Administration, Technical Memorandum NMFS-AFSC-141, 286 p.

17. Hoff, G.R., and Britt, L.L., 2005, Results of the 2004 Eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources: National Oceanic and Atmospheric Administration, Technical Memorandum, 300 p.

18. Hinckley, S., 1987, The reproductive biology of walleye pollock, *Theragra chalcogramma*, in the Bering Sea, with reference to spawning stock structure: Fishery Bulletin, v. 85, no. 3, p. 481–498.

19. Matarese, A.C., Blood, D.M., Picquelle, S.J., and Benson, J.L., 2003, Atlas of abundance and distribution patterns of ichthyoplankton from the northeast Pacific Ocean and Bering Sea ecosystems based on research conducted by the Alaska Fisheries Science Center (1972–1996): National Oceanic and Atmospheric Administration Professional Paper NMFS 1, 281 p.

20. Love, M.S., 2011, Certainly more than you wanted to know about the fishes of the Pacific Coast: Santa Barbara, California, Really Big Press, 649 p.

21. Siefert, D.L., Incze, L.S., and Ortner, P.B., 1988, Vertical distribution of zooplankton, including ichthyoplankton, in Shelikof Strait, Alaska—Data from fisheries-oceanography coordinated investigations (FOCI) cruise in May 1986: National Marine Fisheries Service, NWAFC Processed Report, v. 88, no. 28, 232 p.

22. Kendall, J., Arthur W., Incze, L.S., Ortner, P.B., Cummings, S.R., and Brown, P.K., 1994, The vertical distribution of eggs and larvae of walleye pollock, *Theragra chalcogramma*, in Shelikof Strait, Gulf of Alaska: Fishery Bulletin, v. 92, no. 3, p. 540–554.

23. Duffy-Anderson, J.T., Busby, M.S., Mier, K.L., Deliyanides, C.M., and Stabeno, P.J., 2006, Spatial and temporal patterns in summer ichthyoplankton assemblages on the eastern Bering Sea shelf 1996–2000: Fisheries Oceanography, v. 15, no. 1, p. 80–94.

24. Nishiyama, R., Hirano, K., and Haryu, T., 1986, The early life history and feeding habits of larval walleye pollock *Theragra chalcogramma* (Pallas) in the southeast Bering Sea, *in* Symposium on biology, stock assessment, and management of pollock, Pacific cod and hake in the North Pacific region: Standing Committee on Biology and Research, Anchorage, Alaska, October 1983, International North Pacific Fisheries Commission Bulletin, Issue 45, p. 177–227.

25. Kendall, J., Arthur W., Clarke, M.E., Yoklavich, M.M., and Boehlert, G.W., 1987, Distribution, feeding, and growth of larval walleye pollock, *Theragra chalcogramma*, from Shelikof Strait, Gulf of Alaska: Fishery Bulletin, v. 85, no. 3, p. 499–521.

26. Siefert, D.L., Incze, L.S., and Ortner, P.B., 1990, Vertical distribution of zooplankton, including ichthyoplankton, in Shelikof Strait, Alaska—Data from fisheries-oceanography coordinated investigations (FOCI) cruise in May 1987: National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest and Alaska Fisheries Center (NWAFC) Processed Report v. 90, no. 5, 129 p.

27. Mason, J.C., 1985, The fecundity of the walleye pollock, *Theragra chalcogramma* (Pallas), spawning in Canadian waters: Journal of Fish Biology, v. 27, no. 3, p. 335–346.

28. Dunn, J.R., and Matarese, A.C., 1987, A review of the early life history of northeast Pacific gadoid fishes: Fisheries Research, v. 5, nos. 2–3, p. 163–184.

29. North Pacific Fishery Management Council, 2010, Fishery management plan for groundfish of the Bering Sea and Aleutian Islands management area—Appendices—Fishery management plan for groundfish of the BSAI Management Area: North Pacific Fisheries Management Council, 233 p.

30. Bailey, K.M., Powers, D.M., Quattro, J.M., Villa, G., Nishimura, A., Traynor, J.J., and Walters, G., 1999, Population ecology and structural dynamics of Walleye Pollock (*Theragra chalcogramma*), *in* Loughlin, T.R., and Ohtani, K., eds., Dynamics of the Bering Sea: Fairbanks, University of Alaska Sea Grant, AK-SG-99-03, p. 581–613.

31. Doyle, M.J., Mier, K.L., Busby, M.S., and Brodeur, R.D., 2002, Regional variation in springtime ichthyoplankton assemblages in the northeast Pacific Ocean: Progress in Oceanography, v. 53, no. 2, p. 247–281.

32. Smith, G.B., 1981, The biology of walleye pollock, *in* Hood, D.W., and Calder, J.A., eds.: The eastern Bering Sea shelf—Oceanography and resources, .Volume 1: Seattle, University of Washington Press, p. 527–551.

33. Stahl, J.P., and Kruse, G.H., 2008, Spatial and temporal variability in size at maturity of Walleye Pollock in the eastern Bering Sea: Transactions of the American Fisheries Society, v. 137, no. 5, p. 1,543–1,557.

34. Walters, G.E., 1984, Ecological aspects of larval and juvenile Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*), and Pacific tomcod (*Microgadus proximus*) in Port Townsend, Washington: Seattle, University of Washington, Master's thesis, 129 p.

35. Carlson, H.R., 1995, Consistent yearly appearance of age-0 Walleye Pollock, *Theragra chalcogramma,* at a coastal site in southeastern Alaska, 1973–1994: Fishery Bulletin, v. 93, no. 2, p. 386–390.

36. Johnson, S.W., Neff, A.D., and Thedinga, J.F., 2005, An atlas on the distribution and habitat of common fishes in shallow nearshore waters of southeastern Alaska: Alaska Fisheries Science Center, Technical Memorandum NMFS-AFSC-157, 98 p.

37. Johnson, S.W., Thedinga, J.F., and Lindeberg, M.R., 2012, Nearshore fish atlas of Alaska: National Oceanic and Atmospheric Administration Fisheries, accessed February 2012 at http://www.fakr.noaa.gov/habitat/fishatlas/.

38. Dorn, M., Aydin, K., Barbeaux, S., Guttormsen, M., Megrey, B., Spalinger, K., and others, 2007, Gulf of Alaska walleye pollock, *in* The Plan Team for the Groundfish Fisheries of the Gulf of Alaska, compilers, Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska: Anchorage, Alaska, North Pacific Fishery Management Council, p. 51–168.

39. Tokranov, A.M., and Polutov, V.I., 1984, Fish distribution in the Kronitsky Bay in relation to abiotic factors: Zoologicheskii Zhurnal, v. 63, p. 1,363–1,373.

40. Mueter, F.J., University of Alaska-Fairbanks, written commun., 2010.

41. Brodeur, R.D., and Rugen, W.C., 1994, Diel vertical distribution of ichthyoplankton in the northern Gulf of Alaska: Fishery Bulletin, v. 92, no. 2, p. 223–235.

42. Adams, C.F., Foy, R.J., Kelley, J.J., and Coyle, K.O., 2009, Seasonal changes in the diel vertical migration of walleye pollock (*Theragra chalcogramma*) in the northern Gulf of Alaska: Environmental Biology of Fishes, v. 86, no. 2, p. 297–305.

43. Brodeur, R.D., 1998, In situ observations of the association between juvenile fishes and scyphomedusae in the Bering Sea: Marine Ecology Progress Series, v. 163, p. 11–20.

44. Van Hyning, J.M., and Cooney, R.T., 1974, Association of walleye pollock, *Theragra chalcogramma,* with the jellyfish, Cyanea: Copeia, v. 1974, no. 3, p. 791.

45. Kotwicki, S., Buckley, T.W., Honkalehto, T., and Walters, G.E., 2005, Variation in the distribution of walleye pollock (*Theragra chalcogramma*) with temperature and implications for seasonal migration: Fishery Bulletin, v. 103, no. 4, p. 574–587.

46. Wespestad, V.G., Fritz, L.W., Ingraham, W.J., and Megrey, B.A., 2000, On relationships between cannibalism, climate variability, physical transport, and recruitment success of Bering Sea walleye pollock (*Theragra chalcogramma*): ICES Journal of Marine Science, v. 57, no. 2, p. 272–278.

47. Mito, K.-I., Nishimura, A., and Yanagimoto, T., 1999, Ecology of groundfishes in the eastern Bering Sea, with emphasis on food habits, *in* Loughlin, T.R., and Ohtani, K., eds., Dynamics of the Bering Sea: Fairbanks, University of Alaska Sea Grant, p. 537–580.

48. Wilson, M.T., Jump, C.M., and Duffy-Anderson, J.T., 2006, Comparative analysis of the feeding ecology of two pelagic forage fishes—Capelin *Mallotus villosus* and Walleye Pollock *Theragra chalcogramma*: Marine Ecology Progress Series, v. 317, p. 245–258.

49. Olsen, J.B., Merkouris, S.E., and Seeb, J.E., 2002, An examination of spatial and temporal genetic variation in walleye pollock (*Theragra chalcogramma*) using allozyme, mitochondrial DNA, and microsatellite data: Fishery Bulletin, v. 100, no. 4, p. 752–764.

50. Brykov, V.A., Polyakova, N.E., Priima, T.F., and Katugin, O.N., 2004, Mitochondrial DNA variation in northwestern Bering Sea walleye pollock, *Theragra chalcogramma* (Pallas): Environmental Biology of Fishes, v. 69, nos. 1–4, p. 167–175.

51. Musienko, L.N., 1970, Reproduction and development of Bering Sea fishes, *in* Moiseev, P.A., ed., Soviet fisheries investigations in the northeastern Pacific, Part V: Soviet Fisheries Investigation in the Northeastern Pacific, p. 161–224. [Russian translation by Israel Program for Scientific Translations, Jerusalem (1972).]

52. Baird, T.A., and Olla, B.L., 1991, Social and reproductive behavior of a captive group of walleye pollock, *Theragra chalcogramma*: Environmental Biology of Fishes, v. 30, no. 3, p. 295–301.

53. Simenstad, C.A., Isakson, J.S., and Nakatani, R.E., 1977, Marine fish communities, *in* Merritt, M.L., and Fuller, R.G., eds., The environment of Amchitka Island, Alaska: National Technical Information Center, Energy Research and Development Administration TID-26712, p. 451–492.

54. Yang, M.-S., 1996, Diets of the important groundfishes in the Aleutian Islands in summer 1991: Seattle, Washington, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Technical Memorandum NMFS-AFSC-60, 105 p.

55. Yang, M.-S., and Nelson, M.W., 2000, Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990, 1993, and 1996: Seattle, Washington, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Technical Memorandum NMFS-AFSC-112, 174 p.

56. Sturdevant, M.V., Brase, A.L., and Hulbert, L.B., 2001, Feeding habits, prey fields, and potential competition of young-of-the-year walleye pollock (*Theragra chalcogramma*) and Pacific herring (*Clupea pallasi*) in Prince William Sound, Alaska, 1994–1995: Fishery Bulletin, v. 99, no. 3, p. 482–501.

57. Mueter, F.J., and Litzow, M.A., 2008, Sea ice retreat alters the biogeography of the Bering Sea continental shelf: Ecological Applications, v. 18, no. 2, p. 309–320.

58. Froese, R., and Pauly, D., eds., 2012, FishBase—Global information system on fishes: FishBase database, accessed July 8, 2012, at http://www.fishbase.org.

59. Bean, T.H., 1887, The fishery resources and fishing-grounds of Alaska, *in* Goode, G.B., ed., The fisheries and fishery industries of the United States, Section III: United States Commission of Fish and Fisheries, p. 81–115.

60. Witherell, D., 2000, Groundfish of the Bering Sea and Aleutian Islands area—Species profiles 2001: Anchorage, Alaska, North Pacific Fishery Management Council, 15 p.

61. Laurel, B.J., Spencer, M., Iseri, P., and Copeman, L.A., 2015, Temperature-dependent growth and behavior of juvenile Arctic cod (*Boreogadus saida*) and co-occurring North Pacific gadids: Polar Biology, no. 39, p. 1,127–1,135.

Pacific Cod (*Gadus macrocephalus*)

Tilesius, 1810

Family Gadidae

Pacific Cod (*Gadus macrocephalus*) 597 mm, western Gulf of Alaska, 2005. Photograph by C.W. Mecklenburg, Point Stephens Research.

Note on taxonomy: *Based on analyses of both morphology and mtDNA, the Greenland Cod, Gadus ogac (Richardson, 1836), is a subspecies of* G. macrocephalus [1, 2].

Colloquial Name: *None within U.S. Chukchi and Beaufort Seas*.

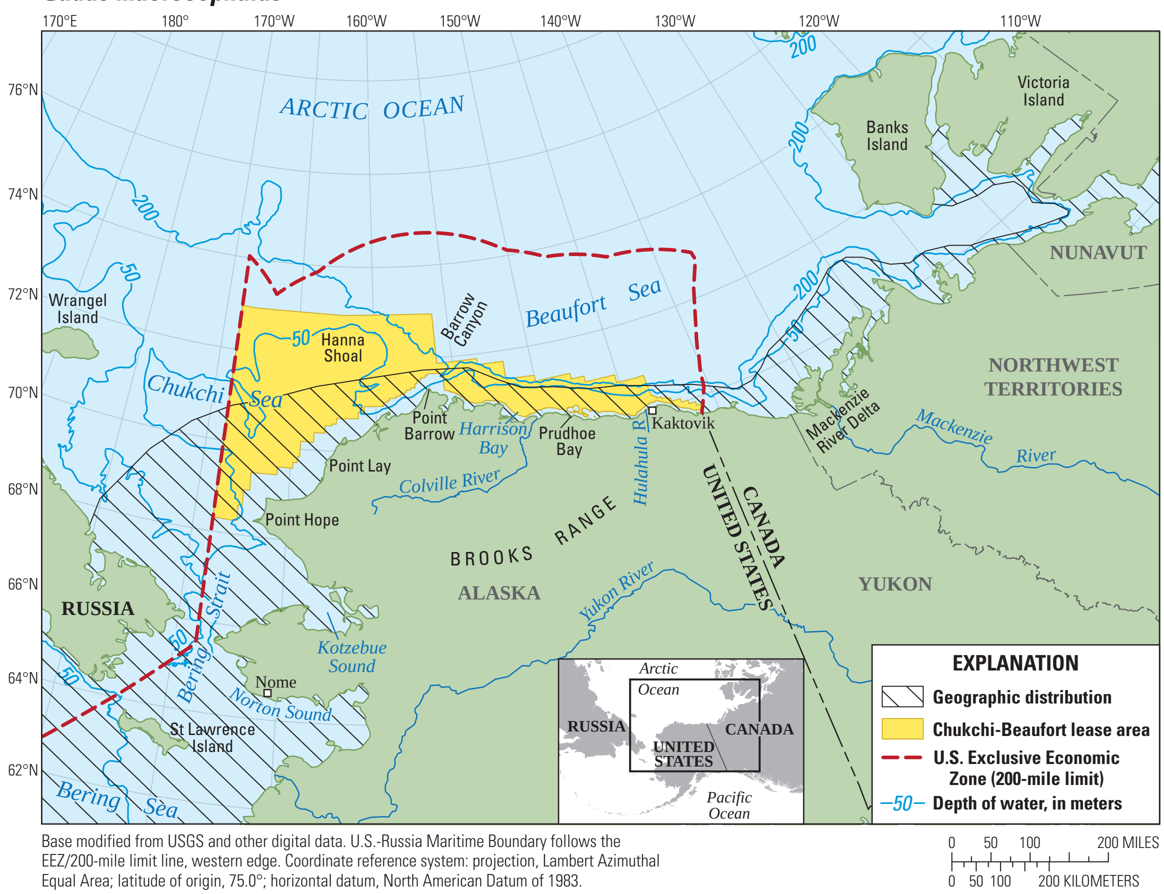
Ecological Role: Of little known ecological importance in U.S. Chukchi and Beaufort Seas. Maybe of small seasonal importance in food webs in the Bering Strait and southeastern Chukchi Sea.

Physical Description/Attributes: Robust body, large head. Light gray-brown with brown to bright golden yellow spots on back and sides to olive-blackish with no distinct spots [3, 4]. For specific diagnostic characteristics see *Fishes of Alaska* (Mecklenburg and others, 2002, p. 296) [3]. Swim bladder: Present [3]. Antifreeze glycoproteins in blood serum: Unknown.

Range: *U.S. Chukchi and Beaufort Seas* [1, 3]. Elsewhere in Alaska, throughout Bering Sea, Aleutian Islands and Gulf of Alaska. Worldwide, in Pacific Ocean south to southern California and to Yellow Sea off Manchuria, China; east across Canada to west Greenland and south to Gulf of St. Lawrence. Isolated population in White Sea [1, 3].

Relative Abundance: *Uncommon in U.S. Chukchi and Beaufort Seas* [1, 3]. Uncommon in northern Bering Sea [1]. Abundant throughout Bering Sea northward to Norton Sound and Gulf of Anadyr [1, 6, 7], and southward to Seas of Japan and Okhotsk [8, 9] and Washington [10].

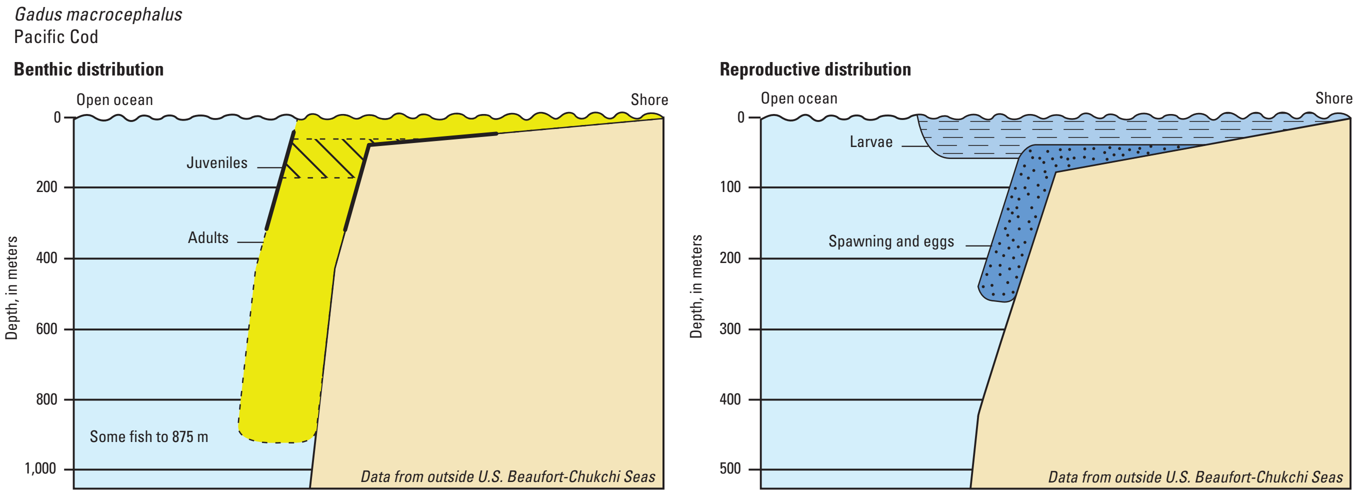
Pacific Cod
Gadus macrocephalus



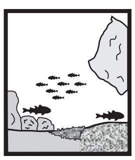
Base modified from USGS and other digital data. U.S.-Russia Maritime Boundary follows the EEZ/200-mile limit line, western edge. Coordinate reference system: projection, Lambert Azimuthal Equal Area; latitude of origin, 75.0°; horizontal datum, North American Datum of 1983.

Geographic distribution of Pacific Cod (*Gadus macrocephalus*) within Arctic Outer Continental Shelf Planning Areas [5] based on review of published literature and specimens from historical and recent collections [1, 3, 4].

Depth Range: In water column, near surface to near bottom depth of 875 m [3], typically 50–300 m; sometimes in surf zone [11–13]. Spawning takes place at 40–265 m [14]. Fertilized eggs are benthic on continental shelf [10]. Newly hatched larvae are primarily in upper 45 m of water column (highest abundances at 15–30 m) [14], moving downward as they grow [15]. Juveniles are mainly at 60–150 m in Gulf of Alaska and eastern Bering Sea [15].



Benthic and reproductive distribution of Pacific Cod (*Gadus macrocephalus*).



Habitats and Life History

Eggs—Size: 1.0–1.2 mm [16, 17]. Time to hatching: 8.5–28 days at 11–4.5 °C. Hatching is most successful at lower temperatures [16, 18]. Habitat: Benthic [10, 16].

Larvae—Size at hatching: 3.0–4.0 mm [16, 17]. Size at juvenile transformation: 2.5–3.5 cm FL [14, 19]. Days to juvenile transformation: Unknown. Yolk sac is absorbed in 10 days [14]. Habitat: Pelagic and neritic [17].

Juveniles—Age and size: 2.5 cm FL to 38–81 cm TL [13, 14, 19]. Habitat: Shallow nearshore waters at [14, 17, 20], initially associated with algae and eelgrass but later in their first year some fish migrate into deeper water and over a wide range of habitats including plants, soft substrates, and mounds formed by sea cucumbers [10, 18, 21–23].

Adults—Age and size at first maturity: In eastern Bering Sea, 50 percent of females were mature at 58.0 cm TL and 4.9 years, whereas 50 percent of those in the Gulf of Alaska were mature at 50.3 cm TL and 4.4 years. A few females were mature at as small as 38 cm TL and a few were immature until about 81 cm TL [13]. Length at maturity is highly dependent on environmental factors and varies widely between areas and years. For example, off British Columbia. Canada, length at 50 percent maturity differed by almost 10 cm between samples taken in the mid-1970s and mid-1980s [24]. In Gulf of Alaska and eastern Sea of Okhotsk, females grow larger than males, although both sexes reach about the same maximum length in the eastern Bering Sea [13]. In Gulf of Alaska (although not in the eastern Bering Sea), male and female growth rates differ. Apparently, cod living in Alaskan waters grow more slowly but reach a larger size and live longer than those living off British Columbia and Washington [14]. Maximum age: 17 years [25], but rarely beyond 14 years [13]. Maximum size: 120 cm TL [3]. Habitat: Pelagic, both near the bottom and in the midwaters [14] over soft sea floors [10, 17, 22, 23].

Substrate—Cobble and rocky bottoms [10, 22, 23]. Coarse sand and cobble for spawning and eggs [14].

Physical/chemical—Temperature: -1.7–18 °C, mainly 0–10 °C [21, 26, 27]. Salinity: Eggs are in polyhaline to euhaline waters. Marine and estuarine [14].

Behavior
Diel—Pelagic juveniles have been found in surface waters in association with medusae [28].
Seasonal—Make annual inshore and offshore movements linked to spawning and feeding. The timing and extent of annual migrations vary with location. Annual migrations in eastern Bering Sea, eastern Aleutian Islands, and Gulf of Alaska, occur when fish attempt to avoid temperature extremes that accompany the seasonal changes [29]. Fish move offshore during winter, as nearshore waters get very cold, and move inshore during summer [30]. Farther south on both sides of the Pacific Ocean (for example, Puget Sound, Korea, and Japan), migrations to deeper waters occur during summer months to avoid excessively heated coastal waters and return inshore for the winter [10]. Some fish move fairly long distances. Pacific Cod in the eastern Bering Sea, for instance, summer on the eastern Bering Sea shelf, then move southward and deeper to the Bering Sea in the vicinity of Unimak Pass and Unalaska Island, Alaska, and in the nearby Gulf of Alaska to spawn [14].
Reproductive—Single batch spawners, releasing all eggs in a few minutes [14]. Spawning depth depends on its depth-temperature profile. For instance, off Washington and southwest Vancouver Island, British Columbia, Pacific Cod spawn in more shallow waters than those in northern British Columbia [10].
Schooling—Forms schools [14].
Feeding—Juveniles and adults are carnivorous and feed at night [14]. Feeding increases during the summer and decreases in winter [31].

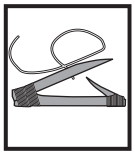
Populations or Stocks
Fish in Puget Sound and the Strait of Georgia may form several semi-isolated populations from fish on the outer coast [14, 32]. Based on analyses of morphology and mtDNA, Pacific Cod are most closely related to Ogac (*Gadus ogac*) and are now considered by taxonomists to be the same species [1, 2, 33].

Reproduction
Mode—Oviparous, external fertilization [14].
Spawning season—Can occur between January and July, although peak spawning takes place in spring in Alaska [13, 34].
Fecundity—225,000 –6,400,000 semi-adhesive eggs [14, 35]. The number of eggs produced per body length decreases with higher latitude [21].

Food and Feeding
Food items—Very wide range of benthic and water column organisms. Cod less than about 20 cm FL feed primarily on a wide range of crustaceans, such as copepods, gammarid and caprellid amphipods, mysids, and euphausiids, and some small fishes [36–39]. Larger fish add large numbers of fishes to their diets as well as shrimps, crabs, hermit crabs, polychaetes, snails, clams, squids, and octopuses [38, 40–42]. As Pacific Cod grow, they feed more heavily on fishes and less on invertebrates [43–44].
Trophic level—4.1 [45].

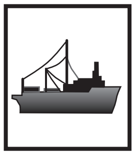
Biological Interactions
Predators—A large number of fishes, sea birds, and marine mammals. Major fish predators include Arrowtooth Flounder, Flathead Sole, Pacific Cod, Pacific Halibut, Sablefish, Spotted Spiny Dogfish, Walleye Pollock, and Yellowfin Sole [40, 46–48]. Seabirds include Common Murres, Horned and Tufted Puffins [49, 50]. Marine mammals include beluga, fin, minke, and sperm whales and orcas; bearded, harbor, northern fur, and ribbon seals; and Stellar sea lions [51–55].
Competitors—Other gadids, along with flatfishes, sculpins, poachers, and eelpouts.

Resilience
Low, minimum population doubling time: 4.5–14 years [56].



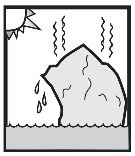
Traditional and Cultural Importance

None reported.



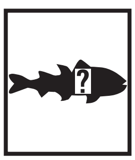
Commercial Fisheries

Currently, Pacific Cod are not commercially harvested.



Potential Effects of Climate Change

It might be expected that Pacific Cod abundance will increase in Arctic waters if fish from the Bering Sea move northward. The probability of this species' colonization of Arctic marine environments may be lower than for other gadid species because of its apparent fidelity to spawning locations in the Bering Sea. However, new experimental results indicate that Pacific Cod and Walleye Pollock grow at 2–3 times the rate of other Arctic gadids when exposed to increasing temperature regimes in laboratory that are similar to field conditions in summer in the coastal Chukchi and Beaufort Seas [57]. This suggests a potential competitive advantage for Pacific Cod under warming conditions.



Areas for Future Research [A]

Little is known about the ecology of this species in the study area. Whether Pacific Cod spawn in the Chukchi or Beaufort Seas is of major interest. Researchers believe that the cod display high fidelity to spawning areas in the Bering Sea and thus improved information about their migratory behavior is needed.

Remarks

This species has long been known to be present in the Beaufort Sea (see [Walters, 1955], between Point Barrow and Smith Bay) [58], under the name, *Gadus ogac* [3], and is common just over the U.S-Canadian border in Canadian waters.

References Cited

Dunn, J.R., and Matarese, A.C., 1987, A review of the early life history of northeast Pacific gadoid fishes: Fisheries Research, v. 5, nos. 2–3, p. 163–184. [17]

Forrester, C.R., 1964, Laboratory observations on embryonic development and larvae of the Pacific cod (*Gadus macrocephalus* Tilesius): Journal of the Fisheries Research Board of Canada, v. 21, no. 1, p. 9–16. [16]

Gustafson, R.G., Lenarz, W.H., McCain, B.B., Schmitt, C.C., Grant, W.S., Builder, T.L., and Methot, R.D., 2000, Status review of Pacific hake, Pacific cod, and walleye pollock from Puget Sound, Washington: Seattle, Washington, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Technical Memorandum NMFS-NWFSC-44. [14]

Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p. [3]

Mecklenburg, C.W., Møller, P.R., and Steinke, D., 2011, Biodiversity of Arctic marine fishes—Taxonomy and zoogeography: Marine Biodiversity, v. 41, no. 1, p. 109–140, Online Resource 1. [1]

Palsson, W.A., 1990, Pacific cod (*Gadus macrocephalus*) in Puget Sound and adjacent waters—Biology and stock assessment: Olympia, State of Washington, Department of Fisheries, Technical Report no. 112, 137 p. [10]

Stark, J.W., 2007, Geographic and seasonal variations in maturation and growth of female Pacific cod (*Gadus macrocephalus*) in the Gulf of Alaska and Bering Sea: Fishery Bulletin, v. 105, no. 3, p. 396–407. [13]

Bibliography

1. Mecklenburg, C.W., Møller, P.R., and Steinke, D., 2011, Biodiversity of Arctic marine fishes—Taxonomy and zoogeography: Marine Biodiversity, v. 41, no. 1, p. 109–140, Online Resource 1.

2. Teletchea, F., Laudet, V., and Hänni, C., 2006, Phylogeny of the Gadidae (sensu Svetovidov, 1948) based on their morphology and two mitochondrial genes: Molecular Phylogenetics and Evolution, v. 38, no. 1, p. 189–199.

3. Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p.

4. Mecklenburg, C.W., Mecklenburg, T.A., Sheiko, B.A., and Steinke, D., 2016, Pacific Arctic marine fishes: Akureyri, Iceland, Conservation of Arctic Flora and Fauna, Monitoring Series Report No. 23, 406 p., accessed May 10, 2016, at http://caff.is/monitoring-series/370-pacific-arcticmarine-fishes.

5. Minerals Management Service, 2008, Beaufort Sea and Chukchi Sea planning areas—Oil and Gas Lease Sales 209, 212, 217, and 221: U.S. Department of the Interior, Minerals Management Service Alaska OCS Region, OCS EIS/EA, MMS 2008-0055, 538 p.

6. Vinnikov, A.V., 1996, Pacific cod (*Gadus macrocephalus*) of the western Bering Sea, *in* Mathisen, O.A., and Coyle, K.O., eds., Ecology of the Bering Sea: Fairbanks, University of Alaska, Alaska Sea Grant College Program, p. 183–202.

7. Hamazaki, T., Fair, L., Watson, L., and Brennan, E., 2005, Analyses of Bering Sea bottom-trawl surveys in Norton Sound—Absence of regime shift effects on epifauna and demersal fish: ICES Journal of Marine Science, v. 62, no. 8, p. 1,597–1,602.

8. Sokolovskaya, T.G., Sokolovskii, A.S., and Sobolevskii, E.I., 1998, A list of fishes of Peter the Great Bay (the Sea of Japan): Journal of Ichthyology, v. 38, no. 1, p. 1–11.

9. Chereshnev, I., Nazarkin, M.V., Skopets, M.B., Pitruk, D., Shestakov, A.V., Yabe, M., and others, 2001, Annotated list of fish-like vertebrates and fish in Tauisk Bay (northern part of the Sea of Okhotsk), *in* Andreev, A.V., and Bergmann, H.H., eds., Biodiversity and ecological status along the northern coast of the Sea of Okhotsk—A collection of study reports: Dalnauka Vladivostok, Russia, Institute of Biological Problems of the North, p. 64–86.

10. Palsson, W.A., 1990, Pacific cod (*Gadus macrocephalus*) in Puget Sound and adjacent waters—Biology and stock assessment: Olympia, State of Washington, Department of Fisheries, Technical Report no. 112, 137 p.

11. Allen, M.J., and Smith, G.B., 1988, Atlas and zoogeography of common fishes in the Bering Sea and northeastern Pacific: National Oceanic and Atmospheric Administration Technical Report NMFS 66, 151 p.

12. Zenger, H.H., Jr., 2004, Data report—2002 Aleutian Islands bottom trawl survey: U.S. Department of Commerce, National Oceanic and Atmospheric Administration Technical Memorandum NMFS-AFSC-143, 247 p.

13. Stark, J.W., 2007, Geographic and seasonal variations in maturation and growth of female Pacific cod (*Gadus macrocephalus*) in the Gulf of Alaska and Bering Sea: Fishery Bulletin, v. 105, no. 3, p. 396–407.

14. Gustafson, R.G., Lenarz, W.H., McCain, B.B., Schmitt, C.C., Grant, W.S., Builder, T.L., and Methot, R.D., 2000, Status review of Pacific hake, Pacific cod, and walleye pollock from Puget Sound, Washington: Seattle, Washington, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Technical Memorandum NMFS-NWFSC-44.

15. North Pacific Fishery Management Council, 2010, Fishery management plan for groundfish of the Bering Sea and Aleutian Islands management area—Appendices—Fishery management plan for groundfish of the BSAI Management Area: North Pacific Fisheries Management Council, 233 p.

16. Forrester, C.R., 1964, Laboratory observations on embryonic development and larvae of the Pacific cod (*Gadus macrocephalus* Tilesius): Journal of the Fisheries Research Board of Canada, v. 21, no. 1, p. 9–16.

17. Dunn, J.R., and Matarese, A.C., 1987, A review of the early life history of northeast Pacific gadoid fishes: Fisheries Research, v. 5, no. 2–3, p. 163–184.

18. Abookire, A.A., Duffy-Anderson, J.T., and Jump, C.M., 2007, Habitat associations and diet of young-of-the-year Pacific cod (*Gadus macrocephalus*) near Kodiak, Alaska: Marine Biology, v. 150, no. 4, p. 713–726.

19. Matarese, A.C., Kendall, J., Arthur W., Blood, D.M., and Vinter, B.M., 1989, Laboratory guide to early life history stages of northeast Pacific fishes: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service Technical Report NMFS 80, 652 p.

20. Blackburn, J.E., and Jackson, P.B., 1982, Seasonal composition and abundance of juvenile and adult marine finfish and crab species in the nearshore zone of Kodiak Island's eastside during April 1978 through March 1979: Outer Continental Shelf Environmental Assessment Program, Alaska Department of Fish and Game, Final Report, Research Unit 552, p. 377–570.

21. Alderdice, D.F., and Forrester, C.R., 1971, Effects of salinity, temperature, and dissolved oxygen on early development of the Pacific cod (*Gadus macrocephalus*): Journal of the Fisheries Research Board of Canada, v. 28, no. 6, p. 883–902.

22. Laurel, B.J., Stoner, A.W., Ryer, C.H., Hurst, T.P., and Abookire, A.A., 2007, Comparative habitat associations in juvenile Pacific cod and other gadids using seines, baited cameras and laboratory techniques: Journal of Experimental Marine Biology and Ecology, v. 351, nos. 1–2, p. 42–55.

23. Busby, M.S., Mier, K.L., and Brodeur, R.D., 2005, Habitat associations of demersal fishes and crabs in the Pribilof Islands region of the Bering Sea: Fisheries Research, v. 75, nos. 1–3, p. 15–28.

24. Welch, D.W., and Foucher, R.P., 1988, A maximum likelihood for estimating length-at-maturity with application to Pacific cod (*Gadus macrocephalus*) population dynamics: Canadian Journal of Fisheries and Aquatic Sciences, v. 45, no. 2, p. 333–343.

25. Kimura, D.K., National Marine Fisheries Service, written commun., 2010.

26. Tokranov, A.M., and Polutov, V.I., 1984, Fish distribution in the Kronitsky Bay in relation to abiotic factors: Zoologicheskii Zhurnal, v. 63, p. 1,363–1,373.

27. Mueter, F.J., University of Alaska-Fairbanks, written commun., 2010.

28. Van Hyning, J.M., and Cooney, R.T., 1974, Association of walleye pollock, *Theragra chalcogramma*, with the jellyfish, Cyanea: Copeia, v. 1974, no. 3, p. 791.

29. Shimada, A.M., and Kimura, D.K., 1994, Seasonal movements of Pacific cod, *Gadus macrocephalus*, in the eastern Bering Sea and adjacent waters based on tag-recapture data: Fishery Bulletin, v. 92, no. 4, p. 800–816.

30. Witherell, D., 2000, Groundfish of the Bering Sea and Aleutian Islands area—Species profiles 2001: Anchorage, Alaska, North Pacific Fishery Management Council, 15 p.

31. Tokranov, A.M., 1992, Features of feeding of benthic predatory fishes of the west Kamchatka shelf: Journal of Ichthyology, v. 32, no. 7, p. 45–55.

32. Gao, Y., Bargmann, G.G., Brand, U., and Noakes, D.L.G., 2005, Stable isotopic and trace elemental compositions of otoliths and the stock structure of Pacific cod, *Gadus macrocephalus*: Environmental Biology of Fishes, v. 74, nos. 3–4, p. 335–348.

33. Carr, S.M., Kivlichan, D.S., Pepin, P., and Crutcher, D.C., 1999, Molecular systematics of gadid fishes—Implications for the biogeographical origins of Pacific species: Canadian Journal of Zoology, v. 77, no. 1, p. 19–26.

34. Hirschberger, W.A., and Smith, G.B., 1983, Spawning of twelve groundfish species in the Alaska and Pacific Coast regions, 1975–81: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Technical Memorandum NMFS F/NWC-44, 50 p.

35. Mito, K.-I., Nishimura, A., and Yanagimoto, T., 1999, Ecology of groundfishes in the eastern Bering Sea, with emphasis on food habits, *in* Loughlin, T.R., and Ohtani, K., eds., Dynamics of the Bering Sea: Fairbanks, University of Alaska Sea Grant, p. 537–580.

36. Walters, G.E., 1984, Ecological aspects of larval and juvenile Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*), and Pacific tomcod (*Microgadus proximus*) in Port Townsend, Washington: Seattle, University of Washington, Master's thesis.

37. Tokranov, A.M., and Vinnikov, A.B., 1991, Diet of the Pacific cod, *Gadus morhua macrocephalus*, and its position in the food chain in Kamchatkan coastal waters: Journal of Ichthyology, v. 31, no. 5, p. 84–98.

38. Yang, M.-S., and Nelson, M.W., 2000, Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990, 1993, and 1996: Seattle, Washington, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Technical Memorandum NMFS-AFSC-112, 174 p.

39. Lang, G.M., Livingston, P.A., and Dodd, K., 2005, Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1997 through 2001: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Technical Memorandum NMFS-AFSC-158, 249 p.

40. Lang, G.M., Livingston, P.A., Pacunski, R.E., Parkhurst, J., and Yang, M.-S., 1991, Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1984 to 1986: Seattle, Washington, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Technical Memorandum NMFS F/NWC-207, 240 p.

41. Ortiz, I., and Aydin, K., 2003, Feeding habits of demersal fish: Alaska Fisheries Science Center Quarterly Report, October–December 2003, p. 49.

42. Yang, M.-S., 2004, Diet changes of Pacific cod (*Gadus macrocephalus*) in Pavlof Bay associated with climate changes in the Gulf of Alaska between 1980 and 1995: Fishery Bulletin, v. 102, no. 2, p. 400–405.

43. Lang, G.M., and Livingston, P.A., 1996, Food habits of key groundfish species in the eastern Bering Sea Slope region: Seattle, Washington, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Technical Memorandum NMFS-AFSC-67, 120 p.

44. Chuchukalo, V.I., Radchenko, V.I., Nadtochii, V.A., Koblikov, V.N. and Slabinskii, A.M., 1999, Feeding and some features of ecology of Gadidae of the western Kamchatka shelf in summer 1996: Journal of Ichthyology, v. 39, no. 4, p. 309–321.

45. Mueter, F.J., and Litzow, M.A., 2008, Sea ice retreat alters the biogeography of the Bering Sea continental shelf: Ecological Applications, v. 18, no. 2, p. 309–320.

46. Bonham, K., 1954, Food of the dogfish *Squalus acanthias*: Washington Department of Fisheries, v. 1, no. 2, p. 25–36.

47. Yang, M.-S., 1996, Diets of the important groundfishes in the Aleutian Islands in summer 1991: Seattle, Washington, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Technical Memorandum NMFS-AFSC-60, 105 p.

48. Yang, M.-S., Dodd, K., Hibpshman, R., and Whitehouse, A., 2006, Food habits of groundfishes in the Gulf of Alaska in 1999 and 2001: U.S. Department of Commerce, National Oceanic and Atmospheric Administration Technical Memorandum, NMFS-AFSC-164, 189 p.

49. Krasnow, L.D., and Sanger, G.A., 1982, Feeding ecology of marine birds in the nearshore waters of Kodiak Island: Anchorage, Alaska, Final Report to the Outer Continental Shelf Environmental Assessment Program, U.S. Fish and Wildlife Service, National Fisheries Research Center, Migratory Bird Section, Contract 01-5-022-2538.

50. Hatch, S.A., and Sanger, G.A., 1992, Puffins as samplers of juvenile pollock and other forage fish in the Gulf of Alaska: Marine Ecology Progress Series, v. 80, p. 1–14.

51. Harry, G.Y., and Hartley, J.R., 1981, Northern fur seals in the Bering Sea, *in* Hood, D.W., and Calder, J.A., eds., The Eastern Bering Sea shelf—Oceanography and resources: Seattle, University of Washington Press, p. 847–867.

52. Antonelis, G.A., Melin, S.R., and Bukhtiyarov, Y.A., 1994, Early spring feeding habits of bearded seals (*Erignathus barbatus*) in the central Bering Sea, 1981: Arctic, v. 47, no. 1, p. 74–79.

53. Frost, K.J., and Lowry, L.F., 1981, Foods and trophic relationships of cetaceans in the Bering Sea, *in* Hood, D.W., and Calder, J.A., eds., The eastern Bering Sea shelf—Oceanography and resources: Seattle, University of Washington Press, p. 825–836.

54. Frost, K.J., and Lowry, L.F., 1981, Trophic importance of some marine gadids in northern Alaska and their body-otolith size relationships: Fishery Bulletin, v. 79, no. 1, p. 187–192.

55. Sinclair, E.H., and Zeppelin, T.K., 2002, Seasonal and spatial differences in diet in the western stock of Steller sea lions (*Eumetopias jubatus*): Journal of Mammology, v. 83, no. 4, p. 973–990.

56. Froese, R., and Pauly, D., eds., 2012, FishBase—Global information system on fishes: FishBase database, accessed July 8, 2012, at http://www.fishbase.org.

57. Laurel, B.J., Spencer, M., Iseri, P., and Copeman, L.A., 2015, Temperature-dependent growth and behavior of juvenile Arctic cod (*Boreogadus saida*) and co-occurring North Pacific gadids: Polar Biology, no. 39, p. 1,127–1,135.

58. Walters, V., 1955, Fishes of western Arctic America and eastern Arctic Siberia: Bulletin of the American Museum of Natural History, v. 106, p. 259–368.

Threespine Stickleback to Antlered Sculpin

Threespine Stickleback (*Gasterosteus aculeatus*)
Linnaeus, 1758

Family Gasterosteidae

Note: *Exhibits highly variable life history patterns with marine, anadromous, riverine, and lacustrine populations* [1, 2]. *Data in this account are from marine and anadromous populations.*

Colloquial Name: Iñuit—Kakalisaura*q* [3].

Ecological Role: In locations where common, for instance in Kotzebue Sound, this species may be of ecological importance in local food webs.

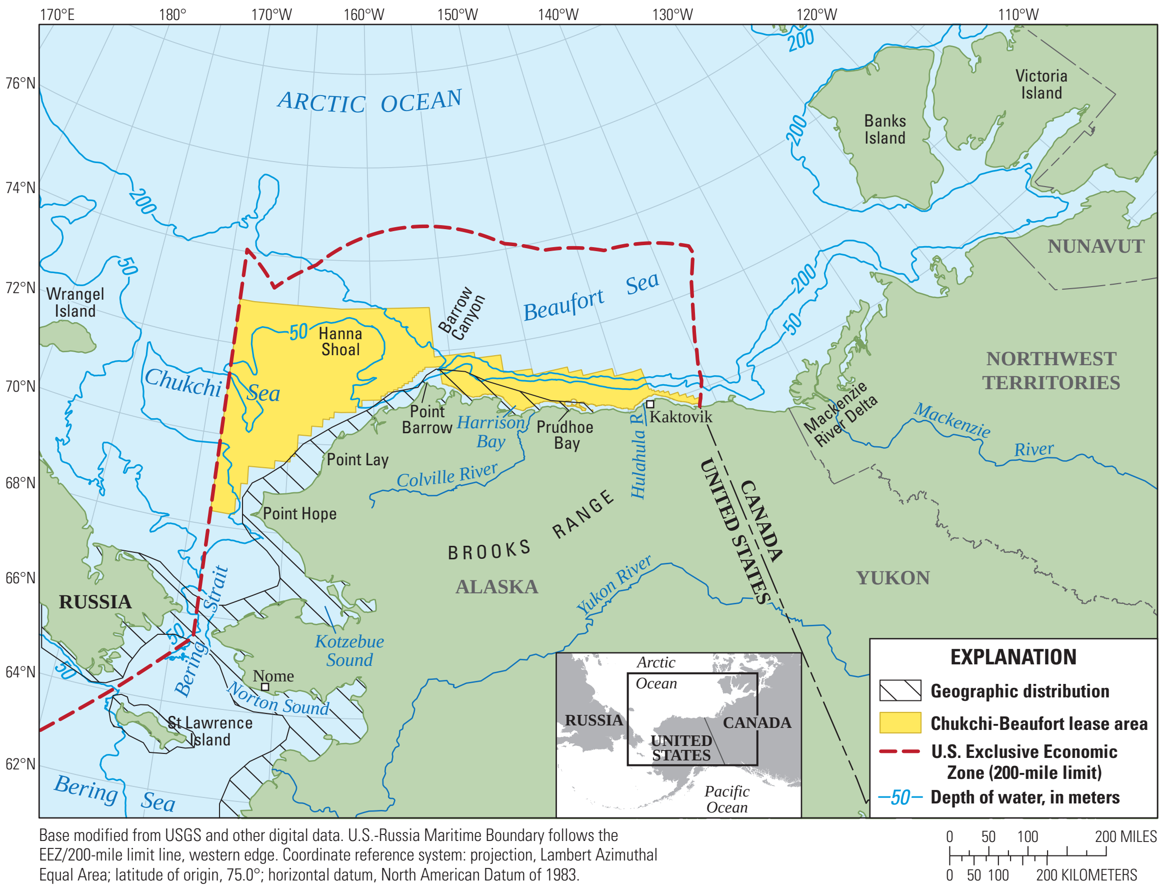
Threespine Stickleback (*Gasterosteus aculeatus*), 42 mm TL, northeastern Chukchi Sea, 2007. Photograph by C.W. Mecklenburg, Point Stephens Research.

Physical Description/Attributes: Moderately elongate body. Anadromous type is blue-black to silvery or greenish with yellow, silvery, or white bellies. Breeding males become bright blue or green with red or orange throats and bellies. For specific diagnostic characteristics, see *Fishes of Alaska* (Mecklenburg and others, 2002, p. 333) [4]. Swim bladder: Present, without pneumatic duct [5]. Antifreeze glycoproteins in blood serum: Unknown.

Range: *U.S. Chukchi and Beaufort Seas* [6]. Elsewhere in Alaska, in all coastal waters. Worldwide, from Bering Sea south to Monterey Bay, central California, and to Seas of Okhotsk and Japan; in Atlantic Ocean from Hudson Bay to southern Greenland, Iceland, and southern Barents Sea to Novaya Zemlya, Russia [6].

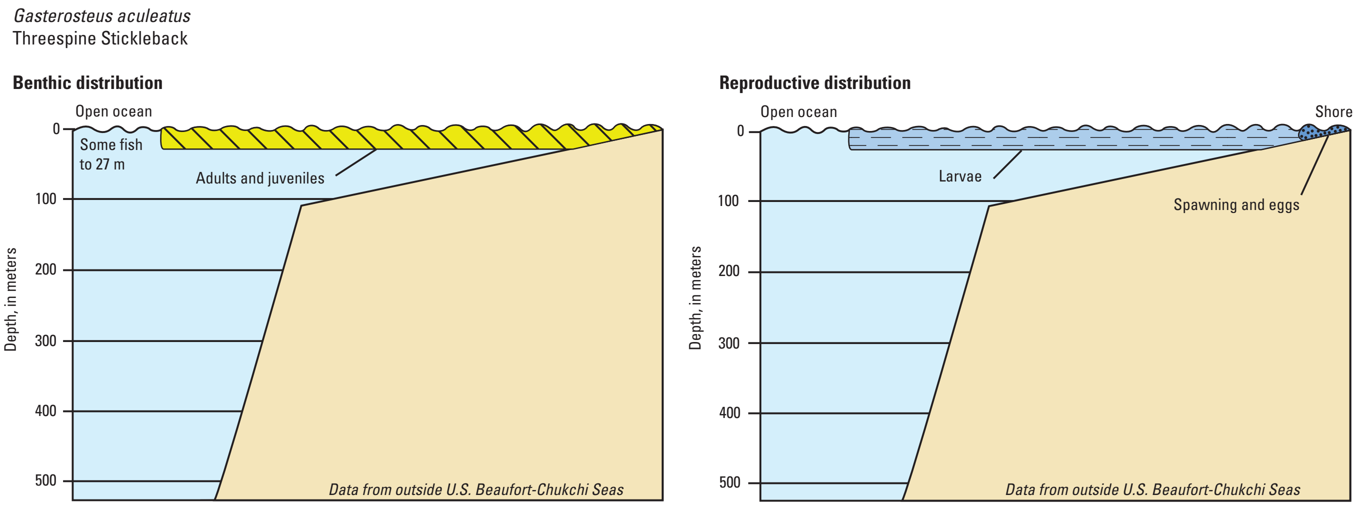
Relative Abundance: *Common in brackish water at least as far north as Kotzebue Sound, U.S. Chukchi Sea, and occasional or rare east in U.S. Beaufort Sea* [1, 9–11]. Rare in Northwest Territories, Canada [1]. Common in southwestern Barents Sea and Sea of Japan [6, 12].

Threespine Stickleback
Gasterosteus aculeatus

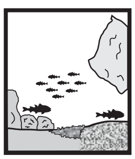


Geographic distribution of Threespine Stickleback (*Gasterosteus aculeatus*), within Arctic Outer Continental Shelf Planning Areas [7] based on review of published literature and specimens from historical and recent collections [6, 8].

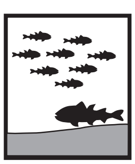
Depth Range: Intertidal to 27 m, as far as 805 km offshore for juveniles and adults [4, 13]. Larvae are abundant in surface waters [14]. Marine type spawns in shallow waters, such as tidepools [15].



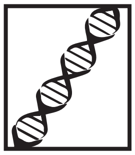
Benthic and reproductive distribution of Threespine Stickleback (*Gasterosteus aculeatus*).



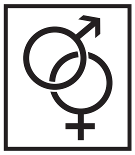
Habitats and Life History
Anadromous and marine [1, 2].
Eggs—Size: 0.11–0.16 cm [16]. Time to hatching: 5–20 days [12]. Habitat: Benthic, in tidepools for marine type [2].
Larvae—Size at hatching: 2.0–5.5 mm [17, 18]. Size at juvenile transformation: About 10.0 mm [19]. Days to juvenile transformation: About 30 days [19, 20]. Habitat: Benthic to pelagic [14].
Juveniles—Age and size: 1–12 months [19], and 11–30 mm TL [19]. Habitat: Benthic to pelagic, staying close to nests for 4–6 days [4], around eelgrass, filamentous algae, and other plants, as well as over sand and rocks [21, 22].
Adults—Age and size at first maturity: Some mature after 1 year (fish spawn once and die), others take 2 years [16]. Growth rates vary with area [16, 23]. Maximum age: 5 years [18], typically 1–3.5 years. Varies with area [16, 23]. Maximum size: 11 cm TL [18]. Habitat: Benthic to pelagic [4], around eelgrass, filamentous algae, and other plants, as well as over sand and rocks, and in offshore waters [21, 22, 24, 25].
Substrate—Over rocks, silt, and sand for spawning [15].
Physical/chemical—Temperature: Marine type has been shown to tolerate temperatures as low as 4 °C and as high as 28 °C in laboratory experiments [26]. Salinity: Fresh to marine waters. *More common in brackish than marine waters in Kotzebue* and Norton sounds [9].



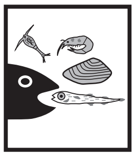
Behavior
Diel—In Puget Sound, both juveniles and adults inhabit surface waters at night [27, 28].
Seasonal—Some fish migrate into coastal water in autumn to over winter [15]. Other fish winter in deep water [16].
Reproductive—Off Alaska, anadromous fish enter freshwaters to spawn in late spring [1]. Anadromous fish may spawn in brackish or fresh waters [15]. Marine fish spawn in quiet areas such as tide pools [2]. Spawning occurs over rocks, eelgrass, silt, and sand [15]. Males construct nests composed of bits of plants and other debris held together by secretions formed in the kidneys. Through a series of courting behaviors, a male leads a female into the nest where she lays her eggs. Many nests contain eggs from more than one female and males guard the eggs until they hatch. Neighboring males not guarding eggs often “sneak” into a nearby nest and fertilize some of the eggs [16, 29]. Some individuals may spawn once and die [16, 30].
Schooling—Forms schools except in spawning season [12].
Feeding—Feeds throughout water column [12].



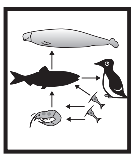
Populations or Stocks
There have been no studies.



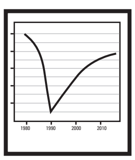
Reproduction
Mode—Oviparous, separate sexes [20].
Spawning season—May–August in Alaska [1, 16].
Fecundity—Batch spawners, laying 50–200 eggs at a time with overall fecundity ranging from 65 to 1,300 [16, 31].



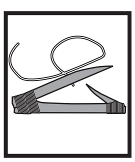
Food and Feeding
Food items—Benthic and midwater prey. Small crustaceans (for example, copepods, euphausiids, mysids, and gammarid and caprellid amphipods) often are quite important, and crustacean larvae, insects, worms, mollusks, fish eggs, and small fishes are also frequently consumed [18, 32–35].
Trophic level—3.51 (standard error 0.49) [36].



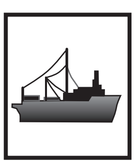
Biological Interactions
Predators—Off Alaskan and British Columbia coasts, are a large number of fishes, sea birds, and marine mammals [12].
Competitors—Likely Polar and Saffron cods, whitefishes, and flatfishes.



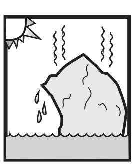
Resilience
High, minimum population doubling time less than 15 months (K=0.6–1.8; t_m=1; t_{max}=4; Fecundity=80) [36].



Traditional and Cultural Importance
None reported.



Commercial Fisheries
Currently, Threespine Stickleback are not commercially harvested.



Potential Effects of Climate Change
Uncertain; however, this is a species with a very plastic life history pattern, with an ability to adapt to a wide range of environmental conditions. Increasing abundance is possible.

Areas for Future Research [B]

Little studied species in the U.S. Chukchi and Beaufort Seas. Research needs include: (1) depth and location of pelagic larvae; (2) depth, location, and timing of young-of-the-year benthic recruitment; (3) preferred depth ranges for juveniles and adults; (4) spawning season; (5) seasonal and ontogenetic movements; (6) population studies; (7) prey; and (8) predators.

References Cited

Evans, C.L., Reist, J.D., and Minns, C.K., 2002, Life history characteristics of freshwater fishes occurring in the Northwest Territories and Nunavut, with major emphasis on riverine habitat requirements: Canadian Manuscript Report of Fisheries and Aquatic Sciences, no. 2614, 169 p. [1]

Love, M.S., 2011, Certainly more than you wanted to know about the fishes of the Pacific Coast: Santa Barbara, California, Really Big Press, 649 p. [12]

Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p. [4]

Morrow, J.E., 1980, The freshwater fishes of Alaska: Anchorage, Alaska Northwest Publishing Company, 248 p. [16]

Richardson, E.S., Reist, J.D., and Minns, C.K., 2001, Life history characteristics of freshwater fishes occurring in the Northwest Territories and Nunavut, with major emphasis on lake habitat requirements: Canadian Manuscript Report of Fisheries and Aquatic Sciences no. 2569, 156 p. [15]

Bibliography

1. Evans, C.L., Reist, J.D., and Minns, C.K., 2002, Life history characteristics of freshwater fishes occurring in the Northwest Territories and Nunavut, with major emphasis on riverine habitat requirements: Canadian Manuscript Report of Fisheries and Aquatic Sciences, no. 2614, 169 p.
2. Kume, M., Kuwahara, T., Arai, T., Okamoto, M., and Goto, A., 2006, A part of the Japan Sea form of the threespine stickleback, *Gasterosteus aculeatus*, spawns in the seawater tidal pools of western Hokkaido Island, Japan: Environmental Biology of Fishes, v. 77, no. 2, p. 169–175.
3. George, C., Moulton, L.L., and Johnson, M., 2007, A field guide to the common fishes of the North Slope of Alaska: Alaska Department of Wildlife Management, North Slope Borough, 93 p.
4. Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p.
5. Moser, F., 1903, Comparative embryology of the swim-bladder: Journal of the Royal Microscopical Society, v. 25, p. 708.
6. Mecklenburg, C.W., Møller, P.R., and Steinke, D., 2011, Biodiversity of Arctic marine fishes—Taxonomy and zoogeography: Marine Biodiversity, v. 41, no. 1, p. 109–140, Online Resource 1.
7. Minerals Management Service, 2008, Beaufort Sea and Chukchi Sea planning areas—Oil and Gas Lease Sales 209, 212, 217, and 221: U.S. Department of the Interior, Minerals Management Service Alaska OCS Region, OCS EIS/EA, MMS 2008-0055, 538 p.
8. Mecklenburg, C.W., and Mecklenburg, T.A., 2009, Arctic marine fish museum specimens, 2nd ed., Metadata report and database submitted to ArcOD, Institute of Marine Science: University of Alaska, Fairbanks, by Point Stephens Research, metadata report accessed August 8, 2012, at http://www.arcodiv.org/Database/Fish_datasets.html.
9. Barton, L.H., 1978, Finfish resource surveys in Norton Sound and Kotzebue Sound: Alaska Department of Fish and Game, Commercial Fisheries Division, p. 75–313.
10. Craig, P.C., and Haldorson, L.J., 1981, Beaufort Sea Barrier Island Lagoon ecological process studies—Final report, Simpson Lagoon—Fish: U.S. Department of Commerce, Biological Studies, p. 384–649.

11. Palmer, D.E., and Dugan, L.J., 1990, Fish population characteristics of Arctic National Wildlife Refuge coastal waters, summer 1989: Fairbanks, Alaska, U.S. Fish and Wildlife Service, Progress Report, 83 p.

12. Love, M.S., 2011, Certainly more than you wanted to know about the fishes of the Pacific Coast: Santa Barbara, California, Really Big Press, 649 p.

13. Simenstad, C.A., Isakson, J.S., and Nakatani, R.E., 1977, Marine fish communities, *in* Merritt, M.L., and Fuller, R.G., eds., The environment of Amchitka Island, Alaska: National Technical Information Center, Energy Research and Development Administration TID-26712, p. 451–492.

14. Jump, C.M., Duffy-Anderson, J.T., and Mier, K.L., 2008, Comparison of the Sameoto, Manta and MARMAP neustonic ichthyoplankton samplers in the Gulf of Alaska: Fisheries Research, v. 89, no. 3, p. 222–229.

15. Richardson, E.S., Reist, J.D., and Minns, C.K., 2001, Life history characteristics of freshwater fishes occurring in the Northwest Territories and Nunavut, with major emphasis on lake habitat requirements: Canadian Manuscript Report of Fisheries and Aquatic Sciences no. 2569, 156 p.

16. Morrow, J.E., 1980, The freshwater fishes of Alaska: Anchorage, Alaska Northwest Publishing Company, 248 p.

17. Wang, J.C.S., 1981, Taxonomy of the early life stages of fishes—Fishes of the Sacramento-San Joaquin Estuary and Moss Landing Harbor-Elkhorn Slough, California: Concord, California, Ecological Analysts, Inc., 168 p.

18. Wienerroither, R., Johannesen, E., Langøy, H., Børve Eriksen, K., de Lange Wenneck, T., Høines, Å., Bjelland, O., Aglen, A., Prokhorova, T., Murashko, P., Prozorkevich, D., Konstantin, Byrkjedal, I., Langhelle Drevetnyak, and G., Smirnov, O., 2011, Atlas of the Barents Sea fishes: IMR/PINRO Joint Report Series 1-2011, ISSN 1502-8828, 274 p.

19. Emmett, R.L., Stone, S.L., Hinton, S.A., and Monaco, M.E., 1991, Distribution and abundance of fishes and inverteprates in west coast estuaries, Volume II—Species life history summaries: National Oceanic and Atmospheric Administration/National Ocean Service Strategic Environmental Assessments Division, ELMR Report no. 8, 327 p.

20. Garrison, K.J., and Miller, B.S., 1982, Review of the early life history of Puget Sound fishes: Seattle, University of Washington, Fisheries Research Institute, 729 p.

21. Murphy, M.L., Johnson, S.W., and Csepp, D.J., 2000, A comparison of fish assemblages in eelgrass and adjacent subtidal habitats near Craig, Alaska: Alaska Fishery Research Bulletin, v. 7, p. 11–21.

22. Johnson, S.W., Neff, A.D., and Thedinga, J.F., 2005, An atlas on the distribution and habitat of common fishes in shallow nearshore waters of southeastern Alaska: Alaska Fisheries Science Center, Technical Memorandum NMFS-AFSC-157, 98 p.

23. Jones, J.W., and Hynes, H.B.N., 1950, The age and growth of *Gasterosteus aculeatus, Pygosteus pungitius* and *Spinachia vulgaris*, as shown by their otoliths: Journal of Animal Ecology, v. 19, no. 1, p. 59–73.

24. Love, M.S., Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2005, Resource inventory of marine and estuarine fishes of the West Coast and Alaska—A checklist of North Pacific and Arctic Ocean species from Baja California to the Alaska-Yukon border: Seattle, Washington, U.S. Department of the Interior, U.S. Geological Survey, Biological Resources Division, OCS Study MMS 2005-030 and USGS/NBII 2005-001, 276 p.

25. Chereshnev, I., Nazarkin, M.V., Skopets, M.B., Pitruk, D., Shestakov, A.V., Yabe, M., and others, 2001, Annotated list of fish-like vertebrates and fish in Tauisk Bay (northern part of the Sea of Okhotsk), *in* Andreev, A.V., and Bergmann, H.H., eds., Biodiversity and ecological status along the northern coast of the Sea of Okhotsk—A collection of study reports: Dalnauka Vladivostok, Russia, Institute of Biological Problems of the North, p. 64–86.

26. Barrett, R.D.H., Paccard, A., Healy, T.M., Bergek, S., Schulte, P.M., Schluter, D., and Rogers, S.M., 2010, Rapid evolution of cold tolerance in stickleback: Proceedings of the Royal Society B, doi:10.1098/rspb.2010.0923.

27. Fresh, K.L., 1979, Distribution and abundance of fishes occurring in the nearshore surface waters of northern Puget Sound, Washington: Seattle, University of Washington, Master's thesis.

28. Miller, B.S., Simenstad, C.A., Moulton, L.L., Fresh, K.L., Funk, F.C., Karp, W.A., and others, 1977, Puget Sound baseline program—Nearshore fish survey: University of Washington, Fishery Research Institute, FRI-UW-7710, 219 p.

29. Zbinden, M., Mazzi, D., Künzler, R., Largiadèr, C.R., and Bakker, T.C.M., 2003, Courting virtual rivals increase ejaculate size in sticklebacks (*Gasterosteus aculeatus*): Behavioral Ecology and Sociobiology, v. 54, no. 3, p. 205–209.

30. Moyle, P.B., 2002, Inland fishes of California: Berkeley, University of California Press, 517 p.

31. Andriashev, A.P., 1954, Fishes of the northern seas of the U.S.S.R.—Keys to the fauna of the U.S.S.R.: Academy of Sciences of the U.S.S.R., Zoological Institute, no. 53, 566 p. [In Russian, translation by Israel Program for Scientific Translation, Jerusalem, 1964, 617 p., available from U.S. Department of Commerce, Springfield, Virginia.]

32. Barraclough, W.E., Robinson, D.G., and Fulton, J.D., 1968, Number, size composition, weight and food of larval and juvenile fish caught with a two-boat surface trawl in Saanich Inlet April 23–July 21 (data record): Fisheries Research Board of Canada, Manuscript Report Series no. 1004, 305 p.

33. Tack, S.L., 1970, The summer distribution and standing stock of the fishes of Izembek Lagoon, Alaska: Fairbanks, University of Alaska, Master's thesis.

34. Cross, J.N., Fresh, K., Miller, B.S., Simenstad, C.A., Steinfort, S.N., and Fegley, J.C., 1978, Nearshore fish and invertebrates assemblages along the Strait of Juan de Fuca including food habits of the common inshore fishes: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Research Laboratories, NOAA Technical Memorandum ERL MESA-32.

35. Simenstad, C.A., Miller, B.S., Nyblade, C.F., Thornburgh, K., and Bledsoe, L.J., 1979, Food web relationships of northern Puget Sound and the Strait of Juan de Fuca—A synthesis of the available knowledge: National Oceanic and Atmospheric Administration/Marine Ecosystems Analysis Puget Sound Project, Prepared for Office of Environmental Engineering and Technology, United States Environmental Protection Agency, 334 p.

36. Froese, R., and Pauly, D., eds., 2012, FishBase—Global information system on fishes: FishBase database, accessed July 8, 2012, at http://www.fishbase.org.

Ninespine Stickleback (*Pungitius pungitius*)
(Linnaeus, 1758)

Family Gasterosteidae

Ninespine Stickleback (*Pungitius pungitius*) 62 mm, northeastern Bering Sea (2007). Photograph by C.W. Mecklenburg, Point Stephens Research.

Note on taxonomy: *Some authors recognize more species in this complex than others. North American Arctic populations have been considered a separate species* P. occidentalis *or to comprise two subspecies:* P. p. pungitius, *and* P. p. occidentalis [1].

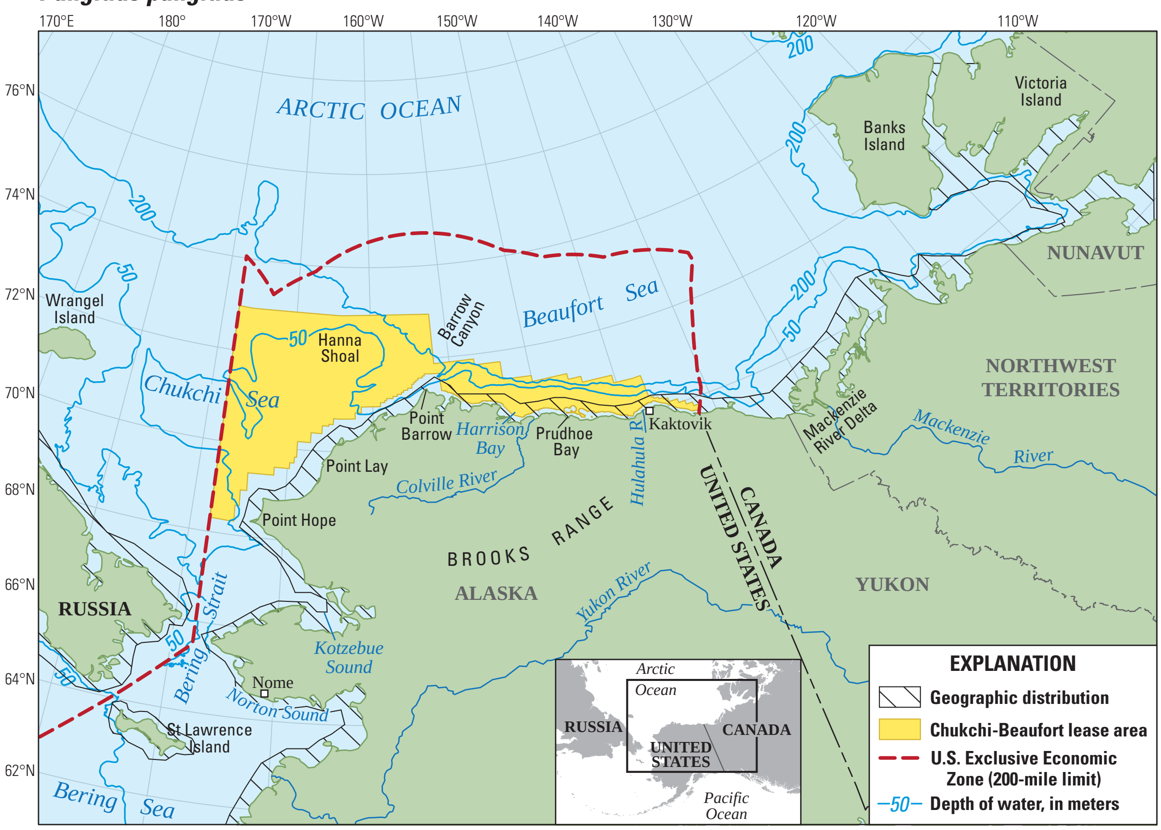
Colloquial Name: Iñupiat—*Kakaliqauraq* [2].

Ecological Role: Likely of considerable seasonal importance as a prey of fishes, sea birds, and marine mammals; occurs in brackish and marine waters near the coast.

Physical Description/Attributes: Slender, elongate body. Olive to pale brown on back, silvery or brassy yellow on sides and belly. Breeding colors vary with population; spawning males often have a great deal of black on sides, belly, and chins [3, 4]. Pure black males have been noted [3]. For specific diagnostic characteristics, see *Fishes of Alaska* (Mecklenburg and others, 2002, p. 334) [4]. Swim bladder: Present, without pneumatic duct [5]. Antifreeze glycoproteins in blood serum: Unknown.

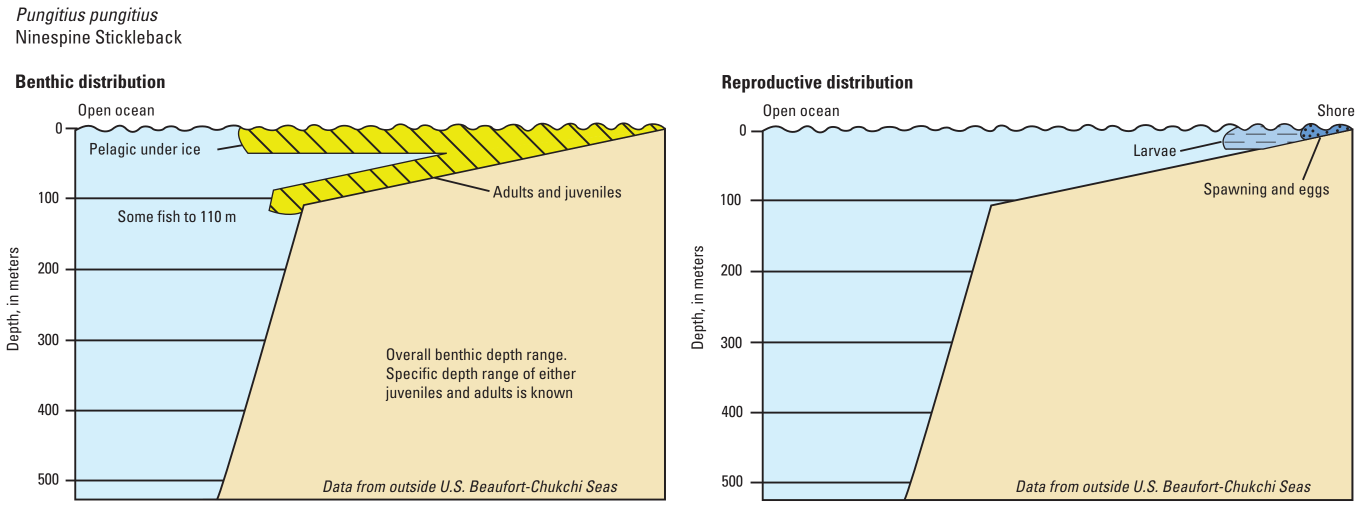
Range: *Along shores of U.S. Chukchi and Beaufort Seas* [1]. Elsewhere in Alaska, along Bering Sea and western and northern Gulf of Alaska coasts inland to northeastern British Columbia. Worldwide, western Pacific Ocean in Seas of Japan and Okhotsk, and along Arctic shores except absent from Canadian high Arctic Archipelago, Greenland, and Iceland [1].

Relative Abundance: *Common, although overall abundance is poorly described. Occasionally taken in large numbers along coasts in U.S. Chukchi and Beaufort Seas* and in Canadian Beaufort Sea [8–12].

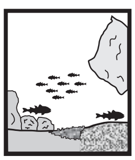


Geographic distribution of Ninespine Stickleback (*Pungitius pungitius*), within Arctic Outer Continental Shelf Planning Areas [6] based on review of published literature and specimens from historical and recent collections [1, 4, 7].

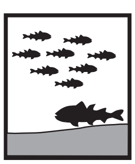
Depth Range: Nearshore, surface waters to depths of 110 m [4]. In ocean, spawning occurs nearshore, in estuary tide pools [13]. Larvae remain near spawning nests [14].



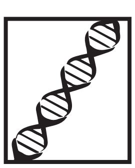
Benthic and reproductive distribution of Ninespine Stickleback (*Pungitius pungitius*).



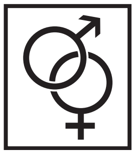
Habitats and Life History
Anadromous, riverine, and lacustrine forms [15].
Eggs—Size: 1.0–1.5 mm [16, 17]. Time to hatching: Unknown. Habitat: Benthic, in nests made of algae and plant material [3, 16].
Larvae—Size at hatching: 5.7 mm on average [17]. Size at juvenile transformation: About 15 mm [14]. Days to juvenile transformation: Perhaps 3 months [14]. Habitat: Benthic, remaining near nests [14].
Juveniles—Size range: About 15–38 mm [14, 18]. Habitat: *In ocean, benthic, and midwaters, often under ice* [9, 19, 20].
Adults—Age and size at first maturity: 1–2 years [16, 21, 22] and at least 38 mm in Baltic Sea [18]. Maximum age: At least 2 years in North America [21]. Freshwater fish in Great Britain live to 3.5 years [23]. Maximum size: 9 cm TL [4]. Habitat: *In ocean, benthic, and midwaters, often under ice* [9, 19, 20].
Substrate—Rocks and sand for spawning [3].
Physical/chemical—Temperature:–1.9–20 °C [19, 21]. Salinity: Fresh to marine [15]. In Baltic Sea, prefers warmer, brackish waters for spawning [14].



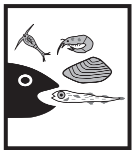
Behavior
Little is known of the behaviors of these fish in Arctic waters.
Diel—*Once at sea, makes offshore excursions, as much as 6 km off the coast in Beaufort Sea* [22, 24].
Seasonal—Toward autumn some fish migrate to marine waters. *Over wintering can occur in estuaries and river deltas* [10, 11, 25, 26].
Reproductive—Spawning occurs at shallow depths in fresh and brackish waters [3, 16]. Nesting occurs in dense vegetation or in more exposed areas, such as in the crevices of boulder fields or under rocks. Males construct tunnel-shaped nests of plant material and lure females to them through a series of courtship behaviors [3, 16]. Males often mate with more than one female [15–17]. Females are batch spawners. Males protect fertilized eggs and larvae through and somewhat after hatching, often retrieving errant young and spitting them back into the nest [3].
Schooling—Juveniles school, adults may form small groups [27].
Feeding—Appears to occur during daylight hours [27].



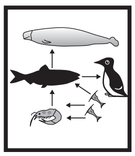
Populations or Stocks
There have been no studies.



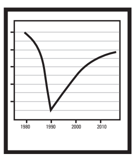
Reproduction
Mode—Oviparous, separate sexes.
Spawning season—*Spring and summer* [3, 16].
Fecundity—350–960 eggs, in batches of 20–80 eggs [28]



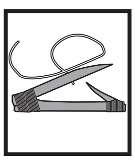
Food and Feeding
Food items—Zooplankton (for example, mysids and ostracods), adult and larval insects, mollusks, and fish eggs [8, 29, 30].
Trophic level—3.29 (standard error 0.40) [31].



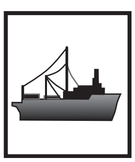
Biological Interactions
Predators—*In U.S. Beaufort and Chukchi Seas, other fishes including Arctic Cisco, Least Cisco, Dolly Varden, Fourhorn Sculpin, and Humpback Whitefish* [8, 32], *as well as belugas (off Point Barrow in May)* [33], *and ringed seals (over much of the year in northeastern Chukchi Sea* [34]. Generally, Ninespine Stickleback are an important prey species for other fishes, birds, and mammals.
Competitors—Likely such zooplanktivores as whitefishes, Pacific Herring, sculpins, and gadids.



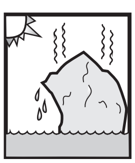
Resilience
Medium, minimum population doubling time 1.4–4.4 years (t_m=1–2; t_{max}=5; Fecundity=350) [31].



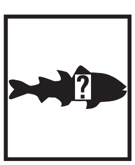
Traditional and Cultural Importance
Historically, Ninespine Stickleback were used as both human and dog food, although currently this species is not used [2, 16].



Commercial Fisheries
Currently, Ninespine Stickleback are not commercially harvested.



Potential Effects of Climate Change
Ninespine Stickleback are a predominantly boreal species with widespread presence along Arctic shores [1], which could be expected to increase in abundance and continue expanding to localities where suitable habitat can be found, as the climate warms.



Areas for Future Research [B]
Little is known about the biology and ecology of this species from the region. Research needs include: (1) depth and location of pelagic larvae; (2) depth, location, and timing of young-of-the-year benthic recruitment; (3) preferred depth ranges for juveniles and adults; (4) spawning season; (5) seasonal and ontogenetic movements; (6) population studies; (7) prey; and (8) predators.

References Cited

Griswold, B.L., and Smith, L.L., Jr., 1972, Early survival and growth of the ninespine stickleback, *Pungitius pungitius*: Transactions of the American Fisheries Society, v. 101, no. 2, p. 350–352. [17]

Jarvela, L.E., and Thorsteinson, L.K., 1999, The epipelagic fish community of Beaufort Sea coastal waters, Alaska: Arctic, v. 52, no. 1, p. 80–94. [20]

Kendel, R.E., Johnston, R.A.C., Lobsiger, U., and Kozak, M.D., 1975, Fishes of the Yukon coast: Victoria, British Columbia, Department of the Environment (Canada), Beaufort Sea Project, Technical Report 6, 114 p. [8]

McPhail, J.D., and Lindsey, C.C., 1970, Freshwater fishes of northwestern Canada and Alaska: Bulletin of the Fisheries Research Board of Canada Bulletin 173, 381 p. [16]

Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p. [4]

Mecklenburg, C.W., Møller, P.R., and Steinke, D., 2011, Biodiversity of Arctic marine fishes—Taxonomy and zoogeography: Marine Biodiversity, v. 41, no. 1, p. 109–140, Online Resource 1. [1]

Bibliography

1. Mecklenburg, C.W., Møller, P.R., and Steinke, D., 2011, Biodiversity of Arctic marine fishes—Taxonomy and zoogeography: Marine Biodiversity, v. 41, no. 1, p. 109–140, Online Resource 1.
2. George, C., Moulton, L.L., and Johnson, M., 2007, A field guide to the common fishes of the North Slope of Alaska: Alaska Department of Wildlife Management, North Slope Borough, 93 p.
3. McKenzie, J.A., and Keenleyside, M.H.A., 1970, Reproductive behavior of ninespine sticklebacks (*Pungitius pungitius* [L.]) in South Bay, Manitoulin Island, Ontario: Canadian Journal of Zoology, v. 48, no. 1, p. 55–61.
4. Mecklenburg, C.W., Mecklenburg, T.A., and Thorsteinson, L.K., 2002, Fishes of Alaska: Bethesda, Maryland, American Fisheries Society, 1,116 p.
5. Moser, F., 1903, Comparative embryology of the swim-bladder: Journal of the Royal Microscopical Society, v. 25, p. 708.
6. Minerals Management Service, 2008, Beaufort Sea and Chukchi Sea planning areas—Oil and Gas Lease Sales 209, 212, 217, and 221: U.S. Department of the Interior, Minerals Management Service Alaska OCS Region, OCS EIS/EA, MMS 2008-0055, 538 p.
7. Mecklenburg, C.W., Mecklenburg, T.A., Sheiko, B.A., and Steinke, D., 2016, Pacific Arctic marine fishes: Akureyri, Iceland, Conservation of Arctic Flora and Fauna, Monitoring Series Report No. 23, 406 p., accessed May 10, 2016, at http://caff.is/monitoring-series/370-pacific-arcticmarine-fishes.
8. Kendel, R.E., Johnston, R.A.C., Lobsiger, U., and Kozak, M.D., 1975, Fishes of the Yukon coast: Victoria, British Columbia, Department of the Environment (Canada), Beaufort Sea Project, Technical Report 6, 114 p.
9. Barton, L.H., 1978, Finfish resource surveys in Norton Sound and Kotzebue Sound: Alaska Department of Fish and Game, Commercial Fisheries Division, p. 75–313.
10. Lawrence, M.J., Lacho, G., and Davies, S., 1984, A survey of the coastal fishes of the southeastern Beaufort Sea: Canadian Technical Report of Fisheries and Aquatic Sciences, no. 1220, 178 p.
11. Palmer, D.E., and Dugan, L.J., 1990, Fish population characteristics of Arctic National Wildlife Refuge coastal waters, summer 1989: Fairbanks, Alaska, U.S. Fish and Wildlife Service, Progress Report, 83 p.
12. Fechhelm, R.G., Griffiths, W.B., Wilson, W.J., Trimm, B.A., and Colonell, J.M., 1996, The 1995 fish and oceanography study in Mikkelsen Bay, Alaska: Anchorage, Alaska, Prepared by LGL Alaska Research Associates and Woodward-Clyde Consultant for BP Exploration (Alaska) Inc., 102 p. plus apps.

13. Poulin, R., and Fitzgerald, G.J., 1989, Early life histories of three sympatric sticklebacks in a salt-marsh: Journal of Fish Biology, v. 34, no. 2, p. 207–221.

14. Sokolowska, E., and Krzysztof, E.S., 2002, Reproductive cycle and the related spatial and temporal distribution of the ninespine stickleback (*Pungitius pungitius* L.) in Puck Bay: Oceanologia, v. 44, no. 4, p. 475–490.

15. Richardson, E.S., Reist, J.D., and Minns, C.K., 2001, Life history characteristics of freshwater fishes occurring in the Northwest Territories and Nunavut, with major emphasis on lake habitat requirements: Canadian Manuscript Report of Fisheries and Aquatic Sciences no. 2569, 156 p.

16. McPhail, J.D., and Lindsey, C.C., 1970, Freshwater fishes of northwestern Canada and Alaska: Bulletin of the Fisheries Research Board of Canada Bulletin 173, 381 p.

17. Griswold, B.L., and Smith, L.L., Jr., 1972, Early survival and growth of the ninespine stickleback, *Pungitius pungitius*: Transactions of the American Fisheries Society, v. 101, no. 2, p. 350–352.

18. Sokolowska, E., and Krzysztof, E.S., 2001, Fecundity of ninespine stickleback (*Pungitius pungitius* L., 1758) in the Puck Bay: Acta Ichtyologica et Piscatoria, v. 31, no. 1, p. 45–60.

19. Green, J.M., and Steele, D.H., 1975, Observations on marine life beneath sea ice, Resolute Bay, N.W.T., *in* Proceedings of the Circumpolar Conference on Northern Ecology, September 15–18, 1975: Ottawa, Ontario, National Research Council of Canada, p. II-77–II-86.

20. Jarvela, L.E., and Thorsteinson, L.K., 1999, The epipelagic fish community of Beaufort Sea coastal waters, Alaska: Arctic, v. 52, no. 1, p. 80–94.

21. Cameron, J.N., Kostoris, J., and Penhale, P.A., 1973, Preliminary energy budget of the ninespine stickleback (*Pungitius pungitius*) in an Arctic lake: Journal of the Fisheries Research Board of Canada, v. 30, no. 8, p. 1,179–1,189.

22. Bond, W.A., 1982, A study of the fishery resources of Tuktoyaktuk Harbour, southern Beaufort Sea coast, with special reference to life histories of anadromous coregonids: Canadian Technical Report of Fisheries and Aquatic Sciences, no. 1119, 90 p.

23. Jones, J.W., and Hynes, H.B.N., 1950, The age and growth of *Gasterosteus aculeatus*, *Pygosteus pungitius* and *Spinachia vulgaris*, as shown by their otoliths: Journal of Animal Ecology, v. 19, no. 1, p. 59–73.

24. Houghton, J.P., and Whitmus, C.J., 1988, Shallow neritic fish of the central Beaufort Sea: Seattle, Washington, Report prepared for Standard Alaska Production Company by Dames an Moore, 17298-002-20.

25. Schmidt, D.R., Griffiths, W.B., and Martin, L.R., 1987, Importance of anadromous fish overwintering habitat in the Sagavanirktok River Delta, Alaska: Anchorage, Alaska, Report by Ecological Research Associates for Standard Alaska Production Company and North Slope Borough, 71 p.

26. Schmidt, D.R., Griffiths, W.R., and Martin, L.R., 1989, Overwintering biology of anadromous fish in the Sagavanirktok River Delta, Alaska: Biological Papers of the University of Alaska, v. 24, p. 55–74.

27. Collette, B.B., and Klein-MacPhee, G., 2002, Bigelow and Schroeder's fishes of the Gulf of Maine (3rd ed.): Washington, D.C., Smithsonian Institution Press, 882 p.

28. Andriashev, A.P., 1954, Fishes of the northern seas of the U.S.S.R.—Keys to the fauna of the U.S.S.R.: Academy of Sciences of the U.S.S.R., Zoological Institute, no. 53, 566 p. [In Russian, translation by Israel Program for Scientific Translation, Jerusalem, 1964, 617 p., available from U.S. Department of Commerce, Springfield, Virginia.]

29. Hatfield, C.T., Stein, J.N., Falk, M.R., and Jessop, C.S., 1972, Fish resources of the Mackenzie River Valley: Winnepeg, Environment Canada Fisheries Service, Interim report 1, v. 1.

30. Percy, R., 1975, Fishes of the outer Mackenzie Delta: Victoria, British Columbia, Beaufort Sea Project, Beaufort Sea Technical Report, no. 8, 114 p.

31. Froese, R., and Pauly, D., eds., 2012, FishBase—Global information system on fishes: FishBase database, accessed July 8, 2012, at http://www.fishbase.org.

32. Griffiths, W.B., Craig, P., Walder, G., and Mann, G., 1975, Fisheries investigations in a coastal region of the Beaufort Sea (Nunaluk Lagoon, Yukon), *in* Craig, P.C., ed., Fisheries investigations in a coastal region of the Beaufort Sea: Arctic Gas, Biological Report Series, v. 34, p. 1–129.

33. Lowry, L.F., Frost, K.J., and Seaman, G.A., 1986, Investigations of belukha whales in coastal waters of western and northern Alaska: Outer Continental Shelf Environmental Program Unit 612, Final Report, p. 359–392.

34. Johnson, M.L., Fiscus, C.H., Ostenson, B.T., and Barbour, M.L., 1966, Marine mammals, *in* Wilimovsky, N.J., and Wolfe, J.N., eds., Environment of the Cape Thompson Region, Alaska: Oak Ridge, Tennesee, United States Atomic Energy Commission, Division of Technical Information, p. 877–924.