Polar Biol
DOI 10.1007/s00300-010-0952-3

ORIGINAL PAPER

Arctic fisheries catches in Russia, USA, and Canada: baselines for neglected ecosystems

D. Zeller · S. Booth · E. Pakhomov · W. Swartz · D. Pauly

Received: 6 October 2010 / Revised: 9 December 2010 / Accepted: 17 December 2010

Abstract The Amerasian Arctic, covering northern Siberia (Russia), Arctic Alaska (USA), and the Canadian Arctic, extends over seven coastal Large Marine Ecosystems and makes up the seasonally ice-free part of FAO Statistical Area 18 (Arctic Sea). Historically, the harsh climate has limited marine fisheries (here excluding marine mammal hunting) to small-scale operations conducted mainly in estuaries and river deltas. Most of the catches have traditionally not been reported to FAO, with the result that total catch estimated here from 1950 to 2006 is 75 times higher than the sum of the catches reported for FAO 18 (Arctic). Catches were reconstructed from data on fishing communities in Canada and Alaska, and from various government and non-government sources for Siberia. Based on national data supplied to FAO since 1950, catches have been reported as 12,700 t *in toto* (reported on behalf of the former Soviet Union). This compares with our reconstructed catches of over 950,000 t, i.e., 770,000, 89,000, and 94,000 t by Russia, USA, and Canada, respectively for the same time period. The reconstructed catch (mainly whitefishes in Siberia, various salmonids in Alaska, and Arctic char in Canada) was 24,100 t year^{-1} in 1950, but declined to 10,200 t year^{-1} by the mid-2000s. Reasons for these trends are discussed by country, along with sources of uncertainty (particularly large for Siberia). Catches were allocated to Large Marine Ecosystems to present ecosystem-relevant baselines for the impact of fisheries on the Arctic, which can be expected to increase, as industrial fisheries move into a warming Arctic following the invasion of boreal species, unless countries apply precautionary ecosystem-based management approaches.

Keywords Catch reconstruction · Amerasian arctic · Small-scale fisheries

D. Zeller (✉) · S. Booth · W. Swartz · D. Pauly
Sea Around Us Project, Fisheries Centre,
University of British Columbia, Vancouver,
BC V6T 1Z4, Canada
e-mail: d.zeller@fisheries.ubc.ca

E. Pakhomov
Earth & Ocean Sciences, University of British Columbia,
Vancouver, BC V6T 1Z4, Canada

Introduction

The Arctic, generally defined as the area within the 10°C summer isotherm, has about 4 million inhabitants. The marine part of this region consists of a large, ice-covered ocean, where the extent of the sea ice has declined in recent years due to climate change. The Arctic is one of the last and most extensive ocean wilderness areas in the world, and its significance in preserving biodiversity and genotypes, particularly given growing climate change pressures, is considerable.

The United Nations Food and Agriculture Organization's (FAO) Fisheries Statistical Area 18 (Arctic), ranging from Novaya Zemlya (Russia) in the east to Hudson Bay (Canada) in the west, and the geographic North Pole as its northernmost point, is comprised of the Siberian coast (Russia), the Arctic coast of Alaska (USA) and the majority of the arctic coast of Canada, or about two-third of the total Arctic (Fig. 1). FAO Area 18 includes eight Large Marine Ecosystems (seven coastal, one oceanic), which are spatial divisions ideally suited for ecologically meaningful assignment of impacts such as fisheries (Pauly et al. 2008; Sherman and Hempel 2008). Of these eight Large Marine Ecosystems (LMEs, Fig. 1), the Arctic Ocean LME covers only offshore, oceanic waters, most of them are

Fig. 1 Map of the arctic region, showing Statistical Areas of the United Nations Food and Agriculture Organization (FAO), as well as the eight Large Marine Ecosystems (LMEs) associated with FAO Area 18 (Amerasian Arctic). Note the purely oceanic nature of the Arctic Ocean LME, which was not included in the present study

permanently covered by ice, and at present not affected by fisheries. Given the focus of arctic fisheries in coastal and estuarine waters, a good comparative reference is catch per Inshore Fishing Area (IFA, Table 1), which is defined as the area of ocean that is within 50 km from shore or 200 m depth, whichever comes first (Chuenpagdee et al. 2006).

Siberia (Russia)

Arctic waters (FAO Area 18) have low fishery productivity, which is particularly the case in north Siberia. However, Russia, and the former USSR, reported catches for this area to FAO which are too low to be credible (Table 2), even considering the remoteness and harshness of the environment, which limits the development of fisheries. This may be due, in part, to Russia not being a member of the FAO until 2006.

Here, we establish a time series of likely total marine fisheries catches for Northern Siberia, based on work reported in Pauly and Swartz (2007). It should be stressed that Pauly and Swartz (2007) was written primarily as a starting point for our Russian or other colleagues with better data to work from. We are under no illusion as to the quality of the data we present for this arctic area. We only believe that they are less wrong than what is publically available to date. Numerous references were found in which 'fishing' by the indigenous peoples of Northern Siberia was mentioned (see also www.raipon.org), notably by anthropologists, but very few of them provided quantitative information, as is also, and regrettably, the case with anthropologists working under warmer climes (Pauly 2006).

Pauly and Swartz (2007) found one very useful source of data, the working papers of the International Northern Sea Route Programme (INSROP) conducted from 1993 to 1999. This project involved scientists from Norway, Russia, Japan, and other countries who were exploring the implications that the possible operation of a regular shipping lane from Northern Europe to Japan and beyond—the legendary Northeast Passage—would have on the Siberian marine ecosystems (see www.fni.no/insrop/). The project, which also studied the potential effect of a northern sea route (NSR) on marine mammals (Wiig et al. 1996; Belikov et al. 1998; Thomassen et al. 1999), seabirds (Gavrilo

Table 1 Major chronological events as applicable to fisheries in the Arctic waters of Russia, USA, and Canada

Year	Country	Event	Influence/impact on fisheries
1950–1980	Russia	Forced labor camps, industrialization: immigration, "banishment"	Increasing demand on fisheries
1991	Russia	USSR collapse and reduction in subsidies: emigration	Lowered demand on fisheries
1962	USA	Formal start of commercial fisheries in Kotzebue Sound	Increases in commercial catches
1967	USA	Formal start of commercial Coleville river fishery	Increases in commercial catches
1963	USA	Snowmobile introduction in Kotzebue Sound area	Decreasing need for fish as dog feed
1965	USA	Snowmobile introduction to other areas	Decreasing need for fish as dog feed
Late-1960s	Canada	Snowmobile introduction	Decreasing need for fish as dog feed
Mid-1970s	Canada	Disappearance of sled-dog teams	Decreasing need for fish as dog feed

Table 2 Key properties of the seven near-shore Large Marine Ecosystems (Sherman and Hempel 2008) used here for reporting reconstructed catches for FAO Statistical Area 18 (Arctic)

Property (unit)	Kara Sea	Laptev Sea	E. Siberian Sea	Chukchi Sea	Beaufort Sea	Arctic Archipelago	Hudson Bay
Area ($\times 10^3$ km^2)	970	539	1,024	783	665	1,245	1,247
Mean depth (m)	133	63	97	400	2,626	244	90
Primary production (mgC m^{-2} day^{-1})	347	429	149	249	326	161	418
Inshore Fishing Area ($\times 10^3$ km^2)[a]	472	220	220	149	76	968	813

For spatial extent and boundaries, see Fig. 1. Data source: www.seaaroundus.org

[a] Defined as area less than 50 km from shore or 200 m depth, whichever comes first (Chuenpagdee et al. 2006)

et al. 1998), and invertebrates (Larsen et al. 1995), included a volume devoted mainly to fisheries (Larsen et al. 1996), which we used extensively here, complemented by other sources.

The fisheries catch data in Larsen et al. (1995), also presented in the atlas of Brude et al. (1998), were obtained from the State Institute of Lake and River Fisheries (GOSNIORKH), at the time the relevant line agency in Russia. For the areas considered here, these data pertain exclusively to non-industrial catches made with fixed and drifting gill nets, drag seines, trap nets, and under-ice nets, which are all small-scale, artisanal gear. There is another management body, the National Administration for Fishery Enforcement, Resource Restoration, and Fishing Regulation (GLAVRYBVOD), which "*regulates the industrial harvest of fish, marine mammals and plants in Russia's internal waters, on the continental shelf and in the two-hundred-mile exclusive economic zone*" (Newell 2004, p. xvi), but its relationship—if any—with GOSNIORKH is not clear.

The data available through these sources and used here are highly fragmented and could be vastly improved by more complete information becoming available from present institutional arrangements and/or from colleagues working on these fisheries. Indeed, we sincerely hope that our Russian and other colleagues with first-hand knowledge of the Arctic will correct and improve our view of their fisheries and ecosystems, and the figures presented here.

Alaska (USA)

The US National Marine Fisheries Service's Alaska branch (NMFS-Alaska), having US federal responsibilities, does not report on US arctic fisheries, because they take place within Alaskan state waters (within 3 nm). At the federal level, the National Marine Fisheries Service (NMFS-National) reports on Alaska's fisheries, but they do not include catches taken in the Arctic, i.e. north of Bering Strait. As a consequence, the United States currently reports zero catches to FAO for the Arctic area (FAO 18). In contrast, the state agency, the Alaska Department of Fish and Game (ADF&G), has collected time series of commercial data and has also undertaken community subsistence studies that are intermittent in space and time. However, no complete time series of total marine catch estimates exist for the arctic coast of Alaska. Here, we present reconstructed estimates of total marine commercial and subsistence catches taken by the 15 coastal communities in Alaska's arctic that form part of FAO Area 18 for the years 1950–2006. These 15 communities account for essentially the entire human population in coastal arctic Alaska. The material used here is based on a preliminary report by Booth and Zeller (2008).

The people living in Alaska's arctic coastal communities have always relied on the Arctic Ocean for part of their sustenance. The area is sparsely populated, and the 15 communities represented in this study (Wales, Shishmaref, Deering, Buckland, Selawik, Kotzebue, Noatak, Kivalina, Point Hope, Point Lay, Wainwright, Barrow, Atqasuk, Nuiqsut, and Kaktovik) have an estimated total population of over 12,000 that grew at an average annual rate of 5.2% per year from 1950 to 2000 (Booth and Zeller 2008). The total population has since been slightly decreasing. Marine commercial fisheries are important in Kotzebue Sound with chum salmon (*Oncorhynchus keta*), the most important component of the catch, while marine subsistence fisheries are an important component throughout the area and target a variety of species including chum salmon, whitefishes, and Dolly varden (*Salvelinus malma*).

Canada

Canada's arctic fisheries occur within both FAO Areas 18 and 21 (Fig. 1). Fisheries and Oceans Canada (i.e., DFO) is Canada's federal agency responsible for fishery statistics, and it reports catch data for Canada, including Canada's arctic regions (DFO 2006). Existing public reports allow for estimation of the marine fish component of catches from arctic waters to be separated from the inland freshwater catches. This study reports on marine fish catches taken by communities that fish the FAO 18 arctic waters of Canada (commercial and small-scale) for the period 1950–2006 and builds on a report by Booth and Watts (2007). Although several studies and reports have been published previously on aspects of Canada's arctic catches, there has been no comprehensive review of potential historical catches, combining both small-scale catches with commercial catches, and spatio-temporal expansion to cover the entire Canadian Arctic.

Productivity in the marine waters of northern Canada is limited by low nutrient availability in the upper water layer caused by vertical stratification, a lack of upwelling and the freeze/thaw cycle that dilutes available nutrients. In Hudson Bay, vertical stratification is amplified by the large amount of freshwater inputs from various rivers. For these reasons, commercial fishery potential has traditionally been considered low (Dunbar 1970).

The arctic region of Canada is characterized by small coastal communities with a high degree of dependence on marine resources, including mammals. The population is spread along an extensive coastline, living in communities that are generally less developed than most others in Canada. Although the significance of subsistence fisheries has been recognized (Berkes 1990), the Arctic has previously received little attention as a fishing culture, due in part to the small population and limited government services. The present study focuses on the marine fish catches of 51 northern communities (Booth and Watts 2007), which are thought to account for essentially all human populations in coastal arctic Canada in FAO 18. These communities are largely populated by Inuit, although some located on the coast of Hudson Bay have large numbers of non-Inuit indigenous peoples (Algonkian, Athapaskan and Métis), as well as non-indigenous people.

Over the time period considered here, there have been large economic and infrastructure changes in these communities. Dog-sled teams, the traditional mode of transportation, were replaced by the snowmobile starting in the early 1960s (Usher 1972, 2002), and the subsistence economy, although still important, has become blended with a government- and market-based infrastructure and food use (Collings et al. 1998). There has also been a 5-fold increase in the indigenous population, with an estimated growth from about 8,000 in 1950 to 40,000 in 2001.

Overall, the aim of this study is to estimate the likely total catches from 1950 to 2006 by country and Large Marine Ecosystem (Sherman and Hempel 2008) for the entire Amerasian Arctic area, as defined by FAO Statistical Area 18 (Fig. 1). Overall, we follow the historical catch reconstruction approach as developed and applied successfully elsewhere (e.g., Zeller et al. 2006a, 2007; Jacquet et al. 2010).

Materials and methods

As the basic methods used for the reconstruction of Canadian and Alaskan catches were similar, but differed from the approach taken for Russia, we present these two approaches separately here. Technical details for each country can also be found in the related reports (Booth and Watts 2007; Pauly and Swartz 2007; Booth and Zeller 2008).

Siberia

Kara Sea LME

The Kara Sea (Fig. 1) has a complex oceanography (e.g., Fetzer et al. 2002) and receives the occasional intrusion of 'warm' water and the accompanying fauna from the Barents Sea (Fleming and Jensen 2002). Otherwise, the fish fauna of the Kara Sea is as species poor as the Laptev and East Siberian Seas further to the east (Pauly and Swartz 2007). The bulk of fisheries catches (70–90%, Larsen et al. 1996) is contributed by six species of the genus *Coregonus* (Subfamiliy Coregoninae, Family Salmonidae; see www.fishbase.org), collectively known as 'whitefishes' ('sig' in Russian). Thus, we assumed that whitefish catches accounted for 80%, and other fish accounted for 20% of catches. Whitefishes are caught in the lower reaches of rivers, and their estuaries and surrounding coastal areas, notably in the giant estuaries of the rivers Ob and Yenisei (Slavin 1964).

The time series of available catch data, from Larsen et al. (1996), based on reports from GOSNIORKH, cover only the years for 1980–1994 for Ob Bay, and 1989 and 1991–1994 for three other tributaries (Yenisei, Pyasina and Taimyskaya rivers). These data show a clear declining trend around a mean catch of 225 t year^{-1}, which, when extrapolated backward, would suggest a whitefish catch of about 12,500 t in 1950.

However, we have four independent sources of evidence suggesting catches of whitefishes in the Kara Sea were higher in the past:

1. Slavin (1964) wrote of a catch of 30,000 t year^{-1}, presumably pertaining to the late 1950s or early 1960s, which is nearly ten times the catch in the 1980s;
2. The catch data of GOSNIORKH (Larsen et al. 1995) on *Coregonus muksun* for the lower Yenisei River, from 1934 to 1943 (360–780 t year^{-1}), which is about twice the mean catch of the same species in the 1980s;
3. The backward extrapolation of the GOSNIORKH data, which yields for 1950 catch estimates three to four times higher than the mean of the 1980s; and
4. Vilchek et al. (1996), who indicated that pre-1950 catches would have been over hundred times the catches in the 1990s.

From these source, we assume that (3) would lead to an estimate for 1950 that is both realistic and conservative, and which can thus serve as an anchor point for interpolation between 1950 and 1980 (for Ob Bay) and up to 1991 for the other three tributaries. Indeed, we believe such values represent an underestimate of the earlier fisheries catch in the region. Under the Soviet regime, Siberia, including its coastal regions, experienced a series of population booms, beginning from 1929 via the dispatching of 'criminals' and, more often, political prisoners to camps, from 1942 onwards German prisoners of war, followed by the workers needed for massive industrialization projects in the region during the 1960s and 1970s (Table 1). With the collapse of the Soviet Union and the loss of subsidies from the central government, Siberia experienced a large emigration of non-indigenous populations through the 1990s with the total population of the Russian 'North' declining by more than 14% between 1989 and 2002 (Hill 2004). Given such changes in the local human population, catches from 1950 to 1980 could easily have exceeded our estimates. For the period after the last available data (i.e., 1995, Larsen et al. 1996), we assumed, optimistically, a decline of half the rate estimated for the earlier period.

Complementing the catches of whitefishes, we added small catches of other species, such as longnose Siberian sturgeon (*Acipenser baeri*) and smelt (*Osmerus mordax*) based on Larsen et al. (1996) and Ministry of Natural Resources (1998). Based on these source, we have estimated the historical catch of *A. baeri* in the Kara Sea to be 300 t year^{-1} from 1961 to 1967, 56 t year^{-1} following the closure of Ob Bay in 1968 and 31 t year^{-1} after 1994, the year of the last reported catch data. Furthermore, we estimated higher catches in the 1950s (500 t year^{-1}) to accommodate the reported catch from the Yenisei River in 1957 (Larsen et al. 1996). As for the catch estimates of *O. mordax*, much of which is caught for non-commercial personal consumption, hence not recorded in any statistics, we took the mean of two reported figures (1989: 516 t, 1991: 28 t, Larsen et al. 1996) as our estimates for all years except 1989 and 1991.

Laptev Sea LME

The Laptev Sea (Fig. 1) is a mostly shallow water body (Table 2) with a complex oceanography (Kosobokova et al. 1998; Thiede et al. 1999). It is frozen nearly year round, with an extremely short summer, during which some parts of the water become ice free as the coastal ice recedes, and into which several large rivers discharge immense quantities of freshwater. The fish fauna of the Laptev Sea is extremely impoverished, as it is remote from both the Barents Sea on the west and Bering Sea to the east (Pauly and Swartz 2007). While there is no commercial marine fishery operating in the Laptev and East Siberian Seas (JETRO 2004), small-scale fisheries yield at least 8,000 t annually (Newell 2004), mainly in the lower reaches of the Lena, Yana, Indigirka, and Kolyma Rivers. This catch estimate pertains to both the Laptev and East Siberian Seas, which we assumed to be distributed equally, or 4,000 t year^{-1} for each sea, based on the similar size of their Inshore Fishing Areas, defined as up to 50 km offshore or 200 m water depth, whichever comes first (Chuenpagdee et al. 2006).

Whitefishes form the bulk of the fishery, but detailed records are available only from the lower reaches of the Lena and Yana rivers, and from Khatanga Bay for the years 1981–1991 (Larsen et al. 1996). These data, amounting to about 3,000 t year^{-1} on average, do not show any consistent trend over time. Therefore, the mean catch of the first 3 years with data (1980–1982) was extrapolated backward to 1950, while the mean catch of the last 3 years with data (1989–1991) was extrapolated forward. There is no information available on catches of any other species. Larsen et al. (1996), however, estimate a range of 10–30% of reported whitefish catches for non-whitefish catches in Arctic Russia. We therefore applied the upper value of this range (30%) as our estimated catches of other fish, which when combined with our estimates of whitefish catches brings our total catch close to the total catch estimate of 4,000 t year^{-1} derived from Newell (2004).

East Siberian Sea LME

The East Siberian Sea (Fig. 1), like the Laptev Sea, is species poor due to its remoteness from the Barents and Bering Seas (Pauly and Swartz 2007). A few large rivers discharge into the East Siberian Sea, notably the Indigirka and Kolyma Rivers, and thus whitefishes are exploited by small-scale fisheries. However, pink (humpback) salmon (*Oncorhynchus gorbuscha*) and dolly warden (*Salvelinus malma*) occur in commercial quantities in rivers discharging into Chaun Inlet, but are threatened by overfishing (Newell 2004).

Data on catches used here are from Larsen et al. (1996), and the same assumptions were applied to their extrapolations as were applied for the Laptev Sea. An estimate of 30% was again assumed for the catches of non-whitefish fish, yielding, for the 1980s, an annual average catch of 3,087 t year^{-1}, a figure conservative with regard to the estimate of 4,000 t year^{-1} derived from Newell (2004). Unlike catches in the Kara Sea which underwent a decline, we expect a more stable yield in the East Siberian Sea, due to a larger share of indigenous inhabitants in the region, who are less inclined to emigrate following the collapse of local industries (Larsen et al. 1995).

Chukchi Sea LME

The Chukchi Sea, being adjacent to the Bering Sea (Fig. 1), includes a greater number of fish species than the East Siberian Sea, notably species that also occur in Arctic Alaska (Raymond 1988), for example the Arctic char, *Salvelinus alpinus*. There are no large river systems feeding into the Chukchi Sea; hence, GOSNIORKH does not report landings data (Brude et al. 1998). However, the area has a number of smaller rivers rich in anadromous salmonids. Given the absence of data, we estimated the catch from the Chukchi Sea as a 'Fermi solution' (von Baeyer 1993), i.e., by breaking down the problem at hand, and making informed guesses about each of the parts, whose errors are likely to cancel each other at the end.

The non-aboriginal population of the Chukotka Region, which borders the Chukchi Sea, is believed to be declining rapidly, while the overwhelming majority of the 17,000 aboriginal people appear to live in the southern parts of the region along the coast of the Bering Sea and the Sea of Okhotsk (Newell 2004). Therefore, we assumed conservatively that only 5% of the total population (or about 1,000 inhabitants) occupy the coast of the Chukchi Sea, and that this coastal population relies extensively on marine resources as a source of food. Hence, we assumed that each person along the Chukchi Sea consumes 100 kg of fish year^{-1}, resulting in an estimated catch of 100 t year^{-1}.

It is interesting to note that since the collapse of the Soviet Union, the region has attracted interest from the sportfishing industry in Alaska, and chartered trips have been organized targeting various Pacific salmon and Arctic char (Jenkins 1991), and their role in local fisheries is expected to grow. We assumed the catches made by these fisheries to be a small part of our estimate for the Chukchi Sea.

Canada and Alaska (USA)

Catches for Alaska and Canada consisted of community-based reconstructions. Time series estimates of commercial catches in Alaska were taken mainly from the 2004 and 2005 Annual Management Reports (Kohler et al. 2005; Banducci et al. 2007), with some additional catches being estimated (see 'Commercial fisheries data'). Estimates of Alaskan subsistence catches were taken from a variety of sources (e.g., Patterson 1974; Burch 1985) and were expanded to incorporate communities and years when no data were available (see 'Small-scale, non-commercial fisheries data').

Estimates of commercial marine fish catches in Canada, in round weight, were taken from reports prepared by Fisheries and Oceans Canada (DFO 1991, 1992a, b, 1993, 1994, 1995, 1996, 1997, 1999), while Canadian small-scale catches were based on reports detailing, by species, the number of fish taken (Anonymous 1979; Gamble 1988; Fabijian and Usher 2003; Priest and Usher 2004). Numbers by taxon were converted to round weight as described below (see 'Small-scale, non-commercial fisheries data'). Since the small-scale reports did not cover the entire time period, catch data were transformed into *per capita* catch rates (by community) and combined with human population data to form the basis of the estimates for years when 'hard' data were not available. This method of interpolation between anchor points of hard data to estimate fishery catches has also been used elsewhere (Zeller et al. 2006a, 2007).

Human population data

The Alaska Department of Commerce, Community and Economic Development maintains a database that provides population data for each community for the first year of every decade (www.dced.state.ak.us), as well as estimates for 2005 and 2006. To estimate the population for each community and year, linear interpolations were performed between years of reported data. For Point Lay (www.dced.state.ak.us did not report population for this community before 1980), we used Point Lay Biographies (Impact Assessment Inc. 1989) to estimate the population between 1950 and 1980. Total population for the 15 Alaskan arctic communities grew from approximately 3,550 in 1950 to 13,000 in 2000 at an average rate of 5.2% per year, before declining to about 12,650 in 2006.

Population data for the 51 Canadian communities were taken from the Canada Census undertaken every 5 years and were adjusted to only represent the indigenous population (Anonymous 1954, 1973, 1977, 1978, 1983a, b, 1996, 2001a). Both the 1996 and 2001 census provide estimates of indigenous population by community, with most communities having greater than 90% of the population being self-identified as indigenous. Therefore, for communities that had this profile, this percentage was assumed to stay constant in time back to 1950 and is likely an underestimate for earlier periods. For communities that had less than 90% of the population identified as indigenous in 1996 and 2001, the indigenous population was assumed to be 90% in 1950 and was scaled linearly to the percentage presented in the 1996 census. Since census data only provided 5-year snapshots of population numbers, linear interpolation was used between census years. However, due to apparent erratic reporting during the early census years, the derived population numbers for each community were interpolated between the 1951 and 1971 estimates. Canada's arctic population grew from around 8,000 in 1950 to 40,000 by the mid-2000s.

Commercial fisheries data

In Alaska, commercial fisheries in the arctic area as defined by FAO 18 occur only in Kotzebue Sound and the northern district of the Yukon-Northern area. This includes a fishery that mainly targets chum salmon (*Oncorhynchus keta*) in Kotzebue Sound, while another fishery in the Colville Delta targets Arctic cisco (*Coregonus autumnalis*) and other whitefishes. The commercial fishery in Kotzebue Sound is thought to have started in 1962 and the Colville River fishery commenced in 1967. The commercial fishery in Kotzebue Sound for chum salmon, along with incidental takes of Dolly varden (*Salvelinus malma*), other species of salmon and sheefish (*Stenodus leucichthys*), is reported by the commercial fisheries department within ADF&G. Recent and historical data for these species were taken from the 2004 and 2005 Annual Management Reports (Kohler et al. 2005; Banducci et al. 2007). For the period 1974–1976 and for 1981, unreported catches of Dolly varden were estimated using the respective average decadal catches. The Annual Management Reports detail the catch in numbers of individuals taken and average weights that were used to convert numbers of fish to round weight. A time series average for weight was used to estimate the weight of the catch in years when the report did not detail average weights. Arctic cisco (*Coregonus autumnalis*) taken in the Colville River fishery were assigned an average weight of 0.45 kg (Daigneault and Reiser 2007). Data for the commercial fishery that targets Arctic cisco and other whitefish in estuarine waters of the Colville River were supplied by S. Murphy (ABR, Inc. P.O. Box 80410, Fairbanks, Alaska 99708-0410, pers. comm.).

Although official documents report the commercial fishery in Kotzebue Sound as starting in 1962, there were local informal 'commercial' fisheries taking place prior to this, consisting of local fishers selling their catch as dog feed to people who ran dog-sled teams, the transportation link prior to the introduction of the snowmobile (C. Lean, Norton Sound Fisheries Research and Development Director, P.O. Box 358, Nome, Alaska, 99762, pers. comm.). Similarly, Stefanich (1973) reported that commercial fisheries taking place in the Colville River prior to 1967 were taking approximately 64,000 specimen of whitefish and Arctic ciscos each year, and Wilimovsky (1956) estimated that about 4,500 kg of whitefish were taken in one instance in 1952. Thus, we estimated unreported catches for these two commercial fisheries back to 1950, i.e., prior to their official reporting by ADF&G.

Finally, there was also a Japanese Distant Water Fleet fishery reported in the Chukchi Sea in 1966 and 1967 (Anonymous 1967, 1968), with most catches being between 66°–67° N and 166°–169° W, an area largely within the present-day boundaries of the US Exclusive Economic Zone. Catches were similar to those for Kotzebue Sound, and thus, this fishery may have been intercepting large numbers of Kotzebue area chum salmon.

Canadian commercial catches of marine fishes taken in the arctic region have been reviewed by Crawford (1989) and Yaremchuk et al. (1989), as well as in a series of publications by Fisheries and Oceans Canada (DFO 1991, 1992a, b, 1993, 1994, 1995, 1996, 1997, 1999). Both Crawford (1989) and Yaremchuk et al. (1989) report on commercial catches taken from both marine and freshwater areas in the Northwest Territories, and the two studies overlap in area and time. The work by Yaremchuk et al. (1989) was more detailed than Crawford (1989) and hence was primarily considered here. The data supplied in Yaremchuk et al. (1989) and the publications by Fisheries and Oceans Canada were geo-referenced using Google Earth, and capture locations were considered to be in marine waters if they were located in ocean or estuarine areas. Commercial fisheries in the Canadian Arctic started in the late 1950s (Yaremchuk et al. 1989). Between 1960 and 1996, 26 communities were known to have commercial marine fisheries. For the period after 1996, the commercial catch data represent a 5-year average from the 1992–1996 Fisheries and Oceans Canada reports. No commercial marine catches for the Canadian coastal communities located in the Hudson Bay area have been estimated, as the majority of commercial fisheries based in these areas are freshwater (Kierans 2001).

Small-scale, non-commercial fisheries data

For Alaska, we defined small-scale fisheries as catches not destined for commercial markets. Alaskan small-scale fisheries catch data came from a variety of reports that are spatially and temporally intermittent (Table 3) and formed the basis for data anchor points (sensu Zeller et al. 2007). Early studies (e.g., Patterson 1974) quantified fisheries catches for several communities representing an average annual catch of important species. The state of Alaska, through its Community Profiles Database (www.subsistence.adfg.state.ak.us), maintains a database on subsistence fish and wildlife catches that includes fisheries data for eleven of the fifteen communities, with most information derived from household surveys. Other studies mostly focus on a given community in a given year or time period. Subsistence catches in Alaska are often reported in terms of edible weight. If the edible weight to round weight conversion factors were not given, a standard conversion factor of 1.3 was used (i.e., round weight * 0.75 = edible weight, Anonymous 2001b). The data sources used to derive estimates of small-scale, non-commercial catches also indicated that the reported catch totals incorporated catches used for dog feed (see below). For years and communities with no reported data, several interpolation methods were used, most commonly via per capita rates, or average catch rates. The detailed application of each method for catches by community is presented in Zeller and Booth (2008).

For Canada, fish were considered to be part of the small-scale fishery if the fish were used in the fisher's community or entered into inter-settlement trade, but fish were not considered part of the small-scale fishery if the fish were for commercial sale. Canadian small-scale catch data used here come from four studies (Anonymous 1979; Gamble 1988; Fabijian and Usher 2003; Priest and Usher 2004). The earliest report, related to the James Bay and Northern Quebec land claims agreement (Anonymous 1979), permitted estimation of marine fish catches for the period 1974–1976. The second study by Gamble (1988) reported data on small-scale fisheries between 1982 and 1985 for several communities in the Keewatin region, now part of Nunavut Territory. The last two studies relate to the 10-year (1988–1997) Inuvialuit Harvest Study (IHS, Fabijian and Usher 2003) and the 5-year (1996–2001) Nunavut Wildlife Harvest Study

Table 3 Sources used and year(s) sources were applied to construct data anchor points for small-scale fisheries catches for 15 communities in Arctic Alaska

Community	Source: Year(s)
Atqasuk	Craig (1987): 1983; Anonymous (2005): 1994
Barrow	Patterson (1974): 1971; Anonymous (2001b): 1987–1989
Buckland	Raleigh (1957) in Mattson (1962): 1957; Anonymous (1967): 1967; Anonymous (1968): 1968; Moore (1979): 1972; Banducci et al. (2007): 1970–1975, 1979, 1981; Mason et al. (2007): 2003
Deering	Raleigh (1957) in Mattson (1962): 1957; Patterson (1974): 1972; Sobelman (1984): 1974–1975; Magdanz and Utermohle (1994)), Anonymous (2001b), Kohler et al. (2005): 1994; Banducci et al. (2007): 1965–1977, 1979, 1981–1985
Kaktovik	Patterson (1974): 1971; Anonymous (2001b): 1985–1986, 1992; Pedersen and Alfred (2005): 2001–2002
Kivalina	Raleigh (1957) in Smith et al. (1966): 1957; Saario (1959) in Burch (1985): 1959; Saario and Kessel (1966): 1959–1960; Patterson (1974): 1972; Burch (1985): 1964–1965, 1982–1983; Anonymous (2001b): 1992; Kohler et al. (2005): 1981–1984; Banducci et al. (2007): 1968–1972, 1979, 1981–1982, 1984–1986
Kotzebue	Raleigh (1957) in Smith et al. (1966): 1957; Anonymous (1967): 1967; Anonymous (1968): 1968; Patterson (1974): 1972; Georgette and Loon (1993): 1986; Anonymous (2001b): 1991; Eggers and Clark (2006): 1962–2004
Noatak	Raleigh (1957) in Mattson (1962): 1957; Anonymous (1968): 1968; Patterson (1974): 1972; Georgette and Utermohle (2000): 1999; Georgette and Utermohle (2001): 2000; Anonymous (2001b): 1994; Georgette et al. (2003): 2002; Banducci et al. (2007): 1969–1971, 1973–1984, 1986–1987, 1989–1993, 1995–1998, 2000–2004
Nuiqsut	Anonymous (2001b): 1985, 1993
Point Hope	Raleigh (1957) in Smith et al. (1966): 1956; Raleigh (1957) in Mattson (1962): 1957; Foote and Williamson (1966): 1959–1960; Patterson (1974): 1971
Point Lay	Anonymous (2001b): 1987
Selawik	Anonymous (1967): 1967; Anonymous (1968): 1968; Patterson (1974): 1972
Shishmaref	Raleigh (1957) in Mattson (1962): 1957; Patterson (1974): 1973; Conger and Magdanz (1990): 1989; Anonymous (2001b): 1995; Banducci et al. (2007): 1967–1968, 1971–1972, 1974–1975, 1995
Wainwright	Patterson (1974): 1971; Anonymous (2001b): 1988–1989
Wales	Raleigh (1957) in Mattson (1962): 1957; Patterson (1974): 1973; Magdanz and Utermohle (1994): 1994; Anonymous (2001b): 1993

(NWHS, Priest and Usher 2004), which examined the basic needs of the Inuit as part of land claims agreements. Data collected in these reports were based on hunters' accounts of their monthly catch, with the term 'hunter' referring to hunters, fishers, and collectors. The data reported by fishers were converted into wet weight using reported average weight and conversion factors (Table 4).

Once all reported catches were converted to wet (round) weight, the data were transformed into per capita rates (kg $person^{-1}$ $year^{-1}$) using the estimated human population of that year for the specified community of each study. Thus, for each year and community represented in one of the four studies, a *per capita fish use rate* was determined, forming the best data anchor points available.

Dog feed

To account for life-style changes of the Canadian and Alaskan arctic communities from the 1950s to the present, an additional time series was derived to account for the amount of fish that was used for feeding sled-dog teams. Sled-dog use declined substantially with the introduction and increasing use of fuel-powered snow-mobiles starting in the 1960s (Usher 1972, 2002).

In Alaska, we assumed that for Kotzebue, the snowmobile was introduced in 1963 and for all other communities in 1965 (Hall 1971). Fish were one of the main sources of feed for the dog teams, and Zeller and Booth (2008) describe the details of how the sled-dog feed

Table 4 Edible weight (kg) and edible to round (wet) weight conversion factors used to transform reported numbers of fish to round (wet) weight (kg) for Canadian arctic small-scale fisheries catches

Scientific name[a]	Common name	Edible weight (kg)	Source	Conversion factor	Source
Anonymous (1979)					
Salvelinus alpinus	Charr	4.500	Anonymous (1979)	1.4375	Usher (2000)
Boreogadus saida	Cod	2.500	Anonymous (1979)	1.4375	Usher (2000)[b]
Salmo sala	Salmon	8.500	Anonymous (1979)	1.4375	Usher (2000)[b]
Triglopsis quadricornis	Sculpin	0.500	Anonymous (1979)	1.2000	Usher (2000)[b]
Gamble (1988)					
Boreogadus saida	Arctic cod	0.225	www.fishbase.org	1.0000	NA
Salvelinus alpinus	Charr	2.500	Gamble (1988)	1.4375	Usher (2000)
Triglopsis quadricornis	Sculpin	0.175	www.fishbase.org	1.0000	NA
Fabijian and Usher (2003)					
Coregonus autumnalis	Arctic cisco	0.450	www.fishbase.org	1.4444	Usher (2000)
Boreogadus saida	Arctic cod	0.225	www.fishbase.org	1.0000	NA
Coregonus nasus	Broad whitefish	1.650	Usher (2000)	1.2121	Usher (2000)
Salvelinus alpinus	Charr (Aklavik)	0.900	Usher (2000)	1.3846	Usher (2000)
Salvelinus alpinus	Charr (Holman)	2.200	Usher (2000)	1.4194	Usher (2000)
Salvelinus alpinus	Charr (Paulatuk)	2.300	Usher (2000)	1.4375	Usher (2000)
Salvelinus alpinus	Charr (Sachs Harbour)	1.000	Usher (2000)	1.4286	Usher (2000)
Salvelinus malma malma	Dolly varden	0.650	Usher (2000)	1.3846	Usher (2000)
Platichthys stellatus	Flounder	0.500	M. Treble, pers. comm.[c]	1.0000	NA
Triglopsis quadricornis	Fourhorn sculpin	0.175	www.fishbase.org	1.0000	NA
Stenodus leucichthys	Inconnu	2.550	Usher (2000)	1.3333	Usher (2000)
Clupea pallasi pallasi	Pacific herring	0.200	Usher (2000)	1.5000	Usher (2000)
Eleginus gracilis	Saffron cod	0.364	www.fishbase.org	1.0000	NA
Priest and Usher (2004)					
Salvelinus alpinus	Charr	2.500	Gamble (1988)	1.4375	Usher (2000)
Coregonus autumnalis	Arctic cisco	0.450	Usher (2000)	1.4444	Usher (2000)
Boreogadus saida	Cod	0.872	www.fishbase.org	1.0000	NA
Stenodus leucichthys	Inconnu	2.550	Usher (2000)	1.3333	Usher (2000)
Coregonus sardinella	Least cisco	0.200	www.fishbase.org	1.0000	NA
Triglopsis quadricornis	Sculpin	0.175	www.fishbase.org	1.0000	NA

[a] Most likely or most common species name was applied

[b] Specific conversion factors were not available, and the closest conversion factor in Usher (2000) was used

[c] M. Treble, Fisheries and Oceans Canada, Winnipeg, MB, R3T 2N6, Canada

component of total catches was estimated. We separated communities into two groups: those that heavily relied on fish as a primary community protein source, and those who did not. In summary, we identified six of the 15 communities (Table 5) as being more reliant on fish as a general protein source for the community, with over 20% of the overall community protein intake sourced from fish (Patterson 1974). We grouped two other communities (Atqasuk and Nuiqsut) that were established in the mid-1970s with these six communities because they were founded as 'traditional' communities, including reliance on fish and wildlife. For 1957, the number of dogs was given in Mattson (1962) for five of the six communities (we estimated the number of dogs for the sixth community, Selawik), and a feeding rate of 1.8 kg dog^{-1} day^{-1} (C. Lean, Norton Sound Fisheries Research and Development Director, Nome, Alaska, pers. com.) was used over a 6 months per year period (fish being fed mainly during winter times, Abrahamson 1968) to establish anchor points for 1957 for total fish catch used for dog feed. We carried this amount unaltered backwards to 1950 and forward to the start year of snowmobile introduction (1963 or 1965). Patterson (1974) estimates the number of dogs and the amount of fish used as dog feed in the early 1970s for the region containing these communities (Table 5). Thus, we linearly scaled the amount of fish used for dog feed in each community from 1963 (or 1965) to the anchor points established in the early 1970s for each community based on Patterson (1974). For the period after the early 1970s, the only information available for these communities regarding the amount of fish used for dog feed was for Noatak. In Noatak, the amount of fish used for dog feed as a percentage of total catch declined from 29% in 1972 to 6% and 3% in 1999 and 2000, respectively (Georgette and Utermohle 2000, 2001). We assumed that the other communities behaved similarly (Table 5). For the 2000s, we retained the estimate of 3% (Georgette and Utermohle 2001). For the regional center of Kotzebue, local data were available for 1986 (Georgette and Loon 1993), and we kept that percentage constant to the end of the time series. For Atqasuk and Nuiqsut, founded in the mid-1970s, we applied the equivalent times series average as derived above. For the other seven communities (Barrow, Kaktovik, Point Hope, Point Lay, Shishmaref, Wainwright, and Wales) that had less than 15% of their protein sourced from fish (Patterson 1974), we assumed conservatively that the amount of fish used for dog feed was negligible given the relatively low catches of fish and the higher reliance by these communities on terrestrial wildlife and marine mammals for food.

In Canada, sled-dogs also formed the primary mode of transportation for Inuit into the late 1960s, but snowmobiles led to a rapid decline in sled-dog teams, with their virtual disappearance as working dog teams by the mid-1970s. Usher (2002) and Jessop (1974 in Usher 2002) present data and information that were used to estimate fish catches used for dog feed. Details of the methods used are described in Booth and Watts (2007). In summary, the sled-dog feed component of per capita seafood use rates was set at 3 times the derived 1960 human component of the per capita use rates (3:1 ratio reported by Usher 2002) and was carried back unaltered to 1950. Going forward in time, the 1960 rate was scaled linearly to zero in 1975 for communities that are largely Inuit. For the mixed population communities along the southern portion of Hudson and James Bay, no sled-dog feed component was estimated.

Results

The reconstructed Alaskan and Canadian catches by community were assigned to Large Marine Ecosystems located

Table 5 Sources used to determine the amount of marine fish used for sled-dog feed in Arctic Alaska communities that are highly reliant on fish as a protein source (over 20%)

Community	1950s	1960s	1970s	1980s	1990s	2000s
Buckland	Mattson (1962)	–	Patterson (1974)	–	Georgette and Utermohle (2000)	Georgette and Utermohle (2001)
Deering	Mattson (1962)	–	Patterson (1974)	–	Georgette and Utermohle (2000)	Georgette and Utermohle (2001)
Kivalina	Mattson (1962)	–	Patterson (1974)	–	Georgette and Utermohle (2000)	Georgette and Utermohle (2001)
Kotzebue	Mattson (1962)	–	Patterson (1974)	Georgette and Loon (1993)	Fixed percentage	Fixed percentage
Noatak	Mattson (1962)	–	Patterson (1974)	–	Georgette and Utermohle (2000)	Georgette and Utermohle (2001)
Selawik	Mattson (1962)[a]	–	Patterson (1974)[a]	–	Georgette and Utermohle (2000)	Georgette and Utermohle (2001)
Atqasuk	NA	NA	Patterson (1974)[b]	–	Georgette and Utermohle (2000)	Georgette and Utermohle (2001)
Nuiqsut	NA	NA	Patterson (1974)[b]	–	Georgette and Utermohle (2000)	Georgette and Utermohle (2001)

Dashes (–) indicate interpolated data

[a] Number of dogs estimated, see Booth and Zeller (2008)

[b] Average percentage of fish used for dog feed (based on previous six communities) applied to the year of community establishment

in US and Canadian FAO 18 waters (Fig. 1), based on the location of each community with respect to LME boundaries, and combined with the Russian data estimated by LME. Thus, we present all our catch estimates by LME, moving eastward from the Kara Sea and ending with the Hudson Bay LME (Fig. 1). Where appropriate (e.g., for Chukchi Sea and Beaufort Sea), we also present estimates by country.

Kara Sea LME (Russia)

The reconstruction of total marine fisheries catches in the Kara Sea LME suggested a decline in catches from around 15,000 t year^{-1} in 1950 to less then 700 t year^{-1} by 2004 (Fig. 2a). The large range in potential catch volume for the early 1950s (Fig. 2a), based on the different data sources as described in "Materials and methods", indicates potential catch volumes ranging from around 8,000 to 150,000 t, suggesting our value of 15,000 t errs on the side of caution. Catches were dominated by whitefishes, mainly *Coregonus sardinella* (6,200–50 t year^{-1}), *C. mulksun* (2,200–110 t year^{-1}), and *C. lavaretus* (1,900–130 t year^{-1}, Fig. 2a). Catches of the slow growing and long-lived Siberian sturgeon, *Acipenser baeri*, while never as large as any of the whitefishes, declined most distinctly, especially in the late 1960s (Fig. 2a).

Laptev Sea LME (Russia)

Due to the very limited data, total catches taken in the Laptev Sea LME appear to have remained fairly flat, with around 3,700 t year^{-1} in 1950 and 3,500 t year^{-1} in 2004, with the only variation shown due to the data anchor point years in the 1980s, when catches peaked at 4,300 t year^{-1} (Fig. 2b). Catches were dominated by whitefishes, mainly *Coregonus sardinella* (around 1,100 t year^{-1}) and *C. autumnalis* (around 500–800 t year^{-1}, Fig. 2b).

East Siberian LME (Russia)

The East Siberian Sea LME seems to be the only area in Russia that appears to have higher catches in the present than in the past (Fig. 2c). Based on the available data, it would suggest that total catches increased from 2,200 t year^{-1} during the 1950 to 1980 period to around 3,600 t year^{-1} in the 2000s (Fig. 2c). Total catches peaked in 1986 at around 4,300 t year^{-1}. Catches were dominated by *Coregonus sardinella*, increasing from around 800 t year^{-1} in 1950 to 1,600 t year^{-1} by 2004. In contrast, catches of *C. autumnalis*, being the second highest in 1950 (around 350 t year^{-1}), declined to around 260 t year^{-1} by 2004 (Fig. 2c). On the other hand, catches of *Coregonus nasus* increased from around 200 t year^{-1} in 1950 to 400 t year^{-1} by 2004.

Chukchi Sea LME (Russia and USA)

Russia

Given the complete lack of data on marine fisheries in the Russian part of the Chukchi Sea LME, a fixed estimate of 100 t year^{-1} for subsistence purposes was derived (Fig. 2d). This catch is non-specific in terms of taxonomic assignment, but may consist of whitefishes as well as other taxa, including other salmonids.

Alaska (USA)

Fisheries catches in the Alaskan part of the Chukchi Sea LME, both commercial and subsistence, varied substantially over the years, driven largely by considerable interannual variation in the catches of *Oncorhynchus keta* (chum salmon), which dominates commercial catches (Fig. 2d). Total catches in the Alaskan part of this LME peaked at just under 3,500 t year^{-1} in 1980, with average catches between 1,500 and 2,000 t year^{-1}. Other taxa contributing significantly to total catches are *Stenodus leucichthys* (inconnu), whitefishes and *Salvelinus malma* (Dolly varden), accounting for around 100–300 t year^{-1} each (Fig. 2d).

Beaufort Sea LME (USA and Canada)

Overall, catches in the Beaufort Sea LME peaked at around 280 t year^{-1} in 1960, before declining to around 90 t year^{-1} by the mid-2000s (Fig. 2e). Early catches were dominated by Canada, while more recently, people from both Canada and the USA seem to catch approximately the same amount of fish. The high catches taken by Canada in the first 2½ decades were mainly for dog feed (see below).

Alaska (USA)

Alaskan catches in the Beaufort Sea increased from just over 30 t year^{-1} in 1950 to a peak of just under 80 t year^{-1} in the early 1990s, before declining to around 40 t year^{-1} in recent years (Fig. 2f). Catches were dominated by *Coregonus autumnalis*, which declined from catches in the earlier periods of around 20–25 t year^{-1} to around 5 t year^{-1} by 2006, while *C. nasus* increased in importance to account for around 25 t year^{-1} in recent years. Catches of *Salvelinus malma* remained relatively steady at around 4–5 t year^{-1} (Fig. 2f).

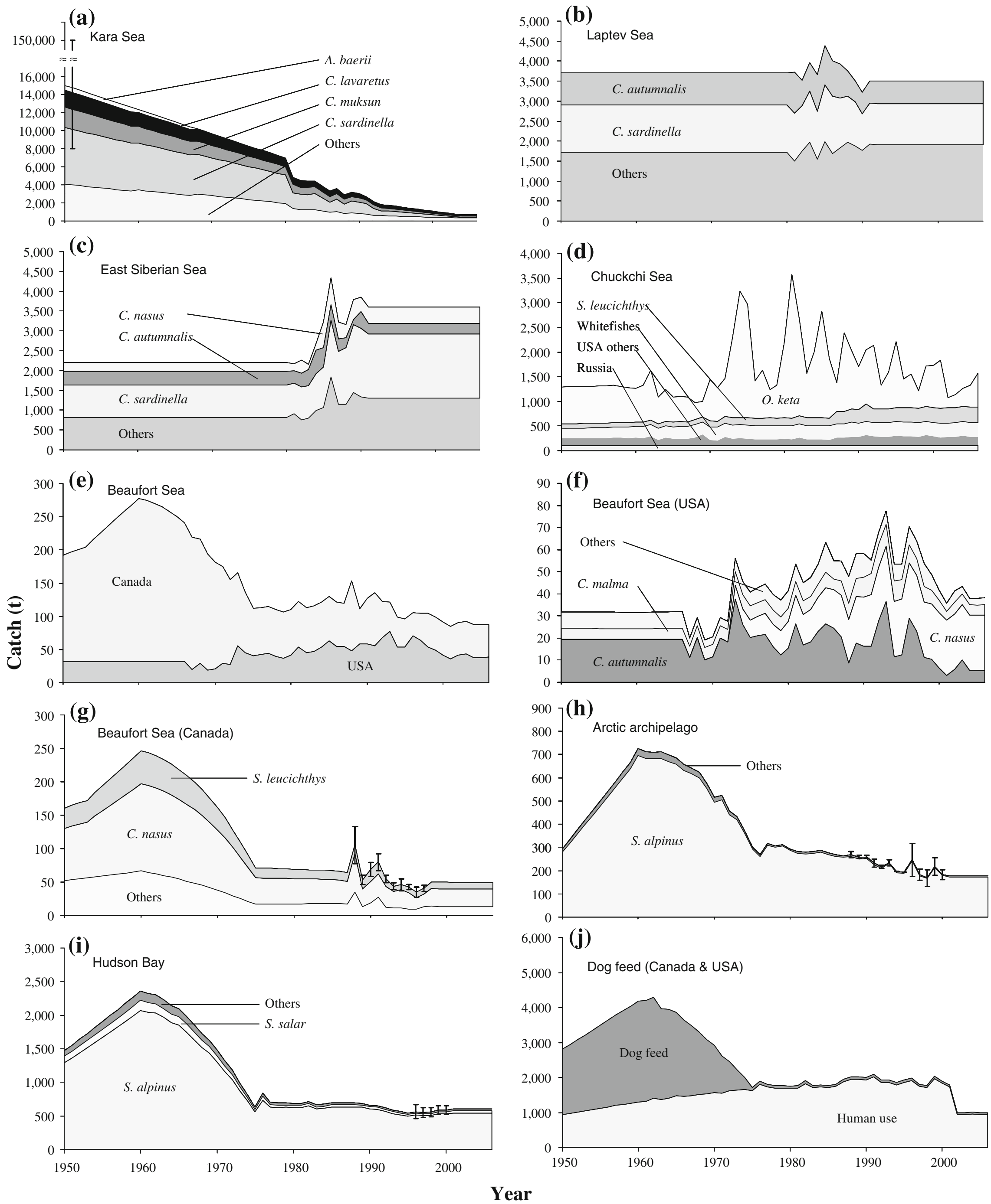

Fig. 2 Reconstructed arctic fisheries catches from 1950 to 2006 presented for the major taxa by **a–i** Large Marine Ecosystems and **j** dog feed versus human use. Ranges are included where the underlying data permitted estimation of likely levels of uncertainty

Canada

Canadian catches in the Beaufort Sea peaked at around 250 t year^{-1} in 1961 before declining to around 50 t year^{-1} in recent years. Catches were also dominated by whitefishes, mainly *C. nasus* (peaking at 130 t year^{-1} in the early 1960s), while sheefish (*Stenodus leucichthys*) was the second most important component (Fig. 2g).

Arctic Archipelago LME (Canada)

Patterns of catches taken by the Canadian indigenous populations in the Arctic Archipelago LME follows the same general pattern found in the Beaufort Sea, with a peak in the early 1960s of over 700 t year^{-1} (Fig. 2h), driven by fish caught for dog feed (see below). Total catches declined to around 200 t year^{-1} in recent years (Fig. 2h). In contrast to previously presented LMEs, catches in the Arctic Archipelago were dominated by the arctic charr (*Salvelinus alpinus*), which accounted for over 95% of total catches (Fig. 2h).

Hudson Bay LME (Canada)

Catches in the Hudson Bay LME peaked at 2,300 t year^{-1} in the early 1960s (driven largely by dog feed, see below), before declining to around 600 t year^{-1} in recent years (Fig. 2i). Similar to the Arctic Archipelago, catches were dominated by arctic charr (*S. alpinus*), accounting for 88% to total catches, while Atlantic salmon (*Salmo salar*) contributed smaller components (Fig. 2i).

US and Canadian dog feed component

The catch reconstruction for Canada and, to a smaller extent, Alaska documented considerable amounts of fish being caught in the earlier decades for the sole purpose of feed for working sled-dog teams. Excluding the purely commercial fisheries for chum salmon in Alaska, this suggested that until the mid-1970s, fish catches for dog feed dominated total catches in the US-Canadian Arctic (around 60–70%), accounting for 1,900 t year^{-1} in 1950, peaking at over 2,800 t year^{-1} in 1960 before declining to around 50–70 t year^{-1} by the mid-1970s (Fig. 2j). This decline was driven by the replacement of working dog teams with fuel-powered snowmobiles and the increasing reliance on industrial dog feed flown in from southern areas for much of the remaining dogs.

Total Amerasian Arctic catches

The total reconstructed catches for the seven Large Marine Ecosystems comprising the near-shore waters of the Amerasian Arctic have declined considerably over the last 50+ years, from slightly over 24,000 t year^{-1} in 1950 to around 10,000 t year^{-1} in recent years (Fig. 3a). In contrast, the data officially reported by the three countries to the global community via FAO suggest that fisheries catches were zero in the Arctic region, with the exception of 4 years of reported catches in the late 1960s, all of which were reported for the former Soviet Union (Fig. 3a, Table 6). Thus, neither the USA nor Canada formally reports any catches for their arctic waters. Overall, estimated total catches taken in Russian waters far outweighed catches taken in the waters of the other two arctic countries considered here, with Russian catches accounting for between 70 and 89% of total reconstructed catches for the Amerasian Arctic (Fig. 3b).

Given that Canada has the largest Inshore Fishing Area (IFA) in the arctic region considered here (Table 2), much of which is uninhabited, it is not surprising that Canadian catch rates per IFA were the lowest, declining from around 1.4 kg km^{-2} in the 1950s to 0.5 kg km^{-2} for the 2000s (Table 7). The values for US waters were higher, but the highest values were from Russian waters, and Russian LMEs, which had the highest area catch rates, although

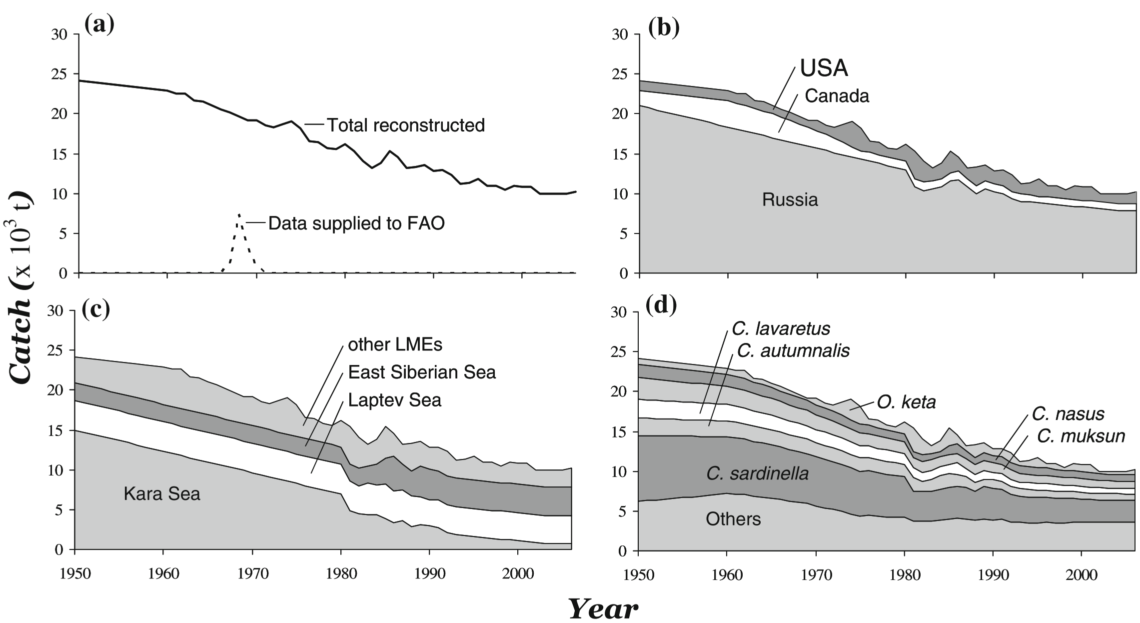

Fig. 3 Fisheries catches in the Amerasian arctic, showing **a** reconstructed total catches versus catches reported to FAO; **b** reconstructed total catches by the three countries covered by FAO Statistical Area 18 (Russia, USA, Canada); **c** reconstructed total catches by the seven near-shore Large Marine Ecosystems comprising FAO 18; and **d** reconstructed total catches by major taxa

Table 6 Landings data (t) reported by FAO for Area 18 on behalf of former Soviet Union, for the period 1950–2006

Reported taxa	Year[a]				Total
	1967	1968	1969	1970	
Greenland halibut (*Reinhardtius hippoglossoides*)	100	1,400	800	200	2,500
Roundnose grenadier (*Coryphaenoides rupestris*)	1,100	5,900	2,600	500	10,100
Miscellaneous marine fish	–	–	–	100	100
Total	1,200	7,300	3,400	800	12,700

[a] Only the 4 years included here had non-zero landings. Russia reported some additional catches for later years not covered here (2007 and 2008) of around 480 t

they declined from around 20.3 kg km^{-2} in the 1950s to 8.3 kg km^{-2} in the 2000s (Table 7). However, even the highest value, from the Kara Sea LME in 1950 (29.2 kg km^{-2}), corresponds to only 1% of the mean catch per area in the tropics (Table 7), which should suffice to highlight the huge difference in productivity between these fisheries systems (see also Ursin 1984).

With regard to catches by Large Marine Ecosystem, most catches over time were taken in the Kara Sea, followed by the Laptev Sea and the East Siberian Sea LME (Fig. 3c). These three LMEs accounted for 80% of total reconstructed catches for the Amerasian Arctic and also had the highest IFA catch rates (Table 7).

Table 7 Reconstructed total arctic catch rates per Inshore Fishing Area (IFA) in FAO Area 18 (by country and Large Marine Ecosystem), and, for comparison, in other parts of the world

	Catch rate (kg km^{-2})	
	1950	2000
Country		
Russia	20.3	8.3
USA	8.8	9.7
Canada	1.4	0.5
LME		
Kara Sea	29.2	1.8
Laptev Sea	16.9	15.9
East Siberian Sea	10.0	16.4
Chukchi Sea	8.7	9.5
Beaufort Sea	2.9	1.2
Arctic Archipelago	0.5	0.2
Hudson Bay	2.3	0.7
Non-arctic areas		
High HDI countries[a]	–	770.0
Low HDI countries[a]	–	2930.0

Inshore Fishing Area is defined as the area of ocean that is within 50 km from shore or 200 m depth, whichever comes first (Chuenpagdee et al. 2006)

[a] HDI refers to 'Human Development Index', which tends to be low in tropical countries and high in countries with temperate climate (from Chuenpagdee et al. 2006)

As expected, the reconstructed catches show the largest inter-annual variation in catches in the commercial catches of chum salmon (*Oncorhynchus keta*) taken by US fishers in US waters (Fig. 3d), which is due to these data being reported on an annual basis within the state of Alaska, but not by the US federal government and, by extension, not by FAO. Overall, however, the largest catches were those of whitefishes, with five species (*Coregonus sardinella*, *C. muksun*, *C. autumnalis*, *C. nasus*, and *C. lavaretus*) accounting for over 65% of reconstructed total catches over the 50+ year time period (Fig. 3d).

Discussion

Cumulative fisheries catches for the Amerasian Arctic (i.e., FAO Statistical Area 18) for the period 1950–2006 have been officially reported as 12,700 t, by Russia (former Soviet Union), while no catches have been reported by USA or Canada. This compares with our reconstructed total catches of over 950,000 t, being 770,000 t by Russia, 89,000 t by USA, and 94,000 t by Canada. Thus, likely total catches for 1950–2006 appear to be 75 times higher than reported data would suggest. With regard to individual LMEs, over 80% of total catches were taken in three exclusively Russian LMEs (Kara Sea, Laptev Sea, and East Siberian Sea LME), illustrating a marked reliance of the relatively large local population on coastal marine resources, especially in the 1950s and 1960s.

While the human population in the Arctic is not very large overall and has declined in some areas (e.g., Siberia), marine fish resources form an important part of food security as well as cultural and customary significance (Usher 2002). Overall, catches per Inshore Fishing Area (ranging from 0.2 to 29.2 kg km^{-2}) are very low, compared to other areas of the world with heavy reliance on subsistence fishing, such as tropical developing countries (Table 7). This suggests that removal of fish due to fishing has been relatively low in many parts of the Arctic, compared to the consumption by marine mammals and birds. Hence, many fish stocks in arctic coastal waters could still be relatively pristine. A likely exception to this might be some anadromous stocks that might have suffered from human-induced habitat changes (river obstructions due to the extensive hydroelectric developments in many Siberian rivers) and pollution due to heavy industrialization in many parts of southern and central Siberia. Given the likely increasing pressures by commercial fisheries activities on arctic marine environments, driven by increased accessibility of arctic areas due to climate change, it is important to place future decisions in the context of best information about past fishing activities. The present study assists in this process by providing best estimates of likely total marine (and estuarine) fish catches in FAO Area 18. Given the importance of, and increased management reliance on, ecosystem-based considerations, such information needs to be considered in the context of LMEs, currently the best descriptor of large-scale ecosystem patterns (Pauly et al. 2008; Sherman and Hempel 2008).

Levels of uncertainty around our estimates may be large. However, the large range of potential catch values for the Kara Sea LME for the early 1950s (8,000–150,000 t, Fig. 2a) illustrates that the value of 15,000 t we utilized remains relatively conservative. In contrast, the high upper bounds (150,000 t, Fig. 2a) suggest that catches in the earlier times may have been substantially higher than suggested here. Since the catches from the Kara Sea LME dominate total arctic catches (Fig. 3), our overall total arctic catch estimations are also likely to be conservative.

While the presently described taxonomic patterns of catches (although rather broad) resemble historic taxonomic distributions, there will likely be considerable changes ahead in terms of taxonomic composition (Cheung et al. 2009), and hence ecosystem patterns and functions, as well as fisheries potentials (Cheung et al. 2010) due to climate change. Whereas in the past, changes in catches were largely driven by socioeconomic changes (such as the demise of sled-dog teams), future changes in catches could be influenced by other factors, including changes in fishing patterns driven by human use patterns, changes in the state of stocks, and changes in the composition of fish populations due to species invasions from southern waters. Thus, the changing face of the Arctic urgently calls for more baseline studies of small-scale and artisanal fisheries.

Russia

Our estimates of catches in Russian arctic waters (FAO 18) are meant to provide an alternative to unrepresentative data supplied by Russia to FAO, as summarized in Table 6, and which pertain to species usually caught by industrial trawlers, not likely to operate regularly (at this time) in any of the ecosystems reported upon here. Trawl catches are also incompatible with the information in a report by the Russian Government (Ministry of Natural Resources 1998):

"*Commercial fishing in the Kara and eastern Arctic seas is not viable. The largest amount of bioresources (mainly semi-migratory fish of the sig family: muksun, pelyad, sig, ryapushka, and omul) are produced in the pre-mouth zones of the Ob and Yenisey Rivers. Along other areas of the coast, fish resources are small (Yakutia, Chukotka) and fishing is only for the subsistence needs of the local population.*"

Much of the information used here for Russia is based on data and inference that are highly uncertain. However, the overall catch level may be within the right ballpark—at least more so than the data presently supplied by Russia to FAO, which reports a catch over 60 times lower than reported here. Our data are also supported by earlier reports on Russian Arctic catches. One published source to compare our uncertain information on Russian Arctic landings is a detailed monograph dedicated to commercial fishes of the pre-WWII USSR (Berg et al. 1949). This monograph summarizes known ecological information and some catch data (documented catches in the sea and estuaries of the most important rivers) for commercial species between 1930 and 1941. For the species of interest here (mainly whitefishes), most of the catch statistics are given for either 1936–1939 or 1939–1941, with 1939 being the year with most complete coverage. Generally, these are commercial catches, but occasionally catches are commercial and subsistence. The total catch in the Russian Arctic reported for 1939 in Berg et al. (1949) is 23,481 t year^{-1}. This value compares well with the 1950 Russian catch reconstructed here (21,000 t year^{-1}, Fig. 3b) using other sources of information.

Another concern is the distinction between marine, brackishwater, and freshwater catches. We are aware that by relying heavily on the reported catches of anadromous whitefishes in our estimates, we have included significant, and, for our purpose, unwanted freshwater catches (although we have omitted catches of *Coregonus peled*, an exclusively freshwater species). Nonetheless, we believe that such a potential overestimate in the catches of anadromous species is compensated for, at least in part, by unreported small-scale fisheries for marine species in larger estuaries. Indeed, it is more or less universal for small-scale subsistence fisheries to be overlooked in governments' statistical systems (Pauly 2006; Zeller et al. 2007).

Siberia suffers to an extreme extent from various forms of industrial pollution, the result of decades of ruthless attempts to extract natural resources from the area without environmental safeguards (Vilchek et al. 1996; Newell 2004; Gordeev et al. 2006). Thus, it would be tempting to attribute the decline of catches observed during the period for which there are data solely to pollution, as is believed to be the case for the whitefish fisheries in the White Sea (Ministry of Natural Resources 1998), and generally for the Russian Arctic (Vilchek et al. 1996). Yet, massive demographic changes have occurred during this period, as ethnic Russians that immigrated into the region during the Soviet era are leaving following the collapse of the Soviet regime. Those who remain are predominantly indigenous peoples, with few options but to (re-)turn to small-scale subsistence fishing.

USA (Alaska)

The data presented here are estimates of fisheries catches for predominantly anadromous species by the 15 coastal communities in Arctic Alaska. Although the Alaskan state agency, the ADF&G, reports on both commercial and subsistence fishery sectors, these data appear not to make it to either the national (NMFS) or international (FAO) reporting agencies. Having a baseline of information available on total fisheries catches is also important in light of global warming (Cheung et al. 2009, 2010).

Commercial catches have been in decline since peaking in the early 1980s, although the drop since 2000 seems due to reduced market options (one buyer only), and subsistence catches have increased during this time (Booth and Zeller 2008). However, the increase in subsistence catches is small compared to the growth in human population, thus resulting in a declining per capita supply. This decline is most likely driven by increased consumption of processed and 'imported' food products (i.e., brought in from southern regions).

Although it appears that the commercial fisheries are well monitored by Alaskan state authorities, a more regular, systematic survey method would lead to a better understanding of subsistence fisheries. It is interesting that subsistence use, which is given priority in the Alaskan state constitution, seems to be lacking consistent, detailed, and comprehensive data. A subsistence survey design incorporating each community in a specified time interval, with interpolations for non-survey years, would assist in clarifying actual subsistence catches. Specific attention to all salmon species would also benefit the efforts to track global warming effects, since species' distributions will be affected (Cheung et al. 2009). For example, chinook salmon (*Oncorhynchus tshawytscha*) do appear to have extended their historical distributions northwards because they have been appearing in the community area of Barrow since the mid-1990s, and there is no local Inupiaq name for them (C. George, pers. comm.[1]).

[1] Craig George, Division of Wildlife Management, North Slope Borough, P.O. Box 69, Barrow, Alaska 99723, (907)-852-2611 [date information received: January 24, 2008].

Canada

Our study seems the first to estimate the full extent of Canada's historic marine fish catches in the Arctic. There has been no consistent or substantial effort undertaken for the small-scale fisheries sector, with previous studies documenting subsistence fisheries over relatively short timespans (e.g., Gamble 1988), with no expansion to consider the entire Canadian Arctic. The approach taken here provides estimates for years when there are no 'hard' data available. The development of community level fisheries self management systems (Berkes 1990) could potentially include periodic data collection with interpolations employed between survey periods, as suggested elsewhere (Zeller et al. 2007), thereby improving the inputs into public policy and decision making. The responsibility would be on the national agency with fisheries responsibility (i.e., the Department of Fisheries and Oceans) to ensure these data are incorporated into annual national and international reporting.

The small-scale catch component estimated here underlines the importance of the non-market economy to many arctic communities. Not formally considering estimates of small-scale catches can also lead to bias in economic indicators (Zeller et al. 2006b). Furthermore, there have already been substantial changes in local diets brought about by the introduction of foods 'imported' from further south. Although country foods such as caribou and charr still play an important role in the mixed economy, the amount of country food on a *per capita* basis has also declined in arctic Canada, with the largest declines seen in the youngest generations (Blanchet et al. 2000). The increased importance of southern foods, including foods rich in carbohydrates and sugars, has led to higher rates of obesity and related diseases, such as Type 2 diabetes (Young et al. 2000). These changes in diet have largely occurred since the 1980s (Collings et al. 1998).

For the Arctic in general, the changing climate and its implications for fisheries (Cheung et al. 2010), and the distances between arctic communities, together with underdeveloped infrastructure and economies, represent major challenges. Regardless of the roles adopted for local and jurisdictional organizations, the collection and use of fisheries and ecosystem data appears to be a growing priority. Be as it may, the present contribution was assembled essentially for the purpose of suggesting an improved baseline of total historic catches of marine fisheries. It is our hope that those colleagues with interest in arctic fisheries can now use our study to improve not only overall data collection for the future, but also maybe improve on our data for the past.

Acknowledgments This work forms part of the *Sea Around Us* Project, a scientific collaboration between the University of British

Columbia and the Pew Environment Group, Philadelphia. Work on arctic Alaska was funded by the Lenfest Ocean Program. We would like to thank the Institute of Arctic Ecophysiology, Canada, for providing access to a resource and report network, and the members of the Department of Fisheries and Oceans Canada who took personal time to assist: J. Mathias, M. Treble, P. Richard, J. Martin, and M. Dyck. In Alaska, we would like to thank J. Menard, J. Magdanz and J. Simon of ADG&G, S. Murphy of ABR, Inc. and B. Wilson, North Pacific Fishery Management Council for providing additional data and insights, and Oceana for support and assistance. We thank C. Ragner of the Norwegian Institute for making available to us reports on Siberia. Our thanks also go to B. Campbell for the GIS work, and to A. Atanacio for preparing the figures.

References

Abrahamson JD (1968) Westward Alaska: The native economy and its resource base. United States Federal Field Committee for Development Planning in Alaska, Anchorage

Anonymous (1954) Ninth census of Canada: population-unincorporated villages and hamlets. Dominion Bureau of Statistics, Ottawa

Anonymous (1967) 1967 Annual Report, Arctic-Yukon-Kuskokwim area. Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage

Anonymous (1968) 1968 Annual Report, Arctic-Yukon-Kuskokwim area. Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage

Anonymous (1973) 1971 Census of Canada: population-unincorporated settlements. Statistics Canada, Ottawa

Anonymous (1977) 1976 Census of Canada: population-geographic distributions. Statistics Canada, Ottawa

Anonymous (1978) 1976 Census of Canada: supplementary bulletins: geographic and demographic-population of unincorporated places. Statistics Canada, Ottawa

Anonymous (1979) Research to establish present levels of native harvesting: harvest by the Inuit of northern Quebec-phase II (Year 1976). James Bay and Northern Quebec Native Harvesting Research Committee, Montreal

Anonymous (1983a) 1981 Census of Canada: place name reference list-Quebec and Ontario. Statistics Canada, Ottawa

Anonymous (1983b) 1981 Census of Canada: place name reference list-Western provinces and the territories. Statistics Canada, Ottawa

Anonymous (1996) 1996 Census aboriginal population profiles. Statistics Canada, Ottawa. Available at: http://www12.statcan.ca/english/Profil/PlaceSearchForm1.cfm. Accessed 10 Jan 2007

Anonymous (2001a) 2001 Census aboriginal population profiles. Statistics Canada, Ottawa. Available at: http://www12.statcan.ca/english/profil01/AP01/Index.cfm?Lang=E. Accessed 10 Jan 2007

Anonymous (2001b) Community profiles database. Alaska Department of Fish and Game, Division of Subsistence, Anchorage. www.subsistence.adfg.state.ak.us/geninfo/publctns/cpdb.cfm. Accessed 15 Oct 2007

Anonymous (2005) Northeast national petroleum reserve-Alaska: final amended integrated activity plan/environmental impact statement. Bureau of Land Management, Anchorage

Banducci A, Kohler T, Soong J, Menard J (2007) 2005 Annual Management Report: Norton Sound, Port Clarence, and Kotzebue. Fishery Management Report No. 07–32. Department of Fish and Game, Division of Commercial Fisheries, Anchorage

Belikov S, Boltunov A, Belikova T, Belevich T, Gorbunov Y (1998) The distribution of marine mammals in the Northern Sea Route Area. INSROP Working Paper No. 118

Berg LS, Bogdanov AS, Kozhin HI, Rass TS (1949) Promyslovye ryby SSSR (Commercial fishes of the USSR). Pichepromizdat Press (in Russian), Moscow

Berkes F (1990) Native subsistence fisheries: a synthesis of harvest studies in Canada. Arctic 43:35–42

Blanchet C, Dewailly E, Ayotte P, Bruneau S, Receveur O, Holub BJ (2000) Contribution of selected traditional and market foods to the diet of Nunavik Inuit women. Can J Dietetic Pract Res 61:50–59

Booth S, Watts P (2007) Canada's arctic marine fish catches. In: Zeller D, Pauly D (eds) Reconstruction of marine fisheries catches for key countries and regions (1950–2005). Fisheries Centre Research Reports 15(2). University of British Columbia Fisheries Centre, Vancouver, pp 3–16

Booth S, Zeller D (2008) Marine fisheries catches in arctic Alaska. Fisheries Centre Research Reports 16(9). Fisheries Centre, University of British Columbia, Vancouver

Brude OW, Moe KA, Bakken V, Hansson R, Larsen LH, Lovas SM, Thomassen J, Wiig O (1998) Northern Sea route dynamic environmental Atlas. INSROP Working Paper No. 99

Burch ES (1985) Subsistence production in Kivalina, Alaska: a twenty-year perspective. Alaska Department of Fish and Game, Division of Subsistence, Juneau

Cheung WWL, Lam V, Sarmiento J, Kearney K, Watson R, Pauly D (2009) Projecting global marine biodiversity impacts under climate change scenarios. Fish Fish 10(3):235–251

Cheung WWL, Lam V, Sarmiento J, Kearney K, Watson R, Zeller D, Pauly D (2010) Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. Glob Change Biol 16:24–35

Chuenpagdee R, Liguori L, Palomares MD, Pauly D (2006) Bottom-up, global estimates of small-scale marine fisheries catches. Fisheries Centre Research Reports 14(8). University of British Columbia, Vancouver

Collings P, Wenzel G, Condon RG (1998) Modern food sharing networks and community integration in the central Canadian Arctic. Arctic 51:301–314

Conger AO, Magdanz J (1990) The harvest of fish and wildlife in three Alaska communities: Brevig Mission, Golovin and Shishmaref. Technical Paper No. 188. Alaska Department of Fish and Game, Division of Subsistence, Juneau

Craig PC (1987) Subsistence fisheries at coastal villages in the Alaskan arctic, 1970–1986. Minerals Management Service, Alaska Outer Continental Shelf Region, Leasing and Environment Office, Springfield, Virginia

Crawford R (1989) Exploitation of Arctic fishes. Department of Fisheries and Oceans, Central and Arctic Region, Winnipeg

Daigneault MJ, Reiser C (2007) Colville River fall fishery monitoring. Unpublished report prepared by LGL Alaska Research Associates, Inc. for ConocoPhillips, Anchorage

DFO (1991) Annual summary of fish and marine mammal harvest data for the Northwest Territories, 1988–1989. Freshwater Institute, Central and Arctic Region, Winnipeg

DFO (1992a) Annual summary of fish and marine mammal harvest data for the Northwest Territories, 1989–1990. Freshwater Institute, Central and Arctic Region, Winnipeg

DFO (1992b) Annual summary of fish and marine mammal harvest data for the Northwest Territories, 1990–1991. Freshwater Institute, Central and Arctic Region, Winnipeg

DFO (1993) Annual summary of fish and marine mammal harvest data for the Northwest Territories, 1991–1992. Freshwater Institute, Central and Arctic Region, Winnipeg

DFO (1994) Annual summary of fish and marine mammal harvest data for the Northwest Territories, 1992–1993. Freshwater Institute, Central and Arctic Region, Winnipeg

DFO (1995) Annual summary of fish and marine mammal harvest data for the Northwest Territories, 1993–1994. Freshwater Institute, Central and Arctic Region, Winnipeg
DFO (1996) Annual summary of fish and marine mammal harvest data for the Northwest Territories, 1994–1995. Freshwater Institute, Central and Arctic Region, Winnipeg
DFO (1997) Annual summary of fish and marine mammal harvest data for the Northwest Territories, 1995–1996. Freshwater Institute, Central and Arctic Region, Winnipeg
DFO (1999) Annual summary of fish and marine mammal harvest data for the Northwest Territories 1996–1997. Freshwater Institute, Central and Arctic Region, Winnipeg
DFO (2006) Fisheries and Oceans Canada: regions. Available at: www.dfo-mpo.gc.ca/regions_e.htm. Accessed 14 Feb 2007, Ottawa
Dunbar MJ (1970) On the fishery potential of the sea waters of the Canadian north. Arctic 23(3):150–174
Eggers DM, Clark JH (2006) Assessment of historical runs and escapement goals for Kotzebue area chum salmon. Fishery Manuscript No. 06-01. Alaska Department of Fish and Game, Anchorage
Fabijian M, Usher PJ (2003) Inuvialuit harvest study data and methods report 1988–1997. The Inuvialuit Joint Secretariat, Inuvik, Northwest Territories
Fetzer I, Hirche HJ, Kosolova EG (2002) The influence of freshwater discharge on the distribution of zooplankton in the southern Kara Sea. Polar Biol 25:404–415
Fleming IA, Jensen AJ (2002) Fisheries: effects of climate change on the life cycles of Salmon. In: Douglas I (ed) Causes and consequences of global environmental change, vol 3, Encyclopedia of global environmental change. Wiley, Chichester, pp 309–312
Foote DC, Williamson HA (1966) A human geographical study. In: Wilimovsky NJ, Wolfe JN (eds) Environment of the Cape Thompson region, Alaska. United States Atomic Energy Commission Division of Technical Information, Oak Ridge, Tennessee, pp 1041–1107
Gamble RL (1988) Native harvest of wildlife in the Keewatin Region, Northwest territories for the period October 1985 to March 1986 and a summary for the entire period of the harvest study from October 1981 to March 1986. Canadian Data Report of Fisheries and Aquatic Sciences 688, Ottawa
Gavrilo M, Bakken V, Isaksen K (1998) The distribution, population status and ecology of marine birds selected as valued ecosystem components in the Northern Sea Route Area. INSROP Working Paper No. 123
Georgette S, Loon H (1993) Subsistence use of fish and wildlife in Kotzebue. Northwest Alaska Regional Centre Technical Paper No. 167. Alaska Department of Fish and Game, Division of Subsistence, Juneau
Georgette S, Utermohle C (2000) Subsistence salmon harvest summary Northwest Alaska 1999. Alaska Department of Fish and Game, Division of Subsistence, Kotzebue, Alaska
Georgette S, Utermohle C (2001) Subsistence salmon harvest summary Northwest Alaska 2000. Alaska Department of Fish and Game, Division of Subsistence, Kotzebue, Alaska
Georgette S, Caylor D, Tahbone S (2003) Subsistence salmon harvest summary Northwest Alaska 2002. Alaska Department of Fish and Game, Division of Subsistence and Kawerak, Inc., Kotzebue, Alaska
Gordeev VV, Andreeva EN, Lisitzin AP, Kremer HH, Salomons W, Mashall-Crossland JI (2006) Russian Arctic Basins: LIICZ global change assessment and synthesis of river catchment—coastal areas interaction and human dimension. LOICZ Report and Studies No 29
Hall ES (1971) The “Iron Dog” in northern Alaska. Anthropologica 13:237–254
Hill F (2004) Siberia: Russia’s economic heartland and daunting dilemma. Curr Hist Oct:324–331
Impact Assessment Inc (1989) Point lay biographies. OCS Study MMS 89-0094, La Jolla
Jacquet JL, Fox H, Motta H, Ngusaru A, Zeller D (2010) Few data but many fish: marine small-scale fisheries catches for Mozambique and Tanzania. Afr J Mar Sci 32(2):197–206
Jenkins JL (1991) Sportfishing in the Soviet Far East? The Angling Report
JETRO (2004) Russia Far East economic review. Japan External Trade Organization. www.jetro.go.jp/biz/world/russia_cis/ru/kyokuto/2004_02.html. [in Japanese]
Kierans T (2001) 21st Century joint Canada–United States water management. In: Phelps D, Sehlke G (eds) World water congress 2001—bridging the gap: meeting the world’s water and environmental resources challenges. Orlando, p 10
Kohler T, Banducci A, Soong J, Menard J (2005) Annual Management Report 2004: Norton Sound, Port Clarence, Kotzebue. Regional Information Report No. 3A05–04. Department of Fish and Game, Division of Commercial Fisheries, Anchorage
Kosobokova KN, Hanssen H, Hirche HJ, Knickmeier K (1998) Composition and distribution of zooplankton in the Laptev Sea and adjacent Nansen basin during summer 1993. Polar Biol 19:63–76
Larsen LH, Evenset A, Sirenko G (1995) Linkages and impact hypothesis concerning the valued ecosystem components (VEC’s): invertebrates, fish, the coastal zone and large river estuaries and deltas. INSROP Working Paper No. 12
Larsen LH, Palerud R, Goodwin H, Sirenko B (1996) The marine invertebrates, fish and coastal zone features of the NSR area. INSROP Working Paper No 53
Magdanz J, Utermohle C (1994) The subsistence salmon fishery in the Norton Sound, Port Clarence and Kotzebue Districts, 1994. Technical Paper No. 237. Alaska Department of Fish and Game, Division of Subsistence, Juneau
Mason R, Magdanz J, Craver A (2007) Subsistence Production and Family Networks in Buckland, Alaska. University of Washington, Seattle. Available at: www.cfr.washington.edu/research.cesu/newsletters/PNWCV_Summer2007.pdf. Accessed 27 Feb 2008
Mattson CR (1962) Chum salmon resources of Alaska from Bristol Bay to Point Hope. United States Fish and Wildlife Service, Washington
Ministry of Natural Resources (1998) Safety and environmental regime for Russian offshore oil and gas operations. The feasibility study: the joint Russian–American–Norwegian project. Ministry of Natural Resources of the Russian Federation, Moscow
Moore GD (1979) Issue background: Buckland food shortage. Technical Paper Number 7. Alaska Department of Fish and Game, Division of Subsistence, Kotzebue, Alaska
Newell J (2004) The Russian far east: a reference guide for conservation and development. Daniel & Daniel Publishers, McKinleyvill, CA
Patterson A (1974) Subsistence harvests in five native regions. The Joint Federal-State Land Use Planning Commission for Alaska, Resource Planning Team, Anchorage
Pauly D (2006) Major trends in small-scale marine fisheries, with emphasis on developing countries, and some implications for the social sciences. Marit Studies (MAST) 4(2):7–22
Pauly D, Swartz W (2007) Marine fish catches in North Siberia (Russia, FAO Area 18). In: Zeller D, Pauly D (eds) Reconstruction of marine fisheries catches for key countries and regions (1950–2005). Fisheries Centre Research Report 15(2), Vancouver, pp 17–33

Pauly D, Alder J, Booth S, Cheung WWL, Christensen V, Close C, Sumaila UR, Swartz W, Tavakolie A, Watson R, Zeller D (2008) Fisheries in Large Marine Ecosystems: Descriptions and Diagnoses. In: Sherman K, Hempel G (eds) The UNEP large marine ecosystem report: a perspective on changing conditions in LMEs of the World's Regional Seas. UNEP Regional Seas Reports and Studies No. 182, Nairobi, pp 23–40

Pedersen S, Alfred L (2005) Kaktovik 2000–2002 subsistence fishery harvest assessment. Alaska Department of Fish and Game Kaktovik, and Inupiat Corporation, Fairbanks

Priest H, Usher PJ (2004) The Nunavut wildlife harvest study. Nunavut Wildlife Management Board, Iqaluit, Nunavut

Raymond JA (1988) Chapter 7: Fish resources. In: Hamedi MJ, Naidu AS (eds) The environment and resources of the Southeastern Chukchi Sea—a review of scientific literature. NOAA Report 86-ABH-0013. OCSEP Research Unit 690, p 103

Saario DJ, Kessel B (1966) Human ecological investigations at Kivalina. In: Wilimovsky NJ, Wolfe JN (eds) Environment of the Cape Thompson region, Alaska. United States Atomic Energy Commission, Division of Technical Information, Oak Ridge, Tennessee, pp 969–1039

Sherman K, Hempel G (eds) (2008) The UNEP large marine ecosystem report: a perspective on changing conditions in LMEs of the World's Regional Seas. UNEP Regional Seas Reports and Studies No. 182, United Nations Environment Programme, Nairobi

Slavin SV (1964) Economic development of the Siberian North. Arctic 17(2):104–108

Smith HD, Seymour AH, Donaldson LR (1966) The Salmon resource. In: Willimovsky NJ, Wolfe JN (eds) Environment of the Cape Thompson Regions, Alaska. United States Atomic Energy Commission, Division of Technical Information, Oak Ridge, Tennessee, pp 861–876

Sobelman S (1984) Background paper on subsistence salmon fishery, Inmachuk River, Deering. Alaska Department of Fish and Game, Division of Subsistence, Fairbanks

Stefanich F (1973) Resources inventory Arctic Region: fisheries resources, preliminary draft. Joint Federal-State Land Use Planning Commission, Anchorage

Thiede J, Timokhov L, Bauch HA, Bolshiyanov D, Dmitrenko I, Eicken H, Fahl K, Gukov A, Hölemann J, Hubberten HW, von Juterzenka K, Kassens H, Melles M, Petryashov V, Pivovarov S, Priamikov S, Rachold V, Schmid M, Siegert C, Spindler M, Stein R (1999) Dynamics and history of the Laptev Sea and its continental hinterland: a summary. In: Kassens H, Bauch HA, Dmitrenko IA et al. (eds) Land-Ocean system in the Siberian Arctic: dynamics and history. Springer, Berlin

Thomassen J, Dallmann W, Isaksen K, Khlebovich V, Wiig O (1999) Evaluation of INSROP valued ecosystem components: protected areas, indigenous people, domestic reindeer and wild reindeer. INSROP Working Paper No. 162

Ursin R (1984) The tropical, the temperate and the arctic seas as media for fish production. Dana 3:43–60

Usher PJ (1972) The use of snowmobiles on Banks Island. Arctic 25:170–181

Usher PJ (2000) Standard edible weights of harvested species in the Inuvialuit settlement region. Ottawa

Usher PJ (2002) Inuvialuit use of the Beaufort Sea and its resources, 1960–2000. Arctic 55:18–28

Vilchek GE, Krasnovskaya TM, VVC (1996) The environment in the Russian Arctic: status report. Polar Geogr 20(1):20–43

von Baeyer HS (1993) The Fermi solution: reflections on the meaning of physics. Penguin, London

Wiig O, Belikov SE, Boltunov AN, Garner GW (1996) Selection of marine mammal valued ecosystem components and description of impact hypotheses in the Northern Sea Route Area. INSROP Working Paper No. 40

Wilimovsky NJ (1956) The utilization of fishery resources by the Arctic Alaskan Eskimo. Occas Pap Nat Hist Mus Stanf Univ 2:1–8

Yaremchuk GCB, Roberge MM, McGowan DK, Carder GW, Wong B, Read CJ (1989) Commercial harvests of major fish species from the Northwest Territories, 1945 to 1987. Department of Fisheries and Oceans, Central and Arctic Region, Winnipeg

Young TK, Reading J, Elias B, O'Neil JD (2000) Type 2 diabetes mellitus in Canada's First Nations: status of an epidemic in progress. Can Med Assoc J 163:561–566

Zeller D, Booth S, Craig P, Pauly D (2006a) Reconstruction of coral reef fisheries catches in American Samoa, 1950–2002. Coral Reefs 25:144–152

Zeller D, Booth S, Pauly D (2006b) Fisheries contributions to GDP: underestimating small-scale fisheries in the Pacific. Mar Resour Econ 21(4):355–374

Zeller D, Booth S, Davis G, Pauly D (2007) Re-estimation of small-scale fisheries catches for U.S. flag island areas in the Western Pacific: the last 50 years. Fish Bull 105(2):266–277