Seafood Watch
Seafood Report

MONTEREY BAY AQUARIUM®

Farmed
Arctic char
Salvelinus alpinus

(Image © Robert Donahue)

Northeast Region

Final Report
03/20/06

Jesse Marsh
Fisheries Research Analyst
Monterey Bay Aquarium

About Seafood Watch® and the Seafood Reports

Monterey Bay Aquarium's Seafood Watch® program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. Seafood Watch® defines sustainable seafood as originating from sources, whether wild-caught or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems. Seafood Watch® makes its science-based recommendations available to the public in the form of regional pocket guides that can be downloaded from the Internet (seafoodwatch.org) or obtained from the Seafood Watch® program by emailing seafoodwatch@mbayaq.org. The program's goals are to raise awareness of important ocean conservation issues and empower seafood consumers and businesses to make choices for healthy oceans.

Each sustainability recommendation on the regional pocket guides is supported by a Seafood Report. Each report synthesizes and analyzes the most current ecological, fisheries and ecosystem science on a species, then evaluates this information against the program's conservation ethic to arrive at a recommendation of "Best Choices", "Good Alternatives" or "Avoid." The detailed evaluation methodology is available upon request. In producing the Seafood Reports, Seafood Watch® seeks out research published in academic, peer-reviewed journals whenever possible. Other sources of information include government technical publications, fishery management plans and supporting documents, and other scientific reviews of ecological sustainability. Seafood Watch® Fisheries Research Analysts also communicate regularly with ecologists, fisheries and aquaculture scientists, and members of industry and conservation organizations when evaluating fisheries and aquaculture practices. Capture fisheries and aquaculture practices are highly dynamic; as the scientific information on each species changes, Seafood Watch's sustainability recommendations and the underlying Seafood Reports will be updated to reflect these changes.

Parties interested in capture fisheries, aquaculture practices and the sustainability of ocean ecosystems are welcome to use Seafood Reports in any way they find useful. For more information about Seafood Watch® and Seafood Reports, please contact the Seafood Watch® program at Monterey Bay Aquarium by calling 1-877-229-9990.

Disclaimer

Seafood Watch® strives to have all Seafood Reports reviewed for accuracy and completeness by external scientists with expertise in ecology, fisheries science and aquaculture. Scientific review, however, does not constitute an endorsement of the Seafood Watch® program or its recommendations on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

Seafood Watch® and Seafood Reports are made possible through a grant from the David and Lucile Packard Foundation.

Executive Summary

Arctic char, *Salvelinus alpinus*, is a circumpolar species found in the polar regions of North America and Europe. Arctic char is a salmonid, and exists in both anadromous (seagoing) and nonanadromous (resident freshwater) forms. Although there is commercial and recreational fishing for Arctic char, aquaculture production is the primary source of Arctic char in the U.S. market. Iceland, Canada, Norway, and the United States are the primary producers of Arctic char, which demands a high price due to its limited availability. Arctic char are raised predominantly in land-based, closed systems with recirculating water systems. There is some limited production in flowthrough systems and netpens. A moderate conservation concern associated with Arctic char aquaculture is the use of marine resources; the ratio of wild fish input (in the form of fishmeal) to farmed fish produced is approximately 1.8:1. The majority of Arctic char aquaculture operations are land-based, closed systems and there is thus only a minor risk associated with escapes of farmed fish to wild stocks. In some operations, only sterile fish are raised and would therefore not be able to breed with wild stocks of Arctic char if they escaped. The risk of disease and parasite transfer to wild stocks is also minor, as most Arctic char aquaculture does not occur in open systems. Additionally, Arctic char have been shown to be more disease resistant than other salmonids. There is also a low risk of pollution and habitat effects from Arctic char aquaculture, as closed systems (particularly recirculating systems) have adequate effluent treatment in the form of biofilters or settling ponds. Management of Arctic char aquaculture varies according to farm, but is generally deemed highly effective. The preceding suite of factors results in an overall ranking of “Best Choice” for farmed Arctic char.

Table of Ranks

	Conservation Concern			
Sustainability Criteria	Low	Moderate	High	Critical
Use of Marine Resources		√		
Risk of Escaped Fish to Wild Stocks	√			
Risk of Disease and Parasite Transfer to Wild Stocks	√			
Risk of Pollution and Habitat Effects	√			
Management Effectiveness	√			

Overall Seafood Recommendation:

Arctic char (closed system):

Best Choice ☑ Good Alternative Avoid

Introduction

Arctic char, *Salvelinus alpinus,* is a circumpolar species found in the polar regions of North America and Europe (Johnson 1980). Arctic char is a salmonid, and can be either anadromous (seagoing) or nonanadromous (freshwater resident). Anadromous Arctic char perform short annual seaward migrations and return to freshwater in late summer or fall (Nordeng 1983). Nonanadromous Arctic char are found in lakes and inland flowing waters in 18 European and North American countries (Maitland 1995). Anadromous Arctic char are found north of 49°N in the U.S. and Canada, and north of 65°N in Greenland, Iceland, Norway, and Russia (Johnson 1980; Maitland 1995). There are over 45 populations in Ireland, and over 200 in Scotland (Maitland and Lyle 1991). The commercial fishery for Arctic char is highly regulated as a result of previous overexploitation of the wild stocks through the use of gillnets. Anadromous Arctic char average 2.3 to 4.5 kilograms (kg), while the land-locked (non-anadromous) Arctic char are generally smaller, at 0.2 to 2.3 kg (DFO 2004a).

Arctic char production
Arctic char are caught both recreationally and commercially, and raised in aquaculture operations. The majority of Arctic char available to U.S. consumers is farmed commercially. In 2000, global production of farmed Arctic char was estimated at about 3,000 metric tons (mt), which is minimal compared to the global estimates of farmed Atlantic salmon (750,000 mt) (Rogers and Davidson 2001). Arctic char are also harvested in subsistence fisheries, with annual production estimated at 500 mt (Maitland 1995). Estimates of annual production vary; according to FAO statistics, Arctic char production increased from 69 mt in 1990 to 990 mt in 1999 (FAO 2002). However, production estimates from the Federation of European Aquaculture Producers (FEAP) are generally higher than the FAO data (Figure 1).

Iceland
In 2000 Iceland was the largest producer of Arctic char (1,100 mt), followed by Canada (960 mt) (Table 1) (Rogers and Davidson 2001). Icelandic farmed Arctic char production totaled 1,540 mt in 2002, and 1,600 mt in 2003 (Directorate of Freshwater Fisheries 2004). For comparison, total Arctic char landings in 2001 were 31.4 mt for the recreational rod fishery, and 15.7 mt for the gillnet fishery (Guðbergsson 2002). Only 20 – 25% of the gillnet fishery is commercial catch (B. Theodorsson pers. com.).

Canada
The Maritimes (42%), Quebec (21%), Yukon (19%), and Ontario (16%) contribute the largest proportion of farmed Arctic char in Canada (Rogers and Davidson 2001). In 2000 Canadian production of Arctic char was estimated at 960 mt (Rogers and Davidson 2001). The commercial fishery catch declined to approximately 120 mt in 2000 (Johnston 2002).

Norway
Estimated production of Arctic char in Norway increased from 100 mt in 1988 to 500 mt in 1994 (Heggberget et al. 1994). The Directorate of Fisheries in Norway estimated that the average annual production of farmed Arctic char was 256 mt during 1992 – 2000, with a minimum of 147 mt in 1993 and a maximum of 498 mt in 1999 (Lillehaug et al. 2003).

United States

In 2001, U.S. Arctic char production was estimated at 375 mt (Rogers and Davidson 2001).

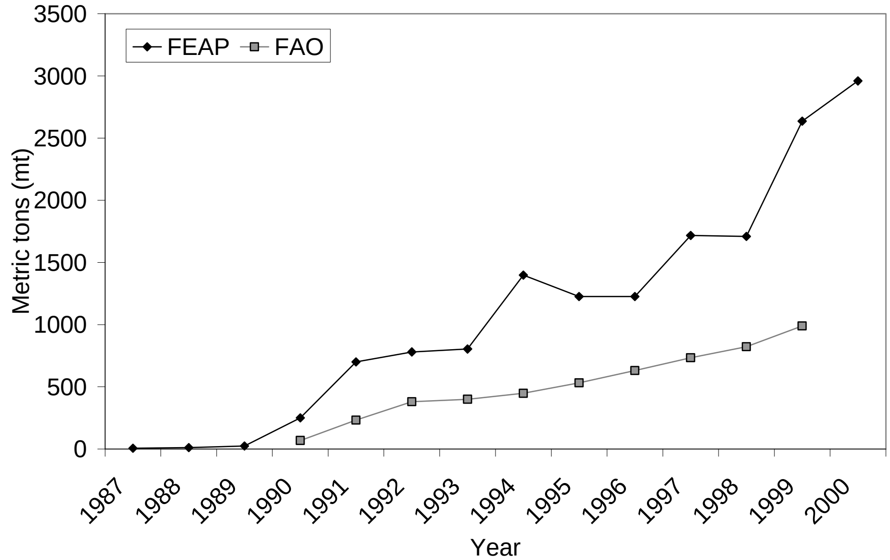

Figure 1. Differing Arctic char production estimates from the Federation of European Aquaculture Producers (FEAP) and the FAO, 1987 – 2000. FEAP data includes Canada and Europe (Data from Johnston 2002; FEAP 2004).

Table 1. World production of Arctic char in 2000 (Table from Rogers and Davidson 2001).

Country	**Volume (mt)**
Iceland	1100
Canada	960
Norway/Sweden	640
United States	375
Ireland	100
Finland	20
TOTAL	3,195

Arctic char is an excellent aquaculture candidate for several reasons. Arctic char tolerate high-density culture, and are a successful species for production in intensive recirculating systems (Summerfelt et al. 2004). Arctic char is also a high value species due to its limited availability, and demands a higher price than more widely farmed Atlantic salmon. Production of Arctic char in North America has been primarily in recirculating systems (Summerfelt et al. 2004).

Types of aquaculture systems

The four general types of aquaculture systems used for raising fish are recirculating systems (closed or semi-closed), flow-through and raceway systems, cages and netpens, and ponds (Stickney 1994). Flow-through, or single-pass, and raceway systems eliminate the need for biofiltration, as the water makes one pass through the holding unit; trout are often raised in raceways (Stickney 1994). Cages and netpens are floating structures placed in open water, such as those used for Atlantic salmon. In recirculating systems ammonia and solids are removed, and disease and temperature are better controlled (Stickney 1994). Recirculating systems generally include one or more settling chambers, a biological filter, and culture chambers (Stickney 1994). There are different types of recirculating systems used to produce Arctic char in North America: single-pass; partial-reuse; and fully recirculating (Summerfelt et al. 2004). Salmonids such as Arctic char are more sensitive to poor water quality than species such as catfish or tilapia, and require more rapid water exchange (Stickney 1994).

Although there are environmental concerns associated with inland pond, flow-through systems, and closed systems, there are fewer problems associated with these systems than with netpens and coastal ponds (White et al. 2004). The use of closed recirculating systems has increased as a result of concerns for water conservation and reduced waste discharges (White et al. 2004). According to White et al. (2004), closed recirculating systems have a "minimal" environmental impact due to the small amount of waste discharge, but are energy intensive. Flow-through and raceway systems have a "moderate" environmental impact due to waste discharge (White et al. 2004). Although recirculating systems may avoid user conflicts in coastal areas, less than 10% of the 4,000 aquaculture facilities in the U.S. use closed recirculating systems (NASS 1999). In Iceland, land-based aquaculture operations rely on freshwater and seawater resources heated by geothermal energy (Georgsson and Fridleifsson 1996). In some land-based operations in Iceland, effluent flows to a settling pond, where the solids (waste and food particles) settle, after which the effluent is channeled to a glacial river (Georgsson and Fridleifsson 1996). In the Appalachian region of the U.S., aquaculture operations also utilize natural spring water in flow-through systems to raise Arctic char.

Rearing Arctic char

Salmonids are generally farmed in two stages: smolts (young salmonids 2-3 years old) are produced in freshwater, and post-smolts are reared in salt water. In the case of Atlantic salmon, the post-smolts are moved to open netpens to achieve faster growth (Heasman and Black 1998). However, when anadromous Arctic char remain in seawater during the fall and winter, mortalities increase and growth rates decrease (Johnson 1980). At low seawater temperatures, adult Arctic char exhibit decreased feed intake and growth rates, hence they are raised in freshwater or brackish water (Arenson et al. 1993). Arctic char are highly resistant to low temperatures, with a lower tolerance limit close to 0°C (Baroudy and Elliott 1994). Growth rates of young Arctic char have been found to be one of the highest of all the salmonid species (Jobling 1983). When Arctic char are presmolts in the freshwater stage of farming, they exhibit faster growth than Atlantic salmon (Heggberget et al. 1994). After 8 months under similar rearing conditions, Arctic char were 40-45 mm longer than Atlantic salmon (Heggberget et al. 1994). However, a major issue for producers associated with Arctic char aquaculture is the inconsistency of growth rates (Rogers and Davidson 2001).

Unlike most salmonids, Arctic char do not show a continuous decline in production with increasing density, and show increased growth rates at higher densities (Wallace et al. 1988; Baker and Ayles 1990). In past studies, rates of weight gain were shown to improve as stocking density was increased from 15 to 40 kg/m^3, with high rates of weight gain achieved at stocking densities in excess of 100 kg/m^3 (Wallace et al. 1988; Baardvik and Jobling 1990; Palsson et al. 1992; Jørgensen et al. 1993). Other studies showed that at low densities, Arctic char suffered greater fin damage (Siikavuopio and Jobling 1995). An improvement in the social environment of farmed fish is likely to lead to increased food intake (Jørgensen et al. 1993). Research examining the influence of feeding frequency on Arctic char growth found that feeding frequency did not affect hierarchy formation (Petursdottir 2002), which is thought to be a major reason for the development of size heterogeneity within fish groups (McCarthy et al. 1992; Jobling and Baardvik 1994). In aquaculture operations, factors such as water current and stocking density can be manipulated to reduce the effects of hierarchy formation, such as differences in growth between fish (Christiansen and Jobling 1990; Jørgensen et al. 1993; Jobling and Baardvik 1994; Damsgård et al. 1997).

Wild Arctic char population and fishery
Acidification and eutrophication are primary environmental threats to Arctic char found in the land-locked waters of northern Europe (Tammi et al. 2003). Fish populations in Sweden and Norway, as well as populations in Ireland and Scotland, have been particularly affected by the poor water quality resulting from acidification and eutrophication (Maitland 1995; Tammi et al. 2003).

In Canada, anadromous Arctic char are targeted by the commercial fishery with gillnets, although commercial effort has declined over time (DFO 2001). Char is primarily caught in Rankin Inlet, Cambridge Bay, Pelly Bay, and Nettilling Lake in Arctic Canada (DFO 2006). The status of the wild Arctic char stocks in Labrador is unknown due to a lack of fishery independent data (DFO 2001). However, it is likely that growth overfishing has resulted in changes in stock characteristics (DFO 2001). Arctic char in North Labrador is commercially caught from three stock complexes, Voisey, Nain, and Okak (DFO 2001). Catch from these areas have exhibited a general decline since the 1970s. An unknown and possibly substantive quantity of char is caught in the recreational and subsistence fisheries (DFO 2001). The Cambridge Bay char fishery encompasses numerous river systems, and discrete stocks may exist within rivers; the relative impact of fishing pressure on these stocks is unknown (DFO 2004b). In 2003, most of this catch was with gillnets (DFO 2004b).

In Alaska, char are found in lakes in the Brooks Range, the Kigluaik Mountains, the Kuskokwim Mountains, the Alaska Peninsula, Kenai Peninsula, Kodiak Island, and in a small area of Interior Alaska near Denali Park (ADF&G 2006). In the NMFS fishery statistics database, there have been no U.S. commercial landings of Arctic char in Alaska since 1977 (NMFS 2006).

Scope of the analysis and the ensuing recommendation:
This analysis encompasses farmed Arctic char from Iceland, Canada, Norway, and the U.S. that is available in the U.S. market. Wild-caught Arctic char is not evaluated in this report.

Availability of Science

Compared to other aquaculture species such as salmon and trout, there is limited information concerning the farming of Arctic char, and much of the available data exists as grey literature. Also, there are no specific data concerning fishmeal use for Arctic char, as they are fed a modified trout feed. As Arctic char are primarily farmed in Iceland there is limited information available in English regarding detailed farming practices and management regulations there.

However, as the prevalence of Arctic char aquaculture operations increases, it is likely that a larger body of scientific information will become available.

Market Availability

Common and market names:
Common names for Arctic char include Arctic charr and Alpine char (Heasman and Black 1998). When used for sushi or sashimi, Arctic char is commonly sold as *iwana*.

Seasonal availability:
Farmed Arctic char is available year-round.

Product forms:
Arctic char is marketed fresh and frozen as whole dressed fish and steaks, smoked, and canned (DFO 2004a).

Import and export sources and statistics:
The National Oceanic and Atmospheric Administration (NOAA) Fisheries Foreign Trade Information database does not contain information on imports and exports of Arctic char. While limited amounts of Arctic char are imported to the U.S. from Canada, it is thought that the majority of Arctic char available in the U.S. is imported from Iceland or produced in the U.S. (J. Rose, pers. comm.). From 2000 to 2002, annual Arctic char imports from Iceland to the U.S. averaged 377 mt (H. Thorarensen, pers. comm.). All of the Arctic char production in Iceland is in land-based facilities (H. Thorarensen, pers. comm.). It has been estimated that 60% of Icelandic Arctic char is exported to the U.S. (G. Jónsson, pers. comm.); however, this number may be closer to 40%. Atlantic salmon, Arctic char, and rainbow trout are the primary species exported by Iceland; whole Arctic char is generally exported to the U.S. while fresh fillets are sold to European countries (IMF 2003).

Analysis of Seafood Watch® Criteria

Criterion 1: Use of Marine Resources

Background
Arctic char are general carnivores, consuming fish and insects in the wild. In aquaculture operations, salmonids such as Arctic char are typically fed a compound feed containing fishmeal and fish oil (Weber 2003). The amount of fishmeal and fish oil used in the feed varies with the species being farmed and the farming method used. Anchovy, sardine, pilchard, capelin, and sandeel are the main species used to produce fishmeal and fish oil (SAMS 2002). A third of the total global fisheries catch is converted to fishmeal (Goldburg et al. 2003). Capelin and herring are the most common industrial fish harvested in Norway, Iceland, and Canada (Hardy and Tacon 2002), where most of the Arctic char production occurs. Although some of these fishes (e.g., sandeel and capelin) are not used for human consumption (FIN 2003), as forage fish they play an important role in marine ecosystems (Weber 2003). Such fish support populations of marine mammals, seabirds, and commercially valuable fishes (Weber 2003), and

overexploitation of some capelin and sandeel stocks has been implicated in the decline of certain cod stocks (Hislop 1996).

It has been argued that the increased harvest of small pelagic fishes in reduction fisheries to produce fishmeal and fish oil has the potential to impact marine ecosystems, and limit the future of aquaculture production of species dependent on compound feeds (Naylor et al. 2000). However, it has also been argued that the aquaculture sector's increased use of fishmeal and fish oil can be addressed by reducing the amount of fishmeal and fish oil used in poultry and pig feed (Barlow 2002). One option for reducing the amount of fishmeal and fish oil in aquafeeds is to substitute plant protein for animal protein, which also has the potential to reduce the amount of phosphorous pollution in aquatic environments (FAO 2003). Potential trade-offs associated with substituting plant proteins for fishmeal and fish oil include changes in the composition, texture, and taste of the fish, as well as human nutritional concerns. Fatty acids from plant oils result in lower levels of omega-3 fats that are healthy for human consumption (Johnston 2002). Additionally, without sufficient levels of certain amino acids, fish may experience nutritional deficiencies (Stickney 1994).

In 1999, the major aquaculture users of fishmeal were salmon (21%), marine shrimp (19%), marine fish (10%), eels (9%), and trouts and sturgeons (8%) (FAO 2002). Aquaculture expansion trends estimate that the major fishmeal consumers will be salmon (24%), marine fish (20%), redfish (20%), and marine shrimp (11%); it is expected that the proportion of fishmeal used in trout and eel aquatic feed will be much smaller due to the average percentage growth rates of these species groups (FAO 2002). In 2002, aquaculture was the primary user of fishmeal, followed by poultry, pigs, ruminants, and other terrestrial farmed species; the use of fishmeal by the aquaculture industry is projected to increase from 34% in 2002 to 48% in 2010 (Figure 2) (Barlow 2002). Fish oil use by the aquaculture industry is projected to increase from 56% in 2002 to 79% in 2010 (Figure 3) (Barlow 2002).

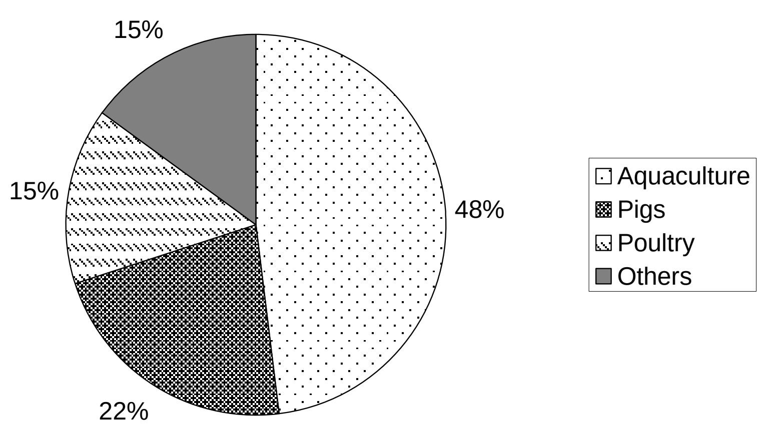

Figure 2. Projected fishmeal use in 2010 (Figure from Barlow 2002).

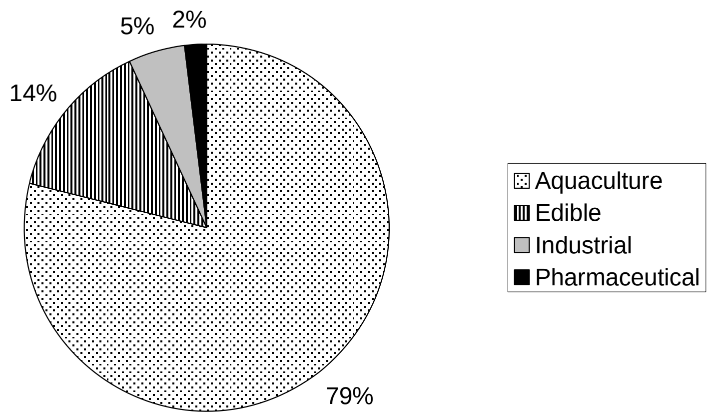

Figure 3. Projected fish oil use in 2010 (Figure from Barlow 2002).

Farmed Arctic char feed use

The primary concern associated with the use of fishmeal and fish oil in aquaculture feed is the high input of wild fish compared to the amount of farmed fish produced. There are three components that need to be considered when determining the quantity of marine resources used to produce farmed fish: the amount of wild-caught fish used to create fishmeal and fish oil; the inclusion rate, or the average percentage of fishmeal and fish oil in Arctic char feed; and the Feed Conversion Ratio (FCR), or the average efficiency that Arctic char convert feed to body weight.

Inclusion rates

Because the farming of Arctic char is limited relative to other salmonids such as salmon and trout, there are few published estimates of inclusion rates for the feed used to raise Arctic char. Inclusion rates vary according to the age of the fish being raised, as well as the feed manufacturer. Arctic char are typically fed a modified trout feed, where fishmeal is the primary source of protein and fish oil is used to provide a high lipid content and therefore higher energy levels for the fish (Hinshaw 1999). Estimates of the percentage of fishmeal and fish oil used in trout feed range from 30% - 35% fishmeal and 15% - 20% fish oil (Naylor et al. 2000; Weber 2003). Therefore, the total inclusion rate for fish products in Arctic char feed ranges from 45% - 55%. While the amount of fishmeal in trout feed is expected to decrease to 25% by 2010, the amount of fish oil is not expected to change (Weber 2003).

Feed Conversion Ratio (FCR)

The general definition of FCR is the amount of dry feed required to produce one unit of wet fish (Weber 2003), and estimates of FCR vary with the aquaculture operation. Despite a low FCR of 1.2:1 for Atlantic salmon (Tacon and Forster 2000; Morris et al. 2003), two to five pounds of wild fish are used to produce one pound of farmed salmon because of high inclusion rates (SAMS 2002). Like other salmonids, Arctic char can exhibit feed conversion ratios ranging from 1:1 (Summerfelt et al. 2004) to 1.2-1.4:1 (J. Rose, pers. comm.).

Ratio of wild fish to farmed Arctic char
Estimates of the ratio of wild fish to fed farmed fish are 3.16:1 for salmon and 2.46:1 for trout (Naylor et al. 2000). The fishmeal industry estimated in 2001 that the ratio of wild fish and fish parts used to produce fishmeal and fish oil was 4.5:1 (FIN 2002). The following calculations were used to estimate the wild fish input to farmed fish output ratio:

Conversion for fishmeal

(4.5 kg wild fish/1 kg fishmeal) (.325 kg fishmeal/1 kg feed) (1.2 kg feed/1 kg Arctic char) = 1.76 kg wild fish/1 kg Arctic char

Conversion for fish oil

(8.3 kg wild fish/1 kg fishmeal) (.175 kg fishmeal/1 kg feed) (1.2 kg feed/1 kg Arctic char) = 1.74 kg wild fish/1 kg Arctic char

These calculations were not added together, as that would result in double-counting the wild fish inputs required to grow the farmed fish. Instead, the larger of the two values, 1.76, represents the ratio of wild fish input to farmed Arctic char output.

Arctic Char Feeding Behavior
The optimum feed particle size is 1.6-1.7% of fork length for 73-110 mm Arctic char, and 2.0-2.4% of fork length for 121-400 mm Arctic char (Tabachek 1993). The greatest weight gain and feed efficiency was obtained with diets containing 54% protein and 20% lipid; diets containing 44% protein and 20% lipid resulted in a minor reduction in weight gain but at a lower cost per kilogram of weight gain (Tabachek 1993). It has also been noted that Arctic char take feed from the bottom and the water column (Jørgensen and Jobling 1989, 1990; Tabachek 1993); this benthic feeding behavior is better suited for tank culture rather than net pens, where a large proportion of the feed would be lost (Heasman and Black 1998). At one farm in Iceland, Arctic char are raised in tanks with salmon, where the char mainly consume the food that has settled to the bottom of the tank, thereby minimizing the waste of fish feed (Georgesson and Fridleifsson 1996).

Stock status of the reduction fishery
Although numerous management measures exist for the majority of the species used to produce fishmeal and fish oil (Barlow 2002), the fish stocks harvested to produce fishmeal and fish oil are considered fully exploited (Hardy and Tacon 2002). For instance, anchovy, sardine, capelin, and herring are managed with total catch limits, area catch limits, minimum mesh sizes, fleet cap controls, closed areas, seasonal bans, and minimum landing sizes (Barlow 2002). In Europe, herring and capelin are the most heavily harvested species for fishmeal; capelin is considered "inedible feed grade fish" while herring is primarily harvested for human consumption (FIN 2004). Capelin in the Barents Sea has been classified by the International Council for the Exploration of the Sea (ICES) as being "outside safe biological limits", and it was recommended that no fishing for capelin occur in 2004 (ACFM 2003). Capelin stocks in Iceland and east Greenland are in better shape; Spawning Stock Biomass (SSB) was 10,000 mt above the minimum amount required of this fishery at the end of the fishing season, and ICES

recommended that areas of high juvenile abundance be closed (ACFM 2003). The status of herring stocks in Europe vary according to location; the status of some stocks are unknown, some are considered within safe biological limits, and one is considered outside of safe biological limits (ACFM 2003).

U.S. trout feeds also contain fishmeal and fish oil derived from anchovy, herring, and menhaden. Peruvian anchoveta (anchovy) are the primary source of fishmeal, and anchovy biomass has been increasing since the 1997/98 El Niño event (FIN 2004). Stocks are managed by licensing, closed seasons, and a minimum landing size (FIN 2004). U.S. stocks of Atlantic menhaden and Atlantic herring are not overfished, and overfishing is not occurring (NMFS 2003). Although Atlantic menhaden are not managed by a federal Fishery Management Plan (FMP), they are managed by the Atlantic States Marine Fisheries Commission (ASMFC) Interstate Fisheries Management Plan for Atlantic Menhaden (AMPRT 2003). Atlantic herring are managed by the New England Fishery Management Council (NEFMC) in coordination with the ASMFC (NMFS 2003).

Synthesis
The stock status of the reduction fisheries used for producing fishmeal and fish oil varies by fishery. The status of capelin, for instance, is a moderate conservation concern; for one capelin stock the current SSB is just slightly above the minimum level required at the end of the fishing season, and the other is considered outside of safe biological limits. The status of herring stocks varies with location, and is considered a moderate conservation concern. Farmed Arctic char are either from closed life cycle hatcheries, or are wild caught but the collection does not result in depletion of the brood stock, wild juveniles, or associated organisms. The ratio of wild fish used in aquaculture feed to farmed Arctic char, according to the calculaitons above, is 1.76, which is a moderate conservation concern

Use of Marine Resources Rank:

Low **Moderate** High Critical

Criterion 2: Risk of Escaped Fish to Wild Stocks

There are a number of risks posed to wild fish stocks by escapes of farmed fish. The genetic diversity of wild stocks can be compromised if escaped farm fish reproduce successfully with wild fish. Escaped farmed fish may also compete with wild fish stocks for resources and habitat, and can spread disease to wild stocks of fish. However, the risk of these issues arising from Arctic char aquaculture is limited, as most Arctic char aquaculture occurs in land-based, closed systems. There is however some Arctic char production in flow-through systems and netpens.

Frequency and Impact of Escapes
Arctic char are generally not farmed in open netpen systems due to the high mortality and reduced growth rates observed when these fish are raised in cold seawater temperatures

(Reinsnes and Wallace 1988). If Arctic char are raised in open netpens, they must be transferred to freshwater or brackish water during the winter months (Heggberget et al. 1994). For this reason, Arctic char are primarily raised in freshwater land-based facilities. As these land-based systems are closed, there is no evidence that farmed fish regularly escape to the surrounding environment. However, even in closed systems, escapes are possible. For instance, in 2003, a burst liner caused water and fish contained in a tank to spill out onto an adjacent gravel road at an aquaculture operation in Canada. According to a government biologist, the Arctic char did not pose any risk to the environment, as there was no link from a nearby creek to the general river system, the aquaculture operation was disease free, and the fish produced there were sterile (Icy Waters 2003). If escapes were an issue, it is not likely that escaped Arctic char would be able to out compete or breed with wild stocks of Arctic char. In North America, the main supplier of Arctic char eggs only sells triploid eggs, which create sterile fish. Therefore, even if farmed char grown from the triploid eggs did escape from an aquaculture facility, they would not be reproductively viable. To date, there is no empirical evidence of competition of escaped farmed Arctic char with wild fish for critical food resources or habitats.

There is no evidence of the establishment of self-sustaining feral stocks, or evidence of genetic introgression through successful crossbreeding. There is also no evidence of spawning disruption to date. Arctic char populations in Canada are not genetically equivalent (Rogers and Davidson 2001). There is evidence of reduced genetic diversity in hatchery-reared Arctic char from Fraser River in Labrador, compared to the wild population that the broodstock originated from (Rogers and Davidson 2001). Nonanadromous char occur in either a benthic or pelagic morph, and are reproductively isolated (Hartley et al. 1992). There are numerous discrete sub-populations of morphologically, ecologically, and genetically distinct sympatric groups of Arctic char (Jonsson et al. 1988). Some wild stocks of Arctic char in both areas have been depleted either due to habitat destruction, caused by eutrophication, or overfishing. The stock status of wild Arctic char varies with location; some wild stocks have been depleted due to eutrophication and acidification of lakes and streams. Although there are numerous strains of Arctic char, introduced fish are not likely to establish a new population in the wild, or hybridize with wild fish (Englbrecht et al. 2002).

Synthesis
Arctic char aquaculture operations pose little risk of deleterious effects to wild fish stocks through the escape of farmed fish. Most Arctic char aquaculture occurs in land-based, closed systems and therefore is unlikely to affect wild stocks of Arctic char through the escape of farmed fish. Although farmed Arctic char in certain areas may be native and genetically distinct from wild stocks, escapes are not likely because the majority of Arctic char aquaculture occurs in closed-systems. To date, there is no evidence of deleterious effects of Arctic char escapes on wild fish stocks. The risk of escaped fish to wild stocks therefore rates as a low conservation concern.

Risk of Escaped Fish to Wild Stocks Rank:

Low Moderate High Critical

Criterion 3: Risk of Disease and Parasite Transfer to Wild Stocks

Another risk associated with escaped farmed fish is the amplification, retransmission, or introduction of diseases or parasites to wild fish stocks. This is more of a problem for open systems than for closed systems such as those used to raise Arctic char. To date, there is no evidence that Arctic char has introduced or translocated novel diseases or parasites to wild stocks. An additional safeguard is that in North America, much of the available seedstock has been tested and certified free from certain salmonid pathogens (Summerfelt et al. 2004). Because of the nature of closed systems, there are low bio-safety risks inherent in the aquaculture operations.

It is economically advantageous to limit the presence of infectious diseases in aquaculture facilities, as such diseases are a primary cause of decreased production and profits (Lillehaug et al. 2003). Arctic char is highly resistant to most known contagious diseases, according to Iceland's Veterinary Office for Fish Diseases. In both Iceland and Norway, all prescriptions for antibacterial drugs used on farmed fish must go through official control (e.g., in Norway, all prescriptions are sent to the Directorate of Fisheries) (Lillehaug et al. 2003; G. Jónsson, pers. comm.). In Norway, Atlantic salmon represented 87% of the prescriptions, rainbow trout 4.5%, turbot 3.8%, halibut 2.1%, Atlantic cod 1.2%, European eel 0.3%, and Arctic char 0.3% over a 10-year period (Lillehaug et al. 2003). From 1991 to 2000 Arctic char were treated for furunculosis (n=10), *Aeromonas salmonicida* (n=4), vibriosis (n=4), bacterial gill disease (n=1), fry disease (n=1), and experiment (n=1) (Lillehaug et al. 2003). During the 1990s, the overall use of antibacterial drugs in aquaculture operations in Norway decreased by 99%, despite an increase in the production of farmed fishes (Grave et al. 1999).

Fish disease monitoring and surveillance in Iceland has been guided by national legislation for over 40 years. Since 1985 all fish farms in Iceland have been under obligatory and regular fish health surveillance (G. Jónsson, pers. comm.). No viral fish diseases have been detected in Iceland and bacterial infectious diseases (e.g., atypical furunculosis, cold water vibriosis, and winter ulcers) have been controlled with the use of vaccines (G. Jónsson, pers. comm.).

Synthesis

There is very little risk of either the amplification or retransmission of diseases or parasites to wild fish stocks from escaped Arctic char. There is likewise no evidence of species introductions or translocations of diseases or parasites to wild fish stocks. This is mainly due to the land-based, closed-systems generally used to raise Arctic char, which have controls on effluent release, thereby reducing any likelihood of contaminating the surrounding environment. The risk of disease transfer to wild fish stocks from farmed Arctic char therefore rates as a low conservation concern.

Risk of Disease and Parasite Transfer to Wild Stocks Rank:

Low Moderate High Critical

Criterion 4: Risk of Pollution and Habitat Effects

Pollution from aquaculture operations has the potential to affect the surrounding environment in the form of animal waste, excess feed, or therapeutants (antibiotics and biocides). There exists a higher potential in open systems than in closed systems to pollute and affect marine habitats, as effluent in open systems is not treated, but discharged directly into the environment. The limited production of Arctic char, in concert with land-based aquaculture operations, minimizes potential pollution and habitat effects. Best Management Practices (BMPs) established by individual farms can further reduce the effect of effluent on the environment surrounding aquaculture operations.

Effluent effects
Fishmeal is a source of phosphorus that occurs in aquaculture effluent (Flimlin et al. 2003). The Environmental Protection Agency (EPA) has established environmental regulations for effluent phosphorous levels (Flimlin et al. 2003). Herbicides may be used in tank-based aquaculture to reduce the presence of aquatic weeds and algal blooms (Goldburg et al. 2003). Effluent water from Arctic char operations is substantially treated before discharge, either as part of a recirculating system or settling ponds. To maintain water quality, recirculating systems contain treatment units to remove ammonia, carbon dioxide, and total suspended solids (TSS), and are also provided with adequate mass and concentration of dissolved oxygen (DO) to meet the carrying capacity of the operation (Summerfelt et al. 2004). There is no evidence of substantial local effluent effects surrounding Arctic char aquaculture operations such as altered benthic communities or the presence of signature species. There is also no evidence of regional effluent effects, such as harmful algal blooms and altered nutrient budgets because of these features. One aquaculture operation in Canada faced a public hearing regarding increased effluent build up and algal blooms in a pond downstream from the aquaculture operation; the company has made an effort to reduce phosphorous effluent by using a phosphorous-reduced diet (Cutland 2004).

Habitat effects
Arctic char aquaculture operations are land-based, and occur in various regions, but generally do not occur in ecologically sensitive areas such as coastal or offshore waters, or coastal wetlands or mangroves. Due to the closed systems used to farm Arctic char, there is a low impact on surrounding habitats.

Synthesis
The risk of pollution and habitat effects is low in most Arctic char aquaculture operations. Effluent water is treated in recirculating systems, settling ponds, or reconstructed wetlands, and there is no evidence of local effluent effects such as altered benthic communities or the presence of signature species. There are no known effluent effects from Arctic char aquaculture. Arctic char aquaculture operations are generally land-based, and located in areas of low ecological sensitivity. Habitat effects of these aquaculture operations are therefore minimal. The risk of pollution and habitat effects rates as a low conservation concern.

Risk of Pollution and Habitat Effects Rank:

Low	Moderate	High

Criterion 5: Effectiveness of the Management Regime

Iceland

The Directorate of Freshwater Fisheries (DFF) is responsible for managing freshwater fisheries and aquaculture operations. The DFF administers and enforces the Salmonid Fisheries Act, issues permits and coordinates salmonid farming licenses in cooperation with environmental and regulatory agencies, and collects statistics regarding freshwater aquaculture operations, in addition to other duties (DFF 2004).

Although much of the Salmonid Fisheries Act refers specifically to salmon farming, the regulations within the Act also apply to Arctic char and trout farming in Iceland. As of 2003, official standards for aquaculture units were being developed. Enhancement of rivers and lakes is only permitted using fish stocks from the same fishing waters, and the transport of salmonids from fish farms into natural fishing waters for angling is prohibited (Ísaksson 2003). All aquaculture operations are under fish health surveillance, and Iceland follows European Union regulations concerning disease control measures (Ísaksson 2003).

Canada

In Canada, a regulatory and policy framework was established by the federal government in the 1995 Aquaculture Development Strategy (Brennan 1999). Department of Fisheries and Oceans Canada (DFO) established an Office of Sustainable Aquaculture (OSA) in 2001, and launched a six-point Aquaculture Action Plan. While the federal government's role includes research, technology transfer, and establishment of the regulatory framework, provincial governments are responsible for issuing licenses and permits and regulating farm activities such as escapes, waste management, and animal health. One of the OSA's mandates includes federal-provincial harmonization. Regional aquaculture issues are handled by the Regional Aquaculture Coordination (RCA) offices; their duties include coordinating the site application process, and regional policy and program development.

There are several DFO sectors with responsibilities related to aquaculture in Canada. The Science Division conducts research on the interaction between wild and cultured finfish and shellfish stocks, and is also responsible for health-related regulations and inspections. The Habitat Management Branch reviews proposals for the establishment of salmon farms, as they use open netpens. The Fisheries Act provides regulatory authority to define and set limits for the discharge of effluent into waters inhabited by fish (Brennan 1999).

United States

There is no federal agency in the U.S. that has been charged with the lead role for aquaculture (Brennan 1999). Agencies with significant regulatory roles include the U.S. Army Corps of Engineers, the EPA, and the FDA (Food and Drug Administration). The National Aquaculture Act of 1980 established the Joint Subcommittee on Aquaculture, which serves as the federal coordinating group (Brennan 1999). The 2003 report of the Pew Oceans Commission made several recommendations pertaining to aquaculture, including strong effluent guidelines for aquaculture under the Clean Water Act, a permitting program for offshore aquaculture, the improvement of state oversight of aquaculture, and a federal approval process for genetically modified fish (Goldburg et al. 2003). The 2004 U.S. Commission on Ocean Policy report recommends the creation of a NOAA Office of Sustainable Marine Aquaculture, which would be responsible for “developing a comprehensive, environmentally-sound permitting, leasing, and regulatory program for marine aquaculture” (COP 2004).

In 2000, the U.S. Environmental Protection Agency (EPA) established discharge standards for commercial and public aquaculture operations. The proposed rule, published in 2002, describes guidelines for controlling effluents from flow-through, recirculating, and netpen systems (EPA 2002). The proposed guidelines will control the discharge of Total Suspended Solids (TSS), and limit the release of drugs, chemicals, pathogens, and non-native species (EPA 2002). The guidelines will apply to aquaculture operations producing at least 100,000 lbs annually in recirculating, flow-through, or netpen systems. EPA recommends TSS limitations for recirculating and flow-through systems, and feed monitoring for netpens. For the three types of aquaculture operations, EPA proposes BMPs to control the discharge of therapeutants, pathogens, and non-native species (EPA 2002). Aquaculture operations must obtain permits for the discharge of wastewaters to surface waters, and also register any chemicals that will be used with the EPA (JSA 2004).

Synthesis
Management of Arctic char aquaculture operations is generally thought to be effective. Better management practices do exist for aquaculture operations, although they vary by country. Licensing is used to control the siting, number, size, and stocking density of farms, and federal, state, and local laws are applied to current aquaculture operations. Siting and monitoring of aquaculture operations in the U.S. and Canada is generally the responsibility of state and provincial governments, respectively (Brennan 1999). There are effective measures to prevent disease and treat outbreaks, such as vaccine programs. There are also regulations on therapeutants, including their release into the environment. Predator controls for marine mammals and birds, such as acoustic deterrent devices, are not used in Arctic char aquaculture. It is unknown whether policies and incentives utilizing a precautionary approach against major risks to guide expansion of the aquaculture industry are in broad use. The effectiveness of the management regime rates as a low conservation concern.

Effectiveness of the Management Regime Rank:

Low Moderate High

Overall Evaluation and Seafood Recommendation

The use of marine resources in Arctic char aquaculture production rates as a moderate conservation concern because the ratio of wild fish input is approximately 1.8 times the amount of farmed fish produced. Because Arctic char are predominantly raised in land-based, closed systems, there is little risk of escaped farmed fish competing with or crossbreeding with wild stocks of Arctic char. Closed systems also reduce the risk of transfer of parasites and diseases to wild stocks. Habitat and pollution effects from Arctic char aquaculture operations are low due to effective effluent controls such as biofiltration and settling ponds. Management of Arctic char operations varies according to country and operation, but is generally thought to be highly effective. Existing management measures address licensing of farms, disease prevention, and effluent release into the environment. Overall, farmed Arctic char is ranked as a "Best Choice"

Table of Ranks

	Conservation Concern			
Sustainability Criteria	Low	Moderate	High	Critical
Use of Marine Resources		√		
Risk of Escaped Fish to Wild Stocks	√			
Risk of Disease and Parasite Transfer to Wild Stocks	√			
Risk of Pollution and Habitat Effects	√			
Management Effectiveness	√			

Overall Seafood Recommendation:

Best Choice ■ Good Alternative ■ Avoid ■

Acknowledgements

Seafood Watch® thanks Dr. Robert Stickney of Texas A&M University, Björn Theodórsson of the Icelandic Institute of Freshwater Fisheries, and two anonymous reviewers who graciously reviewed this report for scientific accuracy. Scientific review does not constitute an endorsement of the Seafood Watch® program or its recommendations on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

References

ACFM. 2003. ACFM Report 2003. ICES Advisory Committee on Fishery Management. http://www.ices.dk/committe/acfm/comwork/report/asp/ACFMRep.asp.

ADF&G. 2006. Arctic char. Alaska Department of Fish & Game. Accessed 2006. Available at: http://www.adfg.state.ak.us/pubs/notebook/fish/a%5Echar.php.

AMPRT. 2003. 2003 review of the fishery management plan for Atlantic menhaden (*Brevoortia tyrannus*). Prepared by the Atlantic Menhaden Plan Review Team.

Arenson, A. M., E. H. Jorgensen, and M. Jobling. 1993. Feed intake, growth and osmoregulation in Arctic charr *Salvelinus alpinus* following abrupt transfer from freshwater to more saline water. Aquaculture **114**:327-338.

Baardvik, B. M., and M. Jobling. 1990. Effect of size-sorting on biomass gain and individual growth rates in Arctic charr *Salvelinus alpinus*. Aquaculture **90**:11-16.

Baker, R. F., and G. B. Ayles. 1990. The effects of varying density and loading level on the growth of Arctic char *Salvelinus alpinus* and rainbow trout *Oncorhynchus mykiss*. World Aquaculture **21**:58-62.

Barlow, S. M. 2002. The world market overview of fishmeal and fish oil. Paper presented to the 2nd Seafood By-Products Conference, Alaska in November 2002.

Baroudy, E., and J. M. Elliott. 1994. The critical thermal limits for juvenile Arctic charr *Salvelinus alpinus*. Journal of Fish Biology **45**:1041-1053.

Brennan, J. 1999. Aquaculture in the Gulf of Maine: a compendium of federal, provincial, and state regulatory controls, policies, and issues. Prepared for the Gulf of Maine Council on the Marine Environment.

Christiansen, J. S., and M. Jobling. 1990. The behavior and the relationship between food intake and growth of juvenile Arctic char, *Salvelinus alpinus* L., supjected to sustained exercise. Canadian Journal of Zoology **68**:2185-2191.

COP. 2004. Preliminary Report of the U.S. Commission on Ocean Policy. Governors' Draft, Washington DC, April 2004. Available at http://oceancommission.gov/documents/prelimreport/00_complete_prelim_report.pdf.

Cutland, L. 2004. Canada's largest Arctic charr producer faces environmental scrutiny. Intrafish News.

Damsgard, B., A. M. Arnesen, B. M. Baardvik, and M. Jobling. 1997. State-dependent feed acquisition among two strains of hatchery-reared Arctic charr. Journal of Fish Biology **50**:859-869.

DFF. 2004. Revision of the Icelandic salmonid management system. Directorate of Freshwater Fisheries. Accessed 2004. http://www.veidimalastjori.is/.

DFO. 2001. North Labrador Arctic charr. Stock Status Report D2-07. Department of Fisheries and Oceans Canada.

DFO. 2004a. Arctic char species description. Department of Fisheries and Oceans Canada. Accessed 2004. http://www.dfo-mpo.gc.ca/zone/underwater_sous-marin/omble/char-omble_e.htm?template=print.

DFO. 2004b. Stock status report 2004/010. Fisheries and Oceans Canada. Accessed March 20, 2006. Available at: http://www.dfo-mpo.gc.ca/csas/Csas/status/2004/SSR2004_010_e.pdf.

Englbrecht, C. C., U. Schliewen, and D. Tautz. 2002. The impact of stocking on the genetic integrity of Arctic char (*Salvelinus*) populations from the Alpine region. Molecular Ecology **11**:1017-1027.

EPA. 2002. Draft guidance for aquatic animal production facilities to assist in reducing the discharge of pollutants. United States Environmental Protection Agency. Accessed 2004. http://www.epa.gov/ost/guide/aquaculture/guidance/complete.pdf.

FAO. 2002. Use of fishmeal and fish oil in aquafeeds: further thoughts on the fishmeal trap. by M.B. New and U.N. Wijkstrom. FAO Fisheries Circular No. 975. Rome.

FAO. 2003. Review of the state of world aquaculture. FAO Fisheries Circular No. 886. Food and Agricultural Organization of the United Nations, Rome.

FIN. 2003. Fishmeal from sustainable stocks 2003. Fishmeal Information Network. Accessed 2004. http://www.gafta.com/fin/sustainability.pdf.

FIN. 2004. Sustainability dossier. Fishmeal Information Network. Accessed 2004. http://www.gafta.com/fin/FINsustain.pdf.

Flimlin, G., S. Sugiura, and R. P. Ferraris. 2003. Examining phosphorous in effluents from rainbow trout (*Oncorhynchus mykiss*) aquaculture. Rutgers Cooperative Extension, New Jersey Agricultural Experiment Station, Rutgers, The State University of NJ, New Brunswick, NJ.

Georgsson, L. S., and G. O. Fridleifsson. 1996. High technology in geothermal fish farming at Silfurstjarnan Ltd., NE-Iceland. Geo-Heat Center Quarterly Bulletin 17 (4). Accessed 2004. http://geoheat.oit.edu/bulletin/bull17-4/art29.htm.

Goldburg, R. J., M. S. Elliott, and R. L. Naylor. 2003. Marine aquaculture in the United States. Prepared for the Pew Oceans Commission.

Grave, K., A. Lillehaug, B. T. Lunestad, and T. E. Horsberg. 1999. Prudent use of antibacterial drugs in Norwegian aquaculture? Surveillance by the use of prescription data. Acta Vet Scand **40**:185-195.

Guobergsson, G. 2002. Icelandic salmon, trout and charr catch statistics 2001. VMST-R/0208. Institute of Freshwater Fisheries, Reykjavik, Iceland.

Hardy, R. W., and A. G. J. Tacon. 2002. Fish meal: historical uses, production trends and future outlook for sustainable supplies. *in* R. R. Stickney and J. P. McVey, editors. Responsible marine aquaculture. CABI Publishing, Wallingford, UK.

Hartley, S. E., C. McGowan, R. B. Greer, and A. F. Walker. 1992. The genetics of sympatric Arctic charr *Salvelinus alpinus* populations from Loch Rannoch, Scotland. Journal of Fish Biology **41**:1021-1031.

Heasman, M. S., and K. D. Black. 1998. The potential of Arctic charr, *Salvelinus alpinus* (L.), for mariculture. Aquaculture Research **29**:67-76.

Heggberget, T. G., P. Grotnes, A. Klemetsen, R. Richardsen, and O. Ugedal. 1994. Culture of Arctic char - possibilities in Norway. Transactions of the American Fisheries Society **123**:435-444.

Hinshaw, J. M. 1999. Trout production: feeds and feeding methods. SRAC Publication No. 223. Southern Regional Aquaculture Center.

Hinshaw, J. M. 2004. Department of Zoology, NCSU. Department of Zoology, NCSU. Personal communication.

Hislop, J. R. G. 1996. Changes in North Sea gadoid stocks. ICES Journal of Marine Science **53**:1146-1156.

Icy Waters. 2003. Burst liner causes fish loss. Accessed 2004. http://www.icywaters.com/news/news.htm.

IMF. 2003. Fish farming - processing and markets. The Icelandic Ministry of Fisheries. Accessed 2004. http://www.fisheries.is/process/farming.htm.

Isaksson, A. 2003. Standing committee on the precautionary approach: how does Icelandic legislation conform to NASCO resolutions. Twentieth Annual Meeting of NASCO, Edinburgh, Scotland, 2 - 6 June 2003.

Jobling, M. 1983. Effect of feeding frequency on food intake and growth of Arctic charr, *Salvelinus alpinus* L. Journal of Fish Biology **23**:177-185.

Jobling, M., and B. M. Baardvik. 1994. The influence of environmental manipulations on interand intra- individual variation in food acquisition and growth performance of Arctic charr, *Salvelinus alpinus*.

Johnson, L. 1980. The Arctic char *Salvelinus alpinus*. *in* E. R. Balon, editor. Chars. Salmonid fishes of genus *Salvelinus*. The Hague, the Netherlands.

Johnston, W. G. 2002. Arctic charr aquaculture. Blackwell Publishing, Osney Mead, Oxford.

Jonsson, B., S. Skulason, S. S. Snorrason, O. T. Sandlund, H. J. Malmquist, P. M. Jonasson, R. Gydemo, and T. Lindem. 1988. Life-history variation of polymorphic Arctic charr (*Salvelinus alpinus*) in Thingvallavatn, Iceland. Canadian Journal of Fisheries and Aquatic Sciences **45**.

Jonsson, G. 2004. Veterinary Officer for Fish Diseases, Institute for Experimental Pathology. Personal communication.

Jorgensen, E. H., J. S. Christiansen, and M. Jobling. 1993. Effects of stocking density on food intake, growth performance and oxygen consumption in Arctic charr *Salvelinus alpinus*. Aquaculture **110**:191-204.

JSA. 2004. Regulatory agencies. Joint Subcommittee on Aquaculture. Accessed 2004. http://ag.ansc.purdue.edu/aquanic/jsa/federal_guide/regulato.htm.

Lillehaug, A., B. T. Lunestad, and K. Grave. 2003. Epidemiology of bacterial diseases in Norwegian aquaculture - a description based on antibiotic prescription data for the ten-year period 1991 to 2000. Diseases of Aquatic Organisms **53**:115-125.

Maitland, P. S., and A. A. Lyle. 1991. Conservation of freshwater fish in the British Isles: the current status and biology of threatened species. Aquatic Conservation **1**:25-54.

Maitland, P. S. 1995. World status and conservation of the Arctic charr *Salvelinus alpinus* L. Nordic Journal of Freshwater Research **71**:113-127.

McCarthy, I. D., C. G. Carter, and D. F. Houlihan. 1992. The effect of feeding heirarchy on individual variability in daily feeding of rainbow trout, *Oncorhynchus mykiss* (Walbaum). Journal of Fish Biology **41**:257-263.

Morris, P., and C. Beattie. 2003. Effects of the timing of the introduction of feeds containing different protein and lipid levels on the performance and quality of Atlantic salmon, *Salmo salar,* over the entire seawater phase of growth. Aquaculture **225**:41-65.

NASS. 1999. 1998 Census of Aquaculture. National Agriculture Statistics Service. Accessed 2004. http://www.nass.usda.gov/census/census97/aquaculture/aquaculture.htm.

Naylor, R. L., R. J. Goldburg, J. H. Primavera, N. Kautsky, M. C. M. Beveridge, J. Clay, C. Folke, J. Lubchenco, H. Mooney, and M. Troell. 2000. Effect of aquaculture on world fish supplies. Nature **405**:1017-1024.

NMFS. 2003. Annual report to Congress on the status of U.S. fisheries - 2002. U.S. Dept. Commerce, NOAA, NMFS, Silver Spring, MD.

NMFS. 2006. NOAA Fisheries Statistics Division. National Marine Fisheries Service. Accessed March 20, 2006. Available at: http://www.st.nmfs.gov/st1/index.html.

Nordeng, H. 1983. Solution to the "char problem" based on Arctic char *Salvelinus alpinus* in Norway. Canadian Journal of Fisheries and Aquatic Sciences **40**:1372-1387.

Palsson, J. O., M. Jobling, and E. H. Jorgensen. 1992. Temporal changes in daily food intake of Arctic charr *Salvelinus alpinus*, of different sizes monitored by radiography. Aquaculture **106**:51-61.

Petursdottir, T. E. 2002. Influence of feeding frequency on growth and size dispersion in Arctic char *Salvelinus alpinus* (L.). Aquaculture Research **33**:543-546.

Rogers, B., and W. Davidson. 2001. Arctic charr (*Salvelinus alpinus*) aquaculture review. Report prepared for the Prince Edward Island Aquaculture Alliance and the Aquaculture Association of Nova Scotia.

Rose, J. 2004. President, Icy Waters. Personal communication.

SAMS. 2002. Review and synthesis of the environmental impacts of aquaculture. Scottish Association for Marine Science and Napier University, Scottish Executive Central Research Unit. http://www.scotland.gov.uk/cru/kd01/green/reia.pdf.

Siikavuopio, S. I., and M. Jobling. 1995. The effect of stocking density on survival and growth of wild caught Arctic charr. Nordic Journal of Freshwater Research **71**:419-423.

Stickney, R. R. 1994. Principles of aquaculture. John Wiley & Sons, Inc., New York, NY.

Summerfelt, S. T., G. Wilton, D. Roberts, T. Rimmer, and K. Fonkalsrud. 2004. Developments in recirculating systems for Arctic char culture in North America. Aquacultural Engineering **30**:31-71.

Tabachek, J. L. 1993. A review of the feeding and nutrition of Arctic charr *Salvelinus alpinus* and priorities for future research. Pages 10-17 *in* S. Collison and J. Holder, editors. Special sessions on Arctic charr culture and intensive salmonid systems. Bulletin of the Aquaculture Society of Canada.

Tacon, A. G. J., and I. Forster. 2000. Global trends and challenges to aquaculture and aquafeed development in the new millenium. Pages 4-25 *in* International Aquafeed - Directory and Buyers' Guide 2001. T.RIA, Uxbridge, UK.

Tammi, J., M. Appelberg, U. Beier, T. Hesthagen, A. Lappalainen, and M. Rask. 2003. Fish status survey of Nordic lakes: effects of acidification, eutrophication and stocking activity on present fish species composition. Royal Swedish Academy of Sciences **32**:98-?

Theodorsson, B. 2004. Aquaculture Specialist, Institute of Freshwater Fisheries. Personal communication.

Thorarensen, H. 2004. Department Head, Holar Agricultural College. Personal communication.

Wallace, J. C., A. G. Kolbeinshaven, and T. G. Reinsnes. 1988. The effects of stocking density on early growth in Arctic charr *Salvelinus alpinus*. Aquaculture **73**:1-4.

Weber, M. L. 2003. What price farmed fish: a review of the environmental and social costs of farming carnivorous fish. Written for the SeaWeb Aquaculture Clearinghouse. Accessed 2004. http://www.seaweb.org/resources/sac/pdf/WhatPriceFarmedFish_high.pdf.

White, K., B. O'Neill, and Z. Tzankova. 2004. At a crossroads: will aquaculture fulfill the promise of the blue revolution? SeaWeb Aquaculture Clearinghouse. Accessed 2004. http://www.seaweb.org/resources/sac/pdf/At_Crossroads.pdf.