VOL 34 NO 10
OCTOBER 2009

Fisheries

American Fisheries Society • www.fisheries.org

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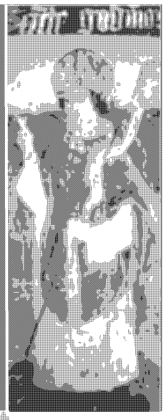

"Even the Evil Need a Place to Live": Wild Salmon, Salmon Farming, and Zoning of the Icelandic Coastline

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ABSTRACT: In this article, we provide an historical overview of Icelandic Atlantic salmon (*Salmo salar*) farming, wild stock management, and the often dichotomous philosophical bases for these activities. We then discuss how Iceland has sought to balance the benefits of salmon farming with the benefits of and risks to wild stock management, valuable recreational fisheries, and protection of native wild fish fauna. Under regulations enacted in 2001 and expanded in 2004, the coastline is zoned with respect to salmon cage-rearing; cage-rearing is not permitted in the bays and fjords into which the most valuable salmon rivers drain. The zoning is provided as a compromise between opposing views. As experience is gained from salmon farming in designated areas, this information will be used to plan future development of the cage-rearing industry in Iceland.

"Incluso los malos necesitan un lugar donde vivir": salmón silvestre, cultivo de salmón y zonación de la línea de costa Islándica

RESUMEN: En este artículo, se muestra un panorama histórico sobre el cultivo del salmón (*Salmo salar*), del manejo de poblaciones silvestres y de las bases filosóficas, y frecuentemente dicotómicas, de estas actividades. Se discute cómo en Islandia se han puesto en balance los beneficios del cultivo de salmón y los beneficios y riesgos del manejo de poblaciones silvestres, el valor de las pesquerías recreativas y la protección de la ictiofauna silvestre nativa. En conformidad con las regulaciones implementadas en 2001 y expandidas en 2004, se zonifica la línea de costa de acuerdo a la idoneidad para el cultivo de salmón; la estabulación del salmón en cajas no se permite en bahías y fiordos, dentro de los cuales descargan los ríos más importantes para el salmón del Atlántico. Esta zonación representa un compromiso entre posturas encontradas. A medida que se adquiera experiencia sobre esta actividad en las áreas designadas, esta información se utilizará para planear el desarrollo de la industria del cultivo de salmón en Islandia.

Bishop Gudmundur Arason from *Prestssaga Gudmundar góda* (*Sturlungasaga*) and a troll by Andreas Bloch (Norwegian, 1860–1917).

INTRODUCTION

Even the evil need a place to live.

In Sturlungasaga, *a collection of thirteenth century Icelandic sagas, the history of Gudmundur Arason (1161–1237; nicknamed "the Good") is recorded. According to one saga, amid the steep cliffs surrounding the island Drangey in Skagafjördur off the north coast dwelt trolls and other evil beings. So many men who sought to hunt the bountiful birds and their eggs fell to their deaths that hunting nearly ceased. When Gudmundur became bishop of Hólar, his kindness led him to send his men to the cliffs of Drangey to hunt, so that the poor could be fed. When several men were killed, Gudmundur, along with several priests, travelled to Drangey with a barrel of holy water. He and the priests descended the cliffs, singing hymns and splashing the holy water. When Gudmundur had nearly wended his way around all the cliff faces, a huge, hairy hand or paw holding a big, sharp knife emerged from the cliff face and cut two plies of the three-ply rope holding the good bishop. The third ply held because it had been soaked in holy water and blessed before the rope was made, and could not be destroyed by evil forces. When the being saw that he could not kill the bishop, he said to Gudmundur: "Stop your blessing…even*

the evil need a place to live." Gudmundur stopped the blessing, asked to be pulled up, and declared that part of the cliffs to be a refuge for the evil creatures to live in. People should not try to descend that cliff, which came to be called Heidnaberg, or "heathen cliff." It is said that nowhere on the island are there so many nesting birds, because no one tries to hunt or pick eggs there. Thenceforth, Gudmundur blessed many places, including places where evil supposedly dwelt, always leaving a place for the evil to live (Skórzewska 2007).

In the early twenty-first century, salmon management worldwide (for *Salmo* and *Oncorhynchus* spp.) faces a knotty problem of how to reconcile the economic benefits associated with salmon farming with the risks to long-term sustainability and biodiversity of wild salmon stocks (Gross 1998; Knudsen 2002; Kocik and Brown 2002). As increases in human population result in accelerated loss of wild habitat (Lackey et al. 2006) and greater emphasis on short-term economic development and fish protein to feed a hungry world (Stier 2007), the need for solutions becomes increasingly urgent (Gross 1998). In this article, we provide a brief historical overview of Icelandic Atlantic salmon (*Salmo salar*) farming and wild stock management. We then discuss how Iceland has sought to balance the benefits of salmon farming with the benefits of and risks to wild stock management and protection of native wild fish fauna.

FISH FARMING AND WILD STOCK MANAGEMENT

Salmon farming and wild salmon management, while superficially two sides of the same *króna* to a casual observer, embody fundamentally different philosophical views of humans' relation to nature. One view, fish farming or husbandry (Old Norse *húsbóndi*, or householder; modern Icelandic *bóndi* = farmer; *húsbóndi* = master of the house), has a production aquacultural philosophy similar to the agricultural perspective typical in Europe, Asia, and North America both before (from some native tribes) and especially after European settlement (Berry 1977; MacNeish 1992; Vasey 1992). It involves intensive or semi-intensive confinement and rearing of productive species or stocks on land (e.g, tanks), hatcheries, or in natural waters (Huet 1970; Andreŝka 1984) for direct or indirect human consumption. Stickney (1979:1) refers to aquaculture simply but appropriately as "underwater agriculture." Emphasis is on controlling as many aspects of the salmon life cycle as possible. While it is true that stocking of farmed fish has long been widely invoked as a potential solution to fish stock depletion from overfishing and habitat destruction (Fry 1854; United States Fish Commission 1884; Allard 1967), the impetus of most fish farming is consumption, and to a lesser extent production for commercial or recreational fishing (Tanner and Tody 2002). This fishing also usually leads to consumption, or is intended to eventually lead to it once stocks are restored or enhanced.

The other approach, wild salmon management, originally arose out of attempts to control harvest and improve simple habitat characteristics such as fish passage. Over the decades, it has come to be framed in a broader preservationist and ecological context, involving concepts such as respect for and preservation of wild, untamed nature (Goldman 1921; Errington 1963; Easley et al. 1990) and local adaptations of populations (the stock concept; Ricker 1972; Schaffer and Elson 1975; Scarnecchia 1983; Gudjónsson 1991a; Bourke et al. 1997), the need to understand natural population fluctuations (Ricker 1954; Ward and Larkin 1964), the ability to predict fluctuations (Jacobsen and Johansen 1921; Peterman 1982; Scarnecchia 1984a,b; Gudjónsson et al. 1995) and the importance of habitat complexity and ecosystem function (Lichatowich 1999). The importance of salmon biodiversity, long implicitly valued but often not articulated, has also been identified (Knudsen 2002). Wild fish management has also traditionally involved harvest, although as stocks have declined and human pressures have increased, greater emphasis has been placed on aesthetic and non-consumptive uses (Whoriskey et al. 2000).

In recent years, significant attempts have been made to reconcile this fish husbandry-wild fish dichotomy based on the idea that scientific and technological advances in raising salmon have been sufficiently great that the two views can be naturally merged. In each era of technological development since the late 1800s, the appropriate time for the merger has been perceived by at least some fish farming proponents to be at hand. The development of hatcheries to replenish and restore wild salmon runs, well-documented more than a century ago (e.g., Fry 1854; Stone 1884; Atkins 1884) has given way to the more subtle concept of supplementation. The idea is that the careful selection and rearing of hatchery fish from native brood stocks can accelerate the recovery of the wild fish stock, resulting in minimal loss of local adaptation (Steward and Bjornn 1990; BPA 2006). These efforts in the salmon realm mirror similar efforts of agrarianism designed to transform modern terrestrial agribusiness into a more ecologically sensitive enterprise (Berry 1977; Wirzba 2003). Despite major advances in salmon rearing technologies, evidence to date of benefits to wild stocks remains equivocal. Advocates for fish farming and wild salmon management continue to clash, as both seek to defend their preferred approach to fisheries management in modern society.

DOMESTICATION AND WILDNESS IN SOCIETY, NATURAL HISTORY, AND MYTH

This dichotomy of the domesticated versus the wild, the advance of society and control of nature versus those things or beings perceived as inimical to societal advance and control, results in a struggle in all modern societies (e.g., North America: Marsh 1864; Hornaday 1913; Goldman 1921), and Iceland is no exception. Hastrup (1990) discussed the roles of different living beings, real and imaginary, domesticated and wild, in the historical Icelandic landscape (1400-1800). Cows were perceived as domesticated (and feminine) and sheep as partly domesticated (and more masculine), but both were of the civilized human world. In contrast, the fox (*Vulpes lagopus*), sea eagle (*Haliaeetus albicilla*), raven (*Corvus corax*), and the occasional polar bear (*Ursus maritimus*) drifting in on pack ice were inhabitants of the wilderness that "played an important role in the Icelandic imagery of the hostile environment" (Hastrup 1990:251). In addition, there was an entire hidden dimension of the landscape inhabited by feral or wild beings outside of the sphere and control of civilized society: out-lying men or outlaws (*útilegumenn*), ghosts (*draugar*), trolls (*tröll*), and hidden people (*huldufólk*). Trolls in particular lived not only in nature, but were part of the wild landscape itself, turning to stone in sunlight. Hastrup (1990) went on to describe the roles of farming and fishing, the two key subsistence activities in the pre-industrial society, characterizing farming as harvest based

on planning and social organization, and fishing as a hunt based on an instantaneous (i.e., less easily planned and orchestrated) relation between man and his prey. In her words,

> *Farming and fishing had unequal positions in the economic order of the Icelanders…[and their]… conceptual world, where boundaries between the social and the wild, between culture and nature, were continually redrawn. Farming was incorporated into the social; … fishing was associated [for the most part] with the non-social, the wild….Farming represented nature domesticated; fishing took place in the untamed wilderness…. The social inside was defined as domesticated, controlled and settled. The outside was untamed, uncontrolled and moving. To fish was to engage temporarily in an appropriation of the wild…[which was] a dangerous activity. By stepping into the wild, Icelanders became vulnerable to forces beyond their control, whether these were…polar bears or útilegumenn* (Hastrup 1990:274-275).

Similar conceptions of the wilderness as something to be feared and domesticated are found among European immigrant settlers to North America (Nash 1973), most of whom had come from agricultural or partly agricultural societies. For native hunting and gathering tribes, who knew no other life, the modern notion of fear of wilderness may be exaggerated or erroneous (Oelschlaeger 1991). Regardless of which interpretation is correct, after settlement, domestic, agricultural societies tend to increase in size, which out of necessity results in still more domestication and control at the expense of the wild.

This age-old struggle between the domesticated and the wild is being waged with many fishes, and perhaps especially with the Atlantic salmon, which has lost most of its original wild habitat to advancing civilization as well as its numerical and economic advantage to domesticated fish (Shearer 1992; Gross 1998). For that species, scientific advances in both fish farming (Nash 2001; Stead and Laird 2002) and wild stock management (Shearer 1992) have been substantial in the past three decades. In the past decade, however, much effort has gone into evaluating the environmental risks of this expanding fish farming industry to aquatic systems, including wild salmon stocks (Waknitz et al. 2002; Jonsson and Jonsson 2006). As in many other salmon producing nations, Iceland's attempt at a solution is indicative of the historical and current importance of wild stocks and the continual advances of a modern technology-based society.

ICELAND'S NATIVE FISH AND FISHERIES

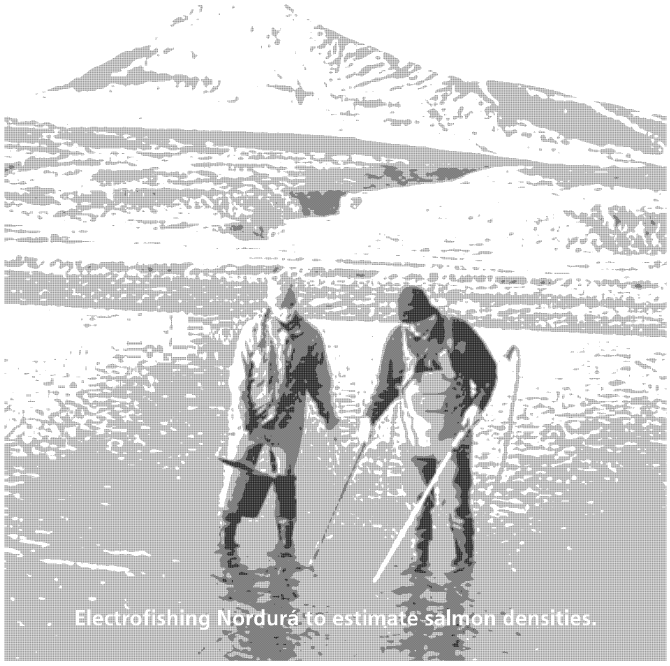
Species—The Atlantic salmon is one of only six native freshwater fish species in Iceland, the others being brown trout (*Salmo trutta*), arctic charr (*Salvelinus alpinus*), American and European eel (*Anguilla rostrata* and *A. anguilla*), respectively (perhaps one species; Williams and Koehn 1984), and three-spined stickleback (*Gasterosteus aculeatus*; Sæmundsson 1926; Jónsson 1972). The low fish species diversity is a result of Iceland's geographic isolation, its young age (Thórarinsson 1968), and the adverse climatic conditions during glacial periods (Buckland et al. 1986; Ingólfsson 1991). Atlantic salmon occur in more than 100 Icelandic rivers.

Fisheries Management—The earliest law in Iceland dealing with management of river fisheries was simple but effective. In early Icelandic law, it is stated: "So shall the gift of God run from coast to mountain," meaning that it was illegal to stop the run of salmonids with fences and traps. (www.am.hi.is/handritasafn/handritasafn.php?fl=6). Most likely this idea was in Icelandic law from the beginning of the Icelandic parliament (*Althingi*) founded in the year 930. For the first years a few men, members of the Althingi council (*lögréttumenn*), knew the law and were present at the parliament. Later (sometime before 1262), the law was recorded in the first written lawbook in Iceland (*Grágás*). A copy of the law was preserved in the old calfskin *Grágás* manuscripts *Stadarhólsbók* and *Konungsbók*. A later lawbook, *Jónsbók*, also included this provision. The purpose of the law was twofold: to allow fish to reach the upriver spawning grounds and to prevent the farmers at the estuary from harvesting all of the fish, so that the farmers further upriver also had a chance to fish. This purpose has been manifested in Icelandic law ever since.

Today, the Icelandic management of freshwater fisheries for migratory salmon, trout, and charr comprises a few key elements (Gudjónsson 1978; Veidimálastofnun 1988; Scarnecchia 1989). Iceland has prohibited ocean fishing for salmon since 1932 (Ísaksson et al. 1997). Private ownership of fishing rights is held by adjacent landowners, who are typically farmers. The landowners along a river must form a fishing association. The association usually leases the river for sport fishing, supervises fishing activities, and manages the finances. Annual limits are set on the number of rod days on each river each year. In many cases these limits have been nearly unchanged for decades. Catches are tallied through the use of logbooks (*veidibækur*), in which are recorded each fish caught, along with its sex and size. These logbooks provide accurate catch statistics for management and economic evaluation of the rivers. This system has historically generated a significant economic benefit to the fishery owners, with low capital investment, while ensuring sustainable use of the resource.

Riverine sport fisheries, principally on wild stocks, provide important revenue, especially to inhabitants of rural areas where alternative sources of income are few. The annual revenue of the sport fishery for Atlantic salmon is approximately 125 million euros and increasing (Agnarsson and Helgadóttir 2004), making it an important component of the tourism industry in Iceland. More than 30% of Icelanders fish on a regular basis (Toivonen et al. 2000), and people from around the world come each year to fish Iceland's salmon rivers (e.g., Thurston 1996). Ísaksson and Óskarsson (2003) reported that the direct and indirect revenues from Icelandic salmon may amount to 800 euros per angled salmon. In rural areas, the sport fishery accounts for up to 50% of all agricultural income.

Applied research—Although early surveys (Feddersen 1886; 1887) and applied research and management activities (e.g., Gudmundsson and Gígja 1942; Gíslason and Gudjónsson 2008) were conducted on selected rivers prior to the Second World War, the establishment of the Directorate of Freshwater Fisheries in 1946 began a new era for applied research and management of Icelandic salmon (Gudjónsson 1978). Significant research activities began soon thereafter (Gudjónsson 1953, 1982), resulting in progressively greater understanding of wild salmon. Populations were shown to have distinct differences in life history traits (Scarnecchia 1983; Einarsson et al. 1990; Gudjónsson 1991a) and genetic structure (Danielsdóttir et al. 1997). These stock differences represented, at least in part, local adaptations to distinct characteristics of salmon rivers found in Iceland (river types outlined by Rist 1956, Gardarsson 1979 and Gudjónsson 1990). Life history characteristics and stock size fluctuations were found to be strongly influenced by large-scale oceanographic and riv-



Electrofishing Nordurá to estimate salmon densities.

erine conditions (Hafsteinsson and Tómasson 1989; Gudjónsson et al. 1995), with distinctly different (and more variable) environmental conditions and stock size fluctuations occurring in the north of Iceland than in the south and west (Scarnecchia 1984a; Scarnecchia at al. 1989; Gudjónsson 1991a). Improvements in fish passage in many rivers resulted in increased production of wild fish (Hannesson 1988; Einarsson and Gudjónsson 1999; Hauksdóttir 1999; Einarsson et al. 2002). Tagging studies provided greater knowledge of salmon movements at sea, including their contributions to distant-water ocean fisheries off west Greenland and the Faroe Islands (Gudjónsson 1978).

ICELANDIC FISH FARMING

Along with increased knowledge of wild stocks came increased interest in rearing salmon (Helgason 1987), both for salmon farming and stocking into the wild (Gardarsson 1985; Ísaksson 1986). Intensive farming of salmon in Iceland for food production has been attempted by ocean ranching, land-based tank rearing, and cage-rearing. Fish farming of various types in Iceland has been reviewed by Gudjónsson (1978), Kristinsson (1992), Ísaksson et al. (1997), Jónsson (2000), Ísaksson and Óskarsson (2002), and Gunnarson (2008a,b); we summarize their reports here.

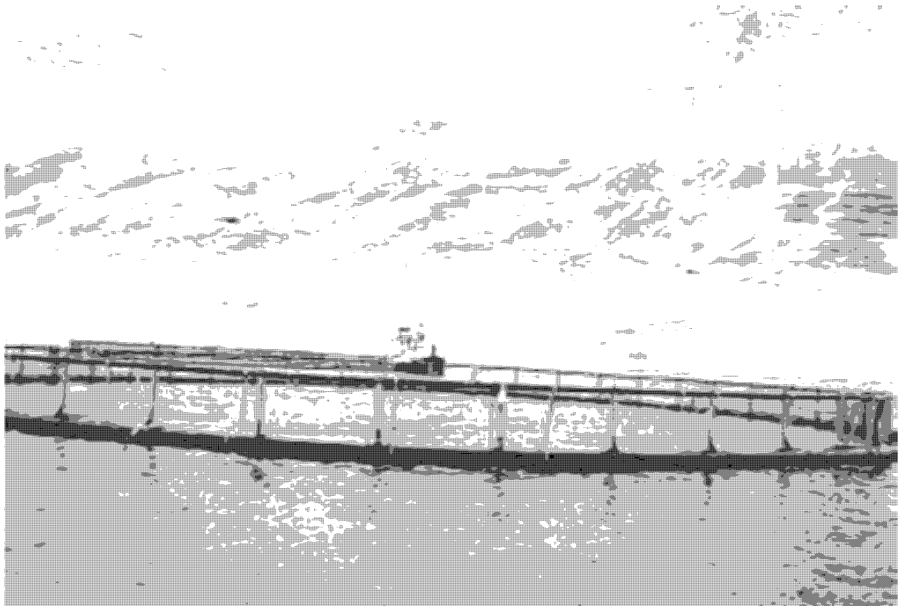
Early developments—Early efforts (1883-1943) were concerned with egg incubation and consisted mostly of small, inefficient operations of short duration. Lack of broodstock and inadequate technological development and expertise forced closures (Thórarinsson 1889). Feddersen (1886) reported on an incubation hatchery built in 1884 at the farm Reynivellir in Kjós near the river Laxá. Many hatcheries were built in the following years; one at the farm Alvidra near the river Sog was in operation for about four decades (Gíslason and Gudjónsson 2008). In 1932, the Reykjavík Municipal Hydro-electric Power Company operated a hatchery at the river Ellidaár with the capacity of hatching 1.2 million salmon ova. This hatchery was also operated for decades (Gudjónsson 1978:34). Salmon rearing was first begun in 1944 in Borgafjördur (Kristinsson 1992), and in 1952 the hatchery on Ellidaár began rearing salmon outdoors. Indoor facilities were added in 1964. In 1961, the Icelandic government built the Kollafjördur Experimental Fish farm near Reykjavík for the purposes of hatching and rearing salmonids to smolt size and to offer fish of various sizes for sale. Numerous rearing and release experiments were conducted over the years in association with this facility and stock, either by itself or in conjunction with other newly developing ranching, tank, or cage rearing facilities (e.g., Ísaksson 1985; Ísaksson and Óskarsson 1986; Jónasson 1996; Jónasson and Gjedrem 1997). By 1978, there were eight hatcheries in Iceland rearing salmonid fishes. Fishes reared at these hatcheries provided a basis and outlet for technology development (see several articles in Mathisen 1978) for future intensive fish farming activities, as well as fish for mitigation and enhancement of fisheries.

Ocean ranching—Ocean ranching of Atlantic salmon (i.e., large scale releases of salmon smolts by private companies with the intent of harvesting all the salmon upon return to the release site; Ísaksson and Óskarsson 2002) began with research at the Kollafjördur Fish Farm in the 1960s. Over the period 1964 to 1998, private ranching was conducted at numerous localities, peaking in the early 1990s when nearly 6 million smolts were released annually (Ísaksson et al. 1997). Ranching sites included two large operations in southwestern Iceland, two in western Iceland, and several smaller operations extending from the south coast to the northeast. Because of low return rates and resulting lack of economic viability, however, the number of ranches declined from nine in 1993 to five in 1996, three in 1997, and had ceased entirely by 2001 (Jónsson 2000; Ísaksson and Óskarsson 2002).

Land-based tanks—Land-based tank rearing began in small trials in the 1950s, but in 1978 the first land-based farm using pumped sea water was established near Grindavík in the southwest. Possible problems with escaping salmon were thus largely avoided. A selective breeding program was established in the early 1990s based on imported salmon strains from Norway. Production peaked in the late 1980s, but because of high investment costs and falling salmon prices (a result of increased salmon farming in other competing countries), few facilities remained by the late 1990s. As of 2008, most tank-based farms produce arctic charr (Gunnarson 2008b).

Cage rearing—Cage rearing of Atlantic salmon in Iceland was first conducted in Hvalfjördur in 1978. Interest grew in the 1980s such that 24 farms were scattered around the edges of the country by 1988. Unlike in Norway and other neighboring countries, however, results were not favourable (see Gunnarson 2008a:Figure 1.1; 2008b). Knowledge of salmon husbandry under Icelandic conditions was often inadequate. In addition, the quality and strength of the cages and related infrastructure varied greatly among farms. Smolts from a number of wild Icelandic salmon populations were used in the farms, but these trials were unsuccessful because of the harsh climatic conditions, including high wind exposure and low sea temperatures. By 2000 only one farm remained in operation.

Early in the new millennium, however, the industry underwent a Lazarus-like resuscitation. Interested salmon farmers claimed that cage rearing around Iceland could be successful because of the availability of better salmon strains, better cage technology, and increased rearing knowledge and experience. They have also



Salmon cage at Mjóifjördur, Eastern Iceland.

especially in the southwest. He analyzed the patterns of straying into rivers in relation to ranching and cage-rearing sites and found that the effects of straying decreased with increasing distance between the rearing sites and the river. A major concern with straying was possible negative genetic effects on locally adapted stocks (Gudjónsson 1988). Danielsdóttir et al. (1997) had shown distinct regional differences in the genetic make-up of Icelandic stocks (to support phenotypic differences observed years earlier; Scarnecchia 1983). They argued that "every effort should be made to avoid genetic mixing and consequent breakdown of stock differentiation" (Danielsdóttir et al. 1997:986). Salmon farming and enhancement should therefore be conducted with consideration for wild salmon in individual rivers.

argued that salmon farming could provide important revenue to the rural Icelandic economy. The new approach uses a combination of land-based and cage rearing: large smolts or small salmon are produced in land-based tanks and transferred to marine cages for rearing to market size. Large commercial fishing companies and fish processors expressed renewed interest in salmon farming, despite a lack of historical success. By 2004, 20 farms were operating. By 2007, the number of farms had decreased to 10 (Gunnarson 2008a). Interest remains strong, however. Some believe that projected climate changes may make cage rearing more feasible and ultimately profitable, not just for salmon but for species such as cod (*Gadus morhua*; Thorarensen 2006), which may be better adapted to the rigors of the Icelandic climatic and coastal conditions.

Past documented environmental problems—River owners, in contrast, have expressed concern that escape of cage-reared salmon into their rivers could damage the natural, comparatively unaltered salmon stocks and the pristine image of the rivers held by anglers. The salmon used in Icelandic salmon cage-rearing originated from Norway and are genetically distinct from Icelandic wild salmon populations (Danielsdóttir et al. 1997). They have also been subjected to a selective breeding program (Stahl 1983; Verspoor 1988). A major concern was that escapees would spawn with wild fish, resulting in genetic mixing and a breakdown of the local adaptations of the stocks. Other concerns were raised for the spread of parasites and diseases (Schiermeier 2003; McDowell 2002), and ultimately for potentially reduced income from the fisheries. Many of the rural areas with the most important salmon stocks and fisheries are the same locations where fish farming has been previously conducted or are most desirable for future development.

Icelandic studies in the 1990s found evidence of straying of cage-reared and ranched fish into rivers. Ísaksson et al. (1997) reported that, based on tag recoveries, at least 13,500 ranched salmon strayed into western rivers over the period 1988-1995, or at least 4.4% of the total wild adult population size in those rivers. Rivers close to ranching stations, such as Leirvogsá and Ellidáar, contained almost 20% strayed salmon. Similarly, Gudjónsson (1991b) found that large numbers of salmon escaped from cages and appeared in Icelandic salmon rivers,

RISK ASSESSMENT

In 2000, it was determined by the Institute of Freshwater Fisheries and the Ministry of Agriculture and Fisheries that a risk assessment, particularly of cage rearing (the only viable industry at the time), was needed. The assessment, which was conducted by the Institute of Freshwater Fisheries, reviewed evidence from cage culture operations worldwide and within Iceland, with emphasis on the potential effects of escaped non-native salmon on wild stocks.

Numerous results from the risk assessment, conducted over a five-month period and completed March 2001, were deemed relevant to management decisions. With regard to straying, evidence from Norway indicated that in the late 1990s, 2% to 5% of farmed salmon escaped from sea cages (Anonymous 1999) depending on the technical specification of the equipment used, the level of maintenance, and the exposure to wind. Survival rates of escapees were related to the season of the year and the stage of maturation at the time of escape: fish escaping in spring and summer had a higher chance of surviving than fish escaping in fall and winter (Hansen and Jonsson 1989). Salmon escaping as smolts or post-smolts tended to return to the site of escape and sometimes enter rivers in the vicinity (Hansen et al. 1989: Heggberget et al. 1993). Salmon escaping later in the year tended to stray more (Hansen et al. 1987). Overall, potential problems with straying were greater the closer the escaped fish were to wild stocks. This conclusion was later confirmed when in late summer of 2003, approximately 3,000 Norwegian-strain salmon escaped from a cage in eastern Iceland, of which about 14% were sexually mature (Gunnarsson and Beck 2004). A few of the escaped salmon from the cage were caught in salmon rivers both north and south of the farm site in the autumn of 2003 (Jónsson and Antonsson 2004).

With regard to return rates of wild fish and strayed farmed fish, return rates of Icelandic wild smolts varied from 2.4 % in the northeast to 7.9 % in the southwest (Antonsson and Gudjónsson 2002). In some rivers the salmon stocks had been enhanced by the release of smolts produced by using local brood stock. Smolts reared in hatcheries and released in rivers frequently had 50% lower

return rates than wild smolts (Jóhannsson et al. 1994; Gunnarsson 2002). It might therefore be anticipated that smolts that escaped from marine cages would return at a lower rate than wild smolts, particularly in northern Iceland. Experimental evidence has consistently indicated that non-native stocks survive less well at sea than native stocks (McGinnity et al. 1997, 2004; Clifford et al. 1998a, b; Naylor et al. 2005). Whether smolts or other life stages of Norwegian strains would return if they were to escape from cages in Iceland, or at what rate, were unknown. It was thought that salmon close to sexual maturation at the time of escape may have a higher chance of surviving and returning to rivers than other fish. Farmed salmon exhibited lower spawning success than wild salmon reducing the risk of genetic mixing (Fleming et al. 1996, 2000).

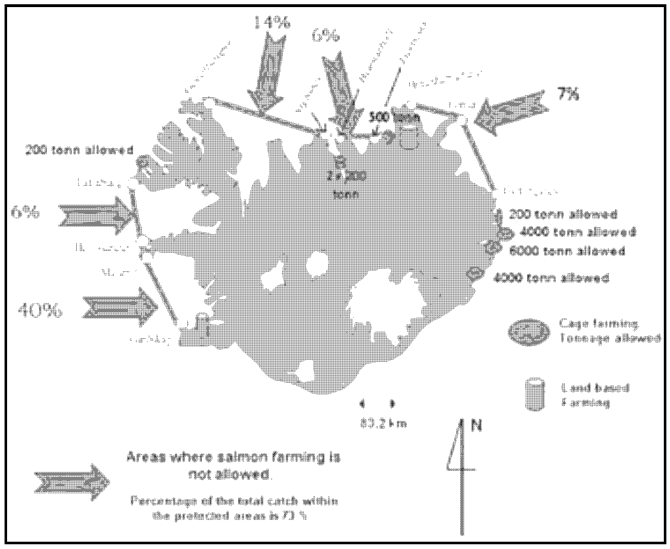
With regard to diseases, wild salmon smolts swimming through areas with salmon farms can in some instances be heavily infected by salmon lice (*Lepeophtheirus salmonis;* Holst and Jakobsen 1998; Holst et al. 2000, 2001). A burden of more than 10 lice per smolt will lead to death (Grimnes and Jakobsen 1996). The risk can be intensified where there are large biomasses of salmon in cages (Naylor et al. 2005).

Based on the risk assessment, it was suggested by the Institute of Freshwater Fisheries that to minimize the likelihood of negative genetic, disease, and parasite impacts, salmon farming should be managed on the basis of protecting individual fjords or bays where significant stocks of wild salmon occur. The exclusion zones suggested by the Institute were set up, with minor revisions, by the Ministry of Agriculture and Fisheries and finalized by the Minister.

NEW REGULATIONS ON SALMON FARMING

In May 2001, soon after the risk assessment, new regulations on salmon cage rearing were enacted that enabled the government to better manage fish farming. The purpose of the new regulations was to protect valuable native salmon rivers and runs and minimize the risk of genetic mixing and spread of diseases and parasites. Under the new regulations, fertile salmonids were not allowed to be cage-reared in specified zones around the Icelandic coastline (Figure 1). These protected exclusion zones are bays and fjords adjacent to important salmon rivers, or into which important salmon rivers drain. Zones in which salmon cage-rearing was prohibited included the western areas of Faxaflói and Breidafjördur, the northern areas of Hunaflói and Skagafjördur, and key areas in the northeast (Figure 1). Conversely, the southeastern and southern coasts, which are heavily influenced by glacial rivers and produce few wild salmon (Scarnecchia 1983), were largely left open to cage rearing, but became subject to more stringent regulations than in the past. Requirements were also enacted for the standardization of cage rearing and inspection of farming activities by governmental officials. One additional important requirement was that fish farmers must micro-tag 10 % of all smolts stocked into sea cages to facilitate detection of stray salmon in harvest as well as fisheries surveys. In 2004, the regulations were revised to exclude not only fertile cage-reared salmonid fishes, but also sterile ones, from the exclusion zones. Although those new regulations did not apply to Icelandic salmon ranching, other new regulations on ranching are more rigorous than in the past for anyone intending to resurrect it

Figure 1. Areas where rearing of salmon is prohibited in Iceland. Farming of salmonids is prohibited in the bays and fjords of Iceland with lines. Arrows depict percentage of annual catch (metric tons) of (mostly) wild fish produced in rivers flowing into those bays and fjords. (Courtesy of S. Óskarsson, Directorate of Freshwater Fisheries.)



RATIONALE FOR EXCLUSION ZONES FOR WILD SALMON

The concept of fish sanctuaries or exclusion zones as a way of controlling harvest or otherwise protecting wild salmon stocks has a long history. For example, J. M. Leith (1882) argued strongly for the elimination or reduction of fixed fishing gear from areas of Scottish rivers and estuaries to allow escapement and protect the salmon runs. Lichatowich's (1999) review of the history of salmon refuges for Pacific salmon begins with early efforts by Livingston Stone (1892), an early salmon culturist, to establish a "national salmon park" not just to protect salmon from excessive harvest, but to protect their habitat. Stone's efforts were largely unsuccessful, although he was successful in getting Afognak Island, Alaska, set aside in 1892. Later efforts of individuals and states to set aside refuges failed. Lichatowich (1999:136) called refuges "the road not taken," noting that hatcheries had been favoured in legislation over protecting the wild salmon. In the following year, however, he and co-authors noted that interest in sanctuaries or exclusion zones had increased in the previous five years, and that the need for some sort of exclusion zones for strongholds of wild salmon and their habitats was greater than ever (Lichatowich et al. 2000). They then proposed a three-step process for protection: identifying and prioritizing watersheds, protecting candidate refuges from further degradation, and designating and managing refuges to conserve salmon, habitat, and biological diversity. In recent years, protected areas have also been established in estuarine (Johnson et al. 1999) and marine areas (Auster and Shackell 2000) to protect habitat, reduce harvest, and protect genetic biodiversity.

For Atlantic salmon, Goode and Whoriskey (2003) suggested that "there needs to be a dialogue between the [Atlantic] salmon farming industry and wild salmon interests to explore the use of exclusion zones." In their words, "From a wild salmon perspective, there are areas where salmon farming is appropriate and places where it is not" (p. 155). In response to potential negative effects on Norway's wild Atlantic salmon stocks, specific rivers and zones have been set aside for wild production, with no salmon farming allowed (Esmark et al. 2005). Exclusion zones have also been used in Sweden around the mouths of rivers. The Icelandic exclusion zones are not intended to exclude harvest, but to prevent excessive detrimental straying of escaped fish which could result in (a) genetic mixing and (b) disease and parasite transmission between farmed and wild fish.

EVALUATING THE RATIONALE FOR AND EFFECTIVENESS OF THE ICELANDIC COASTLINE ZONING

Since the regulations were enacted, there have been important reviews of the effects of fish farming in Norway on native Atlantic salmon stocks (Esmark et al. 2005; Jonsson and Jonsson 2006) and in northwestern North America on the effects of farmed Atlantic salmon on other wild salmonid species (Waknitz et al. 2002; Knapp et al. 2007). Extensive, often contentious debate has ensued about the effects of salmon farming on wild fish and overall wild salmon health and productivity, not so much for Atlantic salmon within their native range, but more so in northwestern North America regarding the effects of farmed Atlantic salmon on other salmonid species (Noakes et al. 2000; Morton et al. 2004; Krkošek et al. 2006). Overall, however, global research on fish farming and wild fish interactions conducted since 2001 has supported and justified the conclusions of the Icelandic risk assessment and the regulations enacted.

The new zoning regulations for the Icelandic coast are to be re-evaluated in the future for their effectiveness after gaining experience. Straying, diseases, and sea lice infestations will be investigated and their effects quantified from recaptures of tagged and marked fish caught in fisheries. Emphasis will be on developing adequate experimental designs for proper evaluation of interactions between farmed and wild fish (Hilborn 2006). In addition, potential effects of culture of cod and other species will need to be monitored for effects on wild salmon (Esmark et al. 2005).

THE FUTURE OF ATLANTIC SALMON FARMING AND WILD FISH

In Iceland and throughout the natural and unnatural range of Atlantic salmon, the production of farmed fish is expected to increase. How must such development be directed by fisheries agencies so that wild stocks are protected? Iceland's attempt at a solution aptly reflects its culture as a modern, science-based society with a mythological past. To feed the hungry, Gudmundur climbed down and blessed nearly all of Drangey's cliffs. A last-minute entreaty by a wild, uncontrolled being kept the last of the cliffs, Heathen Cliff, from being blessed and thereby domesticated and brought under human dominion. Feeding a hungry and often increasing populace is always a rallying cry for fish farming, and with it comes domestication, settlement, control, and short-term economic gain. Science shows that what also comes is a real threat of adverse genetic changes, diseases, and other problems. But the idea of farmed salmon will usually be easier to sell to the general public than wildness, lack of control, and long-term ecosystem values. Thanks to the wisdom of Gudmundur the Good on Drangey, however, evil too had its place to live, and the birds were better off for it. By zoning the Icelandic coastline and isolating the farmed and wild fish from each other, salmon farming can continue in places where potential impacts to wild salmon are reduced. The wild salmon, too often perceived as an evil outside the control of *Homo technologicus* and his plans for economic development, may also be granted a place to live. Ultimately, both we and the salmon will be better off for it.

ACKNOWLEDGEMENTS

The authors thank P. Hutchinson, J. Congleton, C. Moffitt, R. L. Vadas, and R. Hilborn for reviewing drafts of this manuscript.

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