The Effect of Genetic Introgression of Farm-Raised Fish on the Endangered Wild Atlantic Salmon Populations in Maine

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Abstract

This thesis reviews the state of the wild populations of Atlantic salmon in Maine, and in particular their relationship to the farm-raised salmon that escape and interbreed with the wild salmon. This thesis asks whether commercial salmon farms can exist in a common time and place as wild Atlantic salmon, and if so, how?

The research revealed that conservation efforts have been so far unsuccessful in restoring a sustainable population of Atlantic salmon to the rivers of Maine and their diminished numbers put the species at a great risk to even a small influx of escaped farm salmon. Farm escapees interbreed with wild salmon, pass on their artificially selected genes, and leave subsequent generations less fit for survival in the wild.

Though commercial aquaculture is not wholly responsible for the current fragile state of salmon in Maine, the industry can take a leadership role in aiding the wild salmon's recovery. Recommendations include converting Maine's fish farms to closed-system, land-based operations, and thorough salmon habitat restoration focused on dam removal and watershed conservation.

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Chapter 1
An Introduction to Maine's Atlantic Salmon

Though the name "king salmon" belongs to a fish from the Northwest United States, the Atlantic salmon (*Salmo salar*) once ruled the waters of Long Island Sound, stretched its influence into the rivers of Connecticut, New Hampshire, and Massachusetts, and was a well-known symbol of Maine's fisheries. In the 21st century, the Atlantic salmon has become another struggling fish on the ever-growing list of endangered species. Of the three distinct population segments that once existed in the United States (Long Island Sound, Central New England and the Gulf of Maine), only the Gulf of Maine still supports a wild salmon population.

Although the Atlantic salmon is the victim of a variety of harms, including habitat destruction, pollution, development and overfishing, the focus of this thesis is on the relationship between the remaining wild salmon in Maine and salmon that are escapees from fish farms, bred by humans specifically for consumption and not for survival in the wild. The concern with escapees is that as they interbreed with the dwindling wild populations, they pass on their own domesticated genes, diluting the overall gene pool and eradicating the qualities of the wild Atlantic salmon, and perhaps even the wild *Salmo salar* as a species.

There are those who want to save this fish, restore it to its wild abundance and stretch it back across its historical range to Massachusetts and Long Island Sound. To others, this is impossible.

There are those who want to farm this fish, raise it in pens and sell it to an ever-growing world hungering for its protein- and nutrient-rich flesh. To others, this is folly.

It seems at the moment that one of these must fail for the other to succeed, but in fact, the two goals are not mutually exclusive. The primary concern of this thesis is illuminating the courses of action that can be taken to preserve, restore and protect the wild Atlantic salmon in Maine. More specifically, can commercial salmon farms exist in a common time and place as wild Atlantic salmon, and, if so, how? The answer is yes, but to do so, commercial salmon farming must be engaged in the preservation of the wild fish.

Subsidiary questions that this paper must and will address are:

1. What is the difference between farmed salmon and wild salmon?
2. What are "distinct population segments" and "subspecies" and how does their fate relate to the fate of taxonomic classification *Salmo salar*?
3. Why is it important to protect wild Atlantic salmon populations and subspecies?

This thesis will conclude with recommendations on how conservation ideals need not be sacrificed to economic gain, nor prosperity to ecology.

To address these questions it will be necessary to present the history of salmon in Maine, the relationship between wild and farmed fish, and detail the steps now being taken to preserve and revive this once-thriving species in the North Atlantic waters of the United States.

Life Cycle of the Atlantic Salmon

The Atlantic salmon's life cycle is a complicated one, which makes addressing the fish's recovery complicated as well. It is an anadromous fish, which means it hatches in freshwater, but migrates and spends its adult years in the ocean before returning to freshwater to spawn. An understanding of its many stages of development is important to further discussion.

From egg to adult, the Atlantic salmon goes through eight distinct life stages ranging from two weeks to a year (or multiple years in some instances). The first two stages both occur before the salmon has even hatched, beginning with the egg and moving quickly (within 2-6 weeks) to the eyed-egg stage. The second stage is differentiated by the visible appearance of the young fish's two black eyes from within the egg. Upon hatching, the fish becomes known as an alevin, but though it has emerged from the egg, remains buried in the gravel of the redd[1] and gets its nutrition from the yolk-sac that remains (Committee on Atlantic Salmon in Maine, 2004).

The fish becomes a fry when it emerges from the gravel and begins to feed. The timing of this emergence is important, as availability of food can determine whether or not a fry survives to enter the parr stage of growth (Ibid).

In the parr stage, the fish is distinguished by vertical marks on its body, and loses the translucence that lasted through the fry stage. Though this stage typically lasts two years, depending on the rate of growth it can last anywhere from six months to three or more years. The parr-smolt transformation is a crucial time for the fish. Until this point, the young parr has spent its entire life in the freshwater stream where it hatched, but the smolt will make the migration to the sea. Once it enters the marine environment, the fish is known as a post-smolt until the turn of the calendar year, at which point it officially becomes a salmon (Ibid).

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[1] A redd is a salmon's nest. The female moves her tail back and forth to create a depression in the river's substrate. Into this she deposits her eggs and subsequently buries them using the same tail motion just upstream of the redd (USFWS, 1999).

Once at sea, a salmon will typically spend two winters feeding and maturing before migrating back to its home river to spawn. Though most Atlantic salmon are semelparous (spawning only once before dying), some will migrate back to sea, and return to spawn again (Committee on Atlantic Salmon in Maine, 2004).

To complete the life cycle, the female salmon will dig a redd with her tail in the gravel of the river where she was spawned, and lay between 3,000 and 15,000 eggs (depending on her size), which are then fertilized by a male.

As anadromous fish, Atlantic salmon must be conditioned to survive in two completely separate ecosystems, and face the threats present in both freshwater rivers and the saltwater oceans. Though salmon have an advantage of being reared in relatively more protected freshwater habitats, these are also the habitats more immediately impacted by human intervention in the form of fishing, riverbank erosion and disruption of redds, and runoff of pollutants into the rivers themselves. At sea, they face an increase in predators, and periods of low-marine survival for which the causes are not completely understood. This will be discussed further in Chapter Three (see pages 43-46).

With this basic understanding of the Atlantic salmon's life cycle, it is possible to see that the fight to preserve this species is one that must be fought on several fronts. The complexities of the salmon's life cycle also suggest the challenges that aquaculture faces in producing fish.

Farmed Salmon v. Wild Salmon

Since this thesis argues for the importance of preserving the wild Atlantic salmon and protecting the species from the pernicious influence of farmed salmon, it is important to clearly understand exactly what it is that we are trying to preserve. Chapter Two goes into much greater detail about the effects that farmed salmon can have on wild populations, but this brief discussion will set the stage.

Often within a single species there are many genetically distinct populations (or subspecies) that make up the whole. This is especially true of salmon, which will adapt to the specific conditions of the river or stream in which they hatch and to which they return to spawn, resulting in hundreds of different subspecies. In contrast to this, farmed fish are bred to be genetically uniform with the needs of the market in mind. As a result, they are larger, more passive, and not adapted to long-term survival in the wild (Brenninkmeyer, 1999). In a sense, farmed fish are a subspecies beyond all subspecies: they did not evolve naturally, they live in artificial environments, and they are controlled at the genetic level to be most useful to humans. Atlantic salmon is farmed in open ocean net pens, huge floating cages that are susceptible to tears and damage by storms, seals and vandals. When their genetically uniform inhabitants subsequently escape into the wild, they become a threat to the wild salmon by competing with them for space, introducing diseases, and interbreeding with the wild fish, causing hybridization, contaminating their genes, reducing their adaptability to their habitat and resulting potentially in "the extinction or displacement of native populations" (Brenninkmeyer, 1999, p. 84).

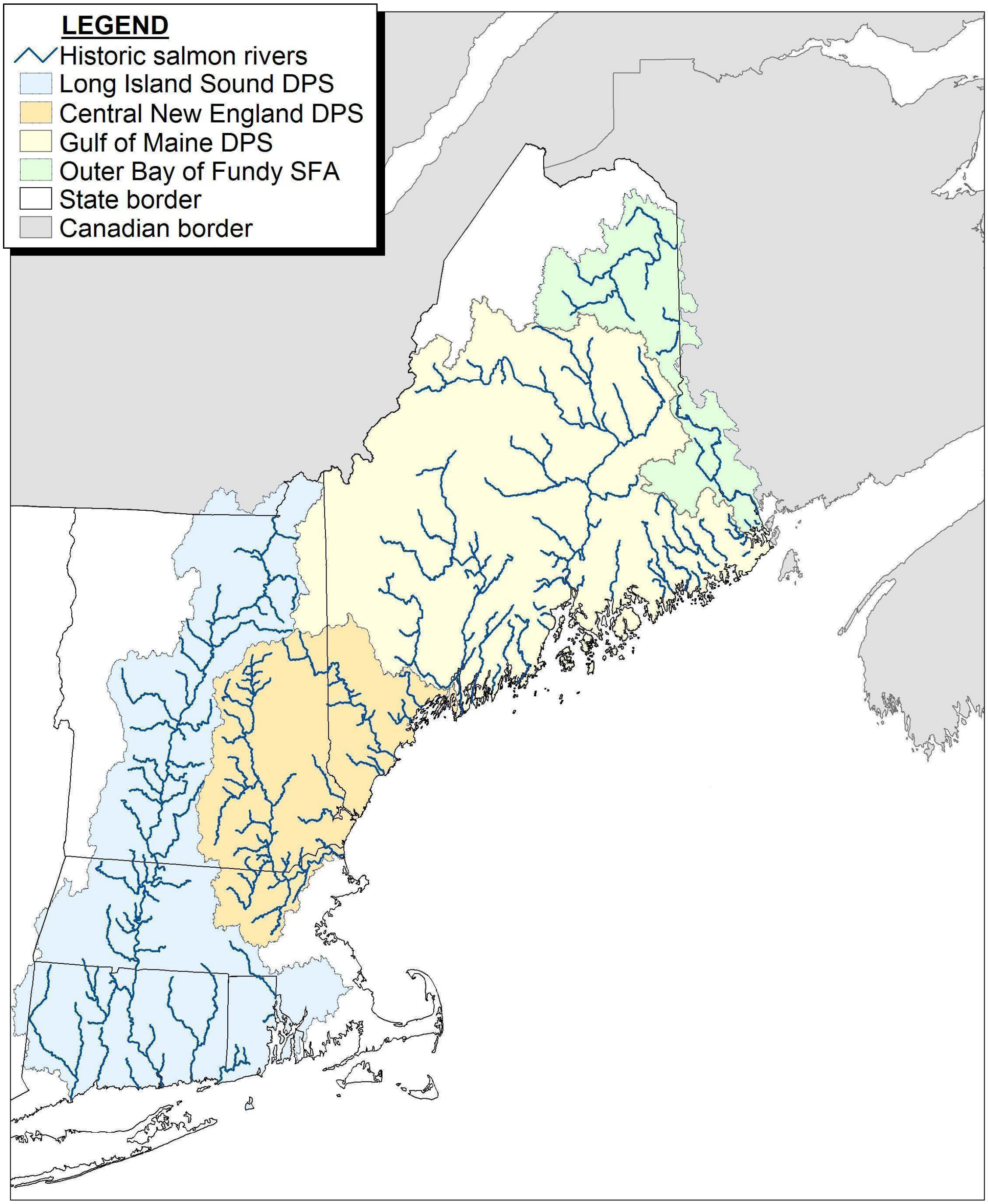
In the case of the Atlantic salmon of Maine, these threats are compounded by the wild fish's low numbers. There are currently 26 salmon farm site leases in Maine (Department of Marine Resources, 2008), which cumulatively produced about 13 million pounds of salmon in 2009 (Department of Marine Resources, n.d.). Map C (page 34) shows the locations of salmon farms, concentrated around the mouths of several rivers in Downeast Maine. A large wild population could simply absorb any invasive genes and breed them out (that is to say, a single farmed salmon's genes would have little to no impact on a robust wild population of millions of fish. In this sense, dilution *could* be the solution to genetic pollution). But being an endangered population that is faced with continuous escapes, the Atlantic salmon does not stand much of a chance (Naylor et al, 2005). So, though the salmon in a given river can be counted as a genetically distinct population, in general I will refer to farmed fish as one broad subpopulation and wild salmon as another, known as the Gulf of Maine distinct population segment.

A Distinct Population Segment

The definition of "distinct population segment" was clarified by the National Marine Fisheries Service and the U.S. Fish and Wildlife Service in 1996 "for the purposes of listing, delisting and reclassifying species under the ESA" (Fay et al, 2006, p. 34).[2] The primary considerations for a sub-population to be classified as a distinct population segment are discreteness (the sub-population is separate physically, physiologically, ecologically, or behaviorally) and significance (the sub-population is important or unusual compared with the greater population due to ecological setting, genetics or the fact that the former is all that remains of historically far greater numbers of the species that previously existed) (Fay et al, 2006). The Atlantic salmon of Maine

[2] The Endangered Species Act (United States Cong. Senate, 1973) was enacted in 1973 to protect listed species and provide for substantial penalties for those who violate it by injuring, killing or harming those species. The act more broadly construes the term "species" than the traditional scientific definition, and allows the Fish and Wildlife Service and the National Marine Fisheries Service to describe subspecies and distinct population segments that might be threatened within geographic or political boundaries, if not within biological ones (Fay et al, 2006, p. 227). This listing and how it came about is discussed in detail in Chapter Four.

fulfills both these criteria. Their classification as a distinct population segment and their listing under the Endangered Species Act separates them from the genetically different



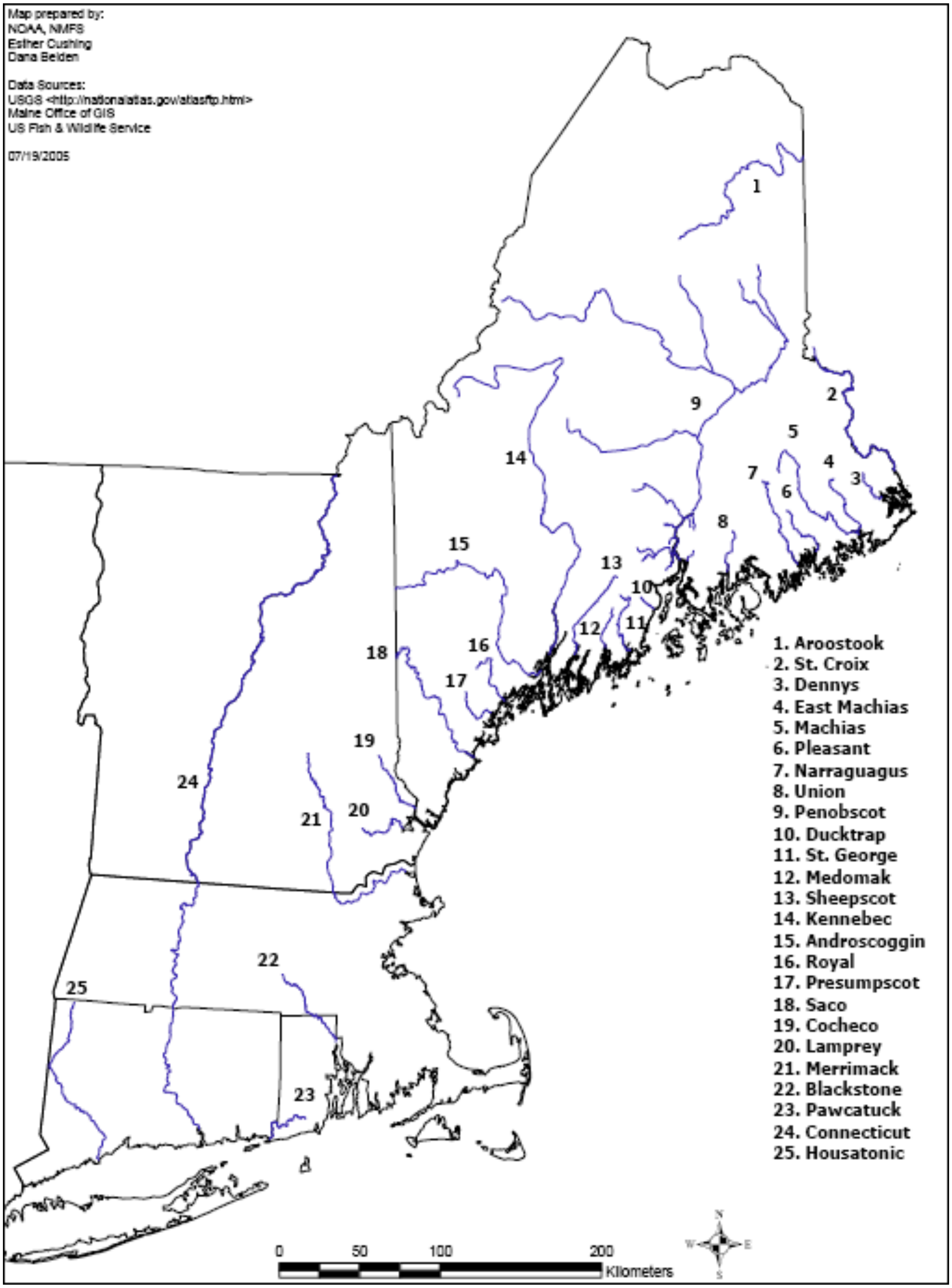
Map A: The three distinct population segments for Atlantic salmon in the U.S. are shown above. Only the Gulf of Maine segment still supports a wild salmon population (NOAA Fisheries Service Northeast Salmon Team, 2008).

salmon raised in Maine fish farms and helps to protect them from the damage the farm-raised fish can cause. But despite this support from law and regulation, the wild population continues to decline.

The Gulf of Maine distinct population (See Map A) segment "includes all naturally reproducing remnant populations of Atlantic salmon from the Kennebec River downstream of the former Edwards Dam site, northward to the mouth of the St. Croix River" and the accompanying watershed (NMFS, 2005, p. v). There are eight rivers in this range known to support salmon populations: The Dennys, East Machias, Machias, Pleasant, Narraguagus, Ducktrap, and Sheepscot Rivers and Cove Brook. The salmon in these eight rivers are the subspecies currently listed as endangered under the ESA.[3] In a 2004 report, the Committee on Atlantic Salmon in Maine cite the Maine Atlantic Salmon Commission as estimating that 940 adult salmon had returned to spawn (Committee on Atlantic Salmon in Maine, 2004). This is a small number when compared with the 300,000 estimated to have returned each year before New England was settled (Lewis, 1991). This number was severely depleted as early as the beginning of the 19th century and by the end of that century, "salmon had been extirpated from three of the five rivers with the largest populations (Androscoggin, Merrimack and Connecticut)" (NOAA Fisheries: Office of Protected Resources, 2007). The decline continued throughout the 20th century, exacerbated by degradation of water quality and construction of dams, until salmon populations reached the low numbers at which they remain today (Ibid). These low numbers are the reason that wild salmon are at risk from farm escapees, which have been genetically compromised to the extent that they "constitute a threat to the continued

[3] Since the writing of this paper, Atlantic salmon have been listed as endangered in three additional rivers: the Penobscot, Kennebec and Androscoggin.

existence of the species in the wild" (Fay et al, 2006, p. 35-36).



Map B: Maine's listed rivers include numbers 3, 4, 5, 6, 7, 10, 13 and Cove Brook, which is on the border of the state and Canada and is not pictured above. Numbers 9, 14, and 15 were recently added to the list (Fay et al, 2006, p. 24).

Chronological History of the Atlantic Salmon: Biological and Regulatory

The Atlantic salmon once thrived in New England, but 19th century development, pollution from textile mills, dams, turbines and overfishing decimated their numbers. "Minimum estimates of pre-contact salmon abundance on the Eastern Seaboard range from 5 million to 12 million fish" (Montgomery, 2003, p. 91) and an estimated 300,000 adults returned to spawn in the rivers of the Northeast each year. Today, the number of salmon that return each season is a mere 1-2% of the pre-colonial population. Most of these cannot even be considered truly wild, having been raised in hatcheries (Lewis, 1991). In 1997, federal officials estimated that only 500 Maine salmon could still truly be called native—meaning none of their ancestors had ever been raised in hatcheries or farms (Fleishman, 1997). It is assumed that today all salmon possess some farm raised ancestors, though wild populations still retain their wild characteristics, despite this (Paul Santavy, personal communication, 12 February 2007).

The reaction to these rapidly declining numbers was almost non-existent until 1991, when the U.S. Fish and Wildlife Service (FWS) and the National Marine Fisheries Service (NMFS) selected the Atlantic salmon as a candidate for listing under the Endangered Species Act (ESA) (*State of Maine v. US Department of the Interior,* 2002). In 1995, the FWS and the NMFS identified distinct sub-populations in eight different Maine rivers, making each a potential endangered subspecies (NMFS 1995). (Map B shows the locations of these rivers.) After much back and forth, these eight populations were listed as endangered under the ESA in 2000 (United States Cong. Senate, 1973). Though officially protected, a Maine Department of Environmental Protection permit still allowed farms to stock non-native salmon for an interim period, in order to balance what is good for the environment, with what is good for the economy (MDEP 2003). This allowed a transition period so that farms did not have to bear an undue cost by destroying their existing stocks. A 2003 U.S. District Court decision superseded this permit and reinforced the rules under the ESA, requiring only native salmon to be stocked from that point on (*USPIRG v. Atlantic Salmon of Maine,* 2003b). All Maine farms now stock only American and Canadian (i.e. genetically similar) Atlantic salmon (*Salmo salar*). Chapter Four goes into much greater detail about this chronology and how each step came about.

Though officially the Atlantic salmon should now be on the road to recovery, the reality is much different.

Options Aplenty

There is a discrepancy between ancient civilizations that practiced sustainable, integrated polycultures (see Appendix A) in a time when their fish were not being threatened with imminent extinction and large-scale monocultures operated today that can damage the already fragile populations and ecosystems.

Many aquaculture practitioners consider the isolated monoculture as the most profitable way to run a fish farm. Financially, in the short term, this may be so. Following the district court's ruling in *USPIRG v. Atlantic Salmon of Maine* (2003b), Atlantic Salmon of Maine complained that such a strict interpretation of the ESA would put them out of business. The court had no sympathy for this argument, concluding that this kind of attitude is just what frustrated so many regulatory efforts, and indeed why such regulations were likely necessary (Price II, 2004). As a result, only North American salmon are now permitted to be stocked in Maine fish farms. Important details of this case will be explored in Chapter Four. Though the fish farms still exist, Atlantic Salmon of Maine sold their interest in them to Cooke Aquaculture in 2004 (Hedlund, 2006).

It seems straightforward enough that the more of the fattest, tastiest fish one can cram into a net pen, raise, and sell, the more money one will make. But this ignores external costs of pollution and damage to the wild population, as well as the possibility of an increased profit from growing multiple species in an integrated polyculture.[4] Penned fish concentrated in a small area produce a lot of waste. Without symbiotic organisms in the same artificial ecosystem, this waste builds up on the sea floor faster than it can be broken down naturally. Chapter Two will show that when these fat, tasty fish—which are bred for the market and not for survival—escape and reproduce with wild fish, the whole population is weakened by their domesticated genes.

This way of doing business continues, but some operations have started investing in polycultures of their own. This involves raising more than one species (plants, shellfish, finfish) in a single location (Brenninkmeyer, 1999, p. 88). Many aquaculture operations, for instance, grow mussels on lines *beneath* their finfish pens (different species, different levels of the water column), and find that the mollusks grow larger and sell for more on the market than their counterparts from Prince Edward Island. The mussels filter feed, and pull usable nutrients out of the waste generated by the fish swimming above them. In this way, the fish farm generates less waste and is more productive at the same time. It is more cost effective than a monoculture because the

[4] Polyculture is the raising of many species of aquatic organisms in a limited space. This technique is based on the realization that aquaculture is three-dimensional, and different species occupy different levels of the water column (Borgese 1980, 16); it maximizes productivity while reducing waste by allowing some of the aquaculture creatures to feed on the wastes generated by others. In this way, polyculture systems have less of a negative impact on the natural environment than a monoculture, which allows disease to spread more easily among the animals, and waste to fall to the ocean floor, creating uninhabitable portions of the ecosystem (Montaigne 2003).

waste from one species becomes the food for another, saving on waste remediation and feed costs, as well as time lost leaving farm sites fallow. Polycultures like the one described above can be done in any marine ecosystem where shellfish are able to grow alongside finfish (like in Maine) (Langan, 2006).

Maybe it is too much to expect all fish farmers to operate their businesses with an eye to the environment. With a much larger population, and a global market for its products, aquaculture today cannot reliably run on the community-managed model of the ancient Hawaiians (see Appendix A). We do not need to sit and pine for the days of primitive polycultures, but in some way we must modify our current practices to sustain the salmon both as a wild animal and as a product. Chapters Four and Five will describe some of the changes that have already been put in place in Maine, and suggest other possibilities for the future.

Conclusion

The Atlantic salmon population is significantly smaller than it once was, with wild fish in a constant struggle for survival. This above all is the reason there is even a question regarding the interaction of farmed and wild fish. Were the wild numbers high enough, any maladapted genes brought in by farm escapees might be bred out again. This is not the case, as farmed fish outnumber wild adults. Globally, the ratio of farm-raised salmon to wild is about 85 to one (Montaigne, 2003). Annual returns to Maine rivers average around 1,000, compared to a historical U.S. population of half a million (Committee on Atlantic Salmon in Maine, 2004; Montaigne, 2003). That many fish can typically be found in net pens in a single aquaculture site (Montaigne, 2003). Ideally, farmed escapes would make up less than one percent of the total wild population (Gibbs, 1996). Given typical current salmon escapes (200,000 in a single storm event (Pietrak and Belle, 1997)) current fish farming would need to be reduced by more than 99% to keep escapes below 1% of existing wild population numbers.

It is impractical to expect that commercial aquaculture will simply pack up and leave Maine, though that scenario would solve this particular problem in one fell swoop (see Chapter Three for a more detailed discussion of Maine's aquaculture economics). Instead, commercial operations have to work with conservationists to increase wild stocks.

Federal hatcheries like the Craig Brook National Fish Hatchery and the Green Lake National Fish Hatchery—which raise salmon intended for release in specific rivers in Maine—assist in the recovery of the wild populations, but there are 8 commercial farms for every federal hatchery, and those commercial farms produce nearly four times as many fish per year (MDMR, 2008; Fay et al, 2006). Despite restocking efforts by these federal hatcheries since the late 19^{th} century (Fay et al, 2006), adult returns to Maine rivers have not significantly improved. As a result, listing Atlantic salmon as a federally endangered species, and the District Court's strict construction of the ESA are necessary to keep their efforts from being completely undone. Indeed, the protection of Maine salmon is not just ecologically prudent, but also required by law.

The introduction of propagated fish into the wild—widely discussed (see Chapter Two), but not yet mastered—is simultaneously a threat to wild salmon (when done accidentally, through escapees from farms), and one of the best options for recovery (when done intentionally, through releases from stock enhancement programs). When done correctly—the technology and motivation exist—restocking programs can help boost wild Atlantic salmon back up to self-sustaining numbers. Nonetheless, this is only one component in overcoming the legacy of more than a century of habitat destruction, pollution and overfishing in Maine.

Chapter 2
Fish Farm Escapees and their Impact on Wild Atlantic Salmon

Can the Atlantic salmon's (*Salmo salar's)* precarious position on the endangered species list be improved through the use of appropriate aquaculture practices? A typical commercial fish farm's first priority is to maximize profits by breeding as many of the biggest, tastiest fish possible, not to be stewards of wild salmon. The latter, at first glance, even seems counter-productive to the farm's goals. But fish farms cannot survive indefinitely without a wild population to provide them with broodstock, or they risk declining yields and possible population collapse (Costa-Pierce, 2006). To protect its interests, if for no other reason, commercial aquaculture must seek to enhance their stewardship of wild stocks (Costa-Pierce, 2006).

Most of the scientific literature agrees that propagated fish[5] present a number of threats to wild Atlantic salmon. Some articles and scientists claim that hatchery fish should not be introduced into the wild at all (Dannewitz et al, 2004; Levin et al 2001; Lewis 1991; Van Zyll de Jong et al, 2004), while others simply counsel caution with regard numbers and quality of fish released intentionally into the wild (Clifford et al, 1998; Naylor et al, 2005; Weir and Grant, 2005; Weir et al, 2004). Still others offer a "how-to" guide on creating stock enhancement programs (Drawbridge, 2002). Considering these varying points of view is essential to creating an effective collaboration that can enhance the wild stocks of Atlantic salmon in Maine.

[5] For the purposes of this paper, "farm" or "farmed" fish will refer to those from for-profit aquaculture ventures, while "hatchery" fish will refer to those from state or federally-run aquaculture projects that intentionally release their products for restocking and species improvement purposes. "Propagated" refers to both of these (any fish bred by humans, rather than existing in the wild). Additionally, "escapees" refers to accidental releases from commercial fish farms and "releases" refers to intentional releases from restocking programs.

Risks of Farm Escapees

Almost across the board, scholars and researchers agree that there are certain risks to introducing propagated fish into the wild (Clifford et al, 1998; Dannewitz et al, 2004; Levin, et al, 2001; Lewis, 1991; Naylor et al, 2005; Weir and Grant, 2005; Weir et al, 2004; Van Zyll de Jong et al, 2004.). Consensus is even stronger when referring specifically to farm escapees (Clifford et al, 1998; Naylor et al, 2005; Weir and Grant, 2005; Weir et al, 2004), but intentional hatchery releases have their own cautionary tales, though these are usually qualified with exceptions (Dannewitz et al, 2004; Levin et al 2001; Lewis 1991; Van Zyll de Jong et al, 2004).

The following are the three main concerns with any introduced group—escapees or releases:

1. Propagated fish will compete with wild fish for resources such as food and mates.
2. Propagated fish, more prone to severe outbreaks of disease because of their close quarters and genetic homogeneity (think: Dutch Elm disease), may spread disease to wild stocks in the same waters.
3. This is the most far-reaching impact—the most destructive to the species as a whole—and the one with which this paper is primarily concerned. Genetic interactions as a result of interbreeding between the wild and the farmed fish will result in decreased adaptability to environmental changes, alteration and hybridization of the wild stocks, and even destruction of the original species (Clifford et al, 1998; Naylor et al, 2005; Weir et al, 2004; Weber, 2002).

Regarding the first item on the list—the issue of competition—and speaking specifically of farmed, but not hatchery salmon, Weir and Grant (2005) and Weir et al (2004) note the physical inferiority of the farm escapees compared to wild fish, particularly with regard to spawning behavior (Weir et al, 2004). In seeming contradiction to their lower fitness, the farmed individuals were observed to be excessively aggressive compared to their wild cousins, with juveniles from farms outcompeting wild salmon for food, habitat and mates, but later being easier targets for predators due to their relative passivity. This is an unfortunate combination as the farmed fish are not contributing positively to the overall population's survival, but are using up resources and food that might otherwise go to the heartier, wild individuals. Weir and Grant (2005) argue that farm escapees should be treated as exotic, invasive species since they behave as such.

Naylor et al (2005) go into more detail on the subject, pointing out that farmed salmon will usually have a size advantage over the wild ones, since they are selectively bred for just that. They echo Weir's comments regarding lack of farmed salmon's effectiveness in spawning and in their displacement of established wild stocks through aggressive behavior.

Selective breeding is the source of much controversy regarding the compromise of wild salmon's genetic integrity. As an anadromous species that begins its life in one of many different coastal rivers, the Atlantic salmon is more genetically diverse than most fish. Within the Gulf of Maine distinct population segment, there are eight separate rivers (Cove Brook, Dennys, Ducktrap, East Machias, Machias, Narraguagus, Pleasant and Sheepscot), with extant populations of Atlantic salmon that are listed individually under the Endangered Species Act (ESA) (United States Cong. Senate, 1973).

These extant populations are continuously coming into contact with escapees from farms—escape events have resulted in the loss of 2,000 to 170,000 salmon in various individual events (Pietrak and Belle, 2007)—which are the exact opposite in terms of diversity: they are selectively bred and therefore a much more homogenous group. Introducing these genetically homogenized populations into the wild can reduce the variability of wild genes, ultimately reducing the long-term adaptability of the species (Clifford et al, 1998). This reduces the species' ability overall not only to adapt to the different habitats they occupy, but also makes them more susceptible to broad environmental changes, a possibility that is becoming more and more real with climate change (Weber, 2002).

The hybridized offspring of farmed and wild fish are also known to be less fit than even their farmed progenitors, causing some to foresee them as the eventual cause of a vulnerable population's extinction (Naylor et al, 2005). None of the literature suggests that farm escapees contribute positively to the overall gene pool. Theoretically, the wild stocks should be able to weed out the weaker genes of the farmed fish over time, but the relentless escapes from net-pens and farms never gives the wild populations a chance to do this. They are simply overwhelmed by numbers of escapees, which reduces the ability of the wild population to rebound at a later time (Ibid).

Additional evidence exists in the form of scientific studies that do not directly address the issue of escapees, but offer their own results as a cure for the problem of escapees. Oppedal et al (2003) and Hayes et al (2005) do not discuss *whether* there is a problem, but accept the problem as fact. Hayes et al (2005) evaluate DNA markers that can be used to trace escapees in the wild and assess their impact and Oppedal et al (2003) offer their sterile triploid salmon as a way to potentially reduce genetic contamination in wild stocks.

Risk of Hatchery Releases

It is reasonably clear that farm escapees could cause trouble for the vulnerable Atlantic salmon, lacking genetic diversity as they do, but what about intentional hatchery releases? In a controlled hatchery that is not profit-driven, it should be easy to breed just the right kind of fish that could contribute positively to the declining wild stocks and even compensate for the negative effects of the escapees, but the sources discussed in this section (Dannewitz et al, 2004; Van Zyll de Jong, et al 2004; Levin, et al 2001; Lewis, 1991) all speak of the same three risks as those previously mentioned—competition for resources, spreading disease and genetic introgression. With the exception of Van Zyll de Jong et al (2004), who are particularly opposed to restocking practices (though with good reason, as we shall see), all the authors qualify their statements in some way that leads to the belief that there is hope in this strategy.

Dannewitz et al are the kindest to the practice of supportive breeding, using hatcheries to improve vulnerable wild populations. Their suggestions will be discussed further in the next section, but the warnings are fairly typical: though this type of program can increase population size, the artificial selection that is inevitable in such a situation still can lead to negative evolutionary changes. This genetic drift is unpredictable and the effects may be complicated. Additionally, reproductive success of the introduced animals can become unreliable, potentially *reducing* the effective size of the population. The introduced fish compete for food and habitat and then fail to reproduce, causing net harm, rather than net good (Dannewitz et al, 2004).

Levin et al (2001) focus on the competition aspect of introduced salmon (for food in particular), but present study results that show negative effects only during periods of "poor ocean productivity" (Levin et al, 2001, p. 1157). In these times of fewer resources, the increase in introduced individuals and the associated competition can lead to less food for the natural inhabitants.

Lewis (1991) simply reiterates the three main concerns, citing Robert Francis, director of the University of Washington Fisheries Research Institute, who suggests that the restoration of natural habitats would be a more effective strategy for population recovery than supportive breeding (this strategy will be discussed in much greater detail in the next section).

Van Zyll de Jong et al (2004) are the most opposed to stock enhancement programs, though it is important to remember that they are writing specifically about a region in Canada where "freshwater fisheries . . . are still relatively intact" (Van Zyll de Jong et al, 2004, p. 189). Though they insist that these comments can be applied worldwide, they are less appropriate for fisheries like the Maine Atlantic salmon, which are not as intact.

They say this tool is too often used, and implicate it in the decline of natural populations in the Pacific Northwest. Though this is certainly possible, they seem too harsh in condemning stock enhancement—treating it as though it is as uncontrollable as the farm escapees. They allow little to no leeway, and do not allow the possibility of improved techniques. Perhaps the most questionable argument is the description of stocking as a self-perpetuating phenomenon, increasing in scope as anglers expect higher and higher yields. However, this implies more than the actual amount of power to anglers, who should be taking a greater interest in the root cause of the declining numbers, and not demanding the government add more fish to their rivers. Anglers are but one stakeholder group to be included in considering the strategies for Atlantic salmon restoration. Insistence on consistent annual sport-fish stocking addresses the symptom, but not the root cause of the problem.

Precautions should indeed be taken, but it does no good to remove stocking strategies from consideration when they could be harnessed very effectively in the fight against declining wild salmon stocks.

Hope Regardless

With all the trouble that escapees and releases seem to cause, it might be simpler just to eliminate all farms and focus instead on intensive fisheries management to revive these populations. But aquaculture currently provides about 40% of our seafood (Naylor et al, 2005) and with an increasing population and growing demand for it, farms will be filling the gap, since capture fisheries have shown almost no increase in yield since 1990 (Drawbridge, 2002). 100% of Atlantic salmon is farmed today, as commercial fishing of Atlantic salmon has been all but eliminated in their natural range, from the American Northeast, through Canada to Iceland, Ireland and the Scandinavian countries (Committee on Atlantic Salmon in Maine, 2004). This is partly due to the dwindling runs, and largely due to government and conservation groups buying out and regulating salmon fishermen from Maine to Norway (Montaigne, 2003). Meanwhile, fish consumption has "more than doubled since 1973" (FAO, 2007, p. 88). Salmon consumption alone has increased "by a factor of 40 during the past two decades" (Hites et al, 2004), with farming rising from 24,000 to 1 million metric tons (Ibid). The farming of Atlantic salmon has turned a seasonal delicacy into an on-demand product available anytime, in any part of the world and is virtually the only way to get Atlantic salmon on grocery store shelves (Montaigne, 2003).

With such a demand for Atlantic salmon—farms produce nearly 700,000 metric tons of fish a year (Montaigne, 2003)—but no significant wild harvest, it seems unlikely that the fish farming business will vanish, so it had best be brought into a harmonious relationship with the natural environment and wild salmon populations. Some of the authors already mentioned (Clifford et al, 1998; Levin et al, 2001; Oppedal et al, 2003; Weir et al, 2005) offer their own suggestions for combating the problems mentioned in this chapter. Others (Dannewitz et al, 2004; Drawbridge, 2002; Lewis, 1991; Weber, 2002) speak positively about stock enhancement programs as a tool for improving vulnerable populations. It is in these suggestions and solutions that we see hope for recovery.

Some authors only take issue with farm escapees, and assert that fish intentionally bred for release are better suited for introduction into the wild (Weir et al, 2005). Levin et al (2001) found a negative effect of hatchery releases, *but only* when ocean productivity was down. With a carefully monitored program, releases could be modified based on predicted ocean productivity for each year, reducing this risk.

A study by Clifford et al (1998) of genetic changes in wild salmon resulting from juvenile farm escapees found that escapees from farms homed back to the part of the river near the site of their farm (see Map C on page 34 for farm sites). A major concern with interbreeding between farmed and wild salmon is that it will eliminate the adaptive differences between rivers. Based on these results, however, it seems possible to site farms on the very rivers in need of recovery, turning the escapees from a total problem to the beginning of a solution. This strategy could only be used on rivers with completely extirpated populations—such as the Merrimack, Connecticut or other rivers in the Central New England or Long Island Sound population segments—in order to prevent the escapees from diluting an extant population. This theory leads to an eventual problem of creating a new, river-specific population based completely on farm escapees down the line. Additionally, there is no guarantee that these salmon will linger near their farms, though the study does suggest this. It does remain a promising approach for conservation hatcheries, though, as discussed below.

Weber (2002) points out that some rivers are now completely devoid of the salmon that once inhabited them. Thanks to dams, pollution and more than a century of attempted restocking (Van Zyll de Jong et al, 2004; Weber, 2002), Atlantic salmon are not as "intact" as some of Van Zyll de Jong's freshwater fisheries. As a result, we do not have to return the species to its pristine state, but, in these extreme cases, merely reestablish the population. Clifford's evidence of homing farm escapees could be the start of a new approach, establishing hatcheries on abandoned rivers in the extirpated distinct populations segments (Central New England and Long Island Sound) and raising salmon from a diverse broodstock to see if they take to these rivers again. This happened in the Penobscot River and is discussed further in Chapter Three (page 39). As no Maine rivers are completely extirpated, but do contain endangered populations, this is not a solution for Atlantic salmon in Maine, but for the species as a whole.

But it's not always a case of simply adding more salmon to the rivers. Dannewitz et al (2004), Drawbridge (2002) and Lewis (1991) note that stock enhancement programs are only part of the solution. In order to regain self-sustaining numbers, the original cause of the population decline must be removed, whether it's a dam, pollution or overfishing. It does no good to add fish to a river if they cannot pass a dam to spawn, for example.

The reduced spawning success of farmed males in the wild discussed by Weir (2005) to some extent counters the fear of genetic dilution due to interbreeding. Though they are not contributing to population numbers, they are also not passing on any mal-adapted genes that can compromise the overall population. The breeding of sterile fish addresses a similar concern, but has a more assured effect (Naylor et al, 2005; Oppedal et al, 2003). Intentional breeding of sterile fish in a farm could potentially eliminate the risk of the escapees interbreeding with wild populations.

Van Zyll de Jong et al (2004) provides some appropriate recommendations. They admit that restocking "may have use where the indigenous stocks are at low levels, or where previous habitat has been restored [and]. . . broodstock should be taken from as large a section of the wild spawning recipient population as possible" (Van Zylle de Jong et al, 2004, p. 188). The wide selection of broodstock would encourage the establishment of a diverse new population in the extirpated rivers. In extirpated rivers, or those where populations are too low to provide sufficient broodstock, the wide selection of different strains of salmon can lead to the development of a new, original population for that river. The Penobscot River is a living example of this. Hatchery stocking for restoration purposes occurred in the 1960s and 70s with fish from the Machias and Narraguagus Rivers. Whether or not any Penobscot fish remained in the river at that time is unknown. Today's population, therefore, either retains some of the historic Penobscot characteristics, or is a "unique mixture of genetic characteristics from each of the . . . source populations" (Fay et al, 2006, p. 58).

Van Zyll de Jong et al also insist that the introduction of new species (i.e., salmon from other rivers, or other species altogether) be banned. Fortunately, Maine already prohibits the use of non-North American strains of salmon for commercial production (*USPIRG v. Atlantic Salmon of Maine,* 2003b).

Dannewitz and Drawbridge are both proponents of stock enhancement. They argue that supportive breeding won't necessarily cause genetic drift and is valuable in increasing the size of the wild populations (Dannewitz et al, 2004). Drawbridge writes what is in effect a "how-to" on creating an effective stock enhancement program (2002).

A Tough Question

Consider the notion that—at a very basic level and to many people—Atlantic salmon are simply a food resource. As long as they keep showing up on our plates, some diners do not care whether they are native Maine salmon, or farmed hybrids from the West. Naylor et al (2005) frame it slightly differently. How much risk for the potential destruction of wild Atlantic salmon is society willing to accept? If a salmon served for dinner is full of healthy omega-3s, and devoid of dangerous chemicals, maybe a transgenic salmon is just as good as the native Maine version for table fare.

Chapter Three discusses a number of other, non-food related reasons why we should preserve wild Atlantic salmon. The possibility of healthy, sustainable, native populations may now be simply out of reach. In the Great Lakes, and some New England rivers, populations of salmon and other species were so far beyond recovery by the early 20th century that releases of Pacific salmon species in those areas were thought of as *complementing* the remaining stocks, not competing with them (Kirk, 1987). This is a far more extreme measure than I am suggesting (though the possibility is discussed in Chapter Five). Although caution should not be tossed overboard, we paradoxically have license to take on even greater risk in the effort to spark the recovery of these depleted species. Because so many and such varied attempts *have already* been made in the pursuit of recovery. Though some are not concerned about the pedigree or provenance of their fish, there are others willing to pay for that native, natural salmon that they may never even see (Naylor et al, 2005).[6] There may be negative effects, but there already *are* negative effects. Right now, we need to maximize the potential positives.

Conclusion

Commercial aquaculture sometimes bills itself as a savior of wild fisheries, reducing pressure on depleted capture fisheries, but if fish farms are simultaneously exerting other pressures on wild populations (whether actively fished or not) then they

[6] As the process of evaluating the worth of environmental resources has never been completely straightforward, contingent valuation is frequently used to assign a monetary value to a resource, such as a leaping salmon, that might otherwise be described as “priceless.” One example is the use of the Atlantic salmon as “an indicator of the spiritual well being of the Penobscot Nation” (Northeast Natural Resource Center of the National Wildlife Federation, 1995, p. v).

must take steps to rectify that aspect of their operations by submitting to regulation or finding other means of augmenting the troubled species. This is especially true over the long term, since farms will need to periodically introduce wild fish to keep the genetic lines of their broodstock vital (Costa-Pierce, 2006).

One approach is to adopt precautionary policies requiring that farms stock only native species from their own nearby rivers. Conservation hatcheries are already combatting “biological pollution” (Naylor et al, 2005, p. 435) of farm escapees with stock enhancement programs. This cannot stand on its own, however, if we wish to arrive at a point where the wild population can become self-sustaining. On its own, a constant, active restocking program could potentially counterbalance the effect of the fish farms, but it would need to be continuously ongoing. Restoration of native habitat and stemming the tide of homogenized farm-bred fish to allow the wild stocks time to recover are important strategies that need to be incorporated into a greater plan to protect wild stocks. An extended discussion of these means-of-recovery appears in Chapter Five.

Chapter 3
The State of Salmon in the State of Maine

The rivers and coastal waters of Maine are the last bastion of the Atlantic salmon in the United States. The distinct population segments that once inhabited the waters of Long Island Sound and Central New England were extirpated in the early to mid-1800s (Fay et al, 2006). As a result, the Gulf of Maine distinct population segment (GOM DPS) is a unique population upon whose continued existence the fate of the wild *Salmo salar* may very well rest. The species may continue to exist in the remainder of its range through Nova Scotia to Northern Europe, but the loss of the GOM DPS would represent another limitation on the continually decreasing salmon range. The 2006 *Status Review for Anadromous Atlantic Salmon* (Salmo salar) *in the United States* (Fay et al, 2006) describes the qualities that make the conservation of the GOM DPS a priority of utmost importance.

1. The GOM DPS represents the southernmost limit of this fish's range and its extirpation would "significantly constrict" the species' range (Fay et al, 2006, p. 57).
2. It represents the "best available" source for reintroducing *Salmo salar* to its historic habitats. Without it, a sizable gap exists in the taxon[7] between remaining stocks through Canada, Iceland, Ireland and Scandinavia and the potential revival of the extirpated population segments (Fay et al, 2006, p. 57). The GOM DPS is the southernmost wild population in the

[7] A taxon is a "taxonomic category or unit, as a species or family" (Webster, 1997, p. 1372).

world. Losing this population decreases the potential to reintroduce salmon to its historic range.

3. Its loss would represent a larger loss in global biodiversity, the complexity of which is crucial for maintaining the health and stability of the planet's ecosystems, as well as compromising global food security (National Parks Conservation Association, 2007; U.S. Mission to the UN Agencies in Rome, 2004; Utter and Epifanio, 2002, Worm et al, 2006).

These only represent the most measurable qualities that make this distinct population segment important. Add to the list the following:

1. Maine's sport fishery. A healthy sport fishery has the potential to pump millions of dollars into the economy. As recently as 2003 Iceland saw $20 million annually from salmon sport fishing alone (Montaigne, 2003).
2. The importance of the fish to the Penobscot and other tribal nations: "[A]n attempt to place a monetary value on the presence of these magnificent fish in the Penobscot Rivers is, to the Penobscot Nation, severely deficient (Northeast Natural Resource Center of the National Wildlife Federation, 1995, p. v).
3. The potential revival of a commercial salmon fishery. Commercial fisheries once saw the capture of nearly 10,000 metric tons of salmon annually in the 1970s throughout the Atlantic salmon's range (Danie, 1984).

Given the six items summarized above, it is surprising that the state of the salmon was ever allowed to deteriorate this far in the first place.

Welcome to Maine! A Brief Timeline of Conservation and Decline

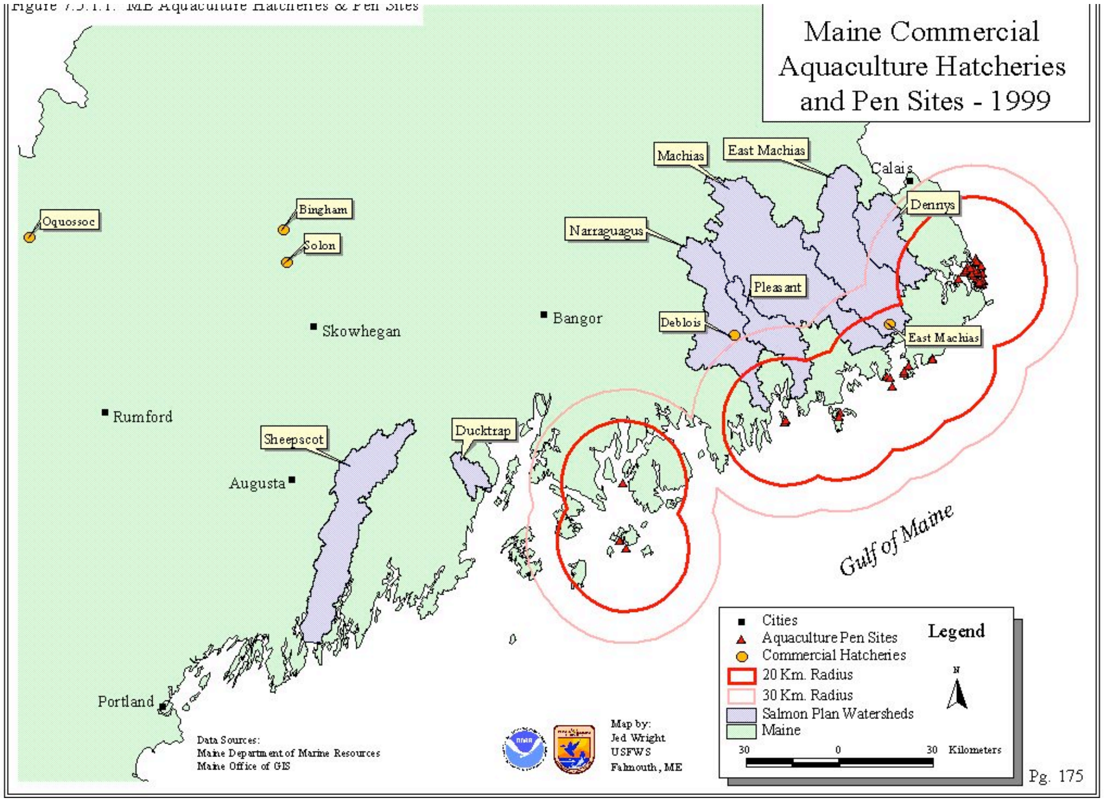
Atlantic salmon have always been targeted by humans as a delicious and nutritious food. Archeological evidence dates back 11,000 years (Committee on Atlantic Salmon in Maine, 2004). While fishing is by no means the only factor affecting salmon populations—sixty-three different impediments have been identified (Ibid)—the direct removal of fish from water is one of the first things to be regulated when a species starts to suffer from decline. At the same time, the last thing a fisherman or government wants to give up is their source of food and income. And so, in 1871, the first eggs were collected to begin restocking wild salmon in Maine (Ibid).

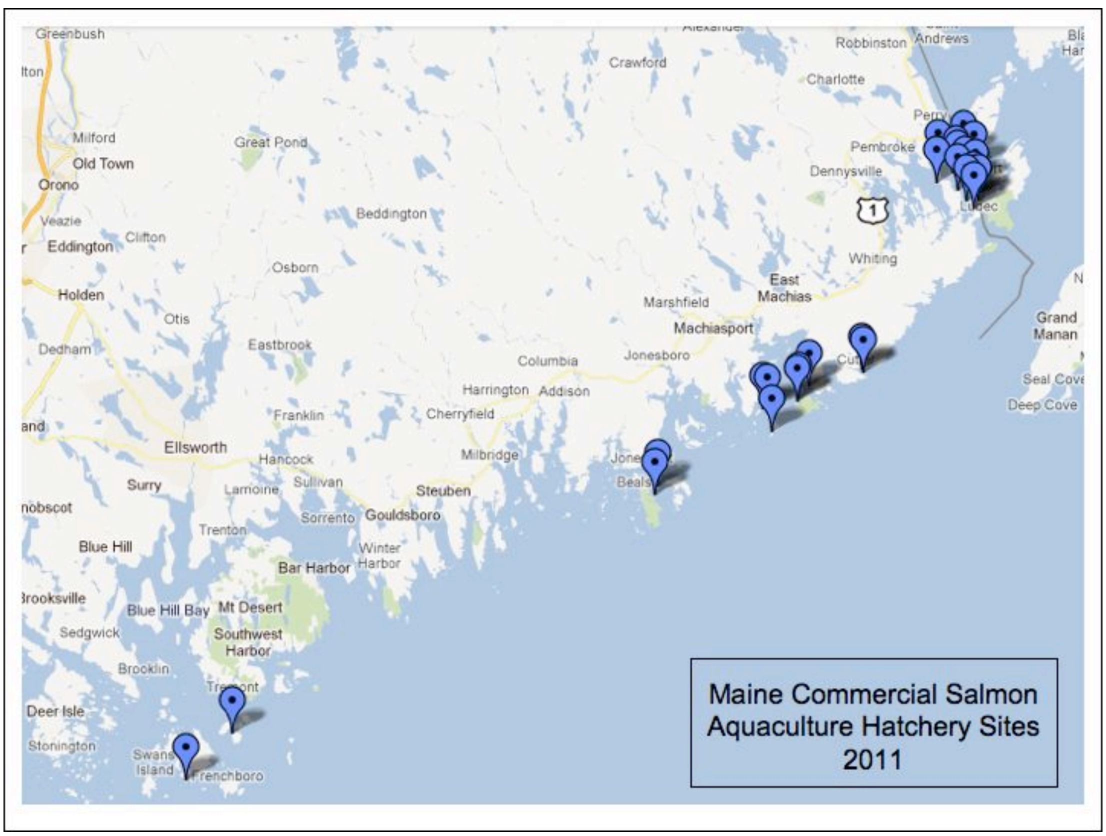
One hundred years of restoration attempts were not enough. Beginning in 1985, high-seas salmon fisheries were gradually reduced. By 1992, "sanctioned fisheries in regions affecting North American stocks" –such as Nova Scotia, Newfoundland, Iceland and the United States—had been all but eliminated (Committee on Atlantic Salmon in Maine 2004, 60).

Still, adult returns to Maine rivers continued to decline, and commercial aquaculture, begun in Maine in 1970, began to grow more and more rapidly, exerting its influence on the local environment and its inhabitants more than ever before. From 1989 to 1998, Atlantic salmon production in the U.S. increased by 468% (Goldburg et al, 2001). Maine production alone went from 1 million pounds in 1988 to 22 million in 1995 (MASTF, 1997). That number peaked at 36 million in 2000, but has since dropped to about 11.5 million pounds in 2005 (MDMR, 2006). This decline can be attributed to a number of factors, including the loss of hundreds of thousands of farmed salmon due to an outbreak of salmon anemia in 2001, the District Court's 2003 ban on non-North American strains of salmon in farming operations (forcing some farms to destroy fish), and below average temperatures during the 2003 and 2004 winters, during which one company, Atlantic Salmon of Maine lost 120,000 fish to death (Duchene, 2004).

Despite this recent decline, aquaculture production of Atlantic salmon remains high, and its impact on the wild populations remains apparent. Chapter Two contains a detailed account of the various negative impacts that farmed salmon can have on wild populations, which include: spreading disease; competing with wild populations for food, space and mates; and, of primary importance to this paper, interbreeding with wild salmon, compromising the unique genetic integrity of each river's population.

How is this possible? Because Maine's wild salmon populations have dropped so low, even a small number of farm escapees can have a significant effect on the overall gene pool. Conservative "best estimates" in known escape events indicate the loss of anywhere from 2,000 fish due to gear failure in 2003, to about 170,000 during a storm in 2000. Four separate incidents of vandalism in 2005 amounted to about 150,000 escapees in New Brunswick waters (Pietrak and Belle, 2007). This information is reported by the Maine Aquaculture Association in their "Final Programmatic Report on the Aquaculture Containment Verification System" though it was compiled by the Atlantic Salmon Federation, a non-profit organization that "promotes the conservation and wise management of the wild Atlantic salmon and its environment" (Atlantic Salmon Federation, 2007).





Maps C (NMFS, 1999) and D (MDMR, 2011): Though the ownership of many aquaculture pen sites has changed hands, the locations remain primarily the same, in close proximity to listed rivers.

Is this a lot of fish? For the most part, the destination of these escapees is unknown, but some find their way up the rivers of Maine, infiltrating some of the most threatened salmon populations (Clifford et al 1998). As discussed in Chapter Two, one study discovered that farm escapees returned to the rivers and areas near the sites of the farms where they were raised (Clifford et al, 1998). Map C shows the locations of the salmon farms in Maine. The concentration of fish farms is at the mouth of most listed rivers, including the Narraguagus, Machias, East Machias, Dennys, Pleasant and Ducktrap. The Maine Aquaculture Association report referenced in the previous paragraph also includes data provided by the Maine Atlantic Salmon Commission (MASC)—a state government organization that works with "local, state, national and international organizations and agencies to manage the wild Maine Atlantic salmon population" (MASC, 2007, para. 1)—on the numbers of "suspected aquaculture escapees returning to rivers in Maine and the St. Croix River" (Pietrak and Belle, 2007, p. 11). (The St. Croix River is on the border between Maine and New Brunswick and is therefore often counted among Maine's rivers.) The MASC estimated that 940 adult salmon returned to spawn in Maine in 2001 (Committee on Atlantic Salmon in Maine, 2004); 124 (13%) of those were suspected of being escapees from farms (Pietrak and Belle, 2007). Declining numbers caused the Fish and Wildlife Service (FWS) and the National Marine Fisheries Service (NMFS) to list Atlantic salmon under the Endangered Species Act in eight different Maine rivers (Price II, 2004). Those eight rivers (Cove Brook, Dennys, Ducktrap, East Machias, Machias, Narraguagus, Pleasant and Sheepscot) had an estimated total 81 returns in 2001 between all of them (Committee on Atlantic Salmon in Maine, 2004). Sixty-two of those returns (76%) were of farmed origin (Pietrak and Belle, 2007). The estimated cumulative returns to these rivers in 2004 were between 60 and 113 individuals. Some had zero observed returns. (National Oceanographic and Atmospheric Administration et al, 2005). When the numbers are this low, escapees do amount to a lot of fish. This is not an issue unique to Maine. Rune Bildeng, special adviser to the Ministry of Fisheries in Norway, referred to their 200,000 to 650,000 escapees (only 1% of their total population) as "a lot of fish" (cited in Gibbs, 1996, p. C4). Ninety percent of the salmon captured in the Saltdals Fjord that year were identified as being of farmed origin (Ibid).

	Total Salmon Returns	Returning salmon of farmed origin	Farmed origin %
All Maine Rivers	**940**	**124**	**13%**
Listed Rivers Only	**81**	**62**	**76%**

Table 1: Estimated Salmon Returns to Maine Rivers (Source: Committee on Atlantic Salmon in Maine, 2004)

While the number of total salmon observed or estimated to exist in the eight listed rivers may be in the hundreds or even thousands, returning adults are used as an indicator since they are the only ones that will be spawning. There is no telling how many of those thousand fish will survive to spawning age or succeed in mating in that case. If 300,000 returning adults spawned each year with a total population of 5-12 million in the 19th century (Montgomery, 2003), then we can estimate a total population of 17,000 to 40,000 salmon based on returns of about 1,000 in 2004.

Wildness Worth Preserving

In the late 1990s the number 500 appeared in many places and was cited as the number of "Atlantic salmon with a truly native genetic makeup" that remained in Maine (Goldburg and Triplett, 1997, p. 11). Paul Santavy, Project Leader at the Green Lake National Fish Hatchery in Ellsworth, ME says that Maine is past the point of having any truly wild salmon left in its waters, each individual likely carrying at least a few artificially selected genes (Paul Santavy, personal communication, 12 February 2007). While the only way to verify this for certain would be to genetically test every salmon in Maine's rivers for domesticated genes, there is an overwhelmingly disproportionate amount of escapees to wild fish (see page 15).

This leaves us with the following questions: what do we mean when we say "wild" and what, exactly, are we trying to preserve in the waters of Maine? To be truly wild, the NOAA Fisheries Service Northeast Salmon Team says that a salmon must be "a link in an unbroken chain of ancestors that all completed their entire life cycle under natural conditions" (NOAA Fisheries Service Northeast Salmon Team, 2008, Wild Forms para. 1). Due to the interbreeding of farmed fish with wild fish and even the release of hatchery-bred salmon for restocking purposes, "a more practical definition of wild is an individual that spends its entire life cycle in its natural environment and whose parents were naturally spawned and reared" (Ibid). This definition provides a realistic goal for salmon restoration. When successive generations of Atlantic salmon can propagate in the wild and spend their full life cycle in their natural environment, without the aid of supportive breeding programs, or being decimated by escapees from fish farms, these efforts can be considered a success.

Without the added influence of domestic genes, time alone drives the evolution of a species or population. Yet, even with ongoing competition and interbreeding with farm escapees, the wild salmon populations of Maine have managed to retain those characteristics which define them as wild instead of domestic or hybrid fish. Chapter Two contains a list of differences between farmed and wild salmon, but I refer here to their specific adaptation to a local river and spawning ground. Wild salmon have a homing ability, not completely understood by humans, that allows them to swim upstream in the very river they came from. Farm escapees "seem to dart up whatever stream is nearest when the urge to spawn strikes" (Gibbs, 1996, p. C4). In contrast, salmon specifically bred for the purposes of restocking the wild population will retain their progenitors' river-specific adaptation. This characteristic, evolved over centuries by each distinct population segment based on water temperature, salinity, currents and smells is what has kept wild fish wild and is in danger of being blown apart by fish-farm strays.

This wildness is worth preserving because it is the best option for restoring extirpated populations, which will, in turn, increase the amount of wildness globally. Experiments have shown that fish from nearby rivers can be interbred and introduced to a third river that once supported wild Atlantic salmon but which is now home to few or none. That first generation will, if introduced at the right time, be able to home to that river. Successive generations will continue to do so and, over time, a unique population of wild salmon will evolve (Fay et al, 2006, Spidle et al, 2004).

This very phenomenon has been demonstrated in the Penobscot, a large river off of which branch a number of tributaries. Though no one knows precisely what happened to the Penobscot River population, it is generally agreed that it either became substantially reduced, if not functionally extinct or even completely extirpated in the early to mid 20th century (Fay et al, 2006). Hatchery stocking for restoration purposes occurred in the 1960s and 70s with fish from the Machias and Narraguagus Rivers. Whether or not any Penobscot fish remained in the river at that time is unknown. Today's population, therefore, either retains some of the historic Penobscot characteristics, or is a "unique mixture of genetic characteristics from each of the potential source populations" (Fay et al, 2006, p. 58). Even assuming that the current population no longer retains those historic Penobscot genes (and this hypothesis cannot be confirmed or falsified as there is not an existing record of those historic genes), a unique population currently resides in that river.

The Penobscot River salmon were subsequently used, beginning in 1976, to repopulate the extirpated Connecticut River population. After twenty years the adult returns to the Connecticut River "scarcely diverged genetically" (Spidle et al, 2004, p. 262) from their Penobscot parents, but the two populations did display a difference in microsatellite allele frequencies.[9] The study which determined this fact attributed the limited divergence to the fact that, until 1996, the Connecticut River population was maintained by "broodstock of Penobscot origin and additional Penobscot broodfish imported most years" (Spidle et al, 2004, p.254). These practices ceased in 1996, and the authors are confident that the two populations will continue to diverge as the Connecticut River population adapts to that river and develops its own unique characteristics (Spidle et al, 2004).

[9] A microsatellite allele frequency is "the proportion of all genetic variants at a locus [a specific location on a chromosome] within a population of organisms" (Ness, 2004, p.). The descendents of the Penobscot River salmon were changing genetically in the Connecticut River, perhaps due to the presence of a few remaining Connecticut River salmon genes.

These two cases—the unique Penobscot population and the restoration of the Connecticut River population—are presented as examples of how wild salmon populations, even on the edge of extinction, can be restored to functional levels. This restoration is important as the loss of these populations will leave a gap in the broader Atlantic salmon taxon between the wild Atlantic salmon populations in Europe and the extirpated American populations. A continued influx of artificially selected farm escapees can delay, compromise, or even prevent the restoration of this fish.

INTERACTIONS BETWEEN PEOPLE and SALMON: HELP, HOPE AND HARM

Humans interact with salmon in a number of ways: we eat them, we grow them, we fish them, we destroy their habitat, we restore their habitat, and we try to help them survive. In this section I will discuss the various ways in which people affect the lives of salmon in Maine. Two of these ways are the propagation of Atlantic salmon in 1) commercial fish farms and 2) conservation hatcheries. The final category involves the ways humans impact wild salmon in ways other than breeding them. These include habitat destruction, pollution and capture fisheries.

I will address these three categories in the order presented, beginning with commercial aquaculture.

The Advantages of Aquaculture

None of the many studies, articles and reports reviewed for this paper advocates abandoning commercial aquaculture. For reasons both environmental and economic, fish farming is a practice that is only gaining momentum.

Environmental

Global fish stocks are declining. This is agreed upon by scientists, policy makers and fishermen. Today, fishermen and scientists get excited over cod numbers of 15,000. But in the late 1980s, "the biomass, the population, was 1.2 million'" (quoted in Kurlanksy, 1997, p. 195). Newfoundland's legal cod fisheries were closed by the Canadian government in 1992 , just as the Canadian salmon fisheries were. Many would-be fishermen are now employed by the government. Still catching fish on the open seas, they no longer catch them for market, but instead are part of a large-scale monitoring project, keeping tabs on the declining populations (Kurlansky, 1997).

National Geographic, The New York Times, The Associated Press and other media regularly publish articles on the damage to the ocean community and the continuing decline of deep-ocean fish. In the waters off the coast of Maine, cod fishermen pushed for a law (ultimately not passed) that would allow them to keep and sell some of their lobster by-catch, a practice long forbidden by Maine's trap-only law in regard to lobster (Sabar, 2007). Their own catches are so low that despite an age-old rivalry, and even, some might say, their own pride, they are trying to claim rights to lobsters they have never touched before.[10] Bluefin tuna, too, are disappearing (Greenberg, 2010b). Catches of many species are producing younger and smaller fish. The April 2007 *National Geographic*'s theme was "Saving the Sea's Bounty" and in one of their features they report that swordfish, "which should grow as thick as a telephone pole, are now caught as juveniles and eaten when no bigger than a baseball bat" (Montaigne, 2007, para. 3).

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[10] On March 16, 2007, the Maine legislature's Committee on Marine Resources voted unanimously against this bill (Maine House of Representatives, 2007).

Many nations' policies are in accordance with these statements. From the closing of the high seas salmon and cod fisheries in the U.S. and Canada to the creation of marine reserves around the world (Pew Oceans Commission, 2003), governments are taking action to restore their fisheries. Despite these regulatory efforts, modern day pirates continue to ply the waters of the world in search of in-demand and high-priced seafood like the Patagonian Toothfish (Chilean Sea Bass) or swordfish (Knecht, 2006). "Tuna laundering" occurs despite international quotas and, as a result, Japan now performs DNA tests on imported tuna to identify its source and, it hopes, curb violations on restricted populations (Onishi, 2006).

This information comes from scientific data collected over years on the status of cod, toothfish and tuna. One recent study analyzed "local experiments, long-term regional time series, and global fisheries data" (Worm et al, 2006, p. 787) to find that decreasing global biodiversity endangers ocean ecosystem services like water quality, species' populations and the ability of an ecosystem to adapt to or recover from environmental changes or harms. If fishing practices do not change, Worm's study projects "all commercial fish and seafood species will collapse by 2048" (Stokstad, 2006, p. 745).

Though regulatory action like limiting the yearly catch of vulnerable species often shows results over time—Maine has seen "record-setting lobster harvests in recent years" (Sabar, 2007, p. A11) thanks to conservation efforts that include the trap-only law—a large part of the ever-expanding human population continues to rely on fish and seafood as a delicacy, a simple meal, or, in the case of many developing nations, the primary source of protein in their diets. Fish consumption has "more than doubled since 1973"

(FAO, 2007, p. 88). Salmon consumption alone has increased "by a factor of 40 during the past two decades" (Hites et al, 2004), with farming rising from 24,000 to 1 million metric tons (Ibid). Aquaculture is a practical answer to a problem that seems to have few, if any, other immediate solutions. Some species have been farmed for centuries or longer simply as an easier way to get fish. Egyptians were growing tilapia in shaded ponds earlier than the 5th century B.C. (Beveridge and Little, 2002). Ancient Hawaiians raised dozens of species, including taro and algae for feed in polycultures 1800 years ago (Costa-Pierce, 2002). Fan Li published the first document on aquaculture in China in the 5th Century B.C. (Ling, 1977). Many of the deepwater fish mentioned above are more difficult to raise in captivity. As if on cue, however, just as their wild populations sit on the brink of decimation—cod stocks dropped 99% in the last 20 years (Kurlanksy, 1997) and there are only an estimated 9,000 Bluefin tuna left in North American stocks (Greenberg, 2010b)—efforts have surged in the pursuit of their farmed counterparts.

In September 2006, Hidemi Kumai, the head of the fisheries laboratory at Kinki University in Osaka, Japan, succeeded in farming the physically and psychologically delicate Bluefin tuna (Onishi, 2006). The University of New Hampshire's Open Ocean Aquaculture Project is perfecting deep-water and sustainable cod farming, domesticating another never-before-farmed creature (Langan, 2006). The hope is that these breakthroughs will take pressure off wild stocks, giving them time to recover to self-sustaining numbers. I have documented the risks associated with these practices in Chapter Two, but for a fish-eating world, there are few other options that work so well.

Economic

The previous section gives evidence of why aquaculture is good concept in general, but economic reasons tell why fish—specifically Atlantic salmon—should continue to be grown in Maine.

This is a nation founded—and has parts that are literally built—on the backs of sea creatures and the industry surrounding them. From New England's historic whaling and fishing traditions, to the oysters that once crowded New York harbor and are now part of the fill beneath downtown Manhattan. According to U.S. Commerce Secretary Carlos Gutierrez, the United States imports 70% of the seafood it consumes, which is equivalent to a $9 billion trade deficit (cited in Bell, 2007). Salmon trade alone had a trade deficit (importing more than exporting) of $494 million in 2005. This is a huge drop from the $500 million *surplus* just ten years before (Knapp et al, 2007). These numbers reflect both Atlantic salmon and salmon from the Pacific Northwest and Alaska where populations are in much better shape. Atlantic salmon, however, are cheaper than wild-caught Pacific salmon, and though we have the capacity to grow them in the United States, the majority of the United States Atlantic salmon are farmed in countries like Canada, Norway and Chile (Knapp et al 2007).

Aquaculture creates jobs, and by keeping commercial aquaculture running in Maine, some of the poorest counties—Washington and Hancock, where the farms are concentrated (Tom King, personal communication, 12 February 2007)—benefit from the employment and increased revenue. These two counties have two of the highest unemployment rates in the state of Maine. The unemployment rates are generally 50%-100% above the state and national averages (Maine Department of Labor, 2009a; 2009b;

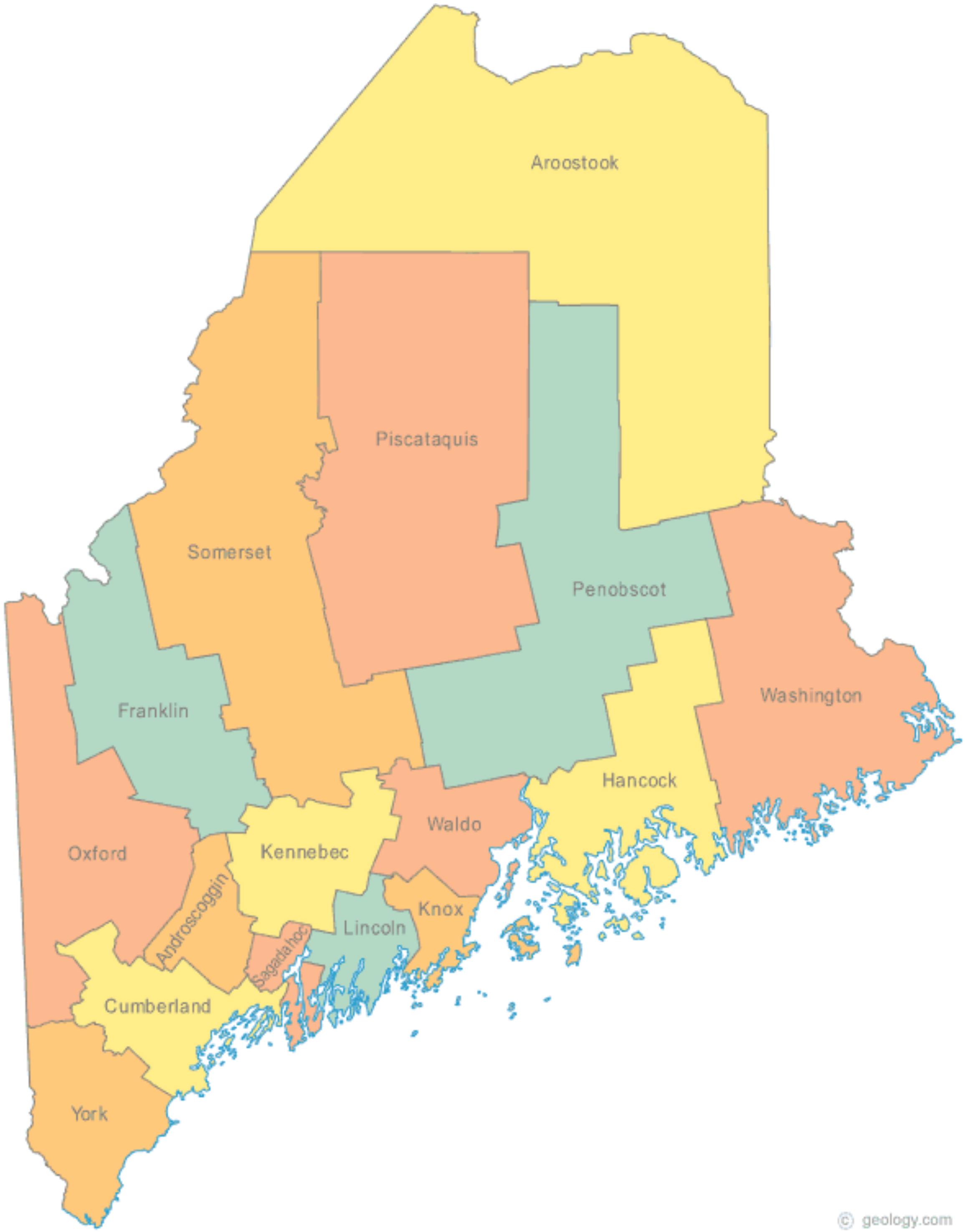
2009c). Maine's aquaculture operations employ over 600 state residents (and untold others in related industries), and generate over $130 million a year (Maine Aquaculture Association, 2006).

Keeping fish production local also decreases the amount of fossil fuels used to transport them from afar; keeps more money in the regions where the fish actually live (or lived), resulting in the potential to put more money toward conservation of the wild populations; and can improve the local economy. Plus, all else being equal, who would eat a frozen fish shipped from South America when you can get one fresh from your very own neighborhood?

For our purposes we have to assume that it is not in the realm of possibility that we can eliminate commercial fish farms from the waters of Maine in order to give wild salmon genetics the time to recover and improve until their numbers are large enough that they can withstand the inevitable rogues that escape the confines of their net pens. The employment benefits mentioned above are too great and the absence of these jobs would be a detriment to the communities.

But even as these escapees take their toll on wild salmon, other forces are working to maintain functional populations until the salmon can once again maintain them on their own.

Maine County Map



Map E: Washington and Hancock counties hold the highest concentration of salmon farms in Maine (Cole, 2009).

Conservation Hatcheries

It is tempting to set these two types of salmon growing as polar opposites. But just as commercial aquaculture is not cruelly bent on destroying wildlife, hatcheries dedicated to wild salmon conservation and restoration—in general a noble and positive goal—have their own problems that raise questions about whether they are the best possible option for salmon restoration.

In general, conservation hatcheries are doing a world of good. Quite possibly they are the only thing that has stood between the wild salmon and complete extinction in Maine. At Craig Brook and Green Lake National Fish Hatcheries project leaders Tom King and Paul Santavy and their staffs raise river-specific Atlantic salmon for release in an effort to bolster the failing populations. By raising them through the fry and parr stages, the hatcheries are protecting the fish during what is normally a very vulnerable period in their life cycles. Released as smolts, the salmon have a better chance of surviving and contributing to the local population. They also have a fry release program, but it has had less positive results (Tom King, personal communication, 12 February 2007).

Despite the general good these hatcheries do, it is important to remember that, like any endeavor, they come with their own negative side effects. Matthew Young of the Maine Department of Environmental Protection (MDEP) points out that the formalin used to inoculate the fish against disease is used in higher levels in the conservation hatcheries' flow-through systems, and ends up in the lakes and streams that the hatcheries adjoin. Due to its toxicity and volatility, formalin is a significant consideration for human and animal health (Matthew Young, personal communication, 12 February 2007). It is

Mr. Young's job to monitor and regulate all aquaculture activities in Maine, commercial or conservation, for just such things, as well as waste stream and associated bacteria, unauthorized releases and others. The awareness of a fault like this by the otherwise helpful hatcheries widens one's vision and insists that we ask ourselves the question, while saving the salmon, what else is being put in danger? If salmon can only be restored at the expense of another species or ecosystem, is that worth it?

The conservation hatcheries persist with the encouragement of the MDEP, and continue to do their best to keep the Atlantic salmon alive. Their efforts are minimally rewarded, however, as salmon numbers show only slight, but erratic signs of improvement.[11] It is at this point that one must remember that the problem of genetic introgression and wild stock depletion does not exist in a vacuum; that even though genetically wild salmon are being restocked in rivers, and farm escapees are being minimized, other factors play into the equation that continue to frustrate restoration efforts.

Other Factors

Salmon are a more difficult species than most to deal with. As anadromous fish, they spend part of their lives in the freshwater rivers along the coast of Maine, and the other part out in the deep saltwater of the ocean. As a result, both of these systems have to be healthy to facilitate a restoration effort. If one is compromised, the task becomes very difficult, if not altogether impossible. Currently, both the ocean system and the

[11] Adult returns in 2009 were up to 2,200 (from 1,000 in 2004), but dropped to 1,300 again in 2010 (Atlantic Salmon Federation, 2011).

freshwater habitats of Maine are under stress and functioning far below their full capacity.

Freshwater Habitat Destruction and Pollution

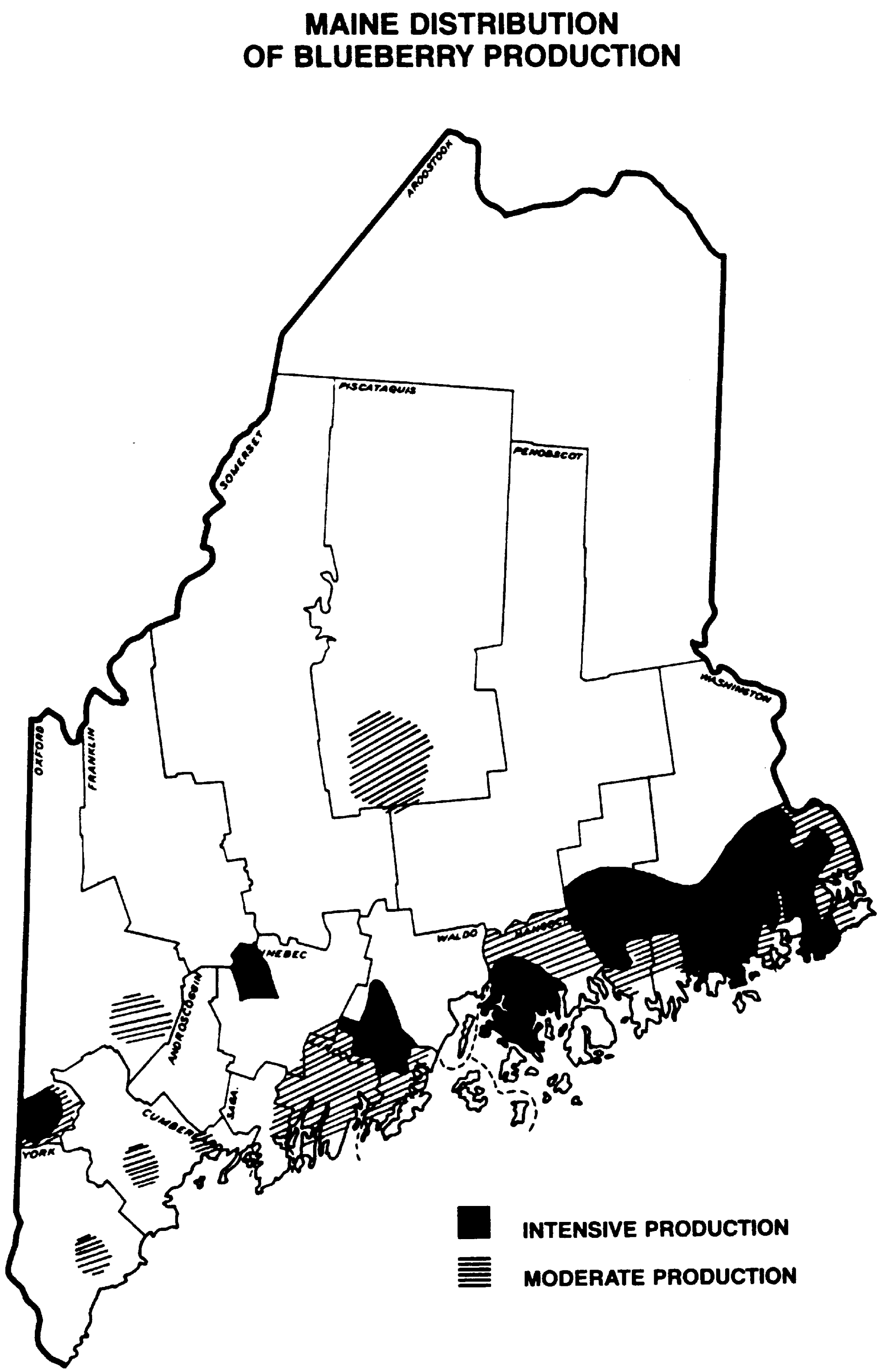
The story of nature suffering in the name of human economic development is as old as civilization itself. Dams dot the rivers of Maine, impeding salmon passage back to their spawning grounds. Sedimentation has increased and water quality has decreased as a result of logging, agriculture and other development. These same human activities have caused erosion on the river banks and have altered the river beds that salmon rely on to create their redds (United States Cong. Senate, 1973).

The National Marine Fisheries Service, the U.S. Fish and Wildlife Service, and the Atlantic Salmon Biological Review have published reports that are generally in agreement on the impact of logging, development and dams on water quality and salmon habitat (NMFS, 2005, USFWS, 1999, Fay et al, 2006).

Sedimentation can kill young salmon, particularly in the fry stage, by smothering them; it alters river substrate and reduces habitat; and negatively affects macroinvertebrate populations that are a crucial food source for Atlantic salmon (NMFS, 2005).

This increased sedimentation is caused by agriculture, logging, and that thing that comes with all new development: roads. Nonpoint source pollution surveys conducted on the Dennys River (one of the eight DPS rivers) found that 84% of the nonpoint source pollution sites were associated with unpaved roads constructed for logging, agricultural or civilian access (NMFS, 2005).

Overall water quality is impaired by these same sources. Blueberry agriculture is a major and important land use in Maine. As can be seen in Map E, blueberry agriculture is concentrated primarily in Downeast Maine, around the mouths of many rivers. Pesticides, herbicides and fungicides used on these crops "can cause immediate mortalities to juvenile Atlantic salmon or can have indirect effects when chemicals enter waterways" (USFWS, 1999, Section 7.1.3, para. 5). Pesticides are also used in forestry, particularly to control the spruce budworm (NMFS, 2005). In the early 1980s Maine rivers saw the double threat of heavy spraying for this pest followed by the massive clearcutting of forests all along Route 9 when it became apparent that the timber companies could salvage usable wood, but only if it was done quickly. All at once Downeast Maine was zigzagged by logging roads which led to increased sedimentation, erosion and runoff carrying the pesticides that had just been dumped on the same land (Tom King, personal communication, 12 February 2007).



Map F: Blueberry agriculture is concentrated around listed rivers (Yarborough, 2009).

Dams are another major threat to salmon. While a juvenile fish making its way out to sea from far up the stem of a river will have no trouble slipping over dams and finding its way through filters and gates, as an adult returning to its birthplace, this same fish will find it nearly impossible to overcome these same obstacles in the opposite direction. Dams have long been connected to salmon population declines. The construction of dams in the late 1800s is followed by a decrease in returning salmon. When fishways were added, however, the numbers increased (USFWS, 1999). At one point, dams existed on every one of the eight DPS rivers in Maine (NMFS, 2005). Though some have been breached and fishways exist on many dams to allow passage, Atlantic salmon still have a difficult time of things.

In the Penobscot River watershed (with the largest historic habitat) 80% of potential spawning habitat is accessible, but most of this lies above at least one dam and 76% of "accessible" habitat lies above at least four dams, which the salmon must cross in order to spawn (Fay et al, 2006). The entire West Branch of the Penobscot is inaccessible due to lack of fishways. Even with fishways installed at the lowest dams, appropriate habitat on this branch would still lie beyond *ten dams* (Fay et al, 2006). While fishways do alleviate the problem of habitat connectivity, they are not perfect. They can fall into disrepair, and they don't work as efficiently as the natural river. Aquaculture once again becomes a problem as farm escapees, unfit for survival in the wild, fail to make it past a dam and block the passage up fishways, preventing any other salmon from making the trip (Dave Bean, personal communication, 8 March 2007).

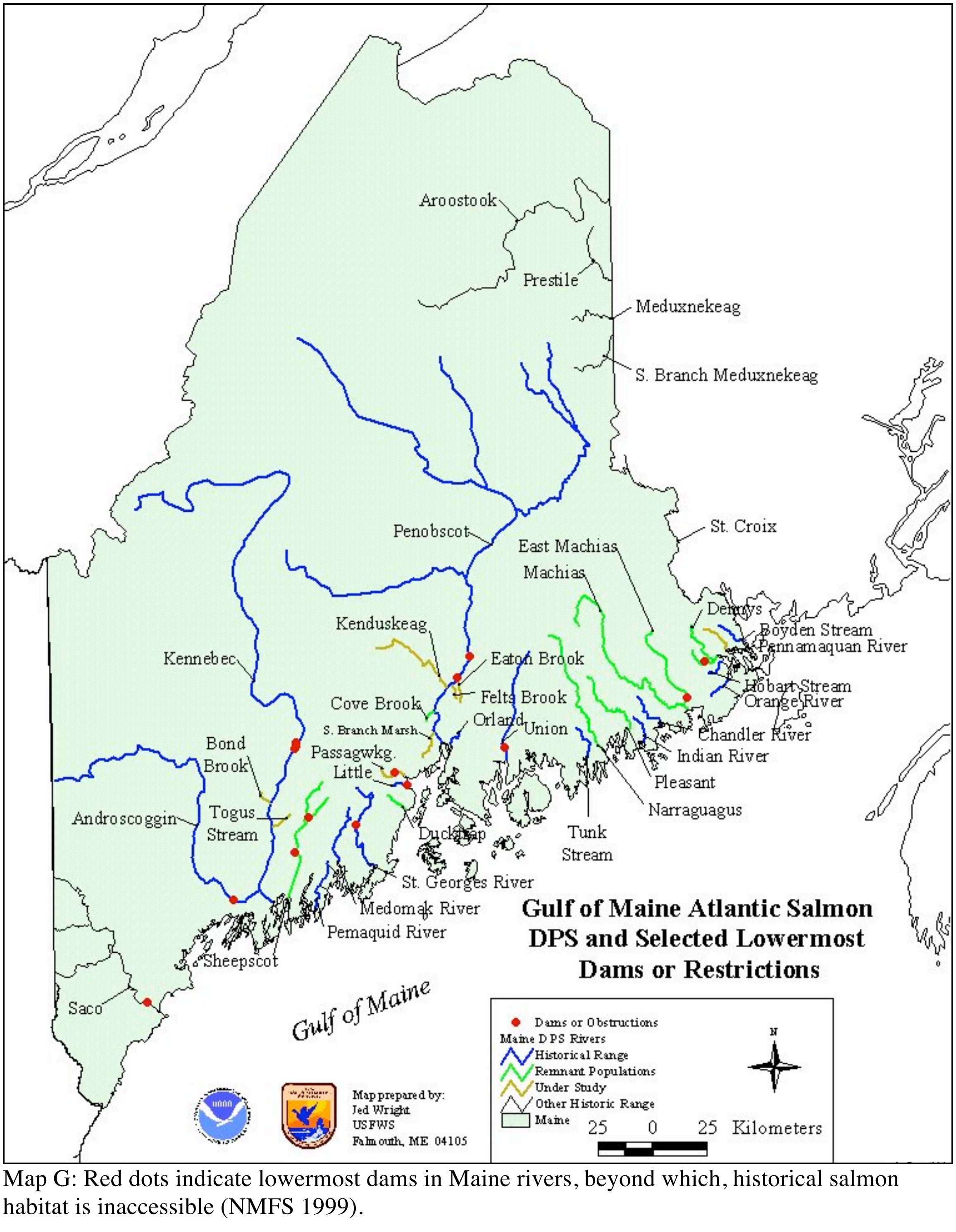
As a result of these dams, miles of potential habitat are inaccessible to salmon that once swam across nearly the entire state. Map F provides a visual representation of where the lowermost dams are in Maine rivers and just how much habitat lies beyond them.

There are other factors that affect freshwater habitat of salmon like water temperature, dissolved oxygen and other to water quality parameters, but even with all that has just been covered it is only half the story. Even should all of these problems be remedied, there is still the matter of that place where salmon spend the other half of their lives, feeding and growing to adulthood in the salty Atlantic ocean.

Low Marine Survival

Though little work has been done on salmon abundance at sea—primarily due to prohibitive costs (ICES, 2006)—some studies that have been done on Atlantic salmon marine survival find a correlation between sea surface temperatures and survival rates (Friedland et al, 2005, Friedland et al, 2003, Jonsson et al, 2003). Support for the hypothesis that salmon sea-survival rate has decreased in recent years ranges from "modest" (Jonsson et al 2003, 908) to confidence in a correlation between survival and temperature (Friedland et al, 2003).

Regardless of enthusiasm, all the studies agree that we are currently in a valley or low-point of Atlantic salmon sea-survival. The survival rate of hatchery fish released into the wild has decreased since 1980 (Jonsson et al, 2003). Jonsson et al cite a corresponding decrease in Pacific salmon survival, indicating a link to broader climatic change (2003). If Friedland et al (2003) are right, and there is a negative correlation between salmon stock size and spring sea surface temperatures (i.e. as temperature increases, stock size decreases), this does not bode well for the future of salmon survival at sea as global climate change begins to raise sea temperatures more and more. For the present, Atlantic salmon face a struggle for survival in both areas that they call home.



Map G: Red dots indicate lowermost dams in Maine rivers, beyond which, historical salmon habitat is inaccessible (NMFS 1999).

Conclusion: Improving Commercial Aquaculture Image

The previous section is not meant to excuse the harm that fish farms cause, but to emphasize that Atlantic salmon face many challenges to their survival outside of farm escapees and that with all the obstacles wild Atlantic salmon in the GOM DPS face on their road to recovery, they can use as many allies as they can get.

Commercial aquaculture should be good at two things: growing fish and making money. As a result, they make an ideal ally for wild salmon. Unfortunately, difficult growing conditions and bad publicity have taken their toll on Maine fish farms and production has decreased in recent years, from 36 million pounds in 2000 to 11.5 million pounds in 2005 (MDMR, 2006). It's possible that commercial salmon aquaculture might one day abandon Maine's waters altogether. Looking strictly at the benefit to the wild salmon, this would be a positive scenario. Since 2004, however, most of the salmon farms, previously operated by at least four separate companies, were bought by Cooke Aquaculture (Hedlund, 2006). Cooke is the largest aquaculture company in Eastern Canada, and has operations in New Brunswick, Prince Edward Island, Nova Scotia, Newfoundland, Maine and Chile, and processes more than 115 million pounds of Atlantic salmon each year (Cooke Aquaculture, 2009; Montaigne, 2003). In present conditions, then, in which the salmon farms continue to operate, salmon conservationists must work with them, taking advantage of and making use of their technology and funds to improve the lot of the wild fish.

While farms create a threat with their potential for escapes on the one hand, they have a lot to offer on the other. As profit-seeking ventures, they have a strong incentive to create the best technologies for their purpose: nutritious feed for heartier fish, effective pens that result in the fewest escapees, breeding techniques that allow people to more precisely choose the genes they want (though farms would choose genes for size and taste, the technology would allow hatcheries to choose genes to match the populations they wish to save). Even though the commercial farms are creating the technology, they are not the only ones who benefit from its creation. Conservation hatcheries are admittedly glad for the advances commercial farmers have made and use the same feed and techniques themselves to grow their conservation salmon (Tom King, personal communication, 2007).

As for making money, if commercial aquaculture is doing that successfully, then it is poised to provide relief to the wild resource that made its own business possible in the first place. Chapter Five goes much further into this concept and its related recommendations.

Simply put, if there are salmon farms in Maine, their abilities and money should be utilized to further the goal of wild salmon restoration. At the same time, to keep farms around is to maintain the presence of farmed genes in the wild populations, so steps must be taken to minimize their impact or to secure compensation should damage occur. Chapter Four looks at the regulatory history related to Maine's Atlantic salmon and explores whether or not salmon are protected effectively by the state and federal government, and how non-governmental organizations are working to fill regulatory gaps, and insure that the laws that get made get enforced.

Chapter 4
Salmon Law

The salmon may be slowly vanishing, but Maine has not been watching idly as it happens. There are many organizations, both government and NGO, that are dedicated to the preservation, conservation and the restoration of the wild salmon populations. This chapter will discuss the ways the Atlantic salmon are protected by law in Maine, illuminate the gaps in these regulations, and explore some non-regulatory efforts and suggestions that have been effective in their own right.

Decidedly Endangered

In 1992, after a one hundred year decline in wild Atlantic salmon numbers—from 5-12 million in the late 19th century (Montgomery, 2003) to less than 40,000 today (Committee on Atlantic Salmon in Maine, 2004)—sanctioned fisheries were all but eliminated (see Chapter Three, page 32), but it was almost another decade before the Atlantic salmon became officially protected in the state of Maine (Committee on Atlantic Salmon in Maine, 2004).

In 1991, the U.S. Fish and Wildlife Service named the Atlantic salmon in Maine rivers as a candidate for protection under the Endangered Species Act (ESA) (*State of Maine v. US Department of the Interior,* 2002). Though not officially on the endangered species list, protection and restoration efforts were already underway for the species and in 1992, a river-specific broodstock and stocking program was implemented for Maine rivers. This refers to the practice of breeding salmon in federal hatcheries specifically using stock *from* and *for release in* specific rivers (i.e. using Dennys River broodstock to raise new stock that will only be released in the Dennys River, thus preserving the genetic integrity of that sub-population).

In late 1993, the National Marine Fisheries Service (NMFS) and the Fish and Wildlife Service (FWS) received a petition, filed simultaneously by three separate parties—RESTORE: The North Woods, Biodiversity Legal Foundation and Jeffrey Elliot[12]—to list the Atlantic salmon under the ESA. In response, the NMFS and FWS formed a biological review team to determine whether such a listing was warranted (DOC, 2006). In 1995 they published the "Status Review for Anadromous Atlantic Salmon in the United States," which provided detailed information on the life history of the Atlantic salmon, its distribution and abundance, and ultimately determined that "based solely on the best scientific and commercial information available after conducting a status review of the species . . . that available biological evidence indicates that listing the Atlantic salmon as endangered throughout its historic range in the contiguous United States is not warranted" (DOC, 1995, p. 14412). This determination was revised six years later, but it is important to note that what they found as unwarranted is listing the salmon as "*endangered throughout its historic range*." The Status Review *did* determine, however, that the Atlantic salmon was in danger of extinction in seven rivers—the Sheepscot, Ducktrap, Narraguagus, Pleasant, Machias, East Machias and Dennys Rivers (Ibid). The petition resulted in "appropriate listing actions" (Ibid) for these rivers and they became designated as candidates for listing under the ESA (NMFS, 1995).

[12]Information about these and other organizations and individuals can be found later in this chapter on page 68.

The listing, not even fully applied yet, was fought every step of the way by business interests and politicians, including Governor Angus King. In order to protect not only the aquaculture industry, but also Maine's blueberry and logging industries (which would be impacted by limits on water withdrawals and land use), the state formed the Maine Atlantic Salmon Task Force (MASTF) and developed their own conservation plan (MASTF, 1997) to protect the salmon in the seven candidate rivers (Glennon, 2002). The State of Maine was invited to create this plan by the NMFS and FWS and in December 1997, they accepted the State's plan in lieu of a federal listing under the ESA (DOC, 2006).

This decision did not remain conclusive for long. 1999 turned out to be a very busy year, beginning in January with the NMFS and FWS's receipt of the State's "Annual Progress Report on Implementation of the Conservation Plan" (DOC, 2006, p. 66299). Upon review of this report, the NMFS and FWS created their own status review (NMFS, 1999) that declared that, despite the conservation plan, the salmon's position in the Gulf of Maine had still declined precipitously. Several lawsuits were also filed this year against the NMFS and FWS to force them to officially list the salmon as endangered as originally intended—in January, by the Defenders of Wildlife (*State of Maine v. US DOI,* 2002) and in August by the Atlantic Salmon Federation and Trout Unlimited, both of which had long deemed the State's plan inadequate (Glennon, 2002). The progress report, the status review and the lawsuits all led up to the decision on the part of the NMFS and FWS to once again propose the Atlantic salmon for listing as an endangered species on November 17, 1999, with this significant difference: the Atlantic salmon was now a candidate as an *entire species*, and not merely in seven critical rivers as in 1993 (DOC, 2006).

Over the next year, the NMFS and FWS held three public hearings and a 150-day comment period during which they received over 200 written comments (DOC, 2000). On November 17, 2000, the NMFS and FWS made a final rule based on these comments, the previous year's status review and additional information, and determined that "the Gulf of Maine DPS is in danger of extinction throughout its range" (DOC, 2000, p. 69459). Upon the publishing of this rule, the Atlantic salmon became officially listed under the ESA (DOC, 2006).

Now definitively listed as an endangered species, the Atlantic salmon is still at risk. The enforcement of the federal law is not always guaranteed, and this responsibility falls to the Maine Department of Environmental Protection, additional court decisions and the day-to-day behavior of those people in industries and organizations with the capacity to do this fish harm.

Atlantic Salmon Under the Endangered Species Act

As a species listed under the Endangered Species Act (ESA), the Atlantic salmon is protected from being imported, exported, possessed, sold or taken. Anyone violating these protections may be fined \$500 to \$50,000 and spend up to a year in prison per violation (United States Cong. Senate, 1973). With the term "take" defined as "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct" (United States Cong. Senate, 1973, p. 6), this would seem to leave very little one can do to interfere with the life of a wild Atlantic salmon. Additionally, the ESA requires that recovery plans be developed and implemented “for the conservation and survival of” the salmon (United States Cong. Senate, 1973, p. 12).

When the Atlantic salmon was listed under the ESA on November 17, 2000, the “Final Endangered Status for a Distinct Population Segment of Anadromous Atlantic Salmon (*Salmo salar*) in the Gulf of Maine” went on to describe specific actions that “could result in a violation of section 9 prohibitions against “take” of the . . . Atlantic salmon” (Department of the Interior 2000, 69479). Pertinent to this thesis, these included both the escape of reproductively viable non-North American farmed salmon, as well as any other domesticated salmon that escape and enter any of the protected rivers (Ibid). Salmon that escape, but do not enter the protected rivers are not included under the law, though still impact the overall population.

What this Act and the listing of the salmon under it do is establish a structure of laws that announce nationally that this fish is not to be harmed, in what ways one would be deemed to be harming it, and prepares for the ensuing conservation and improvement of the species. These documents do not, however, magically restore the salmon populations. The law is on the books, but it does not enforce itself. As a result, nearly three years passed while salmon numbers continued to fall, and no new measures were explicitly taken to modify the heretofore detrimental behavior of people towards this fish (Florida Museum of Natural History, 2003).

It wasn’t until the decision by Judge Carter in *USPIRG v. Atlantic Salmon of Maine* (2003a) that the rules and regulations of the ESA listing were enforced and something was done to actually protect the fish that needed protection (Florida Museum of Natural History, 2003).

The Clean Water Act

Because the Clean Water Act, passed in its modern form in 1972, put limits on how much chemical pollution may be present in American waters, industry, states and communities began to clean them up. This was done in some regions to protect drinking water supplies and the health of those who swam in and ate from these rivers, but also to protect the ecosystems. For a river to be fishable, there has to be fish in it. But in all the words and footnotes of the Clean Water Act, there remained a loophole, leaving the wild salmon of Maine exposed and at risk from biological pollution: their escaping farmed cousins.

Biological pollution is the "introduction of unwanted, non-native species [or subspecies] to natural ecosystems" (Goldburg and Triplett, 1997, p. 49). This is considered pollution because, as explained in Chapter One, wild salmon are adapted to their own specific rivers. Their existence can be threatened by farm escapees interbreeding with the wild fish as much as it can by a non-native predator being introduced and preying on them. "Scientists believe non-native fish from aquaculture provided a contributing factor in the extinction and endangerment of several native fish species" (Brenninkmeyer, 1999, p. 84).

The evidence that farm escapees are a danger to wild salmon is overwhelming (see Chapter Two), but the Clean Water Act is not overwhelming in its language when it comes to regulating this particular pollutant. The Act defines "pollutant" as "dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water" (Environmental Protection Agency, 1977, p. 1362). The language exists—in the words "solid waste, biological materials, and agricultural waste"—to protect wild salmon from farm escapees, but it is never explicitly spelled out that this is a threat from which salmon need protecting. In *National Wildlife Federation v. Consumers Power Co.,* the Sixth Circuit interpreted biological materials as "live fish, dead fish and fish remains" (cited in Brenninkmeyer, 1999, p. 96) and the Washington Pollution Control Board determined that farmed salmon qualify as "'agricultural or industrial waste'" (Ibid).

The consensus is that escaped fish are biological materials, but the sticking point over whether or not they are pollution comes with deciding whether or not they have been "added." In the case of a hydro-electric facility, dead fish parts that were expelled from the plant after being passed through along with the water were *not* considered "added" since they were never technically taken out of the water. Seafood processors, however, *do* add a pollutant, since they remove fish from the water, process them and then return the unused parts and wastes back into the water (Brenninkmeyer, 1999). The case of fish farms and escapees aligns almost perfectly with the latter example, since in both cases the fish are removed from the water (in the farms' case to be put into aquaculture systems as eggs, fry and smelt) and, if they escape, are being returned to the water in different form. This concept is further supported by the Clean Water Act's definition of pollution as "man-made or man-induced alteration of . . . biological . . . integrity of water" (Environmental Protection Agency, 1977, p. 1362).

For a long time, however, salmon farm escapees were also escaping regulation under the Clean Water Act, and seemed destined to continue to do so until Judge Carter of U.S. District Court in Maine ruled in *USPIRG v. Atlantic Salmon of Maine* (2003a) that escaping salmon are, in fact, pollutants under the Clean Water Act, something that had been hinted at, but never explicitly stated. With the federal District Court's final ruling in December 2003, the Clean Water Act now explicitly protects the wild Atlantic salmon of Maine from their domesticated counterparts, and their genes. The ESA declared that Atlantic salmon were in need of protection, but the Clean Water Act and the federal District Court ruling became more specific and demanded that the goals of the ESA listing be actively pursued and that more effective enforcement mechanisms were available (Anderman-Hahn, 2006).

Enforcing the Laws

There is a web of state and federal agencies in Maine that are responsible for various and multiple aspects of salmon conservation and recovery. Their dynamic relationships are made more complex by their interactions with NGOs and nonprofits, but all work for the ultimate recovery of the Atlantic salmon.

Among the most important state agencies in this effort is the Maine Atlantic Salmon Commission (MASC), established in 1999 and tasked with "restoration and management of Atlantic salmon throughout its original range in Maine" (Committee on Atlantic Salmon in Maine, 2004, p. 97). The MASC is the ultimate authority when it comes to introducing Atlantic salmon to Maine's waters, and is therefore the final word on all restocking efforts, which release millions of fry and smolts each year. This is the body responsible for the current restrictions on all recreational fishing for Atlantic salmon in the state, and in addition, carries out monitoring and tagging programs (Committee on Atlantic Salmon in Maine, 2004).

The Department of Inland Fisheries and Wildlife works with the MASC by enforcing the policies they establish, as well as regulations related to the propagation and stocking of fish, such as the restriction against using non-native strains of Atlantic salmon in commercial aquaculture operations (Committee on Atlantic Salmon in Maine, 2004). To aid in the effort to enforce the protection of Atlantic salmon, the Maine Department of Marine Resources and the Maine Department of Environmental Protection research and monitor wild and farmed Atlantic salmon. The Department of Marine Resources regulates marine aquaculture operations, issues permits for farming sites, and administers the Finfish Aquaculture Monitoring Program, which tags and tracks escaped farmed salmon, and through which much has been learned about their movements. The Department of Environmental Protection, meanwhile, issues permits under the Maine Pollution Discharge Elimination System (MPDES) and monitors the water quality at farm and hatchery aquaculture sites. Through their efforts, the MASC and Department of Inland Fisheries and Wildlife are better able to design and enforce protections for salmon (Committee on Atlantic Salmon in Maine, 2004).

The MPDES permit prohibits the use of non-native Atlantic salmon in any commercial fish farm or other salmon hatchery operation, as well as the intentional release of any fish. Additionally, the permit demands the employment of a Containment Management System to prevent the accidental escape of farmed fish. Each Containment Management System is audited annually by the Department of Environmental Protection, and each aquaculture facility must keep inventory of all transfers in and out of the System and report any escapes to the Department of Marine Resources (MDEP, 2003).

Additional state agencies that in some way influence the survival of the Atlantic salmon are the Maine Forest Service, which encourages forest landowners to implement best forest management practices in order to protect watersheds and habitats; the Maine Department of Transportation, which addresses nonpoint source pollution in salmon watersheds associated with roads, and works to reduce erosion and sedimentation; and the Maine Department of Agriculture, Food and Rural Resources, which regulates the use of pesticides within salmon watersheds (Committee on Atlantic Salmon in Maine, 2004).

Complementing the efforts of the Maine state agencies, the U.S. Fish and Wildlife Service (FWS), and the National Marine Fisheries Service (NMFS), administer the Endangered Species Act. The FWS implements programs and regulations in freshwater and land-based species, and the NMFS does the same for marine and anadromous species. As such, both are responsible for the Atlantic salmon (Committee on Atlantic Salmon in Maine, 2004).

More specifically, the FWS works to restore and protect fish and wildlife resources. It operates all national fish hatcheries, including Green Lake and Craig Brook in Maine, and therefore works closely with MASC in releasing fry and smolts as part of Atlantic salmon recovery efforts (Committee on Atlantic Salmon in Maine, 2004).

The NMFS performs similar duties with regard to the marine ecosystems and species, and also plays a role in stock recovery programs. Beyond this, it implements the fishery management plan that disallowed commercial fishing of Atlantic salmon in federal waters, and grants offshore aquaculture permits (more than 3 miles offshore), which thus far has not affected the Atlantic salmon farming industry, as their net pens are typically closer to shore.

The NMFS and FWS also provide representatives to the U.S. Atlantic Salmon Assessment Committee, which provides advice to the Commissioners of the North Atlantic Salmon Conservation Organization, an international body charged with the management of Atlantic salmon stocks on the high seas. As a part of this body, the two services also prepare annual stock assessments of Atlantic salmon in the United States (Fay et al, 2006).

Other federal agencies that influence the survival of the Atlantic salmon include the U.S. Army Corps of Engineers, which regulates aquaculture pen locations and issues permits for dams. It also revised permit conditions for aquaculture leases to prohibit the use of non-native salmon stock and ensure the use of the containment management systems discussed above (Committee on Atlantic Salmon in Maine, 2004; Fay et al, 2006); the Department of Agriculture, which administers the Forestry Incentives Program to support good management practices on privately owned woodlands within salmon watersheds; the Food and Drug Administration, which regulates the safety of farmed salmon for human consumption, therefore affecting the use of non-pesticide artificial contaminants, additives, drugs and transgenic fish (Committee on Atlantic Salmon in Maine, 2004).

Though there are a multitude of governmental agencies tasked with protecting and regulating Maine's Atlantic salmon populations, it is worth considering that for each of these agencies, the Atlantic salmon represent only one of many responsibilities each must deal with daily. This difficulty in finding a sure solution to a perennial problem is the reason we do not rely solely on the legal enforcement of laws and regulations in the effort to revive the Atlantic salmon in Maine, but complement these with voluntary participation and efforts of other individuals and organizations. Non-governmental organizations are just as important, if not more so, in affecting the fate of endangered species. After all, the aquaculture, logging and blueberry industries themselves are non-governmental, and their practices are what need to change if salmon are to thrive. As the following discussion suggests, without the non-profits whose mission is to protect wildlife, ecosystems and Atlantic salmon, it is questionable whether the protections that do exist would ever have been put into place and enforced to the current levels.

Filing the petition to get the Atlantic salmon listed under the ESA (DOC, 2006) was one of the first actions of a young non-profit, RESTORE: The North Woods, founded in 1992 to "begin restoring the health of entire landscapes . . . focus on action, not bureaucracy . . . revive the grassroots spirit that led to the great conservation victories of the past" (RESTORE, 2001b, para. 7). It was one of the first NGOs to "[break] the silence" surrounding the Atlantic salmon's continuing decline (RESTORE, 2001a, para. 3). Though their recent work has focused more on two other imperiled species—the Canada lynx and Eastern wolf—the action-oriented effort of getting the Atlantic salmon listed as endangered was a crucial first step in what will hopefully be that population's continual improvement. RESTORE partnered with the Biodiversity Legal Foundation in 1993 to petition for the initial federal listing of the Atlantic salmon (DOC, 2006), but has since merged with the Center for Biological Diversity (Center for Biological Diversity, 2008). Most recently, the Center for Biological Diversity, along with two other parties (an individual and an organization, as in the 1993 petition), filed suit against the FWS and NMFS in an attempt to get the Kennebec River salmon listed under the ESA along with the other eight rivers already listed (Matteson, 2008).[13]

The investment of these non-government organizations in the fate of salmon keeps people and agencies constantly aware of their condition, and maintains it as a priority. In between direct advocacy actions, they publish reports on the effect of pesticides on Atlantic salmon (Center for Biological Diversity, n.d.) and, in 2006, filed a lawsuit against the FWS and NMFS in an effort to get critical habitat designated for the salmon (Center for Biological Diversity, 2008).

Working alongside the Center for Biological Diversity was the U.S. Public Interest Research Group (USPIRG). They are able to take part in these lawsuits that led (or can lead) to landmark protections for Atlantic salmon because of the Endangered Species Act. Though the Secretary of Commerce and the EPA are given primary responsibility for caring for species once they are on the list, the Act does not presume that they will carry out their tasks flawlessly and provides explicit language that allows individual citizens and organizations to take just this type of legal action:

> "…any person may commence a civil suit on his own behalf—(A) to enjoin any person, including the United States and any other governmental instrumentality or agency . . . who is alleged to be in violation of an provision of this Act . . ." (7 U.S.C. 136, 16 U.S.C. § 1540(g) (2010), p. 45).

In 2003, USPIRG brought their case against private parties (Atlantic Salmon of Maine and other commercial aquaculture operations), but their reach is not limited to private parties. As mentioned above, the Center for Biological Diversity is bringing suit

[13] Since the writing of this paper, the salmon population in the Kennebec River, along with the Penobscot and the Androscoggin have been listed under the ESA.

against two government entities, the FWS and NMFS, basically, in an effort to get them to do their job (Matteson, 2008).

Actions like this—forcing commercial aquaculture to behave responsibly toward the species they affect—are as important as implementing the acts, protecting the habitat, and educating the public.

But so far, only the salmon have been protected, not their habitat. As will be discussed further in Chapter Five, habitat must be protected along with a species. After all, without rivers, where are the fish to go? One organization, Project SHARE (Salmon Habitat and River Enhancement) focuses exclusively on habitat restoration. Chartered in response to the FWS and NMFS's original refusal to list the Atlantic salmon under the ESA in 1993, but to adopt instead a Conservation Plan, Project SHARE is open to all stakeholders who want to contribute to improving the fish and its habitat. Practically the polar opposite of regulation and requirement, Project SHARE is based on voluntary participation and cooperation among its varying members, which include anglers, businesses, government agencies and private landowners. Most of the members of Governor King's designated task force to develop the above mentioned Conservation Plan were first members of Project SHARE (Project SHARE, 2008a).

In cultivating these relationships and drawing members, Project SHARE has a large reservoir of partners with whom they work to implement restoration projects on five of the eight designated rivers in Downeast Maine. These projects take the form of both outreach and action—river monitoring plans, fish ladder restoration, best management practices guidelines, and *The Atlantic Salmon Restoration Handbook*, to name a few

(Project SHARE, 2008b). Their work is ongoing and manages to avoid polarizing the public on what is a controversial subject.

From a broader perspective, the Atlantic Salmon Federation (ASF) works outside the boundaries of Maine (ASF is based in New Brunswick, Canada) for the improvement of the Atlantic salmon population as a whole. While Maine represents the southernmost extent of the salmon's current range, and would likely be the first to disappear, the Atlantic salmon are threatened everywhere, from Nova Scotia to Greenland (Montaigne, 2003).

Greenland is a key party, since just off its shores is where all Atlantic salmon go to overwinter and feed before returning to their natal rivers. ASF is working with Greenland to implement a Conservation Agreement to protect the fish while they are in their ocean-dwelling stage of life (Atlantic Salmon Federation, 2008). Unlike a regulatory agency, ASF goes beyond protecting the fish to providing "long-term economic alternatives for Greenlanders" who might otherwise be fishing for these salmon off their shores (Ibid, "A Leader in Conservation", para. 3).

Because of their long time devotion to the cause (they were founded in 1948) and a diverse array of funding, ASF is able to develop policy and diplomatic solutions, as well as carry out thorough experiments and studies to find out why Atlantic salmon continue to decline despite their efforts. Their work has provided important information, particularly in tracking salmon—wild salmon in the ocean as well as escapees from farms—that can lead to improvements in restoration efforts (Ibid).

It is essential to the survival of Atlantic salmon that these non-profits and citizen organizations continue to work outside the realm of governments and regulations.

Though the Atlantic salmon is still endangered, their decline seems to be leveling off thanks in part to these organizations whose job it is to care about a fish. Trap samples in 2004 estimated 1,000 returns to Maine rivers (Committee on Atlantic Salmon in Maine, 2004). In 2009, returns were up to 2,200, dropping to 1,300 in 2010, and passing 3,000 in 2011 (Atlantic Salmon Federation, 2011).

Conclusion

Federal Acts, court rulings, habitat restoration and creation, endless education, fish tracking and continued legal actions. Without the thousands of person-hours invested in this cause and the multi-pronged approach to saving it, the Atlantic salmon would almost certainly have vanished from Maine's waters by now, if not from the wild altogether. Yet despite these efforts, the Atlantic salmon remains in peril. This is not to say that the cause is hopeless. In fact, the overall feeling is one of success, small and hard-earned as it may be. What these facts say is that there is still more to do: more person-hours to log, more angles from which to explore the problem, and more solutions to add to the growing list of ideas.

Chapter Five discusesses where things are headed, and what kinds of ideas can be tried, both new and familiar, that might mean the difference between life and death for the wild Atlantic salmon in Maine.

Chapter 5
Discussion and Recommendations

Introduction – Coordination and Cooperation

Strict regulation could be a straightforward way to help solve the problem of Atlantic salmon population decline. By limiting or even forbidding net-pen aquaculture operations, Maine could eliminate the threat of genetic introgression and possibly give Atlantic salmon the fighting chance they need to increase their numbers. I say *could* because there are two concepts that challenge this solution: the multitude of obstacles facing salmon recovery and the triple bottom line.

If the interbreeding of wild and farmed salmon was the only threat to the population, then getting farmed salmon out of Maine's waters would be a simple, and perfect solution. But wild salmon also face habitat destruction through dams, pollution and water loss in rivers, as well as threats at sea that scientists have been unable so far to identify (Miller, 2008). The triple bottom line approach considers the environmental, social, and economic costs of a project or idea (Proctor and Straton, 2009). Even if commercial aquaculture was the sole threat, regulating it away would result in such high economic and social costs (e.g. loss of income from the farms and jobs in Washington and Hancock counties) as to make it unacceptable—even if such a solution were to be politically feasible.

So let us turn our attention instead to a catalogue of ideas that, through coordination and cooperation, can secure salmon survival in North America.

The Extirpated Experience

As discussed in Chapter One, the Atlantic salmon once existed in two more distinct population segments in the United States: Central New England and Long Island Sound. These populations were extirpated in the early to mid-1800s (Fay et al, 2006), but the rivers that were their homes remain, and the idea of returning salmon to those waters has never been far from people's minds.

Since the 1960s, state and federal governments have spent $100 million to clean up the Connecticut River, build fishways, remove dams and construct hatcheries that can spawn salmon to restock the river. Though millions of fry are released each year, in 2002 only 44 Atlantic salmon returned to the river to spawn (Montaigne, 2003).

Though the success has been small and these efforts do not address the specific concern of Atlantic salmon's disappearance in Maine, they do offer part of a possible solution to the overall problem of the reduction of Atlantic salmon in the world. These rivers lie beyond the Atlantic salmon's current range, and to return the fish to their historic waters would be a step toward their assured survival. An additional challenge to this possibility, however, is latitude. Most of the Atlantic salmon's lifecycle is governed by water temperature, from egg development and juvenile emergence from redds to homing ability and spawning (Fleming and Jensen, 2002). As climate change becomes more and more apparent, the warming waters, particularly of the more southern states, could become inhospitable to their former residents who have an ideal temperature range of 6° to 22.5° C (Fleming and Jensen, 2002). Even if Atlantic salmon were successfully restored to the Connecticut River and its neighbors, the increasing aquatic temperatures could soon render those efforts obsolete.

Still, Atlantic salmon have exhibited the ability to adapt rapidly to the local environment. Fish imported to the Connecticut River from the Penobscot River began their upstream migration earlier in the year in their first season in the new latitude (Juanes et al, 2004). While this bodes well for a restoration program—indeed, since 1995, all eggs for the Connecticut River Restoration Program have come from adults returning to that river, as opposed to imported eggs from the Penobscot, which had been used for almost 35 years previously (Juanes et al, 2004)—the salmon have a temperature threshold (30º C (Fleming and Jensen, 2002)) beyond which they cannot survive. Waters reach this temperature earlier in the Connecticut River than in Maine rivers. The migration period for the Connecticut River is between April and July, while for the Penobscot it starts in May and lasts through November (Jaunes et al, 2004).Climate change could reduce the period of migration in the Connecticut River even further, limiting the possibility of a population taking hold in these areas (Fleming and Jensen, 2002). The average peak migration of salmon in the Connecticut River is 10-15 days earlier today than it was thirty year earlier as temperatures have warmed, and later migrating adults (in July) have experienced near-lethal temperatures of 30º C (Juanes et al, 2004).

Additionally, farming salmon in Massachusetts and Connecticut as a replacement for the Maine farms does not address the economic and social costs to the counties and individuals who would lose income and jobs if the farms left Maine. It is likely that these southern farms would not be nearly as productive, either, lacking as they do the protected bays, water temperatures of 0-15ºC (32- 59ºF), strong currents, and high tides that Maine and Canadian waters possess and which provide ideal conditions for raising salmon. (Maine Aquaculture Innovation Center, n.d.).

So let us leave Massachusetts and Connecticut to their efforts, and approach the challenge from the North.

Salmon Swap

Replacing Maine salmon farms with Massachusetts and Connecticut salmon farms might improve the problems of genetic introgression in the Maine populations, but would remove a major source of income for Washington and Hancock counties. Aquaculture generates $130 million in “direct economic activity” (Maine Aquaculture Association, 2006).

Short of eliminating all threat of escapes (an ideal, but impossible goal), the best hope is a substitution. By farming salmon that are unable to breed with the wild Atlantic salmon of Maine’s rivers, even a storm event resulting in a mass escape would not pose a threat to the wild salmon’s descendents.

The first way to do this is by farming salmon induced to be sterile. The advantages are clear. Sterile salmon in the wild can only affect native populations while they survive, but do no damage to the genetic line. The technology exists. Oppedal et al (2003) offer a study on sterile salmon as substitutes for fertile salmon to address this concern. In their study, Oppedal et al concluded that sterile salmon performed equally well in net pens “or better than diploid conspecifics of Atlantic salmon” (Oppedal et al, 2003, p. 159). This was also true when they were given continuous light during their growth period, a technique used in commercial aquaculture to accelerate the salmon's growth to market size, which bodes well for the practical application of this technology.

One concern that remains is that escaped sterile salmon, though unable to reproduce, may still compete for food and living space with wild Atlantic salmon (Cohen, 2002; Goldburg and Triplett, 1997; Oppedal, 2003) as well as transmit diseases (The Fish Site, 2008). Further, sterile oysters have been known to revert to their fertile state, and some fish have been discovered to be mosaics, meaning that while they appear to be sterile genetically their genitals are functional. Neither case has been witnessed in salmon, but then again, neither has it been extensively studied (Cohen, 2002). Though sterile salmon are sometimes used in commercial fish farms, the techniques used to render them such are not always 100% effective (Brenninkmeyer, 1999).

Similar to using sterile salmon, a substitution might be made by farming Chinook, Coho, or other salmon native to the west coast in Atlantic waters. Historically, when used to try to restore salmon populations in the east, Pacific salmon have failed to establish populations in these waters (Kirk, 1987). Additionally, Atlantic salmon and salmon native to the Pacific region have been unable to successfully breed and reproduce together (Waknitz et al, 2002). This was found in studies of Atlantic salmon farming operations in the Northwest. Not only their species, but their genus classification differs (Pacific salmon share a genus with many species of trout - *Oncorhynchus*). According to the Pollution Control Hearings Board Atlantic salmon also did not pose a threat to the native Pacific populations when they did escape (cited in Waknitz et al, 2002). All of this evidence points to a potentially valuable solution in the farming of Northwest salmon in Maine's waters. If all these facts hold true in reverse, Pacific salmon could make a possible substitute in Maine. This remains an untested theory, and pending further study, sterile salmon remain a preferable choice.

The use of sterile or Pacific salmon in Maine salmon farms would require careful study prior to their introduction. Transgenic triploid salmon are a viable option, but sterilization would need to be guaranteed, as methods for inducing sterility have not always proven 100% reliable in fish (Goldburg and Triplett, 1997). The possibility that non-native Pacific salmon species could interbreed or reproduce and establish their own populations outweighs the potential positives. Additionally, use of non-native salmon in Maine farms was forbidden by *USPIRG v. Atlantic Salmon of Maine* (2003b).

So far we have only considered ways to reduce the impact of inevitable salmon escapes, but what about the possibility of eliminating escapes altogether?

Urban and Land-based Aquaculture

One way to keep farm-raised salmon from interfering with wild genes is to take them out of the ocean. Land-based and urban aquaculture systems are appealing possibilities with many advantages.

Practitioners of land-based aquaculture farm fish in closed systems, the contents of which (including waste, water, and fish) never make contact with natural bodies of water, or wild species. These systems are secure, reliable, and have controlled inputs and outputs (Freshwater Institute, 2007). This is the type of system employed to farm catfish, barramundi and tilapia, consistently rated three of the top environmentally responsible farmed fish in the U.S. by third-party evaluators (Blue Ocean Institute, 2009; Monterey Bay Aquarium, 2008). These systems are regarded so highly because they treat and recirculate waste water before sending it to a municipal treatment plant, use less food, and help prevent the spread of disease between captive and wild fish (Smith, 2008). Because they are closed systems, there is no risk of escape, and therefore no threat to wild populations genetic integrity.

Urban aquaculture is simply the above-described closed system in an urban setting. The goal is to bring the business of fish farming into urban centers in need of jobs, money and revitalization. Though still relatively small in reach, urban aquaculture has been successfully tested in Brooklyn, NY and Roxbury, MA (Kilgannon, 2004; Matthew Kochka, personal communication, 1 June 2009). In Brooklyn, Dr. Martin P. Schreibman is breeding thousands of tilapia in a lab. He envisions fish farms all over the city, in the Brooklyn Navy Yard, Coney Island, and even people's basements. "Promoting urban aquaculture in New York City and setting up fish farms can help feed the homeless, ease environmental problems and provide jobs" (Kilgannon, 2004, para. 7).

Matt Kochka, the Farm Manager at ReVision House Urban Farm agrees with these principles and the past two years has set up a small tilapia farming operation in Roxbury, MA (Matthew Kochka, personal communication, 1 June 2009). The goals of the program are "small-scale, green, economic development; community food security; and job training and education" (Victory Programs, n.d., para. 4). The aquaculture operation that Kochka operates not only helps achieve the above goals, but also provides fertilizer for the farm in the form of filtered wastewater from the tanks. This integrated system echoes those used in ancient Egyptian fish ponds (see Appendix A), and at a very low cost, utilizing simple materials such as PVC piping, plastic tubs and a single pump (Matthew Kochka, personal communication, 1 June 2009).

The primary challenge with closed systems, however, is that in general they are fed by freshwater and historically tend to be used with freshwater fish like catfish, trout and tilapia. Salmon, of course, are anadromous, spending half their lives in saltwater. But even this is a small obstacle. For one thing, there are entire subspecies of landlocked salmon in inland Maine that never in their life cycle encounter saltwater (Mills, 2009). Geologists D.W. Caldwell and Lindley Hanson theorize that the lakes of Maine were at one point a part of the surrounding salt waters. When the ice caps receded, the land rose up, relieved from their immense weight, creating new inland seas, which remained saline at first, with salmon trapped and migrating up and downstream as before. Over time, as the lakes' freshets carved routes to the sea, the lakes became freshwater, but the salmon, now used to the routes, continued the same migration patterns with the freshwater lakes as their downstream destinations (Caldwell and Hanson, 2003). These species are prime candidates for the closed systems that could be set up in Maine.

But substitutes for anadromous Atlantic salmon are not necessarily required. Thanks to technology developed by MariCal in Portland, ME, fish farmers are able to raise "fish typically harvested from salty coastal environments grown in tanks fed by freshwater sources" (Smith, 2008, para. 13). This proprietary technology combines water treatment and a specialty feed to control the calcium sensing receptors in the fish, allowing them to breed in low-salinity conditions, even miles inland, away from the sea (MariCal, 2009).

Yonathan Zohar is raising cobia, a marine species, in a completely contained, land-based system in his lab at the Center for Marine Biotechnology in Baltimore, MD. Not only does the system recycle 99% of its water, the cobia are growing faster and more efficiently than in a net-pen in the ocean (Halwell, 2008). Though still in its infancy, this holds the greatest potential for an escape-proof solution for Atlantic salmon farmers. The main challenges to the success of closed containment farms are mechanical breakdown and high capital, feed and fuel costs. Systems located far from urban centers would need to be run on generators at high use of fuel (The Scottish White Fish Producers' Association, 2008) and a modeling exercise found that the only closed-containment systems that could turn a profit after five years were those that grew transgenic salmon designed to grow larger on minimal feed (Greenberg, 2010a).

Moving the Atlantic salmon farms out of the oceans and rivers of Maine would remove the threat of escapes and alleviate the stress they place on the wild populations. Systems like these could be replicated in Washington and Hancock counties. These two counties (the site of most commercial aquaculture in the state) have two of the highest unemployment rates in the state of Maine; rates frequently 50%-100% above the state and national averages (Maine Department of Labor, 2009a; 2009b; 2009c). This would be offered as an answer to the problems that would arise by closing down the open-ocean net pen systems currently in place there.

Home Repair

An ideal solution, short of moving all fish farming operations into closed systems on land, would be the perfection of a containment system that is guaranteed to prevent all escapes of farmed salmon. This theoretical system is ideal from the perspective of both conservationists and commercial fish farmers. Neither group wants salmon escaping their pens, since each fish represents a threat to one, and a profit to the other.

Though we can expect net-pen technology to improve, it is generally taken to be impossible to fully prevent escapes from net pens in the fish farming industry. There are simply too many unexpected ways, from seal attacks to storm events to vandalism, that net-pens can be compromised or broken, allowing fish to flee (Pietrak and Belle, 2007).

Even if net pen technology is perfected to the point that can slow the escape of farmed salmon from a flood to a trickle, the aquaculture industry must tackle another problem, and help insure the restoration and protection of a robust native habitat for wild Atlantic salmon in Maine. Though unrelated to the actual business of growing fish, habitat restoration and the protection of wild Atlantic salmon should be a priority for those businesses that make their livings off that same fish. The Maine Aquaculture Association states in its own Guiding Principles they must work for the maintenance of a diverse and intact wild population (Maine Aquaculture Association, n.d.). The United Nations Code of Conduct for Responsible Fisheries also stipulates that "states should conserve genetic diversity and maintain integrity of aquatic communities and ecosystems by appropriate management. In particular, efforts should be undertaken to minimize the harmful effects of introducing non-native species or genetically altered stocks used for aquaculture including culture-based fisheries into waters" (FAO, 1995, p. 9.3.1).

This type of "good neighbor" policy on the part of the aquaculture industry could make a serious difference to the fate of the wild Atlantic salmon. After all, companies like Cooke (which owns most of the net pen farms in Maine) have access to the funds and resources that could seriously aid conservation organizations like the Penobscot River Restoration Trust in their efforts to recreate an environment that can reliably sustain a wild salmon population (Hedlund, 2006).

A significant obstacle to potential spawning habitat for Atlantic salmon (and many other species) are the many dams that have been constructed on Maine's rivers since the 1800s (around the time the Atlantic salmon population began to decline). The Penobscot River, which historically was home to the largest population of Atlantic salmon in the state, has 97% of its salmon spawning habitat upriver from (and inaccessible because of) 3 dams: the Great Works, Veazie and Howland Dams (Saulnier, 2008). These three dams are the targets of the Penobscot River Restoration Trust, a collaboration between a hydropower company, the Penobscot Indian Nation, conservation groups, state and federal agencies, which will decommission and remove dams on the Penobscot to restore the ecosystems and provide accessibility for sea-run fish (Penobscot River Restoration Trust, 2009). The Penobscot is the second largest river in New England (its watershed drains about a third of Maine), and the removal of these dams is the highest priority for restoring the Atlantic salmon, according to the National Academy of Sciences (Committee on Atlantic Salmon in Maine, 2004). According to scientists, this project is the "single-most significant step to take to recover Maine's salmon population" (Penobscot River Restoration Trust, 2009, para. 6).

Quality and availability of habitat is a key factor in Endangered Species Act decisions however, and so the importance of the dam removal cannot be underestimated (Bain et al, 2007). Habitat that is available must also be of a quality to sustain a wild population. Key to insuring the quality of the aquatic habitat is preserving, restoring, and protecting the land that surrounds the rivers, which is the primary goal of organizations like Project SHARE and RESTORE: The North Woods (discussed in Chapter Four).

Forests and trees protect watersheds by reducing erosion and retaining soil moisture (Sharma, 1992). Maine's active logging and blueberry growing industries have left areas of the state deforested, and the rivers in those watersheds susceptible to higher levels of siltation and runoff (Glennon, 2002). The loss of forests in a watershed can have an effect not only on the surrounding area, but far downstream as pollution and particulates are carried by a river's currents (Sharma, 1992). For a recovered salmon population to have the ability to sustain itself, problems like this must be addressed to repair the land. RESTORE: The North Woods is working to create a protected 3.2 million acre park of the Maine woods, and to recover and protect the wild forests of the state (RESTORE: The North Woods, 2001b). Project SHARE works constantly on watershed protection, most specifically with its watershed management plans and the relationship between water quality and nonpoint source pollution as a result of logging, timber harvesting and roads (Project SHARE, 2008b). As previously discussed, Project SHARE relies on the involvement of stakeholders to preserve the resources they rely on. Commercial aquaculture companies can play a role by supporting these efforts so that when the Atlantic salmon population numbers do eventually rise, the habitat is there to support them.

The motivation for these corporations need not be purely altruistic. In this age of "eco-awareness," more and more consumers are basing their purchasing decisions on a product's corporate and geographic source and a company's social and environmental responsibility (FAO, 2007). A salmon farm that directs efforts and funds towards the preservation of an endangered species could sway a lot of customers who are trying to decide between the salmon imported from Chile—where lax regulations and lack of enforcement result in the ongoing pollution of the country's abutting waterways (Langman, 2002)—and Maine salmon farmers going the extra distance to protect the resource on which they rely.

Conclusion

This chapter presents a number of strategies for reducing the impact of farmed salmon on the wild population. The solution to the dilution of the genetic integrity of wild Atlantic salmon does not lie in a single strategy, but by combining several of the approaches listed here it may be possible to restore a self-sustaining population of Atlantic salmon to the waters of Maine.

The two goals that must be accomplished are 1) eliminating the introduction of farmed salmon into the wild and 2) improving the quality and accessibility of the habitat the fish require to spawn and survive.

Pending the creation of an infallible net pen technology, aquaculture operations in Maine should seriously consider switching completely to a land-based industry, with closed-system tanks and no opportunity for fish to escape. This is the only one of the above discussion topics that has not been seriously considered in Maine, though the technology's development is advancing and is being actively pursued in Canada. This type of transition would take a number of years to complete, but it is the only strategy that would provide a sure-fire solution to the problem of genetic introgression of farmed salmon into the wild populations of Maine.

Regardless of what timetable or strategy is adopted, Cooke and all companies that make their living by farming fish should make the restoration and protection of salmon habitat a priority by opening up spawning habitat through the creation of fish ladders or the destruction of dams. This is the second piece, without which, the work to restore the wild salmon population will be in vain.

In the over 40 years since the Endangered Species Preservation Act was passed, not a single fish has been removed from the endangered species list once it was placed on it, and more fish appear on the list than any other vertebrate taxonomic group (Bain et al, 2007). An independent scientific study has shown that one of these fish, the shortnose sturgeon (*Acipenser brevirostrum)* is now at numbers high enough to warrant consideration and possible removal from the list of endangered species (Ibid). This seemingly impossible accomplishment (the sturgeon population in the Hudson River has increased four-fold since the 1970s) was achieved by restricting fishing of that species, and a passionate clean up effort by organizations like Hudson River Sloop *Clearwater* and Riverkeeper (Inman, 2007). Either of these efforts on its own would not have been enough to improve the sturgeon's numbers so significantly. The Hudson River shortnose sturgeon's plight offers a parallel to that of the Atlantic salmon in Maine, and the sturgeon's success offers the hope that, with time and effort, the salmon, too, can rebound.

With a multi-pronged approach in Maine of reducing the number of escapees from farms and improving wild habitat, the wild Atlantic salmon could recuperate and return one day to sustainable numbers. This strategy, however, will rely on the participation of government, non-profits, and the aquaculture industry itself. Through the coordination and cooperation of these three groups, Maine's Atlantic salmon may eventually be saved.

Afterword: Ancient Aquaculture

The many and varied ways that aquaculture has been practiced throughout history can provide a contrast for some of the less admirable ways it is practiced today and lays a contextual foundation for many of the ideas discussed in this paper.

Aquaculture has been around for thousands of years. Strictly speaking, aquaculture applies to any instance in which humans grow things in water, be it seaweed, oysters, a couple of goldfish, or 11 million pounds of Atlantic salmon. *Commercial* aquaculture and fish farming on the other hand, has been used in this paper to refer to the modern day practice of breeding and raising fish in captivity for profit.

Aquaculture has always been less dangerous and more predictable than capture fisheries (the pursuit and "capture" of wild fish by net or hook), but it has never replaced capture fisheries, and fish remain, to this day, the last wild, hunted prey of human beings.

Fish farming is now a very common practice, business and industry, but today's environment is far different from the environment in which aquaculture had its origins. We must now practice aquaculture with a weather eye on the environment and quality of the oceans and estuaries upon which this industry depends, not simply on profit, a luxury its early practitioners may have enjoyed. With dwindling fish stocks and ever-increasing pollution, is aquaculture on a sustainable and profitable track? Can aquaculture be practiced to have a *positive* impact on the wild fish stocks, instead of a negative one, or no impact at all? What lessons can be learned from the ancient practices that, though focused on profit and productivity, might be considered more "green" than anything we do today?

China gets credit for creating aquaculture, partially because the first document concerning the subject was published in that country by Fan Li in the fifth century B.C. (Ling 1977, 6). Other evidence indicates that Egyptians were growing tilapia in shaded ponds even prior to this (Beveridge and Little 2002, 8). As Dr. Barry Costa-Pierce (2002, 30) of the University of Rhode Island points out, however, these were primarily "freshwater developments." The ocean farming systems (mariculture) of ancient Hawaiian civilization provide examples of a more sophisticated and adaptive strategy more akin to the kind of innovation possible with today's technology and know-how.

Asian freshwater farming techniques and Hawaiian mariculture provide examples of how our fish farming forbears ran successful operations, while preserving their aquatic environments. This was before being green was either hip or necessary. In Maine, where Atlantic salmon are currently listed as endangered in several rivers, current aquaculture practitioners should re-adopt and adapt some of these ancient ideas so that we will continue to have fish to farm. Three concepts discussed in this paper—polyculture, community-based aquaculture, and aquaculture/agriculture integration—are described in more detail here.

Learning From the Past

Some modern farming operations are rediscovering the ancient Chinese fish farming techniques such as polyculture, or the raising of many species of aquatic organisms in a limited space. This technique is based on the realization that aquaculture is three-dimensional, and different species occupy different levels of the water column (Borgese 1980, 16); it maximizes productivity while reducing waste by allowing some of the aquaculture creatures to feed on the wastes generated by others. In this way, polyculture systems have less of a negative impact on the natural environment than a monoculture, which allows disease to spread more easily among the animals, and waste to fall to the ocean floor, creating uninhabitable portions of the ecosystem (Montaigne 2003). Ling (1977, 6) suggests that western biologists only began to study the scientific basis of polyculture in China and to carry these practices back to their home countries in the early 20th century.

While the Chinese primarily produced freshwater fish, traditional Indian societies in Goa were developing a system in coastal areas that integrated fish farms with traditional agriculture. They also brought the rich and poor classes into a symbiotic relationship, making this type of system truly a community-managed, coastal operation (Sonak et al 2005, 2).

The major mariculture advances occurred in the Hawaiian Islands some 1500-1800 years ago (Costa-Pierce 2002, 30). Hawaii at this time was speckled with hundreds of artificially created fish ponds, both inland freshwater and brackish and saline ones on the coast. Just one of these large ponds contained thousands of tons of rock and fill and took thousands of people years to build. Projects of this magnitude "obviously required tremendous social organization" (Costa-Pierce 2002, 31) emphasizing the importance of the community in the successful operation of these systems. In these cases, communities were practicing aquaculture to feed themselves and create a sustainable lifestyle. Today in Maine, the communities in Hancock and Washington counties (where most salmon aquaculture is) rely on the jobs fish farms provide and the money it brings to their economies (Maine Department of Labor 2009a; 2009b; 2009c). Instead of creating sustainable systems, though, the imperfect systems leave Hancock and Washington county as two of the poorest in Maine and are home to fish farms that degrade the environment and contribute to the depletion of the wild salmon population.

As in Chinese systems, polyculture prevailed in the Hawaiian ponds. They ingeniously recreated the natural habitats they were located in, and in some cases they could even be considered extensions of those environments. The seawater ponds, or *loko kuapa*, had at least 22 marine species living in them, and were connected to the sea by a grate-covered canal that allowed wild juvenile fish to swim in, but as they grew, would prevent them from returning to the sea (Costa-Pierce 2002, 36). Capturing fish passively eliminated negative impacts on the natural ecosystem.

The freshwater ponds were also used to grow taro and algae on which the critters would feed (Costa-Pierce 2002), and were simultaneously used for agricultural irrigation, as in ancient Egypt (Costa-Pierce 2006).

The modern Western world has largely ignored the integrated aqua-agricultural practices of these ancient societies and the harmony in which they operated with the natural environment. A typical monoculture (growing large amounts of one species in a single place) of the 21st century produces a lot of fish, but has no benefits on the natural environment. As mentioned above, these ancient practices—polyculture, community-based aquaculture, and aquaculture/agriculture integration—not only produce fish, but contribute to the communities that grow them (either in food or in cash) and are a benefit (or at least not a threat) to the natural environment (Costa-Pierce 2002). Recently, certain individuals and businesses, like the Open Ocean Aquaculture project at the University of New Hampshire, have begun heeding the lessons demonstrated so many thousands of years ago by growing finfish and shellfish in a vertical system to make use of as much waste product as possible (Langan 2006). These lessons need to be implemented by all aquaculturists today, especially with the current depleted state of so many of the world's fisheries and the continued degradation of their natural habitats. The Atlantic salmon (*Salmo salar*) of Maine provide an ideal example of a species pushed to its limits. One reason for this may be that salmon have a more complicated life cycle than the strictly fresh or saltwater fish that were being raised in Egypt or China. As a result, it may be difficult to directly apply ancient polyculture techniques to the salmon in particular. What can be applied, however, is the concept of working *with* the natural environment, not in spite of it.

Appendix A:
Personal Interviews

12 February 2007
Thomas King
Project Leader, Craig Brook National Fish Hatchery, Orland, ME.

12 February 2007.
Paul Santavy
Project Leader, Green Lake National Fish Hatchery, Ellsworth, ME.

12 February 2007
Matthew Young
Maine Department of Environmental Protection, Bangor, ME

8 March 2007
David Bean
Fisheries Biologist, NOAA, Gloucester, MA

1 June 2009
Matthew Kochka
Farm Manager, ReVision House Urban Farm, Boston, MA

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