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History and Description of the Atlantic Salmon Aquaculture Industry in Maine

E. T. Baum
State of Maine
Atlantic Salmon Authority
650 State Street
Bangor, Maine 04401-5654 USA

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ABSTRACT

The successful rearing of Pacific salmon in Maine in the early 1970's (and Atlantic salmon in nearby Nova Scotia in the late 1970's) led to the culture of Atlantic salmon in the early 1980's. Large-scale operations began in Maine in 1986 utilizing technology developed in Norway that was adapted to conditions in the Passamaquoddy region of Maine and New Brunswick. Although several European salmon stocks have been used in Maine, only three stocks are currently utilized. Two stocks originated from Bay of Fundy rivers (Penobscot River, Maine and Saint John River, New Brunswick); the third stock (Landcatch) originated from Norway, having been originally imported from Scotland in 1989. Hybridized strains with European genetic influences now account for approximately 30-50% of production fish in Maine. The current salmon farming industry in Maine is composed of twelve companies that operate 33 sea cage sites with 773 cages on about 800 acres of leased water, five freshwater smolt rearing hatcheries, and five fish processing plants. More than 4.0 million smolts are stocked into sea cages each year, and the annual production (harvest) exceeds 12,000 metric tons. Information pertaining to escapes, potential impacts to wild salmon stocks, and current measures being taken in Maine to reduce potential negative impacts of escapes upon wild Atlantic salmon stocks are discussed.

RÉSUMÉ

La réussite de l'élevage du saumon du Pacifique obtenue au Maine au cours des années 1970 (ainsi que le saumon de l'Atlantique aux environs de la Nouvelle-Écosse vers la fin des années 1970) a donné lieu à l'élevage du saumon de l'Atlantique au début des années 1980. Les exploitations à grande échelle ont débuté au Maine en 1986 à partir d'une technologie élaborée en Norvège qui s'est ajusté aux conditions dans les environs de Passamaquoddy du Maine et du Nouveau Brunswick. Bien que de nombreux stocks de saumons européens ont été utilisés au Maine, seulement trois stocks sont utilisés actuellement. Deux des stocks ont pour origine des rivières de la baie de Fundy (la rivière Penobscot au Maine et la rivière Saint-Jean, au Nouveau-Brunswick); le troisième stock (Landcatch) provient de Norvège mais a tout d'abord été importé d'Écosse en 1989. Des lignées hybridées avec des gènes influencés de l'Europe, sont maintenant responsable d'approximativement 30 à 50 pour cent de la production du Maine. L'industrie actuelle d'élevage de saumon au Maine est formée de douze sociétés qui exploitent 33 sites comptant 773 cages réparties sur 800 âcres environ de fonds marins loués, cinq piscicultures de production de saumoneaux en eau douce et cinq usines de transformation du poisson . Plus de 4,0 millions de saumoneaux sont placés en cages marines à chaque année et la production annuelle (récolte) dépasse les 12 000 tonnes métriques. Des renseignements relatifs aux poissons échappés d'élevage, à leurs incidences sur les stocks de saumon sauvages et aux mesures qui sont prises au Maine pour limiter les effets nuisibles des poissons échappés sur les stocks de saumon sauvages de l'Atlantique font l'objet d'une discussion.

Introduction

Aquaculture of Pacific salmonids (primarily coho salmon, *Onchorynchus kitsuch*) began in 1970 in the mid-coast region of Maine. These early ventures were unsuccessful due to adverse environmental conditions at grow-out sites, low market values for the products grown, and a lack of infrastructure to support the industry (DMR 1997).

Atlantic salmon (*Salmo salar*) farming was initially tried in the mid-1970's in the Blue Hill area of Maine, but the site was eventually abandoned. A new site was established in Cobscook Bay in 1982 and production remained low until 1986, when a second site was added; it was at this time that rainbow trout (*Onchorychus mykiss*) were also first reared commercially. Utilizing salmon farming technology developed in Norway and adapted to local conditions, the rearing of Atlantic salmon in the Maine aquaculture industry increased from two active sites with 16 cages, to 19 sites and 458 cages from 1986 through 1990. From 1990 to 1998 the number of sites nearly doubled (to 33), while the number of cages deployed increased by 70% (to 773).

The production of Atlantic salmon increased from 10 mt in 1984 to 450 mt in 1988, then doubled annually through 1991, and in 1997 production was 12,250 mt. Although rainbow trout are reared commercially, Atlantic salmon have accounted for 99% of the salmonids harvested in Maine in recent years.

The Department of Marine Resources (DMR) has always been the primary agency responsible for permitting and monitoring aquaculture operations in Maine coastal waters. In the 1980's the application process was complicated and growers were required to provide monitoring results to the state and two federal agencies. Monitoring requirements varied by site and were poorly coordinated among agencies which eventually led to a streamlined application and monitoring process in 1992. The Maine Department of Marine Resources Aquaculture Coordinator now receives all applications and monitoring information and disseminates relevant information to other state and federal agencies involved in the aquaculture program.

Legislative Responsibilities and Legislative Controls

Several state and federal laws currently regulate aquaculture in the State of Maine. State laws include the following:

I. Aquaculture Lease Law (12 MRSA → 6072)

Any person seeking to grow marine organisms using structures or desiring exclusive use of a portion of the submerged lands of the State must obtain a lease from the Department of Marine Resources. An applicant must file an application that includes:

- a description of the proposed lease site;

- a list of species to be cultured and the source of the organisms;
- an environmental evaluation of the site including bottom characteristics, resident flora and fauna, tide levels and current speed and direction;
- a description of the recreational and commercial fishing activity in the vicinity of the proposed lease;
- evidence of financial and technical capability;
- any other information the Commissioner of the Department may require;
- an application fee of $100 - $1,000, depending upon acreage applied for.

Once the Commissioner of Marine Resources has determined that the application is complete, a public hearing is scheduled. The Department notifies all riparian owners (whose land lies within 1,000 feet of the proposed lease site) and a general public notice is also issued. Prior to the public hearing, the Department conducts its own on-site investigation of the proposed lease site. The Commissioner bases the decision to grant a lease with regard to:

- effects on the ability of the riparian owners to navigate to their lands;
- impacts on navigation;
- interference with fishing in the area;
- impacts on other aquaculture operations in the area;
- interference with the ability of the area to support existing ecologically significant flora and fauna;
- the source of organisms to be cultivated;
- interference with public facilities.

Additional requirements and restrictions applicable to commercial net pen aquaculture in Maine include:

- sites in close proximity to bald eagle nests may require additional review and consultation with the US Fish and Wildlife Service and/or the Maine Department of Inland Fisheries and Wildlife.
- it is unlawful to import any Atlantic salmon, live or as eggs, that originate in any Icelandic or European territorial waters or any other species of salmon, exclusive of rainbow trout, originating from west of the North American continental divide.
- monitoring is required for all aquaculture leases having a discharge to the water (see section 3).
- applicants must comply with the New England Salmonid Health Guidelines or state health guidelines, whichever is more restrictive.
- a transfer permit is required from the Maine Department of Marine Resources to transfer or import fish or eggs.
- A harvest fee of 1 cent per pound of harvest must be paid monthly, along with the submission of the designated production report form.

Leases are:

- limited to 10 years;
- not allowed to cover an aggregate of more than 250 acres;
- no single lease may exceed 100 acres in size.
- the Department requires that a buffer of at least 2,000 feet exist between finfish sites, unless both parties agree to be closer.

In addition to the above requirement, the Maine Department of Environmental Protection must also certify the application with regard to water quality standards, prior to the DMR decision to grant the lease.

I. Waste Discharge License (38 MRSA → 464)

The Department of Environmental Protection requires that any operation directly or indirectly discharging any pollutant obtain a license. However, aquaculture leases granted by the Department of Marine Resources are exempt from this provision since as a condition of the lease the DEP certifies that it will not have a significant adverse effect on water quality or violate the standards of the water classification.

II. Water Quality Classification Program (38 MRSA → 464 *et.seq.*)

Aquaculture leases are generally not permitted (although not specifically prohibited) in Maine waters classified SA. This is the highest quality classification and is generally assigned to waters off state parks and federal park and wildlife reserves, among other areas.

III. Finfish Monitoring and Research Fund (12 MRSA → 6078)

A tax of one penny per pound of whole fish harvested supports a monitoring program (by the Department of Marine Resources) to assess the impact of net pen culture on the marine environment. The program includes an annual site evaluation and a characterization of the benthic substrate and associated community along with descriptions of the bottom conditions (see Section 3).

IV. Freshwater Aquaculture (12 MRSA → 6074)

Anyone interested in cultivating fish in inland waters requires a license from the Maine Department of Inland Fisheries and Wildlife. The Department issues licenses for the selling of commercially grown or imported fish, the importation of live fish or eggs, permits to stock inland waters, and permits to introduce or cultivate fish in a private pond.

.V. Disease Control (12 MRSA ➔ 6074)

The Departments of Inland Fisheries and Wildlife and Marine Resources jointly administer inspection and control programs. Fish health inspections are required when freshwater fish are transferred from freshwater to saltwater. The Department of Marine Resources has incorporated the provisions of the New England Salmonid Fish Health Guidelines (Anon. 1996) regarding the importation of live fish, the movement of stocks and the reporting of serious pathogens in their regulations.

Federal laws governing aquaculture in Maine include the following:

VI. US Army Corps of Engineers, Section 10 of the Rivers and Harbors Act of 1899 (33USC ➔ 403)

Any aquaculture lease, which requires the placement of temporary or permanent structures, including experimental ones, in navigable waters must obtain a permit from the Army Corps of Engineers. In Maine, the Army Corps of Engineers and the Department of Marine Resources has developed a joint application, which may be used for most aquaculture proposals.

VII. Fish and Wildlife Coordination Act (16 U.S.C. 661-667e; 48 stat. 401, as amended)

The U.S. Fish and Wildlife Service and National Marine Fisheries Service have authority to review and comment on the effects of fish and wildlife activities proposed to be undertaken or permitted by the U.S. Army Corps of Engineers.

VIII. US Environmental Protection Agency National Pollution Discharge Elimination System, Clean Water Act (33 U.S.C. 1341-1345; 86 stat. 877).

The Federal Environmental Protection Agency regulates any discharge into federal waters. The addition of feed, therapeutics and pesticides are considered discharges and must be permitted by EPA; however, no pesticides regulated by the EPA are used in Maine salmon aquaculture.

IX. US Food and Drug Administration

The USDA regulates drug availability to the aquaculture industry. Only three drugs (Terramycin, Romet, and sulfamerazine) are permitted to be used for disease control in fish grown for human consumption.

Finfish Aquaculture Monitoring Program

A Finish Aquaculture Monitoring Program (FAMP) went into effect in the spring of 1992. Under this program, the Aquaculture Coordinator for the Maine Department of Marine Resources is the focal point for submission of all monitoring information. The Aquaculture Coordinator then assumes responsibility for disseminating relevant information to the other state and federal agencies involved.

The FAMP focuses on benthic impacts and includes video recording of the bottom beneath and adjacent to the cages and benthic macrofauna community analysis. Video recordings have been conducted semi-annually in the spring and fall, while benthic analyses have been carried out biennially on a rotating basis so that each site is sampled every other year. Beginning in 1998, however, video recordings will be made only in the fall. Sediment analyses for redox discontinuity layer depth (a measurement of the depth to which oxygen penetrates into the sediment), total organic carbon content of the bottom surface layer, and sediment granulometry were previously included in the monitoring program but were discontinued in fall 1996 due to inability to correlate the results of these tests with any specific environmental effect resulting from finfish cage operations.

The FAMP also includes dissolved oxygen monitoring through water column profiles conducted in September of each year (the original oxygen monitoring procedure was modified in 1994). Due to time constraints caused by contracting difficulties, oxygen monitoring was not required in 1997, but this requirement was resumed in the fall of 1998.

The monthly production reporting by leaseholders (initiated in July 1991) is compiled and analyzed separately; however, this is confidential information and is not available to the general public.

A detailed description of each of the monitoring program's environmental assessment components (water quality, benthic monitoring, and video monitoring) follows (condensed from Heinig 1998).

Water Quality Survey

Dissolved oxygen profiles are taken at three specific distances from the finfish cage structures: 1) at 100 meters, or ~300 feet, upcurrent of the structure; 2) within 5 meters, or ~15 feet, downcurrent of the structure; and 3) 100 meters, or ~300 feet downcurrent of the structure.

All sampling is carried out using the Maine Department of Marine Resources Sea-Bird Electronics, Inc. model SBE 19 SEACAT Profiler. The SBE 19 is equipped with a pump, a Senso-Metrics Sp 91FFS pressure sensor, a temperature-conductivity sensor, a Beckman dissolved oxygen sensor, and an Innovative pH sensor.

Measurement *consistency* is verified in the field by replicate casts at each station. Replicate casts of several randomly selected stations are reviewed at mid-day and/or nightly to insure *reasonable* consistency between profiles. If significant, unexplainable discrepancies between replicate profiles are detected, sampling is discontinued until the problem is corrected.

Dissolved oxygen *measurement accuracy* is verified by Azide Modified Winkler titrations of triplicate samples of water taken with a General Oceanics, Inc. 3-liter sampling bottle at a depth of ten meters at random stations toward the beginning, middle and/or end of each sampling day. These values are compared to those collected by the SBE 19 profiler to determine if any discrepancy exists between the values obtained using the two methods. As above, if discrepancies are detected between the two methods, sampling is discontinued until the problem is identified and corrected.

Video Monitoring

Video monitoring has been carried out semi-annually in the spring and fall of each year. In 1998, this schedule was modified to require video recordings only in the fall since this is the time of year when impacts are most likely to be observed. The purpose of the underwater video recording is to provide those unable to dive beneath the cages with visual images of conditions adjacent to and beneath cage systems. This component of the monitoring program represents an instantaneous representation of shorter-term effects and changes.

Transect lines, consisting of 60 meter (~200 ft) ropes, are marked in 10m alternating black and white sections, with the exception of the first and last 10m which are marked as two 5m sections, the last five of which are marked in alternating 1m black and white increments. One 60m transect line is deployed at each end of the cage system to allow measurement of distance from the cage edge along the bottom. The line is weighted at each end with yellow window weights to provide highly visible starting and ending points. The line is deployed by allowing one end-weight to drop to the bottom immediately adjacent to the cage edge. The remaining line is payed out from a boat running parallel to the predominant current direction until the line becomes taught, at which point the end-weight is allowed to drop to the bottom.

The diver survey and video recording are begun 60m from the cage(s) on the upcurrent side allowing the diver to flow with the current. Once the diver reaches the end of the transect line at the pen edge, the survey continues either adjacent to or directly beneath the cage(s) until the second transect line is found at the opposite end of the system where the survey continues along the transect line to a distance 60m downcurrent of the cage(s). The video recording is taken with an underwater video camera package using Hi8 format. Lighting is provided by at least one 50-watt video light during the dive. The video recording is started at the end-weight and runs continuously throughout the dive, with the exception of certain instances when the diver becomes disoriented and considerable time is required to relocate the transect lines. In such cases the camera is turned off to conserve videotape and ensure sufficient tape and battery power for completion of pertinent video recording of the bottom.

Benthic Monitoring

Benthic monitoring is carried out immediately adjacent to and at various distances from selected cage systems on a schedule such that each cage system is monitored in alternating years. The purpose of the benthic monitoring is to detect and document any changes, which take place in the macrofaunal community structure on the sites as a result of the cage system operations. This component previously included analysis of sediment composition, or granulometry, but this component was dropped in the Fall of 1996 after little correlation could be found between sediment granulometry and environmental effect. The benthic monitoring portion of the monitoring program seeks to track the longer-term effects and changes related to cage culture operations.

Single sediment cores for benthic macrofauna analysis are taken at pre-selected stations around and under the cage systems using 4-in. diameter PVC pipe coring devices. These are inserted to a depth of 10 cm or to resistance, whichever is reached first. The contents of the cores are washed through an U. S. Standard No. 50 sieve (1.0-mm mesh). All material retained on the sieve is transferred into sample containers, and the containers filled with 10% buffered formalin. Several drops of a 1% Rose Bengal staining solution are added to each sample to assist in highlighting the organisms for sorting. After 5 days of fixing in 10 Formalin, the formalin solution is decanted from the sample containers through a 500M mesh sieve and the formalin volume replaced with 70% ethanol to insure preservation of the organisms' integrity, particularly the bivalves and other calcareous forms.

The benthic macrofaunal community analysis is the most time-consuming and expensive part of the monitoring program. In addition to being highly labor-intensive, the identification of the organisms requires specific expertise in taxonomy. Although costly, these analyses yield a great deal of information and provide a clearer understanding of the subtle, yet complex changes which take place beneath the cage systems once the systems are installed and operations begin.

Several computer spreadsheets have been developed to tabulate all of the data and facilitate comparisons between individual samples as well as between sites. The spreadsheet lists all species found to date in the rows and provides column space for entering the number of individuals of each species found at each station. The spreadsheets also carry out several calculations to assist in understanding and interpreting these data.

Four values continue to be used to evaluate the benthic condition. First is *abundance*, a derivative of the total number of organisms reported as number of organisms per $0.1m^2$, (or a*bundance* = total no. organisms x 12.345, where 12.345 is used to convert the surface area sampled by the 4-inch diameter corer to $0.1m^2$).

Second, *species richness* is simply the number of species represented in the sample. Species richness serves as an index of diversity indicating either a heterogeneous community where numerous species are represented or a homogeneous community where only a few species are present.

Third is *relative diversity*, also referred to as *evenness*, an index that relates the number of species represented to the number of individuals of each species. Thus, while a large number of species may be represented, most may be represented by a small number of individuals, while two or three may be represented by the bulk of the individuals found.

Consequently, while the species richness may be high, the representation of the species, *relative to one another*, may be far from evenly split. The diversity index H used (Shannon 1948) is expressed as:

$$H = \frac{n \log n - \sum_{i=1}^{k} f_i \log f_i}{n}$$

where n is the total number of organisms in the sample, k is the number of species in the sample, and f_i is the number of individuals in each species i.

The theoretical maximum diversity is given as:

$$H_{max} = \log k$$

and the following proportion can be used to compare the actual and theoretical maximum diversity, thus yielding a relative diversity J:

$$J = H/H_{max}$$

Theoretically, under "normal," unaffected conditions, the actual diversity should approach the theoretical maximum diversity and J should approach 1. In actuality "normal," unaffected conditions are now difficult, if not impossible, to find. Where environmental degradation favors certain tolerant species, the actual diversity can be considerably less than the theoretical maximum and J may approach 0. Theoretically then, the smaller J becomes, the more affected the environment is assumed to be; however, this is not always necessarily the case.

The fourth value is the percent of the total population represented by the indicator species *Capitella capitata*. *C. capitata* is very tolerant of hypoxic, or oxygen depleted, conditions and is therefore considered a good indicator of environmental degradation, particularly degradation associated with organic loading. A determination of % *C. capitata* therefore allows a comparison of this species' relative abundance from one sample to another and provides some indication of the bottom conditions.

Each of these values or indices provides a means of interpreting the mass of numbers generated through the benthic analyses. However, no single value or index taken by itself can be relied upon to reflect the "complete story." For example, consider a case where two samples have similar *J* values of 0.335 and 0.314, and % *C. capitata* of 69% and 79%, respectively, but species richness values of 64 and 10, respectively. On the basis of *J* and % *C. capitata* the two samples may appear rather similar, but the fact that the first sample comes from an area supporting 64 species and the second from conditions supporting only 10 species suggests that the latter represents a more degraded environment than the former.

To avoid relying on either one of these values and better reflect he relationship between relative diversity and species richness we have simply multiplied the relative diversity value *J* by the species richness (**RD*SR**). Thus, the larger product, the better the environmental condition.

Summary

The FAMP calls for the benthic monitoring of all finfish aquaculture sites in Maine every other year. In this way, all active sites are monitored over a two-year period and the same sites are sampled in alternating years. The first full round of sampling of all sites was first completed over the falls of 1992 and 1993. A second round of sampling was completed in 1994 and 1995. Sampling for the third round of benthic monitoring was completed in the fall of 1997 and results for the period 1992 - 1997 may be found in Heinig (1998). Repeated biennial sampling offers the opportunity to compare benthic fauna results over time and allows conclusions to be drawn on the effects of finfish aquaculture on benthic communities over time.

Freshwater and Marine Operations

The aquaculture industry in Maine is currently composed of 46 finfish site leases (787.19 acres), 29 shellfish site leases (320.84 acres), and 4 seaweed leases (127.14 acres). Most of the finfish and the seaweed leases are located in eastern Maine (Cobscook Bay area), while most of the shellfish leases are located in the south central coastal area. The distribution of all aquaculture lease sites is shown in Figure 1, while the location of finfish sites are shown on a regional basis in Figures 2 - 4. Atlantic salmon is the primary species of finfish under cultivation, with rainbow trout a distant second. Other species of finfish that have been (or currently are) reared include: Atlantic halibut (*Hippoglossus hippoglossus* L.), haddock (*Melanogrammus aeglefimus* L.), and Atlantic cod (*Gadus morhua* L.), and Arctic charr (*Salvelinus alpinus*).

Of the 46 finfish site leases, 33 are actively rearing Atlantic salmon (as of October 1998). These sites are owned and operated by 12 companies; there were as many as 18 companies in the 1980's. In a 1989 survey of the industry for the US Department of Agriculture's Regional Aquaculture Center, 335 sea cages were in operation (Battencourt and Anderson 1990). A 1998 survey by the Maine DMR identified 773 cages in use.

Also, in recent years, there has been a shift to the use of modern, large diameter (25m) high-density polyethylene (HDPE) circular cages of Norwegian manufacture. A few smaller diameter (15m) HDPE circular cages are also used, however, the most often used cages are 12-15 meter square steel net pens that are manufactured in New Brunswick, Canada. Site intensity has increased markedly in recent years, from 2 cages/site in 1989 to a maximum of 30 per site in 1996. Salmon farms today deploy as many as 82 cages per site, with an average of 23.4 deployed per lease site.

The Maine industry is comprised of five freshwater smolt-rearing hatcheries, (and one trout hatchery) that are capable of producing up to four million Atlantic salmon smolts annually. Additional smolts are often imported from New Brunswick and New Hampshire. Although several European stocks (from Iceland, Scotland, Norway, and Finland[1]) were initially tried in Maine, there are three current stocks under production. Penobscot River (Maine, USA) stocks were originally provided to the industry by the State of Maine (100,000 smolts in 1983 and 50,000 smolts in 1985), while Saint John River (New Brunswick Canada) stocks were originally provided by the federal government of Canada (Department of Fisheries and Oceans). The third stock, commonly referred to as the Landcatch strain - which is a mixture of several Norwegian stocks - was originally imported to Maine from Scotland in 1989. Hybrids from previously used European stocks also probably exist in Maine. Approximately 30-50% of all salmon currently under production are either pure or hybridized Landcatch/European strains, with either of the other two stocks.. The exact percentage of Landcatch/European hybrids being reared in Maine is difficult to ascertain due to incomplete and/or inadequate record keeping by a rapidly changing industry. The Maine industry has also recently (1997 and 1998) imported milt from Iceland (the Bolak strain from Norway). Milt was imported because (as of 1995) Maine law prohibits the importation of live fish or eggs from Europe, although exemptions exist for the Maine Department of Maine Resources and the Maine Atlantic Salmon Authority.

More than 4 million Atlantic salmon smolts are now stocked annually in Maine waters (Table 1 and Figure 5). Cage rearing to harvest requires about 18 months, yielding an average standing crop of about 6 million salmon in two-year classes. Most salmon are harvested from October through March, and the total harvest has increased from 20 mt in 1984 to more than 12,000 mt in 1997 (Figure 6).

Information Pertaining to Escapes from Salmon Farms

The number of salmon that escape from Maine aquaculture sites is unknown and there is no legal requirement to report such occurrences. Generally speaking, industry representatives in Maine and New Brunswick tend to keep such information confidential for business and/or insurance reasons. Additionally, salmon farmers may also be hesitant to publicly acknowledge accidental escapes for fear of overreaction by government

[1] Icelandic stocks were: Eldi and Isno river stocks; Norwegian stocks (via Scotland) were the Mowi strains (from the Landcatch Company); Finnish (Baltic Ocean) stocks originated from the Moorum River.

regulatory agencies. However, storm-related accidental escapes are sometimes reported in the media.

Escapes of juvenile and adult Atlantic salmon from sea cages in eastern Maine are usually concentrated in the winter months (Figure 7) when threats to equipment integrity from storm damage and seal attacks are most common (McGonigle et al 1997). Post-smolts nearing the completion of the first sea winter are the preponderant age class present on sea cage sites during this period of greatest risk. Full maturation - another 6 to 15 months at sea - would have to be achieved before significant interactions between wild and farmed salmon would occur in Maine rivers. Where escapees survive to sexual maturity there is evidence from Europe indicating that spawning sometimes occurs later in the year (Lura and Saegrov 1991; Jonsson et al. 1991) and often occurs in lower portions of rivers (Webb et al. 1991). Late spawning may help limit the opportunity for direct genetic interchange with wild salmon stocks, while downriver spawning may help to limit the opportunity for disruption of redds constructed by wild salmon that spawned earlier in the autumn. Farmed salmon have been identified in Maine rivers by their poor fin condition (e.g., deformed pelvic and/or pectoral fins, "broomed" caudal fins, etc.), their size (most are larger and heavier than wild 1SW (one sea-winter) salmon (grilse), but smaller and lighter than MSW (multi sea-winter) salmon, averaging approximately 63 cm FL, and by growth patterns exhibited on their scales.

The first documented incidence of farmed salmon in Maine rivers occurred in 1990, when a minimum of 17 percent (14 of 83 fish) of the rod catch in the East Machias River was of farmed origin (Baum 1991). There were few reports of farm origin salmon in Maine rivers in 1991 and 1992, although in 1993 there were an estimated 20 aquaculture strays in the Dennys River (which had a documented run of 40-50 wild salmon). In 1994, of a total of Dennys River weir catch of 47 salmon, all but five were farmed origin; one aquaculture stray was also observed in the Narraguagus River. Trap catch results for 1995 identified four farm escapees in a total of nine salmon on the Dennys River. Farmed origin salmon were also apparently caught (and released) by anglers fishing the Dennys and East Machias Rivers in 1995.

Those rivers in close proximity to the Maine/New Brunswick aquaculture cage sites (e.g., St. Croix, Dennys and East Machias) have shown the highest incidence of escapees, with farmed salmon comprising >50% of adult returns in some rivers in recent years. Most aquaculture escapees observed in Maine are sexually immature; however, beginning in 1996, a small number of sexually mature escapees have been documented in a total of 3 Maine rivers annually. In the St. Croix River, 17 escapees were sacrificed in September 1998, and 5 (30%) exhibited evidence of sexual maturation. The effects of intrusions of farmed-origin salmon in Maine rivers are currently unknown. A summary of documented aquaculture escapees identified in 8 Maine rivers is presented in Table 3 (Baum et al. 1997; Horton et al. 1998; ICES 1998).

Potential Impacts to Wild Atlantic Salmon Stocks

The rapid growth of the Atlantic salmon aquaculture industry in Maine (as well as on a worldwide basis), coupled with the rising number of cultured salmon observed in the wild, has caused international concern. For example, in Norway farmed salmon have recently been estimated to comprise 47% and 42% of catches in coastal and fjord net fisheries, 9% of rod catches and 27% of broodstock samples (ICES 1998). In addition, data from previous years of commercial fishing at the Faroe Islands have shown a high proportion of catches to be of farmed origin. In the Bay of Fundy area of North America, aquaculture escapees in the Magaguadavic River, New Brunswick have comprised from 33-90% of total fishway counts since 1992. In the nearby St. Croix River, farmed salmon have comprised from 13-54% of the total run since 1994 (ICES 1998). Similarly, in the Dennys River, Maine during the same period aquaculture escapees have comprised from 44-100% of known runs (incomplete counts, however). All three of these rivers are located in proximity to the center of aquaculture production areas of eastern North America.

Escapes of salmon from farms are inevitable and are usually a result of storms, predator damage, equipment failures, and accidental human error. It is also likely that some fish are intentionally released, because some operators may be reluctant to dispose of culls and/or surplus production in the belief that they are benefiting the resource or enhancing sport-fishing opportunities. It should be emphasized that there is no evidence that this practice occurs to any great degree or extent in Maine. Interactions between wild and aquaculture salmon (including spawning) have been documented in both Europe and North America Youngson et al. 1998, although there have been few documented interactions involving spawning in Maine. Interactions between wild and farmed fish are generally classified into the following categories: genetics, ecological interactions, parasites and diseases, habitat (water quality) interactions, and management interactions. The brief overviews of these potential interactions that follow are more thoroughly discussed in Heggeberget et al. 1993, USFWS/NMFS 1995, and Youngson et al. 1998.

Genetic Interactions

Most scientists believe that each river with a "native" Atlantic salmon population is inhabited by at least one genetically distinct stock. Larger rivers, for example, the Miramichi in Canada, may support several distinct stocks within the system. Farmed Atlantic salmon that have escaped have demonstrably spawned with wild salmon in both Europe and North America (Youngson et al. 1998); however, the significance of the interbreeding that has occurred is unknown. What is known, however, is that farmed salmon often differ genetically from wild salmon, and farmed salmon often demonstrate reduced fitness and survival in the wild (although at younger ages farmed salmon sometimes outgrow and displace wild salmon). Obviously, the small, native salmon populations in eastern Maine would be potentially most vulnerable to genetic interactions by intrusions of large numbers of farmed-origin salmon.

Ecological Interactions

The most common potential ecological interactions between farmed and native salmon involve competition and reproduction. Reproductive behavior is altered and reproductive success is negatively impacted. In space-limited stream habitat, competitive displacement - and therefore increased mortality rates - of wild fish is likely to result (Youngson et al. 1998). Thus, it is theorized that while farmed origin salmon exhibit what often appears to be superior performance in freshwater, they demonstrate lower fitness as adults, resulting in reduced recruitment in future generations. The risks to Maine wild salmon populations from ecological interactions with farmed salmon are currently unknown.

Parasites and Disease Interactions

Diseases affecting Atlantic salmon are endemic in the natural environment and the Maine salmon aquaculture industry has an excellent record in the area of disease prevention and control through the use of vaccines, animal husbandry techniques, and site maintenance measures. Nevertheless, diseases can potentially spread through transfers of pathogens with infected stocks or through the movement of supplies, personnel and equipment (Youngson et al. 1998). The most notable examples of this type of occurrence are the transfers of furunculosis (a bacterial disease) between Scotland and Norway and of *Gyrodactylus salaris* (an external parasite) between Sweden and Norway (Youngson et al. 1998). One of the more important fish health issues in recent years includes infestations of sea lice (*Lepeophtherius salmonis*). High infection rates can result in skin damage, stress, osmoregulatory problems and death of Atlantic salmon (Bjorn 1996). A 1996 ICES workshop on the Interactions Between Salmon Lice and Salmonids concluded that associating high levels of lice in wild salmonids with aquaculture was circumstantial and that more research is necessary. More recent studies conducted in the Faroe Islands revealed that lice were significantly more abundant in escaped 1SW farmed salmon, but there was no difference at the MSW stage. Similarly, in Ireland lice densities on escaped-farmed salmon were observed to decrease rapidly with distance from farms (Youngson et al. 1998). Obviously, the extent and possible consequences of sea lice infestations in the Maine aquaculture industry warrant further investigation.

Habitat Interactions

Wastes from salmon farming, unlike wastes from most "conventional" farming, are released directly into the natural environment. Thus, there is a potential to affect water quality, benthic (bottom dwelling) organisms and algal blooms. Wastes can be in the form of excretory wastes from fish, uneaten food, and chemical pollution from the use of antibiotics and pesticides to control diseases and parasites, hormones used to induce maturation, sex reversal or spawning, anesthetics used during the transportation or handling of fish, and feed supplements such as vitamins, minerals, and pigments.

Currently, only three antibiotics are specifically approved by the U.S. federal government for use in aquaculture: oxytetracycline, sulfamethoxine-ormetroprin and sulfamerazine, although drug regulations allow for the experimental use of other drugs under certain conditions.

Considering the small total area devoted to aquaculture in Maine coastal waters (800 acres), and the extensive environmental monitoring that has occurred in recent years, there is no evidence of negative impacts to wild Atlantic salmon habitat, water quality, or benthic organisms from wastes or the use of drugs and chemicals in the aquaculture industry.

Management Interactions

The presence of farmed salmon in the wild, especially if numerous, could potentially mask the status of wild stocks and complicate the regulation of fisheries and management of wild salmon stocks. It has been recommended that managers of wild salmon stocks ensure that those stocks are in a strong condition so that they can withstand impacts from aquaculture, as well as other threats (Youngson et al. 1998). Current management measures being undertaken in Maine to reduce potential impacts from aquaculture are discussed in the following section of this paper.

Measures Currently Being Undertaken to Reduce Potential Impacts of Aquaculture

About 60% of the Maine farmed salmon production occurs close to the New Brunswick production and 90% occurs within 50 km. of the Canadian border (McGonigle et al. 1997). Since the Canadian production in the Passamaquoddy Bay area is about double that of the Maine production, the effectiveness of management strategies in Maine alone would be compromised without international agreement and universal application.

Measures currently in place or planned (ASTF 1997; Baum et al. 1995; Baum et al. 1997) to reduce the potential impacts of aquaculture upon wild Maine Atlantic salmon stocks include the following:

1. Measures to address transmission of diseases and parasites

- state, New England, and federal fish health inspection protocols are in place to assure the highest quality of fish health of stocks used in the industry.
- smolts are vaccinated to minimize the risk of contracting endemic diseases prior to stocking into sea cages.
- seal-induced escapes are minimized through the use of predator guard nets, and acoustic and visual deterrent devices.
- freshwater culture facilities screen water intake and discharges to minimize escape of juvenile fish into the wild.
- an emergency disease eradication plan involving steps to be taken in the event of detection of exotic fish pathogens is being developed.

- an ongoing epidemiological monitoring program will be expanded to determine the type, incidence, and geographic distribution of salmonid pathogens in Maine.
- The University of Maine and the Maine Aquaculture Association have developed a draft Fish Health Codes of Practices.
- a Fish Culture Code of Practices for the culture of salmon in freshwater and at sea cage sites was adopted in October, 1998; this plan is designed to minimize accidental escapes.

2. Measures to address genetic and ecological interactions

- a river specific stocking program (initiated in 1992) is in effect for most Maine rivers with existing salmon runs. In those rivers located close to aquaculture operations, the goal is to increase the number of wild salmon to reduce the potential impacts of interbreeding with farmed salmon. Stocking is based upon fry releases (up to $100/100m^2$ unit of habitat), as well as parr and smolts. Smolts (some originally collected as wild parr) are also being reared to sexual maturity in freshwater hatcheries (by the US Fish and Wildlife Service and the aquaculture industry) and in sea cages (by the Maine aquaculture industry) to provide eggs for restocking programs or to supplement spawning escapement in the wild. Supplemental parr and smolt rearing is also being conducted by the Maine salmon farming industry.
- weirs will be installed in several eastern Maine Atlantic salmon rivers to intercept (and remove) aquaculture escapees and to monitor returns of native salmon (numbers, timing, spawning escapement, collect biological data from individual fish, etc.).
- a proposed marking system will be developed cooperatively with the industry that would compliment the effectiveness of weirs by enabling farmed salmon to be more easily distinguished from wild salmon. Any marking system should: (a) be universal, including Canada; (b) be cost-effective for the industry; (c) not reduce the market value of the fish; and (d) not increase the incidence of disease.
- research into seal behavior around sea cages and site and cage vulnerability to seal attack will be investigated. The results of this research will be used to evaluate the need for seeking reauthorization of limited lethal take of seals at farm sites (ASTF 1997).

Future Research and Management Recommendations

1. Adoption of an international agreement between Canada and the US to implement joint wild Atlantic salmon population protection strategies. The agreement must be universally applied to the salmon farming industry on both sides of the international border, and must address issues such as genetics, fish health, cross-border movements, containment measures, etc.

2. Adoption of a marking program that can be applied to all farmed Atlantic salmon, in order to be able to readily identify farmed salmon in the wild. Marking must be universally applied in Canada and the US, and not negatively impact marketability of farmed salmon product(s).

3. Development of viable methods of sterilization of farmed salmon. Method(s) must be universally applied in the US and Canada, cost-effective, acceptable to the industry and not affect marketability of product(s).

4. Universal reporting of escapes (numbers, dates, sizes, species, stock origin, location, etc.) to a central North American clearinghouse. Requirements should be universally applied in Canada and the US; individual grower confidentiality must also be maintained, where appropriate.

5. Universal reporting of disease/parasite outbreaks in the salmon farming industry to a central North American clearinghouse. Reporting requirements and recommended remedial actions must be universally applied and acceptable to all parties.

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Table 1. Number of Atlantic salmon smolts (including age 0+ parr) stocked into netpens in the Maine aquaculture industry, 1982-1997. Data from Maine Department of Marine Resources: 1994-97 information pertaining to number of smolts by strain subject to change.

	Number of Smolts						
Year	Penobscot	%	Saint John	%	Landcatch[1]	%	Total
1982	-	-	-	-	-	-	85,000
1983	-	-	-	-	-	-	155,000
1984	-	-	-	-	-	-	30,000
1985	-	-	-	-	-	-	131,000
1986	-	-	-	-	-	-	65,000
1987	-	-	-	-	-	-	265,000
1988	-	-	-	-	-	-	1,108,875
1989	-	-	-	-	-	-	2,739,000
1990	-	-	-	-	-	-	2,319,565
1991	-	-	-	-	-	-	2,809,765
1992	-	-	-	-	-	-	2,730,375
1993	-	-	-	-	-	-	3,048,330
1994[2]	274,350	9.0	2,103,350	62.0	670,630	29.0	3,609,515
1995[2]	938,475	26.0	1,624,280	45.0	1,046,760	29.0	3,862,275
1996[2]	1,042,815	27.0	2,047,005	53.0	772,455	20.0	4,082,115
1997[2]	1,701,350[3]	35.0	2,576,330	53.0	583,320	12.0	4,861,000

[1]Either pure Landcatch/European or crossed Penobscot and/or Saint John stocks.
[2] Data as reported to the Maine DMR; however, industry representatives estimate that the actual proportion of stocks containing European genetic material may currently (1998) range from 30-50%.
[3]Includes 122,465 Penobscot x Saint John crosses

Table 2. Production (harvest) of Atlantic salmon and rainbow trout in the Maine aquaculture industry.

	Production (mt.)			
Year	Atlantic salmon	%	Rainbow trout	%
1984	20	-	-	-
1985	-	-	-	-
1986	-	-	-	-
1987	365	-	-	-
1988	455	-	-	-
1989	905	-	-	-
1990	2,085	-	-	-
1991	4,560	96.7	155	3.3
1992	5,850	95.4	282	4.6
1993	6,755	95.2	337	4.8
1994	6,130	95.8	266	4.2
1995	10,020	98.9	113	1.1
1996	10,010	99.7	33	0.3
1997	12,140	99.0	117	1.0

Table 3. Documented Atlantic salmon of farmed-origin in Maine rivers, 1994-1997. (Data from ICES 1998 and Maine Atlantic Salmon Authority files).

	River[1]					
	Saint Croix		Dennys[2]		Narraguagus	
Year	Number	% of Run	Number	% of Run	Number	% of Run
1994	98	54	42	89	1	2
1995	13	22	4	44	0	0
1996	20	13	21	68	8	22
1997	27	39	2	100	0	0
1998	25	38	Unknown	Unknown	0	0

[1]Additional Maine rivers where salmon of farmed origin have been observed. Boyden Stream, Pennamaquan River, Hobart Stream, East Machias River, Penobscot River (1 fish in 1990).

[2]Incomplete counts.

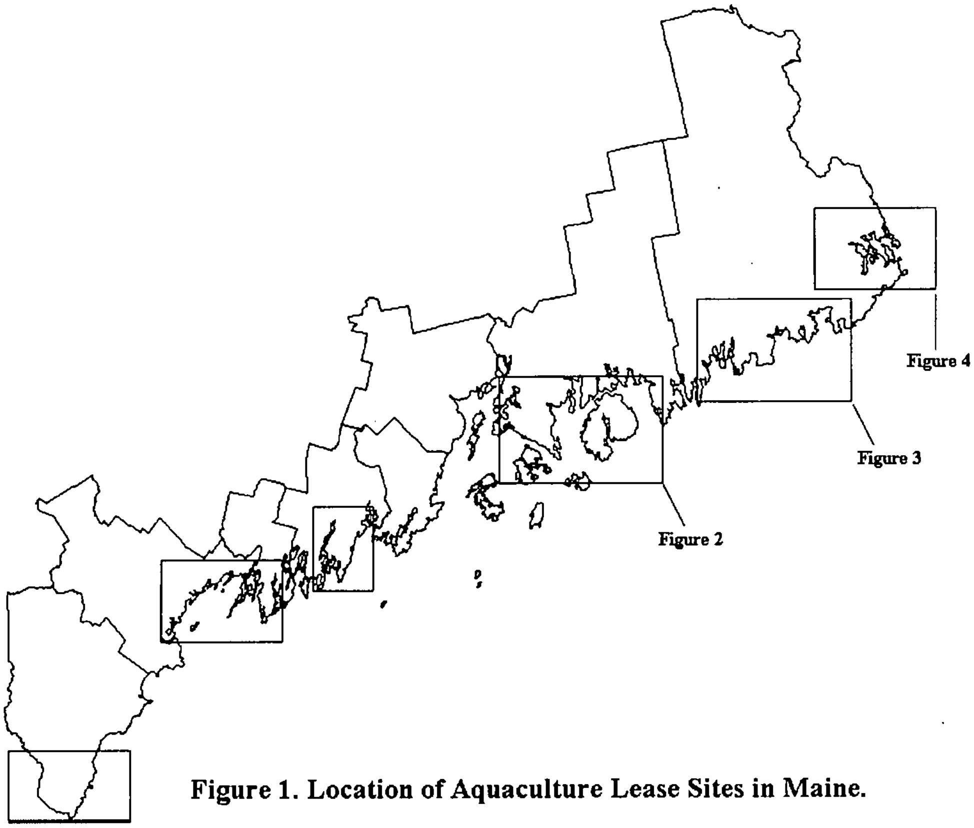

Figure 1. Location of Aquaculture Lease Sites in Maine.

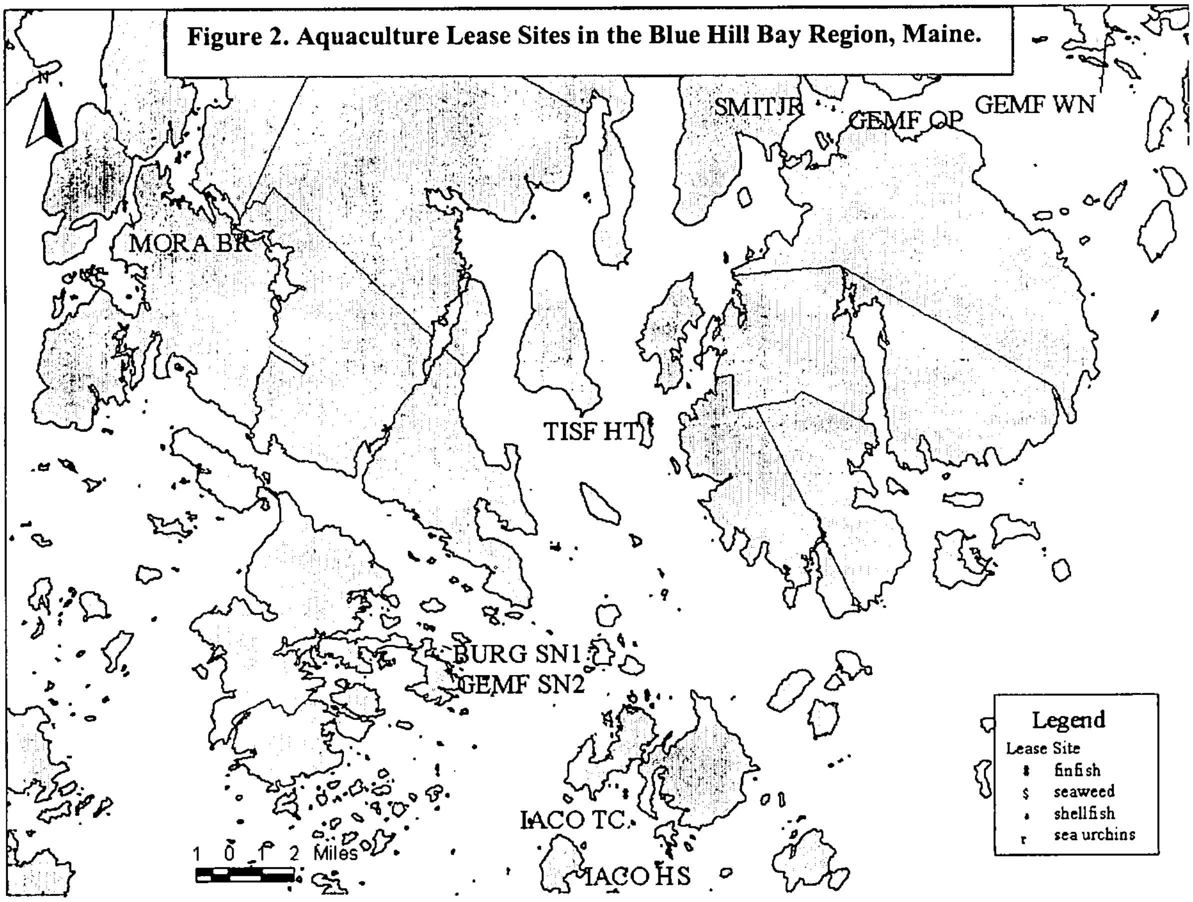
Figure 2. Aquaculture Lease Sites in the Blue Hill Bay Region, Maine.
SMITJR
GEMF OP
GEMF WN
MORA BR
TISF HT
BURG SN1
GEMF SN2
IACO TC
IACO HS
1 0 1 2 Miles
Legend
Lease Site
finfish
seaweed
shellfish
sea urchins

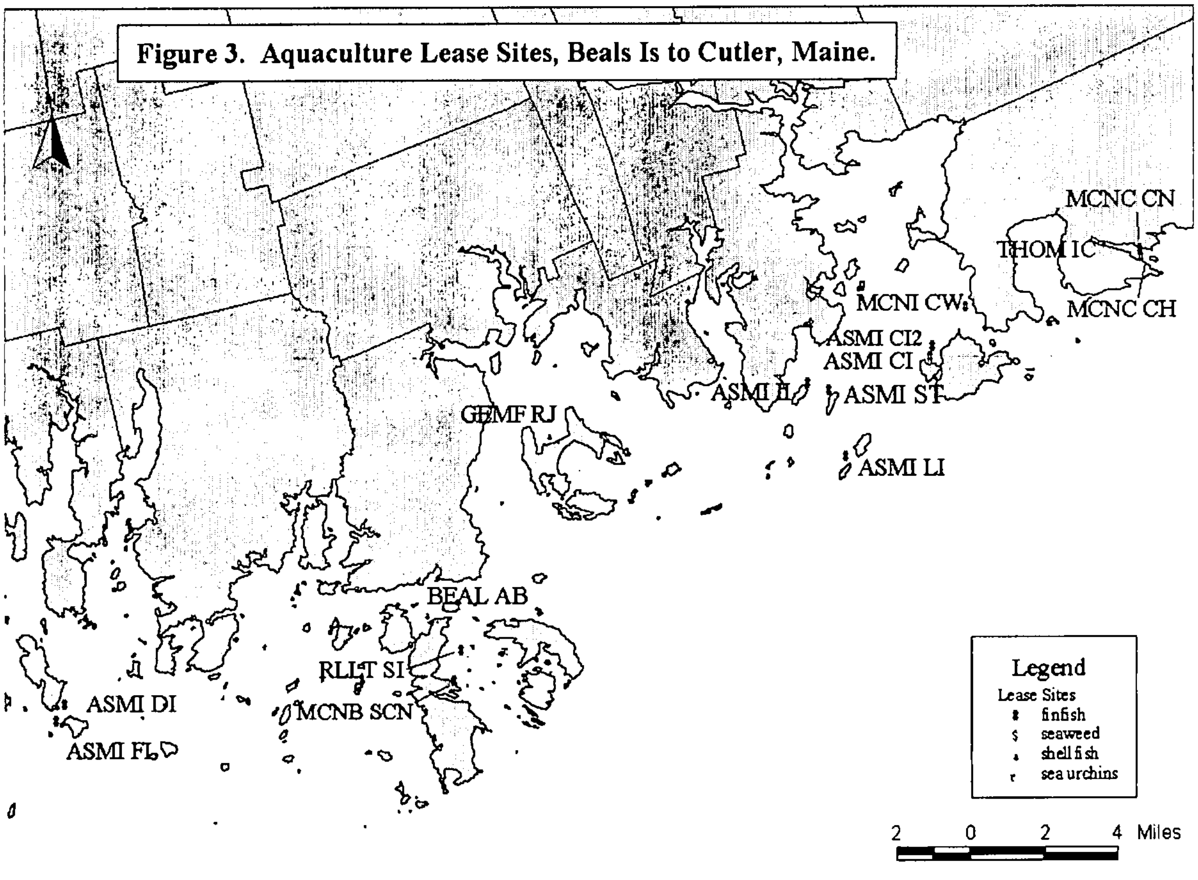

Figure 3. Aquaculture Lease Sites, Beals Is to Cutler, Maine.

Figure 4. Aquaculture Leases in the Cobscook Bay Region, Maine.

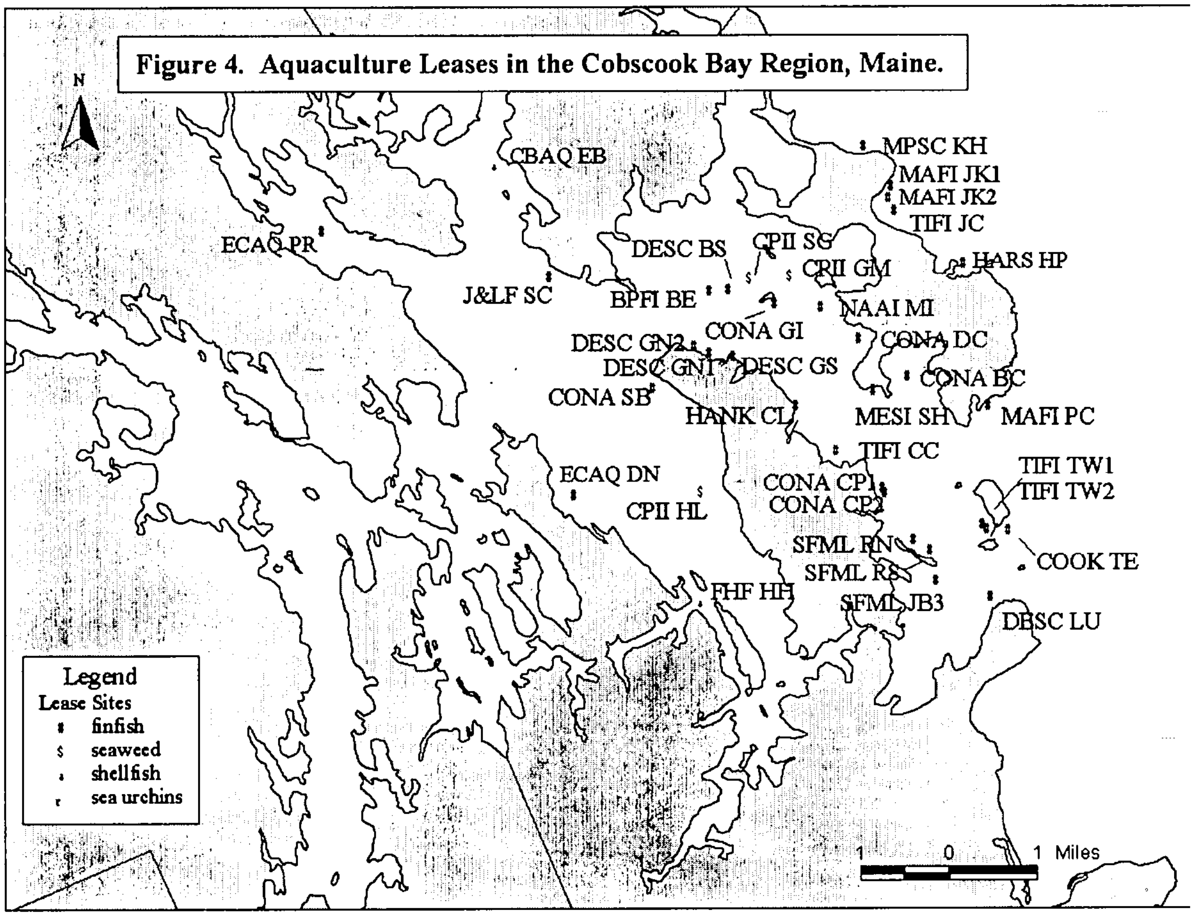

Figure 5. Number of Atlantic salmon smolts stocked into netpens in the maine aquaculture industry.

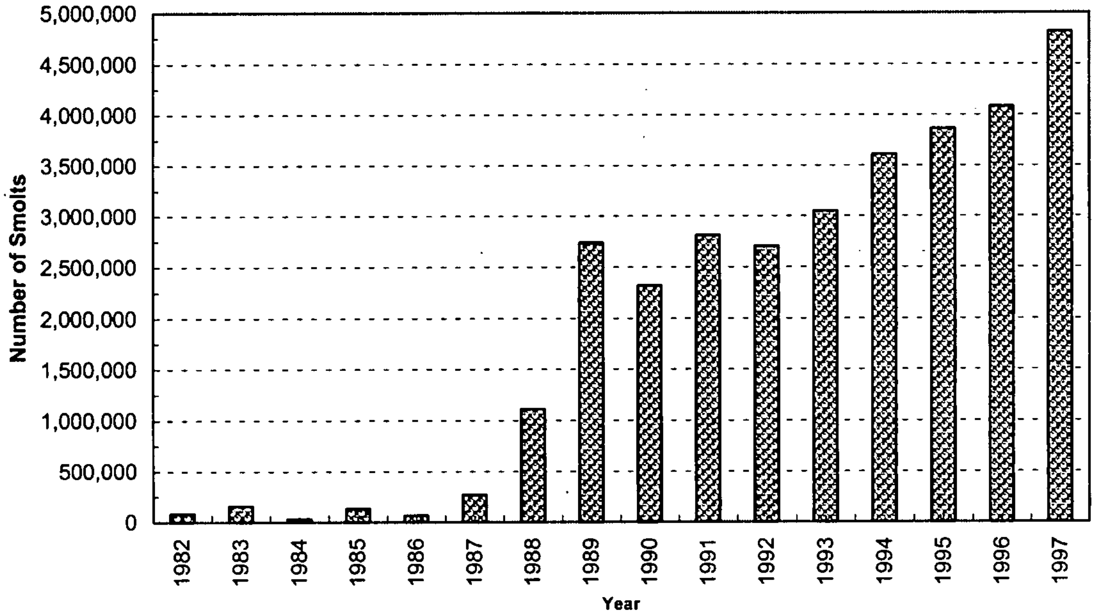

Figure 6. Production of farmed Atlantic salmon in Maine.

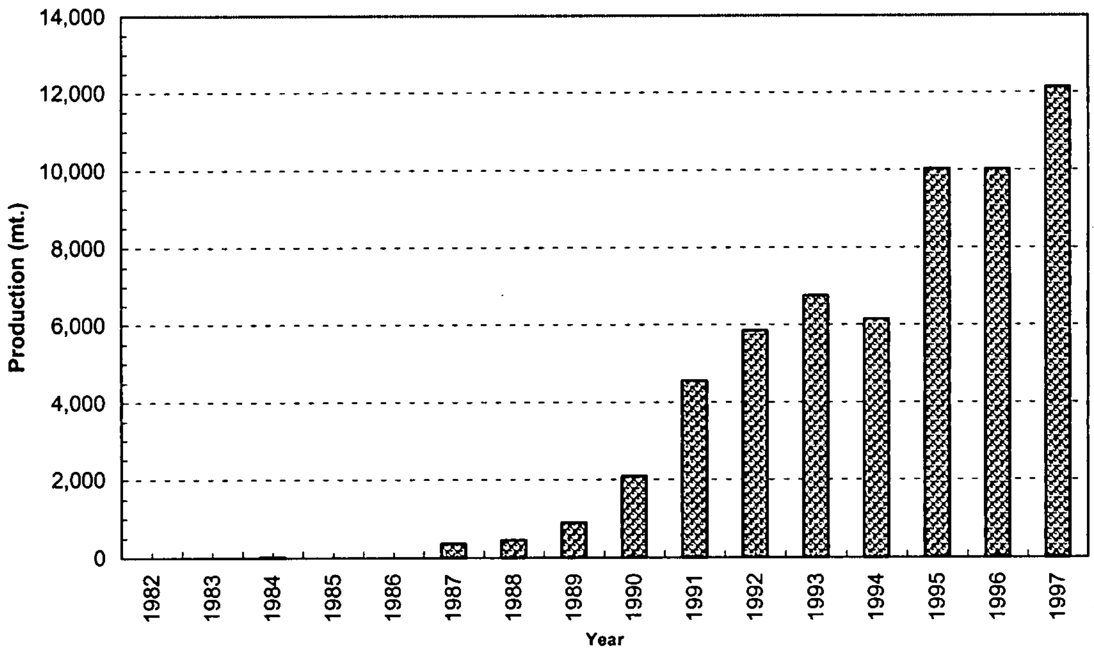

Figure 7. Incidence of insurance claims for Atlantic salmon losses due to storms, equipment failure and predation. Data from McGonigle et al. 1997.