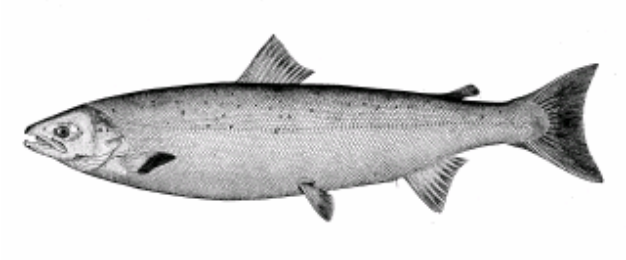

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Atlantic Salmon

by

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Distribution, Biology and Management

The Atlantic salmon, *Salmo salar*, is a highly prized game and food fish native to New England rivers (Figure 41.1). The historic North American range of Atlantic salmon extended from the rivers of Ungava Bay, Canada, to rivers of Long Island Sound. As a consequence of industrial and agricultural development, most populations native to New England were extirpated. Remnant native populations of Atlantic salmon in the United States now persist only in Maine. Restoration and rehabilitation efforts, in the form of stocking and fish passage construction, are underway in the Connecticut, Pawcatuck, Merrimack, Saco, Kennebec, Penobscot, and eastern Maine rivers of New England.

Atlantic salmon life history is extremely complex owing to its use of both freshwater and marine habitats and long ocean migrations (Figure 41.2). Atlantic salmon spawn in freshwater during fall. Eggs remain in gravel substrates and hatch during winter, and fry emerge from the gravel in spring. Juvenile salmon, commonly called parr, remain in freshwater one to three years in New England rivers, depending on growth. When parr grow to sufficient size (>13cm) they develop into smolts and migrate to the ocean in spring. Tagging data for New England stocks indicate that US salmon migrate as far north as Greenland.

After the first winter at sea for US salmon (the fish are now referred to as 1 sea-winter or 1SW salmon), a small portion (~ 10%) of the cohort, typically males, become sexually mature and return to natal rivers to spawn. Those remaining at sea feed in the coastal waters of West Greenland and Canada (off the Newfoundland and Labrador coasts). Historically, it has been in these foraging areas that commercial Northeast Atlantic gillnet fisheries for salmon occurred. After their second winter at sea (2SW), most US salmon return home to spawn. Three sea-winter and repeat-spawning salmon life history patterns also occur in New England populations but have become rare (< 5%) with declining stock size.

Significant declines in abundance of Atlantic salmon populations in the US prompted an endangered listing of the species under the Endangered Species Act (ESA, 65 Federal Register 69459, November 17, 2000). The ESA of 1973 was amended in 1978 to define a species as "...any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature". A Distinct Population Segment (DPS) is a subgroup of a vertebrate species that is treated as a species for purposes of listing under the Endangered Species Act. It is required that the subgroup be separable from the remainder of and significant to the species to which it belongs (61 Federal Register 4722).

The strong homing capability of Atlantic salmon fosters the formation and maintenance of local breeding groups resulting in intraspecific sub-structuring. Stocks from a given area exhibit heritable adaptations to local riverine ecosystems. The importance of maintaining these local adaptations has been demonstrated in Atlantic salmon. Assessing DPS structure requires broad scale consideration of geologic and climatic features that shape population structure through natural selection. For Atlantic salmon, factors such as climate, soil type, and hydrology are particularly important because these factors influence ecosystem structure and function including transfer of energy in aquatic food chains. Numerous ecological classification systems were examined which integrate the many factors necessary to perform such a DPS analysis (Colligan et al. 1999; Fay et al. 2006). Biologists have delineated US Atlantic salmon populations into four discrete DPSs for the purpose of management: 1) Long Island Sound DPS; 2) Central New England DPS; 3) Gulf of Maine DPS and the 4) Outer Bay of Fundy SFA (Figure 41.1). Both the Long Island Sound and Central New England DPS were extirpated in the 1800's. Atlantic salmon stocks from the Penobscot River in Maine were used in the restoration programs in the Connecticut (Long Island Sound DPS) and in the Merrimack and Saco in the (Central New England DPS). Outer Bay of Fundy SFA populations are supplemented by St. John River Atlantic salmon stock and the core populations of this DPS have freshwater nursery areas in Canadian watersheds.

Gulf of Maine Distinct Population Segment

The Gulf of Maine (GOM) DPS comprises all anadromous Atlantic salmon whose freshwater range occurs in the watersheds from the Androscoggin River northward along the Maine coast to the Dennys River, including all associated conservation hatchery populations used to supplement natural populations; currently, such populations are maintained at Green Lake and Craig Brook National Fish Hatcheries. Excluded are those fish raised in commercial hatcheries for aquaculture.

Both physiographic information and biological information from extant stocks were used to delineate the boundaries of the GOM DPS. The biological information included genetic and life history information that was not available for the extirpated DPSs to the south. The geographical northern limit of the Gulf of Maine DPS as the northern boundary of the Dennys watershed (including the Dennys River). This conclusion is supported by the observed life history similarities (Baum 1997) and genetic structure among populations within the range of the GOM DPS (Spidle et al. 2003), life history similarities and genetic structure among salmon stocks to the north (Verspoor et al. 2002), and differences in life history strategies and genetic structure between the GOM DPS and salmon stocks to the north (Spidle et al. 2003, Baum 1997).

Outer Bay of Fundy Statistical Fishing Area

These headwater streams of the St. John River system lie in northern Maine but flow into the Bay of Fundy in St. John New Brunswick. The St. John River is one of a number of salmon rivers in eastern Canada that flows into the outer Bay of Fundy region. Native populations of Atlantic salmon still exist in a number of these systems, but these populations as a whole have dropped to critically low levels. The Outer Bay of Fundy salmon rivers are considered to be separate from the GOM DPS based on life history and genetic difference (Colligan et al. 1999; Fay et al. 2006).

US ATLANTIC SALMON

The Fishery

Homewater Fisheries

Atlantic salmon were likely targeted by Native Americans but US Atlantic salmon commercial fisheries started in Maine during the 1600's with records of catch by various means. Around the time of the American Revolution, weirs became the gear of choice and were modified as more effective materials and designs became available (Baum 1997). Weirs remained the primary commercial gear with catches in Maine exceeding 90 mt in the late 1800s and 45 mt in some years during the early 1900's (Baum 1997). Penobscot River and Bay were the primary landing areas but when the homewater fishery was finally closed in 1948, only 40 fish were caught in the Penobscot Fishery.

Recreational angling for Atlantic salmon had historically been important. Reportedly, the first Atlantic salmon caught on rod and reel was captured in the Dennys River, Maine in 1832 by an unknown angler (Baum 1997). The dynamics of Atlantic salmon fishing are very ritualistic with fly fishing being the most generally acceptable method of angling and the advent of salmon clubs among many US Rivers creating an important and unique cultural and historical record (Beland and Bielak 2002). Recreational angling has been closed in the USA for decades with the exception of Maine where regulations became more restrictive, but the fishery remained open **(Table 41.1).** However, in 1999 when low salmon returns threatened sustainability of even hatchery populations, the remaining catch-and release fishery was closed. There remain some unique fisheries for Atlantic salmon in New Hampshire where fish retired from hatchery broodstock are released for angling and in Maine where an experimental fall catch-and-release fishery has been opened in 2006.

According to the Atlantic salmon fishery plan completed in 1997 by the New England Fishery Management council: "The management unit for the Atlantic salmon FMP is intended to encompass the entire range of the species of U.S. origin while recognizing the jurisdictional authority of the signatory nations to NASCO." Accordingly, the management unit for this FMP is: All anadromous Atlantic salmon of U.S. origin in the North Atlantic area through their migratory ranges except while they are found within any foreign nation's territorial sea or fishery conservation zone (or the equivalent), to the extent that such sea or zone is recognized by the United States." Presently there is a prohibition on the possession of salmon in the EEZ.

Effectively this protects the entire US population complex in these marine waters and is complementary to management practiced by the States in riverine and coastal waters. However, distant water fisheries must be managed as well to conserve and restore US salmon populations. Additionally, after the GOM DPS was listed as endangered the Services and State of Maine developed a recovery plan for these populations that is also influencing salmon management (Anonymous 2005).

Commercial fisheries for Atlantic salmon in Canada and Greenland are managed under the auspices of the North Atlantic Salmon Conservation Organization (NASCO), of which the United States is a member. The mixed-stock fisheries in Canada were managed by time-area closures and quotas, however all commercial fisheries for Atlantic salmon in Canada have been closed since 2000. The Greenland fishery has been managed by a quota system since 1972. In 1993, a modified quota system was agreed to that provided a framework for quotas based on a forecast model of salmon abundance. From 1993-1994, quotas were bought out through a private initiative, but the fishery resumed in 1995, still under forecast modeling-based quotas. In 1997, the NASCO agreement was modified to allow for a local use fishery and to provide for data collection when stock abundance is particularly low. Since 2002, scientific advice from ICES recommended no commercial harvest due to continued low spawner abundance. Salmon conservationists have acted on this advice and in August 2002, an annual agreement renewable for up to five years was signed by conservation organizations and the commercial fishermen's organization in Greenland. This agreement suspended all commercial salmon fishing and allows only a limited annual local-use harvest. This agreement is set to terminate after the 2006 fishing season.

Aquaculture

Despite declining natural populations, the Atlantic salmon mariculture industry continues to develop worldwide. In eastern Maine and Maritime Canada, companies typically rear fish to smolt stage in private freshwater facilities, transfer them into anchored net pens or sea cages, feed them, and harvest the fish once they reach market size. In the Northwest Atlantic, 66% of production is based in Canada with 99.4% of Canadian production in the Maritimes and 0.6% in Newfoundland. The balance (44%) of Northwest Atlantic production is in eastern Maine. US production trends for Maine facilities and areas occupied by marine cages have grown exponentially for two decades. By 1998, there were at least 35 freshwater smolt-rearing facilities and 124 marine production facilities in eastern North America. Since the first experimental harvest of Atlantic salmon in 1979 of 6 mt, the mariculture industry in eastern North America has grown to produce greater than 32,000 mt annually since 1997. In Maine, production increased rapidly and peaked at about 16,500 mt in 2000 but abruptly declined to below 6,000 mt in 2005 (Figure 41.3). Current management efforts focus on the recovery of natural populations and support of sustainable aquaculture to ensure both resource components are managed in a sustainable fashion.

Research Vessel Survey Indices

Atlantic salmon in the ocean are pelagic, highly surface oriented and of relatively limited abundance within a large expansive area and therefore are not typically caught in standard

NEFSC bottom trawl surveys or midwater trawls used to calibrate hydroacoustic surveys. However, researchers in Canada and Norway have successfully sampled Atlantic salmon postsmolts using surface trawls. The NEFSC has been experimenting with these techniques to test them in US waters while learning more of the distribution and ecology of Atlantic salmon in the marine environment. Since 2001, a total of 4,000 postsmolts have been collected and sampled (Figure 41.4). All postsmolts were counted, weighted and measured. The presence of any marks and clips were also recorded as well as their external appearance in terms of fin condition and deformities, which can aid in origin determination, and the degree of smoltification. These assessments are providing novel information on salmon ecology and status at sea.

Stock Assessment

US Atlantic salmon populations are assessed by the US Atlantic Salmon Assessment Committee, a team of state and federal biologists tasked with compiling data on the species throughout New England and reporting population status. Population status of salmon can be determined by counting returning adults either directly, at traps and weirs, or indirectly using redd surveys. Total returns also include retained fish from angling where allowed. Some mortality can and does occur between counts returns and actual spawners – the actual number of spawners is termed spawning escapement and is not estimated for US populations, though redd counts provide a reasonable proxy for some rivers. A unique element of Atlantic salmon populations in New England is the dependence on hatcheries. Since most US salmon are products of stocking, it is important to understand the magnitude of these inputs to understand salmon assessment results.

All US Atlantic salmon hatcheries are run by the US Fish and Wildlife Service. Hatchery programs in the US take two forms; 1) conservation hatcheries that produce fish from remnant local stocks within a DPS and stock them into that DPS or 2) restoration hatcheries that produce salmon from broodstock established from donor populations outside their native DPS. Hatchery programs for the Gulf of Maine DPS are conservation hatcheries. All other New England hatcheries are restoration hatcheries. These restoration hatcheries developed broodstock primarily from donor stocks of Penobscot River origin. However, because these programs have been ongoing for more that 25 years, the majority of fish reared for Long Island Sound and Central New England DPS units are progeny of fish that completed their life cycle in these waters for 3 or more generations. The number of juvenile salmon stocked in New England waters totaled 13.8 million in 2005, a number typical of the decade. Fry stocking dominates numerically overall with 12.7 million fry and fry are used in all systems stocked. Six river systems are stocked with parr and seven river systems stocked with smolts. Almost 700,000 smolts are stocked annually in US waters with about 530,000 of them comprised of age-1 smolts stocked in the Penobscot River. Penobscot River smolts consistently produce over 70% of the adult salmon returns to the US. Cost and logistical issues prevent more extensive use of smolts. However, fry stocking is an important tool because it minimizes selection for hatchery traits and naturally reared-smolts have a higher per capita marine survival rate than hatchery smolts. Building sustainable Atlantic salmon populations in the US will require increasing natural production of smolts in US river systems and using hatchery production to optimally maintain population diversity and effective population sizes.

The modern time series of salmon returns to US rivers starts in 1969. Average annual Atlantic salmon returns to US rivers from 1969 to present is 2,156 and the median is 1,645. The time series of data clearly shows the rebuilding of US populations from critically low levels of abundance in the early part of the 20th century (Figure 41.3). Because many of these populations in southern New England were extirpated, the salmon returns graph (Figure 41.5) illustrates the sequential rebuilding of the populations through restoration efforts in the 1970s – with success first in the Penobscot River then the Merrimack and Connecticut Rivers. The remnant populations of the smaller rivers in the Gulf of Maine DPS and the Penobscot River were the donor material for all rebuilding programs during this time. Unfortunately, the trajectory of this recovery did not continue in the late 1980s and early 1990s. Starting in the early 1990s there was a phase shift in marine survival and an overall reduction in marine survival occurred in all US and most Canadian populations (ICES 2003). There has been a downward trend in production of salmon on both side of the Atlantic (particularly populations dominated by 2SW fish) that have affected US populations. In addition, recovery from historical impacts was never sufficient so US populations were at low absolute abundance when the period of lower marine survival began.

Returns to US waters were 1,320 fish – this ranks 25 out of the 39 year time series and is over 300 fish below the median. However, relative to the average during the last 5 years (1999-2004) of 1,208 - returns in 2005 demonstrated a slight improvement. To gain a better sense of the relative status of the stocks, it is best to examine target spawning escapements. Because juvenile rearing habitat can be measured or estimated efficiently, these data can be used to calculate target spawning requirements from required egg deposition. The number of returning Atlantic salmon needed to fully utilize all juvenile rearing habitats is termed Conservation Spawning Escapement (CSE). These values have been calculated for US populations and total just over 29,000 spawners (Table 41.2). In the last decade, total returns have accounted for less than 2 percent of these target values in Long Island Sound and Central New England DPS. However, salmon returns to the Penobscot River have been as high as 10% of CSE during this period and the Gulf of Maine DPS ranged from 3-4 percent for other populations. These CSE levels are minimal recovery targets since they are based on spawning escapement that could fully seed juvenile habitat. In self-sustaining populations, the number of returns would frequently exceed this amount by 50 to 100 percent allowing for sustainable harvests and buffers against losses between return and spawning. As such, the status of US Atlantic salmon populations is critically low for all stocks, with the remnant populations of the Gulf of Maine DPS listed as endangered.

Over the past 5 years, the contributions of each stock group to total US returns averaged: Penobscot stock (75%), Central New England (12.5%), Gulf of Maine DPS (6.6%), and Long Island Sound (4.6%), with other regions making up less than 2%. Returns in 2005 were typical in that the Penobscot River population accounted for 75% of the total return. Overall, 24% of the adult returns to the USA were 1SW salmon and 76% were multi sea winter (MSW) salmon. From 1967–1985, the ratio of three-seawinter (3SW) salmon to 2SW fish averaged 2% and was as high as 7%. However, from 1986 to 2005 this average declined to 0.6% and the highest ratio was only 1.2%. Most (78%) returns have been hatchery smolt origin and the balance (22%) originated from fry or parr stocking and natural reproduction.

Return rates also provide an indicator of marine survival. The adult return rate (1SW plus 2SW) of hatchery smolts released in the Penobscot River in 2005 was 0.17%, with the 2SW fish return rate 0.12%. Smolt survival on the Penobscot River correlates well with other large restoration programs in the Connecticut and Merrimack rivers. Return rates for wild and naturally reared smolts on the Narraguagus River in recent years have mirrored those trends as well but in general are between five and ten fold higher.

Biological Reference Points

Biological reference points for Atlantic salmon vary from most other species assessed because they are managed in numbers not biomass and also because they are a protected species with limited fisheries targets. Fisheries targets (MSY, B_{MSY}, F_{MSY}, F_{Target}) have not been developed because current populations are so low relative even to sustainable conservation levels. A proxy for minimum biomass threshold for US Atlantic salmon would be Conservation Spawning Escapement since this provides the minimum population number needed to fully utilize available freshwater nursery habitat. This number is based on a single spawning cohort not the standing stock of all age groups. As such, a number for comparison to CSE would be estimated returns. Natural survival of Atlantic salmon in the marine environment is estimated to be 0.03/month resulting in an annul M of 0.36/year.

Summary

Historic Atlantic salmon abundance in New England probably exceeded 30,000 returns annually. Overfishing and habitat destruction resulted in a severely depressed US population restricted to Maine and by 1950 with adult returns of just a few hundred fish in a handful of rivers. Hatchery-based stock rebuilding occurred from 1970-1990 reaching a peak of 5,624 fish in 1986. A widespread collapse in Atlantic salmon abundance started around 1990. In the past decade, US salmon returns have averaged 1,600 fish and returns in 2005 were 1,320 fish. All stocks are at very low levels, only the Penobscot River population is at 10% or greater of its conservation spawning escapement. Most populations are still dependent on hatchery production and current marine survival regimes are compromising the long-term prospects of even these hatchery-supplemented populations.

Table 41.1. Recreational (reported in numbers), aquaculture production (thousand metric tons) and commercial (no fishery) landings of Atlantic salmon from Maine.

Category	1986-95 Average	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
U. S. Recreational (#)	314	-	-	-	-	-	-	-	-	-	-
U.S. Aquaculture	3.7	10.0	13.2	13.2	12.2	16.5	13.2	6.8	6.0	8.5	5.3
Commercial											
United States	-	-	-	-	-	-	-	-	-	-	-
Canada	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-
Total Nominal Catch	3.7	10.0	13.2	13.2	12.2	16.5	13.2	6.8	6.0	8.5	5.3

Table 41.2. Conservation spawning escapement requirements for US River populations and reported returns (with % of CSE) as determined by US Atlantic Salmon Assessment Committee (2006) and consolidated by DPS where possible. (* - composite of some GOM and CNE rivers).

DPS or Other Composite	CSE	Returns 2005 (%)
Long Island Sound DPS	10,094	165 (1.6)
Central New England DPS	2,599	26 (1.0)
Gulf of Maine DPS	8,402	766 (9.1)
Maine Restoration Rivers*	8,104	27 (0.3)
Total	29,199	984 (3.4)

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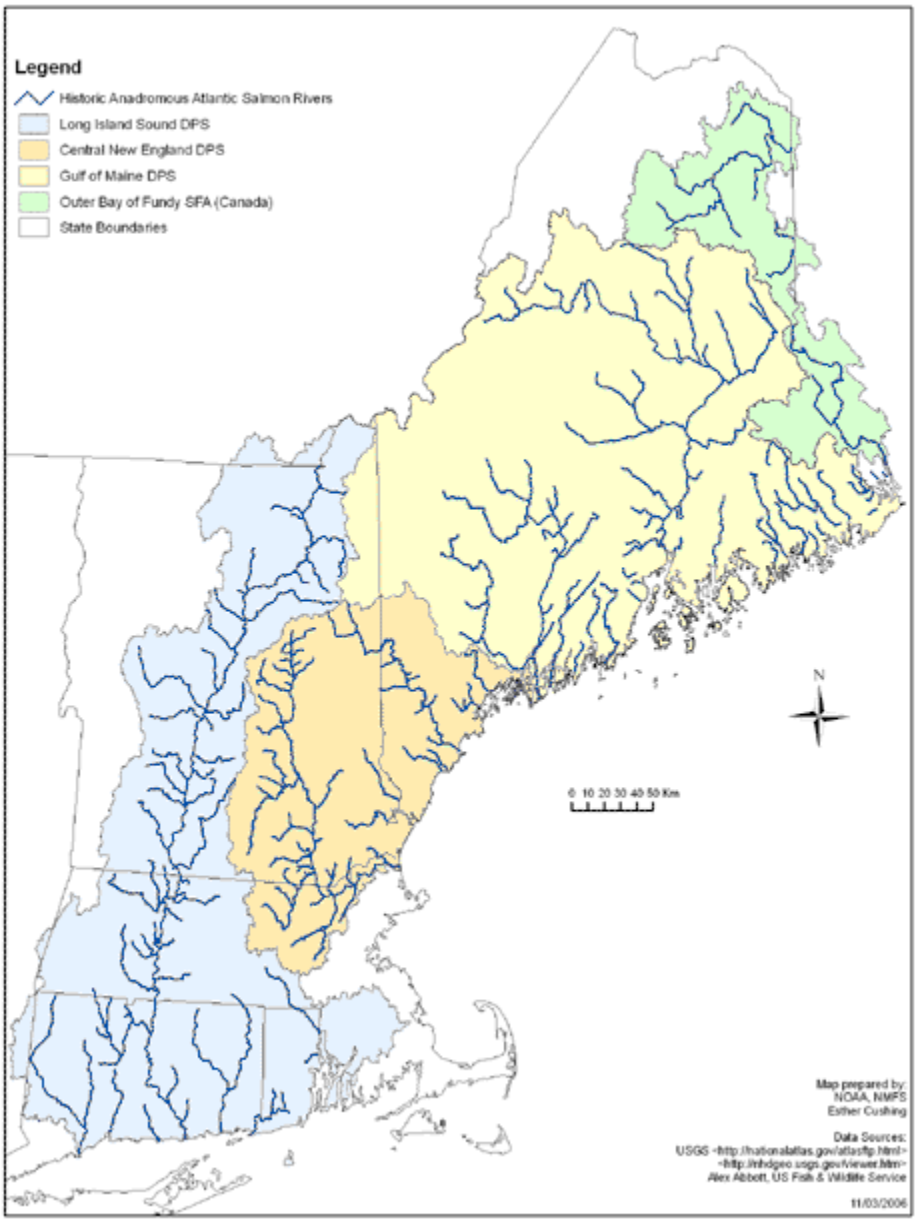

Figure 41.1 River systems used to define the Atlantic salmon stock areas.

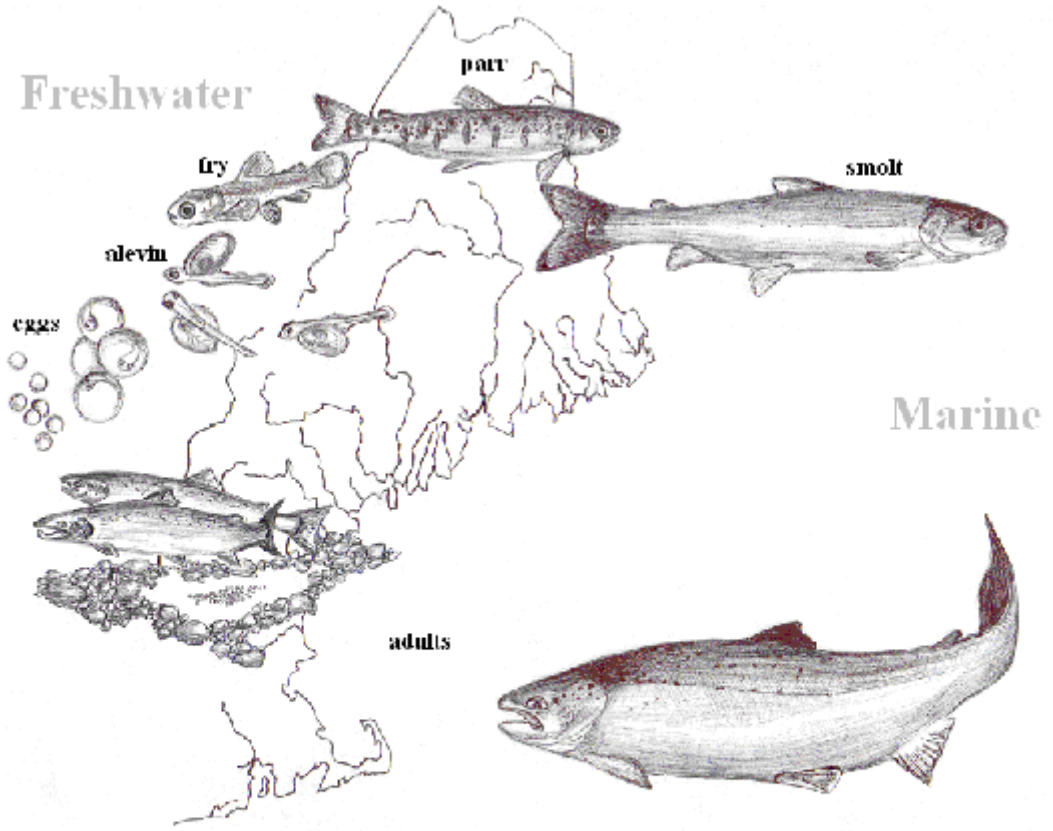

Figure 41.2 Life Cycle of the Atlantic salmon (*Salmo salar*).

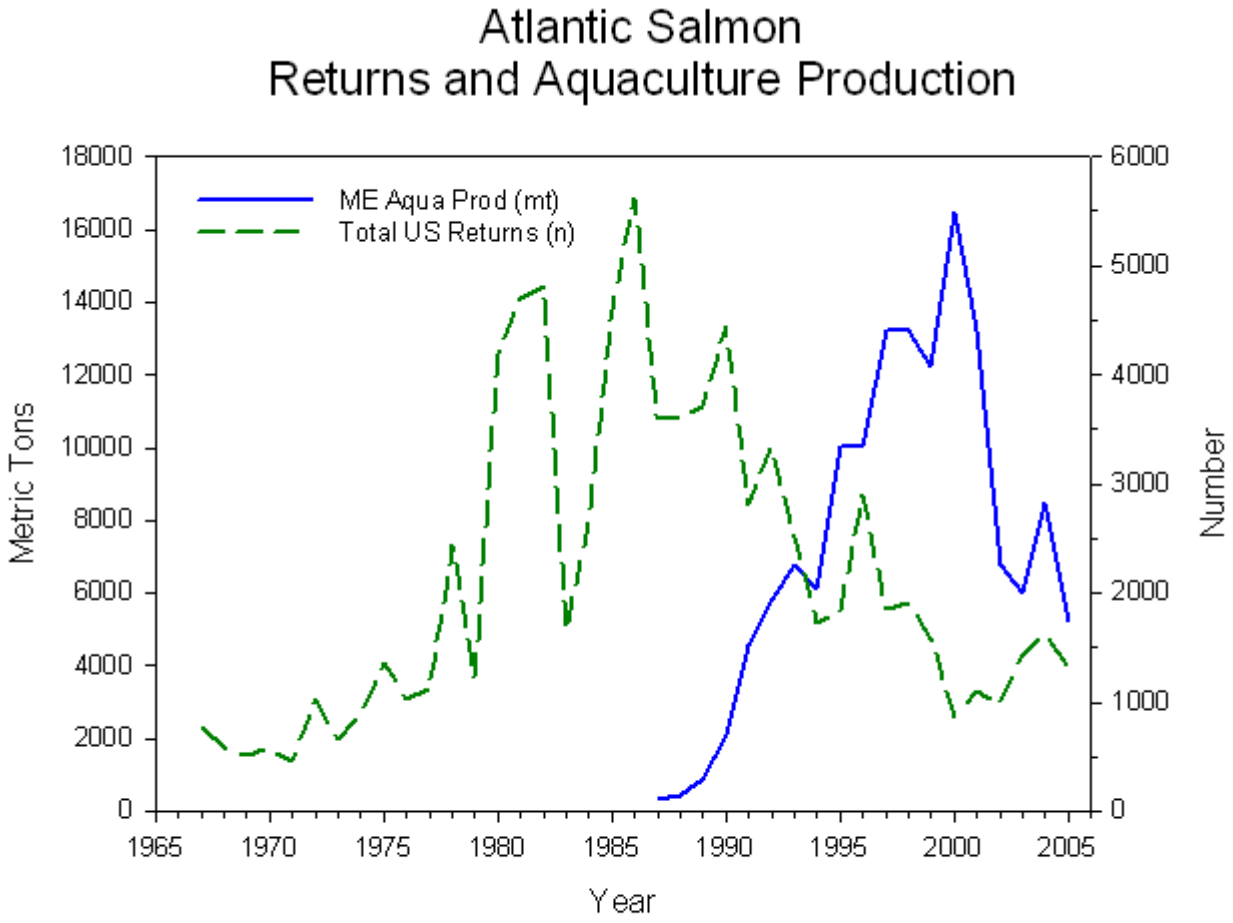

Figure 41.3. Time series of total US returns of Atlantic salmon (number of adults) and commercial aquaculture production in the eastern US (metric tons).

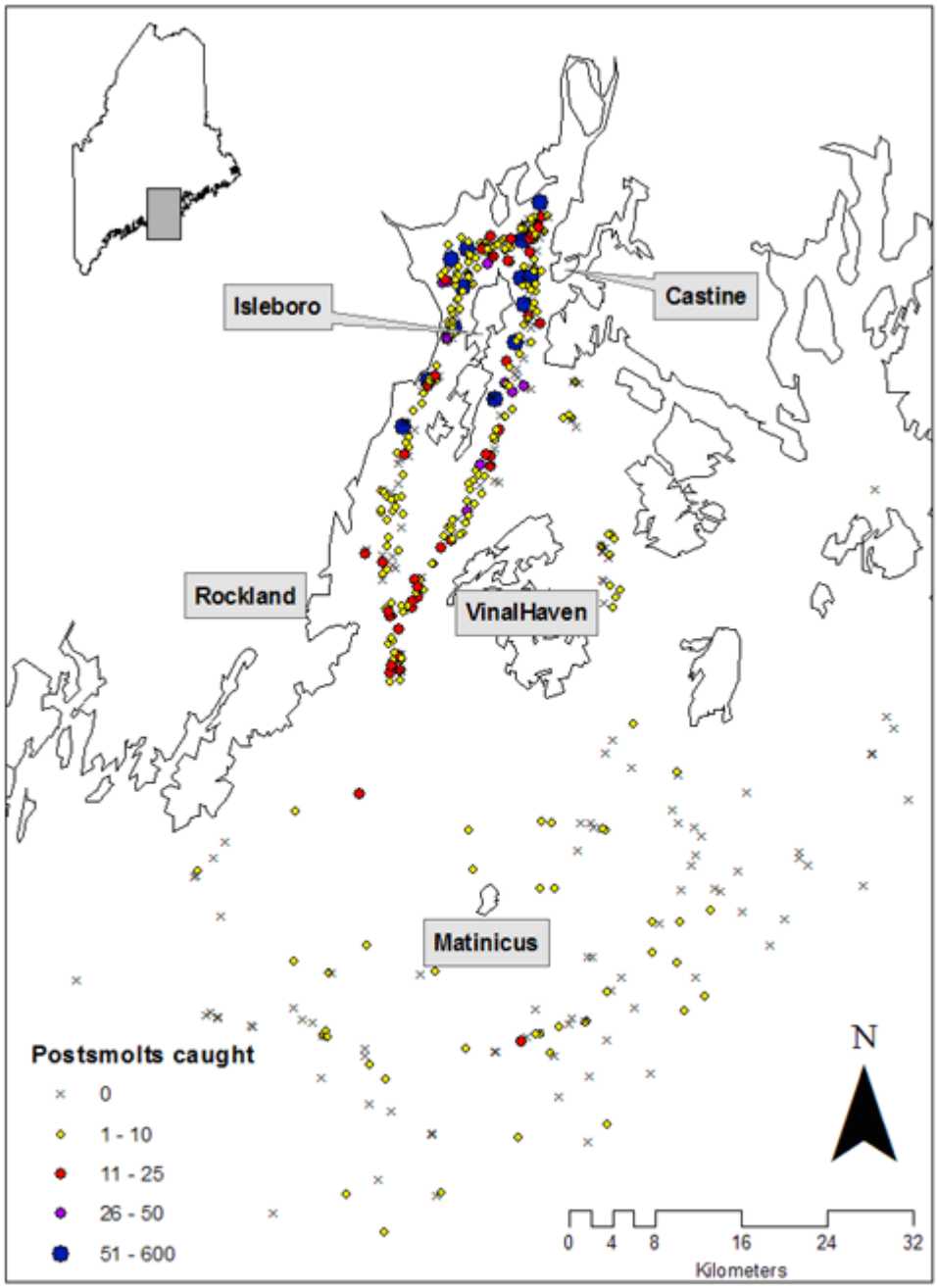

Figure 41.4 Postsmolt catches per station during the 2001-2005 Postsmolt Trawl surveys in Penobscot Bay, Maine.

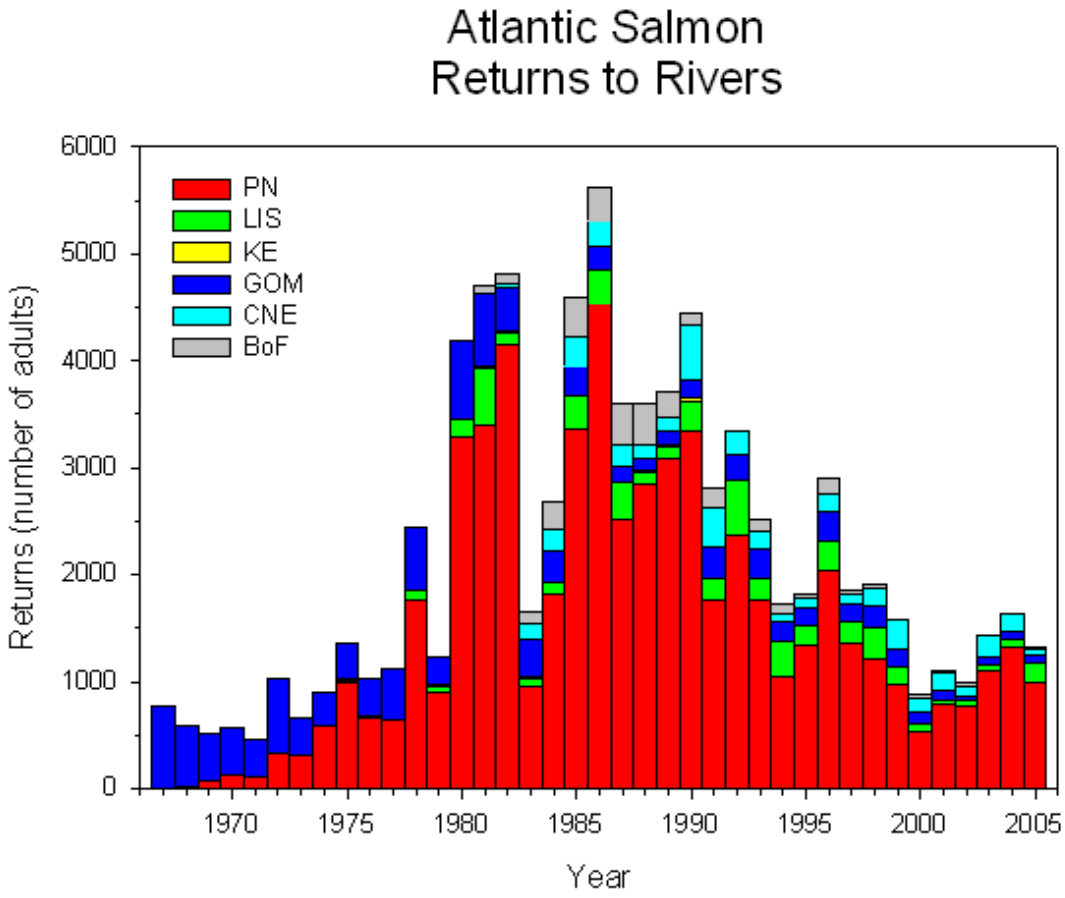

Figure 41.5. Time series of total US returns of Atlantic salmon (number of adults) for each distinct population segment and for larger rivers of Maine (Penobscot River–PN and Kennebec River-KN). Distinct population segments are: Bay of Fundy (BoF); Central New England (CNE), Gulf of Maine (GOM), and Long Island Sound (LIS).