RESTORATION OF THE ATLANTIC SALMON IN THE CONNECTICUT RIVER BASIN: A GLASS HALF FULL

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Introduction

On October 28, 1983 President Reagan signed Public Law 98-138.[1] It was the culmination of years of effort by the leading fisheries officials of Connecticut, Massachusetts, Vermont and New Hampshire. Since 1967, they had been working in concert with representatives of the U.S. Fish & Wildlife Service and the National Marine Fisheries Service as a Committee to restore anadromous fish species to the Connecticut River Basin. The Committee operated on a wholly voluntary, cooperative basis. Anadromous fish are those that spawn in fresh water and mature in salt. When they began, the flagship anadromous species of the Connecticut River was *Alosa sapidissima*, the American shad. This delicious large member of the herring family is the harbinger of spring along the eastern seaboard as far south as Florida. There had once been another even more prominent resident species: *Salmo salar*, the Atlantic salmon.

By 1983 the Committee could report substantial progress in restoring shad to their former habitat. Atlantic salmon restoration, however, was a challenge of a far different order. Whereas tens of thousands of shad frequented the Connecticut River in 1967 when the Committee began its work, there were absolutely no salmon whatsoever. They had been extirpated for almost one hundred fifty years. The Committee felt the need for a more formal and

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1 97 Stat. 866.

structured relationship to provide a long term legal foundation for its work. A binding agreement among the basin states was needed, as well as assurance of continued federal participation. The Committee negotiated and drafted the requisite legislation, and saw it passed in the four participating states. Their next stop was Washington. Compacts or agreements between two or more states require the consent of Congress.[2] The result was Public Law 98-138.

The federal statute expresses the consent of the United States to the compact negotiated by the Committee by and among Connecticut, Massachusetts, Vermont and New Hampshire. It assures federal participation, and incorporates the substance of the compact itself. At the outset is a simple statement of purpose:

> The purpose of this compact is to promote the restoration of anadromous Atlantic salmon...in the Connecticut River Basin by the development of a joint interstate program for stocking, protection, management, research and regulation. It is the purpose of this compact to restore Atlantic salmon to the Connecticut River in numbers as near as possible to their historical abundance.

Pursuit of this goal has been a task of extraordinary difficulty and complexity. Simply put, nothing like this has ever been successfully accomplished before.[3] The task is far from over.

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2 U.S. Const. art. I, § 10.

3 R. White, Hatchery versus Wild Salmon in S. Calabi and A. Stout, A Hard Look at Some Tough Issues (1994) [hereinafter cited as "HLSTI"] 90, 92-93.

I. <u>The Fish</u>

> We have an interest in Atlantic salmon that transcends the simple urgency of preventing the disappearance of a magnificent fish which has brought profit and pleasure to millions. If we act successfully to save the salmon and clean up rivers it has abandoned, we will be making it possible for other things to go on living too, and the life of each one of us will be enriched, even if we never ever see an Atlantic salmon. We now know only too well the price which will be exacted eventually if we continue the relentless confrontation with nature. When we see conditions restored in rivers which enable the salmon to return again, we will have reached a proper understanding of the earth's life support systems. Then there will be hope that man himself can survive.
>
> Phillip Lee, Editor,
> Atlantic Salmon Journal

Some time in mid-October a hen salmon, weighing about ten pounds after two winters at sea, turns into a small stream off a tributary of the main river. She had entered the river from the estuary over one hundred miles away in late June. Gradually, deliberately but without haste, she had worked her way upstream, through fishways, over rapids and around the wicked sandbars thrown up by an August drought. She had to avoid otters, murky still water impoundments that threatened to throw her off the scent, sport fishermen and the invisible monofilament nets of poachers. She had traveled mainly at night, resting in the deeper pools by day. She didn't eat once she entered the river, and the journey has sapped her strength.

She had hovered below the mouth of the small stream for about two weeks during an Indian summer warm spell. When that snapped, and when the chill October rains cooled and raised the water, she sensed that it was time. She knew that it was the place. Something in her memory had been triggered by the smell she had detected beyond the estuary, and with implacable determination she had followed it here. It was the place where she herself had been born over four years ago.

She studies the stream bed carefully, noting the stretches of smooth current and uniform gravel, about the size of ice cubes. She picks her place with deliberation and rolls on her side, flapping her tail repeatedly against the bottom to loosen and dislodge the gravel. It is not an easy task, this construction of a redd, or nest, for her eggs. She may work it and fuss with the symmetry for several hours, even over a day or two, to get it right. She wants a depth of about six inches. She also wants larger stones in particular positions at the bottom, about three, to form a rough frame in which she can brace her body when she's ready.[4] When she's satisfied with her work, she moves into position to deposit. A male fish of her class, watching carefully, rushes to her side to quickly fertilize the eggs in a cloud of milt. The hen fish then moves upstream of the redd, and again flaps her tail repeatedly on the bottom. The purpose now is to dislodge more gravel so that it will drift down with the current to

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[4] G. Anderson, Atlantic Salmon and the Fly Fisherman 23 (1985).

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April 21, 1997

Professor Robert Behnke
Department of Fish and Wildlife Biology
Colorado State University
Fort Collins, Colorado 80523

Dear Professor Behnke:

Thanks for your recent note.

I am returning a somewhat cleaned-up version of my paper. Also please find a copy of the book which got me started on this, A Hard Look at Some Tough Issues. This is a collection of papers given at the New England Atlantic Salmon Management Conference in Danvers, Massachusetts, April 22-23, 1994, edited by Silvio Calabi and Andrew Stout. I hope you find it interesting. I read the recent issue of Trout with great interest!

Sincerely,

Richard G. Bell

RGB/cs
Enclosures

the redd, and cover it, protecting the eggs. Thus her first spawning is complete. But she's not finished; she will go on in the same way to build up to five or perhaps even seven more redds in the same manner. She carried about seven thousand five hundred eggs upstream, and laying these in multiple deposits is one of nature's ways of trying to compensate the salmon for the enormous odds it faces. Multiple redds reduce the risks of imperfect fertilization, loss by flood and depredation by marauding predators. When she is finally done, she will be exhausted, and will slide back to a deep pool in the tributary to rest. She may not die, as all her pacific cousins - male and female - will. She may defy extraordinary odds and return to the sea to repeat the long journey to the north Atlantic feeding grounds next winter, and return again in the spring. But many cannot, and will not, survive the spawning.

Most of the eggs will be covered by the protective gravel, although some will drift downstream immediately, or will be dislodged by winter floods. There are always hungry trout or other takers for these. Others fall to predators or disease. In late April or May, most of those left will hatch, and tiny creatures about a half inch in length will wriggle forth. They are called "alevin". They carry the residual egg attached at the stomach as a yoke sac, and this sac will be their sole food supply for the next several weeks. During this period, they will stay hidden in the gravel. With the consumption of the sac, the fish will emerge and must learn to forage on their own. They will then be known as "fry", miniature specimens of the species, feeding on microorganisms in the stream.

In a few short weeks, the fry start another transformation. It is one to the "parr" stage. The little fish will darken on the back, and this darkness washes in lines down the sides in characteristic parr "marks", among newly emerging bright black and red speckles. They grow slowly, and will reach a length of five to six inches. They look very much like young wild brown trout. Parr are voracious feeders, often trying to swallow creatures fully half their size. They are proficient athletes as well, capable of leaping about three feet in the air after flying insects. They are also prime targets for a host of predators: fish, mammals and, perhaps the deadliest of all, fowl. Kingfishers and American merganser ducks make their living off parr. It has been estimated that a single merganser, which eats one-third of its body weight each day, will consume 1,584 parr in a single year on a good salmon river.[5] One predator species they need not fear is their own kind. The adult salmon moving upstream to spawn are programmed not to feed in fresh water, another risk reduction factor which protects the species.

In the spring there comes another summons of nature's clock. Some parr begin to drift downstream and lengthen slightly, losing their color and turning first whitish and finally silver until they are transformed into "smolts". They will enter the estuary in

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[5] J. Anthony, The Significance of Predation on Atlantic Salmon in HLSTI 240, 245.

great numbers, and there they will stay for a short time as their body chemistry and buoyancy adjust to the salt water. There are new dangers here they have not seen before, for seals, striped bass and cormorants - perhaps the deadliest birds of all - have learned of this cycle over the years and are waiting. But again nature has helped against these odds. Only a portion of a given year class are two year parr and have "smolted" in this year; some of the class will come down the river as smolts next year, and some the year after that. The parr that transform into smolts in a given year are of mixed hatch year classes.[6] In this way, the risks of the passage are diluted, and the chances for some of the birth class to survive are enhanced.

Once acclimated to salt water, the young smolts, now gleaming silver in ocean camouflage, start a six thousand mile odyssey not yet fully understood. Smolts leave the estuary in large groups. They will travel in this manner for the remainder of the year. After that, dispersal occurs. At times, they will mingle with stocks from other North American rivers; at times they travel alone or in small numbers. While still smolts, the Connecticut fish will appear in the Bay of Fundy and off the south shore of Nova Scotia by July of their first summer. In August, they will appear off the eastern coast of Newfoundland. During the late summer and fall, as

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[6] G. Anderson, supra at 14.

they make the transition to mature salmon, they will appear in the Labrador Sea.[7]

Most of the Connecticut fish will spend two winters at sea.[8] A few, however, will return to spawn after only one winter at sea. This is not a different stage; these are fully mature fish. They are called "grilse" and are distinguished from multi-sea winter fish by their size, about four pounds upon return, and by the fact that their caudal fins, or tails, are slightly forked. Fish returning after two winters at sea will, by comparison, average about ten pounds, and have heavy, almost square tails. Some river systems have high percentages of grilse returns.[9]

Where Connecticut salmon will over-winter in their first year at sea is unclear; possibly in the area of the Grand Banks.[10] In their second year at sea, they will push into the northwest Atlantic. Their range is governed generally by water temperature. The ideal feeding grounds are characterized by a temperature range of 4°C to 8°C. This can be plotted geographically as a defined area in the north and northwestern Atlantic. Only recently, it has been determined that the area fluctuates considerably in size over short periods of time. It was thought to be relatively large in the 1970's. In 1984, it was observed to shrink dramatically to

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7 K. Friedland, Marine Survival of Restoration Stocks in HLSTI 223, 224.

8 Id. at 229.

9 G. Anderson, supra at 6, 16.

10 Friedland, supra at 225.

about five hundred and twenty thousand square miles. It increased slightly thereafter, but in the early 1990's, it was again in significant decline.[11] The variability of this ocean habitat may be a significant factor in ocean mortality. If so, it may be particularly affected by the consequences of global warming. The most recent decline in the size of the range is thought to be the result of a cooling of the North Atlantic caused by a melting of the polar ice cap, a global warming phenomenon.[12]

There is an area of significant winter concentration of salmon in the Davis Strait, which separates Canada's Baffin Island and Greenland. Salmon from North America and Europe come here to feed in large numbers. This was first ascertained in 1958, but it was not until 1965 that commercial fishermen sought to exploit it in ernest.[13] A second common feeding ground for salmon was subsequently discovered off the Faroe Islands, involving mostly European and Icelandic stocks. Thus deep sea fishing has only recently became a significant mortality factor.

Commercial fishing is not the only hazard faced by salmon at sea. After passing through the smolt stage, the good news is that they have outgrown some predators. The bad news is that they have become even more attractive to others. Seals head the list. In an era where the salmon is under enormous pressure even to survive, these large, clever predators have enjoyed a significant population

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[11] Id. at 233.

[12] P. Lee, Home Pool 62, 203 (1996).

[13] Id. at 25, 34.

increase. Grey seals, the most injurious to salmon, are reported to have increased in the UK from a total herd of thirty-five thousand in 1960 to over one hundred thousand by 1990. Similarly, the population of harbor seals off the northeastern United States has more than doubled in ten years.[14] Seals are particularly damaging to salmon, not just because of their direct toll, but also because they compete for the salmon's favorite prey, capelin and sand eels. These small fish, populating the northeastern seas in once unbelievable numbers, have also recently been discovered by commercial fishing interests.

At the end of the second winter, nature's clock again calls the salmon. The survivors are now powerful, silver specimens of eight to fifteen pounds. They are possessed of incredible strength, speed and endurance, with the athleticism to leap falls or other obstructions up to ten feet in height, characteristics that make them the ultimate quarry for sport anglers. They will need all of these attributes to complete the long journey home to spawn. How they navigate over distances of over two thousand miles is unclear. One suggestion is a genetic response to population specific pheromone trails left by migrating smolts. Other possibilities include reliance on the sun, stars and electrical impulses from the earth's gravitational field.[15] The fact is, we don't know, but return they will with great precision. By the late

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[14] Anthony, supra at 250-254.

[15] L. Hansen, Farmed Atlantic Salmon - Interactions with Wild Fish in HLSTI 72, 75-76; Lee, supra at 25.

spring of this year, they will enter the estuary, and pause for a period of acclimatization from salt water back to fresh.

It is impossible to be precise about the statistics of survival. However, there have been enough data accumulated from many years of tagging in North American rivers to support a profile: of the seven thousand five hundred eggs deposited by the hen fish we met earlier, four thousand five hundred eggs will hatch; six hundred fifty will reach the fry stage; two hundred will become parr; fifty will complete the downstream migration as smolts; four will return.[16]

II. The River

> ...everything that liveth, which moveth, whithersoever the rivers shall come, shall live: and there shall be a very great multitude of fish, because these waters shall come thither: for they shall be healed; and everything shall live whither the river cometh.
>
> Ezekiel 47: 9.

Adriaen Block was a tough Dutch sailor, not easily discouraged. Ocean voyages held no terrors for him, and he looked forward to the long journey home. Why shouldn't he? His ship was loaded with rich furs from the inland forest, which would fetch top prices on the Amsterdam Exchange and make him a very wealthy man. However, as he waited on the tide in the Mauritius (later "Hudson") River off the island called Manhattes, disaster struck. His ship Tiger burned to the waterline and her cargo was lost. Block could

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[16] G. Anderson, supra at 25.

have called it quits in the new world and sailed home on a companion ship. He chose, however, to try to mend his fortunes. He thought there might be profit in exploring the body of water which extended eastward. He and his crew hunkered down in crude cabins they constructed on the banks of the river to lay over for the winter. There was no settlement yet, and they were among the first Europeans to do so in this wilderness. When at last the ice broke, he was ready with a new vessel he had built, Onrust, or Restless. She was much smaller than her predecessor, less than fifty feet in length, but she would do for coastal waters. So it was that he set about his purpose, and on a bright spring day in 1614 discovered a large estuary on the north shore of Long Island Sound.[17] Block put it down on his chart as "Van De Versche Rivier", for "Fresh River". The indians called it "Quinatucquet".[18]

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17 Block performed great service exploring Long Island Sound and, in fact, first identifying Long Island as an island. His explorations were the basis of the first Dutch maps of the approaches to what is now New York harbor. However, it would be another 19 years before the Dutch opened a trading post on the Connecticut River, on the west bank where Hartford now stands. One of his discoveries, Block Island, is named for him and appears on some early Dutch maps as "Adriaen's Island". He also initiated the settlement of Greenwich, Connecticut and found time to go Salmon fishing in the Thames River. Livermore, History of Block Island, 9, 11 (1961); F. Blanchard, Long Island Sound 3, 4 (1958); W. Bixby, Connecticut: A New Guide 29, 134 (1974). Charred ship timbers believed to be from Tiger can be seen at the Marine Gallery of the Museum of the City of New York.

18 W. Hard, The Connecticut 5 (1947); W. Cross, Connecticut 319 (1938).

Block sailed upstream, the first European to do so. Rounding the bend at what is now Middletown he saw an indian fort and went ashore to investigate. This was a strong point built by a tribe called the Senquins as a point of defense against marauding Pequots. Block's intentions were overtly friendly, and were accepted as such by his hosts. Gifts were exchanged, and that evening Block and his officers were treated to a feast featuring the firm, pink flesh of Atlantic salmon, fresh from the river.[19]

The Connecticut River originates just below the Quebec border, in New Hampshire's Fourth Connecticut Lake. It is at elevation one thousand six hundred eighteen feet. It is the principal drainage of New England, with a watershed basin of eleven thousand two hundred sixty-five square miles in New Hampshire, Vermont, Massachusetts and Connecticut. It traverses varied typography on its four hundred and six mile journey south to Long Island Sound. In northern New Hampshire, it cuts through rugged mountainous country and then flows through steep ravines as it separates the states of New Hampshire and Vermont. It turns pastoral in Massachusetts, with wide fertile bottomland on either side. This continues in Connecticut's central valley, once extensively devoted to growing leaf tobacco in the rich, riverine soil. The river turns generally southeast at Middletown, Connecticut, and meanders through gently rolling country to its mouth at Old Saybrook. In all, some sixty percent of the drainage is forested; some twenty

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[19] Hard, supra at 28. Others have referred to these indians as the "Podunks" or "Nawaas". Bixby, supra at 29.

percent farm land; the balance is highly developed for residential and/or commercial/industrial use. The river is fortunate in that, unlike many salmon rivers in Maine and Canada, there is no large industrial development acting as a barrier at its mouth.

Some twenty-four major tributaries join along the river's route to the sea. Tributaries are all important to the salmon, for the fish do not spawn in the main stem of the river. They use it as a highway to home, to upper reaches of the large tributaries and the smaller streams feeding into these. Six of these important tributaries are rated as of "primary" importance for the purposes of salmon restoration: in Vermont they are the White and West Rivers, in New Hampshire the Ammonoosic and Cold; in Massachusetts the Deerfield and Westfield; in Connecticut the Farmington and the Salmon. The Farmington is a substantial sub-system in itself: the river is seventy-five miles long, and it drains six hundred nine square miles. Three other important tributaries are rated as "secondary" ones for the purpose of salmon restoration, and some of the remainder are thought to have future promise.[20]

If there is a weakness in the Connecticut basin from the salmon's perspective, leaving aside the effects of post-colonial human activity, it is simply geographic. The Atlantic salmon is a cool water fish. Ideal parr growing temperatures are around 16°C. The ideal north Atlantic feeding grounds range from 4°C to 8°C. Spawning occurs at a slightly lower threshold. While it has a

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20 Technical Committee for Fisheries Management of the Connecticut River Basin, Connecticut River Atlantic Salmon Restoration Program (1971).

greater range of thermal tolerance than, say, Salvelinus fontinalis, the eastern brook trout, temperatures in excess of 22°C (or 70° Fahrenheit), even for a short time while migrating upstream, became increasingly stressful, while fatal limits are reached between 27°C or 30°C.[21] The Connecticut River is at the southern end of the salmon's historic range.[22] Summer temperatures in the southern portions of the basin may approach dangerous levels. This requires careful adaptation for the salmon. At this end of its range, it must be able to adjust to and take advantage of acceptable thermal windows for mainstream river entry and transit, as well as, in the smolt stage, for the purposes of downstream migration. The timing of these events at the extreme boundary of acceptable temperature is a complex and critical matter, one of the many specific genetic characteristics which was once unique to Connecticut River salmon stocks. One can also imagine the additional hazards, and the additional need for adaptive strategies, presented by the mere fact of extreme distance from the North Atlantic feeding grounds. Not only is the journey that much longer, harder and complicated, but the exposure to predators is both more prolonged and infinitely more complex. Connecticut salmon will face completely different and changing arrays of prey and predator relationships. All of this compounds

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[21] Lee, supra at 63.

[22] A. Meister, Atlantic Salmon Restoration in New England in HLSTI at 307, 308. An added problem associated with being at the Southern extremity of the range is the vulnerability of the river to general global warning trends. Lee, supra at 63.

the risks to survival. Specific mechanisms to deal with or minimize these risks evolved, over thousands of years, genetically encoded in Connecticut river stocks.

It is probably folklore that you could walk across small Connecticut streams on the backs of salmon in colonial times, or that farmhands insisted upon limiting the meals of salmon they could be fed to not more than a specific number per week.[23] But salmon originally frequented all of the significant rivers along the Connecticut coast, and the early Dutch settlers noted their presence even further south around New Netherland.[24] Salmon were

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[23] Chapman, New England Village Life 28 (1937). Salmon were found down the coast to and including what is now Greater New York. An early Dutch report of the natural history of New Netherland noted that "Salmon existed in some places." The author also discussed shad, so the difference was appreciated. His description of New Netherland, which ran as far south as the Delaware River, expressly excluded Van De Versche Rivier - the Connecticut - for interesting reasons. It was noted as "...yet another good location and navigable water course.... But as the river and the adjacent country had been widely invaded and are still held by the English nation, to the great detriment of the Honorable West India Company and at a loss of thousands every year, it would only distress us to review this matter..." A. Van Der Donck, A Description of New Netherland 23, 72 (1656), translated for the New York Historical Society by D. Goedhuys. It should be noted that Atlantic Salmon probe the extremes of their range as well as the areas around their natal rivers within the range. This "rate of strays" is about 2% of the returning fish, which suggests that they can rapidly colonize new adjacent watersheds, given favorable environmental conditions. C. Carlson, The Insignificance of Atlantic Salmon in Federal Archeology 23, 28 (Fall/Winter 1996).

[24] C. Carlson, The Insignificance of Atlantic Salmon in Federal Archeology 24, 25 (Fall/Winter 1996). Ms. Carlson, an assistant professor of archeology at University College of the Cariboo, Kamloops, British Columbia, specializes in ichtho-zooarcheology and

established throughout the entire Connecticut basin in all four states. They were caught as far upstream as Beecher's Falls, Vermont, on the Quebec border over four hundred miles from the mouth of the river.[25] They probably never achieved the colossal

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historical archeology. In her paper she argues that the absence of salmon bones in New England archeological digs indicates that Salmon were not a major, but only a minor, resource. She does not dispute their presence, so we are left with a question of how much is a lot. In some ways, it is a puzzling conclusion, especially to the extent it is based on Maine excavations given what is known of the early Maine runs, traces of which remain. Estimates of these are as much as 500,000 fish in the aggregate. E. Baum, Evolution of the Atlantic Salmon Restoration Program in Maine in HLSTI 36. However, her comparative base is the Pacific Northwest, and surely the runs even in Canada, much less New England, never equalled the incredible numbers there. For instance, in the Kvichak River, in modern times, 42,000,000 Sockeye salmon could be observed. (Letter to the author from Professor Robert Behnke, Fishery and Wildlife Biology, Colorado State University, February 25, 1997.) Runs quite modest by Pacific standards might still be quite substantial on the Atlantic coast. Resolution of this is beyond the scope of this paper, but it must be that some might insight would be gained in turning the question around to ascertain the basis of the dependence of Northwest aborigines on salmon. Ms. Carlson's caution regarding the vulnerability of Salmon at the extremity of their range is well taken.

25 Delaney, The Connecticut River 88, 89 (1983); T. Meyers, The Program to Restore Atlantic Salmon in the Connecticut River in HLSTI 11, 12. Meyers notes that "Historical accounts reference large numbers of Salmon and their significant use by aborigines and early settlers". Id. at 12. It may be that both the fish and the numbers were large. As noted above, most Connecticut returning fish have spent at least 2 winters at sea. It is likely that substantial numbers of 3 winter or more fish were present in the 18th century. Justus Riley was an enterprising Wethersfield, Connecticut merchant, selling everything from rum to raincoats to the area townspeople, as well as to passing Connecticut River sloops such as Dove, Dolphin, Nancy and Black Joke. Fresh salmon were included in his inventory. The firm's account book for the spring of 1783 notes 26 transactions into early June

runs of their Pacific cousins, but the Connecticut watershed's capacity for salmon is enormous, and runs of up to forty thousand fish would be a conservative figure. By about 1820, they were all gone.

The man made threats to a species like the Atlantic salmon are, generally, habitat degradation, over fishing, pollution and denial of access to spawning grounds, which is to say, dams. All made their contribution, and took their toll on the Connecticut. They were harvested with abandon by early settlers. Salmon require especially pure water and are very intolerant of pollution and of disruption of the stream bed. Their habitat was extensively damaged by thoughtless farming and forestry practices as well as by the traditional kinds of industrial pollution with which we are only too familiar.[26] But of all factors, by far the most prolific

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acquiring 205 salmon for resale weighing in the aggregate 4,712 pounds, or an average of 22.9 pounds per fish (one entry of 2 fish excluded as illegible). Justus Riley & Co., Account of Salmon Bought, April 12, 1783, WHS Manuscript Coll. Book 19 [Courtesy of Wethersfield Historical Society]. G. Anderson speculates that the Connecticut "...may have been the most prolific Salmon river in North America". G. Anderson, supra at 212. P. Lee suggests that it "...was once one of North America's best Salmon rivers". Lee, supra at 31. See, for a general discussion of salmon in New England rivers including, in Connecticut, the Thames, Connecticut, Hammonassett, Quinnipiac and Housatonic, United States Commissioner of Fish and Fisheries, Report of the Commissioner for 1872 and 1873, Part II (1874).

26 A. Bielak and R. Angus, Pollution and Salmon: What's the Problem? in HLSTI 200, 202. A good summation of the effects of early pollution appears in D. Howard, A New History of Old Windsor (1935). The author recounts a description of early fishing by a gentleman from Windsor, Connecticut described as "the town's best informed authority" on the subject (then 82 years of age): "He

and efficient killers were the dams which obstructed transit up tributaries and eventually on the main stem of the river itself. A report of the Connecticut Fish Commissioners in 1870 summarizes this fact in the case of the sixteen foot high dam erected across the main stem of the Connecticut at Turner's Falls, Massachusetts. This is about one hundred miles from Long Island Sound. The dam, completed in 1798, was the first to span the entire river:

> The fish ascended the river as far north as the dam, and the first year were taken there in great numbers, while vainly trying to find passage up the stream. The following year they were still plenty, and then they began rapidly to decrease in numbers...at the end of a dozen years, they had nearly all disappeared, and have never been seen since.[27]

In 1967, when the restoration effort got underway, there were seven hundred barrier dams in the watershed.[28]

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attributes the great decline in the number of fish now caught in the Farmington and other streams flowing into the Connecticut River to the sewage and factory pollution that it rendered the streams unfit for the propagation and growth of young fish. He recalls the time when a wagon load of shad and salmon in about equal numbers could be taken by two men in a single day...." at 234 [Courtesy Windsor Historical Society].

27 R. Jones, Restoration: The Early Days in HLSTI 3, 4 quoting from W. Hudson, et al., Fourth Report of the Commissioners of Fisheries of the State of Connecticut (1870).

28 Meyers, supra at 13.

III. The Restoration Effort

...an organization established on little more than a handshake...

Robert A. Jones, Chief
Bureau of Fisheries and Wildlife
Connecticut Department of
Environmental Protection (Retired);
Commissioner, Connecticut River
Atlantic Salmon Commission

The current restoration effort was preceded by an even one hundred years. In 1867, the fisheries commissioners of the four basin states joined to try and reintroduce salmon to the Connecticut River. The effort, quite ahead of its time, utilized mostly Penobscot River (Maine) stocks. The proponents could indeed induce salmon to return but they lacked the ability to control commercial fishing and the technology to solve the problems of fish passage and fish rearing. The attempt fizzled out in the 1870's.[29]

The current effort finds its genesis in landmark environmental legislation in 1965. On October 30 of that year, the Anadromous Fish Conservation Act became law.[30] Enlightened leadership in the Kennedy and Johnson administrations, especially Secretary of the Interior Stewart Udall and his understaff of the U.S. Fish & Wildlife Service, felt a growing concern for the depletion of valuable anadromous fish populations. This statute was an effort to encourage a broad approach to reverse the decline by authorizing the Secretary of the Interior to enter into cooperative agreements with one or more states. These, in turn, would generate projects

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[29] Jones, supra at 4.

[30] P.L. 89-304; 79 Stat. 1125.

involving stream clearance, spawning bed protection, hatchery production and fish passage. This statute, and its companions which provided funding support, brought the full resources of the Federal Department of the Interior into play as a partner with state conservation agencies. Included in the grouping of anadromous fish were Great Lakes fish which moved upstream into tributaries of those waters to spawn, such as trout and recently stocked Pacific coho salmon.

According to the Senate Commerce Committee Report, the major concern was for the "drastic reduction" of these fisheries resources, due to pollution, loss of habitant as well as dams and similar barriers:

> In the absence of effective action, growing competition for water resources may cause fish populations, especially anadromous fish populations, to decline so far that rehabilitation will not be possible. The valuable migratory fish resources must be given a higher priority among the varied uses of the nation's water supply.[31]

Secretary of the Interior Stewart Udall specifically referred to the plight of Atlantic Salmon in his supporting letter to the Chairman of the House Committee. He stated:

> Almost every New England stream now has one or more dams. No passage facilities for upstream-migrating Atlantic Salmon were provided in the early dams, and even in relatively recent years such facilities when provided have not been adequate. Under such circumstances, the present results were

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31 Senate Commerce Committee Report No. 860.

> inevitable. The great numbers of Atlantic Salmon were eliminated from most streams. Now only Maine has a few thousand adults ascending its many extra excellent streams each year. In other states to the south, dams and pollution combined effectively to destroy this resource.[32]

As if to frame some of the hardest challenges ahead in the Connecticut watershed, the Federal Power Commission[33] waded in with a letter to the Committee taking careful note to preserve its private turf but generally supporting the legislation. In this letter, the Commission recited the licensing mechanisms applicable to the Connecticut River main stem dams:

> The Licensee shall, for the conservation and development of fish and wildlife resources, construct, maintain, and operate, or arrange for the construction, maintenance and operation of such facilities and comply with such reasonable modifications of the project structures and operation as may be ordered by the Commission upon its own motion or upon the recommendation of the Secretary of the Interior or the fish and wildlife agency or agencies of any State in which the project or a part thereof is located, after notice and opportunity for hearing <u>and upon findings based on substantial evidence that such facilities and modifications are necessary and desirable</u>, reasonably consistent with the primary purpose of the project, and consistent with the provisions of the Act. (Emphasis added).[34]

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32 Letter from Stewart Udall, Secretary of the Interior, to the Honorable Herbert C. Bonner, Chairman, Committee on Merchant Marine and Fisheries, June 1, 1965.

33 Its successor agency is the Federal Energy Regulatory Commission ("FREC"), 42 U.S.C. § 7172 <u>et seq</u>.

34 Federal Power Commission Report on H.R. 23, H.R. 800 and H.R. 3927, 89th Congress, Joseph C. Swindell, Chairman.

In response to the Act, the chiefs of the fisheries sections of the conservation agencies of Connecticut, Massachusetts, Vermont and New Hampshire, in concert with federal representatives from the U.S. Fish & Wildlife Service (Department of the Interior) and the National Marine Fisheries Services (Department of Commerce) began discussions regarding implementation in the Connecticut River basin. These discussions lead to a gentlemen's agreement to support an anadromous fish program on a voluntary, cooperative basis. Thus the Connecticut River Fisheries Management Committee was formed in 1967. The Committee was aided by a technical committee of senior biologists from each of the state departments. The function of the technical committee was to achieve scientific consensus on particular issues, most importantly the design and implementation of necessary research initiatives, and the recommendations of sound fisheries practices.[35]

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[35] Jones, supra at 5. The fates of shad and salmon have been closely intertwined along the Connecticut. Delaney, supra at 89, 90. It is reported that they were marketed together in early times, customers being required to buy the salmon that were caught along the shad, the price of one pound of salmon being equal to that of one whole shad. J. Hayden, <u>Windsor Locks: Is Early Settlers and Their Successors</u>, 55 (1880). It is noted that shad as an article of diet is not discussed in the Windsor, Connecticut records before to 1720, leading the observer to conclude that it was a late arrival to the river, and that "so late as 1785, the salmon were more numerous that the shad". J. Stoughton, <u>Windsor Frames</u> 114 (1883) [<u>Courtesy Windsor Historical Society</u>]. Another explanation of this is as follows: "Up until about 1,740, any shad caught in the nets along with the salmon were thrown back by the fishermen. Until that time, Shad were despised and considered a poor man's fish. by the time of the revolution, shad had become accepted and were being caught along with salmon, salted down and shipped

The primary purpose of the Committee was to restore American shad to their historical spawning area. A secondary goal was to restore Atlantic salmon to "some portion" of their historical range.[36] With respect to shad, the dominant issue was river passage. Shad were still plentiful in the Connecticut River and could access some spawning areas. Restoration to their original spawning area really meant a coordinated drive to provide fish passages at the several main stem river dams, as well as certain significant tributary dams. Salmon, however, the secondary target of the Committee, presented a far different problem. There were no salmon, so any restoration at all had to begin with the conception of a plan for the reintroduction of the species. The major challenge here was the fact that the Connecticut River salmon gene pool had disappeared.

The significance of this was only just beginning to become apparent. It was in 1972 that the first accepted definition of a "stock" of a fish species came into common usage. A stock is,

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by the thousands of barrels from the East Haddam landings to our troops fighting the British." K. Stofko, Remarks on the History of Commercial Fishing in East Haddam During the Eighteenth Century (1982) [Courtesy East Haddam Historical society]. See, also, D. Field, Statistical Account of the County of Middlesex (1819): "Within the memory of persons living, there was very little demand for salmon, and as for shad it was disreputable to eat them. But as this prejudice gradually died away, and as profitable markets for fish were opened, fishing became an important business thirty or forty years ago, and has continued so ever since." Id at 10 [Courtesy of The Middlesex County, Connecticut, Historical society.]

36 Jones, supra,. at 5.

generally, a group of a species of fish spawning in a particular stream or (in the case of a large river) a portion of it, which do not interbreed with other groups of that species.[37] In other words, the Connecticut River Atlantic salmon, while congeneric or of the same species as Atlantic salmon from the Penobscot in Maine or the Restigouche on the Gaspé, historically bred only among themselves and created a river-specific gene pool of adaptations specialized to the conditions of the Connecticut River basin. Similarly, other Atlantic salmon from all of the rivers around the North Atlantic constitute a wide range of river-specific stocks.

The process of introducing salmon in the Connecticut got underway somewhat before the stock concept became widely accepted and understood. Given the total absence of mature fish, it was a program that started literally from ground zero. The first eggs were procured from a variety of Canadian sources, and were reared at a federal hatchery on the White River in Vermont. The first release was of five thousand parr in the Cold River in New Hampshire in 1967. The early releases were largely experimental, with much to learn not only about the rearing of fish from eggs but about release strategies and survival rates. Early releases included fry, parr and smolts. Early on, it was determined that parr were not preferred for stocking purposes.[38]

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[37] White, supra at 90, 97-98. The Miramichi River in New Brunswick, a large system, has a dozen distinct genetic stocks and many substocks. Lee, supra at 21.

[38] Meyers, supra at 16.

The smolt and fry stocking programs proceeded in tandem for several years, with full capacity for smolts, approaching two hundred thousand, achieved by the White River and Kensington (Connecticut) hatcheries in 1990. Later, smolt stocking was discontinued for economic reasons, and fry stocking became the stage of choice. For 1997, the program will nurture about ten million eggs derived from its own brood stock, and will release between seven and ten million fry.[39]

Beginning in 1974, with the full impact of stock genetics becoming widely understood and accepted in professional fisheries circles, the priority became to establish a Connecticut-specific gene pool. Efforts were made to obtain eggs from stocks with attributes similar to those believed to be relevant to the Connecticut system, such as the Penobscot River in Maine. In 1976, the first returned Connecticut River salmon, a male, to survive until spawning was used to fertilize forty thousand eggs from a Penobscot female.[40]

The returns from the early stockings from Canadian eggs were very thin. Between 1966 and 1977, only thirteen fish returned.

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39 Figures supplied through courtesy Stephen R. Gephard, Senior Fisheries Biologist, Connecticut Department of Environmental Protection.

40 Jones, supra at 8, 9. Salmon returning to North America from the Davis Strait face a basic decision as they round Newfoundland towards Cape Breton Island: a right turn into the Gulf of St. Lawrence or a left along the coast of Nova Scotia towards the Gulf of Maine. To the extent such decisions are genetically triggered, fish derived from Maine stocks would be preferable to Canadian for the purposes of the Connecticut restoration program.

But the 1976 smolt releases of Maine origin proved different. In 1978, ninety salmon from these releases returned. Of these, seventy-nine were taken from traps at the Holyoke and Rainbow Dams to the Berkshire National Fish Hatchery at Great Barrington, Massachusetts to be the base, it was hoped, of a new gene pool.[41] This was an agonizing experience for the Committee, for they had still much to learn about the handling and transport, and the subsequent holding, of these mature wild fish, each of about ten pounds. Sadly, all but two died of stress or disease before spawning. But two did live to spawn, and it was the general feeling of the Committee that the future of the Salmon Restoration Program rested in the offspring of these two fish. The stocking program would now be based on the inheritable characteristics of sea-grown salmon coming back to the Connecticut, with special efforts directed at holding and attaining multiple spawning years from returning fish. After trial and error, it was determined over time that a returning female salmon could be kept to spawn for three to five additional years. Moreover, the first generation from these fish could also be kept to spawn in multiple years after maturity, without ocean exposure. Eventually, these first generation fish came to be the most important source of eggs for the restoration program. New holding facilities were constructed for the maintenance of these fish, and having determined to use

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41 Id. at 9.

substantially all of the natural rearing habitat available, the concentration on fry releases increased.[42]

Originally, it was feared that the general pollution level of the river and a number of its tributaries would be a major problem. However, the momentum of the national environmental movement mooted this question. Such was the effect of the Clean Water Act,[43] and the popular support given this cause throughout New England, that it could be said early in the program that water quality was not a limiting factor.[44] Some loose ends did remain on the main river at Springfield and on the Chicopee in Massachusetts, one of its tributaries. In addition, new pollution questions were raised, as power development advanced. The advent of nuclear power plants involved the discharge of high temperature thermal effluent; what would be the effect of this to temperature sensitive returning salmon? A five year research study was initiated by the Committee which showed this to be a minimal deterrent.[45]

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42 Meyers, supra at 19. Stocked parr have demonstrated lower long term survival rates then stocked fry. Similarly, stocked smolts have a lower survival rate than wild or wild-raised smolts. The conclusion the obvious one that the earliest introduction to the natural environment is best.

43 33 U.S.C. § 1251 et seq. Similarly, the Clean Air Act, 42 U.S.C. § 2172 et seq., has substantially reduced acid rain depredations. It came too late for many salmon, and the problem still persists. See Windsor, supra at 176-177, Jones, Rain Check in Adirondack Life 48 (April 1977).

44 Bielak and Angus, supra at 203.

45 Jones, supra at 6.

Early in this century, a network of investor owned electric power companies built or assumed operation of some thirty-two hydro-electric facilities in the basin.[46] Five of these were main stem dams deemed critical by the Committee for fish passage. All had been licensed for fifty years by the Federal Power Commission, and four of these five licenses were coming up for renewal in the 1970's. These main stem dams were as follows:

Name	Miles From the Sea	Height	Owner
Holyoke (MA)	86	30 feet	Holyoke Power Company
Turners Falls (MA)	122	36 feet	Western Mass. Electric Co.
Vernon (VT-NH)	142	35 feet	New England Power Co.
Bellows Falls (VT-NH)	173	32 feet	New England Power Co.
Wilder (VT-NH)	217	61 feet	New England Power Co.

The licensing language provided that the licensee would be subject to construct fish passage facilities provided that the Federal Power Commission (or its successor, the Federal Energy Resource Commission) could find, after public hearing, on the basis of "substantial evidence", that these facilities were "necessary and desirable".[47] Relicensing is not the only occasion where modifications might be pressed; indeed, the improvements subsequently made at Holyoke were on the basis of negotiation outside of the relicensing process. Nonetheless, such an occasion

[46] M. Anderson, Connecticut River Upstream & Downstream Fish Passage Facilities in HLSTI 151, 152.

[47] n. 34, supra; Jones, supra at 7.

was an opportune one for presenting the case and the Committee took up the task with respect to the other four dams. By cajoling, marshalling public support and occasionally table pounding, the Committee reached accommodation with the owners on, as it turned out, all five main stem dams.[48] In doing so, it called freely upon the resources of the U.S. Fish & Wildlife Service for specific technical assistance and for presentation of detailed facility construction proposals to be thrashed out with utility company engineers. Much design progress had been made in the 1950's to the 1970's with respect to the technology of fish passage. The critical importance of entrance locations and attraction flow was understood and incorporated in these new designs, as were sophisticated elements relating to the control of velocity and turbulence in the carefully measured step pools of the fish transit structures.[49] Issues of stream flow regulation were also important. While the Connecticut River, on average, has an abundant flow of water, hydropower generation can create occasional extreme lows in the main flow which must be compensated for during periods of peak migration.[50] That these negotiations were difficult should surprise no one. These were private investor owned companies on the other side of table, accountable for their own bottom lines and

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48 Jones, supra at 7.

49 M. Anderson, supra at 152; Jones, supra at 7.

50 High water flows of 150,000 C.F.S. are normal in the Connecticut, but they may reach peak levels of 250,000 C.F.S. The historic mean at Thompsonville, reflecting 94% of the watershed, in 16,600 C.F.S.; the lowest recorded is 968 C.F.S. Meyers, supra at 15.

with legal obligations to stockholders.[51] That they cooperated as well as they did is a credit to their corporate citizenship. They can be forgiven if they acted like businessmen and:

> ...would like to understand the behavior of the fish before they made major commitments in funds.[52]

A special word of thanks is due <u>Alosa sapidissma</u>, the good old American shad. If the case rested on the salmon alone during this fish passage-relicensing process, it would not have gone unnoticed by the hard-eyed utility engineers that there were none in the river; they hadn't been seen near any of these dams in one hundred and fifty years. It is highly unlikely that the public interest standard of "necessary and desirable" could have been met. It was in fact met on the basis of the presence of large numbers of migrating shad for whom these passages were equally useful and important.

It was probably during this process that the Committee's salmon dye was cast. Public imagination for salmon restoration was gaining a force and public favor never evidenced in the case of shad. In the public imagination, the salmon became a symbol for pure, clean watersheds. In fact, the achievement of the Committee's primary goal, restoration of shad to its original

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51 It has been estimated that the cost of these upstream facilities was "about %55 million". M. Anderson, supra at 154.

52 HLSTI at 170.

spawning area, was accomplished almost without public notice when the fish ladder was completed at Bellow's Falls in 1982.[53]

The construction (or rehabilitation) of upstream passage facilities on the main stem dams was accomplished as follows:[54]

Name	Mile	Upstream Completion	First Salmon Passage
Holyoke (MA)	86	early 1970's	1975
Turners Falls (MA)	122	1980	1980
Vernon (VT-NH)	142	1981	1981
Bellows Falls (VT-NH)	173	1982	1985
Wilder (VT-NH)	217	1987	1987

Much can be seen of the determination of the spawning run in these statistics. While the first salmon to reach Bellows Falls and traverse its new fish ladder was a full ten years after the clearance at Holyoke, it was hard on the heels of the opening of passage at the intervening Vernon and Turner's Falls dams. The first salmon passed through Turner's Falls in 1980, but in 1981, nine more did so. Of the nine, eight also passed Vernon. They may well have kept on going had the facilities upstream been ready. But when they were, the experience at Wilder was the most telling of the salmon's urgency to crown these efforts with success. The fish that christened the fifty-nine foot high Wilder dam fishway, two hundred eighteen miles from the sea, did so within one hour of

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[53] Jones, supra at 8.

[54] M. Anderson, supra at 152-154.

its opening in 1987.[55] With this passage, eighty-eight percent of the river's main stem waters were now cleared. Although there are further dams upriver, there seems little reason to develop further fish passage until the number of returning fish increases substantially.

Simultaneously, efforts were pursued on the major tributaries. Rainbow Dam on the Farmington River in Connecticut is owned by The Stanley Works, international manufacturer of tools and building equipment. The dam was the source of that company's auxiliary power for its New Britain, Connecticut manufacturing operations. It had been cleared in 1976. It was the company that first proposed a three way split of the costs involved in this effort, dividing the charges between itself, the state and the federal government.[56] Leesville Dam on the Salmon River, also in Connecticut, is owned by the Connecticut Department of Environmental Protection. Clearance at Leesville followed in 1981, and efforts continued on other major tributaries, beginning with the Deerfield and Westfield Rivers in Massachusetts, and on up the watershed.[57]

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55 Id. at 154.

56 Jones, supra at 8. The allocation was U.S. Fish & Wildlife Service $375,000; The Stanley Works $200,000; Connecticut DEP $175,000. The fish ladder at Rainbow Dam is 720 feet long, with a 57 foot lift. Capacity is 20,000 shad and 5,000 salmon per year. Connecticut Department of Environmental Protection, Bulletin, Vol. 3 No. 2 (1975).

57 Jones, supra at 5, 9. The first dam on the Salmon River at Leesville, Connecticut, was built around 1765. It interrupted the run of salmon up that tributary, and led

When the first salmon in almost two hundred years entered Vermont's White River in 1985, the Committee could say that its initial goal for salmon restoration - that of restoring salmon to "some portion" of its historical range, had been completed. Anticipating this, it had ambitiously restated its goal in 1982 to be "...provide and maintain a sport fishery..." and to ...restore and maintain a spawning population in selected tributaries..."[58] By this time, the Committee had come to recognize the need for a more formal coordinating body to deal with the increasingly complex interstate matters on its agenda. It decided to transform its gentlemen's agreement into a binding contract by and among the four basin states. The Committee negotiated and drafted this legislation, and successfully steered a four state agreement past four governors and four state legislatures. Because "compacts" by and among two or more states require the consent of Congress, the Committee undertook that task as well, calling in a long time friend and supporter of the restoration effort, Congressman Silvio Conte (D. Mass.) for consultation and guidance. Conte, a member of the House Appropriations Committee, and a dedicated fisherman/conservationist, had been in a position to be of

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the rapid demise of an active commercial salmon fishery at the junction of the Salmon and Connecticut Rivers. Stofko, supra.

58 The restated goal was ambitious: 19,265 adult salmon entering the river every year; 7,470 from natural reproduction and 11,795 from hatchery releases. The numbers are expected to produce a sport harvest of 4,000 fish and a spawning population of 5,570 fish. Jones, supra at 5.

substantial help to the restoration effort, and contributed further by sheparding the compact through Congress. The consent legislation, Public Law 98-138, was signed into law on October 28, 1983. It established the Connecticut River Atlantic Salmon Commission.[59]

The Commission is charged with the purpose of restoring Atlantic salmon to the Connecticut "...in numbers as near as possible to their historical abundance". It calls for the joint development by the four participating states of a program for stocking, protection, management, research and regulation. The Commission was enlarged from its Committee predecessor, with each state now having two representatives. One of these is the executive officer of the state fisheries and natural resource agency (e.g., in Connecticut, the Commissioner of the Department of Environmental Protection) and the second a private citizen with "...a knowledge and interest in Atlantic salmon" appointed by the Governor. The Secretary of the Interior and the Secretary of Commerce also participate as members. A technical committee was established, paralleling the one previously serving the Committee on a voluntary basis. Thus, the essential management structure closely follows the one created on a handshake sixteen years earlier. The technical committee consists of a fisheries biologist from each of the four states together with scientists from U.S. Fish & Wildlife Service and the National Marine Fisheries Service.

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[59] 97 Stat. 866.

The technical committee was given specific authority to call in other expert opinion on any matter necessary.

The Commission may "make inquiry" and ascertain methods for bringing about the restoration; it may "recommend" legislation. It may also "recommend" to the state management and agencies research initiatives, practices and procedures, but with the heads of these agencies on the Commission, this really confirmed a coordinated four state administrative program. The Commission also has the authority to regulate and license main stem fishing. Connecticut and Massachusetts specifically agree to provide brood stock from the Farmington and Holyoke passage facilities. The Commission has the clout of combined and focused state resources, and of key federal agency participation. Its composition permits a totally integrated and coordinated program at the state agency level. Its ultimate regulating and licensing power is potentially significant. It appears to be well designed for its task, and very efficiently builds upon and retains the best attributes of the old Committee structure. It has a twenty year life, from October 28, 1983.

The work of restoration proceeded through the transition from the Committee to the Commission without losing a step. Of immediate concern was the completion of upstream passages on the five targeted main stem dams, accomplished in 1987 at Wilder. Simultaneously, the Committee needed to address downstream passage. This issue had been deferred with the consent of the Federal Power Commission at the four relicensing proceedings. Now, with the stocking of fry proceeding in high numbers, it was appropriate to deal with downstream passage as expeditiously as possible.[60] Consultations, meetings, design presentations and revisions all followed at multiple sites. The problem with downstream passage - finding a safe way around power generating turbines - is that it is surprisingly less precise than the other way around. Larry Stolte of the U.S. Fish & Wildlife Service, put it this way in 1994:

> "We don't yet know the techniques that need to be put in place to safely pass our fish by some of these hydro dams. We're looking at a lot of alternatives. I think that's why we're in the state we are in. People push us against the wall and say "You're not doing this fast enough!" Well, we don't know exactly what to do; a lot of things have been thrown on the table.[61]

On the basis of many studies of smolts and fry at specific locations, downstream accommodations were gradually made on all of the main stem dams and completed by 1993.[62] They will be subject to continual study and no doubt will require substantial refinement. Work on the tributaries, as in the case of upstream passage, has been substantial and is continuous.

Returns of salmon through 1996 are summarized below.[63] The figures represent counts from Holyoke dam, Rainbow (beginning in

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[60] Jones, supra at 8.

[61] HLSTI at 51.

[62] M. Anderson, supra at 154-156.

[63] The return figures were furnished through the courtesy of Stephen R. Gephard, Supervising Fisheries Biologist, Connecticut Department of Environmental Protection by letter to the author, February 24, 1997.

1976), Leesville (1981) and Westfield (1982), together with a small number of angler and miscellaneous entries. It is not a perfect process, and the error, while quite small, is on the side of understatement.

1967-73	0	1985	310
1974	1	1986	318
1975	3	1987	353
1976	2	1988	95
1977	7	1989	109
1978	90	1990	263
1979	58	1991	203
1980	175	1992	489
1981	529	1993	199
1982	70	1994	326
1983	39	1995	189
1984	92	1996	260

The first few years show an agonizing start. The year 1978, however, was one of great satisfaction. The quantum leap to ninety fish was heralded as providing the foundation for future broodstock. Three short years afterwards, the remarkable total of five hundred twenty-nine fish was recorded, bringing a sense of jubilation and a bad case of overconfidence. The fact is that the 1981 total has never yet been equalled, and the immediate and precipitous fall-off in 1982, 1983 and 1984 showed just how long and how hard the journey was going to be. What accounts for such volatility in the numbers from one year to the next? Given the high degree of professionalism achieved in the program, and the extent of stocking and habitat availability, why can't the low ceilings be raised? These questions are posed against the backdrop of recent sharp declines in wild salmon stocks in Maine, in Canada and all around the Atlantic.[64] Are some things occurring in the ocean - far beyond the control of the Commission - which are decisive? These are not easy questions to answer.

IV. The Wine Dark Sea

> Who hears the fishes when they cry? It will not be forgotten by some memory that we were contemporaries.
>
> Henry David Thoreau

North American salmon stocks have been fished on the high seas since the mid-1960's. Before this time, while offshore fishing along the coasts and in the river estuaries had long been practiced, the salmon's routes at sea were largely unknown. As the growing human population put increasing pressures on ocean fishing, spurred on by expansive technologies, the veil of protective mystery began to unravel. A major step was made in 1965 in the Davis Strait between Greenland and Canada. Two Greenlander fishing boats drift netted over ten thousand salmon on a single cruise, a figure that would double or more for many subsequent years.[65] New monofilament nets, extending over twelve miles in length, could take enormous numbers of migrating fish. In 1971, the total catch

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64 O. Vigfusson, Saving the Atlantic Salmon in HLSTI 180, 181. It should be noted that while salmon have been around for about 10,000 years, we have reliable statistics dating only from about 1960. M. Windsor in HLSTI 198.

65 J. Bates, Jr., Atlantic Salmon Flies & Fishing 18 (1970).

in the Davis Strait was seven hundred fifty thousand salmon.[66] Long lines, with miles of baited hooks, came into play, particularly off the Faroe Islands, where another major congregating location for feeding salmon was discovered in the early 1970's.[67] Radar and better navigational aids, together with fish finding sonar, played their part. Also important was the development of service ship and refrigeration capacity, which has enabled protein-starved nations to extend their fishing ranges around the world. At the peak of commercial fishing for Atlantic salmon, over two million were being taken per year.[68]

It is easy to see how particular river stocks can be disproportionately damaged by indiscriminate ocean fishing. When concentrated at a particular feeding ground, or traveling in groups on a particular route pattern, a stock may be particularly vulnerable to a given catch or series of catches. It is though all of the troops in a military unit, the Twentieth Maine, for instance, were hometown boys from the same locale and sustained heavy casualties in a particular battle.

Estimates of river-specific losses to ocean fisheries are imperfect. However, tagging evidence suggests that the Connecticut stocks, while traversing the Davis Strait, were less damaged there than in the offshore Canadian fishery. This, in Newfoundland and

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66 Lee, supra at 34.

67 Id. at 25.

68 Id. at 206.

Labrador, was believed to have taken between one and two out of every three ocean ranging Connecticut fish.[69]

Salmon, of course, are not the only species to feel the effect of deep sea fishing technologies. Ocean catches generally since 1965 have increased from about five million tonnes to over eighty million tonnes.[70] There is hardly a significant food species in the world that is not under extreme pressure and some have been forced close to extinction. The northern cod of the Grand Banks is a good example. This species has been reduced to less than three percent of its former spawning capacity. A moratorium was imposed in 1992 but whether it will have any effect remains to be seen.[71]

Human appetite has also led to species hitherto ignored. A new process of biomass fishing, using huge trawlers or fine mesh seine, is designed to catch and kill everything, regardless of species, in its path. It is all edible in the last analysis, or at least commercially useable. The byproducts can be used for fertilizer or pet food and, ironically, farm fish food. Some small fish are very attractive in some markets. Lowly capelin and sand eels once roamed the shores of the North Atlantic in unimaginable numbers. They are a prime food supply for both cod and salmon. They have now become the targets of this new technology, both as

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[69] Meyers, supra at 20.

[70] Lee, supra at 47.

[71] Id.

human food and, in the case of the oily fleshed capelin, as fuel for electric power generating plans.[72]

The great losses of salmon to ocean fishing are only a small part of the global problem. What the case of a species like the capelin illustrates is that we are, as Philip Lee has said, "eating our way down the food chain." When a primary species is seriously damaged and we turn on its food supply, we practically eliminate the possibility of managed restoration. In the best of circumstances, obtaining international consensus on the regulation of such fishing problems is inordinately slow and extremely difficult. Technology, meanwhile, does not hesitate. The newest ocean trawling devices have a mouth big enough to ingest, in one bite, six Boeing 747 jet liners stacked in two piles of six.[73]

The beginnings of the international movement to control ocean fishing for salmon were in 1978. An Atlantic Salmon Symposium was convened in Edinburgh, Scotland under the sponsorship of Scotland's Atlantic Salmon Trust and the North American Atlantic Salmon Federation. The Federation is comprised primarily of sport fishermen-conservationists, effectively uniting both Canadian and U.S. interests in a powerful and well connected salmon advocacy and support movement. The symposium focused on ocean fishing, calling for an international ban beyond the traditional twelve mile limit; it also called for further conservation, regulation, enforcement and scientific cooperation among the nations bordering the North

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[72] Id. at 59-62.

[73] Id. at 47.

Atlantic. The United States government was brought into the circle and, by 1979, the State Department had a treaty drafted establishing control mechanisms. For two years, this document circulated in draft form among the foreign offices in Brussels, Ottawa, Oslow and Copenhagen. By 1983, substantial agreement had been reached and State could advise that between March and October of that year, the Convention for the Conservation of Salmon in the North Atlantic Ocean would be open for signature in Reykjavik, Iceland. The final signatory nations were, in addition to the United States, Canada, Denmark (on behalf of its territories Greenland and the Faroe Islands), Finland, Iceland, the European Community, Norway, Russia and Sweden.[74]

Under the terms of this convention, or international treaty, the North Atlantic Salmon Conservation Organization ("NASCO") was formed with the mission of the:

> "...conservation, restoration, enhancement and rational management of salmon stocks in the North Atlantic ocean."

Three sub-commissions deal with the specific issue of catch limits for three major Atlantic regions: North America, Northeast, West Greenland. These commissions can act only on the basis of unanimous consent. Recognizing that the sensitive decisions of NASCO require the most solid scientific footing, the organization was authorized to engage such expert counsel as it felt necessary.

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[74] Convention for the Conservation of Salmon in the North Atlantic Ocean (1982), T.I.A.S. No. 10,789.

The International Council For Exploration of the Seas ("ICES"), the oldest scientific advisory body in marine science, of Woods Hole, Massachusetts, is NASCO's primary scientific adviser.[75] In 1985, an office for the minimal executive staff was established in Edinburgh, and NASCO was open for business.

The treaty gave NASCO the immediate impetus of success by effecting a ban on all ocean fishing in the North Atlantic beyond the twelve mile territorial limit, with only two exceptions. Directly affected by this ban, and not included in the exceptions, was the Northern Norway Fishery, utilized by Norway, Denmark, Sweden, Finland and Germany. The annual catch at this fishery was approximately nine hundred tonnes per year. Thus, immediate conservation gains were realized upon its closure. The exceptions to the ban were the fisheries in the Davis Strait off West Greenland and those in the Faroe Islands. The former is of most concern to North American stocks. By 1995, after years of patient negotiation by and within NASCO, the Greenland and Faroe quotas have been set and reset. The West Greenland quota, originally two thousand seven hundred tonnes, was reduced to two hundred thirteen tonnes and, in 1995, to seventy-seven tonnes. The Faroe Island quota, originally one thousand tonnes was reduced by 1995 to five hundred tonnes.[76] These two fisheries are so-called "interceptory" fisheries, where ships under the flags of seafaring nations

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[75] Windsor, International Cooperation Through the North Atlantic Salmon Conservation Organization, in HLSTI 174, 178; A. Peterson in HLSTI at 179.

[76] Lee, supra at 188.

intercept stocks eventually travelling to the home waters of other nations. Greenlander fishermen intercept North American and European stocks off West Greenland; the Faroese intercept European stocks, including Russian, Norwegian and those of the U.K. There are many other interceptory instances; most notable for our purpose is the Canadian (Labrador) interception of U.S. stocks in its offshore fishery. NASCO has attempted to mitigate these instances wherever possible with some successes. Norway, for instance, banned all drift netting inside its twelve mile limit in 1990.[77]

The reduction of commercial fishing in Canada preceded NASCO. However, Canada has long enjoyed the commercial value-and occasionally suffered the burden - of the salmon as a tourist attraction. For years, affluent sportsmen from around the world convened on the fabled Miramichi, or the Gaspé Rivers, or the North Shore. Large numbers would be Americans, not a few owning choice properties on salmon waters in Canada. Like tourists everywhere on a healthy budget, these visitors would buy supplies, equipment and licenses; they would stay at lodges, motels or private guest camps, all of which employed large local staffs. They would eat and drink with gusto. They would engage guides, require transport and seek collateral diversions and entertainments. This pumps a lot of money into the local economies. Canada's calculation is that the economics of sport fishing for salmon generate eight jobs for

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[77] Id.

Canadians for every one job generated by commercial fishing.[78] Accordingly, a serendipitous conjunction of good economics and good conservation gave the Canadian government the political will to reduce commercial netting in the face of declining river stocks. It deserves great credit. It was not an easy thing to take jobs away from rural fishermen, for whom there are few other options. Beginning in 1971, the Canadian government has bought out and retired more than five thousand two hundred Atlantic commercial fishing licenses. It has closed permanently or imposed a multi-year moratorium on all commercial fishing in the Atlantic provinces, except in Labrador and two small locations in Quebec. The multi-year moratorium applied to Newfoundland in 1992, for a five year period. The Quebec open areas are small, one on the lower end of the North Shore of the St. Lawrence, and the other at the extreme northerly range of the salmon at Ungava Bay. These two exceptions are based on the near total economic dependence of the

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[78] A. Eno, Can We Afford to Wait? in HLSTI 325, 332. "I think there's a growing recognition of the fact that the economic benefits of the recreational fisheries exceed those associated with the commercial fishery." M. Rochon in HLSTI at 197. The sport fishing catch has historically been a small fraction of the Canadian commercial catch. So great has the commercial reduction been in Canada, that these lines first crossed in the eastern provinces in 1993. Rochon, supra at 187. Iceland is a model for salmon management. It banned salmon netting at sea off its shores in 1932 in favor of the cultivation and preservation of its far more valuable sport fishing. Lee, supra at 195.

remote local economies, which is essentially the same justification held out for Labrador.[79]

In Canada, that leaves only the Labrador fishery of some two hundred nets intercepting U.S. salmon stocks at the present time. What is the residual impact of this? In the 1970's, Canada's total commercial catch was more than seven hundred fifty thousand salmon. Of the commercial catch, one Canadian authority has estimated that only some two thousand were of U.S. origin. That figure may be arguable. The historical dimensions of the Labrador catch were on the order of two thousand one hundred tonnes of fish, or five hundred ninety thousand salmon at its height; this has been reduced under present circumstances to approximately one hundred seven tonnes or thirty thousand fish. The argument is that U.S. interception should be negligible from this residual Labrador fishery.[80] So fragile, however, are U.S. wild stocks that the recommendation of ICES to NASCO is to close the Labrador fishery altogether. This has not been politically possible.

In the view of Orri Vigfusson, a dynamic Icelander and committed Atlantic salmon fisherman-conservationist, any quota, no matter how low, is excessive. Alarmed at the continual drop in wild salmon stocks throughout the North Atlantic, Vigfusson formed the North Atlantic Salmon Fund in 1989 with a view to buying out

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[79] M. Rochon, Canadian Management Measures to Reduce the Commercial Atlantic Salmon Fishery in HLSTI 180, 188-189.

[80] Id. at 189.

the West Greenland and Faroese fisheries.[81] He raised funds in both Europe and North American for these purposes. In 1991, the Fund acquired the Faroese quota at about 27% of the estimated land value, or approximately $650,000. This has been renewed each succeeding year. In 1993, a two year deal with the Greenland home rule government was made to buy up the West Greenland fishery for about $400,000.[82] This was to last two years, with provisions for three additional years of extension, subject to annual agreement. It failed, however, in 1995 and fishing returned to about a seventy tonne catch. Einar Lemke, a Greenlander spokesman to NASCO, described it this way:

> Though we may from time to time refrain from utilizing our family silver, we are certainly not going to sell it.[83]

The Greenlanders do not accept ICES' statistics or predictions of the salmon's demise. They see catchable fish in the Davis Strait, which is all the livelihood many of them have known. Besides, this business of buying quotas is not a conservation device: it is merely a shifting of the locus of the catch from Greenlander fishermen to affluent American and Canadian sport fishermen. One can argue that, to the extent that assertion is true, sportfishing in North America has an intrinsicly higher value in terms of

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81 Lee, supra at 204.

82 The totals were North America $1.2 million; Europe $2.8 million. Lee, supra at 205, 206.

83 Lee, supra at 208.

contribution to local economies. Moreover, it is far easier to regulate the taking, which can be specific on a river by river basis, something that cannot be done at sea.

Notwithstanding great gains in addressing ocean fishing depletion, the stocks of wild salmon have continued to decline. The ICES' models suggest a need for a minimum of 200,000 large salmon from North American rivers wintering in the North Atlantic for the purposes of sustaining a viable population. In the late 1960's, that population figure was estimated to be a substantial 850,000 fish. In 1995, it was estimated at approximately 150,000.[84]

V. Down on the Farm

> "In our arrogation of control - in putting most of our eggs in the expedient techno-politico basket of artificial propagation - it is we, not the fish, who have been revealed as wasteful and inefficient and, contrary to the traditional assumptions of fish culturists, nature has been revealed as having ecologic and genetic efficiencies that we cannot match with technology.
>
> Ray J. White
> Consulting Fisheries Biologist

In 1979, the first home grown North American farm salmon went to market. They were raised in the Bay of Fundy. Salmon farming, already well underway in Norway, Scotland and Ireland, had come to North America. From approximately thirty thousand tonnes of

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[84] Id. at 22.

product at the beginning, the industry was producing around three hundred thousand tonnes less than ten years later.[85]

It seems like an ideal solution. The commercial threat to the Atlantic salmon can be nullified and our appetites satiated by bringing farm fish to market. There are also efficiencies in the employment of indigenous labor forces for these purposes. Moreover, farm salmon can be harvested throughout the year, not just in the spring on a seasonal basis. The industry has become very efficient and has demonstrated the ability to survive significant price reductions which were created in the first place by its own production successes. What's wrong with all of this? It should be a very good thing for the salmon. Shouldn't it?

The farming of salmon is in a familiar tradition. The fish are raised from the egg stage and kept in tanks or pens all of their lives. There may be one or more transfers between pens at various stages of their life. The last, after the salmon has reached the smolt stage, will characteristically be to wire mesh pens in a salt water estuary. Here they will be fed and grow as a group to market size.

A variation on this practice is that of salmon "ranching", whereby the smolts are altogether released from captivity and permitted to go wild to sea.[86] Their exposure to their rearing site waters through the smolt stage has been sufficient to imprint

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[85] G. Friars, Genetic Aspects of Sea Ranching and Aquaculture in HLSTI 56, 59; Lee, supra at 191.

[86] A. Isaksson, Perspectives on Atlantic Salmon Ranching in HLSTI 64, 65.

them substantially. They will be harvested as they return to the general vicinity - they don't have a home river - of their release sites in the following years. This practice is well advanced in Iceland, Ireland and Norway. The major advantages of ranching lie in the quality of the flesh of the fish: It has survived on natural prey and has been toughened by ocean endurance. There are some disadvantages in the overall return rate, and the fact that all of the product becomes available at one time, thus shortening the market period.

As hatchery products, both farm and ranch fish have many differences from their wild cousins, all of them centering on the fact that their survival rates will be markedly lower. These differences are more pronounced in farm fish. What is important is that the rearing and breeding of farm (and ranch) fish are focused on matters of growth rate, size, adaptability to congested environment, flesh quality, resistance to those diseases which are a function of or are encouraged by their concentration in pens, and similar matters. None of these attributes is on the agenda of their wild counterparts. Moreover, the learned behavior of hatchery fish is far different. They have not had to make decisions with respect to predator avoidance or food search, to name just a few examples.[87]

There are other concerns. In the course of transporting, selling or exchanging eggs, fry or smolts, a not infrequent practice in the hatchery rearing of salmon, the risk is run of the

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[87] Hansen, supra at 76, 77.

introduction of diseases or hostile agents from one place to another for which there are no immune responses. In 1975, a transfer of eggs to a Norwegian hatchery from a Baltic source introduced the highly dangerous parasitic fluke Gyrodactylus saleris to Norway. Baltic salmon were immune to infections from this creature; in Norway, it was like the introduction of small pox to North American indians and it is now a major problem in over thirty-five Norwegian rivers.[88]

The numbers of farm fish today are enormous. They simply dwarf the wild populations. The number of escapees from farms itself may approach the numbers of wild salmon now surviving in the Atlantic.[89] The problem is the genetic bouillabaisse represented by these farm stocks, and the effect of their interbreeding with wild stocks. Farm escapees will travel great distances, from Europe to Canada, and will join schools of wild fish to go up river to spawn.[90] The question is what effect this has on the residual wild populations? The concern is the dilution or dissipation of stock genetics. With wild stocks in continuous decline, notwithstanding the curtailment of ocean fishing, some observers look to genetic pollution as the cause and there are these are responsible scientists who argue that the sheer weight of numbers of escaped farm fish and ranch nomads will simply collapse the gene

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88 Hansen, supra at 78-79.

89 Windsor, supra at 177.

90 Hansen, supra at 73. Salmon escapees from Norway have been caught at West Greenland. Hansen, supra at 75.

pools of wild fish beyond the point of return.[91] The fact is we simply don't know and time alone will tell.

Conclusion

The restoration effort has proven more difficult and will take far longer than anyone imagined. This is due to some new factors which have conspired against the Commission, as well as some old ones, the degree of difficulty of which was not fully understood at the beginning.

There are four wild cards in the deck. The first is the salmon itself. It is a particularly complex creature, with many life forms and many habitats and a life cycle stretched out over multiple, changing predator exposures for at least four years and over thousands of miles. You could not design or find in nature a harder subject matter.

Secondly, the issue of fish stock genetics changed everything. It emerged fully only after the restoration effort was well underway. It was not just a refinement of technique; the restoration would have had absolutely no hope whatsoever had not a commitment to these new principles been made. What we don't know is how long it takes to create a self-sustaining stock. It is made all the more difficult today because of the farm and ranch fish genetic threat. A ray of hope comes from the possibility that many factors we believe to be genetic may be more properly environmental

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[91] Id. at 73, 79; Lee, supra at 65-66; Windsor, supra at 177.

selection, or adaptation. The hopeful aspect of this is that it can occur within very few generations.[92]

Third is the ocean itself. We really don't know very much about marine ecology as it impacts the salmon. The distances are vast and the behavior patterns are simply not observable. No doubt further research will help but the fact is that for very substantial periods of its life, when it's exposed to many natural and even more threatening man-made predations, we virtually lose both sight of and control over this species and lack the knowledge to penetrate the darkness.

Finally, there is geography. Mounting a marine restoration effort at the edge of the salmon's geographic range introduces not only added degrees of difficulty, but new elements of risk and vulnerability. The longer the salmon has to travel, the higher the loss from predators and natural hazards of all kinds. Moreover, changes in ocean temperature, or in world climate if that comes about, will have their most immediate impact at the extremes of the salmon's range.

It could be argued that, knowing what we know today, a judgment to undertake this effort should not be made. The odds are simply too long. The other side of that is we should be very grateful it did get underway in the innocent, unjaded time that it did because in fact it has shown very substantial progress. The returns to date are disappointing, and they seem both fragile and volatile. They are at the same time not inconsiderable, and

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[92] Meister, supra at 310.

perhaps just about what could be expected given the geographic location of the Connecticut basin. That the program could have achieved the extent it did of river passage success in, really, so short a time, is outstanding. That a river-specific stock could be so far developed to successfully execute its four year, five thousand mile life cycle in the manner intended, and storm upstream with the energy and velocity of that fish that christened the Wilder Dam passage, is nothing sort of miraculous. It is a question of whether the glass is one half full or half empty. I see it as half full.

Richard G. Bell

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Factors Influencing Standing Crops and Survival of Juvenile Salmon at Barrows Stream, Maine[1]

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ABSTRACT

Biological and physical variables influencing survival and standing crops of juvenile salmon are treated by regression analyses to determine those variables of greatest significance. Stream flow in dry seasons as indicated by rainfall proved to be the most important single factor influencing survival from age 0+ to age I+ in the presence of such other variables as standing crops of other fishes and water temperatures. A Chi-square test indicated that the various species of fish present in Barrows Stream during the 6-year study reacted to electrofishing as though they were a single species. Indications are that construction of small water storage dams at appropriate sites in the headwaters of salmon nursery areas could increase survival and growth rate of juvenile salmon occupying the nurseries.

INTRODUCTION

Fishery scientists of the Maine Department of Inland Fisheries and Game are giving increasing attention to measurements of standing crops of juvenile landlocked salmon, *Salmo salar*, living in stream nursery areas. We are attempting to learn which physical and biological variables of the nursery areas exert the greatest influence upon magnitudes of standing crops, survival, and growth of salmon. Refined information concerning these variables is needed if we are to develop management guidelines useful in promoting optimum utilization of the nurseries by salmon. For a generalized life history of landlocked salmon refer to Everhart (1966).

This publication describes a study carried out from 1960 through 1965 at Barrows Stream (lat 45° 01′ N, long 67° 31′ W) in Crawford Township, Washington County, Maine. The precise location of Barrows Stream in the East Machias River drainage is shown in Figure 1.

The study is part of a project at Love Lake where several aspects of landlocked salmon life history and behavior are under investigation. Barrows Stream, a tributary, is presently the major spawning and nursery area of landlocked salmon in the Love Lake sub-drainage.

The Barrows Stream study has included examination of effects on juvenile salmon populations of only the most obvious of measurable habitat variables of the nursery. Salmon of the sizes and ages studied at Barrows Stream are not legally vulnerable to angling. Fishing pressure is negligible.

DESCRIPTION OF STUDY AREA

Barrows Stream is 7,900 ft long from its main source at Barrows Lake (281 acres) to its junction with Love Lake. The stream bed has a mean width of 22 ft and comprises approximately 4 acres. Drainage area of the stream is approximately 7.85 square miles. Mean gradient is 21.4 ft per mile, but gradient in suitable salmon spawning and nursery segments is somewhat steeper. Approximately 3,750 linear feet (2 acres) of Barrows Stream is suitable salmon spawning and nursery area

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[1] Contribution from Dingell-Johnson Project F-14-R, Maine.

[2] Presently with Natural Resources Institute, University of Maryland, LaVale, Maryland.

—suitable as described by Warner (1959, 1963). The remaining 4,150 linear feet (2 acres) is comprised of sluggish flats with unstable bottom soils of sand and silt underlain mostly by clay.

Water flows at Barrows Stream normally fluctuate from 0.25 ft^3/sec to about 100 ft^3/sec. However, during August and September, 1965, the stream was dry except for apparently stagnant water in shallow pools, and in May, 1961 flows exceeding 200 ft^3/sec occurred.

Bank vegetation ranges from grasses and ferns in unshaded meadowland to dense stands of second growth hemlock (*Tsuga canadensis*), red spruce (*Picea rubens*), balsam fir (*Abies balsamea*), and mixed hardwoods which provide near total shading of the stream. *Fontinalis* sp., *Vallisneria* sp., *Potamogeton* sp., and *Nuphar* sp., comprise most of the aquatic vegetation of Barrows Stream.

The water is essentially colorless at source but becomes light brown in lower stream reaches. The stream is slightly acid and total alkalinity probably never exceeds 10 ppm. Resistivity approximated 45,000 ohms in September, 1967. Stream temperatures rarely exceed 72 F. Normal rainfall for the subdrainage is between 40–50 inches per year.

Fishes that inhabit Barrows Stream include:

Petromyzon marinus—Sea lamprey
Alosa pseudoharengus—Alewife
Salmo salar—Landlocked salmon
Salvelinus fontinalis—Eastern brook trout
Osmerus mordax—American smelt
Esox niger—Chain pickerel
Notemigonus crysoleucas—Golden shiner
Notropis cornutus—Common shiner
Rhinichthys atratulus—Blacknose dace
Semotilus atromaculatus—Creek chub
Semotilus corporalis—Fallfish
Catostomus commersoni—White sucker
Ictalurus nebulosus—Brown bullhead
Anguilla rostrata—American eel
Roccus americanus—White perch
Lepomis gibbosus—Pumpkinseed
Micropterus dolomieui—Smallmouth bass
Perca flavescens—Yellow perch

Alewives and smelts are seasonal residents only. Their occurrence as adults and juveniles is associated with their activities during spawning migrations in April, May, and June or as emigrating young during April or May (smelts) or during August and September (alewives). American eels are primarily transients in September or October. Sea lampreys (standing crops of which could not be estimated within the scope of this study) are continuing residents only as ammocoetes. Salmon, chain pickerel, white suckers, brown bullheads, white perch, yellow perch, pumpkinseeds, and smallmouth bass are resident species but only as juveniles. Brook trout, golden shiners, common shiners, blacknose dace, fallfish, and creek chub are thought to be permanent residents of the spawning and nursery segments, both as juveniles and adults.

Data presented in this paper are from work conducted exclusively on the spawning and nursery area of Barrows Stream in closest proximity to Love Lake. The study section (Figure 1) begins about 800 ft upstream from the lake, continues upstream for 1,800 ft, and terminates at a beaver dam marking the beginning of a sluggish flat 1,025 ft in length. Area of the 1,800-foot-long study section, as determined by plane table survey, is one acre.

The study section is made up of gentle riffles interspersed with nine evenly distributed pools ranging from about 15 inches to about 40 inches deep at normal low-water flows. Bottom materials, by area, range from silt, mud, and clay (about 10%) to sand (about 15%) through gravel (about 25%) to boulders (about 50%). The study area is well shaded (Figure 1). Cover consists of logs, large boulders, undercut banks, and aquatic vegetation.

The study section receives side-flow from one tiny tributary of spring origin.

TECHNIQUES AND MATERIALS

Estimation of Standing Crops

We estimated standing crops once each year during the study period. Dates of estimates were 1960—27, 28, 29, 30 September and 5 October; 1961—11, 12, 18, 19 October; 1962—23, 24, 25 September; 1963—23, 24, 25 September; 1964—14, 15, 21, 22 September; 1965—13, 14, 15 September.

We used a d-c electrofishing apparatus (500-v) to capture fishes. The positive electrode was a wand with controllable switch;

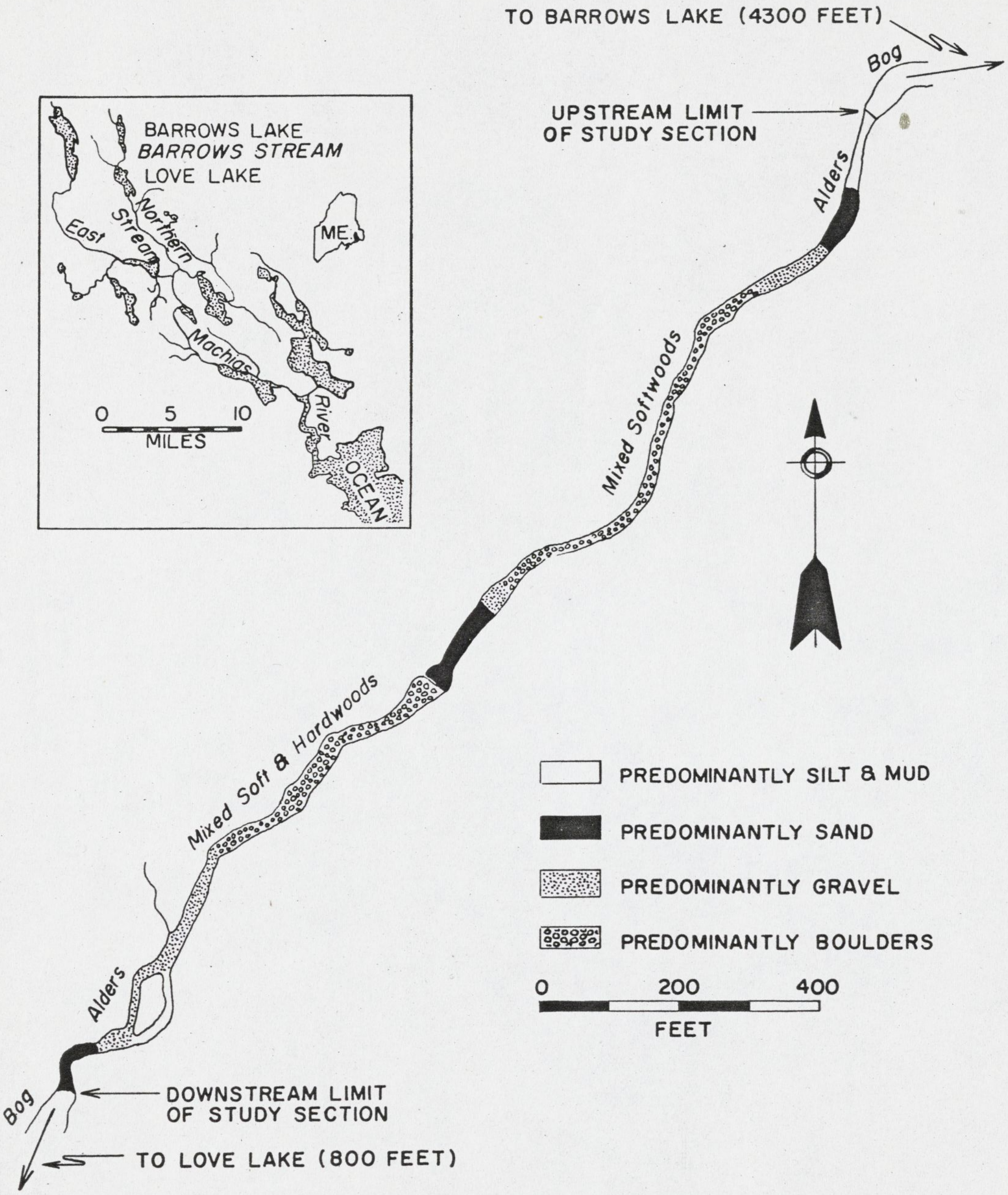

FIGURE 1.—Morphometric features of the study section of Barrows Stream.

the negative electrode was aluminum wire laid in the stream bed throughout the length of the study section. Whenever necessary, we used blocking seines to isolate the study area.

Fish were weighed alive in the field to the nearest gram. For weighing we used a Welch 250 g by 2 g spring scale or a Hanson dietetic scale with a capacity of 500 g by 1 g. We usually weighed 20 to 50 fish of each species within 2-inch size classes. Most fish in the 0.0–1.9-inch size class were weighed in groups, as such tiny fish could not be accurately field-weighed individually with our equipment. We weighed virtually all fish over 3.0 inches, total length, individually.

In some years, size classes for particular species were extremely scarce though the species itself was abundant. Again, in some years, only a few individuals of certain species were represented in the population. In such situations we weighed all individuals captured in the scarce size classes or in the populations of poorly represented species. We always attempted to secure weights for at least 20 fish in each 2-inch size class but could not always fulfill this goal.

Individuals to comprise the weight subsample were selected as follows: Every 300 ft or so along the stream fish on hand were processed. During processing species were first separated into size classes. Then from the respective size classes so separated, individuals or groups of individuals were drawn for weighing. Number of any species of a given size class weighed at a given processing station depended upon number needed. As stated above, paucity of some species or of certain size classes within a species necessitated weighing all individuals captured. We attempted to weigh sub-samples over the entire length of the study section and drew them from the holding buckets as randomly as is possible under field conditions. We believe our weight sample is random.

Need and justification for combining data for species.—Ricker (1958) states that combining data for two or more species to make a common estimate should be avoided, and he cites examples of gross differences resulting from such combined data.

In our Barrows Stream study we were faced with the problem of working in part with very small fish, especially certain minnows, for which recaptures were few. In addition, in most years we encountered species barely represented in the population for which no recaptures were made. In the former situation confidence intervals were extremely wide. In the latter situation, no estimates at all were possible for the particular species involved. Our dilemma was that the small fish and those species barely represented in the population comprised a part of the standing crops that we believed could be significant in relation to standing crops of salmon, the species of primary interest. A method for including them reliably in estimates of total standing crops would be highly desirable. A method of seeming promise was a pooling of data to allow an estimate including all species and having relatively narrow confidence intervals.

In Petersen-type methods for estimating fish populations, if percentage recoveries of several species previously marked are the same then point estimates calculated for each of the species and summed are equal to estimates derived by combining data for the several species.

An algebraic demonstration of this fact is as follows:

Let M_i = Number of fish marked of species i

C_i = Total catch of species i taken for examination

R_i = Number of marks in total catch of species i taken for examination

$i = 1, 2, \ldots\ldots. n$ = Number of species

u_i = Fraction recaptured of species i

$R_i = u_i M_i$ and if $u_i = u$

$R_i = u M_i$ and

$\Sigma R_i = u \Sigma M_i$

Then:

$$\sum^{n} \frac{M_i C_i}{R_i} = \sum \frac{C_i}{u} = \frac{1}{u}(\Sigma C_i), \qquad (1)$$

and since

$$\frac{1}{u} = \frac{\Sigma M_i}{\Sigma R_i}, \qquad (2)$$

$$\frac{1}{u}\Sigma C_i = \frac{\overset{n}{\Sigma} M_i \overset{n}{\Sigma} C_i}{\overset{n}{\Sigma} R_i}. \qquad (3) \text{ from } (1)$$

Moreover, if the ratio R_i/C_i remains constant among several species, sum of individual estimates is equal to an estimate using pooled data.

A routine Chi-square test provided the means for testing null hypotheses that: (1) percentage recoveries of marked fish were independent of fish species and that (2) proportion of marked fish among recoveries was independent of fish species. Non-rejection of either of the hypotheses for a given body of

TABLE 1.—*Contingency table of values serving as bases for Chi-square derivations for several species of fish in the 0.0–1.9-inch size class, Barrows Stream, 1960–1965. M is number marked, R is number recovered and M-R is number not recovered*[1]

Year	Creek chub			White sucker			Fallfish			Brook trout			Smallmouth bass			Pumpkinseed		
	M	R	M-R	M	R	M-R	M	R	M-R	M	R	M-R	M	R	M-R	M	R	M-R
1960	52	3	49	2	0	2	4	1	3	1	0	1				1	0	1
1961	1	0	1										1	0	1			
1963	15	1	14	9	1	8	146	42	104									
1964	11	4	7				13	2	11									
1965	20	2	18	29	3	26												

[1] Size class not represented in 1962 sample.

data would permit pooling of those data to secure the combined population estimate desired.

Values for deriving Chi-squares for testing the null hypothesis that percentage recoveries of marked fish were independent of fish species are presented in Tables 1, 2, and 3. A summary of the Chi-square values and associated data are in Table 4. The three contingency tables are based on field data summarized in Tables 7, 8, 9, and 10 in the analysis portion of this paper.

Among 17 computations of Chi-square values for testing the null hypothesis that percentages of marked fish were independent of fish species, 11 (Table 4) yielded values that indicated that the null hypothesis should not be rejected. However, when data associated with computation of these six Chi-squares were treated to test the null hypothesis that proportion of marked fish in the recovery sample (R/C) was independent of species, three of the Chi-squares (Table 4) indicated that species and recoveries were indeed independent. Chi-square values for these latter calculations were as follows: 1960—2.0–3.9 inch size class, 8.54 with 5 df; 1961—2.0–3.9 inch size class, 5.60 with 7 df; 1963—4.0–8.9 inch size class, 5.15 with 4 df.

Thus, indications are from 14 of 17 Chi-square tests based on our data, that the various species responded to capture and recapture as though they were a single species. We consider the data poolable for purposes of analysis.

Cooper (1951) showed that large trout in the Pigeon River, Michigan were more readily captured by electrofishing than small trout.

TABLE 2.—*Contingency table of values serving as bases for Chi-square derivations for several species of fish in the 2.0–3.9-inch size class, Barrows Stream, 1960–1965. M is number marked, R is number recovered and M-R is number not recovered*

Year	Creek chub			White sucker			Fallfish			Brook trout			Smallmouth bass		
	M	R	M-R	M	R	M-R	M	R	M-R	M	R	M-R	M	R	M-R
1960	118	26	92	129	52	77	51	15	36	5	2	3	6	5	1
1961	51	4	47	15	6	9	1	1	0	2	0	2	7	1	6
1962	7	1	6	33	4	29				2	0	2	1	0	1
1963	211	45	166	167	61	106	132	46	86	10	3	7	25	8	17
1964	268	124	144	345	178	167	77	37	40	7	3	4	1	1	0
1965	161	93	68	65	33	32	27	15	12	4	2	2			

Year	Common shiner			Pumpkinseed			Chain pickerel			Golden shiner			Yellow perch		
	M	R	M-R	M	R	M-R	M	R	M-R	M	R	M-R	M	R	M-R
1960							5	0	5						
1961	34	4	30	6	2	4				1	0	1			
1962				1	0	1				1	1	0			
1963	14	6	8												
1964	2	2	0												
1965	3	3	0				3	2	1				2	1	1

TABLE 3.—*Contingency table of values serving as bases for Chi-square derivations for several species of fish in the 4.0–8.9-inch size class, 1960–1965, Barrows Stream. M is number marked, R is number recovered and M-R is number not recovered*

	Species																							
	Creek chub			White sucker			Fallfish			Brook trout			Smallmouth bass			Common shiner			Chain pickerel			Yellow perch		
Year	M	R	M-R	M	R	M-R	M	R	M-R	M	R	M-R	M	R	M-R	M	R	M-R	M	R	M-R	M	R	M-R
1960	23	11	12	16	9	7	16	8	8	16	12	4							7	4	3			
1961	8	2	6	31	11	20	6	1	5	3	0	3	3	0	3	1	0	1	5	1	4	1	0	1
1962	7	1	6	15	5	10				6	1	5												
1963	21	7	14	59	11	48	12	8	4	15	6	9				1	0	1						
1964	31	19	12	61	29	32				13	11	2												
1965	102	60	42	40	13	27				17	13	4							1	0	1			

Cooper and Lagler (1956) determined that efficiency of electric shocking varied markedly for small and large trout.

Tiny fish stunned by the electric field are less easily seen than larger individuals, and larger fish apparently respond more markedly to the electricity. Both factors probably contribute to the phenomenon of greater captures of larger fish.

Readers will have noted that the above described procedure for determining if data might be pooled used data broken into various size classes. The Barrows Stream data very strongly indicate that fishes of different sizes differ markedly in vulnerability to capture by electrofishing.

Table 5 compiled from six years of data from Barrows Stream, (see Tables 7, 8, and 9) reveals how percentage capture of estimated fish available increased with increasing fish size. A Chi-square tabulation (Table 6), designed to test the null hypothesis that fish size was independent of vulnerability to electrofishing, was rejected with probability beyond the 0.001 level (Chi-square, 320.7) that the observed differences could have arisen by chance.

Numerical estimates.—It has been demonstrated above that fishes of different sizes responded differently to electrofishing during the Barrows Stream work. Thus, calculation of annual numerical standing crops by lumping all size classes would not have yielded accurate estimates. What was needed was a method of computation that would permit estimates of populations of fish of different size classes (or age groups in the case of salmon) and then addition of the individual estimates to obtain total numerical standing crop. But this method had to include a way by which confidence intervals for the total estimate could be derived. A pooled variance for the total estimate based on variance of sub-estimates for size classes or age groups was required.

A suitable procedure is provided by a

TABLE 4.—*Chi-squares and associated data for three size classes of fish of several species at Barrows Stream, 1960–1965. Chi-squares are for testing the null hypothesis that percentage recoveries of marked fish is independent of fish species*

	Size class (inches)								
	0.0–1.9			2.0–3.9			4.0–8.9		
Year	Number of species	df	Chi-square[1]	Number of species	df	Chi-square[2]	Number of species	df	Chi-square[2]
1960	5	4	2.57	6	5	21.48**	5	4	3.20
1961	2	1	0.00	8	7	20.82**	8	7	7.84
1962	0			6	5	7.35	3	2	1.42
1963	3	2	4.95	6	5	13.51*	5	4	18.47**
1964	2	1	1.40	6	5	5.45	3	2	6.02*
1965	2	1	0.002	7	6	3.51	4	3	29.10*

[1] Chi-square values not marked by asterisks indicate that the null hypothesis in question should not be rejected.
[2] Chi-square values marked by a single asterisk indicate that the null hypothesis in question should be rejected. Values marked by a double asterisk indicated that the null hypothesis in question should be rejected on the basis of percentage recoveries of marked fish, (R/M), but not on the basis of proportion of marked fish in the recovery sample, (R/C).

TABLE 5.—*Captures of fishes of different size in percentage of estimated numbers available at Barrows Stream, 1960–1965*[1]

Size class (inches)	Estimated population summed for years 1960–1965[1]	Number of fish captured in first sample	Percentage captured in first sample
0.0–1.9	1,519	305	20.1
2.0–3.9	4,960	2,001	40.3
4.0–5.9	924	500	54.1

[1] Only salmon not included.

TABLE 6.—*Contingency table of values serving as basis for comparing fish size and proportion recovered by electrofishing in relation to availability for several species of fish, Barrows Stream, 1960–1965*

Size class (inches)	Estimated population summed for years 1960–1965	Number captured in first sample	Estimated number not captured in first sample
0.0–1.9	1,519	305	1,214
2.0–3.9	4,960	2,001	2,951
4.0–5.9	924	500	424

method given by Bailey (1951), through which the large-sample variance, V, of $\hat{N}$ is computed by

$$V = \frac{M^2(C+1)(C-R)}{(R+1)^2(R+2)}$$

and the point estimate of the population, $\hat{N}$, by

$$\frac{M(C+1)}{R+1}.$$

Variances for $\hat{N}$, whether for size classes or age classes are additive as are the point estimates, $\hat{N}$. With pooled variances so determined it is an easy task to construct confidence intervals about $\hat{N}$ using z, the standardized normal variable.

Weight estimates.—Computation of total weight standing crop in any year required calculation of a mathematically weighted mean weight for the entire fish population. This weighted mean weight was determined as follows.

Mean weight for each species within size classes was determined as previously described. Then for each of the species within the respective size classes, mean weight so determined was multiplied by the number of individuals captured in our first sample run through the study section to secure fish for marking and release. The products were summed and divided by total numbers of fish so captured giving weighted mean weights for the size classes based on the estimates of relative numbers of each species present and their mean weights.

At this point a weighted mean weight for each of the size classes of fish (except salmon which were treated by age groups) was available. There remained but the task of securing the population mean weight by multiplying the weighted mean weight of each size class by the Bailey estimate of abundance of that size class and dividing the products by the Bailey estimate of abundance for the entire population of fish (excluding salmon). But salmon must be brought into the calculations to secure the mean weight of the whole population. This calculation included multiplying mean weight of salmon of ages 0+, I+, and II+ by numerical estimates made independently for this species and again weighting the two kinds (salmon and other fish) by mean weights and numerical abundance to secure mean population weight.

Total weights of the annual numerical standing crops were determined by multiplying mean population weights calculated as de-

TABLE 7.—*Number of fish marked (M), number recaptured (R), and number of fish in sample for marks (C), for several species of fish in the 0.0–1.9-inch size class at Barrows Stream, 1960–1965*

Year	Creek chub			White sucker			Fallfish			Brook trout			Smallmouth bass			Common shiner			Pumpkinseed		
	M	R	C	M	R	C	M	R	C	M	R	C	M	R	C	M	R	C	M	R	C
1960	52	3	16	2	0	0	4	1	3	1	0	0	0	0	0	0	0	1	1	0	0
1961	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
1962	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1963	15	1	4	9	1	11	146	42	201	0	0	0	0	0	3	0	0	0	0	0	0
1964	11	4	15	0	0	0	13	2	6	0	0	0	0	0	0	0	0	0	0	0	0
1965	20	2	10	29	3	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 8.—*Number of fish marked (M), number recaptured (R), and number of fish in sample for marks (C), for several species of fish in the 2.0–3.9-inch size class at Barrows Stream, 1690–1965*

	Species																																
	Creek chub			White sucker			Fallfish			Brook trout			Smallmouth bass			Common shiner			Pumpkinseed			Chain pickerel			Golden shiner[1]			Yellow perch			Salmon		
Year	M	R	C	M	R	C	M	R	C	M	R	C	M	R	C	M	R	C	M	R	C	M	R	C	M	R	C	M	R	C	M	R	C
1960	118	26	80	129	52	112	51	15	32	5	2	2	6	5	19	0	0	1	0	0	6	5	0	2	0	0	0	0	0	0	395	158	527
1961	51	4	24	15	6	17	1	1	8	2	0	4	7	1	3	34	4	22	6	2	0	0	0	0	1	0	0	0	0	0	157	40	100
1962	7	1	6	33	4	36	0	0	0	2	0	0	1	0	0	0	0	4	1	0	0	0	0	0	1	1	1	0	0	0	105	39	106
1963	211	45	223	167	61	161	132	46	175	10	3	9	25	8	27	14	6	26	0	0	0	0	0	0	0	0	0	0	0	0	88	33	78
1964	268	124	254	345	178	327	77	37	92	7	3	5	1	1	2	2	2	5	0	0	0	0	0	0	1	1	4	0	0	0	113	57	119
1965	161	93	151	65	33	66	27	15	30	4	2	2	0	0	0	3	3	7	0	0	0	3	2	4	0	0	0	2	1	2	0	0	0

[1] Value for 1964 for golden shiner not included in Chi-square derivation because of doubt concerning species identification.

TABLE 9.—*Number of fish marked (M), number recaptured (R), and number of fish in sample for marks (C), for several species of fish in the 4.0–5.9-inch size class at Barrows Stream, 1960–1965*

	Species																										
	Creek chub			White sucker			Fallfish			Brook trout			Smallmouth bass			Common shiner			Chain pickerel			Yellow perch			Salmon		
Year	M	R	C	M	R	C	M	R	C	M	R	C	M	R	C	M	R	C	M	R	C	M	R	C	M	R	C
1960	23	11	17	16	9	17	14	7	11	9	7	8	0	0	0	0	0	0	7	4	7	0	0	0	57	33	41
1961	8	2	5	27	11	30	6	1	5	2	0	3	3	0	0	1	0	2	3	1	6	1	0	0	62	43	69
1962	7	1	3	14	5	11	0	0	0	5	1	4	0	0	0	0	0	0	0	0	0	0	0	0	66	39	72
1963	18	6	16	58	11	34	10	7	12	12	4	15	0	0	0	1	0	3	0	0	0	0	0	0	95	58	96
1964	30	18	37	61	29	42	0	0	0	12	10	12	0	0	0	0	0	0	0	0	0	0	0	0	45	36	50
1965	100	60	79	39	13	25	0	0	1	12	8	9	0	0	0	0	0	0	1	0	4	0	0	0	32	26	28

TABLE 10.—*Number of fish marked (M), number recaptured (R), and number of fish in sample for marks (C), for several species of fish in the 6.0–8.9-inch size class at Barrows Stream, 1960–1965*

Year	Species: Creek chub M	R	C	White sucker M	R	C	Fallfish M	R	C	Brook trout M	R	C	Chain pickerel M	R	C	Brown bullhead M	R	C	Salmon M	R	C
1960	0	0	0	0	0	0	2	1	2	7	5	6	0	0	0	0	0	0	1	0	1
1961	0	0	0	4	0	0	0	0	0	1	0	2	2	0	1	0	0	0	0	0	0
1962	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
1963	3	1	4	1	0	0	2	1	2	3	2	6	0	0	0	0	0	0	17	9	14
1964	1	1	1	0	0	0	0	0	0	1	1	2	0	0	0	1	1	1	1	0	1
1965	2	0	0	1	0	1	0	0	0	5	5	5	0	0	0	0	0	0	0	0	0

scribed above by respective estimates of numerical abundance.

Ideally, of course, population estimates for every species present in every size class would have been computed and used to serve as the basis for weight of the numerical standing crops. As explained, such computations were not possible, so index of abundance values were utilized as an alternative.

Stream Flows

Stream flows were not measured directly throughout the project period, but an index of their magnitude was determined from rainfall records. Monthly rainfall records from 1958 through 1965 were provided by United States Department of the Interior, Geological Survey, Water Resources Division. The recording station was about 10 miles from the study area.

Temperatures

Air and water temperatures were recorded with a Taylor recording thermograph. Temperature records were usually kept from mid-April through mid-December although year-around temperatures were kept during one study year.

ANALYSES AND DISCUSSION

As stated earlier, the primary purpose of the Barrows Stream work has been to learn which physical and biological variables of the nursery influence standing crops and survival of juvenile salmon most significantly.

Tables 7 through 10 contain the raw data used for computing standing crops of salmon and other fishes as summarized in Table 11 and in Figures 2 and 3. Confidence intervals (Table 11) for numerical estimates are at the 95% level. Coefficients of variation ranged from about 3.5 to about 26.0%, but most were between about 5.0 and 15.0%.

Linear regression analysis was utilized to determine how different physical and biological variables of the environment affected survival, standing crops, growth and so forth of juvenile salmon. Using selected dependent and independent variables, numerous equations of the form $Y = a+b_1 X_1 + b_2 X_2 + b_3 X_3$ were fitted and significance of the fitted regressions tested by analysis of variance in the manner outlined by Freese (1967). In these regression analyses, all possible combinations of terms of the regressions were

TABLE 11.—*Summary of population estimates and standing crops at Barrows Stream, 1960–1965*

Year	Age group 0+ salmon: Number per acre	Weight in pounds per acre	Age group I+ and older salmon: Number per acre	Weight in pounds per acre	All salmon: Number per acre	Weight in pounds per acre	All other fish: Number per acre	Weight in pounds per acre	Total standing crop: Number per acre	Weight in pounds per acre
1960	1,311±169	4.3±0.5	70±10	2.1±0.3	1,381±169	6.4±0.8	1,149±214	12.8±2.3	2,530±272	19.2±2.1
1961	386±91	2.2±0.5	99±18	2.8±0.5	485±93	5.0±1.0	781±237	11.4±3.4	1,266±264	16.4±3.4
1962	322±79	1.4±0.3	138±29	5.5±1.2	460±84	6.9±1.3	434±233	4.9±2.6	894±245	11.8±3.2
1963	236±60	1.2±0.3	210±31	10.1±1.4	445±67	11.3±1.6	3,639±400	30.2±3.7	4,084±412	41.5±4.1
1964	268±49	1.4±0.2	75±13	2.4±0.4	343±53	3.8±0.6	1,873±114	24.3±1.4	2,216±142	28.1±1.8
1965	0±0	0±0	39±3	1.0±0.1	39±3	1.0±0.1	1,246±232	18.3±3.4	1,285±233	19.3±3.5

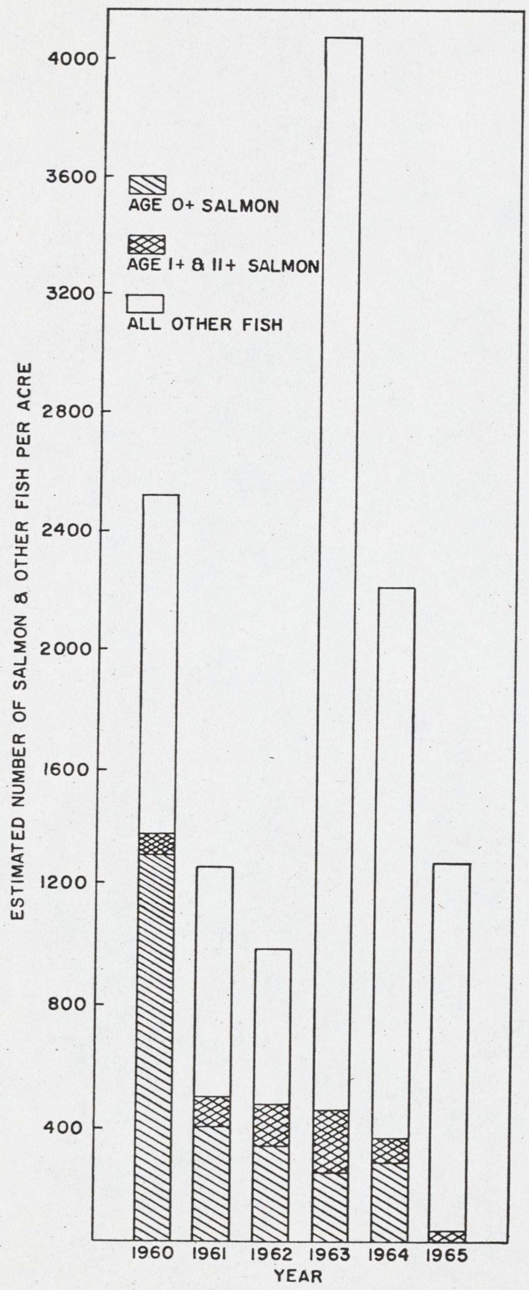

FIGURE 2.—Numerical standing crops of salmon and other fishes at Barrows Stream, 1960–1965.

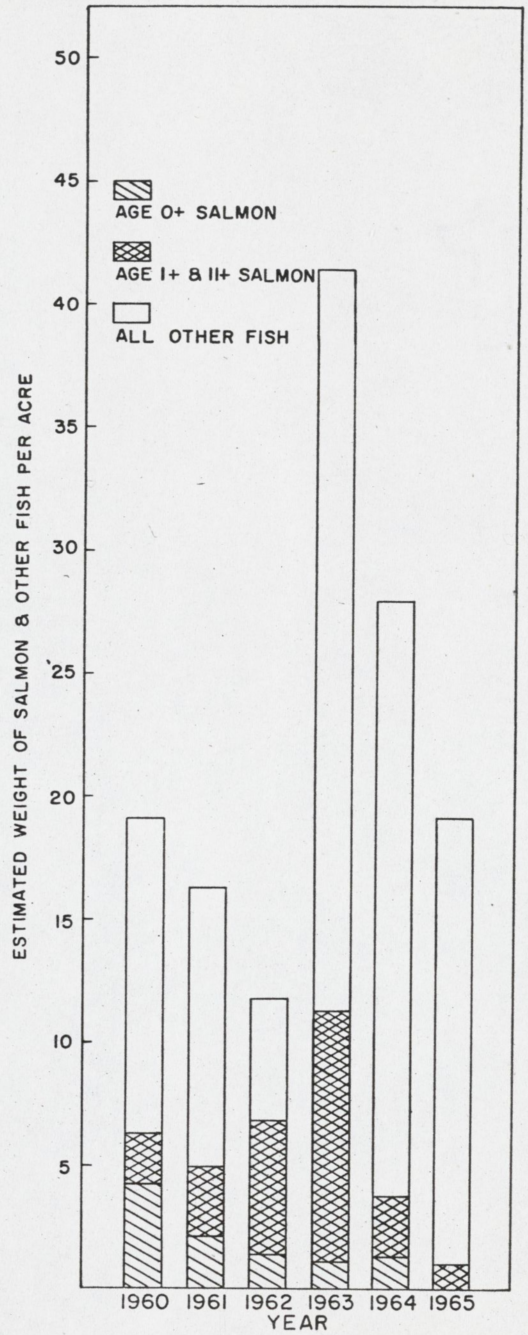

FIGURE 3.—Weight standing crops of salmon and other fishes at Barrows Stream, 1960–1965.

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TABLE 12.—*Equations,*
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Equation number	Equatio
1	Ŷ = −21.94 + 4.3
2	Ŷ = −9.30 + 4.02
3	Ŷ = −13.26 + 4.9
4	Ŷ = −15.16 + 5.1
5	Ŷ = −13.06 + 4.5
6	Ŷ = −11.08 + 4.7
7	Ŷ = −13.88 + 4.4

* Significant at 95% c
** Significant at 99% c

tested. Such testing revealed the contribution of each X term or group of X terms to the prediction of Y. In a precautionary vein, it should be pointed out that some inferred cause-effect relationships may not be demonstrated at the indicated level of significance because of the large number of other variables examined.

In considering the calculations it should be remembered that the assumption has been made that the variance of Y about the regression line is homogenous and that the relationship of Y to X is linear over the range of X values involved. Too, the F and z tests assume normality. Our equations have estimated the mean of Y for a given X or group of X's with the assumption that values of X are known exactly.

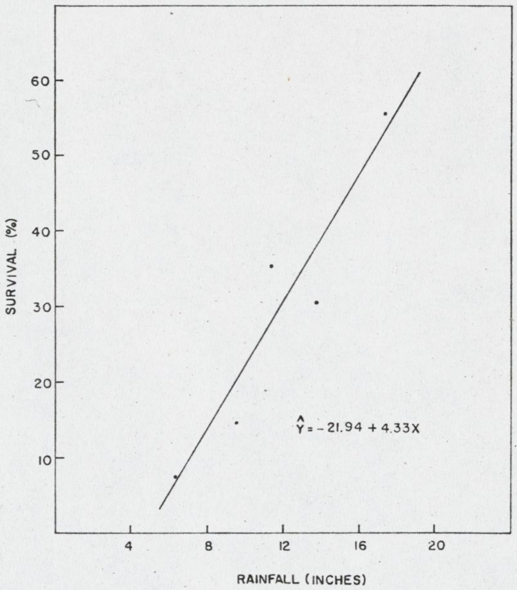

FIGURE 4.—The relationship between July and August rainfall and survival of salmon from ages 0+ to I+ at Barrows Stream, 1960–1965.

Relationships between survival of age group 0+ salmon and other variables

July and August rainfall alone and in association with other variables was closely related to survival of salmon from age 0+ to age I+ during the study years (Table 12). Associations between survival and rainfall only are summarized in Table 13. When rainfalls for July and August were summed for the first two years that year classes inhabited the stream and then expressed through linear regression in their relationship to survival of the respective year classes, the positive single variable regression indicated that survival indeed could be reliably predicted from rainfall (Table 12, equation 1). The relationship is graphed as Figure 4.

Further evidence of the importance of rainfall as a variable affecting survival of salmon from ages 0+ to I+ was derived from a regression of the same model as that fitted above but included rainfall during July and August when year classes were age I+ only

TABLE 12.—*Equations, description of variables, F values, and coefficients of determination for significant linear regressions of survival of age group 0+ salmon ($\hat{Y}$), on other variables, Barrows Stream, 1960–1965*

Equation number	Equation	Description of independent variables				
		X_1	X_2	X_3	F	R^2
1	$\hat{Y} = -21.94 + 4.33X_1$	Rainfall (inches)	Number standing crop, all fish, in year preceding estimate	Weight standing crop, all fish except salmon, paired years	22.76*	0.884
2	$\hat{Y} = -9.30 + 4.02X_1 - 0.004X_2$	Same	Same	Same	20.58*	0.953
3	$\hat{Y} = -13.26 + 4.93X_1 - 0.46X_3$	Same	Same	Same	642.83**	0.998
4	$\hat{Y} = -15.16 + 5.13X_1 + 0.001X_2 - 0.54X_3$	Same	Same	Same	26,919.21**	0.999
5	$\hat{Y} = -13.06 + 4.53X_1 + 0.008X_2$	Same	Number standing crop, all fish, in year of estimate	Number standing crop, all fish, except salmon, in year of estimate	804.13**	0.998
6	$\hat{Y} = -11.08 + 4.70X_1 + 0.007X_3$	Same	Same	Same	85.55*	0.988
7	$\hat{Y} = -13.88 + 4.47X_1 + 0.011X_2 - 0.004X_3$	Same	Same	Same	3,982.61**	0.999

* Significant at 95% confidence level.
** Significant at 99% confidence level.

TABLE 13.—*Relationships between rainfall and survival from age 0+ to I+ in salmon, Barrows Stream, 1960–1965*

Year class	Survival (percentage)	July and August rainfall (inches): While salmon were age I+	July and August rainfall (inches): While salmon were ages 0+ and I+
1960	7.5	2.18	6.41
1961	35.7	9.15	11.31
1962	55.6	8.04	17.19
1963	30.4	5.67	13.71
1964	14.4	4.06	9.73

(Table 13). While F, with a value of 8.55 barely misses significance, this positive, single variable regression certainly strengthens evidence from the significant positive regression discussed previously (Table 12, equation 1) that rainfall magnitude was closely related to salmon survival from ages 0+ to I+ during years of the study.

During the time interval between estimates of standing crops of salmon year classes at age 0+ and at age I+, survival was very strongly associated with July and August rainfall in conjunction with number of all fish per acre (Table 11) the latter estimated when the year classes were at age I+ (Table 12, equation 5).

Also during the time interval between estimates of standing crops of salmon year classes at age 0+ and at age I+, survival was closely related to rainfall during July and August considered together with number of all fish per acre except salmon (Table 11), again the latter estimated in autumn when the year classes were at age I+ (Table 12, equation 6).

In the latter two equations (Table 12) rainfall continues to be the dominating entity. Regression of survival on number of all fish per acre considered together with number of fish except salmon per acre did not approach significance.

Relationships between weight and numerical standing crops of age 0+ salmon and other variables

In single variable regression, weight standing crop of age 0+ salmon was strongly and positively related to numerical standing crop of *all* salmon (Table 14, equation 1). A deduction from these data is that salmon size (assuming linearity) had not yet begun to decrease with increasing numbers of salmon, at least within the range of our data.

Weight standing crops of age group 0+ salmon at Barrows Stream can also be predicted with reliability from multiple variable regression equations 2 and 3 (Table 14) with the latter equation yielding an extremely high R^2 value. Note that the coefficients of X_2 are negative in sign in both equations 2 and 4 in Table 14 indicating perhaps a tendency of weight standing crop of all fish except salmon to depress weight standing crop of age group 0+ salmon.

Numerical standing crops of age group 0+ salmon can be predicted from two single variable regression equations based on our data—one positive, the other inverse (Table 15, equations 1 and 2 respectively). In addition, numerical standing crop of age group 0+ salmon was significantly associated with numerical standing crop of *all* salmon coupled with weight standing crop of all fish except salmon (Table 15, equation 3). Also, numerical standing crop of age group 0+ salmon was significantly related to numerical standing crop of *all* salmon per acre and mean weight of all fish (Table 15, equation 4).

TABLE 14.—*Equations, descriptions of variables, F values, and coefficients of determination for significant linear regressions of weight standing crops of age groups 0+ salmon ($\hat{Y}$), on other variables, Barrows Stream, 1960–1965*

Equation number	Equation	Description of independent variables: X_1	X_2	X_3	F	R^2
1	$\hat{Y} = 0.120 + 0.003X_1$	Numerical standing crop, all salmon	Weight standing crop, all fish except salmon	Mean weight of all fish	69.86**	0.945
2	$\hat{Y} = 0.31 + 0.003X_1 - 0.009X_2$	Same	Same	Same	28.05*	0.949
3	$\hat{Y} = -4.47 + 0.005X_1 + 0.716X_3$	Same	Same	Same	947.67**	0.998
4	$\hat{Y} = -4.29 + 0.005X_1 - 0.006X_2 + 0.705X_3$	Same	Same	Same	2,710.95**	0.999

* Significant at 95 percent confidence level.
** Significant at 99 percent confidence level.

TABLE 15.—*Equations, descriptions of variables, F values, and coefficients of determination for significant linear regressions of numerical standing crops of age group 0+ salmon ($\hat{Y}$), on other variables, Barrows Stream, 1960–1965*

Equation number	Equation	Description of independent variables X_1	X_2	X_3	F	R^2
1	$\hat{Y} = -106.58 + 1.002X_1$	Numerical standing crop, all salmon	Weight standing crop, all fish except salmon	Mean weight of all fish	219.02**	0.982
2	$\hat{Y} = 2226.14 - 349.51X_3$	Same	Same	Same	16.39*	0.804
3	$\hat{Y} = -63.77 + 0.990X_1 - 2.15X_2$	Same	Same	Same	89.15**	0.983
4	$\hat{Y} = -341.54 + 1.09X_1 + 36.59X_3$	Same	Same	Same	89.01**	0.983
5	$\hat{Y} = -278.42 + 1.07X_1 - 1.98X_2 + 32.92X_3$	Same	Same	Same	43.52**	0.984

* Significant at 95 percent confidence level.
** Significant at 99 percent confidence level.

Again, weight standing crop of all fish except salmon seems to exert a depressing effect on standing crop of age group 0+ salmon (Table 15, equations 3 and 5), here on numerical standing crop rather than weight standing crop as discussed above.

Relationships between standing crops of salmon older than age group 0+ and other variables

Weight standing crop of salmon older than age group 0+ (henceforth termed parr in text) can be reliably predicted, as would probably be expected, from numerical standing crop of parr (Table 16, equation 1). Predictions with greater R^2 values can be determined by coupling numerical standing crop of parr with July and August rainfall (Table 16, equation 2) and with November rainfall in year prior to estimate (Table 16, equation 3). We think that the November rainfall variable in the latter regression equation may be a parallel entity acting as an indicator of fall and winter flows between estimate years.

Numerical standing crop of parr can be predicted from weight standing crop of *all* salmon in year of estimate (Table 17, equation 1). Moreover, numerical standing parr crop is predictable from numerical standing crop of *all fish* in year prior to estimate coupled with weight standing crop of all salmon in year prior to estimate and again coupled with weight standing crop of all salmon in year of estimate (Table 17, equations 2 and 3, respectively). Furthermore, numerical standing parr crop in year of estimate is predictable from weight standing crop of all salmon in year *prior* to estimate considered together with weight standing crop of all salmon in year of estimate (Table 17, equation 4).

These regressions involving numerical standing crops of parr and variables related to them present at least two implications of a practical nature.

First, an increase in the number of all fish in the year prior to estimation appears to have a slight depressing effect on abundance of salmon parr the following year. Secondly, if the assumption of linearity is valid, then the fact that weight standing crop of *all* salmon in year of the estimate can alone be used to predict numerical standing crop of parr sug-

TABLE 16.—*Equations, description of variables, F values, and coefficients of determination for significant linear regressions of weight standing crops of salmon older than age group 0+ ($\hat{Y}$), on other variables, Barrows Stream, 1960–1965*

Equation number	Equation	Description of independent variables X_1	X_2	X_3	F	R^2
1	$\hat{Y} = -0.06 + 0.04X_1$	Numerical standing crop of parr	Rainfall, combined for July and August in year of estimate and previous year	November rainfall in year prior to estimate	24.81*	0.861
2	$\hat{Y} = -2.85 + 0.036X_1 + 0.28X_2$	Same	Same	Same	23.66**	0.940
3	$\hat{Y} = -0.061 + 0.04X_1 + 0.07X_3$	Same	Same	Same	9.63*	0.865

* Significant at 95 percent confidence level.
** Significant at 99 percent confidence level.

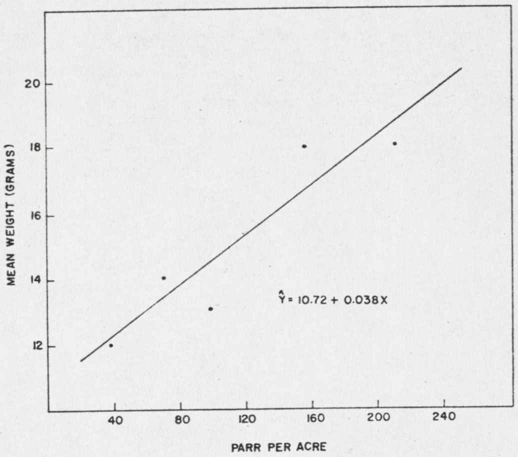

FIGURE 5.—Relationship between standing crop of parr and their mean weight, Barrows Stream, 1960–1965.

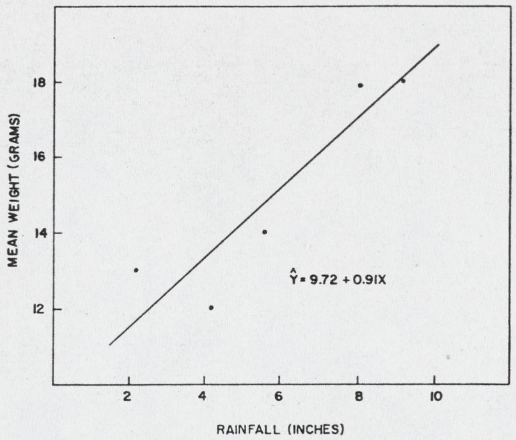

FIGURE 6.—Relationship between rainfall and mean weight of parr, Barrows Stream, 1960–1965.

gests that salmon populations of Barrows Stream never reached such an abundance during the study that mean salmon weight declined as an effect of abundance.

Other relationships

Mean weight of 4.0–5.9-inch-long parr was significantly associated with number of all parr per acre in single variable regression (Figure 5). F (10.60) is significant at the 95% confidence level. R^2 is 0.779. Mean weight of 4.0–5.9-inch-long parr was also closely related to rainfall in July and August in year of the estimate (Figure 6). F (14.82) is significant at the 95% confidence level and R^2 is 0.831.

MANAGEMENT IMPLICATIONS

Within the limits of our regression data magnitude of stream flow as indicated by rainfall appears to be the most important single variable influencing standing crops of juvenile salmon at Barrows Stream. From the fishery manager's viewpoint, this is indeed fortunate for many salmon spawning and nursery areas in Maine lend themselves to water control through construction of small, inexpensive water storage dams that can be utilized to maintain minimum flows throughout dry months.

The exact effects of such a dam are now being studied at Barrows Stream—effects that will be the subject of a later paper.

TABLE 17.—*Equations, description of variables, F values, and coefficients of determination for significant linear regressions of numerical standing crops of salmon older than age 0+ ($\hat{Y}$), on other variables, Barrows Stream, 1960–1965*

Equation number	Equation	Description of independent variables				
		X_1	X_2	X_3	F	R^2
1	$\hat{Y} = 16.94 + 17.01X_3$	Numerical standing crop of all fish, year prior to estimate	Weight standing crop of all salmon, year prior to estimate	Weight standing crop of all salmon, year of estimate	555.80**	0.994
2	$\hat{Y} = 120.79 - 0.071X_1 + 22.29X_2$	Same	Same	Same	44.00*	0.977
3	$\hat{Y} = 33.36 - 0.005X_1 + 15.99X_3$	Same	Same	Same	3,387.69**	0.999
4	$\hat{Y} = 26.69 - 1.55X_2 + 17.12X_3$	Same	Same	Same	1,199.25**	0.999
5	$\hat{Y} = 41.80 - 0.011X_1 + 2.35X_2 + 14.38X_3$	Same	Same	Same	270,000**	0.999

* Significant at 95 percent confidence level.
** Significant at 99 percent confidence level.

We were rather surprised at the low degree of interaction in general between standing crops of salmon and standing crops of species other than salmon. We suspected at the inception of the study that analysis by regression and correlation would reveal that competition from other species, particularly white suckers, would tend to depress standing crops of salmon. While correlation coefficients usually revealed an inverse relationship between these variables, none of the correlation relationships even approached significance.

In general, salmon and other species tended to respond to rainfall concurrently but with salmon apparently showing the greatest response. We suspect that increased flows create a disproportionate amount of habitat in favor of the salmon. That is, more of the stream becomes riffle area than becomes a lentic-type environment, presumably preferred by species such as the creek chub and fallfish.

ACKNOWLEDGMENTS

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The Weight-Length Relationship of the Atlantic Salmon

By William S. Hoar
University of New Brunswick

(*Received for publication September 12, 1939*)

ABSTRACT

Changes in the condition of the Atlantic salmon have been traced throughout the life of the fish. During two periods only does the coefficient of condition—studied through comparisons of the weight-length relationships—deviate widely from a value of one. At the beginning of the river life (on emerging from the gravel), and at the beginning of the sea life (during smolt metamorphosis), the coefficient is lower. For parr and adult salmon the factor varies with the size, age, and sex of the fish, the season of the year and the environment. The last three factors influence the condition of the smolt. For adult salmon, no constant difference is found in the condition of "spring" and "summer" fish, nor between fish which migrated to the sea as two- or three-year smolts. Spawned fish, taken during commercial fishing, are as well conditioned as maiden fish.

The relationship between the measurements of the different bodily parts of any species of fish remains relatively constant throughout life. In so far as this is true the weight varies as the cube of the length. Since, however, this relationship is not absolutely constant we have fat and slender fish. Fish are often compared as to condition or fatness on the basis of the factor obtained by dividing 100 times the weight by the cube of the length. This factor, most frequently referred to as the "coefficient of condition", approximates unity when the weight is expressed in grams and the length in centimetres. It is evident that any increase of weight over length will raise the factor, while its value will fall if the animal becomes thinner.

Our data can be most readily presented by treating separately (1) those for the parr stage when the fish are living in the river; (2) those for the stage of transformation into the smolt before going to sea; and (3) those for the larger salmon as taken in the sea.

MATERIALS AND METHODS

The data are derived from salmon of the Margaree river, N.S., collected during the summers of 1936 and 1937; and from salmon of Saint John harbour, N.B., and vicinity collected in 1938. The parr and smolt were all of the Margaree river, while adult salmon were examined from both localities.

The fresh water salmon were preserved in a 2% to 4% solution of formaldehyde, and, at a later date, measured as to total length to the nearest millimetre, and weighed to the nearest centigram. Calculations show that no error is involved in an answer correct to the second decimal place by such measurements and weights. Preservation in formaldehyde, however, raises the coefficient of condition by increasing the weight and decreasing the length of the fish. The precise amount of this increase varies considerably, depending on the strength of the formaldehyde and the physiological condition of the fish. For smolt the weight increases for 3 days after preservation and thereafter decreases slightly for about 2 days. Parr preserved in 1% and 4% solutions show the same order of change, although the fish takes up water for a longer time (11 to 12 days) and continues to lose it longer thereafter (12 to 15 days). Parr preserved in 2% formaldehyde, on the other hand, absorb much more water than those in 1% or 4% solutions and do not lose it subsequently. As to shortening, neither parr nor smolt show any change after the first 2 or 3 days. It is evident from the summary of results given in table I that, for parr, 2% formaldehyde produces a greater increase in

Table I. Changes in the coefficient of condition caused by preservation in formaldehyde

	Fish (no.)	Formaldehyde (percentage)	Original length (cm.)	Original "K"	Ultimate per cent increase in "K"
Smolt.........	11	4	15.9	0.74	11.0
	1	2	19.3	0.77	9.1
Parr..........	5	1	14.5	1.00	19.4
	5	2	15.6	0.93	31.0
	5	4	12.7	0.97	19.5

the coefficient of condition that either a 1% or a 4% solution (31% increase as compared to a 20% increase), and that the increase is greater for parr than for smolts (20% as compared to 11%).

Since the material under consideration was preserved in solutions ranging in strength from 2% to 4%, we consider a 30% increase in the coefficient of condition to be maximum for the parr and a 10% increase to be maximum for the smolt. No attempt has been made to adjust the factors for this increase since the exact percentages of solutions used in preservation were not always known. However, sufficient measurements have been made on fresh fish to show that the same order of change prevails in both fresh and preserved specimens.

Mature salmon were measured to the nearest centimetre (total length) and weighed to the nearest one-half pound. The weight in pounds was converted into the equivalent gram weight using the conversion factor, 1 lb. = 0.4536 kg. The possible error in the coefficient of condition as based upon measurements and weights of such limited accuracy has been calculated for four representative fish. This ranges from ±5% for a 26.5-pound fish to ±9% for a 10-pound fish.

The errors involved in calculation are such that it is necessary to have a fair number of fish from each locality or of each stage if the average value is to be representative. However, even when the numbers of individuals were not sufficiently great to give statistically significant differences, the fact that the same sequence of change was found repeatedly in going from locality to locality or from stage to stage leads one to believe that such sequence is an actuality. It is upon such changes as these that we base the following conclusions.

EARLY RIVER LIFE

In Relation to Age

Belding (1936), in his study of Newfoundland parr, has shown that there is a progressive increase in the coefficient of condition throughout the fresh water

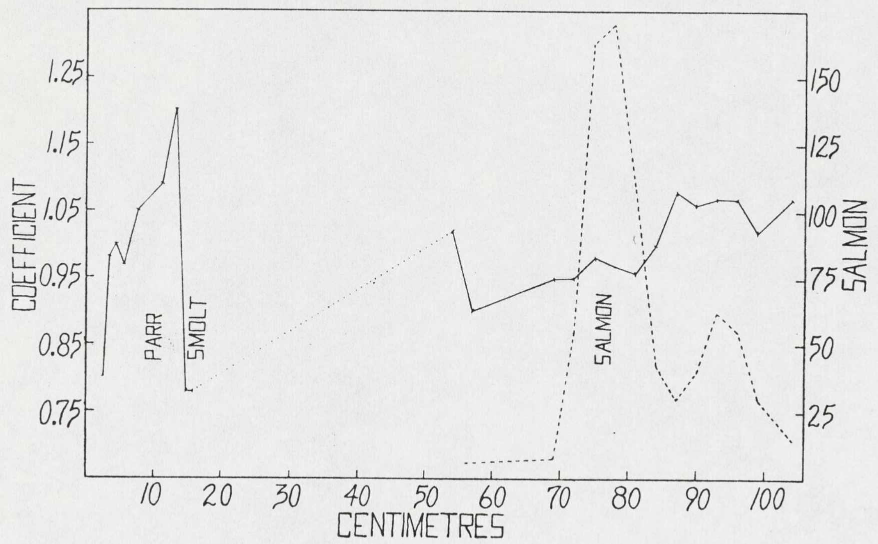

Figure 1. Changes in the coefficient of condition of the Margaree salmon of 1937 in relation to their lengths is shown by the continuous line. The broken line represents numbers of mature salmon. The interval represented by the dotted line is for the post-smolt period where no figures are available.

Table II. The coefficient of condition of parr of different ages

Source of material	1-year parr				2-year parr				3-year parr			
	Specimens (no.)	Aver. length (cm.)	Coefficient		Specimens (no.)	Aver. length (cm.)	Coefficient		Specimens (no.)	Aver. length (cm.)	Coefficient	
			Range	Aver.			Range	Aver.			Range	Aver.
Entire river, 1936.	37	9.6	0.93–1.24	1.07	17	12.6	0.95–1.45	1.16				
Entire river, 1937.	51	7.8	0.85–1.25	1.04	33	11.0	0.87–1.38	1.09	6	13.0	1.03–1.33	1.17
Forest Glen brook, Aug. 4, 1937 ..	21	7.7	0.89–1.13	1.00	17	10.6	0.87–1.38	1.06	3	12.4	1.03–1.33	1.16
River below Forks, June, 1937....	18	7.7	0.85–1.25	1.09	7	10.6	1.01–1.28	1.11				

life. The data for parr of the Margaree river are summarized in table II, and the results show graphically in figure 1.

In detail the figures show that the condition factor of the yearling parr is lower than that of the two-year-olds by 5%, and lower than that of the three-year-olds by 11%. Moreover, the two-year-olds have a factor 7.5% lower than that of the three-year-olds. Thus, there is a progressive rise in the coefficient of condition of the parr with increasing size. Clark (1928), Hart (1931) and Keys (1928) have found the same thing for other species of fish, although the results differ from those of Crozier and Hecht (1914) or Hecht (1913 and 1916). It is conceivable that conditions may differ in the different species of fish studied by these workers.

Seasonal Changes

Superimposed on this progressive improvement in condition which occurs with the ageing of the fish there are definite seasonal variations within the different year classes. A study of figure 2 and table III will show that the condition of

Table III. Seasonal changes in the coefficient of condition of the parr

Place	Date	Fish (no.)	Aver. length (cm.)	Coefficient of condition	
				Range	Average
Margaree Forks.....	June 12-15 July 27	25 18	2.9 4.5	0.66–1.11 0.82–1.15	0.89 1.00
Margaree Forks.....	June 11 July 7	5 10	8.3 9.2	0.96–1.13 1.00–1.10	1.02 1.06
Doyle's bridge......	July 5 Aug. 16	16 10	3.9 6.1	0.90–1.16 0.88–1.13	0.999 0.992
Forest Glen brook ...	July 4 Aug. 4	8 21	6.0 7.7	1.01–1.17 0.89–1.13	1.07 1.00
Forest Glen brook ...	July 4 Aug. 4	5 17	12.0 10.6	1.05–1.21 0.87–1.38	1.13 1.07

parr of different ages improves rapidly during June and early July. After the middle of July, however, it remains constant or actually decreases although the fish continues to increase in length. This is parallel to the condition found in the mature salmon. It is probably due to the cessation or slackening of feeding in both cases.

The rise in the coefficient of condition of salmon during their first summer after emerging from the gravel is particularly pronounced and rapid (figure 1 and table III). In both 1936 and 1937 the average coefficient reached a value of 1.00 by the second week of July, and thereafter showed no further seasonal increase. Hence the young salmon, beginning active life with a comparatively low condition factor (average value of 0.89 on June 12), attains, in four weeks, its maximum degree of fatness for the first year.

In Relation to Environment

Belding (1936) has studied the effect of the environment on the contour (hence also the coefficient of condition) of salmon parr. He finds that the coefficient of the parr in four similar Newfoundland rivers, irrespective of the rates of growth of the fish, is the same, but different from that of two dissimilar rivers. The higher coefficients are associated with a smaller number of vertebrae and a deeper contour. Temperature is considered to be the causal factor.

A study of the Margaree river is of interest in this connection. This river

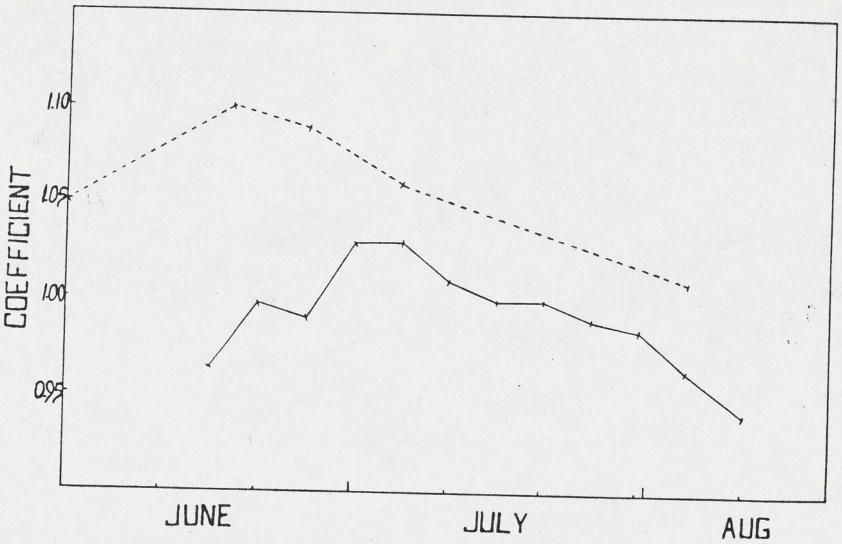

Figure 2. Variations in the coefficient of condition of yearling parr (broken line) and of mature salmon (continuous line) in relation to the season, 1937

has two main branches of very different character. The Northeast Margaree arises in the highlands where the snow remains long in the spring. The temperature of its water is much lower than that of the Southwest Margaree, flowing through the lowlands and having a large shallow lake to control its volume and temperature. In the former, long stretches of clean gravel covered with rapid and shallow waters must yield a very scanty food supply in comparison with the deeper and warmer waters of the Southwest branch.

It is evident from table IV that the parr from the Southwest branch are both longer and fatter than those from the Northeast. The highest conditioned salmon obtained (factors as high as 1.45) were parr from the Southwest Margaree. Belding and Clark (1938) found condition factor differences of a similar order in their parr collections from this river in 1934. They attribute such differences

Table IV. The environment and the coefficient of condition of yearling parr

Source of material	Specimens (no.)	Aver. length (cm.)	Coefficient	
			Range	Average
Southwest Margaree				
June 15, 1936	14	10.9	1.02–1.24	1.13
June 15-26, 1936	4	8.4	1.16–1.22	1.19
Northeast Margaree				
June 11, 1936	10	8.3	0.99–1.13	1.01
July 4, 1937	8	6.0	1.01–1.17	1.07
Aug. 4, 1937	13	8.2	1.00–1.30	1.08

to variations in the environmental conditions, water temperature and food supply being most important. Our data have afforded an example of the effect which variations in the latter factor may have on the coefficient of condition. Salmon parr were collected from Forest Glen brook on August 4 of both 1936 and 1937. For both the youngest and older year classes the factors were higher in 1936. Food supply is suggested as an explanation since it has been found that, due to the control of the fish eating birds, the numbers of salmon feeding were much greater in 1937 (White 1939). In detail the average coefficient of the youngest for 1936 was 1.14, in contrast to 0.99 in 1937; and for the older fish 1.08 in 1936 as against 1.04 in 1937. Since there were more yearling fish in the former year the actual difference for the older fish is greater than indicated. The figures serve as a concrete example of the expected condition factor variations brought about by feeding conditions. It is quite evident that the environment (temperature and food) is a potent factor influencing the condition of the fish and will explain the difference in fatness of the parr from the Northeast and Southwest Margaree rivers.

In Relation to Sex

Menzies (1924), studying the mature salmon, finds that male fish are invariably thinner than female fish of the same length (our mature fish could not readily be sexed with accuracy). Hile (1936), on the other hand, points out that there is no constant difference in the coefficient of condition of male and female ciscoes. For the parr of both 1936 and 1937, our data, as given in table V, show opposite conditions.

The male salmon regularly attains sexual maturity while in the river, and it was thought that this might account for the higher factors of the male parr. The table shows, however, not only that male parr taken in June before the testis shows any evidence of increased growth, and when the ovary is of greater size than the testis, have higher factors than the females, but also that the factors of males taken in August are higher, relative to the females, than those taken in June. Hence, although sexual maturation may cause a slight increase in the

Table V. Differences in the coefficient of condition of male and female parr

Date	Age (yrs.)	Females				Males				
		Specimens (no.)	Aver. length (cm.)	Coefficient		Specimens (no.)	Aver. length (cm.)	Coefficient		
				Range	Aver.			Range	Aver.	% greater than female factor
1936	1+	23	9.6	0.92–1.21	1.06	14	9.5	0.96–1.24	1.09	
	2+	5	12.5	0.95–1.20	1.10	9	12.4	0.98–1.38	1.19	
1937	1+	33	8.1	0.89–1.23	1.04	18	7.7	0.96–1.25	1.06	
	2+	14	10.8	0.87–1.21	1.04	17	11.0	0.99–1.38	1.11	
June	1+	30	9.2	0.93–1.23	1.07	15	9.2	0.96–1.25	1.12	4.7
	2+	7	10.6	1.01–1.17	1.08	11	12.2	0.99–1.38	1.16	7.4
August	1+	12	7.4	0.89–1.08	0.98	9	8.0	0.96–1.13	1.03	5.1
	2+	6	10.7	0.87–1.06	0.96	10	10.5	1.00–1.25	1.10	14.6

coefficient of condition, nevertheless immature males have higher factors than females.

Individual Variations

Finally, as might be expected, there are individual variations among the fish from any part of a stream and of all ages. Numerous examples can be given to show that fish of the same length, taken at the same time and from the same place and hence preserved together, may have very different factors. Table VI illustrates this point. Certainly such variations in fatness occur in any group of animals. The examples are given to show that care must be taken in attaching a great significance to small variations in the coefficient of condition. The variations which we have discussed, however, seem to be of sufficient magnitude, and to have shown a sufficient degree of order during the two years to be of significance.

Table VI. Individual variations in the coefficient of condition

Source of material	Length (cm.)	Coefficient for different fish
Forest Glen brook July 4..	5.8	1.03 and 1.10
Aug. 4..	10.1	0.88 and 1.10
	11.4	0.99 and 1.06
	7.5	0.89 and 0.98
S. W. Margaree June 26..	8.1	1.16 and 1.22

THE TRANSITIONAL PERIOD

Before entering upon its life in the sea the salmon undergoes a characteristic metamorphosis, assuming the appearance of a miniature adult fish through a silvery layer of guanin crystals covering the prominent parr markings. Figure 1 shows the coefficient of condition of the smolt in relation to that of salmon of other stages. The factor is, on the average, lower than that of any salmon with the exception of the emerging fry. In comparison with parr the average factor for smolts is lower than that of the lowest parr studied, while the highest smolt condition factors are less than 4% greater than those of the lowest parr in the corresponding age group.

Although stomach analyses show that the smolt is feeding voraciously, gross dissections reveal the fact that the visceral fat deposits, so prominent in the parr, have been lost. It should be pointed out also that, although the coefficient of condition is falling, the fish is presumably increasing in length, since scale studies show that spring growth is made in over 95% of the Margaree smolts. This growth, as shown by table VII, is slightly less rapid than that made by the parr during the same period. It will be recalled that the coefficient of condition of

Table VII. Comparison of the spring growth of parr and smolt scales

Source of material	Specimens		No. of circuli		Width of circuli		% growth	
	No.	Aver. length (cm.)	Range	Aver.	Range	Aver.	Range	Aver.
Margaree river, 1936								
June 11-15, 2-year parr	8	12.1	4–8	6	0.20–0.28	0.23	20–40	30.2
2-year smolt	15	14.5	2–8	5	0.21–0.32	0.29	10–36	27.5
Forest Glen brook, 1937								
July 4, 2-year parr	5	11.9	4–8	6	0.16–0.22	0.19	18–34	25.0
July 6, 2-year smolt	4	12.5	3–4	3½	0.22–0.36	0.27	17–24	21.5
July 22, 3-year parr	1	13.2		9		0.19		31.0
3-year smolt	4	14.3	5–9	7	0.14–0.26	0.20	14–34	26.0

the latter is rising at this time. This seems to indicate that the fall in the smolt's condition involves something more than an apparent loss in weight due to the increase in length.

In Relation to Time and Place of Capture

Average values of the coefficient of the smolt's condition are given in table VIII. From the standpoint of time, the 1936 data show that the fish taken at Margaree Harbour during the first week of June had a factor 9% lower than that of those taken during the second week; while in 1937 the average value of the coefficient of condition for May smolts at the Harbour was 12% lower than that

TABLE VIII. The coefficient of condition of smolt taken at different times and in different places

Source of material		Speci-mens (no.)	Aver. length (cm.)	Coefficient	
				Range	Average
Margaree Harbour,	June, 1936	89	15.1	0.69–1.01	0.84
"Up river",	June, 1936	14	14.3	0.82–0.98	0.90
Margaree Harbour,	June, 1937	118	15.1	0.57–1.00	0.77
Forest Glen Brook,	June, 1937	41	14.0	0.72–1.07	0.87
Margaree Harbour,	June 1-7, 1936	50	15.4	0.69–0.99	0.80
	June 9-13, 1936	39	14.7	0.72–1.01	0.88
Margaree Harbour,	May 22-30, 1937	18	15.4	0.66–0.88	0.74
	June 1-10, 1937	73	15.0	0.57–1.00	0.75
	June 11-29, 1937	27	15.1	0.71–0.96	0.84

for June fish. The examples indicate that the smolt which leave the river earlier in the season are thinner than those which leave later. A study of the coefficient in relation to the place of capture shows that, in every case, those fish farthest up river from the harbour mouth have the highest factors.

Thus we see that the smolts with the highest coefficients are those taken farthest up the river earliest in the season. Or, those fish nearest the sea, both in point of time and place, have the lowest condition factors. The gradual character of the smolt metamorphosis will explain this—at least in part. Some of the fish taken up river and classed as smolts are doubtless incompletely transformed. A progressive widening of the circuli on the smolt scale is evidence of the gradual character of the smolt transformation. However, the data do not exclude the possibility that the smolt, following the loss of weight concurrent with the metamorphosis, improves in condition again as it lingers in the river. Lovern (1934) suggests that the fat deposits are used up to effect the transformation. Our data may indicate that following this loss the fish commences to gain weight again as a "new individual".

In Smolt Retained in Fresh Water

In 1937 an artificial barrier in Forest Glen brook prevented certain smolts from descending to the sea, thus interfering with their normal behaviour. Average condition factors for the 2- and 3-year fish collected here between June 1 and 10 were 0.92 and 0.89 respectively as compared to 0.79 and 0.81 for fish taken between July 11 and August 7. These differences in the coefficient of condition may not be due primarily to the retention of the smolt in fresh water, since "smolt" taken in Forest Glen brook as late as June 10 may be only incompletely transformed. However, factors as low as 0.79 and 0.81 suggest that the fish at any rate did not increase in weight following the metamorphosis. Scale studies confirm this conclusion. The scales of the fish taken between July 11 and August 7 show a distinct narrowing of the circuli and indicate that conditions were not suitable for the continued normal growth of the fish. The coefficients of condition are in marked contrast to those of fish which go to the sea in the usual manner, since grilse have, on the average, a factor of more than 1. Growing conditions are admittedly very slow in Forest Glen brook where 73% of the fish are 3-year smolts as compared to 27% for the Margaree river as a whole; and where fry taken during the first week of August are only, on the average, 4.0 cm. long in contrast to the 4.9 cm. fish at Widow Lord's brook or the 6.1 cm. fish at Doyle's bridge. However, even in lake Ainslie, at the mouth of Trout brook, where very rapid scale growth takes place and growing conditions are presumably excellent, there is little change in the coefficient of condition. On August 2, 1937, a 22.6 cm. fish was taken there showing excellent smolt growth for the current year but with a condition factor of only 0.85. Examples of dwarfing produced in Atlantic salmon through retention in the fresh water may be found in the literature (Menzies 1912). Salmon of the post-smolt stage are dependent for their rapid growth upon reaching the salt water.

In Relation to Sex

From table IX it will be seen that the variations in the coefficient of condition

Table IX. The coefficient of condition of male and female smolt

Date	Age (yrs.)	Females				Males			
		Specimens (no.)	Aver. length (cm.)	Coefficient		Specimens (no.)	Aver. length (cm.)	Coefficient	
				Range	Aver.			Range	Aver.
1936	2+	60	14.8	0.69–0.98	0.84	17	14.2	0.80–1.01	0.89
	3+	13	15.5	0.78–0.99	0.87	7	15.5	0.73–0.99	0.90
1937	2+	62	14.6	0.64–1.07	0.77	20	15.0	0.66–0.96	0.81
	3+	19	15.4	0.57–1.07	0.74	12	15.7	0.66–1.05	0.79

of male and female smolt are of the same order as those of the male and female parr. In every case the males have the advantage over the females.

In Relation to Age

The coefficient of the smolt's condition was examined in relation to the age of the fish at migration. In 1936 the average factor for 3-year smolts was 0.89 as compared to 0.85 for the 2-year fish. In 1937 the average coefficient for fish of both ages was the same (0.78), although the 3-year salmon were a full centimetre longer than the 2-year fish. It will be recalled that the older salmon parr have higher coefficients. The condition found in the smolt may be interpreted in one of two ways. The 3-year smolts may represent the "runts" of the parr, since they did not go to sea as 2-year fish. Hence their condition would be lower than is normal for fish of that age. Or, the smolt metamorphosis may erase any difference in condition attained by the parr of different ages and initiate a new period in the growth of the salmon.

THE SEA LIFE

In Relation to Age of Migration as Smolts

Nall (1926a) finds no real difference in the condition of the sea trout of the river Ewe and loch Maree which migrated as 2-year smolts and those which migrated as 3-year fish. On the other hand, in his studies of the river Ailort and loch Eilt fish (1926b) he concludes that trout migrating as 3-year smolts have a distinct advantage in fatness over the 2-year migrants. In this connection we have examined the June collection of the Saint John fish. No relationship between the coefficient of condition and the migrating age is evident (table X). This is in agreement with our conclusions as to the effect of the smolt metamorphosis. It will be recalled that in the Margaree fish this transformation seemed to erase the differences so evident in the parr.

Table X. The coefficient of condition of the mature salmon in relation to its age as a migrating smolt

Source of material	2-year migrants				3-year migrants			
	Specimens (no.)	Aver. length (cm.)	Coefficient Range	Coefficient Aver.	Specimens (no.)	Aver. length (cm.)	Coefficient Range	Coefficient Aver.
Saint John.......	41	82	0.87–1.19	1.03	94	82	0.87–1.19	1.04
Lorneville.......	59	82	0.84–1.28	1.01	92	82	0.76–1.19	1.00
Dipper harbour..	71	82	0.94–1.33	1.12	56	82	0.89–1.37	1.12

In Relation to Sea-age and Length

For both Margaree and Saint John salmon there is a progressive rise in the coefficient of condition with the increase in length of the fish (figures 1 and 3). Menzies (1924) has shown that this occurs in the salmon on the coast of Scotland. For other species of fish, Clark (1928), Keys (1928), and Hart (1931) have shown with an abundance of material that the weight increases at a slightly greater rate than the cube of the length. It is evident, however, that for our salmon the curve is not a continuous one. In figure 1, for Margaree fish, three distinct peaks—occurring at approximately 75 cm., 90 cm., and 100+cm.—are noted. The graph for 1936 was identical in form. Scale studies of these fish show that 92.5% of the salmon between the lengths of 75 and 85 cm. have spent two full years in the sea; 100% of those between 85 and 100 cm. are 3-year fish; and 75% of the small number measuring over 100 cm. have been to sea more than three years. The three points, then, correspond to the three sea feeding ages. In the same figure, the curve for numbers of salmon indicates that the peaks of condition are coincident also with maximum numbers of fish. The majority of the fish of any sea year have reached a certain length which varies only within narrow limits. Those fish which have not attained that length, the "runts" of the sample, are thinner. Menzies (1924) expresses the same thing when he says that the long fish of one age group are heavier than fish of equal length to themselves but which are the shorter fish of the next older age group. It should be pointed out, however, that this does not seem to be the rule for certain other fishes. Thus, Hile (1936) finds the coefficient of condition of the cisco to be independent of age in fish of the same length.

The Saint John fish (figures 3 and 4) indicate that further factors modify

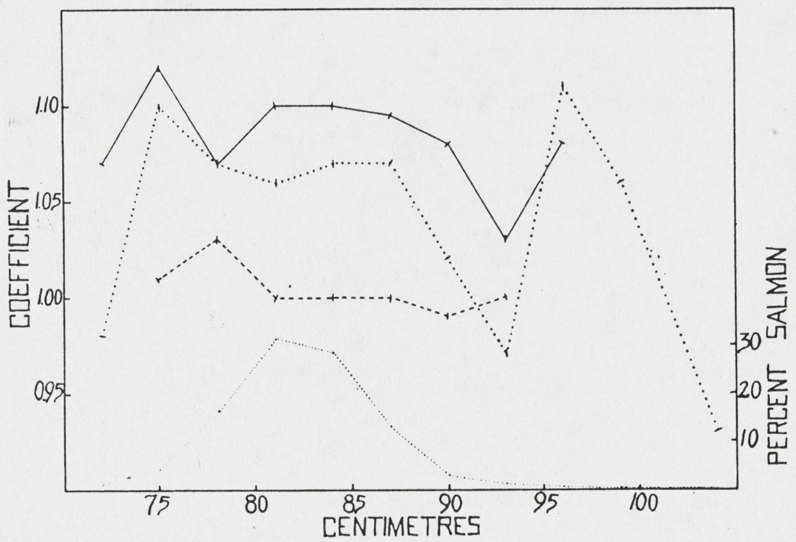

FIGURE 3. The coefficient of condition in relation to the length of the fish at Dipper harbour (continuous line), at Saint John harbour (heavily dotted line) and at Lorneville (broken line). The line of fine dots represents the percentage of salmon of various lengths in the Saint John harbour catch. The per cent curve was almost identical at the other places.

the simple rise in condition with increasing length. An analysis of the numbers of fish in relation to the various lengths (figures 3 and 4) shows that the majority of the Saint John salmon range from 78 to 88 cm. in length. Maiden fish between the lengths of 72 and 90 cm. have, almost uniformly, spent two full years in the sea. From our study of the Margaree data we should expect that the fish measuring between 80 and 90 cm. would have the highest coefficients of condition. In no case is this the simple relationship. A separation of the 2-sea-year salmon into the "spring" and "summer" groups emphasized by many writers shows essentially the same condition (figure 4). In general it seems fair to say that the fish between the lengths of 78 and 88 cm. have the highest coefficients, but it is also evident that salmon of 75 cm. (presumably the "runts" of the group) are as fat or fatter than those of 85 cm., and that 2-sea-year fish of either extreme in length (70 to 73 cm. or 88 to 90 cm.) are in poorer condition than most of the fish. Figure 1 does not contradict this, although the scale studies were not extensive enough to analyze the data completely. The results seem to be in partial agreement with Menzies results for the salmon of Scotland. His diagrams for the fish

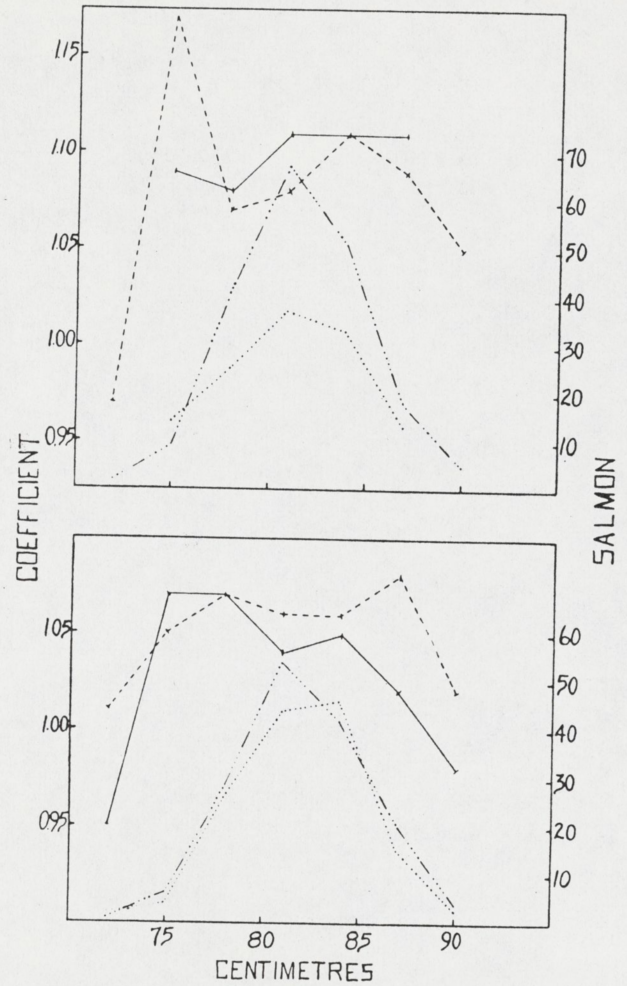

FIGURE 4. Variations in the coefficient of condition for 2-year salmon (continuous line) and for 2+-year salmon (broken line) of different lengths; at Dipper harbour (upper graph) and at Saint John harbour (lower graph). The continuously and discontinuously dotted lines represent, respectively, the numbers of 2- and 2+-year fish in the different samples.

of the Spey (1923a, p. 15) show that salmon of all age groups have much lower factors at the extreme lengths. He relates this to the small number of fish. The other studies do not show the same uniformity. Thus, for the river Dee (Menzies and MacFarlane 1924b, p. 17) there is a falling off in the condition at the extreme lengths for the 1+and the 3-year fish, but not for the 2- and the 2+-year salmon; while the Spey studies (Menzies and MacFarlane 1924a, p. 16) show a continued rise with length for the fish of all age groups. However, a comparison of the diagrams (Menzies 1923a, p. 15, and Menzies and MacFarlane 1924a, p. 16) suggests that the extremes were not as great in those cases exhibiting no fall at the extreme length. It seems that the exceptionally long fish as well as the "runts" are thinner than the average.

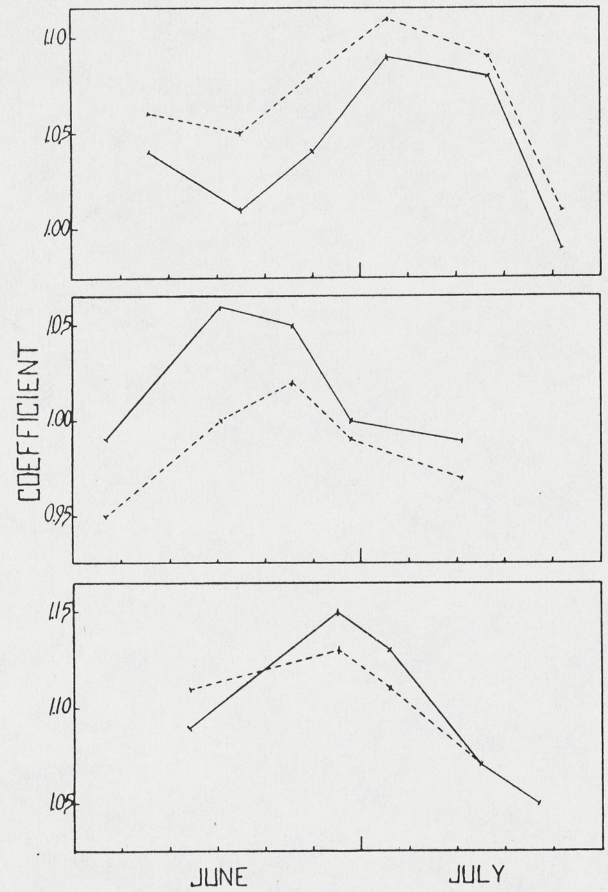

FIGURE 5. Seasonal variations in the coefficient of condition of the 2-year salmon (continuous line) and the 2+-year salmon (broken line) at Saint John (upper graph) at Lorneville (middle graph) and at Dipper harbour (lower graph).

In "Spring" vs. "Summer" Fish

It is customary to divide the salmon of any sea year into "summer" fish (those which have added wide circuli to the scales during the current season) and "spring" fish (those which show no growth for the current year or have added bands of the winter type). The significance of these types of growth seems to be quite unknown (Menzies and MacFarlane 1924b). However, the Saint John data have been analyzed in this light for the sake of comparisons. Figure 5 shows the results for salmon taken in Saint John harbour and for Saint John fish taken at two different points in the sea. "Summer" fish in the harbour were uniformly in better condition than "spring" fish (figure 5); a condition similar to that generally found in the rivers Dee and Spey in Scotland (Menzies and MacFarlane 1924a and b). In contrast, however, "spring" fish had the advantage very definitely at Lorneville and to a small degree at Dipper Harbour (figure 5). This latter condition is similar to that found in the rivers Moisie of Quebec and Wye of England (MacFarlane 1928), and occasionally in Scottish rivers (Menzies and MacFarlane 1932). Corbett (1922) finds that, in general, "spring" salmon are fatter and heavier than the "summer" or "autumn" fish. What the apparent contradictions in the Saint John data may mean is not evident.

In Maiden vs. Spawned Fish

Lee (1913) states that salmon which have spawned once are as fat and well-conditioned as maiden fish. Menzies, on the other hand, in his studies of the rivers Spey and Dee, finds that this class of fish has invariably a lower coefficient of condition than maiden fish of the same age. In his study of the river Conon (1928) he points out that small "spring" fish of the short absence type have not recovered to the condition of maiden fish, but that grilse spawners of the short absence type and small "spring" fish of the long absence type have recovered well. Nall (1926a and b) finds little real difference in the condition of spawned and maiden sea trout.

The data for the Saint John salmon are presented in table XI. In this the 2-sea-year maiden fish are compared with the grilse spawners of the long absence type, and the 3-sea-year maiden fish with the 2-year spawners of the long absence

Table XI. Saint John salmon. Coefficient of condition of fish with different histories and at different places

Material	Saint John harbour				Lorneville				Dipper harbour			
	Specimens (no.)	Average length (cm.)	Coefficient		Specimens (no.)	Average length (cm.)	Coefficient		Specimens (no.)	Average length (cm.)	Coefficient	
			Range	Aver.			Range	Aver.			Range	Aver.
Maiden fish												
2-sea-years	296	82	0.72–1.38	1.06	186	84	0.79–1.28	1.00	330	81	0.81–1.37	1.09
3-sea-years	4	92	0.86–1.03	0.95	6	86	0.92–1.11	1.02	20	88	0.81–1.26	1.07
Spawned fish (long absence type)												
All ages	22	92	0.87–1.32	1.05	12	86	0.87–1.17	0.99	16	90	0.89–1.44	1.12
1-sea-year, spawned	5	85	0.87–1.11	1.02	3	83	0.93–1.07	1.01	5	83	1.07–1.29	1.19
2-sea-years, spawned	17	93	0.89–1.32	1.06	9	87	0.87–1.17	0.98	8	91	0.89–1.19	1.08
Spawned fish (short absence type)												
All ages	13	89	0.76–1.11	0.97	2	84	1.00–1.03	1.01	10	81	1.02–1.29	1.14

type, since in either case these fish are of approximately the same size and have spent the same length of time in the sea. A comparison of the condition of spawned and maiden fish of the same age (total number of years) would not be justified because of the larger size of the maiden fish and the effect which this has on the condition. Table XI fails to show any definite order between either maiden and spawned fish or between short and long absence types. It is concluded that, on the whole, these fish have recovered well by the time they come within range of the nets.

Seasonal Variations

Seasonal variations in the condition of mature salmon are shown graphically in figures 2, 5, and 6. As pointed out by Menzies (1923, etc.) for the salmon of

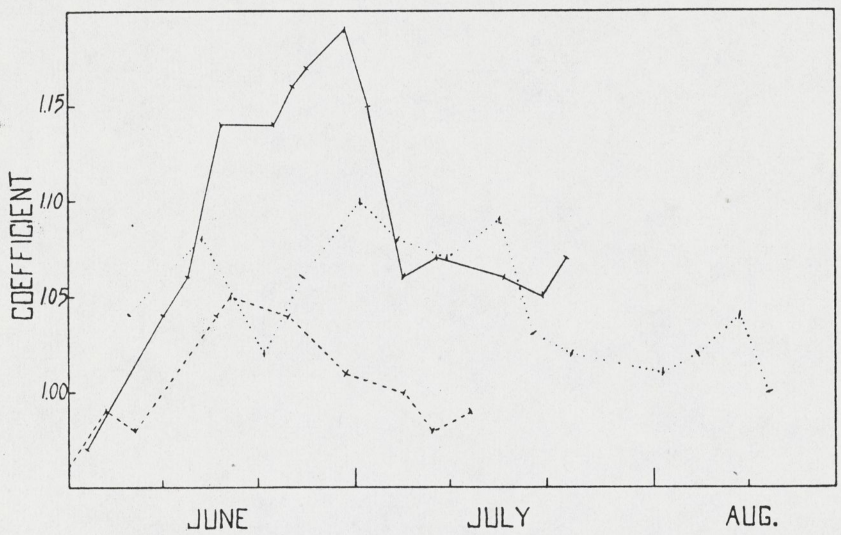

Figure 6. Seasonal changes in the coefficient of condition for the salmon taken at Dipper harbour (continuous line), in Saint John harbour (dotted line), and at Lorneville (broken line).

Scotland there is, in general, a rapid spring improvement followed by a falling off in condition during the late summer and autumn. He concludes that the rise is due partly to an increase in the size of the fish and partly to a real seasonal improvement. Thus two factors are to be considered, the relative size of the fish being caught and the changes in fatness—including the seasonal increase in size—due to summer feeding.

That the improvement is not dependent upon increasing numbers of larger and older fish appearing on the shore is proved by the Margaree data of 1935, where the average size of the fish declined while the coefficient of condition rose. Moreover, exactly the same order of change prevails in the salmon of Dipper harbour, where fishing is presumably in the salmon's feeding grounds and the size and age of the fish are quite uniform.

That the seasonal change is largely due to feeding habits is indicated by a series of about 500 digestive tract analyses of the Margaree fish in 1937. The cessation of feeding seemed quite abrupt and the coefficient of condition commenced to decline at about the same time (cf. fig. 2 and table XII). The evidence is not entirely conclusive since only about 30% of the fish at any time show evidence of feeding. The decrease in the proportion of fish having tape-worms was even more striking—90 to 100% of the salmon being parasitized before the first of July and only about 15% after that date. It would seem that tape-worms are dropped when the salmon ceases feeding. A less complete series of analyses on the Saint John fish in 1938 indicates that although there is a decrease in the number of fish feeding between the first and second week of July, some fish take food at least until the end of July—July 28, at Dipper harbour. Differences between the feeding times of the Margaree and Saint John fish are probably

TABLE XII. Digestive tract analyses of mature salmon.

Source of material	Specimens examined	Percentage feeding	Percentage parasitized
Margaree Harbour, 1937			
June 14	55	10.9	94
16	17	29.4	92
17	12	16.6	92
19	34	11.7	94
21	51	7.8	96
22	15	0.0	93
24	15	13.3	100
26	4	0.0	100
28	14	7.1	14[1]
29	22	45.4	77
30	13	23.0	23[1]
July 2	30	0.0	37[1]
5	52	0.0	25[1]
7	19	0.0	16[1]
9	41	0.0	19[1]
12	28	3.5	29[1]
Saint John[2], 1938			
June 18	147	5.4	
25	88	8.0	
July 2	19	21.0	
9	54	11.0	
16	62	4.8	
23	21	4.8	

[1]These percentages are high, since in most cases the majority of the tape-worms had been dropped and only small ones in small numbers remained. Tape-worms were reported as present if they were found at all.

[2]Scattered samples at Dipper harbour showed the presence of food until the end of the fishing—July 28.

correlated with the more abrupt seasonal rise in the water temperature in the gulf of St. Lawrence, resulting in an earlier peak in feeding conditions there. It may account for the lack of continuity in the curves of bay of Fundy fish (figure 6) in comparison with those for the fish of the Cape Breton coast (figure 2).

Menzies and MacFarlane (1924a), for the river Spey, conclude that condition in any age group improves as the season advances until August for "summer" fish and until the end of the main run for "spring" fish. In another river (1924b), however, "spring" fish showed a deterioration from month to month throughout the run. Figure 5, for Saint John fish, shows exactly the same order in both groups. We can only conclude from our data that salmon of any age show a rapid spring improvement in condition with a falling off in summer and autumn; and suggest feeding conditions as the most obvious explanation.

In Relation to Environment

That the environment has a very potent influence on the condition of the mature salmon will appear from a comparison of the curves in figures 1 and 6. It is evident that the coefficient of condition of the Margaree fish is consistently the lowest and that of the Dipper harbour fish the highest of the four series. Fish from the Cape Breton coast are both shorter and thinner than those of the bay of Fundy. Menzies (1923b) finds a similar contrast in his studies of the rivers Dee and Spey in Scotland. He discusses racial tendencies in his explanation of the differences shown by the fish of the two rivers. The differences shown by our salmon seem to be due to simple differences in environment. The bay of Fundy, in contrast to the gulf of St. Lawrence, provides a more uniform environment—due to the strong tide action—and a very excellent food supply. The herring fishery may be given as evidence of the latter fact. This is of great commercial importance in the bay of Fundy while on the Cape Breton coast herring are taken in very small numbers and only for local use. Moreover, within the bay itself feeding improves steadily on going westward toward the gulf of Maine. Thus, in 1936 there were only 3,380 barrels of herring from the coast of Saint John county as compared to 242,988 barrels from Charlotte county (Fisheries Statistics, 1937, p. 100). Feeding conditions would, then, be progressively better from Margaree harbour to Lorneville and to Dipper harbour. The coefficients of condition show the same order. Environmental influences seem to be more evident here than racial differences.

Figure 6 suggests further differences in the samples of salmon from the New Brunswick coast. There seems to be a rather definite difference in the time at which the seasonal height of the coefficient is reached at the three places. In order, the condition of the fish at Saint John, at Lorneville, and at Dipper harbour reaches a maximum and declines. Also, the coefficient continues to rise and is maintained for the longest time at Dipper harbour and for the shortest time at Saint John harbour. The fish at these different places, as far as the coefficient of condition is concerned, behave as distinct groups during the early part of the season. It is suggested that the salmon of the Saint John river are rather precisely distributed in the bay of Fundy, and that they tend to maintain their same relative position, at least up until the latter part of the summer when they are returning to the river in large numbers. Scale studies of these fish have led to the same conclusion (Hoar, unpublished). The complications of the latter part of the Saint John harbour curve are probably due to additions or subtractions of fish in the harbour.

SUMMARY

The condition of the Atlantic salmon, as studied through comparisons of the weight-length relationship of the fish, is found to vary considerably from place to place, from year to year, and from time to time during the same year. Minor variations are of little significance, but the same sequence of changes in the data of the different years and different places has led to the following conclusions.

The coefficient of condition of the fry on emerging from the gravel is less than one, but rises rapidly during the first four or five weeks to remain constant or to fall off toward the latter part of the summer.

The factor for parr is greater than one, and as high as that of the salmon at any time in its life history. The older parr have the higher factors. Male parr are fatter than females of the same age. The environment—food and temperature—has a definite effect. The coefficient rises rapidly during the spring and early summer to decline in the late summer and autumn.

The smolt transformation is marked by a distinct fall in the coefficient of condition. Smolt factors resemble those of the emerging fry. The earliest smolt to leave the river are the thinnest. If forced to remain in the river, smolt do not gain weight and grow as well as salmon which reach the sea.

The factor for the mature salmon shows pronounced variations but is, on the average, greater than one. The age of the smolt at migration is without effect on the condition factor of the mature salmon. In general the older fish have the higher coefficients. No constant relationship could be found between the factors of the "spring" and "summer" salmon in different places. In any age group the mass of the fish have a higher coefficient of condition than either the "runts" or the exceptionally long individuals. Spawned fish have recovered to the condition of maiden fish of the same size and sea-age by the time they are captured in the nets. The condition of the adult salmon improves rapidly during the spring and early summer, but declines in the late summer and autumn. The extent of this rise and its duration depends on the local feeding conditions.

This work has been carried out under the direction of Dr. A. G. Huntsman, Fisheries Research Board of Canada, to whom the writer acknowledges his indebtedness for numerous suggestions and for helpful criticism.

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KURT D. FAUSCH

SALMON GENETICS RESEARCH PROGRAM

ANNUAL REPORT

1980

The Salmon Genetics Research Program is a cooperative research program of the Department of Fisheries and Oceans and the International Atlantic Salmon Foundation. The core genetics research component is under scientific contract to the Huntsman Marine Laboratory, St. Andrews, N.B.

General

The year 1980 was one of increasing activity and significant progress with some long-term research projects. In accordance with suggestions from the Scientific Advisory Committee, the main scientific objective of the Program is the development of strains of salmon with traits appropriate for sea ranching. The approach is that such strains developed would not necessarily be taken to appropriate rivers for sea ranching but rather the technology of breeding to produce them would be transported. This change in emphasis was made easily as sea ranching has been an important component in the Program since its beginning; it was at first used as a tool to study survival, growth and maturity among the various strains produced at NASRC and appropriate practices and facilities have been in place since 1976-77.

Computer terminal facilities have been established with a link to the computer at the Biological Station. This allows direct entry of data and will eliminate the backlog which has developed since the beginning of the program. Reporting on adult returns from the first three year-classes (1974-76) has been done with useful results already pointing the way towards productive breeding studies in connection with sea ranching.

There were 52 returning two-sea-winter adults in 1980. No smolts were planted in 1979; therefore, there were no grilse in 1980. However, over 66,000 one- and two-year smolts were planted in 1980, the largest planting so far. When this smolt release was made, there were few herring in Passamaquoddy Bay and it is believed few smolts were destroyed as a result of incidental capture with herring. The year 1981 could be a record year for grilse returns at NASRC. A large number of smolts will probably be released in 1981 so adult returns should be high through 1983. The high production of smolts is owing to the competence of the fish culture staff and familiarity with the unique character of the hatching-rearing facilities which is developed, in any plant, only as a result of several years' experience. Having been in operation since 1974, the program achieved this high level of production for the first time in 1979-80.

An additional geneticist, Dr. Charles B. Schom, began collaboration with the NASRC staff in 1980. Dr. Schom is employed by the University of New Brunswick and has access to research facilities at NASRC under the terms of a position funded by I.B.M. Canada. Dr. Schom resides in St. Andrews and conducts research at NASRC. He has teaching and academic responsibilities at UNB Saint John. His research at NASRC concerns genetic aspects of resistance to low environmental pH and heavy metals and reduced generation time. Dr. Schom also interacts with the other scientists involved with ongoing research projects at NASRC.

A significant development in 1980 was the provision, through contractual arrangements with Marine Research Associates Ltd., of facilities to rear some of the NASRC smolts in sea cages. This allows the comparison of survival and growth-maturity patterns between sea ranching and intensive culture through the whole life cycle. Moreover, cage culture assures the preservation of strains which might give too few or no returns from sea ranching for subsequent breeding.

A number of cooperative programs with other scientists and graduate students are in progress as described below. The SGRP has been enlisted in a program to produce seed stock for aquaculture. This is done by accelerating hatching and early rearing using heated water. Advanced fry were provided in 1980 to a DFO fish culture station for production of smolts for 1981. Similar arrangements were made for smolt production in 1982. Kelts were supplied to the University of Rhode Island for genetics-aquaculture studies. Advanced parr beyond SGRP requirements were supplied to the Freshwater and Anadromous Division for release in the Petitcodiac system.

There is growing awareness on a national and international basis of the SGRP. This is reflected in the number of enquiries for genetics information and for opportunities to conduct graduate or joint research at NASRC. In addition to the primary activity associated with genetic aspects of sea ranching, the SGRP is in a position to provide valuable data for the emerging salmonid cage rearing industry in Atlantic Canada.

Sea Ranching

Sea ranching involves release of hatchery-reared salmon smolts which migrate, feed and grow at sea during 1-3 years before returning to the release site. This practice may be used as a means of enhancing runs of salmon for angling and commercial fisheries or as a form of aquaculture where individuals or companies harvest salmon upon return to their release sites. Sea ranching is based on the highly developed homing behavior of salmonids which results in segregation into more or less genetically distinct stocks which return to the tributary in which they spent their juvenile lives. Sea ranching, as employed at the NASRC, is a tool for evaluating the several stocks and many families reared in respect to percentage return as adults and age and size at maturity. As a result of advice given by the Scientific Advisory Committee in 1980, the main activity of the SGRP has been directed towards developing Atlantic salmon stocks with appropriate traits for sea ranching. The selection of wild stocks and the breeding program have been altered accordingly. In 1981 the SGRP, together with the Applied Fish Physiology Section at the Biological Station, will participate in a pilot study to demonstrate the commercial and biological feasibility of sea ranching in cooperation with an aquaculturist at Grand Manan. The data gathered at NASRC and through the pilot study from Grand Manan should give useful data for another application of sea ranching, the development of salmon runs in rivers as an enhancement technique to produce fish for angling and commercial fisheries.

Fish Culture Improvements

As part of a continuing upgrading of the fish culture facilities at NASRC the following modifications have been implemented or are in the planning stage. Cooling units were installed in the incubation water supply line to reduce the water temperature from 12°C to 8°C. High water temperatures during early incubation resulted in significant egg mortalities in previous years. A water supply pipeline extension to a greater depth in Chamcook Lake is scheduled for completion in spring (1981). Cooler water will then be available for improved summer parr growth, for early incubation, and for broodstock maintenance. Slightly warmer water will be available in winter and the supply line freeze-up hazard will be reduced.

Sand filters were installed in the incubation water supply lines to eliminate severe sedimentation on the eggs. Bird screens were installed over some of the smolt tanks. Their effectiveness is being assessed before the remaining smolt tanks are covered. Designs for "homemade" automatic feeders are being considered for the fry tanks. The use of pituitary preparations to accelerate maturity of broodstock effectively reduced the fall spawning period.

Cage Rearing Operations

One of the main objectives during Phase II of the SGRP was to develop the capability of rearing salmon from smolt to adult stages in sea cages to provide data on growth and maturation for selected strains and families and to ensure survival of such groups (not always possible through sea ranching) for genetic continuity. The SGRP does not have the financial or manpower capability, by itself, to undertake a cage rearing operation even on a modest scale. A contractual arrangement was made between the SGRP and Marine Research Associates Ltd. (a firm involved in salmonid aquaculture on Deer Island) whereby the SGRP provided smolts to be reared to market size or to maturity by MRA. About 25,000 smolts, representing several strains and with families identified by microtags, were moved in May to acclimation facilities on Deer Island and thence to sea cages at the MRA facility. MRA are collecting data on survival (and mortality), growth and maturity of these fish. In September 1981, an inventory will be conducted and 10% of the fish surviving will be set aside to be reared for another year to provide broodstock for the SGRP and to generate data on maturation as two-sea-winter salmon. The remaining fish will be the property of MRA and will be marketed during autumn and early winter of 1981. This contractual arrangement is excellent for both parties. The SGRP will generate valuable data on survival, growth and maturation patterns of its selected lines at no cost to the program. MRA is benefitting in the early stages of its aquaculture development by having access to large numbers of smolts not otherwise available. Similar arrangements will be made in 1981 and for the forseeable future to have NASRC smolts reared in sea cages by suitable entrepreneurs to be chosen by tender.

Ongoing Research Projects

Breeding Program NASRC Strain A

In 1980 the first generation hybrids of NASRC strain A were produced. The original objective was to produce approximately equal numbers of reciprocal Big Salmon x Magaguadavic and reciprocal Big Salmon x Rocky Brook crosses, each containing 2500 eggs per cross. According to this plan the ratio of Big Salmon, Magaguadavic and Rocky Brook genes in the f_1 generation would be 2:1:1 respectively. The Rocky Brook run in 1980 was very small and broodstock collection was not possible. Attempts to secure an alternate stock were unsuccessful and the only available source of Rocky Brook genes was precocious parr which had been reared at the Miramichi hatchery. Accordingly, Rocky Brook parr were crossed with Big Salmon females but the reciprocal crosses (Big Salmon males x Rocky Brook females) were not possible. Reciprocal Big Salmon x Magaguadavic crosses were made.

However, in order to compensate for the loss of Rocky Brook eggs, the number of eggs kept from each Magaguadavic female was doubled. Thus, while the ratio of Big Salmon, Magaguadavic and Rocky Brook parents was approximately 3:2:1, respectively, the ratio of their genes among the f_1 generation will be approximately 4:3:1. The number of families and eggs produced in each of the three hybrid crosses is summarized below:

Sire	Dam	#Families	#Eggs
Big Salmon	Magaguadavic	27	124,900
Magaguadavic	Big Salmon	22	55,900
Rocky Brook (parr)	Big Salmon	25	63,600
		74	244,400

Adult Returns, 1980

Adult salmon of the various pure strain and strain crosses produced in the diallel experiments have been intercepted annually since 1977. The return information for the first 3 years (1977-79) has been summarized in a report in 1980 to the Anadromous and Catadromous Committee of ICES (see published reports). In 1980, 52 returning adults were captured. All identifiable fish were larger salmon of the 1976 year-class which had been released as 1^+ smolts in 1978. This completes the grilse and larger salmon returns for the first three year-classes (1974-76). The 1976 year-class has been the most successful to date, returning 338 (or 2.2%) grilse and larger salmon of the original 15,500 smolts released. The complete 1976 year-class return information is summarized in Table 1.

Precocious Parr Studies

The survey to determine the incidence of precocious males among progeny from matings involving various combinations of precocious parr, grilse and salmon (approximately 107 family groups) was completed in 1980. The results indicate the rearing of full sibs as 1^+ and 2^+ smolts produced similar numbers of precocious parr. Generally, the age of maturity of the parents did not influence the number of precocious offspring. The selected families (all sired by precocious parr) and a group sired by salmon males (no family identification) subsequently reared in a single sea cage were harvested and data on sexual maturity and size taken. The incidence of mature individuals among salmon was consistent with maturity trends for the same strains when sea ranched in previous years. The incidences of grilse in hybrid strains were intermediate to parental strains. No correlation existed between the number of precocious parr in a family and the number of individuals which eventually matured as grilse. However, the mean incidence of precocious males was correlated to the proportion of grilse within strains. Relative to the progeny of large males, the use of precocious sires did not alter the proportion maturing after one sea winter. Similar data for sea ranched progeny of precocious and anadromous parents will be forthcoming in 1981.

Effects of pH on Sperm Motility and Fertilization Rate

The effects of varying levels of pH on fertilization and sperm motility were studied. The first apparent reduction in the duration of sperm activity occurred at pH 6.5. Subsequent reductions in activity followed a

Table 1. Atlantic salmon release and recapture summary for the 1976 year-class 1^+ smolts released in 1978. MM = Magaguadavic River, SS = Saint John River, RR = Rocky Brook, BB = Big Salmon River.

	Release 1978		Return 1979				Return 1980				Total		Ratio
Geno.	No. rel.[a]	Mean F.L. (cm)	No. ret.	% ret.	Mean F.L. (cm)	Mean wt. (kg)	No. ret.	% ret.	Mean F.L. (cm)	Mean wt. (kg)	No. ret.	% ret.	Grilse/ salmon
MM	455	20.8	3	0.66	57.7	2.0	5	1.10	79.6	6.3	8	1.76	0.6:1
MS	420	21.3	7	1.67	59.6	2.2	5	1.19	75.8	5.0	12	2.86	1.4:1
MR	565	20.6	11	1.95	55.2	1.8	1	0.18	76.0	5.8	12	2.12	11:1
MB	1477	18.0	12	0.81	57.8	2.3	6	0.41	77.2	5.4	18	1.22	2:1
SM	137	23.1	0				0				0		
SS	1058	19.4	8	0.76	55.5	2.0	6	0.57	82.2	6.1	14	1.32	1.3:1
SR	539	20.4	1	0.19	53.5	1.6	5	0.93	76.6	5.3	6	1.11	0.2:1
SB	939	18.6	6	0.64	57.8	2.2	3	0.32	77.7	5.6	9	0.96	2:1
RM	283	19.4	2	0.71	54.0	1.9	1	0.35	79.0	5.4	3	1.06	2:1
RS	306	22.0	2	0.65	54.0	1.9	0				2	0.65	2:0
RR	942	17.7	5	0.53	54.6	1.8	1	0.11	69.0	3.8	6	0.64	5:1
RB	1499	18.0	17	1.13	54.4	1.8	1	0.07	68.0	4.0	18	1.20	17:1
BM	397	20.8	10	2.52	58.6	2.5	0				10	2.52	10:0
BS	1037	18.5	8	0.77	59.5	2.0	2	0.19	76.0	5.2	10	0.96	4:1
BR	1171	18.4	21	1.79	57.2	2.2	1	0.09	80.0	5.2	22	1.88	21:1
BB	4618	15.5	129	2.79	58.5	2.3	3	0.06	73.0	4.5	132	2.86	43:1
Unknown[b]			44		58.6	2.3	12		78.8	5.7			3.7:1
Total	15483	18.0	286	1.81	57.8	2.2	52	0.33	77.3	5.5	338	2.13	5.5:1

[a] Correct for effective smolt release based on bimodal length frequency distributions of samples taken in November 1977.

[b] Includes salmon which lost microtags. Scale ages correspond with those of identifiable fish.

sigmoidal pattern with decreasing pH, the greatest rate of activity decrease occurring at a pH of approximately 5.5. No sperm activity was noted at pH 4.0 or lower. In the presence of an excess of sperm, the fertilization rate was unaffected by pH 4.5 or greater. Fertilization rate rapidly decreased in a linear fashion between pH 4.5 and 4.0. Even though no sperm activity was noted at pH 4.0 and below, a small proportion of the eggs were fertilized. No eggs were fertilized at pH 3.5 or less.

Intra-female Egg Grading Study

In 1979 an experiment was initiated to evaluate the effects of egg size variation on smolting rate among the progeny of individual females. After fertilization and water hardening the eggs of 10 female salmon were graded and approximately equal numbers of three categories (control, large eggs and small eggs) were incubated and reared separately. The fry were sampled, branded and transferred to a 50-ft holding pond in September 1980. During late November and early December 1980 the entire population (11,000 parr) was individually measured and identified according to female parent and egg size category. Preliminary analyses of length-frequency distributions indicate that egg size may have influenced smolting rate in some of the females. Large eggs tend to produce more 1^+ smolts than small eggs within the same female.

Induced Ovulation Study

Ovarian ripening was accelerated this fall by injections of chum and Atlantic salmon pituitary extracts. Treated females matured significantly earlier than a saline injected control. The fertilization rate exceeded 90% among all egg lots. When pituitary preparations were used to accelerate maturity in 1979, the fertilization rate was highly variable. This resulted from injections too early in oocyte development. The delayed treatment in 1980 proved more successful.

Cooperative Projects

Egg Size and Sperm Quality

Spermatocrit (packed cell volumes) and egg diameter data for SRC broodstock were sent to Dr. Gil Farmer (Fish Culture Section, Resource Branch, Halifax). Dr. Farmer is collecting similar data from other Maritime hatcheries to determine the effects of various broodstock holding conditions on gamete quality. The data suggest that broodstock maintenance in constant temperature groundwater reduces egg size and spermatocrit values over those of adults held on surface water.

Genetic Basis of Precocious Maturation

Dr. Robert Blake (University of Maine) has set up a breeding experiment to examine the incidence of precocious males among progeny of parents of varying ages of maturity. The mating design will also test the hypothesis that genes determining precocious maturity are sex linked. In anticipation of NSF funding, mating sets involving Big Salmon River and Saint John River broodstock have been completed. Cytogenetic and biochemical comparisons of precocious males, grilse and salmon are planned.

Ives, Merrill and Associates (IMA), Argyle, N.S.

A cooperative study to compare the genetic components of growth and survival in two hatchery environments was initiated using SRC returns. Gametes from ten females and six males were combined in two 2 x 3 and one 2 x 4 factorial mating sets. Each of the 20 crosses was then subdivided into two groups of 2000 fertilized eggs per cross. One group is being reared at the IMA hatchery in Argyle, Nova Scotia and the second was retained at NASRC. A common sampling regime has been established and comparable genetic statistics will be determined for each site. The scientific contact for this cooperative study is Dr. Gary Newkirk.

Ms. Linda A. Clarke, Ph.D. Candidate, University of New Brunswick - Genetic Aspects of Salmon Smolt Migration

Observations on migration and orientation of Atlantic salmon smolts were continued in cooperation with the SGRP. The purpose of the study is to learn whether or not there are stock specific migratory patterns discernible in the early phases of sea life. Smolts were released in Chamcook Harbour at normal smolt migration time and their performance compared with that of others released after a delay until July. Both groups were tracked using sonic tags. Orientation studies were conducted using a set of chambers in which observations were made of compass direction of smolts representing various stocks before, during and after normal smolt migration time. For the two stocks released together, one-third of tracks had significant differences in prevailing direction. The prevailing direction of the tracks appears to parallel the current direction when the entire track is considered. The direction of initial travel (during the first hour) appears to be different from the prevailing direction of the entire track. These initial directions were in the same prevailing direction shown by smolts of the same stock observed at the same time in the orientation tanks.

Publications and Reports

Published Reports

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Presentations

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