State of Vermont **Agency of Natural Resources**

VERMONT DEPARTMENT OF FISH AND WILDLIFE

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Bob,

I enjoyed your letter on Carlson's dissertation - I agree completely with your thoughts. Sorry about the missing pages - they are missing in my copy, too. Next time I'm at UMass I will try to get them copied & send copies to you. It won't be soon though.

I've enclosed a copy of DeCola 1970 for you.

I'm also enclosing an economic study that was done by Cornell on salmon restoration.

I agree with your comments on Icelandic fish in your letter to Carlson and certainly mistakes were made in past genetic mgmt of the program. However, the program is a well integrated cooperative - each Agency does NOT "doing it's own thing." We have had a sound breeding & genetics plan in place for several years. The lesson others should learn is that it is far easier to save a native stock than to restore a stock without native genetic material.

Let me know if you have questions.

JAY

RR #1, Box 33, North Springfield, VT 05150-9726

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UNIVERSITY OF MASSACHUSETTS
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Department of Anthropology

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September 29, 1993

Secretary Bruce Babbitt
Department of the Interior
Washington, DC 20240

Dear Secretary Babbitt,

Following your August statements in Connecticut about supporting the salmon restoration project in New England, I write to acquaint you with research done here at the Department of Anthropology at the University of Massachusetts. This information suits very well the recommendation in your department's recently promulgated "National Strategy for Federal Archaeology"--"Public Use of the Archeological Paleoenvironmental Record...to help shape our present responses to changing environments."

Archaeological research at the Universities of Maine and Massachusetts has confirmed the absence of Atlantic salmon in the archaeological record prior to about A.D. 1300. Dr. Catherine Carlson completed a dissertation here evaluating and interpreting this evidence. A summary of her work, very well received recently at a regional historical conference, is enclosed to provide details and references for the argument.

Carlson's data strongly indicate that climatic warming, not industrial construction, ended the brief habitation of New England waters by the Atlantic salmon. The salmon were not native to this continent during or after the last Ice Age. They appear to have arrived via Greenland with the cooling climates of the Little Ice Age, perhaps only a century or so prior to the arrival of Europeans. They were never abundant in southern New England waters, as Carlson's careful review of historical data clearly establishes. The presence of the "noble salmon" in waters not restricted by game marshals enchanted the English, who advertized the salmon lavishly in their recruitment literature. Similar public relations exaggeration is a well known aspect of the exploration narratives from North America-- you are likely familiar with the claims for gold.

Late in the 18th century, at the time of industrialization and the construction of dams and canals, atmospheric carbon dioxide began its modern rise. Climatic warming following the Little Ice Age was essentially coincident with the industrialization of New England's rivers and also with the disappearance of salmon from the waters of southern New England. In this case, only the coincidence of development with the salmon disappearance was interpreted as causal.

Among the advisors for Catherine's dissertation was a very competent fisheries biologist at the University of Massachusetts, who finds no problems in her argument or conclusions. However, when the information was presented to persons associated with the salmon restoration project locally, their response has been denial and dismissal. Although all of their objections are anticipated in the dissertation, nothing new has been offered in rebuttal or refutation of any of the data.

Given the results of this research, I believe that additional federal financial support of the salmon restoration project in southern New England is unlikely to be rewarded by results. The disappointing results to date fit Dr. Carlson's expectations very well. I urge that your department (the National Biological Survey?) inquire further into this matter and reevaluate the level of support appropriate for the agendas of optimistic game fishermen. Only a return of near-glacial climates will bring Atlantic salmon south again.

Sincerely,

Dena F. Dincauze, PhD
Professor of Anthropology

ENC: text of "THE (IN)SIGNIFICANCE OF ATLANTIC SALMON IN NEW ENGLAND, 13 pp.

United States Department of the Interior

FISH AND WILDLIFE SERVICE
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Hadley, MA 01035-9589

In Reply Refer To:
FWS/Region 5/83041

NOV 1 1993

Dr. Dena F. Dincauze
Professor of Anthropology
University of Massachusetts at Amherst
Machmer Hall
Amherst, Massachusetts 01003

Dear Dr. Dincauze:

Secretary Babbitt has asked me to respond to your letter of September 29, 1993, regarding the historical significance of Atlantic salmon in New England. Ms. Carlson's research has fascinating implications for traditional biological interpretations of data. Her work should definitely be considered in evaluating modeled expectations for successful recovery efforts.

We certainly agree that the size of fisheries populations is often cyclic which can be due, in part, to long-term natural climatological cycles. Ms. Carlson makes a good argument for this in her paper, *The (In)Significance of Atlantic Salmon In New England*. The international scientific community, in fact, has strong evidence to support a similar theory explaining the present short-term worldwide depressions in Atlantic salmon populations. Cyclical changes in ocean temperatures over a 10-20 year period impact the size of salmon ocean feeding grounds in the North Atlantic which cause increases and decreases in the marine survival of salmon regardless of other variables.

It is important to note that while Atlantic salmon were never extremely abundant for extended geological periods here at the edge of their range in the lower New England rivers, they have had a significant historical presence. Unquestionably, their presence has been severely impacted in the last 200 years by industrialization. Salmon populations have been destroyed, and cause and effect relationships have been demonstrated directly implicating dams and associated lack of passage and loss of habitat. For example, the successful restoration of Atlantic salmon in the Merrimack River in the 1870-1890s was abruptly terminated when a flood destroyed a primitive, but effective, fish passage facility at the Lawrence dam in 1896.

The U.S. Fish and Wildlife Service recognizes the value of Atlantic salmon as indicator species within discrete river basin ecosystems. Their numbers reflect water quality and quantity, fisheries management, river development, and land management on or near watersheds. Conditions that favor salmon favor most other native species and aquatic life including American shad, river herring, and sturgeon. To this day, these rivers and their resident species continue to provide both economic and social benefits to communities within the watersheds.

Our attention to these particular fishery resources in no way diminishes our concern for other fisheries. Ms. Carlson cites the relatively greater historical importance of groundfish, like cod, to New England's commercial fisheries. In the last two decades, the New England Fisheries Management Council (of which the U.S. Fish and Wildlife Service is a member), in cooperation with the Department of Commerce, National Marine Fisheries Service, has expended many more dollars and agency resources to manage the New England groundfishery (cod and haddock) than has ever been expended on Atlantic salmon. Clearly, over fishing is the primary environmental factor influencing cod and haddock populations.

It has and will continue to be our goal to conserve and restore native fish populations and their habitats which have been recognized as critical components of larger ecosystems. This is especially important since we are both stewards of and elements of these ecosystems. Whether a species has been a significant naturally occurring element of a particular ecosystem for centuries or millennia should not be a factor in weighing our relative stewardship responsibilities among species.

Thank you for expressing your historical viewpoint on our Atlantic salmon restoration program. It interested me greatly and I assure you that we will consider its implications in our future evaluations.

Sincerely,

Ronald E. Lambertson

Regional Director

228 McMenemy

CWT 10-16

WATER QUALITY REQUIREMENTS
FOR
ATLANTIC SALMON

By

Joseph N. DeCola

U. S. Department of the Interior
Federal Water Quality Administration
Northeast Region
New England Basins Office
Needham Heights, Massachusetts

August 1970

TABLE OF CONTENTS

Background and Scope

Under Section 3(a) of the Federal Water Pollution Control Act, the Secretary of the Interior is directed to develop comprehensive programs for eliminating or reducing pollution of interstate waters and tributaries thereof considering the improvements which are necessary to conserve such waters for legitimate uses including propagation of fish and other aquatic life.

Section 3(b) of the Act states that in the survey or planning of any reservoir by the Corps of Engineers, Bureau of Reclamation, or any other Federal agency, consideration shall be given to inclusion of storage for regulation of streamflow for the purpose of water quality control. The need for and value of storage for this purpose shall be determined by these agencies with the advice of the Secretary.

In both the development of comprehensive water quality management programs and streamflow regulation systems for water quality control, the future potential uses of the waters and the associated levels of water quality must be recognized.

Under the provisions of the Anadromous and Great Lakes Fisheries Restoration Act of 1965, a cooperative fishery restoration program has been initiated for the Connecticut River Basin. A copy of the restoration agreement between the participating State and Federal fishery agencies is included in Appendix B. The objectives of this

program are to realize the full potential of the fishery resources of the River including both anadromous and resident species. Small runs of Atlantic Salmon (Salmo salar) have been restored in the Machias, Dennys, Pleasant, East Machias, Narraguagus and Sheepscot Rivers in Maine, and the possibility of restoring them in other New England rivers is being explored. From the standpoint of water quality, the salmon is one of the most sensitive species which is being considered under the restoration program. The water quality requirements for the Atlantic Salmon will, therefore, play a large role in the development of a water quality management program.

Objectives

The objective of this report is to present a summary of the results of research and investigations on the water quality requirements for Atlantic Salmon. It should be noted, however, that the information available on water quality requirements for Atlantic Salmon is limited. Although adequate information exists on oxygen and temperature requirements at the egg stages, few sources deal with water quality requirements during other fresh water stages.* Much of the recorded experimentation during fresh water stages examines only lethal or near lethal temperatures and dissolved oxygen concentrations which barely permit salmon survival. Near lethal levels of water quality are totally inadequate for feeding activities, growth, reproduction and normal

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* The life cycle of the Atlantic Salmon is contained in Appendix A

swimming performance and, thus, cannot be used as water quality requirements. Some excellent information exists on the requirements of Pacific Salmon during fresh water stages. This information can supplement the available data on Atlantic Salmon and can aid in establishing tentative water quality requirements until further research is carried out.

II. SUMMARY

Concentrations of dissolved oxygen, carbon dioxide, toxic pollutants, together with temperature and pH levels greatly affect productivity of fish. Near air-saturated dissolved oxygen concentration with maximum temperatures not exceeding 19°C is optimum for growth and activity of Atlantic Salmon. Extended exposure of Atlantic Salmon to dissolved oxygen concentrations below 5.0 mg/l, temperatures above 20°C, or various toxicants causes their reduction or elimination from the environment.

Dissolved oxygen requirements for Atlantic Salmon are highest during hatching and at other stages during periods of high activity, such as swimming against currents and foraging for food. The oxygen required to sustain activity varies with water temperature and also with apparent water velocity during embryonic stages. As temperature rises, metabolic activity rises causing an increase in oxygen requirements for all stages. During embryonic development, apparent water velocities of 100 cm/hr and above are necessary to insure delivery of oxygen to eggs and alevins which are buried within the gravel of the streambed. Spawning areas should remain free of silt since sedimentation causes reduction in apparent water velocity.

During embryonic development of salmonoids, sustained dissolved oxygen concentrations below 4 or 5 mg/l or low apparent water velocities cause retarded development, hatching of weak sac-fry, malformity, and mortality. During other stages, concentrations of dissolved oxygen below

6 mg/l seriously restrict swimming ability and reduce growth. Although juvenile Atlantic Salmon are able to exist in the laboratory at dissolved oxygen concentrations as low as 3 mg/l at temperatures of 20°C, such low concentrations are inadequate in nature.

For good development and hatching of Atlantic Salmon, intragravel dissolved oxygen concentrations should be at least 7 mg/l with apparent water velocities not less than 100 cm/hr. If apparent water velocity is low, then an intragravel dissolved oxygen concentration at or near air saturation is necessary for normal development.

At parr, smolt and adult stages, normal productivity requires dissolved oxygen concentrations of 6 mg/l and above. Minimum dissolved oxygen levels may range between 5 and 6 mg/l for short periods. For those portions of the river used during migration, sustained dissolved oxygen concentrations should be above 5 mg/l. Dissolved oxygen concentrations below 5 mg/l could produce a block to migrating salmon.

Water temperatures are extremely important to the production of healthy Atlantic Salmon. Temperature greatly affects metabolism and generally a 10°C rise in temperature doubles the oxygen consumption of salmonoids. Growth, activity and migrations of Atlantic Salmon are also largely controlled by ambient water temperatures which must undergo seasonal cooling before spawning and normal incubation of eggs will occur. For example, temperatures in excess of about 12°C preclude maturation of sexual products in adults while spawning occurs at temperatures of about 5.6°C to 4.4°C. Normal growth and development of eggs does

not proceed at temperatures above 9°C. At 12°C, at least 50% mortality of eggs can be expected, and hatching alevins will be weak or deformed. Subsequent to hatching in the spring, however, warmer temperatures are required for optimum growth of the young salmon. Optimum temperatures for best food consumption and growth rate of salmon parr are in a range of about 15°C to 19°C. The optimum temperature for post-smolt salmon has been recorded as 15°C with salinities of about 10°/oo. Although thermal optima for the growth of adult Atlantic Salmon are not available, mature salmon apparently require much cooler water than juveniles. Adult salmon in Greenland waters have been found feeding and growing at temperatures as low as 2°C--a temperature known to inhibit feeding and growth of parr in rivers. Why adult salmon seem to prefer cooler temperatures is not known, but is probably related to physiological changes that occur during and after smoltification, as well as acclimation of adults to cooler sea temperatures.

Atlantic Salmon do not tolerate high temperatures, and excessive stress or mortality of salmon occurs as temperatures exceed 27°C - 29°C. In addition to dissolved oxygen concentrations, principal among the factors determining the tolerance of Atlantic Salmon to thermal elevations is the prior acclimation temperature. Lowering or raising the acclimation temperature causes a corresponding reduction or elevation in the upper limit of thermal tolerance. Salmon that are acclimated to low temperatures are particularly susceptible to death from thermal elevations. Sudden 10°C - 15°C temperature rises will cause serious adverse effects. In the laboratory, juvenile Atlantic Salmon acclimated to 20°C were just able to tolerate temperatures of 27.5°C. At an acclimation temperature of 13°C, however, a 14.5°C rise to the same temperature of 27.5°C produces 50 percent mortality in just under 2½ hours for the same age salmon.

In nature Atlantic Salmon parr undergo a continual year-round process of acclimation to changing water temperatures, while adult salmon returning from the sea to spawn, may not fully acclimate to the warmer fresh water, and thus, would be more susceptible to death from high temperatures. Mortality of adult Atlantic Salmon from heatstroke can be expected when temperatures exceed 29°C - 30°C.

Temperatures do not have to reach lethal levels to cause undesirable effects upon salmon populations. Migrations of smolts will cease when water temperatures exceed 10°C, and adults may not enter Maine rivers when temperatures exceed 23°C. Temperatures above 20°C, however, reduce activity of adult salmon and are not conducive to fishing. When Atlantic Salmon are subjected to such high temperatures, they will require about 10 days at reduced water temperatures before they will be active enough to respond to angling. In addition to these effects, temperatures in a range of about 20°C to 27°C, although not directly lethal to Atlantic Salmon, greatly increase oxygen requirements, favor the growth of undesirable disease organisms which are rapidly lethal to salmon at high temperatures, and enhance the development of more thermal tolerant fish that replace salmon through predation and competition. Maximum temperatures for rearing of juveniles and migration of adult Atlantic Salmon should not exceed 20°C.

During fresh water stages, Atlantic Salmon in Maine are typically found in very soft waters with a total alkalinity less than 20 ppm and with a pH ranging from 5-7. In other areas, Atlantic Salmon have been found in alkaline waters with a pH above 8. Most productive populations of fish are found in waters where the pH ranges from 6.5 to 8.5.

Salmonoids are tolerant of relatively high carbon dioxide concentration at all stages in development. However, since carbon dioxide causes an increase in the dissolved oxygen requirements, carbon dioxide concentrations should not exceed 25 mg/l.

Threshold or incipient lethal concentrations of copper and zinc for Atlantic Salmon parr have been recorded as 0.032 mg/l of copper and 0.42 mg/l of zinc or a mixture containing half of these concentrations in soft water (14 mg/l as $CaCO_3$). Avoidance by adult salmon in nature to copper and zinc pollution below lethal levels has been documented by Canadian biologists. Utilizing the concept of toxic units to express pollution levels (toxic unit = concentration of substance actually found ÷ the incipient lethal concentration) investigators have shown that adult salmon migrating to spawning areas may be completely blocked by a level of 0.8 toxic unit, while significant avoidance reactions of salmon occur at about 0.35 to 0.43 toxic units of Cu^{2+} + Zn^{2+}. In streams supporting runs of Atlantic Salmon, levels of zinc and copper pollution should be minimized as much as possible and levels not exceeding 0.25 to 0.30 toxic units should not cause avoidance reactions in salmon, providing other water quality is favorable.

Information concerning the effect of toxicants upon Atlantic Salmon is limited. Based upon available data, the National Technical Advisory Committee (4) has recommended the following: Concentrations of materials that are nonpersistent (half life of less than 96 hours) or have non-cumulative effects after mixing with receiving waters should not exceed 1/10 of the 96-hour TLm value at any time or place. The 24-hour average of the concentration of such substances should not exceed 1/20 of the TLm value after mixing. For other toxicants, concentrations should not exceed 1/20 of the 96-hour TLm value at any time or place and the 24-hour average of the concentrations of these materials should not exceed 1/100 of the 96-hour TLm.

Because of adverse existing water quality, the TLm value of heavy metals, pesticides and other toxicants can be considerably lower than the estimated or anticipated concentration. Stream temperatures above 20°C and dissolved oxygen concentrations below 4 or 5 mg/l greatly increase the susceptibility of salmon to industrial and agricultural toxicants. For this reason, existing guidelines on safe levels of toxicants may be inadequate in some cases.

Table 4 in this paper, McKee & Wolf's Water Quality Criteria (42) and the Report of the Committee on Water Quality Criteria (4) contain some good information on TLm values and the recommendations on determining safe levels may be employed to determine tentative guidelines for Atlantic Salmon until further research is undertaken.

III. DISSOLVED OXYGEN REQUIREMENTS

Introduction

Dissolved oxygen requirements of Atlantic Salmon vary with the different stages of their life cycle. Dissolved oxygen concentrations during embryonic stages should be near saturation. Similarly high concentrations of oxygen are necessary at the parr and adult stages during periods of high activation, such as swimming against currents, and foraging for food. Low concentrations of oxygen such as 3 or 4 mg/l are inadequate since they cause serious reduction in the activity and growth rate of salmon.

Water velocity and temperature also influence the dissolved oxygen requirements for salmon. During the embryonic stage, a high apparent water velocity* is necessary to carry the oxygen supply to the developing embryos which lie in the interstices of gravel beds (redds) at an average depth of ten inches. If the apparent water velocity is insufficient, few developing embryos will receive enough oxygen for normal metabolism. Temperature greatly affects the oxygen requirement during every stage of the fish's life. Oxygen demand can be increased or decreased by corresponding changes in water temperatures. Generally, an increase in water temperature will raise the amount of oxygen that is necessary to maintain proper metabolism and activity of salmon.

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* The apparent water velocity is an estimate of the true velocity of the water flowing through the spawning bed (redd) and is calculated by dividing volume discharge per unit time by the cross-sectional area.

Oxygen Requirements During Embryonic Stages

Laboratory studies upon developing Atlantic Salmon eggs demonstrate that oxygen demand increases greatly with age. While working with Atlantic Salmon embryos at constant temperature, Hayes (1;2) found that respiratory rates were lowest just after fertilization and highest just prior to hatching. Other experimenters, working with Pacific Salmon embryos, also found that increased development is directly related to an increase in oxygen demand (3). Thus, for salmon embryos, there is a continual increase in oxygen demand that culminates near hatching.

Experimenters have determined critical dissolved oxygen concentrations at various incubating temperatures just prior to hatching which is the most crucial period for the developing eggs. Below a critical dissolved oxygen concentration normal metabolic activity of Atlantic Salmon will be restricted. As shown in Figure 1, a linear relationship is established when incubating temperatures and critical dissolved oxygen concentrations are plotted just prior to the hatching of Atlantic Salmon eggs. At a temperature of 17°C, which is substantially above normal incubation temperature, Atlantic Salmon eggs just prior to hatching require minimum dissolved oxygen concentrations of 8.7 mg/l to maintain respiratory demands. At 9°C, normal development of Atlantic Salmon eggs just prior to hatching is sustained by dissolved oxygen concentrations of about 7 mg/l. At a temperature of 6°C, the critical dissolved oxygen concentration is 6 mg/l.

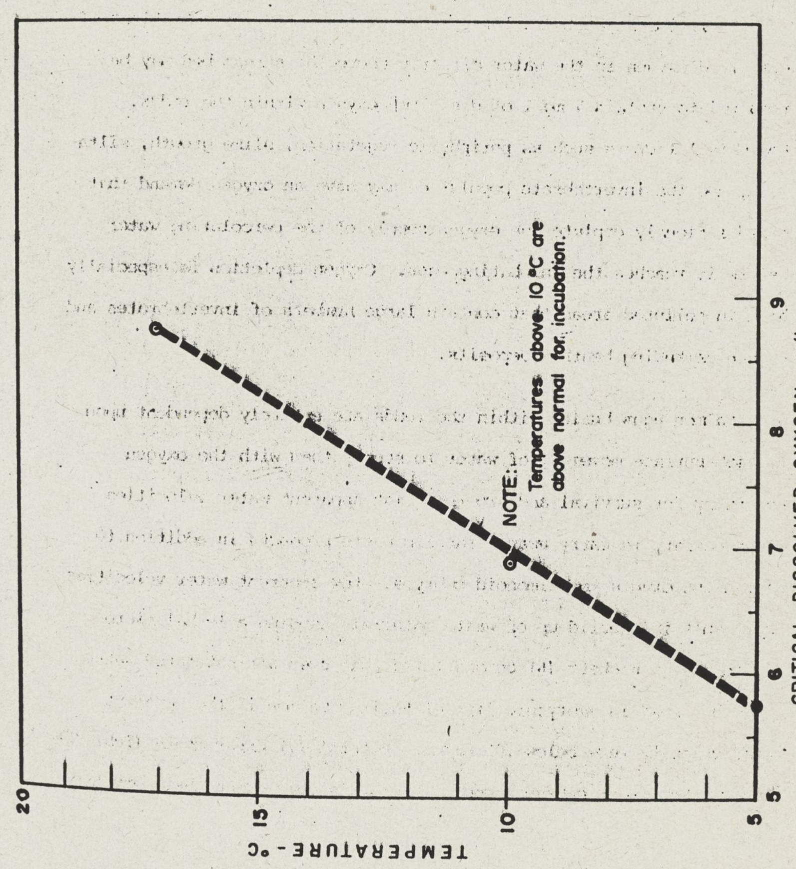

FIGURE 1. Critical dissolved oxygen levels for Atlantic Salmon eggs just prior to hatching at various temperatures. Data from Hayes (1;2) and Lindroth (5).

The National Technical Advisory Committee (4) recommends an absolute minimum dissolved oxygen concentration of 7 mg/l in spawning areas of salmon and trout. This recommendation is quite consistent with the data presented in Figure 1, since embryonic development of Atlantic Salmon occurs in water temperature up to about 9°C.

It is important to realize that near saturated concentrations of dissolved oxygen in the water directly above the stream bed may be required to sustain 7 mg/l of dissolved oxygen within the redds. Ecological factors such as periphytic vegetation, slime growth, siltation, and the invertebrate population may have an oxygen demand that could seriously deplete the oxygen supply of the percolating water before it reaches the incubating eggs. Oxygen depletion is especially high in polluted areas that contain large numbers of invertebrates and oxygen demanding benthic deposits.

Salmon eggs buried within the redds are entirely dependent upon the sub-surface movement of water to supply them with the oxygen necessary for survival and growth. High apparent water velocities are necessary to carry away metabolic waste products in addition to delivering oxygen to salmonoid embryos. Low apparent water velocities may result in a build-up of waste materials causing a lethal micro-environment. Wickett (6) demonstrated that even air-saturated water would not sustain embryonic life of Pacific Salmon if the apparent water velocity were below .05 cm/hr. Peters' (7) experiments (Table 1) with rainbow trout embryos support Wickett's conclusion that mortality

TABLE I. Trout egg mortality compared with intragravel oxygen concentrations and intragravel apparent velocities at winter incubation temperatures. Taken from Peters (7).

Station Number	Mortality, %	Oxygen Concentration, PPM		Apparent velocity, cm/hr	
		Average	Range	Average	Range
I	5	7.8	7.4 to 8.1	82	75 to 90
II	39	7.8	7.3 to 8.1	61	55 to 85
III	90	7.6	7.1 to 8.1	43	15 to 85
IV	100	7.3	6.4 to 8.1	21	5 to 90
V	100	7.1	6.4 to 7.9	23	10 to 85

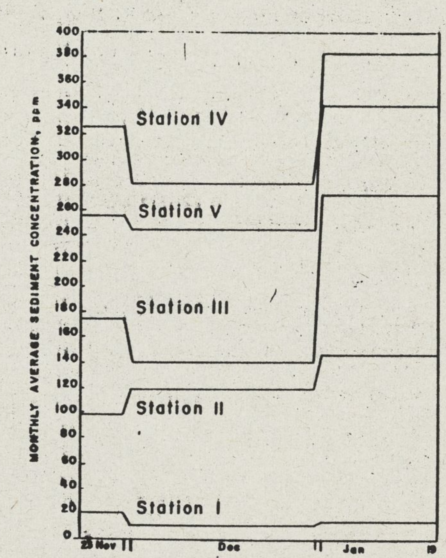

FIGURE 2. Monthly average sediment concentrations from five sampling stations in Bluewater Creek from November, 1961 through January 1962. Taken from Peters (7).

of salmonoid embryos is affected by the apparent water velocity since rainbow trout eggs, like salmon, incubate in redds. Coble's (8) experiments have also demonstrated that mortality rates of salmonoid embryos are increased with low apparent water velocities.

Changes in stream bottom composition from siltation can restrict the percolation rate of water through the redds. If the stream bed is heavily silted, the apparent water velocity is so drastically reduced that even air-saturated water would not produce successful hatching of salmonoids. Table 1 shows the effect of apparent water velocity upon mortality of rainbow trout eggs placed seven inches deep within gravel redds at Bluewater Creek, Montana during winter conditions. The concentrations of dissolved oxygen within the redds (the intragravel dissolved oxygen concentrations) during the experiment were continually above 6 mg/l. Based on data from Table 1 and Figure 2, a decrease in apparent water velocity at each station is associated with a corresponding increase in sedimentation and trout mortality. At Station III (Table 1) when the average apparent velocity is 43 cm/hr, a 90 percent mortality occurs; this velocity is insufficient to meet the oxygen demands of the developing trout embryos. At Station I, where sedimentation is minimal (Figure 2) and where the average apparent velocity is 82 cm/hr (Table 1), the mortality is estimated to be only five percent. Therefore, high sedimentation of the spawning beds reduces the apparent water velocity and decreases the supply of oxygen to the developing embryos which results in increased mortality. Low apparent water velocities could also cause

covering of the eggs by suspended sediment resulting in oxygen deficiency.

Based on the observations of Wickett (6) and Peters (7), assuming sufficient intragravel dissolved oxygen concentrations (see Figure 1), apparent water velocities greater than 100 cm/hr may result in the successful hatching of healthy salmonoid sac-fry.

Laboratory experiments on salmonoid embryos have demonstrated that the usual result of oxygen deficiency during embryonic stages is a significant reduction of successfully hatching sac-fry. In flowing water experiments with coho salmon embryos, Warren (9) demonstrated that dissolved oxygen concentrations even as high as 5 mg/l at a water temperature of 12.5°C did not produce satisfactory hatching. Garside (10) reported that extended exposure of lake trout embryos to an average oxygen concentration of 4.2 mg/l at a water temperature of 10°C resulted in high or total embryo mortality. Alderice (3) recorded that seven-day exposure of chum salmon embryos at various developmental stages at a constant temperature of 10°C and dissolved oxygen concentrations less than 2 mg/l resulted in three prominent responses: retarded embryonic development, deformed sac-fry, and mortality. The apparent water velocity for these experiments was 82 cm/hr. The median lethal dissolved oxygen concentration was estimated to be 1.2 mg/l at hatching. Silver (11) noted that all the embryos of chum salmon and steelhead trout died after exposure to a temperature of 11°C in flowing water at a dissolved oxygen concentration of 1.6 mg/l. In another experiment, Silver raised the dissolved oxygen concentration to 2.15 mg/l and obtained a successful hatching of sac-fry. However, the sac-fry that hatched were exceptionally weak and small. Such individuals would not be strong enough to survive emergence from the overlying gravel in nature. Thus, low concentrations of dissolved oxygen during embryonic development for salmonoid species result in retarded development, hatching of weak and small sac-fry, malformity, and mortality.

Oxygen Requirements During Juvenile and Adult Stages

The concentration of dissolved oxygen that is required by free-swimming salmon is largely dependent upon water temperature and activity of the fish. Active salmonoids consume from three to five times the amount of oxygen as resting fish, while a temperature increase of 10°C generally doubles oxygen consumption.

Fry (12a) demonstrated the relationship of oxygen uptake and temperature for three species of yearling trout, genus Salmo, in both active and resting conditions (see Figure 3) The oxygen consumption for either Salmo gairdneri or Salmo kamloops ranged approximately from 60 cc/kg/hr at 10°C to 140 cc/kg/hr at 20°C when resting. For the same fish during periods of activity, the oxygen consumption ranged from 235 cc/kg/hr at 10°C to about 390 cc/kg/hr at 20°C. When Fry tested the oxygen consumption rate for Salmo fario, he found that at 10°C and 20°C for resting fish the consumption was 60 cc/kg/hr and 135 cc/kg/hr respectively. The active respiratory rate at 10°C and

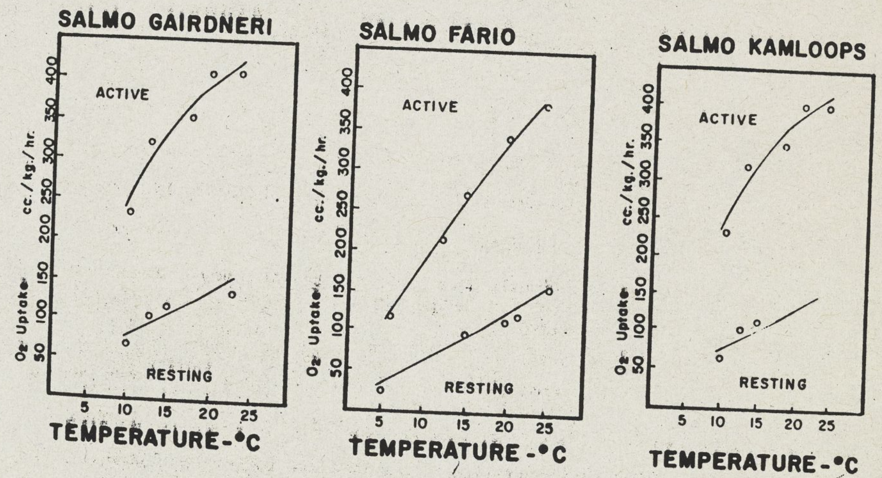

FIGURE 3. Relation between oxygen uptake and temperature. Taken from Fry (12a).

20^{o}C was about 200 cc/kg/hr and 350 cc/kg/hr respectively. Several other experimenters have also demonstrated that the oxygen required by salmonoids is affected by temperature and activity (12b; 13; 14; 15; 16).

The activity of salmon can be seriously limited in oxygen deficient conditions. Table 2 gives the dissolved oxygen concentrations below which the activity of various fish, including certain salmonoids, begins to decline. To be successful in a natural environment, salmon must be capable of resisting high currents, escaping from predators, and foraging for food. Such activities necessitate a high oxygen consumption that can be maintained only by high concentrations of ambient dissolved oxygen. Low concentrations of dissolved oxygen seriously restrict activity which may be measured by laboratory experiments.

Davis (17) demonstrated that reduction of dissolved oxygen causes a marked reduction in the swimming speed of juvenile coho and chinook salmon. Oxygen concentration from saturation to levels of 7, 6, 5, 4, and 3 mg/l reduced the maximum sustained swimming speeds of juvenile coho salmon by about 5, 8, 13, 20, and 30 percent respectively. The corresponding percentage reductions of the swimming speed of chinook salmon were somewhat greater and averaged 10, 14, 20, 27, and 33 percent respectively. Thus, activity as measured by swimming performance is considerably restricted at low dissolved oxygen concentrations.

TABLE 2

OXYGEN CONCENTRATIONS BELOW WHICH THE ACTIVITY OF THE FISH NAMED BEGINS TO BE RESTRICTED

Taken from Jones (16)

KIND	OXYGEN CONCENTRATION	Temp. ^{o}C
Goldfish	2.5 p.p.m.	20
Goldeye	9.0 p.p.m.	10
"	11.0 p.p.m.	15
Perch	7.0 p.p.m.	20
Speckled trout	6-7 p.p.m.	5
" "	6-7 p.p.m	10
" "	9.0 p.p.m	20
Lake trout (1 yr)....	abt. 2/3 saturation	9.5-18
" " (2 yr)....	abt. 3/4 saturation	9.5-18

Experiments by Davison (18) with juvenile coho salmon show that growth rate and conversion of food to body tissues are significantly reduced at low levels of dissolved oxygen. After five tests at oxygen concentrations of 4, 5, 6 and 8 mg/l in 20°C water, the mean weight gains after approximately twenty-four days were recorded as 56, 68, 85 and 92 percent respectively. The increase in weight of each fish per gram of food consumed averaged 168, 188, 216, and 220 mgms, respectively. Warren (9) obtained results similar to Davison's and also reported that high oxygen concentrations produce the best growth rates and efficiency in conversion of food to body weight. The experiments of Davison (18) and Davis (17) indicate that significant reduction in swimming speed and in growth rate of salmon occurs as dissolved oxygen concentrations are reduced below 6 mg/l.

The dissolved oxygen concentration at which the activity of free-swimming salmon is completely restricted and is only capable of existence is referred to as the limiting level, below which mortality will occur. Limiting or survival concentrations of oxygen have been determined experimentally for some free-swimming salmonoids at various temperatures (Table 3). The limiting oxygen concentration for Atlantic Salmon fingerlings is 1.51 mg/l at 15°C and 2.85 mg/l at 25°C. For yearling Atlantic Salmon, limiting dissolved oxygen concentrations are 1.89 mg/l and 2.78 mg/l at 16°C and 25°C, respectively. For parr, the limiting oxygen concentrations at 10°C and 20°C are 2.15 mg/l and 2.90 mg/l, respectively. Although these data demonstrate temperature

TABLE 3

LIMITING OR SURVIVAL CONCENTRATIONS OF OXYGEN
FOR
SALMON AT VARIOUS TEMPERATURES

Species	Dissolved Oxygen mg/l	Temperature-°C	State	Reference
Atlantic Salmon	1.51	15	Fingerling	(19)
"	2.85	25	"	(19)
"	1.89	16.0	Yearling	(19)
"	2.78	25.0	"	(19)
"	2.15	10	Parr	(5)
"	2.90	20	"	(5)
Sockeye Salmon	2.4	21	Adult	(20)
Chinook Salmon	2.3-2.7	21-23	"	(20)
Pink Salmon	1.99	17	"	(19)
"	3.36	25	"	(19)
Coho (Silver) Salmon	1.2-1.24	12.1-12.7	Fry	(20)
"	1.5-1.6	16	"	(18)
"	1.65	20	"	(18)
"	1.80	22	"	(18)
"	2.13*	23.5	"	(18)

* Concentration represents mean of test dissolved oxygen which ranged from 2.05 - 2.2 mg/l; only 97 percent survival recorded in this range.

effects on limiting oxygen concentrations, other variables such as growth, swimming, and normal overall activity as they apply to the natural environment are excluded. In nature, oxygen concentrations adequate to maintain productive levels of growth and activity are considerably higher than near lethal oxygen concentrations as determined by laboratory analyses. This factor is significant in evaluating the data presented in Table 3. Recommended minimum dissolved oxygen requirements for salmon in a natural environment should be 2-3.5 mg/l above the concentrations indicated.

Dissolved oxygen concentrations which are necessary for salmonoid fish to maintain healthy populations are high, particularly near spawning areas. Ellis (21) demonstrated by field observation that streams which produce a good fish population do not have dissolved oxygen concentrations below 5 mg/l. Tarzwell (22) noted that trout and salmon are not usually found in waters where minimum dissolved oxygen concentrations are less than 4-5 mg/l. Havey (23) recorded that Atlantic Salmon of the Union River in Maine maintain good populations when water temperatures are below 21.1^{o}C and when dissolved oxygen concentrations are 5 mg/l and above. The National Technical Advisory Committee (4) recommends that for good growth and general well-being of trout and salmon, dissolved oxygen concentrations should not be below 6 mg/l, but in extreme cases may range between 6 and 5 mg/l for short periods provided that other water quality is favorable. The Committee also indicates that in streams which serve as migratory routes only, dissolved

oxygen concentrations may be as low as 5 mg/l for periods up to six hours, but should never be below 4 mg/l at any time or place. It is important to realize that sustained concentrations of oxygen below 5 mg/l would be inadequate for Atlantic Salmon and could cause a block to migration.

IV. TEMPERATURE REQUIREMENTS

Introduction

Atlantic Salmon cannot tolerate very high temperature elevations. For example, temperatures of 27° to 28°C cause 50 percent mortality of Atlantic Salmon fingerlings in under five hours. Thermal requirements are especially exacting at early embryonic and larval stages during which time tissue and organs are not yet fully developed. With an increase in age, however, Atlantic Salmon are capable of tolerating higher temperatures (24). Thermal tolerance refers to a temperature zone in which existence is possible for extended periods and in which death is not due solely to temperature changes. The upper limit of the thermal tolerant zone is defined by an incipient lethal temperature, beyond which mortality occurs (25; 26).

Thermal tolerance of fish is particularly affected by acclimating temperature, which is that temperature to which fish are physiologically adjusted. In nature, acclimation is a continual year round process. For every acclimating temperature, there is a corresponding lethal temperature defined as that temperature at which 50 percent of a population will die (25; 26). A rise in acclimating temperature will produce a corresponding elevation in the lethal temperature until a point is reached at which the acclimating temperature reaches the lethal temperature. This point is termed the ultimate upper lethal temperature (16; 26).

Within the thermal tolerant zone, there is a preferred temperature which is physiologically suited to the salmon and which provides desirable activity and growth. The preferred temperature is affected by the acclimation temperature and an increase in acclimation temperature will effect an increase in the preferred temperature (12a; 26; 27, 28).

Temperature also governs metabolism and thus affects oxygen consumption and growth rates. Temperature controls activity and movement in salmon populations. Temperature can also favor the growth and reproduction of undesirable species which grow at the expense of the salmon population.

Temperature Requirements During Embryonic Stages

Incubating temperatures of 0.5°C to 7.2°C apparently do not affect mortality in Atlantic Salmon embryos (29; 30). In air-saturation, flowing water, continued exposure of Atlantic Salmon eggs and sac-fry in the hatchery to temperatures at or near 10°C caused excessive mortality (29). Markus (31) found that an incubating temperature of 12.2°C in air-saturated and flowing water caused approximately 50 percent mortality of 450,000 hatchery-reared Atlantic Salmon eggs. Most of the hatching sac-fry were either deformed or very weak. In most cases, hatching of Atlantic Salmon eggs will be unproductive when incubation temperatures exceed 9°C.

Range of thermal tolerance increases with age for Atlantic Salmon. Bishai (32) demonstrated that 50 percent mortality of Atlantic Salmon alevins (sac-fry) reared in well-oxygenated water at 5° to 6°C occurred after three days when water temperatures were raised to 24°C in six hours. At a test temperature of 20°C, which is lethal for eggs, salmon alevins did not die, nor were there any signs of distress.

Temperature Requirements During Juvenile and Adult Stages

Markus (31) found that the best growth rates for hatchery reared Atlantic Salmon occurred in a temperature ranging from 15.6°C to 18.3°C. Although acclimation affects the preferred temperature, several authors indicate a final temperature preferendum exists which fish eventually select in a temperature gradient regardless of prior acclimation (26; 33). Javaid (34) working with 3.8 to 7.6 cm. underyearling Atlantic Salmon in various temperature gradients, found that at an acclimation temperature of 15°C and 20°C the juvenile fish initially selected temperatures of 15.7°C and 18.2°C respectively, but had a final preferendum of 17°C. It is also interesting to note that when Elson (34) subjected salmon parr to an electrical stimulus, the greatest response occurred at a temperature of 15°C. Optimum temperatures for normal growth of juvenile Atlantic Salmon lie in a range of about 15°C to 19°C.

Adult Atlantic Salmon appear to have optimum temperatures somewhat lower than those for juveniles. Ferguson (27) reported that landlocked salmon, *Salmo salar sebago* (exact age unknown) were found living in an area where the temperature ranged from 13.5°C to 16.2°C. Saunders and Henderson (47) in a laboratory experiment found that a temperature around 15°C and a salinity near the isosmotic level

(ca. 10°/oo) gave better food consumption and growth in post-smolt salmon than temperatures of 10°C or 18°C or salinities higher or lower than isosmoticity.

Saunders also pointed out an observation of Elson who noted that when parr in the Pollett River in New Brunswick had stopped growing as shown by their scales when water temperatures fell below 4°C, salmon taken in Greenland waters at 2° - 4°C were still active and had not yet formed winter bands on their scales. Apparently adult salmon are capable of growth at temperatures far below what is considered optimum for parr in fresh water, and obviously are physiologically suited to much colder waters than are pre-smolt salmon.

Excessively high temperatures cause stress in young salmon and in time result in mortality. Elson* indicates that as temperatures rise much above 27°C or 28°C, salmon parr may desert their usual homes and drift downstream; in doing so they may accumulate in cooler areas associated with inflowing springs and brooks. Figure 4 records the amount of time involved for a 50 percent mortality of fingerling Atlantic Salmon acclimated to various temperatures to occur. The short horizontal lines in Figure 4 indicate the incipient lethal temperature which denotes the boundary of the zone of tolerance (12a; 12b). At an acclimation temperature of 20°C, 50 percent mortality of the Atlantic Salmon occurred within six hours at 28°C and within

* Elson, P. F., Biological Station, St. Andrews, New Brunswick. (Personal Communication)

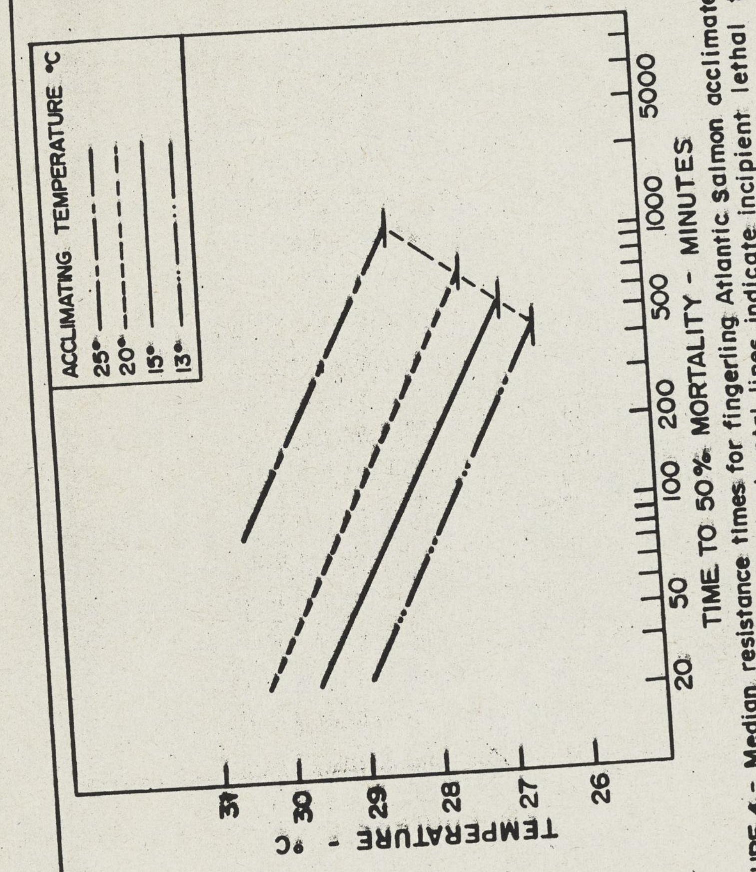

FIGURE 4 - Median resistance times for fingerling Atlantic Salmon acclimated to various temperatures. Short horizontal lines indicate incipient lethal temperatures.
Taken from Fry (12a)

one hour at 29.6°C. At an acclimation temperature of 13°C, 50 percent mortality of the salmon fingerlings occurred within six hours at 26.7°C and within one hour at 28.3°C. These data indicate that mortality of Atlantic Salmon occurs at 27-28°C in just a few hours, the exact time to mortality varying with the acclimation temperature.

Temperature is an important factor in the migration of salmon. Meister* of the Atlantic Salmon Sea Run Commission indicated that temperatures above 10°C will halt the migration of Atlantic Salmon smolts while temperatures of 12°C will preclude maturation of sexual products in adults. At 23°C, Maine salmon will not enter rivers, although some movement occurs with fish in the rivers prior to the advent of the high temperature (Meister). Meister and Elson both agree that temperatures above 20°C severely restrict success in fishing for adult salmon, and necessitate approximately ten days of reduced water temperatures before the fish will again respond to angling. Apparently, activity of migrating adult salmon can be severely reduced at temperatures above 20°C.

The loss of activity at temperatures of 20°C to 23°C is in part a result of acclimation. Adult Atlantic Salmon returning from the cold sea to fresh water streams may not remain in estuary areas long enough for them to become acclimated to the warmer brackish and fresh water. Such salmon would be vulnerable to high thermal elevations. Huntsman (35) found that adult salmon returning from the sea to

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*Meister, A., Atlantic Sea Run Commission, University of Maine, Orono, Maine. (Personal Communication)

Canadian streams and not fully acclimated to river temperatures died at 29°C to 29.5°C in a few hours, while those salmon already in the river prior to the development of lethal temperatures died at 30.5°C.

Stream temperatures do not have to attain lethal levels to cause undesirable effects for salmon. Sustained temperatures in a range of 20°C to 27°C, although probably not directly lethal in themselves, favor the reproduction and survival of more thermal tolerant species that replace salmon through competition and predation. Temperatures above 20°C also enhance the growth of bacteria and other disease organisms that can be lethal to salmon. Elson (see note, Page 29) indicates that in one Canadian stream under study during two recent years, serious bacterial epidemics occurred during the warm, low water of summer. Pippy and Hare (48) pointed out that sustained high temperatures in a range of about 20°C to 28°C apparently contributed to mortality of salmon from bacterial diseases. In addition to these effects, temperature elevations cause an increase in oxygen demand (see Figure 3) while at the same time lower the amount of oxygen dissolved in water.

For good growth and migration of salmonoids, the National Technical Advisory Committee (4) recommends that temperatures should not exceed a maximum of 20°C. This temperature maxima is consistent with the information gathered upon Atlantic Salmon.

V. OTHER ENVIRONMENTAL FACTORS

pH

The term pH designates the logarithm (Base 10) of the reciprocal of the hydrogen ion concentration. For example, if the hydrogen ion concentration designated $H^+ = 10^{-7}$ moles per liter, then the pH would equal 7. The National Technical Advisory Committee (4) indicates that in a pH range above 6, acids which dissociate to a high degree do not appear to be toxic to fresh-water fish; below a pH of 9, alkalies that dissociate to a large degree are also not considered hazardous to fish. In the same pH range from 6-9, however, weakly dissociated acids and alkalies, if present in sufficient quantity, are toxic and can be lethal to fresh-water fish (36). Such substances, however, do not occur naturally in lethal concentrations and are associated with industrial waste effluents. Thus, even at neutral or near neutral pH, waters may contain acids and bases which could be toxic to fish.

Fresh-water fish grow more rapidly and are more productive in water which is slightly alkaline than water which is strongly acidic. Good well-rounded populations of fish are found normally in waters where the pH ranges from 6.5 to 8.5 (21; 37); however in Maine, Atlantic Salmon are typically found in fresh water where the pH ranges from 5-7.

Carbon Dioxide

Salmonoids are tolerant of high concentrations of carbon dioxide.

Alderice (38) found that chum salmon eggs were relatively resistant to high levels of carbon dioxide under low-dissolved oxygen concentrations. He recorded a 50 percent mortality when the concentration or carbon dioxide was raised to 90 mg/l. Concentrations of 40 mg/l of carbon dioxide had little effect upon juvenile coho salmon (16). However, increases in the carbon dioxide concentrations cause an increase in the dissolved oxygen requirements of salmonoids (16;38; 39). Carbon dioxide concentrations not exceeding 25 mg/l are recommended by the National Technical Advisory Committee (4).

<u>Threshold Concentrations of Copper and Zinc</u>

Laboratory tests carried out by Sprague (40a) in water with a total hardness of 14 mg/l as $CaCO_3$* at 17°C demonstrated that the incipient lethal levels** or threshold concentrations of copper and zinc sulfate solutions for juvenile Atlantic Salmon were 0.032 mg/l of copper alone, or 0.42 mg/l of zinc alone. The incipient lethal level for mixtures of zinc and copper are half of the above concentrations. Similar results have been obtained for rainbow trout (Figure 5).

In a ten-year study Saunders and Sprague (40b) analyzed avoidance reactions of spawning migrations of Atlantic Salmon to copper and zinc pollution from mining operations in the Northwest Mirimachi River in

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* Atlantic Salmon of North America are typically found in very soft water with a total hardness less than 20 ppm.

** Incipient lethal level, or lethal threshold concentration, is that level of the lethal identity beyond which the organism can no longer survive for an indefinite period of time.

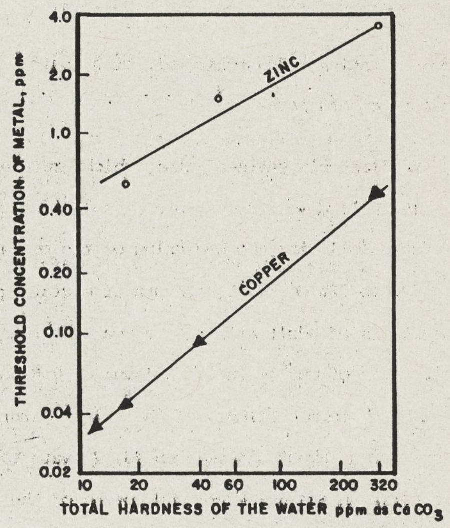

FIGURE 5. Relation between the hardness of the water and the threshold concentrations of zinc, and copper salts for rainbow trout. Taken from Lloyd (41).

Canada. These observations are pertinent since they took place in the natural environment without the usual limitations inherent in laboratory experimental conditions. The authors expressed the pollution levels of copper and zinc in terms of "toxic units". The toxic unit can be expressed as the concentration of the pollutant actually found, divided by the lethal threshold concentration obtained from laboratory experiments. A toxic unit of 0.5 would be half as strong as the lethal threshold concentration and a toxic unit of 2 would be twice as strong as the lethal threshold level.

During the first six years of study which preceded the mining pollution, a 1% to 3% downstream return of salmon was recorded, while in the four years following the beginning of the copper and zinc pollution, a 10% to 22% downstream return of migrating salmon occurred. Avoidance reactions of adult Atlantic Salmon occurred at about 0.35 to 0.43 toxic units of $Cu^{2+} + Zn^{2+}$. A level of 0.8 toxic unit may cause a total block to migration. Of the salmon returning downstream because of pollution, about 31% reascended, 7% were taken by fishing and 62% were not seen again. Estimated losses of the total salmon run were as high as 15%. Another interesting result that occurred after the mining pollution began was a delay and reduction of early run salmon (June-July) to the headwaters.

__Levels of Pesticides for Certain Salmonoids__

With the exception of a few insecticides, there have been few research efforts to determine the effect of pesticides on Atlantic Salmon. Laboratory research, however, has been performed with other salmonoids. Table 4 records median tolerance limits (TLm)* of three salmonoids to various pesticides. Because the values in Table 4 do not indicate maximum safe levels, concentrations of materials that are nonpersistent (half life of less than 96 hours) or have noncumulative effects after mixing with receiving waters should not exceed 1/10 of the 96 hour TLm value at any time or place. The 24-hour average of the concentration of such substances should not exceed 1/20 of the TLm value after mixing. For other toxicants, concentrations should not exceed 1/20 of the 96-hour TLm value at any time or place and the 24-hour average of the concentration of these materials should not exceed 1/100 of the 96-hour TLm after mixing. This level was established in 1968 by the National Technical Advisory Committee (4). Due to existing stream conditions**, the suggested safe levels of toxicants may prove to be inadequate in some cases. For a more complete review of pesticides and their effects upon fish life, the reader may wish to refer to McKee and Wolfe's study entitled __Water Quality Criteria__ (42) and the __Report of the Committee on Water Quality Criteria__ (4).

* Median tolerance limit (TLm) - The concentration of the tested material in experimental water at which just 50 percent of the test animals are able to survive for a specified time of exposure.

** High water temperature or low dissolved oxygen concentration generally increase the action of toxicants.

TABLE 4

MEDIAN TOLERANCE LIMITS OF VARIOUS TOXICANTS IN PARTS PER MILLION FOR 3 SALMONOIDS (FROM KATZ 43; BOND 44)

Commercial Common or Code Name of Toxicant	MEDIAN TOLERANCE LIMITS IN PARTS PER MILLION — Chinook Salmon 24 hr.	Chinook Salmon 48 hr.	Chinook Salmon 72 hr.	Chinook Salmon 96 hr.	Coho Salmon 24 hr.	Coho Salmon 48 hr.	Coho Salmon 72 hr.	Coho Salmon 96 hr.	Rainbow Trout 24 hr.	Rainbow Trout 48 hr.	Rainbow Trout 72 hr.	Rainbow Trout 96 hr.
Toxaphene	.0079	.0033	.0027	.0025	.013	.0105	.010	.0094	.0115	.0084	.0084	.0084
Aldrin	.0124	.0106	.0087	.0075	–	.061	.0486	.0459	.0424	.0239	.0203	.0177
Dieldrin	.0079	.0067	.0061	.0061	.0175	.0153	.0144	.0108	.0157	.013	.0099	.0099
DDT	.038	.017	.014	.0115	.066	.046	.044	.044	.042	.042	.042	.042
Lindane	.056	.042	.042	.040	.060	.056	.056	.050	.042	.041	.039	.038
Methoxychlor	.028	.0279	.0279	.0279	.0662	.0662	.0662	.0662	.0626	.0626	.0626	.0626
Heptachlor	.0324	.0266	.023	.0173	.0619	.0604	.0604	.059	.0367	.0338	.0251	.0194
Chlordane	.059	.059	.057	.057	.1	.086	.082	.056	.056	.044	.044	.044
Endrin	.002	.0012	.0012	.0012	.0013	.0008	.00052	.00051	.00079	.00058	.00058	.00058
Guthion	.0068	.0062	.0043	.0043	.007	.005	.0048	.0042	.0047	.0038	.0038	.0032
Malathion	.0245	.0239	.0236	.023	–	–	–	–	–	–	–	–
Co-Ral	–	–	–	–	22	20	18	15	–	1.8	1.5	1.5
Sevin	–	–	–	–	1.3	.997	.997	.997	–	1.6	1.35	1.35
ACP-M-569	185	155	–	–	–	–	–	–	Data Not Available			
Aminotrizaole	–	–	–	–	325	325	–	–	"	"	"	
Baron	2.62	2.3	–	–	–	–	–	–	"	"	"	
Dowpon	–	–	–	–	340	340	–	–	"	"	"	
Diquat	29.5	28.5	–	–	–	–	–	–	"	"	"	
Diuron	–	–	–	–	33	16	–	–	"	"	"	
Endothal	155	136	–	–	–	–	–	–	"	"	"	
F-98	.08	–	–	–	–	–	–	–	"	"	"	
Hyamine 1622	–	–	–	–	57	53	–	–	"	"	"	
Kuron	1.35	1.23	–	–	–	–	–	–	"	"	"	
Monuron	–	–	–	–	115	110	–	–	"	"	"	
Omazene	.83	.83	–	–	–	–	–	–	"	"	"	
Phygon XL	–	–	–	–	Not toxic up to .042			–	"	"	"	
Simazine	7.0	6.6	–	–	–	–	–	–	"	"	"	
Sodium TCA	Not toxic up to 870		–	–	–	–	–	–	"	"	"	

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VII. APPENDIX A

Life Cycle

Atlantic Salmon are an anadromous species which ascend cool fresh-water rivers in order to spawn. Spawning grounds include the waters extending from just above tidal areas to headwater reaches. Spawning occurs in the fall, and the eggs hatch in the late winter or early spring. The newly-hatched salmon live in fresh water two or more years before they migrate to the sea. Here, the salmon remain for at least one year before they return to fresh water and spawning areas. After spawning, some adult salmon immediately make their way back to sea while others remain in fresh water the whole winter before returning the following spring. Because of the great energy expended during the physiological preparations of reproductive organs and spawning itself, many of the salmon which return to sea after spawning are so weak that they fall easy victims to predation and disease.

The time at which salmon migrate to spawning grounds varies with different streams. Many rivers have distinct runs both in spring and fall; while in others, the migrations are limited to one peak run occurring either during the spring or fall. Regardless of when migration occurs, Atlantic Salmon spawn in late October or early November in North America when the water temperatures drop to 5.6 - 4.4°C (23).

Female salmon deposit their eggs in gravel beds (redds) and cover them to average depth of ten inches. Shallow, swift-running water areas with clean coarse gravel beds that contain many stones from 2 to 8 inches in size provide the most suitable spawning areas for Atlantic Salmon(45). This type of stream bed produces a stable environment and affords the buried eggs a constant supply of oxygenated water. Fine or loose gravel and sand is unsuitable because of its shifting nature and low porosity. Water depth of spawning areas, varying from 6 - 48 inches is also important and must be sufficient to protect the spawning areas from ice and freezing (45).

The incubation of the eggs lasts about 5 - 6 months depending upon temperature. The eggs will hatch in early spring when the temperatures are just beginning to rise. The newborn salmon are termed alevins or sac-fry and are so called because they hatch with their yolk-sac still attached. Once the yolk-sac is nearly absorbed, the fry or underyearlings make their way out of the over-lying gravel and begin to feed on their own.

The duration of the fresh water phase of the salmon's life cycle is usually not longer than two or three years, and it is passed in the same general area from which the salmon hatched. Juvenile salmon, termed parr, inhabit riffles and pools which contain large protective rocks under which they hide when alarmed (45; 46). The parr are characterized by eleven black bars or "parr Marks" running vertically down the sides and by bright red spots arranged near the lateral line. Before migration to the sea, the parr undergo a process called smoltification. When the parr reach a length of about five inches, the following

spring, they lose their coloration and turn silvery on the outside. After this physiological change in preparation for life in salt water, the fish, termed smolts, are ready for their seaward migration. Smolts migrate in spring or early summer when the water temperatures are cool.

At sea, the young salmon grow rapidly on the abundant food supply and usually gain an average of 4 - 5 pounds a year (27). Although some salmon return to fresh water after spending only one winter at sea, most Maine salmon remain two winters at sea before returning to spawn. The salmon that return to fresh water after one winter are termed grilse while those that return after two winters are termed bright or maiden salmon.

Subsequent to entering fresh water, Atlantic Salmon cease feeding and expend great amounts of energy in the ascension of rivers, and in the transformation of body material for the build-up of the reproductive organs. Large amounts of energy are also expended during actual spawning. Without feeding, such activity causes an excess drain upon the salmon's reserve energy materials which results in a 31 to 40 percent loss of body weight. Consequently, the salmon are very close to physiological death (45). Thus after spawning, the salmon return to sea in an excessively weak condition. Such salmon are incapable of osmoregulation and are easy victims of predators and disease. Only 10% or less of the salmon return to spawn a second time.

VIII. APPENDIX B

STATEMENT OF INTENT
FOR
A COOPERATIVE FISHERY RESTORATION PROGRAM
FOR THE
CONNECTICUT RIVER BASIN

The States of Connecticut, Massachusetts, New Hampshire and Vermont as well as the United States Bureau of Sport Fisheries and Wildlife and the United States Bureau of Commercial Fisheries agree to and support a fisheries program for the Connecticut River Basin. The following statement shall constitute the official intent of the above-named States and Federal Agencies.

Objectives

The objectives of this program are to realize the full potential of the fishery resources of the River including both anadromous and resident species. The intent of this program is to provide a public with high quality sport fishing opportunities in a highly urbanized area as well as to provide for the long term needs of the population for sea food.

Anadromous Fish

American Shad - *Alosa sapidissima* - Historically, the Connecticut River supported shad runs as far unstream as Bellows Falls which lies in the River between Vermont and New Hampshire, approximately 35 miles north of the Massachusetts border. The exact magnitude of the historic run is unknown but it might have approached six million adult fish at the mouth of the River. It probably would not be practical to restore the run to its historical numbers but an evaluation of present spawning and nursery areas as far north as Bellows Falls indicates that a run of up to two million fish could be realized. The two million figure is based on the production of 2.8 adult shad produced per 100 square yard unit of spawning habitat. The 2.8 figure assumes rather low production, as production as high as 6.5 adult shad per unit has been realized.

A run of two million shad would require passage facilities for one million fish at Holyoke, 850,000 at Turners Falls, and 750,000 at Vernon. If the navigation dam under consideration by the Corps of Engineers is constructed at Hartford, Connecticut, facilities would have to be provided for a run of two million shad. In addition to sustaining the run, the passage facilities should provide an annual harvest of 100,000 shad above Hartford, 50,000 shad above Holyoke, 42,500 above Turners Falls, and 37,500 above Vernon.

Atlantic Salmon - *Salmo salar* - The magnitude of the original salmon run in the Connecticut River is unknown, although there are many historical references that indicate that the run was sizeable and originally went as far as Beecher Falls near the Canadian Border. Utilizing a unit area technique similar to that used with shad and evaluating the River as far as the Cummerford Dam, reveals a potential run of adult salmon at the River's mouth of 38,000.

This figure is based on the production of three smolts per unit area

with a survival to maturity of five percent. A realistic approach to natural production of salmon indicates that man-made changes in the tributaries prevent the actual attainment of a natural run of 38,000 fish. However, there is no reason why the 38,000 figure cannot be realized or exceeded through a smolt stocking program.

The problem of salmon passage on the main stem does not require lengthy discussion as facilities adequate for the anticipated large shad runs will readily pass the number of salmon involved.

Other Anadromous Species - Various other species occur in the River that will benefit from a program designed to develop shad and salmon fisheries. The only species that probably would use passage facilities to a large degree is the blueback herring, *Alosa aestivalis*. If a commercial fishery can be developed for this herring, passage facilities would have an additional benefit.

Resident Species - In addition to establishing and maintaining runs of anadromous fishes, we also intend to maintain and enhance various resident species found throughout the basin.

Benefits - It is always difficult when dealing with a resource that is not entirely commercial to establish the value of said resource. Nevertheless, an attempt has been made although it should be realized that the value, for example, of an angler-caught Atlantic Salmon from the Connecticut River is probably far beyond anything that we could establish with simple dollars and cents.

Some data is available on the value of resident species, but more information is required and overall fishery values for the River will be subject of a later report.

Information indicates that the present average annual retail value of the shad commercial fishery is approximately $150,000. If economics and the market permitted, it appears that this annual value could be doubled with the increased predicted runs.

The present shad sport fishery has an annual value of $150,000 based on 50,000 angler days. Predicted catches based on a run of 2,000,000 fish indicate a sport's harvest of 100,000 fish in Connecticut; 50,000 from Holyoke to Turners Falls; 42,500 from Turners Falls to Vernon and 37,500 above Vernon. Based on current fisherman day value of $3.00 and one fish per man per day, the predicted annual additional value gained from proper management would amount to $537,000.

A run of 38,000 salmon should produce a catch of 9,600 fish based on a 25 percent harvest. Considering the extreme pressure that might be generated by a salmon run in the Connecticut River, this figure may be low. Using the current figure of $120,[redacted] per angler caught salmon, the annual value would amount to $1,152,000. The potential combined annual value for new shad and salmon sport fisheries amounts to $1,689,000.

<u>Problems</u> <u>and</u> <u>Needs</u> - To attain the objectives that have been discussed, many problems must be surmounted and much work must be done.

The water quality of the River must be maintained and improved. All of the Connecticut River States are now active in classifying their waters as to water quality and it appears that the standards to be set will be suitable for shad and salmon. The threat of thermal pollution is a very real one with one nuclear plant shortly going into operation in Connecticut and another one proposed at Vernon, Vermont. The Connecticut Yankee Atomic Power Company, as a condition of their construction permit, is presently supporting a study to determine the effects of their heated discharge water on shad. We need more information regarding thermal pollution tolerance and effects on salmon and this type of work will be outlined in the Research Plan to be drawn up by the Technical Committee for Fisheries Management of the Connecticut River Basin. Although subject to future research finding, it appears that any increase in the water temperature at Vernon could seriously hinder salmon and shad restoration in the upper basin.

The Corps of Engineers is considering the construction of a dam at Hartford for navigational purposes. The dam will create fish passage problems and perhaps more important, eliminate fishing sites and excellent shad spawning areas. We must oppose the construction of this dam because it would be inconsistent with the aims of the fishery restoration program.

Based on the present fragmentary data available on the Northfield Pump Storage Project, it appears that this project poses definite limitations to an anadromous fish restoration program. These limitations involve the physical loss of eggs, larvae and young fish of both anadromous and resident species, and an orientation problem for both upstream and downstream migrants attributed to pumping large volumes of water. Studies designed to minimize the potential adverse effects to fishery resources should be undertaken in development of the design for the Northfield Pump Storage Project. In related studies, fish screens, barriers and deflectors and flow regimen must be thoroughly investigated.

If the runs outlined are to become a reality, there are also major problems to be solved for the passage of both upstream and downstream migrants over existing dams. Larger runs may require modification of the Enfield Dam; facilities must be developed by Holyoke, Turners Falls and Vernon for shad and a fishway for salmon will be required at Bellows Falls. There are many unsolved problems concerning fish passage facilities particularly with regard to shad. Members of the Technical Committee have made a start on these problems and a full-fledged research project will be forthcoming in the near future. Considerable work must be done on the various tributaries to evaluate fish passage needs.

Lack of low flow augmentation is another problem, and the Technical Committee proposes to develop these needs and to work with the Corps of Engineers and private companies to solve this situation.

A thorough review must be made of the many proposals to build multi-purpose dams in the basin, particularly with regard to their effects on the fishery restoration program.

When the proposed fisheries become a reality, the four States involved will cooperate to establish regulations that will maintain the fisheries as well as assure that each State receives its just share of the fishery harvest.

There is presently a need for fishermen access sites on the River and the need will greatly increase as the program progresses. Connecticut and Massachusetts have already made progress in providing access and all of the States will develop a large scale program in the near future.

We endorse and support the Technical Committee for Fisheries Management of the Connecticut River Basin as the group designated to design and implement needed research programs as well as to develop and recommend sound fishery management procedures. The Committee shall consist of representatives from the Connecticut Board of Fisheries and Game, the Massachusetts Division of Fisheries and Game, the Massachusetts Division of Marine Fisheries, the New Hampshire Fish and Game Department, the Vermont Fish and Game Department, the United States Bureau of Sport Fisheries and Wildlife and the United States Bureau of Commercial Fisheries.

April 20, 1967

By: Director, Connecticut Board of Fisheries and Game
Director, Massachusetts Division of Fisheries and Wildlife
Director, Massachusetts Division of Marine Fisheries
Director, New Hampshire Fish and Game Department
Commissioner, Vermont Fish and Game Department
Regional Director, United States Bureau of Sport Fisheries and Wildlife
Regional Director, United States Bureau of Commercial Fisheries

APPENDIX V

THE ECONOMIC BENEFITS OF THE RESTORATION OF ATLANTIC SALMON TO NEW ENGLAND RIVERS

by

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November 1987

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APPENDIX V

Table of Contents

APPENDIX V

List of Tables

Introduction[1]

New England is graced with close to three dozen major rivers or river systems, each of which empties into the Atlantic Ocean. At the time Europeans began to colonize the region, wild salmon populations were plentiful in at least 28 of the rivers, ranging from the Housatonic River in Connecticut north to the Aroostook River in Maine. It has been estimated that the number of salmon entering New England rivers annually at that time might have been greater than 300,000 individual fish.[2]

Two and a half centuries of human population growth and economic development devastated New England's Atlantic Salmon population. Overfishing, water pollution, and (above all else) dam construction accounted for the salmon's retreat. Were Atlantic Salmon to be restored now to their full historical range, upstream fish passage facilities would have to be provided at a minimum of 65 dams, and downstream fish passage facilities at almost 100 dams.[3]

Today only seven of the original twenty-eight Atlantic Salmon rivers support fairly stable but small wild Atlantic Salmon populations. Adult salmon in varying numbers return annually to eight additional rivers. The total number of salmon returning to all New England rivers adds up to less than 7,000 fish. Of these, only about 1,000 are not of hatchery origin.[4]

Atlantic Salmon restoration activities were first initiated well over a century ago, and revitalized with the formation of the Maine Atlantic Salmon Commission in 1947. Since then, state and federal agencies have coordinated efforts with private sector groups to promote, instigate, and explore the feasibility of a regional restoration program. Between 1967 and 1983 over 76 million dollars were spent on restoration efforts in New England. Given the fruits of these accumulated expenditures, the U.S. Fish and Wildlife Service believes the feasibility of the Restoration Program has now been demonstrated. However, the costs of a planned 25 years of further restoration activities exceed $100 million.[5]

The Fish and Wildlife Service is poised to make a decision about the future of the Atlantic Salmon Restoration Program. Either substantial restoration efforts will continue as planned, or the Program will be cut back to minimum levels of legislatively mandated activity. Although many factors will influence this decision, it must ultimately rest on some

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[1] Financial support for this study was provided by Region Five of the U.S. Fish and Wildlife Service via Cooperative Agreement 14-16-009-1553, Work Order No. 5 with the Cooperative Fish and Wildlife Research Unit, Cornell University.

[2] US Fish and Wildlife Service, 1984, pp. 9-10.

[3] Ibid, p. 28.

[4] Ibid, p. 9.

[5] Ibid, p. 27.

comparison of the advantages and disadvantages, or costs and benefits, of the alternatives.

The costs and benefits of each alternative can and should be broadly defined by the Fish and Wildlife Service. Nevertheless, it is common to consider costs and benefits within the comparatively restricted vocabulary of economics. While this vocabulary necessarily distorts or excludes consideration of some deeply held values that are important to a comprehensive assessment of Atlantic Salmon restoration, it does permit an important level of argumentation in the persuasive language of money. The strength of an economic cost-benefit analysis is that it can reduce a complex set of economic relationships to a single decision parameter. This strength can be a weakness to the extent that the single parameter belies the richness of projection, analysis, assumption, judgment and prejudice that supports it.

The practice of conducting formal economic cost-benefit analyses of public investments has become increasingly commonplace, and has indeed been required for most federal programs since Executive Order 12991 was issued in 1981. But public programs that involve the protection or preservation of natural resources (e.g. the Atlantic Salmon Restoration Program) are of a class that poses special conceptual and practical difficulties for cost-benefit analysis. Because the economic "good" in question is not (and possibly could never be) traded in an established marketplace, there is no readily available economic measure of its value (e.g. market price). Thus, even though the dollar costs of investing in preservation or restoration activities may usually be estimated with some degree of precision and confidence, the measurement of benefit has been more difficult and more controversial. "Contingent valuation" methods address this difficulty.

A form of economic cost-benefit analysis using contingent valuation techniques has therefore been applied to the decision facing the Fish and Wildlife Service about the Atlantic Salmon Restoration Program. The contingent valuation methodology used in this study is an economic tool that has recently received a great deal of scrutiny and growing acceptance by the economics profession. It is the only method that can assign a "total economic value" to projects like the Atlantic Salmon Restoration Program.[6] Contingent valuation methods are based on questionnaires and survey responses to direct questions, and hence display many basic presumptions and assumptions more transparently than other methods economists normally apply.

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[6] This measure of total economic value is grounded in a theory of individual preference. The measure represents - at least theoretically - the maximum amount of money which an individual would be willing to sacrifice rather than do without the Atlantic Salmon restoration program. Thus, any value the individual can translate into a maximum "willingness-to-pay" will be counted. The values are total because they include value that may be based in current or prospective use (e.g. consumer surplus and option values, respectively) plus any value the individual may place on Atlantic Salmon that may be wholly independent of use of the resource (eg. "existence value"). Traditional benefit measures, based on estimated areas under a demand curve, account only for consumer surplus.

The purpose of this paper then is to report on estimates of the public value, or benefits, that would be associated with continuation of the restoration program. Numerical estimates of benefit will be presented first, together with some estimates of cost. It is clear, even under moderately conservative assumptions, that the total economic benefits of Atlantic Salmon restoration outweigh the costs.[7] The questionnaire sources and methodology used to develop the benefit estimates are described next, followed by a brief discussion of their validity.

Program Benefits

The benefits of the Atlantic Salmon Restoration program were calculated from a survey of New England households. After being presented with some initial information, questionnaire respondents were asked whether or not they "cared one way or the other whether there are Atlantic Salmon in any New England rivers". It was presumed that persons answering "No" to this question would place zero economic value on the restoration project. Everyone answering "Yes" to this question was asked to estimate the maximum amount they would be willing to pay in order to ensure that Atlantic Salmon would be found in the fourteen New England rivers primarily targeted by the Atlantic Salmon Restoration Program.[8] Persons who said they expected to someday fish for Atlantic Salmon were asked to express this value in two parts. First, they were asked about the most they would be willing to pay for an Atlantic Salmon fishing license valid only for these fourteen rivers. Second, if they noted that the economic value of finding Atlantic Salmon in those rivers exceeded the maximum amount they were willing to pay for a fishing license, they were asked how much additional money they would be willing to pay through other means (e.g. increased taxes) for continued restoration.

Persons who indicated that they had no intention of ever fishing for Atlantic Salmon were asked only to estimate the maximum amount they would have been willing to pay for restoration through increased taxes, electric bills, or other such payment vehicles.

A surprisingly large proportion (82%) of persons responding to the mailed questionnaire noted that they "cared" whether Atlantic Salmon were found in New England rivers. However, a nonrespondent follow-up survey

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[7] This does not necessarily mean that there is an economic imperative to continue this project, since an agency with limited funds might determine that other projects were even more worthy of investment. No attempt has been made to compare expenditures on Atlantic Salmon restoration with other project choices.

[8] See map, Appendix I. The Fish and Wildlife Service asserts that, with continued restoration effort, Atlantic Salmon can be successfully reestablished in all fourteen streams within a 25 to 50 year period. The minimally mandated levels of restoration (including some Federal support of state fishery agencies and certain administrative activities) would be required to sustain existing populations in a few of the seven other rivers shown, given that state restoration efforts also continued.

revealed that the mail questionnaire was more likely to be returned by persons who care about Atlantic Salmon. On the basis of the nonresponse analysis, a very conservative adjusted proportion of persons who "care" about Atlantic Salmon was estimated to be 58.3%.[9]

Not everyone who cares about Atlantic Salmon was willing or able to sacrifice money to further the restoration program: 43% of those "caring" respondents expecting never to fish; 24% who might someday fish; and 6% of those certain they would someday fish for Atlantic Salmon on the 14 rivers in question did not express a positive willingess to pay.

Table 1. Average willingness to pay for Atlantic Salmon Restoration: In addition to fishing license fees.

Will respondent fish for AS?	Mean WTP	Respondents who care about AS restoration	Total Willingness-to-pay (Millions)
Certainly will	$31.93	19.1%	$13.6
Might	$10.81	35.3%	$ 8.5
Probably won't	$27.45	45.6%	$27.9
		(100%)	SUM $50.0

As shown in Table 1, given that a respondent said he or she cared about Atlantic Salmon, the respondents expecting to "certainly fish" for Atlantic Salmon someday were willing to pay an average (inclusive of the zero values just noted) of $31.93 above and beyond their maximum willingness to pay for a fishing license. Persons who said they "might" fish for Atlantic Salmon someday said they were willing to pay for an average of $10.81 above and beyond their maximum willingness to pay for a fishing license. Persons who were not expecting to ever fish for Atlantic Salmon were willing to pay an average of $27.45 in increased taxes or other revenues.[10]

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9 This assumes that persons about which no information was available (either because they could not be reached or would not cooperate) did not care about Atlantic Salmon. Appendix II has details of the nonresponse analysis. A second conservative assumption about the benefit estimates is that the sample was restricted to New England residents. This effectively assumes that no one who lives outside this region is interested in New England's Atlantic Salmon. This is assuredly an inaccurate simplification.

10 The willingness to pay asked about was for a maximum one time payment. This payment could be thought of as a "present value" that would be equivalent to a stream of annual payments that have been discounted to the present (see section on costs below).

Extrapolating from census reports, we estimate that there are 4,442,522 occupied households in New England.[11] We estimate that 86% of these households were in the sampling frame,[12] and that all of the uncovered households have zero willingness to pay for Atlantic Salmon restoration. This implies that 2,227,392 households[13] "care" about Atlantic Salmon restoration. The total willingness to pay for Atlantic Salmon is then found by combining this information with that in the first two columns of Table 1.

The data presented in Table 1 do not include those values elicited about willingness to pay for Atlantic Salmon licences. Such values were asked of respondents who indicated they certainly would, or might, someday fish for Atlantic Salmon. These respondents were asked to predict the maximum amounts they would pay for a license that allowed them to keep no salmon, one salmon, five salmon, ten salmon, or more than ten salmon. The survey informed respondents that the state of Maine currently sells Atlantic fishing licenses, with an annual limit of five fish, at a cost of $10 for in-state residents and $30 for out-of-state residents. The averaged maximum amount that these respondents suggested for any of the five licenses is reported in Table 2.[14]

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[11] This extrapolation was calculated from 1980 ratios of occupied housing to state population totals (Bureau of Census, 1980 Census) applied to 1984 population figures (Bureau of Census, Current Population Reports). The calculations are therefore probably a conservative estimate of households at the time of the survey (late 1986).

[12] The 1980 Census indicates that 95.4% of New England households have telephones. In 1973, it was estimated that 14.7% of New England households with phones had unlisted numbers. This is lower than the national average of 17.8% (Blankenship, p. 41). These figures suggest that about 81% of New England households have a telephone or a listed number. However, our sample was drawn from a commercially supplied phone list supplemented by auto registration that covers 86% of all households nationally (Survey Sampling, Inc.). We adopt the 86% figure as a seemingly conservative approximation for New England.

[13] 58.3% who "care" * 86% coverage * 4,442,522.

[14] These numbers are also conservative. Respondents were actually asked to give the maximum amount that they would be willing to pay <u>annually</u> over a three or five year period in order to reserve an Atlantic Salmon license at the end of that period. Following Brookshire, Eubanks and Randall, this approach was adopted to 1) try and minimize the conceptual possibility of "free riding", and 2) try and allow more time for continued restoration activities that might enable license limits to be legitimately raised above the current level of 5 salmon per year. The numbers reported in Table 2 used only a single year's payment. Using this figure is equivalent to discounting payments from years two and up at 100%. This is done on grounds of conservatism and because there are indications that the three or five year payment mechanism was not understood by some respondents.

Table 2. Average willingness to pay for Atlantic Salmon Restoration: Maximum fishing license fees.

Will respondent fish for AS?	Mean WTP	Respondents who will fish for Atlantic Salmon	Total Willingness-to-pay (Millions)
Certainly will	$31.92	35.1%	$13.6
Might	$22.55	64.9%	$17.7
			SUM $31.3

The grand total willingness to pay for Atlantic Salmon restoration is the sum of the license fee figure from Table 2 and willingness to pay other increased fees from Table 1.[15] This grand total, at $81.3 million, exceeds the estimated costs (see below) of continued restoration with adoption of any rate of discounting future expenditures that exceeds three percent.[16] Given that the benefit estimates have many conservative assumptions built into them, the economic costs of Atlantic Salmon Restoration appear to be clearly less than the benefits.

Comparisons with Wildlife Valuations in Other Studies

The results for mean willingness-to-pay appear to be in the range found by other researchers using a variety of contingent valuation techniques to estimate the economic value of wildlife. Brookshire, Eubanks and Randall found a range from $9.70 to $29.16 for mean bids big game hunters were willing to pay for grizzly bear and bighorn sheep hunting licenses under various conditions; while non-use related mean bids ranged from $6.90 to $24.00. Boyle estimated mean willingness-to-pay bids for bald eagle preservation between $10.62 and $75.31; while estimated mean bids for preservation of a less popular animal, the striped shiner, were close to $5.00. Other studies of the economic value of Canada Geese (Bishop, Heberlein, and Kealy) and of elk (Brookshire, Randall, and Stoll) found mean bids that are generally bracketed by this range.

Program Costs

The economic costs considered for the Atlantic Salmon Restoration program are of three varieties. First, there are the construction costs associated with building upstream and downstream fish passage facilities. These were assumed to be incurred in the single year in which the Fish and Wildlife Service plans to construct each fish passage facility.

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15 The validity of this summation depends on the extent to which the nonangling valuations reported by anglers are truly increments to their willingness to pay for a fishing license.

16 The official discount rate for federal water and land related resource projects during fiscal year 1986 was 8 5/8% (Water Resources Council).

Table 3. Estimated costs of Atlantic Salmon Restoration on New England Rivers.

Value of foregone electricity production

Discount Rate	Dollar value at 12 cents per kilowatt-hour (millions of 1986 dollars) (Total of 313,000 Megawatt-hours between 1986 and 2036)	Dollar value at 9 cents per kilowatt-hour (millions of 1986 dollars)	Combined construction, operation and maintenance costs for fish passage facilities on New England rivers (1986 to 2036) (millions of 1986 dollars)
0%	$38.4	$28.8	$109.7
1%	$29.5	$22.1	$ 93.5
2%	$23.1	$17.3	$ 81.2
3%	$18.5	$13.9	$ 71.6
4%	$15.0	$11.2	$ 64.0
5%	$12.4	$ 9.3	$ 57.9
6%	$10.5	$ 7.9	$ 52.8
7%	$ 8.9	$ 6.7	$ 48.6
8%	$ 7.7	$ 5.8	$ 45.1
9%	$ 6.7	$ 5.0	$ 42.0
10%	$ 5.9	$ 4.4	$ 39.3
15%	$ 3.4	$ 2.6	$ 29.9

Second, there are annual operating and maintenance (O&M) costs of each facility. These costs were assumed to be incurred each year following the year of fish passage construction through the end of a fifty year program period (ie. the year 2036). Third, there is the cost of foregone hydroelectric power that is incurred because the fish passages must divert some water around the turbines. These costs were assumed to begin the same year as construction begins, whether for an upstream or downstream passage.[17]

The program cost sensitivities to varying rates of time discounting are detailed in Table 3. All estimates of construction and O&M costs and

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[17] Although upstream passages normally divert more water, some water is required for downstream passages. Upstream and downstream passages are not necessarily planned for the same year at each dam. Since the estimates of annual foregone megawattage did not distinguish between up- and downstream facilities, the annual energy loss was conservatively assumed to begin at the date of construction of the first type of fish passage. A high value of 12 cents per kilowatt-hour was applied to the energy losses. This is a penny or so higher than the current highest marginal residential electricity prices in New England. (Gene Heinze-Fry, personal communication; see also Heinze-Fry, 1984.)

annual foregone megawatt-hours were provided by the U.S. Fish and Wildlife Service for each dam, as was a timetable for implementation.

Description of Questionnaire Responses

The contingent valuation estimates were derived from a questionnaire that collected much related information besides that already reported. In the following discussion, some of this information is presented and compared where possible with known characteristics of the New England population from which the questionnaire sample was drawn.

The questionnaire was divided into six sections.[18] The first section asked several questions regarding the familiarity of the respondent with Atlantic Salmon, and also asked for basic fishing and outdoor recreational experience. The second section provided a brief (two paragraph) description of the situation and history of Atlantic Salmon in New England. It also stated that the Atlantic Salmon Restoration Program would 1) leave the fish in only 7 of the smaller Maine rivers if reduced to minimally mandated levels, or 2) eventually secure a salmon population in 14 additional New England rivers if restoration were continued. A map detailed the rivers affected. The third section asked respondents whether they care one way or the other that Atlantic Salmon can be found in New England rivers, and if so, why. The fourth and fifth sections separated probable salmon anglers from probable non-anglers, and provided the core of the contingent valuation information discussed previously. Anglers were presented more detailed information about the purchase of several types of fishing licenses, then queried as to their willingness to purchase such licenses. Nonanglers, and anglers whose economic self-valuation of Atlantic Salmon exceeded their willingness to pay for a fishing license, were asked similar contingent valuation questions using "payment vehicles" other than a fishing license. The final section asked respondents a standard series of demographic questions (age, sex, income, etc.).

Respondent Demographics

In 1984 the 12.5 million residents of New England were distributed in households across the six states of the region as shown in Table 4. As can also be seen from Table 4, this distribution is closely reflected in the questionnaire responses.

Table 4. New England population proportions distributed by state, 1984 US Census figures and 1986 survey responses.

State	Census (1984)	Survey (1986)
CT	25.0%	23.0%
ME	9.1%	11.8%
MA	46.2%	46.5%
NH	7.7%	9.0%
RI	7.7%	6.3%
VT	4.2%	3.5%

[18] A copy of the questionnaire is found in Appendix I.

Although just over half of the total New England population is female, 77% of the respondents to the mail questionnaire were male. The primary reason for this difference is that questionnaires were addressed to the household member in whose name the telephone was listed. These persons are overwhelmingly male. Since males tend to be more interested in fishing than are females, it is also possible that some females passed questionnaires on to more interested household males.

The 1980 Census figures show mean New England household sizes to have ranged from 2.7 persons per household in Rhode Island to 2.76 persons in Connecticut. The Atlantic Salmon survey results indicate an overall New England average household size of 2.9 persons (68% of households are comprised of two or fewer persons). The small positive difference may well reflect the "baby boomlet" that has gathered force in the seven years separating the surveys.

The age of survey respondents is presented in Table 5. The average age of the respondents was 46 years (median of 43). The median age of New Englanders in 1980 was 31.2 years. Respondent ages are much greater than for the population as a whole for obvious reasons: children and young people are unlikely to have their own telephone and hence are not included in the directories from which the sample was drawn. Census data on household heads only shows an age distribution closer to that found in the sample. Of course, it makes most sense anyway to direct questions regarding willingness to pay for salmon restoration at non-dependent adults.

Table 5. Age of respondents.

Age group	Percent
Over 70 years	8.1
66 to 70 years	6.4
31 to 65 years	67.3
19 to 30 years	16.9
18 years or less	1.3

Even after adjusting for the observed nonresponse bias (see Appendix II), the survey results show that substantial proportions of the sample were fairly well educated professionals with sizable household incomes. Just under two fifths (39%) had obtained a college degree, which was slightly more than the 37% who had terminated their educations at or before their high school graduation. The remaining 24% finished some college.

Similarly, one quarter of the responding New Englanders could be classified as managers or professionals. A second quarter of the sample noted that they were already retired. The remaining half of the respondents were engaged in a variety of occupations, though approximately 4% said they were unemployed.

Over a fifth of respondents (21% - unadjusted for nonresponse bias) answering the income question reported total 1985 household incomes of

$50,000 or greater. A similar proportion (23.7%) reported annual incomes under $20,000. The median 1985 household income reported by survey respondents was in the range between $30,000 and $39,999.

Respondent outdoor recreation experience and familiarity with Atlantic Salmon

Salmon are a popular and well known fish, and the Atlantic Salmon Restoration Program is one which is recognizably of general interest.[19] Still, an unexpectedly high 69% of mail questionnaire respondents claimed they knew even before receiving our survey that Atlantic Salmon could be found in some New England rivers.[20] Furthermore, just over half of the respondents said they had personally seen some kind of salmon at least once in their lives. Of this half, most had viewed salmon at a visit to some kind of special observation center such as a dam or museum, but almost as many had seen salmon while fishing (not necessarily for salmon).

Many respondents (22%) had fished specifically for some kind of salmon at one time or another. While the majority of these salmon anglers had fished for either coho or chinook or other kinds of salmon, approximately 7% of all survey respondents said they had themselves fished for Atlantic Salmon. Furthermore, 34% of the respondents had eaten some kind of salmon that "they or someone else had caught while fishing for sport".[21]

Since there were only a few thousand Atlantic Salmon licenses sold in 1986 by the state of Maine, it was a fair assumption that few or none of the randomly selected New England residents would have actually purchased one of these licenses. In fact, only 30% of the respondents explicitly expressing an interest in fishing for Atlantic Salmon someday were even aware that it was possible to buy a Maine fishing license for Atlantic Salmon. The persons who were aware were asked why they had not purchased a license. Table 6 lists the reasons given. Note that distance from home was by far the most common, and that as more rivers are restored, these distances will decline for many New Englanders.

When asked about general outdoor recreation activities in 1986, over one-third (34%) of the respondents indicated that they had engaged in some kind of freshwater fishing during the year. A somewhat smaller proportion (28%) had enjoyed saltwater fishing during the year, while 13%

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[19] The New York Times, for example, carried several general interest stories on the restoration efforts during the course of this research (see July 27th, 1986 and January 25, 1987 papers).

[20] It was not possible to adjust for suspected nonresponse bias to this question and many of the other questions next discussed, except as noted.

[21] Less than half of these had caught the fish themselves.

Table 6. Reasons for not buying a Maine salmon license for people who knew of its existence.

COST OF LICENSE	19%
DISTANCE OF RIVERS FROM HOME	68%
SCARCITY OF SALMON IN RIVERS	31%
SIZE OF SALMON	7%
LICENSE LIMITATIONS ON FISH	5%
COST OF GEAR	11%
CROWDING AT FISHING SITES	34%

had hunted in 1986.[22] Forty-four percent of respondents had been camping or hiking during the year, and a substantial majority of 71% had been boating or swimming in lakes, rivers or the ocean in the past year.

Respondents were asked to describe the type of area in which they lived. Approximately one-fifth of them said they lived in large cities (primarily Boston), and slightly less than a fifth in the suburbs of large cities. An additional fifth of the respondents said they lived in small cities, while the largest single proportion of the New England respondents (about a third) said they lived in small towns. Finally, the remaining tenth classified their surroundings as rural.

Reasons for interest in Atlantic Salmon

Respondent who indicated that they care about Atlantic Salmon restoration were asked additional details about their interests in the fish. The vast majority (91%) had no special interest in any smaller subset of the 14 rivers included in the restoration program. Of the few who did name specific rivers, the Connecticut River was most often mentioned by far. Similarly, 83% of respondents said their interest in Atlantic Salmon was neither more nor less than in other wildlife. These results intimate that some of the value of Atlantic Salmon that was developed earlier in this report might also be at least partly a proxy measure for willingness to pay for wildlife preservation in general.[23]

Less than one-third of the respondents who cared about Atlantic Salmon said they expected to personally see or fish for them someday.

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[22] Statistics from the 1980 National Survey of Fishing, Hunting, and Wildlife Associated Recreation showed approximately 760,000 exclusive freshwater anglers over 16 years of age, about 489,000 saltwater anglers, and about 507,00 anglers in both salt and freshwater. The data show that the number of hunters was about one-third the number of anglers. (Tables 43 and 45)

[23] When asked to list something of more or less equal value to Atlantic Salmon upon which they already had spent money, most respondents did not answer. Of the 31% who did, about one fourth of them made comparisons to other fish or fishing expenditures, another fifth made comparisons to other kinds of wildlife expenditures, while another fifth gave answers in a more general conservation or environmental category.

However, more than three-fourths said they would be pleased to know that Atlantic Salmon could be found in New England rivers even if they never did see or fish for salmon themselves. Just as many (over three-fourths) agreed with the statement that, "I think the return of Atlantic Salmon is an important sign that river pollution has been cleaned up". And only slightly fewer (73%) felt that there was a need to act on restoration now for the benefit of future generations of people. A lower proportion, but still the majority (61%), agreed with the statement that, "I think that Atlantic Salmon should be returned to New England rivers to restore the lost balance of nature".

Alternative Calculations of Benefit

An attempt was made to validate the estimates of Atlantic Salmon valuations reported in Tables 1 and 2 through alternative calculations. Instead of calculating mean willingness-to-pay from the highest values reported by survey respondents, related calculations were derived from a "Yes/No" question. Questionnaire recipients were asked whether they would be willing to pay a certain preselected dollar amount for Atlantic Salmon restoration. The dollar amount selected varied across individuals. Hanneman (1985) has hypothesized that individuals are more likely to be able to answer a yes/no question than to give a specific maximum figure. This type of question also avoids the possibility of starting point bias, where respondents anchor their maximum answers to the initial dollar figure presented them. Bishop and Heberlein (1979) first implemented this procedure, while Hanneman (1984a) has developed it in a utility-theoretic framework.

As suggested by these authors, logistic regression was used to predict how the probability of being willing to pay for restoration varies with the dollar amount presented to the respondent. The estimated logistic equation serves as the basis for calculating willingness-to-pay.[24] As can be seen from Table 7, the dollar values that are generated by this process are higher than shown in Tables 1 and 2.[25] The values in Tables 1 and 2 are preferred only on grounds of developing a conservative estimate of benefits.

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[24] Calculations of mean and median willingness to pay depend upon the explicit or implicit assumption of a particular utility function. The values reported in Table 6 implicitly assume a simple utility function that is linear in income and a constant. Hanneman (1984a) shows that under this assumption the median and mean are equal.

[25] All respondents had the opportunity to answer the willingness to pay questions in the discrete choice form and then as a maximum value. In a number of cases (37 - or about 7% of all respondents) people agreed to pay an amount that was higher than the maximum bid they then entered in the following question. In about half as many cases (20) people refused to pay an amount that was lower than the highest amount they subsequently entered. In this sense, more people revised their bids downwards than upwards when given a chance to reconsider their answer to the question in the yes/no format.

Table 7. Median and mean willingness-to-pay estimated from equations predicting the probability of agreeing to pay for Salmon restoration.

	Median and mean payment
Willingness topay for a special licence allowing five salmon to be kept	$43.25
Willingness to pay increased taxes or other fees to help restore Atlantic Salmon	$40.44

The measurements of willingness to pay presented earlier presume that New Englanders must purchase, in effect, the right to enjoy the benefits of Atlantic Salmon. An alternative, and equally valid, microeconomic perspective starts from the presumption that New Englanders begin with the right to enjoy the benefits of Atlantic Salmon in the region's rivers. From this perspective, the value of the restoration program must be measured as the minimum payment that New Englanders will accept (eg. in tax savings), on average, to forgo successful restoration. Note that values are not constrained by income here. Empirical estimates of "willingness to sell" typically yield values that are an order of magnitude greater than that of payments.[26] They are also more difficult to assess because it is harder to present a realistic or believable contingent situation in which repondents would sell their "rights". Although no dollar estimate of willingness to sell will therefore be reported, it will be noted that only 5 out of 364 relevant respondents said they would rather take the dollar savings offered (which ranged from $1 up to $600) in return for discontinuation of the Atlantic Salmon Restoration Program.

Summary and Conclusions

The data which has been reported reveals a strong and widespread interest in Atlantic Salmon restoration throughout the New England area. The benefit calculations indicate that this interest translates, at least within the artificial context of the contingent valuation questionnaire, into a substantial dollar value. Because even conservative estimates of this dollar value exceed, when expanded over the New England population, the Fish and Wildlife Service's estimates of program costs, it can be concluded that there are economically as well as politically convincing grounds for continuation of Atlantic Salmon restoration in New England.

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[26] Hanneman (1984b) suggests that, in general, large empirical differences between the measures may be indicative "of a general perception on the part of the individuals surveyed that the private market goods available in their choice set are, collectively, a rather imperfect substitute for the public good under consideration."

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APPENDIX I

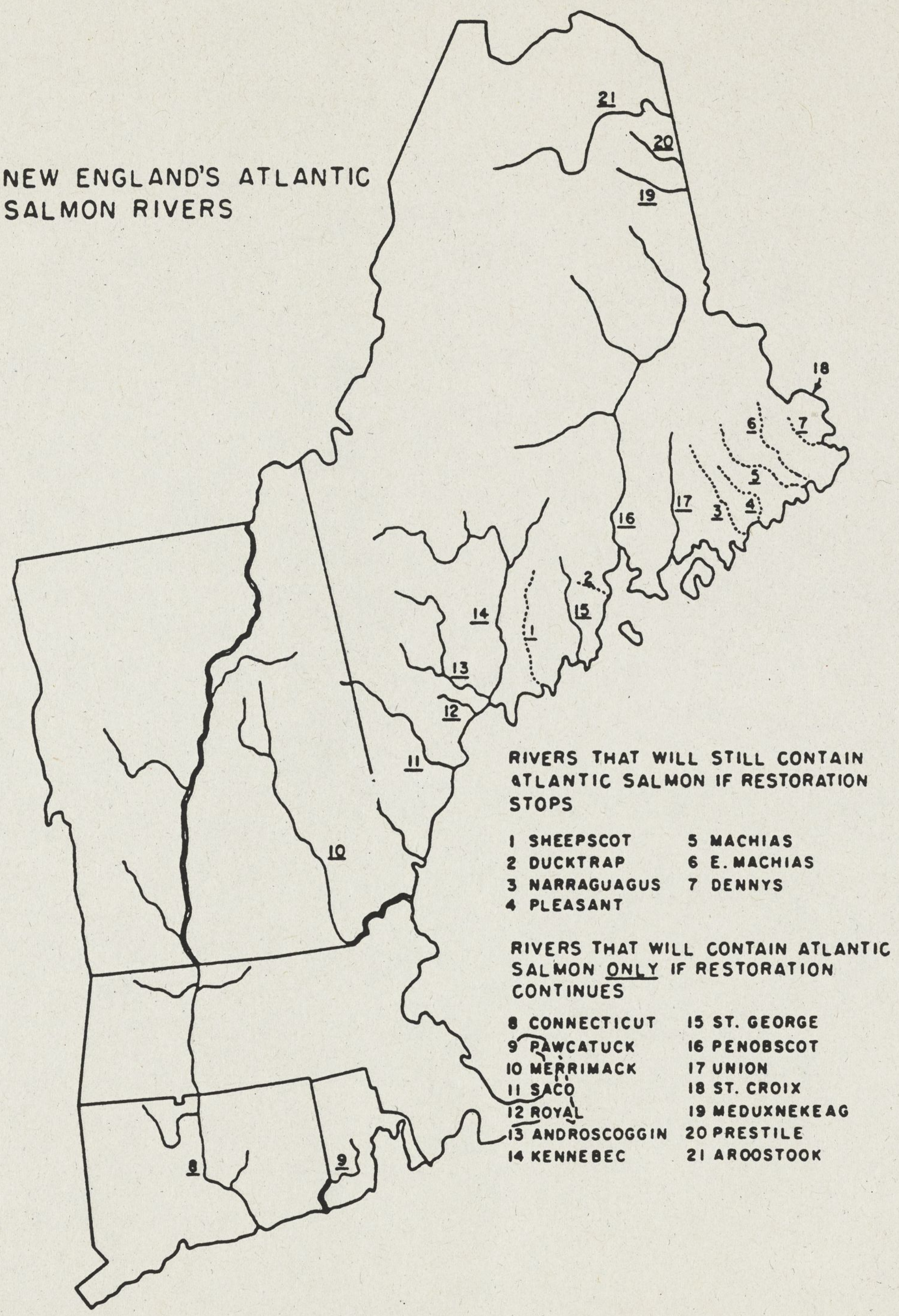
Mail Questionnaire

ATLANTIC SALMON RESTORATION:

A PUBLIC OPINION SURVEY

Department of Natural Resources
New York State College of Agriculture and Life Sciences
A Statutory College of the State University
Cornell University, Ithaca, N. Y.

NEW ENGLAND'S ATLANTIC SALMON RIVERS



I. FIRST WE WOULD like to get a sense of how familiar you are with ATLANTIC SALMON. By ATLANTIC SALMON we mean only those salmon that spend part of their lives in northeastern rivers (see our map) and part of their lives in the Atlantic Ocean.

1. Did you know before today that Atlantic Salmon could be found in some New England rivers? .... [ ]NO [ ]YES

2. Have you ever seen any kind of live salmon? .... [ ]NO [ ]YES

If YES, how did you see the fish? (check answers that apply)

[ ]WHILE FISHING
[ ]VISIT TO A SPECIAL OBSERVATION CENTER
[ ]BY CHANCE IN OPEN WATER
[ ]OTHER (explain: ________________________)

3. Have you ever fished for any kind of salmon? .... [ ]NO [ ]YES

If YES, for what kind of salmon? (check answers that apply)

[ ]DON'T KNOW
[ ]ATLANTIC SALMON
[ ]PACIFIC SALMON (eg coho or chinook)
[ ]OTHER (explain: ________________________)

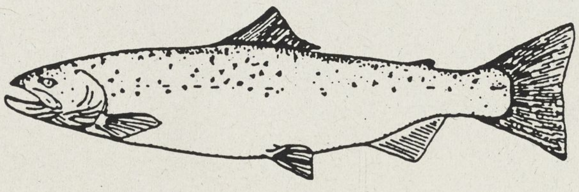
4. Have you ever eaten any kind of salmon that you or someone else caught while fishing for sport? .... [ ]NO [ ]YES

5. Which of the following outdoor recreation activities have you participated in during the past year? (check all that apply)

[ ]FRESHWATER FISHING (other than for salmon)
[ ]SALTWATER FISHING
[ ]HUNTING
[ ]HIKING OR CAMPING
[ ]BOATING OR SWIMMING IN LAKES, RIVERS, or OCEAN

6. How would you describe the area in which you live?

[ ]RURAL
[ ]SMALL TOWN or VILLAGE
[ ]SMALL CITY (less than 50,000 people)
[ ]LARGE CITY (more than 50,000 people)
[ ]SUBURB OF A LARGE CITY



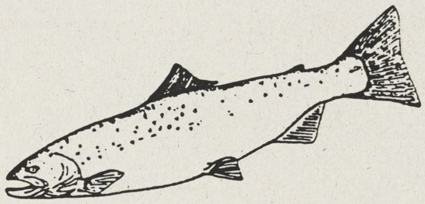
II. IN THIS SECTION we present a little more information about Atlantic Salmon in New England's rivers.

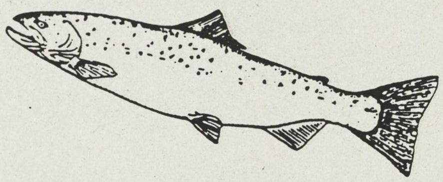
Many years ago large numbers of Atlantic Salmon lived in most of New England's rivers. That is no longer true. As the number of people grew, the number of salmon fell. The decline was caused by **over-fishing, water pollution,** and **the building of dams** that blocked many rivers. Today, hydro-electric dams are the biggest barrier to the return of the Atlantic Salmon.

There are now small but secure numbers of salmon in 7 of the shorter Maine rivers (see map, dotted lines). State and federal programs have already begun to restore Atlantic Salmon to other New England river systems. The programs could lead to secure levels of salmon in each of these 14 additional river systems within 25-50 years (see map, solid lines). Of course, if the programs are stopped, no salmon will be found in these rivers. The programs work by:

* releasing young salmon into the rivers;
* providing ways, such as "fish ladders", for the salmon to safely get past barriers like dams;
* improving the condition of the rivers in ways that benefit the salmon; and
* regulating the type and amount of salmon fishing allowed.

Assuming the Program continues, within 10-15 years there should be several thousands of adult salmon returning to the Connecticut River and the Merrimack River, and even more to the Penobscot River. Fewer fish would return to the other 11 river systems.





III. NOW WE WOULD like you to answer some questions about how important it is to you to have salmon in New England rivers.

7. Do you care, one way or the other, whether there are Atlantic Salmon in any New England rivers?..............[ ]NO [ ]YES

If NO, skip ahead to **The Final Section** on the last page.
If YES, in which of the rivers do you care about the presence of Atlantic Salmon? (See our map, then check one answer)

[ ] MOST OR ALL OF THEM
[ ] ONLY THE RIVER WHICH IS CLOSEST TO MY HOME: ______________
[ ] ONLY THE FOLLOWING RIVERS: (please list the river names)

______________ ______________
______________ ______________
______________ ______________
______________ ______________
______________ ______________

8. How does your interest in Atlantic Salmon compare to your interest in other wildlife, including other wild fish? (check one answer)

[ ] I HAVE COMPARATIVELY MORE INTEREST IN ATLANTIC SALMON
[ ] MY INTEREST IS ABOUT THE SAME AS IN OTHER WILDLIFE
[ ] I HAVE COMPARATIVELY LESS INTEREST IN ATLANTIC SALMON

9. Which of the following statements or opinions apply to your interests in Atlantic Salmon? (check all answers you agree with)

[ ] I VERY PROBABLY WILL SEE OR FISH FOR WILD ATLANTIC SALMON

[ ] IT WOULD PLEASE ME JUST TO KNOW THAT ATLANTIC SALMON WERE IN NEW ENGLAND RIVERS EVEN IF I COULD NEVER FISH FOR THEM OR SEE THEM MYSELF

[ ] IT MATTERS TO ME THAT WE ACT NOW SO THAT FUTURE GENERATIONS OF PEOPLE WILL FIND ATLANTIC SALMON IN NEW ENGLAND RIVERS

[ ] I THINK THE RETURN OF ATLANTIC SALMON IS AN IMPORTANT SIGN THAT RIVER POLLUTION HAS BEEN CLEANED UP

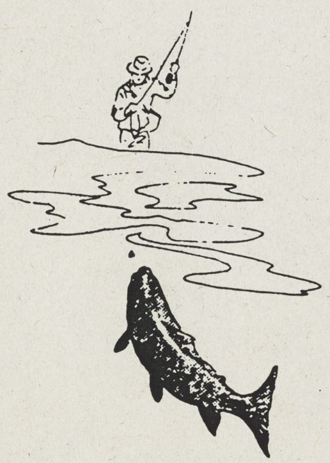
[ ] I THINK THAT ATLANTIC SALMON SHOULD BE RETURNED TO NEW ENGLAND RIVERS TO RESTORE THE LOST BALANCE OF NATURE

[ ] I THINK THAT THE EFFORT TO RESTORE ATLANTIC SALMON TO THE 14 NEW ENGLAND RIVERS IS A MISTAKE (please explain)
____
____

IV. NEXT, WE ARE INTERESTED in finding out how strongly you value the return of Atlantic Salmon to any or all of the 14 rivers that are affected by the Salmon Restoration Program.

10. Might you ever fish for Atlantic Salmon on any of the 14 river systems affected by the Program to restore Atlantic Salmon (see map)?

[ ] I ALMOST CERTAINLY WILL (continue on next page)
[ ] I MIGHT (continue on next page)
[ ] I PROBABLY WON'T (skip to SECTION V, Q. 20 on page 6)



FISHING: Because of the need to protect Atlantic Salmon from over-fishing, the amount of fishing is tightly controlled. You must have a license to legally fish for Atlantic Salmon on any river, even if you do not plan to keep any salmon. The number of fish you may keep is also limited, and only fly fishing is allowed. About 2,500 Atlantic Salmon licenses were sold for fishing in Maine this year.

11. Did you know you could buy a license to fish for Atlantic Salmon in Maine this year? .... [ ]NO [ ]YES

    If YES, which of the following strongly influenced your decision to buy or not buy the license this year?

    (check any that apply)

    [ ] COST OF A SALMON LICENSE
    [ ] DISTANCE OF THE SALMON RIVERS FROM HOME
    [ ] NUMBER OF SALMON IN THE RIVERS
    [ ] SIZE OF THE SALMON
    [ ] LICENSE LIMITS ON THE NUMBER OF FISH CAUGHT
    [ ] THE COST OF SALMON FISHING GEAR
    [ ] CROWDING AT SALMON FISHING SPOTS

We would like to know whether you would buy an Atlantic Salmon license if the Program to restore Atlantic Salmon were stopped, and salmon lived only in the 7 rivers not affected by the Program.

The existing license allows you to keep up to 5 Atlantic Salmon each year. This year a license cost $30 for people who do not live in Maine, and $10 for people who do live in Maine.

12. Assume that the Program to restore Atlantic Salmon is stopped. Then Atlantic Salmon fishing will only occur on the 7 rivers not affected by the Program (dotted lines on map). If the price ($30, or $10 for Maine residents) and the limit on the number of fish (up to 5) stays the same, how likely is it that you would buy a license in the next few years?

    [ ] I ALMOST CERTAINLY WOULD BUY A LICENSE.
    [ ] I PROBABLY WOULD BUY A LICENCE.
    [ ] I'M NOT SURE IF I WOULD BUY A LICENSE.
    [ ] I PROBABLY WOULD NOT BUY A LICENSE
    [ ] I ALMOST CERTAINLY WOULD NOT BUY A LICENSE

13. What is the very highest price (if any) you would seriously consider paying for such a license?....$__________

14. What is the very highest price (if any) you are almost certain you would be willing to pay for such a license?...........................$__________

Out of a total of about 750 Atlantic Salmon caught on all New England rivers this year, almost 600 were caught by people traveling to the Penobscot River. Still, the average fisherman on the Penobscot must now fish almost 20 times to catch one salmon. The Atlantic Salmon Program will increase the number of salmon in each of 14 river systems - including the Penobscot (see map).

15. What is the greatest distance you would be willing to travel away from home for the sole purpose of fishing for Atlantic Salmon? .... _________ MILES

Any decision to go ahead with the Program must consider the number of people who will be interested enough in fishing to buy an Atlantic Salmon license. If there are not enough people interested in buying licenses, the Program may have to be stopped. We next ask if you would be willing to pay a kind of "special restoration fee" for a license to fish the 14 river systems affected by the Program.

Assume for the purposes of this questionnaire that only people paying the special fee would be allowed to fish for salmon on those river systems, though you could still buy a license to fish on the other 7 salmon rivers.

Because of the small number of salmon now in the 14 rivers, fishing would have to be very restricted until more fish have been restored to them.

16. Would you be willing to pay a special fee of $_______ each year to reserve a license for fishing on the restored salmon river systems _____ years from now? [ ]NO [ ]YES

Would you pay this fee if it...

....did not allow you to keep any salmon you caught? [ ]NO [ ]YES

....allowed you to keep just one salmon you caught? [ ]NO [ ]YES

....allowed you to keep up to five salmon you caught? [ ]NO [ ]YES

....allowed you to keep up to ten salmon you caught? [ ]NO [ ]YES

....allowed you to keep more than ten salmon? [ ]NO [ ]YES

17. What would be the very highest yearly fee you could be charged to reserve a license for _____ years from now before you would feel that the license for the 14 river systems wasn't worth the cost - if such a license....

...did not allow you to keep any salmon you caught? $____________

...allowed you to keep one salmon each season? $____________

...allowed you to keep five salmon each season? $____________

...allowed you to keep ten salmon each season? $____________

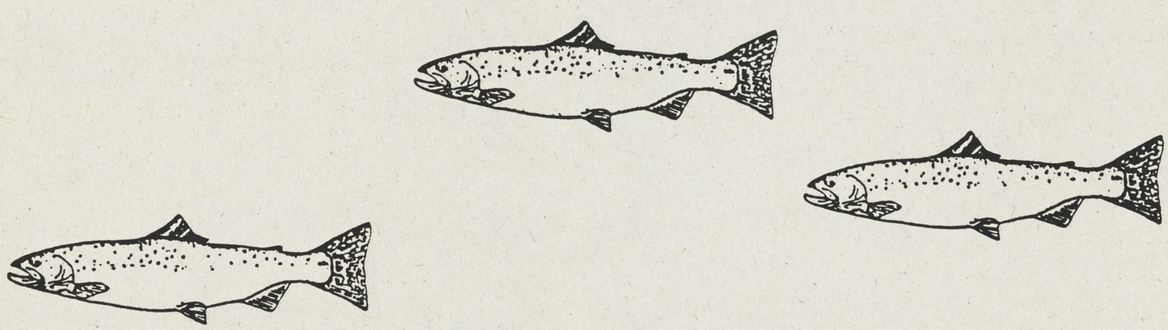
...allowed you to keep more than ten salmon? $____________

18. If the yearly fee to reserve a license turned out to be set $5 higher than the amounts you just listed as your highest, how likely is it that you might reconsider and decide to pay for a license anyway?

[ ]VERY UNLIKELY
[ ]SOMEWHAT UNLIKELY
[ ]UNCERTAIN
[ ]SOMEWHAT LIKELY
[ ]VERY LIKELY

19. Is the total value of having Atlantic Salmon in the 14 rivers worth any more to you, in money terms, than the highest dollar amounts you have said you would be willing to pay for a fishing license?..................................[ ]NO [ ]YES

If NO, skip to Question 28 on last page.
If YES, continue here.



V. AS YOU MIGHT expect, the Program to restore Atlantic Salmon will cost money to complete. For this reason we will be asking you to think a little about the full dollar value, to you personally, of having salmon in New England's rivers. Your answers to the following questions will help policy makers decide whether or not to continue restoring Atlantic Salmon to the 14 river systems shown on our map; and how to best pay for the Program if it is decided to continue.

20. Can you think of anything you already spend money on that has about the same value to you as the Atlantic Salmon Program does? Please describe it if you can:
____

21. Have you donated any money for wildlife protection this year?.. [ ]NO [ ]YES

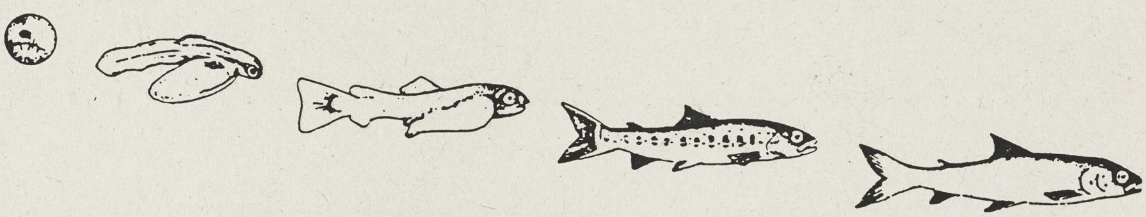
22. Several methods might be used to raise extra money for the Salmon Restoration Program. Of course, not everyone is affected in the same way by each method of payment. Of the type of payment that you normally must make anyway, which would you prefer to see used to pay for the Atlantic Salmon Program?

[ ]FEDERAL INCOME TAXES
[ ]STATE INCOME TAXES
[ ]SALES TAXES
[ ]ELECTRICITY BILLS
[ ]OTHER (explain:______________________________________)

[ ]NONE - I'M NOT WILLING TO PAY ANYTHING (skip to last page)

23. Would you be willing to pay $_______ more next year to help bring Atlantic Salmon back to the 14 affected river systems - if it were decided to raise money using the payment method you just said you would prefer?...........[ ]NO [ ]YES

24. What is the very highest extra payment you would be willing to pay rather than see the Program stopped?.....$__________



If too little public support for the Program to restore Atlantic Salmon to New England rivers is found, it could be stopped. Then some of the money that has already been budgeted for the Program would not be spent. This money could then be returned to you as lower taxes, as lower electricity bills, or maybe even as a special cash payment to people who do not normally pay such bills.

25. Imagine for a moment that you could be guaranteed a one-time "rebate" of $______ if the Program was stopped. Would you then prefer to see the Program continue or to get those money savings?

[ ] CONTINUE THE PROGRAM
[ ] GET THE SAVINGS AND HAVE THE PROGRAM END

26. Try to think carefully about what you would do with a rebate if you got one - and then answer this question:

What would be the very smallest one-time rebate you would prefer to get rather than see Atlantic Salmon continue to be restored to the 14 river systems?................$__________

27. If you happened to be near one of several dams with Special Visitor's Centers at the right time of year, you would be able to watch the annual migration of Atlantic Salmon in progress. Assuming the Program continued and you were able, would you have any interest in stopping to watch Atlantic Salmon swim past and to learn more about them? .... [ ]NO [ ]YES

If YES: What is the very most you would be willing to spend on an entry ticket? $__________

VI. THE FINAL SECTION - Your answers to this section will help us predict the number of people interested in Atlantic Salmon in all of New England. Your answers will be kept strictly confidential, and will never be linked to your name.

28. In what year were you born? .... 19_____

29. What is your sex? .... [ ]MALE [ ]FEMALE

30. What was your main occupation this year (if student, unemployed, or retired, please indicate)________________

31. In what city or county and state is your home? __________________ COUNTY OR CITY
____________________________ STATE

32. How many other people live with you in your household? ____ OTHERS

33. What is the highest year of school that you have completed?

[ ] 1-6 YEARS
[ ] 7-9 YEARS
[ ] 10-11 YEARS
[ ] HIGH SCHOOL GRADUATE
[ ] SOME COLLEGE
[ ] COLLEGE GRADUATE
[ ] SOME GRADUATE SCHOOL

34. What was your approximate total household income, before taxes, in 1985?

[ ]$0 - 9,999
[ ]$10,000 - 19,999
[ ]$20,000 - 29,999
[ ]$30,000 - 39,999
[ ]$40,000 - 49,999
[ ]$50,000 - 75,000
[ ] more than $75,000

Kindly return this questionnaire within two weeks of receiving it. Simply seal it in the enclosed stamped self-addressed envelope and deposit in any mail box. The postage has been provided.

THANK YOU FOR YOUR TIME AND EFFORT!

APPENDIX II

Nonresponse Bias

NONRESPONSE BIAS

The questionnaire mailed to 1500 New England residents was eight pages long and relatively demanding of participants. Moreover, it was not anticipated that Atlantic Salmon restoration would be a subject of deep interest for most questionnaire recipients. These considerations led us to expect a relatively low response rate.[1] The 42% response rate discussed in the body of the report confirmed that expectation.

Because of the large proportion of nonrespondents, it was not possible to rule out a priori the possibility that our data were seriously biased or unrepresentative of the full population. In order to ascertain whether or not there were significant differences between respondents and nonrespondents, a telephone follow-up survey was conducted. A number of key questions - concerning nonrespondent interest in Atlantic Salmon, their willingness to pay for restoration, and a few standard demographic parameters - were extracted from the mail questionnaire and adapted slightly for the telephone (see Appendix III for questions).

At the time of sample selection for the nonrespondent survey, 772 of the initial questionnaire recipients had not responded. Because the original sample had been selected from telephone directories, telephone numbers were available for all of these nonrespondents. Attempts to interview nonrespondents continued in a randomly determined order until 118 contacts were made with persons willing to answer at least the key question: did they care one way or the other whether or not there were Atlantic Salmon in any New England rivers? Sixteen additional persons who had not returned the mail questionnaire were contacted, but they refused to answer even this question. Attempts to reach another 41 nonrespondents failed because the person had moved, died, or discontinued phone service at the given number. Finally, another 41 nonrespondents were called but never successfully reached after a minimum of at least two further calls (see Table II-1).

Administering the questions over the phone generally took less than a minute if the individual indicated no interest in Atlantic Salmon, and less than five minutes if some interest was expressed and all the follow-up questions asked.

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[1]Closely related issues for telephone surveys are discussed in Sharp, Laure M. and Joanne Powell. 1983. "Respondent Burden: A Test of Some Common Assumptions". Public Opinion Quarterly. Vol 47:36-53. Much of the literature cautions against expecting returns from more than 30% of the general public with mail questionnaires, but many authors demonstrate that persistent follow-ups can generate 70% response rates and higher. (See citations in Goyder, John. 1985. "Face-to-Face Interviews and Mailed Questionnaires: The Net Difference in Response Rate." Public Opinion Quarterly. Vol. 49:234-252; see also Brown, Tommy L. and Bruce T. Wilkins. 1978. "Clues to Reasons for Nonresponse and its Effect upon Variable Estimates". Journal of Leisure Research. Vol. 10:226-231 and Brown, Tommy L., Chad P. Dawson, Deborah L. Huston, and Daniel J. Decker. 1981. "Comments on the Importance of Late Respondent and Nonrespondent Data from Mail Surveys." Journal of Leisure Research. Vol. 13:76-79, for experiences with recreation and land use questionnaires.)

Table II-1. TELEPHONE FOLLOW-UP RESPONSE RATES

772	nonrespondents; from which random selection produced
118	at least partially cooperative random contacts;
16	total noncooperators;
41	deceased or otherwise unreachable parties; and
41	nonrespondents who could not be reached after several repeat calls; comprising a total of
216	nonrespondents called and
556	nonrespondents not called.

The statistical depiction of nonrespondents that follows is therefore based on a sample of 118, accounting for 15% of all nonrespondents, or 55% of the nonrespondents called. Are these 118 nonrespondents representative of the remaining nonrespondents, especially with respect to interest in the Atlantic Salmon Restoration program? Because of the random calling order used, it can be assumed that the 216 nonrespondents called are collectively representative of the 556 not called. But there is not enough information available to unambiguously determine how closely the 118 cooperators may resemble the remaining 98 nonrespondents called.

Some assumptions must therefore be made.[2] It should be a reasonable if not entirely accurate[3] assumption that the 41 nonrespondents who could not be reached would not have differed significantly in their responses from the 134 (118 + 16) nonrespondents with whom personal contact was made (ie. about 5 of the 41 would probably have refused to cooperate, the remainder would have mirrored the interest in Atlantic Salmon of the 118 cooperators.) Thus, a total of about 10% [(16+5)/216] of the nonrespondents would be reasonably classified as noncooperators. We have

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[2]Some techniques exist for trying to avoid such informal assumptions, eg. by predicting nonrespondent characteristics on the basis of a small amount of known information (see Daniel, Wayne W. 1975. "Nonresponse in Sociological Surveys". Sociological Methods & Research. Vol. 3:291-305; and Smith, Tom W. 1983. "The Hidden 25 Percent: An Analysis of Nonresponse on the 1980 General Survey", Public Opinion Quarterly. Vol. 47:386-404). However, Smith notes ultimately that "we come close to the conclusion that nothing works in estimating nonrespondent bias".

[3]Smith (ibid) found that availability of respondents for interview was in fact related to labor force participation, socioeconomic status, age and marital status, health, and sex. Ignoring the difference in the types of people likely to be available for phone compared to mail interviews probably overstates the real differences between the mail nonrespondents and mail respondents, since the attempt to contact the mail nonrespondents was made over the phone.

essentially no relevant information about the noncooperators. Still, the most conservative and probably reasonable assumption about them would be that they have no interest in Atlantic Salmon restoration. Similarly, the most conservative assumption about the 41 deceased or otherwise unreachable contacts is that they also have no interest in Atlantic Salmon restoration. This assumption is perhaps overly conservative, since even the deceased nonrespondents might have had an interest in Atlantic Salmon at the time the sampling list was compiled; and some of the unreachable nonrespondents who have changed phone numbers or moved surely do have an interest in Atlantic Salmon.

In conclusion, the reader should bear in mind that for only 55% (118/216) of the nonrespondent subsample is analysis based on direct telephone responses. Since only 42% of persons receiving the mail survey returned a questionnaire, this means that there is little or no information on approximately 345 of the 1320 persons who received questionnaires. After accounting for the 180 undeliverable mail questionnaires, the figure rises to 525 of the initial 1500 questionnaires sent out; i.e. 35% of the population of households have been assigned by assumption to either the "no interest in Atlantic Salmon" group or the "just like the respondents" group. Thus, while the nonresponse follow-up increases knowledge about the magnitude and importance of possible bias, it does not eliminate the problem altogether.

Before proceeding to the mail/telephone follow-up response comparisons, a related consideration must be addressed. The corporation that selected the initial sample of 1500 (Survey Sampling, Inc.) warns that its data base covers only 86% of all households nationally. This coverage is based on listed phone numbers as supplemented in 26 states by auto registration data. Although 1980 census statistics show that 95.4% of New England households had phones,[4] mail coverage is lower because no addresses can be associated with unlisted telephone numbers.[5]

MAIL RESPONSES COMPARED TO TELEPHONE RESPONSES

The answers of the 559 mail respondents and the 118 telephone follow-up respondents were compared for 20 specific items. It was not possible to conclude that there were no significant differences between the two groups.

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[4]Table 149, Detailed Characteristics, US Summary, 1980 Census of Housing.

[5]Telephone directories of listed numbers only have been shown to disproportionately exclude households of lower socioeconomic status, a problem generally most problematic for surveys in urban areas. A recent study confirms that "telephone directories provide an acceptable and efficient sampling frame for general population mail surveys of rural areas". (Kviz, Frederick. 1984. "Bias in a Directory Sample for a Mail Survey of Rural Households". Public Opinion Quarterly. Vol. 48:801-806.) Over the whole of New England, this source of bias is probably small compared to other sources of bias.

Table II-2. Questions asked of every cooperator.

Variable Described	Mail Results	Follow-up Results	Difference*
Educational Level	(n=540)	(n=79)	
High School Grad	29%	42%	Large
Some College	25%	24%	Small
College Grad	46%	34%	Large
Occupation	(n=529)	(n=93)	
Professional	22%	13%	Large
Retired	20%	29%	Large
Other	48%	48%	Small
Age	(n=543)	(n=95)	
Over 50 years	40%	43%	Small
31-50 years	42%	42%	Small
Up to 30 years	18%	15%	Small
Sex	(n=556)	(n=118)	
Male	77%	73%	Small
Female	23%	27%	Small
State of residence	(n=544)	(n=118)	
Connecticut	23%	35%	Large
Maine	12%	8%	Small
Massachussetts	47%	37%	Large
New Hampshire	9%	7%	Small
Rhode Island	6%	6%	Small
Vermont	3%	7%	Large
Cares about Atlantic Salmon Restoration	(n=556)	(n=118)	
Cares	82%	60%	Large
Doesn't Care	18%	40%	Large

* "Large" and "Small" indicate whether or not the difference between the two samples is statistically significant for a two-tailed test at a 95% confidence interval. Note that the differences between categories within a question are not independent of each other; hence sequential statistical tests of categories are invalid. Also, the number of respondents differs from question to question because of item nonresponse.

Table II-2 lists the six items that applied to every respondent: state of residence, sex of respondent, interest in Atlantic Salmon restoration, educational level, occupation, and age of respondent.

The differences between the two groups generally followed expected patterns. The people who did not read through and answer the complex 8 page mail questionnaire but who were willing to answer some questions over the phone were markedly less well-educated than the mail questionnaire respondents. Given reports of 13%-26% functional illiteracy among the general public,[6] it seems likely that the written survey was simply overwhelming for some people. Similarly, the mail survey respondents were more likely to be working professionals than the telephone follow-up respondents, a finding which is probably directly related to both the observed educational differentials and the difficulty of catching working professionals at home with telephone calls. Both differences are indirect indications that income levels of the mail respondents are probably higher than for the telephone follow-up sample, though because of expected respondent sensitivity about revealing incomes, this question was not asked over the phone.

It is also consistent with other studies that the telephone sample of nonrespondents contained a greater proportion of retirees than the mail survey. Retirees can be expected to be less active in general than working people. Some have greater difficulty in seeing the printed page, and some have less tolerance for the exertion, both mental and even to some extent physical, required to fill out a complicated questionnaire. While these problems are normally thought of in the context of age, it is noteworthy that despite the discrepancy in retirement status, the age and sex distributions of the two groups are very similar. Better understanding of the discrepancy would require a more sophisticated look at the relationships between age and retirement.[7]

The fact that a significantly lower (higher) proportion of mail respondents were from Connecticut (Massachussetts) is curious. The discrepancy may be due to different levels of coverage of restoration efforts by the Connecticut and Massachussetts media.

The most important discrepancy between the two samples is the much higher proportion of mail survey respondents claiming they care whether or not Atlantic Salmon will be found in New England rivers. Again, the discrepancy is in the direction expected: people with less interest in the issue should be less motivated to expend effort on a mail

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[6]US Bureau of Census figures cited in Publishers Weekly (May 23, 1986, Vol. 229:30) indicate that 13% of the English speaking population over 20 years of age is "functionally illiterate", as determined by a more liberal criterion than the sixth grade reading level often used to peg "functional illiteracy" at 26%.

[7]Again, it is possible that differences between the samples have been distorted because of a telephone nonresponse bias.

questionnaire; whereas the effort and attention required to give a short telephone response is much less.[8]

Because several of these discrepancies are significant,[9] the mail survey's single variable results have been adjusted where possible. Only a subset of the mailed questions were asked over the telephone. Because of the absence of some variables in the telephone follow-up survey, it is not possible to test or carry over all nonresponse adjustments into an analysis using multivariate models.

Table II-3. Interest questions asked only of cooperators who "care" about Atlantic Salmon.

Variable Described	Mail Results	Follow-up Results	Difference*
Will see or fish for Atlantic Salmon	(n=453)	(n=66)	
Yes	32%	44%	Large
No	68%	56%	Large
Atlantic Salmon pleasing even if will never fish for or see them	(n=452)	(n=64)	
Yes	77%	100%	Large
No	23%	0%	Large
Act now for future generations	(n=453)	(n=64)	
Yes	73%	98%	Large
No	27%	2%	Large

* "Large" and "Small" indicate whether or not the difference between the two samples is statistically significant for a two-tailed test at a 95% confidence interval.

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[8]Similarly, questionnaire respondents who returned their questionnaires promptly were more likely to "care" about Atlantic Salmon than those who responded only after several follow-up letters (chi-square value of 18.08).

[9]Since most of our research interest is directed only at the portion of the public with some interest in Atlantic Salmon, nonresponse bias was also investigated for the mail and phone sample subsets of only those persons indicating interest in Atlantic Salmon. Since most respondents were interested in the fish, the same patterns of mail and phone differences appear in the subsamples.

Responses to all of the questions displayed in Table II-3 show significant differences between mail and phone follow-up respondents. Though fewer phone follow-up cooperators cared about Atlantic Salmon restoration, Table II-3 reveals that the respondents who cared about Atlantic Salmon were more likely to expect to personally see or fish for them. It might then be concluded that these people were more likely to care about Atlantic Salmon because they had a direct or "use" interest in the fish. However, these same people also expressed much stronger indirect or altruistic interests in Atlantic Salmon: essentially all the people who cared about Atlantic Salmon indicated that they cared whether or not they would ever see or fish for Atlantic Salmon, and because they were interested in passing on a legacy to future generations. While these results can be taken at face value, a cautionary note might again be made with reference to differentials in the way people respond over the telephone and through the mails. Dillman, a survey research expert, has noted informally that there seem to be consistent differences in the way people answer identical questions over the telephone versus in a mail questionnaire versus in face-to-face interviews. In particular, people may be influenced by the relatively shorter time allowed for consideration of an answer in an interview, and tend to give more extreme responses on scaled variables.[10] The lower educational levels of the telephone follow-up respondents may relate to their greater interest in Atlantic Salmon restoration, since through analysis of mail responses it was determined that lower levels of education were positively correlated with willingness to pay to restore the fish.

Table II-4. Recreation participation questions asked only of respondents who "care" about Atlantic Salmon.

Variable Described	Mail Results	Follow-up Results	Difference*
They fished or hunted during the past year	(n=449)	(n=63)	
Yes	52%	48%	Small
They boated or swam in lakes, rivers or the ocean during the past year	(n=449)	(n=63)	
Yes	77%	76%	Small

* "Large" and "Small" indicate whether or not the difference between the two samples is statistically significant for a two-tailed test at a 95% confidence interval.

[10] Lecture, 1986, Cornell University.

Table II-5. Willingness to pay questions asked only of respondents who "care" about Atlantic Salmon.

Variable Described	Mail Results	Follow-up Results	Difference*
Would prefer to pay increased federal income tax	(n=449)	(n=60)	
Yes	48%	43%	-----
Would prefer to pay increased state income tax	(n=449)	(n=60)	
Yes	32%	40%	-----
Would prefer to pay increased electric bills	(n=449)	(n=60)	
Yes	12%	8%	-----
Would prefer to pay in some other fashion	(n=449)	(n=60)	
Yes	17%	8%	-----
Would prefer to not pay anything	(n=449)	(n=60)	
Yes	10%	18%	-----
Willing to pay the amount we specified	(n=102)	(n=25)	
Yes	79%	79%	-----
Average maximum willingness-to-pay for Salmon	(n=88) $38.47	(n=24) $50.37	-----

* Answers to these questions are reported only for that portion of each sample that cares about Atlantic Salmon and that expected to see or fish for them someday. Because of differences in the routing of anglers through the two surveys, even these subgroups are not strictly similar, so statistical comparisons could be misleading (see text that follows).

Table II-4 displays the differences in mail and telephone follow-up responses regarding recreational behavior for those persons indicating interest in Atlantic Salmon. Despite the differences noted for other variables, the recreational behavior of mail and phone respondents is similar.

Table II-5, finally contrasts the two groups with respect to questions about willingness-to-pay to continue the restoration program. The telephone follow-up did not differentiate willingness-to-pay questions for anglers versus non-anglers. Mail respondents expecting to fish for Atlantic Salmon someday would have first answered questions about willingness-to-pay for fishing licenses before answering (or skipping over) these questions, whereas all phone respondents interested in Atlantic Salmon would have answered only these willingness-to-pay questions. Since anglers as a group expressed greater total willingness-to-pay for Atlantic Salmon restoration in the mail responses,[11] it follows that had all anglers in the mail questionnaire directly answered the general willingness-to-pay question, then the $38.47 figure would have been higher. Since $38.47 and $50.37 are in any event not statistically different from each other with high levels of statistical confidence (for the given sample size), it will be assumed that there is no nonresponse bias in the mail sample estimate of maximum willingness-to-pay, given that the respondents have said they "care" about Atlantic Salmon restoration. Similarly, the revealed preferred methods of payment are assumed to be accurately depicted in the mail sample results.

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[11]Total willingness-to-pay of persons saying they were certain they would fish for Atlantic Salmon someday was almost twice as high as persons saying they might someday fish for Atlantic Salmon, which was in turn somewhat higher than the total willingness-to-pay of nonanglers.

APPENDIX III

Nonrespondent Follow-up Questionnaire

The U. S. Fish and Wildlife Service must decide whether or not enough people are interested in Atlantic Salmon to justify continuing with their plans. They've already begun to restore this fish to many of the rivers in New England where Atlantic Salmon used to live. But the Fish and Wildlife Service may decide it is better not to spend the public's money on salmon restoration if not many people are interested. So...

1. Do you care one way or the other whether there are Atlantic Salmon in any New England rivers?

[ ] NO - skip to question 7.

[ ] YES - continue.

2. Now please tell me if any of the following statements about Atlantic Salmon apply to you:

NO	YES	
[ ]	[ ]	I VERY PROBABLY WILL SEE OR FISH FOR WILD ATLANTIC SALMON SOMEDAY
[ ]	[ ]	IT WOULD PLEASE ME JUST TO KNOW THAT ATLANTIC SALMON WERE IN NEW ENGLAND RIVERS EVEN IF I COULD NEVER FISH FOR THEM OR SEE THEM MYSELF
[ ]	[ ]	IT MATTERS TO ME THAT WE ACT NOW SO THAT FUTURE GENERATIONS OF PEOPLE WILL FIND ATLANTIC SALMON IN NEW ENGLAND RIVERS

3. If the program to restore Atlantic Salmon is continued, several methods might be used to raise extra money. Which of the following four kinds of payments would you prefer to see used to pay for the Atlantic Salmon Program? You may choose more than one, or none of these, but please choose a method of payment you normally make yourself. The choices are: (read the four)

[ ]FEDERAL INCOME TAXES
[ ]STATE INCOME TAXES
[ ]SALES TAXES
[ ]ELECTRICITY BILLS

(Dont read) [ ]NONE - I'M NOT WILLING TO PAY ANYTHING (skip to Q. 6)

[ ]OTHER ____________________

4. Using an increase in [choice from Q. 3], would you be willing to pay $_______ more next year only - in order to help the Salmon Restoration Program succeed in bringing Atlantic Salmon back to New England rivers?

[ ]NO [ ]YES

5. What is the <u>very highest</u> extra payment you <u>would</u> be willing to pay rather than see the Program stopped? $__________

6. Now, could you please tell me if you have participated in any of the following outdoor recreation activities during the past year?

[ ] HIKING OR CANOEING
[ ] FISHING OR HUNTING
[ ] BOATING OR SWIMMING IN LAKES, RIVERS, or the OCEAN

7. In what year were you born? .... __________ YEAR

8. What was your main occupation this year (such as unemployed, laborer, secretary, doctor, etc.) ______________

9. And finally, what is the highest year of school that you have completed?

[ ]1-6 YEARS
[ ]7-9 YEARS
[ ]10-11 YEARS
[ ]HIGH SCHOOL GRADUATE
[ ]SOME COLLEGE
[ ]COLLEGE GRADUATE
[ ]SOME GRADUATE SCHOOL

THANK YOU VERY MUCH FOR YOUR COOPERATION!