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Proceedings of a Workshop on Research Strategies into the Causes of Declining Atlantic Salmon Returns to North American Rivers

12 –14 June 2000
Dalhousie University
Halifax, Nova Scotia

Sponsored by
Fisheries and Oceans Canada
Science Branch

Shane O'Neil, John Ritter and Kimberly Robichaud-LeBlanc (Editors)

Fisheries and Oceans
Diadromous Fish Division
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FOREWARD

These Proceedings are a record of the submissions to and discussions at the International Workshop of June 12, 13 and 14, 2000, on research strategies into the causes of declining Atlantic salmon returns to North American rivers. The activities and discussions of the meeting, including a description of the process, attendance, project proposals, research recommendations, and minority opinions raised are included in the document. The report records as faithfully as possible the contributions and discussion that transpired at the meeting. However, the individual interpretations and opinions expressed at the meeting are not necessarily or in all cases scientifically sustainable or supported by other participants. The discussion summaries document the deliberations, which led to the tabled proposals. No statements are to be taken as reflecting the consensus of the meeting unless they are clearly identified as such. Moreover, additional information and further review may result in a change of decision where tentative agreement has been reached.

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ABSTRACT

In response to the decline in the abundance of Atlantic salmon returning to rivers in North America and limited directed research programs on salmon at sea, Fisheries and Oceans Canada convened a special workshop to define a research strategy and to lay the groundwork for an intensive and integrated research campaign. The workshop took place from June 12 to 14, 2000, at the Dalhousie University in Halifax, Nova Scotia, with participants from government agencies in Canada, United States (New England) and Europe, as well as Canadian universities and the Atlantic Salmon Federation.

The workshop format included a plenary session for introducing the subject, terms of reference, and a brief overview of background material, followed by division of participants into three working groups defined by the life stage of Atlantic salmon (freshwater, estuarine/nearshore and marine). Each subgroup was assigned the tasks of reviewing the most plausible reasons for the salmon's decline and ranking research programs on the basis of likelihood of success, feasibility, and fundability.

Products from the workshop include 15 project proposals summarizing background information, databases necessary to test hypotheses, time frame for completion, resources required, and the value of the proposal related to the consequences for better understanding the decline in salmon. In addition, this Proceedings document was produced to archive the activities and discussions during the meeting.

RÉSUMÉ

Face au déclin de l’abondance des saumons de l’Atlantique qui reviennent dans les rivières d’Amérique du Nord et de la recherche limitée sur le saumon en mer, Pêches et Océans Canada a tenu un atelier spécial visant à établir une stratégie de recherche et à jeter les bases d’une campagne de recherche intensive et intégrée. Cet atelier a eu lieu du 12 au 14 juin 2000, à l’Université Dalhousie de Halifax (Nouvelle-Écosse). Y assistaient des représentants d’organismes gouvernementaux du Canada, des États-Unis (Nouvelle-Angleterre) et d’Europe, des universités canadiennes et de la Fédération du saumon Atlantique.

L’atelier a commencé par une séance plénière au cours de laquelle on a présenté le sujet à l’étude et le cadre de référence, et on a effectué un survol des renseignements disponibles. Ensuite, les participants ont été divisés en trois groupes de travail correspondant aux cycles biologiques du saumon (vie en eau douce, vie en eau estuarienne ou côtière et vie en eau de mer). Chacun de ces groupes était chargé d’examiner les raisons les plus plausibles du déclin du saumon et de classer les programmes de recherche selon leur probabilité de succès, leur faisabilité et le financement dont ils pourraient bénéficier.

L’atelier a débouché sur la production de quinze propositions de projets exposant sommairement les renseignements de base et faisant état des bases de données nécessaires pour tester les hypothèses, du calendrier d’exécution, des ressources nécessaires et de la valeur des propositions pour l’amélioration de notre compréhension du déclin du saumon. Le présent compte rendu s’ajoute à ces documents et rend compte des activités et discussions ayant eu lieu durant l’atelier.

1.0 EXECUTIVE SUMMARY

This report provides a summary of proceedings of an international workshop to define research strategies to address the causes of declining Atlantic salmon returns to North American rivers. A steering committee was formed to develop the approach and terms of reference. Members of the steering committee were: David Cairns, Gerald Chaput, Larry Marshall, Dave Meerburg, Rex Porter, Dave Reddin, John Ritter, and Kimberly Robichaud-LeBlanc, all of DFO Science.

The workshop was held June 12 to June 14, 2000 at Dalhousie University, Halifax, Nova Scotia and was chaired by Jake Rice, Science Directorate of DFO, Ottawa. Participants included representation from marine and diadromous stock assessment groups, as well as oceanography and climate change scientists from DFO Science from the Gulf, Maritimes, and Newfoundland regions and Headquarters, the provincial governments of New Brunswick, Nova Scotia, Newfoundland, British Columbia and Québec, the State of Maine, Canadian universities (Universities of Dalhousie, New Brunswick, Memorial, Laval, and British Columbia), government laboratories in England and Ireland, and the Atlantic Salmon Federation. Participants were selected to bring to the deliberations a wide range of knowledge and expertise pertaining to this particular issue (Appendix 1).

Invitees to the workshop were provided with copies of background information and papers prepared for discussion at the meetings (Anon. 2000; DFO 1998, 2000b and 'in prep'). The workshop began with a plenary session, which introduced the subject and terms of reference, and provided a brief overview of background material. The meeting then broke into three subgroups which were defined by the life stage of Atlantic salmon (freshwater, estuarine/nearshore and marine) (Appendix 2). Subgroup chairs were: Freshwater - G. Chaput, DFO, Science Branch, Gulf Fisheries Management Region; Estuarine - J. Ritter, DFO Science Branch, Maritimes Region; Marine - D. Meerburg, DFO Science Directorate, Ottawa. Subgroup membership was pre-assigned. Subgroup deliberations are summarized in sections 5.0 to 8.0 of these Proceedings.

The workshop developed 15 project proposals, listed below and summarized in Section 6.0:

- Size-dependent survivorship (*survival at sea is determined by smolt size*);
- Freshwater conditioning (*freshwater density-dependent determinants of smolt quality*);
- Physical characteristics of fresh water (*freshwater density-independent factors modify density-dependent determinants of smolt quality*);
- Temperature transitions (*changes in the hydrography of the transitional zone from freshwater to marine environment*);
- Coastal migration routes and energetic costs (*migration routes and costs have changed*);

- Estimation of survival rates with technology (*identification of factors affecting survival rates of emigrating smolts, returning adults and post spawning kelts in estuaries and coastal waters*);
- Marine fish predation (*predation by marine fish has increased*);
- Seals and seabird predation (*bird and seal predation reduces survival of smolts and adults in estuaries*);
- Aquaculture – interactions (*aquaculture operations and escapees interact adversely with wild salmon*);
- Aquaculture – disease effects (*aquaculture fish are a vector for disease transmission to wild salmon*);
- Salmon distribution – models (*models would explain migration patterns and serve to probe research directions*);
- Salmon distribution – coastal field studies (*using electronic tags to determine distribution*);
- Salmon distribution – high seas field studies (*using cruises and electronic tracking studies to determine distribution*);
- Marine mammal predation (*marine mammal observations and biological sampling*); and
- Gannets as predators (*predation by gannets and indicators of ecosystem changes*).

Details on each of the projects proposed (i.e., background information, available databases to test hypotheses, time frame for completion, resources required, and the consequence for salmon if hypothesis is correct) are provided in Appendix 3.

The workshop's principal recommendation is for a new multi-disciplinary research initiative aimed at identifying the cause(s) of the decline in sea survival experienced by North American Atlantic salmon. This proposed initiative would build on and expand the historical time series of data developed for the freshwater areas and aggressively research the marine areas from the estuaries to the high seas. Some of the potential factors identified were reduced smolt quality (freshwater effects), adverse estuarine conditions, increased predation in the marine environment, and changes in ocean migration patterns. A number of these factors may be linked to changes in climate and/or oceanographic conditions.

2.0 INTRODUCTION

2.1 Background

Pre-fishery abundance of North American Atlantic salmon has decreased by one-half to two-thirds in the past 15 years despite extensive closures of fisheries that generally led to increased spawning escapements, at least initially. Substantial declines are also evident in Atlantic salmon returns to some European rivers.

Measured sea survivals in eastern Canada salmon stocks have either declined or failed to reflect improvements anticipated from fisheries closures. Densities of juveniles in some major salmon rivers have remained high while adult returns have declined consistent with a problem in sea survival. In some areas, stocks have already been lost or are at critically low levels. Freshwater (including nearshore) effects (for example: acid rain, dams, low productivity) are exacerbating the situation for stocks of some rivers.

A DFO salmon science workshop held in 1997 (DFO 1998) concluded that the decline in survival at sea was coincident with fundamental changes in the ecology of the Northwest Atlantic. Subsequent efforts have failed to identify the factor(s) responsible for the broad scale decline in North American Atlantic salmon abundance. Accordingly, a second special workshop was convened by DFO to develop an inter-Regional research focus to determine the cause(s). The proceedings of that workshop, which took place June 12-14, 2000, at Dalhousie University, Halifax, Nova Scotia, follow.

2.2 Objectives and Scope

The objectives of the workshop were: 1) to define research strategies to address the decline in the abundance of Atlantic salmon in the Northwest Atlantic; and 2) to lay the groundwork for an intensive and integrated research campaign by: a) reviewing the most plausible reasons for the salmon's decline; and b) prioritizing research programs on the basis of feasibility, fundability, and likelihood of success.

2.3 Workshop Planning and Participation

Invitees to the workshop were multi-disciplinary in make-up, and originated from government agencies in Canada (including British Columbia), New England and Europe, as well as Canadian universities and the Atlantic Salmon Federation.

2.4 Workshop Format

The workshop was convened over a three-day period from June 12 to 14, 2000. On the first day the workshop was opened by the Chair with a brief summation of the objectives of the meeting and schedule. The opening address was then given on behalf of the Assistant Deputy Minister for Science (Dr. John Davis) by the DFO Science Director for the Gulf Fisheries Management Region, Dr. Michael Chadwick. Summaries of background material and terms of reference were provided to round out the plenary session.

On day two, the Chair reminded participants of the approach and asked them to join their pre-assigned working groups (freshwater, estuarine/nearshore, or marine). Each working group was given the task of reviewing the hypotheses provided prior to the meeting, narrowing down their list of potential causes (hypotheses) of low marine survival to a shortened list of the most likely causes, reviewing feasible methods of investigating these hypotheses, and defining research programs that would test the ‘short-listed’ hypotheses. Chairs of each subgroup presented the results of their deliberations in an afternoon plenary session, which was then open for discussion. During an evening session, representatives of each sub-group assembled a summary of project proposals for review on day three.

The concluding session of the workshop on day three consisted of a plenary session. The Chair presented the summarized projects identified the previous day and led participants through a rating exercise to categorize the various proposals presented. Following this, there was a general discussion of issues raised during the workshop. It was agreed in the final plenary that the workshop steering committee would finalize the proceedings, documented herein.

3.0 OPENING ADDRESS

Michael Chadwick
Science Director for the Gulf Fisheries Management Region
Fisheries and Oceans Canada

I’d like to thank the organizers for how they prepared this useful meeting. First, they have included participants from a broad spectrum of viewpoints and interests: Department of Fisheries and Oceans (Gulf, Maritimes, Newfoundland, Quebec, and National Capital Regions); provincial governments in Quebec, British Columbia, New Brunswick, Nova Scotia, Newfoundland; federal governments in the United Kingdom, Ireland, United States; universities (Laval, New Brunswick, Massachusetts, Dalhousie); and, private organizations (eg. Atlantic Salmon Federation and it’s affiliates). Second, they have provided a convenient summary and selection of background information on the various hypotheses that could be used to explain the apparent decline in returns of salmon over the past two decades.

There appear to be at least six types of hypotheses that need to be examined. First, there is the impact of fisheries. Commercial salmon fisheries were once extensive. Over 2000 km of nets were set for six months a year to catch salmon along the shores of Newfoundland and Labrador. These fisheries are now mostly closed. Second, aquaculture for salmon and incidence of new diseases have greatly increased. Third, predation of salmon by seals and other organisms has also been cited but it is only fair to say that salmon is a small player in the marine ecosystem, less than 0.1% of the marine biomass in the Southern Gulf of St. Laawrence for example. Fourth, I have had some experience with the freshwater aspects of salmon life history and have found them to be mostly density-dependent, which means that high density resulted in slower growth and higher mortality. Fifth, freshwater and marine contaminants are known to affect the survival of Atlantic salmon. Finally, it is clear that the world's environment has been changing. Paradoxically, the terrestrial environment of North America has been warming, while the waters of the North Atlantic have been cooling. Atlantic salmon are therefore vulnerable twice, in the freshwater environment and during their migration at sea.

It would seem that any large-scale research to study the reasons for the decline in abundance of adult returns would require a strategic approach. Here we can turn to lobster for guidance. I have had the opportunity to help procure funding for additional lobster research. This species, in contrast to salmon, has been at unprecedented high levels over the past decade. The reasons for this increased abundance cover a suite of complex hypotheses and have been the focus of strategic science funding at about $1 million for a three-year time period. This funding was just renewed for another three years.

Let me end by summarizing the main lessons from the lobster experience. First, it is helpful to study several hypotheses at the same location, allowing information to be shared. Second, there is a need to be realistic about the expected funding. We developed a research program for twice as much as we actually received. Third, it is useful to have pre-agreed evaluation criteria for selecting projects. Fourth, it is important to step outside of our individual paradigms because each of us will inherently favor research in our area of interest. Finally, we need to thoroughly evaluate what we have learned so far. Remember, Atlantic salmon is one of our most studied fish species and there is a considerable wealth of knowledge, which may help us to whittle-down our list of plausible hypotheses. Good luck.

4.0 INTRODUCTORY PRESENTATIONS

4.1 Geographic and temporal patterns of changes in Atlantic salmon populations in eastern North America

Gérald Chaput
Head, Diadromous Fish Section
Gulf Fisheries Management Region
Fisheries and Oceans Canada

The status of returns of salmon relative to spawning requirements (in terms of eggs) for eastern Canada was summarized. The entire Canadian requirement for eggs is about 1.54 billion. Overall returns do not provide a trend but only once, in 1980, have returns met the requirement. The relative performance of the various regions is quite variable. In many of those areas, declines have occurred in the last 5-10 years. For example, returns to the larger rivers that are monitored in the Scotia-Fundy area met requirements until about 1989. Populations have declined since then. In rivers tributary to the Gulf of St.

Lawrence, returns declined below requirements on monitored rivers beginning in the mid-1990s.

Additional summary information was provided and copies of the presentation made available to workshop participants.

Much of the information presented can be found in Anon. (2000) and DFO (1998, 2000a and 2000b).

Questions and Responses

Q: Are rivers producing smolts at capacity?
R: Egg deposition requirement is used and once met is assumed to yield smolt at capacity.

Q: Are there precipitation and temperature data for the rivers?
R: Yes.

Point of correction: Angling for salmon is no longer permitted in Maine, a clarification provided to correct an inference that angling for salmon continues to be practiced in the State of Maine.

Q: How do you estimate smolt production?
R: Some are complete counts, some are mark and recapture experiments.

Q: You state that length measurements have increased for returning salmon (statement pertained to data series for grilse returns to Miramichi sampling traps) – have weights increased also?
R: We have no time series of weights. There are however time series of juvenile measurements for a couple of locations.

Q: How many hatchery smolts are being stocked in the western Atlantic?
R: About 650,000 smolt in the Scotia-Fundy area of the Maritime Provinces and about 600,000 in Maine.

Q: Are there unique genetic stocks in eastern Canada?
R: Yes, but genetic typing is not complete and results are not yet available.

Q: Would you agree that smolt size and the corresponding size of the returning adult are not necessarily linked and that there has not been a consistent trend?
R: Agreed.

4.2 The migrations of Atlantic salmon in the Northwest Atlantic

Dave Reddin
Research Scientist for the Salmonids Branch
Northwest Atlantic Fisheries Centre
Fisheries and Oceans Canada

This presentation summarized current understanding of Atlantic salmon migrations in the Northwest Atlantic as based on tag returns and some limited sampling conducted at sea. These data have provided a fairly good understanding of salmon migration in and around the coastal areas but relatively little knowledge of salmon movements in the open ocean.

Relative to the open ocean it is well documented that large numbers of salmon can be found at any time of the year in the Labrador Sea and probably overwintering in the area just north of the Flemish Cap/Grand Banks. In spring salmon are generally found in the Grand Banks /Labrador Sea areas.

Much of the information presented can be found in Reddin (1988) and Reddin and Short (1991).

Questions and Responses

Q: Have you noted any recent difference in migration patterns?
R: Basically, for the offshore areas there may be changes in migration routes from year to year but because our information base is the research trawlers of which there has been one or so the last decade, we would not know whether routes had changed or not. However, from change in numbers of North American salmon apparently going to Greenland one could speculate that routes have changed.

Q: Any evidence of change in diets for smolts or post-smolts?
R: The normal diet of post-smolt salmon in the sea is comprised of amphipods and euphausids. Diet generally switches to benthic-pelagic fish later in the sea life of salmon. No apparent change in diet is evident over time. Data are poor for the recent time interval.

Q: Is there any evidence that the timing of migrations has changed in recent years?
R: Yes, some river data indicates that in warmer years, salmon arrive earlier. In colder years, fish appear to have been pushed further south.

Q: Are there recent data on the marine distribution of salmon?
R: No, there has been no funding for research cruises to collect such data.

Q: How long does it take a smolt to reach some of these marine sites?
R: In a general sense we have the information. Dr. Montevecchi has picked-up tags in the gannet colony on Funk Island in July from post-smolts originating from rivers as far south as Maine (Montevecchi 2000). Other tag return data have allowed us to get a

general sense of the time required by salmon to reach certain locations along their migration route but such tag returns are few and insufficient to document annual variability in migration timing. Generally, by early fall post-smolt salmon can be found spreadout over much of the Labrador Sea from a wide distribution of its range in North America.

Q: What is the status of stock identification using various techniques?
R: For North American versus European, DNA analysis from scales or tissue material works well. These same types of analyses also allow us to identify major stock groupings. Although this latter type of stock separation is currently possible, such analyses are generally unavailable.

Q: What is the size of a post-smolt as it enters the Labrador Sea?
R: Approximately 35 cm; later as it moves north, it achieves a size of about 50cm, and as it approaches the west Greenland coast in the late summer of its second year at sea, it is about 55 cm.

4.3 Overview of methods to compile and rank hypotheses

4.3.1 An examination of possible causes of the decline of Atlantic salmon in New England, Quebec, and the Maritime Provinces

David Cairns
Research Scientist for the Diadromous Fish Section
Gulf Fisheries Management Region
Fisheries and Oceans Canada

David Cairns provided a brief overview of the draft manuscript, which stated and reviewed 60-some hypotheses pertaining to the cause of the decline in North American Atlantic salmon. It also proposed a process for evaluating the various hypotheses. The manuscript had been prepared by DFO Maritimes and Gulf regions with input from Quebec and New England representatives, and published as a Canadian Technical Report of Fisheries and Aquatic Sciences series (Cairns 2000; Cairns and Reddin 2000; DFO in prep).

Questions and Responses

Q: What about synergism or cumulative effects of different factors addressed by more than one hypothesis?
R: It is obvious they occur and those factors which might be coincident or cumulative should be considered together.

Q: Who evaluated the various areas because there appears to be some consistency in the apparent results?

R: Usually the assessment scientist for an area provided the evaluations but the "consistent" results are probably more due to common factors in neighboring areas than any bias.

Q: Some hypotheses have been refereed and others have not. Are we to consider the refereed hypotheses more valid than others are?
R: No, but there is probably a less likely chance for "egregious error" if a hypothesis has been refereed.

4.3.2 Newfoundland and Labrador Atlantic salmon (*Salmo salar*) stock status for 1999, and methods to address possible causes for continuing low abundance and survival

Rex Porter
Head, Salmonids Section, Pelagic Fishes, Shellfish and Salmonids Branch
Northwest Atlantic Fisheries Centre
Fisheries and Oceans Canada

Rex Porter provided a brief summary of the approach by salmon scientists in Newfoundland to short-list the most likely causes for the decline in North American salmon. He indicated that a review of Sydney workshop results (DFO 1998) and related information lead them to propose four principal hypotheses to account for the current state of marine survival for salmon. Those hypotheses are presented in Dempson and Reddin (2000).

Questions and Responses

Q: In regards to Figure 3 in the working paper: (1) Are survival rates corrected for marine exploitation, (2) how were those rates arrived at, and (3) do you have confidence in these estimates?
R: (1) Survival rates were corrected for commercial exploitation using the return rates from just prior to 1992 and after 1992. (2) Those survival rates after 1992 were assumed to be exclusive of exploitation so we corrected backwards for survival without exploitation. (3) Yes, we are fairly confident based on a review of available tagging data but this approach does not account for any inter-annual variability.

Q: Trends presented in the review document are based on information since 1984. What are you doing with the marine habitat index that you used previously or have you discarded it because of a lack of fit in the past few years?
Some concern was expressed that the marine habitat index may not have been a valid index since it fit the data applied but wasn't consistent with other things known about salmon mortality/survival at sea.
R: The Chair deferred discussion of this question to the Marine Subgroup, which he noted would be meeting next.

4.4 Process for review and ranking of hypotheses

The workshop participants were divided into three subgroups organized according to life cycle phase of the Atlantic salmon (Appendix 2):

- Freshwater life stages (including effects in fresh water that affect marine mortality)
- Estuarine life stages (including salmon when they occupy nearshore areas)
- Marine life stages

Instructions from the Chair:

We do not want the group to reopen the consideration of background information, which has led to the list of hypotheses. We can assume that there has been some previous knowledge and research which has contributed to each of the hypotheses and the organization of this workshop. If the background for a hypothesis is weak, the subgroup may wish to address the suitability of that particular theory.

Objective: What can we do as scientists to better explain the pattern in returns/population size and how can we as scientists provide advice on what direction we should go to explain those changes in survival?

As scientists we should identify what could be the cause and not shy away from a possible cause just because we don't have data or do not think we can afford to confirm it.

Proposed approach: Step 1. Identify the most important/likely areas to focus on to explain what is going on with salmon. Step 2. Estimate how long and how much might it take/cost to produce a result.

Identifying what needs to be pulled together to appropriately evaluate a hypothesis could be a research project in itself.

Q: What was the intent of section V.1.c. in the draft manuscript distributed prior to the workshop and tabled by David Cairns (Marine mortality after commercial fisheries is higher than presumed in fisheries models)?
R: Some new view of marine mortality might be useful in estimating pre-fishery abundance. Currently, marine mortality is estimated at 1.0 percent per month. This rate of mortality is not accounting for the low return of fish to North American rivers. It is suggested that the pre-fishery abundance model be re-run to look for the rate necessary to account for losses.

It was noted that some alternate perspective on the hypotheses and their rating could be obtained from non-authors.

Other statements, criticisms and suggestions:

- Recommended that mutual incompatibilities be identified.

- Freshwater questions are insufficient.

- Some local bias seems apparent in the review and ranking of hypotheses but otherwise the exercise is good.

- Local effect hypotheses are not really critical for this type of meeting. Several could be eliminated.

- Noted that a single factor could affect salmon in one local area, which in turn could negatively impact on the entire population.

- The working group needs clarification of what we are trying to explain? Noted that in Newfoundland, returns to rivers are at all time highs. Are we trying to explain marine survival changes only? Survival rates seem to be higher in more northern areas.

- Counter points were made that although returns have increased on the northeast and northwest coasts of Newfoundland, the overall population size has not increased. The increased returns to rivers can be explained by the closure of the commercial fisheries. Some rivers particularly on the south coast have shown declines in returns. Increases in smolt production, due to previous increases in spawning escapement, have not resulted in an increase in adult salmon returns, apparently due to a decrease in survival at sea.

- Concern was expressed that a regional difference in perspective could help in defining the problem because the comprehensive list (of hypotheses) is too broad for a good perspective.

- Addressing the marine survival question is critical for this review, more so than local issues.

- Opposing comments were offered regarding the survival of fish in fresh water. Some data indicate that the number of smolts emigrating from a system is consistent with good freshwater production. The alternate view was that just looking at numbers out would mislead since condition and timing could affect survival in the marine environment for a variety of reasons.

- Perhaps an indicator species that has similar habitat requirements could be examined for some reference point, for example the slimy sculpin in fresh water; some other species in the estuary and another in the open marine environment. Is there room in this process to consider such a proposal?

R: Maybe in some manner. Subgroups should consider if beneficial. It was suggested that we should examine the other species that have experienced similar declines for clues.

- Examination of what has taken place on the West Coast of Canada could improve our understanding.

- Several hypotheses in the short list are concerned with predation. Maybe there are shifts in prey choice by predators.

- It was observed that there is considerable variation in the merit of the different hypotheses. It was suggested that a triage of the hypothesis list would be useful to limit one's consideration to those that something can be done about.

- Atlantic salmon in the Northeast Atlantic are also in a state of decline. This exercise could be broadened to include the eastern side as well.

- Concern expressed that the environmental effects must be considered even though nothing can be done about them.

- Clarification was requested of the Chair on the direction regarding "acceptance of fact" and objectives for this workshop.

- Noted that several of the hypotheses in the short list are directed at marine mammal predation on salmon yet there is very little data to support or refute those hypotheses.

- A request was made for clarification about the amount of detail which should be considered with each hypothesis.
  R: Chairman indicated that the order or ranking of the various proposals is not critical but what is required is a selection of the desired research programs which can validate or eliminate hypotheses.

- It might be unclear what information is out there to test many of these hypotheses, such as how prevalent are endocrine disrupters in the environment, how much has their use changed, etc. How can we move forward selecting hypotheses if we don't have such information?

- The high returns of the 1970s have produced unrealistic expectations of what returns (marine survivals) should be so the lows of the 1960s and 1990s may not be out of synchrony with the actual normal fluctuations in the salmon abundance.

R: Salmon harvest in commercial fisheries used to take three-quarters of a million fish. Smolt production has not declined to any great degree. Returns are lower than ever before so this decline is real. That is what this workshop is all about.

- Impact of aquaculture or freshwater habitat are not an issue in Labrador but Labrador stocks are still in decline.
  R: Perhaps mixed stocks come in contact with disease from fish that have had close contact with aquaculture areas and so impact on Labrador salmon in this manner.

- Salmon could be considered as a freshwater animal when you consider its evolutionary history. Freshwater phase seems to be doing well but the marine phase of the animal's life history is not doing well. This provides support for a look at the species in a different manner.

- Reference was made to a paper presented at the Sydney workshop (DFO 1998) by Gerald Chaput which described trends in salmon returns noting that such trends were not uniform around the western Atlantic. Concern was expressed that the salmon situation is not global. Counterpoint was made that survival in all areas is less than would be expected after closure of commercial and most other fisheries.

5.0 DEVELOPMENT OF RESEARCH THEMES

Instructions from the Chair

The Chair chose not to triage the short list of hypotheses in plenary session. The plenary group then broke into the three subgroups: freshwater, estuarine and marine.

5.1 Freshwater life stages

(Subgroup chair: G. Chaput)

Overview of discussions:

- Fundamental premise:
  - There is a limit to carrying capacity in fresh water; and
  - Cannot treat what happens to salmon while in the estuarine and marine environments in isolation from what they previously encountered in fresh water.

- Freshwater production is defined in terms of quantity and quality of smolts produced.

- Subgroup did not look at hypotheses one by one. Rather, its members discussed general principles and brainstormed about what we know.

Research themes:

- How much of sea survival is determined during the freshwater life stage?
  - Is size of smolt correlated with survival?
  - If yes, how is size-of-smolt determined in fresh water?

- How much of the described variation (decline in the recent decade) is attributable to loss of freshwater habitat (e.g., 10%, 50%)?
  - The global abundance picture is an integration of abundance from all areas.
  - With habitat loss over time, the trend in overall abundance will also decline.
  - Need to quantify how much habitat has been lost.

- The role of density dependence.
  - Clear evidence of importance in fresh water.
  - Population responses to density and characteristics of migrating smolts.
  - Summarize/analyze data, define the functional form (over-compensatory versus asymptotic), define optimum spawning escapements.

- Habitat constraints on smaller scales.
  - Changes in temperature regimes that have occurred throughout the Northwest Atlantic.
  - Requirements of individual fish and competition for limited resources which can be physical/chemical (examples, parr schooling when water temperatures are high, effects on susceptibility to predation).
  - Effects on smolt quality.
  - Reconsider how to characterize physical variables (average conditions may not be relevant for individuals), frequency of extremes, variance rather than averages.

Comments in plenary session:

- A review of co-variation in stock abundance was conducted during the Sydney workshop. This type of analysis would be useful for looking at regional differences.

- Information on stock abundance is scarce for some areas (e.g., Labrador) and it cannot be assumed that abundance in such areas is similar to those for which more information exists.

- Concern was expressed that the proposed themes do not relate to reduced survival at sea. There is little convincing evidence that there is some holistic freshwater effect causing declines in smolt survival.
  R: Can't de-couple freshwater from the marine situation. There may be some freshwater effect that contributes to lower marine survival. If we improve smolt enumeration we can better determine that there is a lower survival at sea.

- Multi-species assemblages have not been taken into account in your proposal. Nor have the impact of aquaculture escapees.
  R: Those issues may have to be revisited in the freshwater proposals.

- Smolt condition information may be available from the aquaculture industry. They have information on smolt physiological condition and smolt survival.

5.2 Estuarine life stages
(Subgroup chair: J. Ritter)

Overview of discussions:

- Fundamental premise: There is increased mortality in the marine environment, including the estuary and in-shore areas.

- Freshwater group will deal with assessing the smolt output and quality.

- Most of the hypotheses from the short list are mainly regional in effect.

Research themes:

- Increased predation from birds, seals and fish;

- Assessment of survival rates of the different life stages could shed light on the cause of the elevated mortality;

- Changes in freshwater and estuarine hydrological conditions (e.g., freshwater discharge, temperature difference between the river and the estuary) could affect the success with which smolts survive the transition from fresh water to salt water;

- Various sources of pollution, assumed to be largely local in their effects; and

- Aquaculture interactions, largely regional in effects except for diseases and parasites which could have global effects.

Comments in plenary session:

- Delineation of where and when predators are a problem would help scope the extent of this issue. In which rivers and estuaries are there high levels of predation on salmon? Which predators are involved, fish, birds or seals? A summary of the information available from monitoring stations could contribute to evidence on the frequency of attacks.

- Some measure of other prey availability at the time that smolts/adults are present in an estuary would be necessary. Certain study areas (estuaries, bays) could be selected to examine this issue. A more thorough estuary study to encompass 3-4 areas would expand the information gained on all predators, not just mammals or birds.

- Studies could examine evidence for aggregations of predatory sea birds during times of peak migration periods for salmon. Another study would be to sample gull colonies for evidence of gull predation on salmon.

- Changes in survival of salmon in an estuary could be accomplished using a passive array of detectors and tagging fish with electronic tags. Seek lost tags by tracking likely predator locations and use a variety of sites to monitor predation. Care should be taken to ensure river estuaries which are monitored include the full array of common predators.

- Radio or ultrasonic tracking of fish released both outside and inside the estuary could be used to assess losses in the estuarine and nearshore areas. This could be done in a paired experiment where aquaculture operations are present and also in areas where they are absent.

- Archival tags could be employed to obtain information on salmon movement in the estuary. Information collected through use of archival tags could be incorporated into a GIS system where predator information is also used to develop overlays to look at coincident spatial distributions.

- Changes in the chemical or physical make up of the transitional zone from the fresh water to the marine environment could affect survival. Two proposals developed to examine this include: (a) Transition from fresh water to salt water through the interface might result in a temperature shock of 3 degrees C or more and the resulting stress on a smolt may result in a delayed mortality. The recent change in freshwater and saltwater temperatures may have exacerbated this problem. This could be studied in a laboratory. (b) A bioenergetic model could be developed to explain energy requirements for post-smolts swimming against oceanographic currents to reach the Labrador Sea. Such a model would provide information regarding temperature clines along the coast and the cost to fish to make such a journey through the various temperature regions. Recent changes in those temperature regions would also affect smolt energetics.

- Aquaculture impacts on salmon in estuaries: multiple proposals would be necessary to examine this issue. Some of the obvious gaps in knowledge include: (a) The effects of the use of antibiotics and chemicals; (2) Seals or other predators attracted to aquaculture areas; and (3) Diseases associated with farmed fish; plus additional hypotheses.

- It would be possible to monitor seal predation in a small estuary by doing controlled removals and examining stomach contents.

- Harbour seals could be tagged and tracked to identify if movements are coincident with salmon being tracked.

- Some consideration and discussion has taken place regarding predator removal experiments but their potential effectiveness is quite uncertain, particularly since a small relative change in mortality of salmon would be extremely difficult to detect in these kind of studies.

- Regarding post-smolt energetics and oceanographic currents, there have been changes in the Labrador current but most of these changes have occurred on the shelf edge where the currents are weaker and more diffuse. To investigate this hypothesis, one could model the existing environmental data but it is unlikely that one would be able to detect changes in energy requirements by looking for recent changes in currents.

- Look in more detail at survival of consecutive vs. alternate spawning fish to see if the mortality is near shore or more distant. A kelt survival database would be an excellent source of data to mine to look at this hypothesis.

- The difficulty in studying predation effects is that without historical predation data you cannot relate new information to the decline in salmon populations. But you might at least determine that it is not the cause for the decline.

- Q: Do you feel you could determine if diseases present in aquaculture are affecting wild stocks because it would be difficult to determine that there is a disease transfer from aquaculture fish to wild fish?
  R.: Yes, and it is worthy of investigation.

5.3 Marine life stages
(Subgroup chair: D. Meerburg)

Overview of discussions:

- Considerable discussion took place regarding the application of various technologies to monitor fish movements and detect predator-prey interactions in the marine environment.

- General concern was expressed that the cost of determining the location and timing of Atlantic salmon lost in the ocean due to natural mortality or predation would preclude examination of many hypotheses.

Research themes:

- Use of electronic tags to monitor fish movements at sea;
- Examination of existing data in more thorough fashion to see if predation could be causing the large scale effects noted;
- Look at relevance of age-at-maturity to survival and see if it contributes to an understanding of the losses at sea;
- Feasibility of finding Atlantic salmon at sea and capturing marine mammal or fish predators at sea;
- Marine mammal predation on salmon could be further examined with data and samples not yet processed;
- *In vivo* and *in vitro* studies could be run concurrently to explore predator-prey hypotheses;
- Definition of study areas and design (e.g., timing, transect locations for surveys) in the Northwest Atlantic Ocean and relevance to the particular hypothesis;
- Critical that current monitoring programs which track marine survival be continued;
- Use of scales to back-calculate smolt size and size of fish over time relative to marine mortality;
- Develop smolt migration pathway model;
- Use of elemental scale analysis to investigate changes in marine migration/behaviour;
- Use of stock identification methods to determine which stocks are where in any sampling of mixed stocks; and
- Relate changes in survival to oceanographic data.

Comments in plenary session:

- Regarding predation in the marine environment (open ocean), it was concluded by the marine predation working group that a single study could not be designed which would conclusively give us evidence that seals prey on salmon in the open ocean and that predation has increased. It was suggested that all offshore research programs include sampling of marine mammals where possible.

- Suggestion was made to adapt marine mammal lipid analysis to look for some of the persistent antibiotics used in the aquaculture industry or the lipid signatures for Atlantic salmon. The resources necessary for such research has already led to a back-log of marine mammal samples.

- Regarding bird predation, one could continue and expand the gannet colony monitoring program. At the Funk Island gannet colony there was a major shift in diet of birds coincident with change in marine temperatures. Salmon became a measurable part of the gannet's diet in the 1990s. Gannets are still feeding on the same species and have not shifted back to pre-1990s species even though temperatures have changed back to previous levels. There are six gannet colonies in North America, three in Newfoundland and three in the Gulf of St. Lawrence. Propose to expand sampling and test null hypothesis that gannet predation has no effect on salmon. One could use mitochondrial DNA to establish origin of fish found in diet since fish are no longer tagged.

- There is a good historical record of harp seal diets. Records indicate that the diet has exhibited similar shifts in prey species as was noted for the gannets. The data analysis for this information is not complete. Samples up to 1994 have been analyzed and more recent samples will be examined for evidence of the warming of the Northwest Atlantic from the cooler temperatures of the early 1990s.

- We should ensure that the inverse mortality relationship (original analysis was done by Doubleday et al. 1979) be revisited in research proposals (with the use of scales).

- We should examine information from prior to ten years ago on oceanographic conditions and where salmon were in the ocean (where a marine habitat index was used) and compare that with recent information.

- In the past there has been a strong relationship between salmon and marine winter habitat but that relationship has recently deteriorated. Has some other variable overridden the effects of this environmental variable?

- Q: Should we look at other species (such as other salmonids) to see if there are parallels or noted differences?
  R: Brown trout in the British Isles have been looked at because they have more local migrations. They have not exhibited the same decline as salmon have. This would lead one to believe the factor(s) causing the decline in salmon is not local to the rivers.

- Q: Has the Marine Subgroup considered modeling the salmon decline with possible changes in oceanographic conditions?
  R: Yes, we have considered it and will include it in our project proposal list.

Follow-up:
The Estuarine Subgroup indicated that it chose not to examine the hypotheses related to predation in the coastal marine areas and were deferring that subject to the Marine Subgroup. The Marine Subgroup indicated that it was limiting its review of marine predation to the open ocean and excluding the coastal zone.

Consequently, the Chair established a separate subgroup to review hypotheses related to predation in the marine environment. Participants were to review the issue(s) and develop research proposals pertaining to predation of salmon in the marine environment. The Predation Subgroup included B. Sjare, D. Cairns, R. Porter, M. Hammill and W. Montevecchi.

6.0 PROJECT PROPOSALS

6.1 Freshwater Proposals

6.1.1 Size dependent survivorship (project number 1-F)

Hypothesis: Size of out-migrating smolts and the smolt size of surviving adults returning to rivers has changed such that increased mortality at sea occurs on a different subset of the migrating smolts.

Research Approach:
Analysis of existing samples and data (scale samples) for size of smolt (backcalculation) and growth rates.

Comments from the floor:

- This hypotheses and research proposal will not explain the change in marine survivals.
  R: It will assist in our understanding and should not be excluded. It may give us a sense of whether mortality at sea is related to size of emigrating smolts.

- Merrimack River data would support this somewhat but we have found widely varying conditions for various smolt sizes.

- The Newfoundland Region has examined annual mean size of smolts and found no correlation between mean size and survival of returning grilse.

6.1.2 Freshwater conditioning (project number 2-F)

Hypothesis: The characteristics of the smolts which determine sea survival are conditioned by mechanisms in fresh water.

Research Approach:
Maintain and improve existing index river programs to define population dynamics of Atlantic salmon throughout the range of salmon in eastern North America. Linked to projects 1-F and 3-F.

Comments from the floor:

- In order for this proposal to work it would have to cover a wide range of abundances on rivers.

- This proposal is essential to be able to move forward and gain any additional insight into the cause for the decline in salmon populations.

- We have looked at a lot of different rivers for life history characteristics but do not have a complete set of data for a series of systems. Eleven index rivers proposed. Maintaining these facilities for data collection would cost about $500,000 over 5 years. This is incremental to existing spending. Rivers would cover overall geographic range from US to Labrador. Location and selection of Labrador rivers has not been set nor has it been confirmed that it would be doable given the lack of time series on any river in the area.

<u>6.1.3 Physical characteristics of fresh water</u> (project number 3-F)

Hypothesis: Physical characteristics of the freshwater environment (density-independent factors) modify the density-dependent factors (project proposal 2-F) which condition quality of emigrating salmon smolts.

Research Approach:
Maintain and establish hydro-meteorological stations on the index rivers to assess the variance contribution of these variables on population dynamics and to assess trends in these variables relative to predictions associated with climate change.

Comments from the floor:

- It has been difficult to tie chemical / physical data to fish condition based on research done elsewhere.

- Can’t get sufficient information over a three to five year time scale so these projects would have to run for a long period of time.

- Once you collect three to five years of data you may be able to "hind cast" by finding a neighboring monitoring station with some history that correlates with the new station.

- These freshwater proposals have a great deal of merit but encourage inclusion of the Big Salmon River as an Inner Bay of Fundy river index because smolt movements in this area are different than for other areas, in addition to the other unique features of these inner Bay of Fundy stocks.

6.2 Estuarine Proposals

6.2.1 Temperature transitions (project number 4-E)

Hypothesis: Smolt survival is negatively associated with the magnitude of difference in temperature between freshwater and coastal marine environment at time of smolting.

Sub Hypothesis – For a given magnitude of temperature difference, smolt survival is negatively associated with the steepness of the gradient. (This may interact synergistically with magnitude of gradient, if estuaries stratify more strongly when the temperature difference is greater. It also introduces a geographic component depending on size of the estuary and its location.)

Research Approach:
1. Investigate relationship between size of temperature transition and physiological stress experienced by the smolts. (Laboratory studies)

2. Conduct retrospective analyses of smolt survival rates relative to historic information on the difference between freshwater and coastal temperatures. (Analyses of historic data – some reconstructed. Contrasts across estuary sizes / gradients and over years.)

Comments from the floor:
- Could be strong stock related variation in this effect which has to be taken into account in any study design.

- Could do this with a streamside tank set up.

- Southern and northern area rivers could be selected for variation overview.

- A wide range in rivers selected for this work might result in a gradient-performance result.

6.2.2 Coastal migration routes and costs (project number 5-E)

Hypothesis: Changes (intensifications?) to the current patterns along the coastal areas and continental slope have changed both the distribution of post-smolts in space along the coast and the bio-energetics of making the outward migration to the Labrador Sea.

Research Approach:
1. Develop bio-energetic model of the cost of post-smolts migrating upstream against the major currents and temperature fields, tied to estimates of the density of food they would have to encounter to grow and migrate. Model would be driven with historic conditions.

2. Quantify the area (volume?) of water of various temperatures available in the coastal area during the post-smolt period for a number of years.

Comments from the floor:

- Variability in shelf-edge currents would probably override any consistent effect that would result in a measurable change in the energy requirements for the fish.
- The variability in ocean current information would make this difficult to model.
- Perhaps this would fit with the smolt migration route modeling project (10-M).
- Sampling in the open ocean to find diet composition to estimate/model bioenergetics would be difficult.
- Modeling bioenergetics as it relates to oceanographic currents would be difficult and compounded by the fact that smolt movement would be quite variable.

6.2.3 Estimation of survival rates with technology (project number 6-E)

Hypothesis: Variation in estuarine survival is an important component of total marine survival from smolt to returning spawners.

Research Approach:

1. Track smolts through the estuaries and nearshore marine environment (dovetail studies with offshore arrays).
2. Track adult salmon as they migrate through estuaries (capture wild smolts, raise in pens, tag and release as adults).
3. Examine the use of archival tags to study habitat preferences for larger salmon.
4. Examine presence of predators and overlaps in timing with Atlantic salmon presence.

Comments from the floor:

- This is one of the only areas where we could use electronic tags to obtain much of this data.
- Rivers with small numbers of returning adult salmon would benefit from this approach.
- The sea-pen rearing of wild stocks would contribute to our understanding of return rates.

- Fits in well with estuary modeling.

6.2.4 Marine fish predation (project number 7-E)

Hypothesis: Predation of post smolts by marine fishes in the estuaries or nearshore has increased, thereby reducing the marine survival rates from smolt to adult returns to rivers.

Research Approach:

1. Conduct mark-recapture population estimates for predator fishes in conjunction with stomach content analysis in the estuaries of rivers with smolt/adult enumeration facilities. This would determine the magnitude of predation and possible impact on sea survival and adult returns.

2. Apply acoustic tags to smolts, which would be subsequently tracked in the estuaries and near shore areas to determine the length of time the post-smolts spent in the estuary and nearshore.

Comments from the floor:

- This proposal could be addressed with some form of mark-and-recapture study of predator fishes; electronic tagging of emigrating smolt would also contribute information in such a study.

- One of the changes which may have occurred in recent years is a change in near shore predators, i.e., fish and marine mammals. Difficult to estimate impact of those changes in any other way. Cost is estimated at about $100k per site per year but could be tied in with other project initiatives.

- This hypothesis and associated studies would not account for population-wide decline in adults. Caution should be exercised to avoid this approach becoming a development of technology at the expense of a better understanding of the problem.

- May be able to define predation rates with this but would not be able to compare with previous data for a better understanding of those rates. It would be difficult to know that fish predation is the cause without prior information (i.e., before the decline).

- Existing Newfoundland fisheries, such as sentinel fisheries, would provide good baseline data.

- The data would be quite variable.

6.2.5 Seal and seabird predation (project number 8-E)

Hypothesis: Predation by seals and seabirds has increased thereby reducing the marine survival rates from smolt to adult returns to rivers.

Research Approach:
Estimate consumption by seals and seabirds (gulls and cormorants) as a proportion of outgoing smolts and incoming adult salmon in selected estuaries based on predator numbers, daily consumption rates, and salmon biomass. Availability of alternate prey will also be estimated.

Comments from the floor:

- No suggestion in this proposal that we have means of overcoming previous problems in obtaining this data.

- Marine mammal specialists have not quantitatively assessed diets of seals in estuaries.

- The predation argument will not go away. If we carefully select the estuaries that this experiment is conducted in, we may be able to get data which would help us realize the magnitude of the problem.

6.2.6 Aquaculture interactions (project number 9A-E)

Hypotheses:

- Presence of salmon in sea-cages disorients outgoing smolts.
- Presence of salmon in sea-cages disorients returning adults.
- Captive and escaped aquaculture salmon transmit disease to outgoing smolts.
- Captive and escaped aquaculture salmon transmit disease to returning adults.
- Aquaculture sites attract predators thereby increasing predation on outgoing smolts.
- Aquaculture sites attract predators, thereby increasing predation on returning adults.
- Aquaculture escapees increase competition for resources in the estuary.
- Escaped fish provide a vector for disease transfer to wild fish.

Research Approach:

1. Identify and quantify the scope for interaction between farmed and wild salmon (either captive or caged fish).
2. Conduct predator population census, behaviour and sampling in the area of the cages (seals and large predatory fish).
3. Conduct bioassays in cage culture embayments and in control areas (disease and parasites).
4. Assay all escaped fish captured for disease and parasites.
5. Assay wild populations for disease and parasites.

Comments from the floor:

- In Britain there has been research along this same suggested approach which may be of relevance .

- Aquaculture effects would generally be local, rather than global, except for the potential for disease transmission which could be both local and global in scope.

6.2.7 Aquaculture disease effects (project number 9B-E)

Included in proposal 6.2.6. This project has been separated out because disease has the potential to be global in its effects, rather than local or regional as are the potential effects of other aquaculture related factors.

Comments from the floor:

- Assay for disease would be relatively inexpensive.

- Industry should be expected to pay for this kind of research.

6.3 Marine Proposals

6.3.1 Salmon distribution- models (project number 10-M)

Hypothesis 1- Major changes in the oceanographic conditions of the North Atlantic have occurred since the 1980s. These conditions have altered the temporal and spatial distribution of preferred habitat for Atlantic salmon.

Hypothesis 2- Lower temperatures in the Northwest Atlantic have reduced marine survival of Atlantic salmon.

Hypothesis 3 - Ocean productivity, or some other factor which affects survival of salmon, has been depressed in local areas of the Northwest Atlantic. Salmon stocks migrate to these areas or pass through them at critical stages due to fixed migration patterns. These salmon suffer lower marine survival.

Hypothesis 4 - The decline in North American Atlantic salmon has been caused by the synergistic effects of cold water and predation by marine endotherms, according to the following causative chain:

a) water cools;
b) endothermic predators increase in population because cold water gives them a relative advantage over ectothermic prey;
c) predation on salmon increases because -
    i) numbers of endothermic predators are higher,
    ii) cold water gives endothermic predators an increased advantage over salmon which are ectothermic, and

iii) salmon must spend more time in the warm surface layer, where predation risk is high, in order to achieve target growth rates.

Research Approach:
Develop migration models to probe possible research directions. These would summarize the current level of understanding of the distribution of salmon post-smolts coupled with the physical oceanographic factors that affect their movements.

Comments from the floor:

- Concern was expressed about the product of this exercise since the proposed modeling exercise isn't really a test of a hypothesis.

- Model would be useful in directing research effort since it would aid our understanding of where salmon are and when.

- Recommended that this project include tie to GIS.

6.3.2 Salmon distribution - coastal field studies (project number 11-M)

Hypotheses: Same as Proposal 6.3.1.

Research Approach:
Track salmon post-smolts in coastal marine areas as they leave the estuary and as they start to migrate toward open ocean areas; positioning of sensors to detect acoustic tags could be optimized at constricted points on the salmon's migration.

Comments from the floor:

- Strong objection raised relative to this proposal as described because of the high cost and small amount of information that would be obtained; opposition suggested that other approaches could be more cost effective.

- In some areas there are platforms other than positioned sensors from which to record acoustic tagged fish (e.g., ferries).

- Proponents seem to be getting mired in the technology approach rather than the information that we would hope to obtain.

6.3.3 Salmon distribution – marine field studies (project number 12A-M)

Hypotheses: Same as Proposal 6.3.1.

Research Approach:
Conduct *research vessel transects* in the ocean areas off the east and northeast coasts of Newfoundland and between Labrador and Greenland through the Labrador Sea. Coupled with the research cruises and tracking studies would be intensified oceanographic

measurements where salmon are found and sighting and sampling surveys of potential predators. Stock identity determination will be done using results of new genetic studies.

Comments from the floor:

- Financing this project may occur differently than some other projects because the department has ships and priority assigned to a particular project is generally associated with internal departmental priority.

- This project is supported by a NASCO proposal to obtain better information on salmon in the sea.

- Project of this nature would have to be tied to specific hypotheses before being pursued.

6.3.4 Marine mammal predation (project number 12B-M)

Hypothesis:
Predation by marine mammals reduces marine survival of post-smolts and adult salmon.

Research Approach:
Document the distribution and relative abundance of marine mammals through systematic visual observations in the course of offshore salmon cruises. Seal and salmon distributions will be compared. Seal stomachs will be sampled when possible.

Comments from the floor:

- Comment made that the information collected under this proposal would be the same as would be available from the research cruise data (Proposal 12A-M).

- Concern expressed that considerable attention has been given to fish, bird or marine mammals as predators but no proposals have been developed to cover human harvesting. Unreported incidental harvests of salmon was raised as a potential source of loss.

- Effort and resources should be expended to explore the capabilities and knowledge of those who work in the fisheries and the marine environment in general. For example, traditional fishers might be able to collect specimens cheaper and more efficiently than scientific teams. Similarly, these same individuals working in the marine environment may be able to provide new insights on the salmon decline.

- Concern expressed that no matter how many seals you sample you won’t know whether the impact on salmon has gone up or down.

6.3.5 Gannets as predators (project number 13-M)

Hypothesis: Gannets are significant predator of salmon and/or an indicator of changes in the marine migration patterns of salmon.

Research Approach:
Monitor salmon contribution to gannet diet monthly from June to September at five colonies in the Gulf of St. Lawrence and Newfoundland. Estimate salmon consumption as a proportion of North American post-smolt biomass . Incidence patterns will be used to clarify migration patterns. Samples of fresh post-smolts will be used for scale analysis.

Comments from the floor:

- Doable project over three years. Results would include tissue samples for DNA analysis. 60 data points over three years.

- Q: How would you identify the origin of salmon in the diet?
  R: Tags, magnetic pit tags, scales and possibly DNA analysis would be performed on the samples of salmon collected. Even if rivers could not be determined, we would still be able to project mortality estimates from different regions in the Gulf of St. Lawrence and in southern and eastern Newfoundland.

- Q: Would this result in anything quantitative, or would the result be a snapshot in time?
  R: Could extrapolate to biomass of diet taken by the birds.

- Q: Ambitions are overstated. Information is sparse. Only 21 salmon that you could measure have been collected over the 25 years of past sampling. Also your estimate of the post-smolt biomass consumed, based on the model, is greater than the biomass available to them.
  R: Ambitions were understated, and the significance of salmon predation at sea by birds could be comprehensively assessed in eastern Canada. Information is sparse because as was made clear in the presentation salmon are a rare item in the diets of gannets. This is a common problem in food web considerations and reconstructions, e.g. seals and salmon. We are trying to assess the potential predatory significance of seabirds that on an individual basis consume minute quantities of salmon at sea. You are incorrect - the model does not estimate that gannets are consuming more salmon than available biomass.

7.0 RANKING OF THE PROPOSALS

Instructions from the chair:
Requested that each workshop participant reviews the list of Project Proposals and evaluate them as "Essential", "Important", "Valuable", or "No, should not be done".

Results of ranking:

Project Proposals		Votes			
No.	Title	Essential	Important	Valuable	No
1-F	Size dependant survivorship	10	12	11	1
2-F	Freshwater conditioning	22	8	1	3
3-F	Physical characteristics of fresh water	7	12	13	2
4-E	Temperature transitions	8	10	15	1
5-E	Coastal migration routes and costs	8	12	10	4
6-E	Estimation of survival rates with technology	14	12	6	1
7-E	Marine fish predation	2	7	19	5
8-E	Seal and seabird predation	6	14	11	3
9A-E	Aquaculture interactions	4	4	17	8
9B-E	Aquaculture disease effects	9	8	15	2
10-M	Salmon distribution – models	15	6	11	2
11-M	Salmon distribution – coastal field studies	18	11	3	1
12A-M	Salmon distribution – marine field studies	16	10	6	1
12B-M	Marine mammal predation	4	12	10	7
13-M	Gannets as predators	7	10	13	3

Discussions:

- If we proceed with an index river program, how would the index rivers be selected?
  R: Planning to be done at zonal level with consensus from the regions.

- Need to tie index rivers to abundance indices.

- Chair: Will the workshop participants agree to have the organizing committee for the workshop carry the production of the report from the meeting forward?
  R: General agreement with the understanding that the Province of Quebec needs to be brought in on planning for this exercise.

- Local input should be sought in putting the research proposals together.

- This exercise of identifying key research concepts and proposals is not meant to exclude work which is already ongoing even if it was not identified in this exercise. That work would have to be taken into account in any project proposals.

- It is important that this work does not proceed without some form of input from the eastern North Atlantic and development of a cooperative approach.
  R: Europeans would see the value in cooperation and working through NASCO / ICES would allow the development of collaborative projects. Some joint projects are already underway.

- We have concentrated on those rivers where salmon migrate to the Northwest Atlantic and the Northwest Atlantic Ocean itself during this workshop. No emphasis has been placed on Inner Bay of Fundy (IBoF). NGO's and governments are involved in IBoF planning and some Species at Risk funding may be made available for work in this area but this initiative is not on the table here. It is important for participants here to realize that some emphasis will have to be placed on the IBoF because of the perilous state of those stocks, regardless of the outcome of this workshop.

- Partners in research must include the U.S. and private stakeholders (such as the Atlantic Salmon Federation).

- The planning group which uses the material from this workshop was urged to avoid giving credence to issues that are not tied to the current severe decline in all North American salmon stocks. What is happening in freshwater habitat cannot account for the current "global" decline in salmon abundance.

- Chair: Workshop organizational team will use the input from this workshop to develop a five to ten-year plan for salmon research. Team will seek to involve the Province of Quebec and some international members.

- Ability to successfully carry out many of the proposed projects is limited. Feasibility of success must be considered when assembling the plan from this workshop.

- Organizational team cautioned that they need to construct a ranked list of action items now and not wait for additional longer term planning. There was general consensus that the exercise has momentum, thereby emphasizing the urgency to follow-up on the workshop.

- Chair: The science community should not produce a program plan which would not deliver a product. A hard-nosed look must be taken at the options and the probability of success. For example, the northern cod research concept was developed in a public-opinion climate with so much political pressure that the good products that were achieved fell far short of what has come to be expected of the project. Scientists here are cautioned that we don't duplicate that result.

- There was general consensus on the urgency of following-up on the workshop and that feasibility and results should be the goals used to guide the planning process.

- The Research Concept Summary table is a good start but additional winnowing will be required during the follow-up planning process.

8.0 CONCLUSIONS AND RECOMMENDATIONS

- The Workshop re-affirmed that higher mortality is occurring after the salmon leave their rivers. This abnormally high marine mortality, seemingly common to all North American Atlantic salmon spawning populations, is in many cases coupled with local factors (e.g., acid rain, habitat deterioration) in some freshwater and/or nearshore areas.

- There could be multiple causes for the lower marine survival and causes identified may act synergistically. The freshwater phase might be implicated through factors that cause a delayed reaction.

- Finding evidence to explain the cause of the decline in survival of North American Atlantic salmon will require a new multi-disciplinary research initiative. This proposed initiative would build on and expand the historical time series of data developed for the freshwater areas and aggressively research the marine areas from the estuaries to the high seas. The more probable factors identified were reduced smolt quality (freshwater effects), adverse estuarine conditions, increased predation in the marine environment, and changes in ocean migration patterns. A number of these factors may be linked to changes in climate and/or oceanographic conditions.

- Maintaining current freshwater monitoring programs and expanding them to areas or stocks not adequately covered were also identified as essential initiatives.

- The proposed research initiative would complement and be linked to local initiatives such as the recovery plan for the genetically unique inner Bay of Fundy salmon which do not migrate to the north Atlantic.

9.0 CLOSING REMARKS

Summary statements by the Chair and workshop organizers:

A considerable amount of work will be required to develop a comprehensive research plan for Atlantic salmon. The products from the workshop will provide guidance to the development of that plan.

The workshop has served as an important first step in planning for a new research thrust to address the current severe decline in Atlantic salmon. The Minister will be briefed on the progress made through the workshop and a proposal for new funding to support an expanded research effort will be prepared. Participants will be kept informed of progress.

10.0 ACKNOWLEDGEMENTS

In addition to all members of the Planning Committee, special thanks are also owed to a number of individuals who contributed to and helped make this workshop a success: Shelly Brown, Jenny Baechler and staff of the Dalhousie Conference Service for their excellent service and versatile facility; Carolyn Harvie for providing the computer support; Kimberly Robichaud-LeBlanc who capably facilitated the arrangements for the workshop and provided both rapporteur and editing services; Sonya Melnyk for ably assisting Kimberly as facilitator; Karen Rutherford for performing rapporteur duties, Shane O'Neil for providing both rapporteur and editing support; Peter Amiro and his wife Esther for graciously hosting the evening mixer; Michael Chadwick for his encouraging opening remarks to the workshop; Dave Meerburg, Gerald Chaput and John Ritter for leading the three subgroups; Jake Rice, who as the Workshop Chairperson, skillfully and successfully guided the participants through what was a very complex and hurried process; and last, all the workshop participants who took the time and effort to contribute to developing this important theme.

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Group photo:

Back to front, left to right:
1st row: Julian Dodson, Shane O'Neil, Don MacLean, Fred Whoriskey, Ted Potter, Bruce Ward, Wayne Fairchild, Steve Rideout, Ken Drinkwater, Bill Montevecchi, Rod Bradford
2d row: Daniel Stechey, Peter Cronin, John Ritter, John Kocik, Dave Meerburg, Jake Rice, Karen Rutherford, Fred Kircheis, Doug Swain, Rick Cunjak, François Caron, Niall O'Maoleidigh
3d row: Gérald Chaput, Becky Sjare, Ed Baum, Dave Reddin, Kimberly Robichaud-LeBlanc, Peter Amiro, Mike Hammill, Larry Marshall
4th row: Ken Curnew, Rex Porter, Daniel Caissie, Jeff Hutchings

(missing from photo are: David Cairns, Micheal Chadwick, Alan McNeill and Sonya Melnyk).

Appendix 2: Subgroup participants

Freshwater	Estuarine	Marine
Gérald Chaput (chair)	**John Ritter** (chair)	**Dave Meerburg** (chair)
Daniel Caissie	Daniel Stechey	Becky Sjare
Don MacLean	Fred Kircheis	Bill Montevecchi
Ed Baum	Jake Rice	Bruce Ward
Julian Dodson	Jeff Hutchings	Dave Reddin
Ken Curnew	John Kocik	David Cairns
Larry Marshall	Mike Hammill	Doug Swain
Micheal Chadwick	Peter Cronin	François Caron
Rick Cunjak	Rex Porter	Fred Whoriskey
Steve Rideout	Rod Bradford	Ken Drinkwater
Wayne Fairchild	Ted Potter	Niall OMaoleidigh
		Peter Amiro
Karen Rutherford (rapporteur)	Kim Robichaud-Leblanc (rapporteur)	Shane O'Neil (rapporteur)

Appendix 3: Details of Project proposals

FRESHWATER LIFE STAGES

PROJECT NUMBER: 1-F

Factor: Life History

Title: Size dependant survivorship (*survival at sea is determined by smolt size*)

Hypothesis:
Size of emigrating smolts and the smolt size of surviving salmon returning to the rivers has changed because increased mortality at sea acts upon a different subset of the emigrating smolt cohort.

Background:
There is evidence that survival of smolts at sea is size-dependent (see summary in Hansen and Quinn 1998). But other factors such as time of entry into the ocean (Dempson et al. 1998), which also appears to have a size-dependent function (larger smolts leave first) are associated with variations in sea survival (Hansen and Quinn 1998). Body size could be important for several reasons: osmoregulatory ability, swimming ability affecting predator avoidance, or range of available prey sizes. Studies have shown that mean smolt length at

age decreases as juvenile density in fresh water increases (Gardiner and Shackley 1991, Korman et al. 1994, Orciari et al. 1994).

Research approach:

1. Adult scale analysis and the size of the original smolt cohort for comparing smolt size distributions of emigrating smolts and the surviving adults. Two databases would be analysed: wild smolts and adults, hatchery smolts and adults.

- Hatchery datasets: between 20 and 30 years of adult scale data and smolt quality data (mean length, standard deviation, raw data?), 1SW and 2SW sea age groups
    - Eastern shore of Nova Scotia – 20 years
    - South shore of Nova Scotia – 30 years
    - Southwest New Brunswick – 30 years
    - Penobscot (Maine) – 1969 to present

- Wild salmon dataset: data sets of varying length
    - Western Arm Brook (NFLD) – 1971 to present (1SW salmon)
    - De la Trinite (North Shore Quebec) – 1984 to present (1SW and 2SW)
    - St. Jean (Gaspé Quebec) – 1988 to present (1SW and 2SW)
    - Conne River (south coast Newfoundland) – 1986 to present (1SW salmon)
    - Campbellton, Highlands, Rocky, Freshwater (Newfoundland) – 1988 to present (1SW salmon)
    - LaHave River, Nashwaak, Miramichi (Maritimes) – 1996 or 1998 to present (1SW and 2SW salmon)
    - Narraguagus River (USA) – 1960s, 1970s and 1990s (1SW and 2SW)

2. Returning adult scales: divided into blocks of time characterised by different fisheries exploitation regimes, different relative abundances of salmon.

- Several data sets with over 30 years of scale sample collections from USA, throughout Canada and Europe
- In addition to backcalculated smolt size, characterise variations in growth rates at sea, by stock, by region, by time period

3. Direct smolt cohort information obtained from recoveries of individually tagged salmon recovered at sea.

- Data from the 1960s and 1970s from Penobscot River
- Hatchery smolts from the Saint John and LaHave rivers

Time frame for completion:

Data set 1 – two years of lab and data analysis assuming inkind collaborations from regions and external technical support.

Data set 2 – three years of lab and data analysis assuming inkind collaborations from regions and two year post-doc fellowship.
Data set 3 – half year of data compilation, and analysis assuming inkind collaborations from regions and six months of technical support.

Resources required:

Facilities: inkind laboratory and office space
Materials: digital analysis systems (2), computers (3), materials for preparing scale materials for analysis ($25K)
Personnel: technical support (5.5 person years) = $160K
post-doctoral fellow (2 years) = $85K

Likelihood that the proposed program will test the hypothesis:

- The data sets are comprehensive, are representative of salmon stocks through the entire range of distribution in North America.
- Hypothesis is simple to test given the data.
- Substantial amounts of data can be collected to address differential survival rates among stocks, among sea age at maturity, among exploitation regimes.

Links to other hypotheses and life stages:

Forms the basis for addressing the link between the freshwater life stages and survival at sea.

Consequences to atlantic salmon if hypothesis is correct:

Actions during the freshwater phase either directed (managing fisheries or other removals to increase or maintain spawning escapement) or undirected (climate change, water regulation) can directly effect sea survival.

Possibility of mitigation if hypothesis is correct:

- Definition and adjustments to “optimum” spawning requirements.
- Modifications of fish culture practices to augment sea survival.

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PROJECT NUMBER: 2-F

Factor: Life History

Title: Freshwater conditioning (*freshwater density dependent determinants of smolt quality*)

Hypothesis:
The characteristics of the smolts which determine sea survival are conditioned by density-dependent mechanisms in fresh water.

Background:
Atlantic salmon juveniles are territorial and competitive (Gibson 1993). Year-class abundance declines over time as a result of competition for limited resources (Grant 1993). Inter-stage survival rates decline with increasing egg deposition with the result that the relationship between egg deposition and juvenile abundance is compensatory. Precocious parr have been noted throughout the range of Atlantic salmon (Myers et al. 1986). While higher winter mortality of precocious parr is suspected (Power 1969, Dalley et al. 1983), fully re-conditioned previously precocious smolts have also been observed. The survival of precocious parr, which affects the number of smolts produced, may be dependent on latitude of the river. Precocity rates are dependent on growth rate and photoperiod combined. Growth rate of parr is dependent on density (Bohlin et al. 1994). Whether precocity of parr can be significantly altered by parr density without a coincident increase in photoperiod or an increase in productivity, is unknown.

High densities of spawners may result in redd super-imposition in favorable habitat or displacement of spawners to sub-optimal habitat.

The major avian predators of juvenile Atlantic salmon are common mergansers and belted kingfishers. Kingfishers tend to take juvenile salmon of the smaller size ranges, while mergansers can take juvenile salmon of any size. Predation may occur at low prey levels if predators are attracted to the area by other prey. Predation rates may increase if juvenile salmon densities are high, leading to greater attraction of predators.

Research approach:
1. Existing set of index rivers (DFO, Faunes et Parcs Québec) and directed research programs on some systems (Catamaran Brook, Ste-Marguerite (Centre Interuniversitaire de Recherche sur le Saumon Atlantique)) have and continue to

collect data of relevance to the examination of population dynamics in freshwater. Index rivers data set would include from North to South: Western Arm Brook, Highlands River, Conne River in Newfoundland, de la Trinite and Ste-Marguerite in Quebec, Miramichi, LaHave and Nashwaak in Maritimes (and possibly Stewiacke River in Inner Bay of Fundy), Narraguagus and tributary of Conneticut River.

2. Enhanced initiatives

- The data being collected at these index rivers will be enhanced to allow a comparison of intra and inter-river freshwater population dynamics and its determinants of smolt size and condition.
- Estimation of eggs, juvenile and smolt life stages for the characterisation of interstage growth, survival, precocious maturation, end of growing season condition, determination of fish species assemblages, winter dynamics.

Time frame for completion:
Minimally, one generation should be completed such that five to seven years of monitoring are required. Analysis of historical data collected from index rivers and non-index rivers would be conducted to augment temporal and inter-river data sets.

Resources required:

Facilities:	support of index river monitoring facilities (seven by DFO, two in Quebec, two in USA) including counting fences, fishways, trapnets, smolt wheels, field stations, laboratories and office space ($25K per site per year)	
Materials:	expendable field materials, tags, field sampling equipment (electrofishers, etc.), laboratory supplies, computers ($15K per site per year)	
Personnel:	technical support:	existing – 2 person years per site per year additional – 1.5 person years per site per year
	professional time:	existing – 0.5 person-years per site per year additional – 0.5 person-years per site per year (post-doc)

Likelihood that the proposed program will test the hypothesis:
A comparative approach to freshwater population dynamics covering a wide range of river systems with standardized collection and analysis techniques will provide an indication of the intra- and inter-river variability. Although data are available from several index rivers, only one river (Catamaran Brook, tributary to Miramichi) has a data set of greater than five years which quantifies the abundance and dynamics of all the life stages in the fresh water. In the absence of information on the interstage dynamics, it is not possible to identify the constraints to freshwater production and the determinants of smolt size/condition.

Links to other hypotheses and life stages:
This research initiative forms the basis for addressing the link between the freshwater life stages and subsequent survival at sea.

Consequences to alantic slmon if hpothesis is correct:
If density-dependent factors are important in defining the quality of the smolt going to sea and the subsequent sea survival, then adult abundance may be negatively impacted by high spawning escapements.

Possibility of mitigation if hypothesis is correct:
Determination of spawning requirements to "optimize" the life stage of interest (i.e. juveniles, smolts, adults).

Sources:
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PROJECT NUMBER: 3-F

Factor: Environment: Temperature/physical/biological/chemical

Title: Physical characteristics of fresh water (*freshwater density independent factors modify density-dependent determinants of smolt quality*)

Hypothesis:
The characteristics of the smolts which determine sea survival are conditioned by both density-dependent and density independent mechanisms in fresh water.

Background:
Adult salmon return to rivers in eastern North America between late spring and fall, depending on local run-timing patterns. Because salmon will not enter waters above their thermal tolerance, the presence of low water and warm zones in rivers may force spring- and summer-running fish to delay their ascent until the water cools in late summer or fall. If temperatures rise after fish have ascended the river and entered in-river pools, high

temperatures may impose stress and lead to increased risk of disease. River temperatures may be influenced by local effects (shallow impoundments which act as solar collectors, reduction of riparian shade, deforestation in the drainage area) or broader scale effects (climate change).

Infilling by sediment reduces water movements, causing developmental delays or death to the eggs, preventing emergence, and in some cases intense bedload movement events can physically displace and destroy eggs and/or juvenile salmonids.

Juvenile salmon also require interstitial spaces for cover. As juvenile salmon increase in size, larger interstitial spaces are needed. Such cover is particularly important in winter when fish activity is reduced. Sediments may fill spaces between gravel, cobble, and boulders in the stream bed, thereby denying appropriate habitat to juvenile salmon. In general, moderate flow regimes are favourable to the survival of juvenile salmon, and flow regimes characterised by extreme events are harmful.

Fish which change habitats to avoid high temperatures may be subject to crowding which lowers feeding opportunities and increases risk of predation and disease.

Juvenile Atlantic salmon may enter cool water refugia when water temperatures in their normal habitat surpass their tolerance limit. Thermal refugia are commonly either areas of water with seepages of cool groundwater, or tributaries with lower temperatures than the main river. Climate change models project a worldwide rise of 2^{o} (range 0.9-$3.5^{o}C$) in the next century. However temperature changes are expected to be uneven and the scale of available model results is too coarse to make firm predictions for the freshwater range of North American Atlantic salmon. Overall, freshwater temperatures are expected to rise because temperature changes in these habitat are about 0.9 times air temperature changes, and because groundwater temperatures are approximately mean annual air temperature + 1-$2^{o}C$.

The parr-smolt transformation and subsequent seawater adaptability can be impaired by exogenous treatments with gonadal steroids. There is a suggested link between past pesticide use and declines of some Atlantic salmon populations. The estimated levels of 4-nonyl phenol (4-NP) present after forest spraying were similar to those currently found in industrial effluents, pulp mill discharges and municipal sewage outfalls. Long-range atmospheric transfer is also a potential means of delivering endocrine disrupting compounds to salmon.

The metabolic impairment hypothesis is that increasing exposure to UV-B radiation during freshwater rearing first causes metabolic damage that results in increased mortality during the stressful period of smoltification, ocean migration, and adaptation to salt water.

Research approach:
1. Existing set of index rivers (DFO, Faunes et Parcs Québec) and directed research programs on some systems (Catamaran Brook, Ste-Marguerite (Centre Interuniversitaire de Rechereche sur le Saumon Atlantique)) have relevant data for assessing the relative importance of environmental variables to growth of juveniles, survival and smolt condition. One of the best data set (longest time series) to correlate population dynamics in fresh water to freshwater environmental conditions is Catamaran Brook, tributary to Miramichi.

2. Enhanced initiatives: Establish hydro-meteorological stations on all the index rivers currently being monitored (see freshwater research theme 2). Parameters to measure include air temperature, water temperature, water level, conductivity, precipitation (year-round), and pH. Intermittent sampling for UV-B absorbance would also be collected. These stations would collect hourly measurements of the air and water parameters.

3. More specific questions related to toxic chemicals, endocrine disruption compounds, and UV-B radiation would be considered in more formal laboratory experiments to address dose response mechanisms. These would be considered as specific problem areas. A proposal to address the UV-B hypothesis is attached as an example.

Time frame for completion:
Monitoring stations can be established with minimal delay. Lifespan is a few years for some probes to decades for others. The data can be accessed remotely at any time.

Resources required:
Facilities: minimal (secure location not necessarily requiring buildings). Can be powered at remote sites by solar power.
Materials: hydro-met stations, power supply, remote access to data ($15K per site, one time installation) ($165K)
replacement and maintenance: ($2K per year per station) ($22K per year)
Personnel: initial installation:
technical: existing – 2 person days per site ($5K)
additional: 2 person days per site ($5K)
annual maintenance, data archiving, analysis:
technical: 0.1 person years per site per year ($60K)
professional: 0.1 person years per site per year ($60K)

Likelihood that the proposed program will test the hypothesis:
A comparative approach to freshwater population dynamics covering a wide range of river systems with standardized collection and analysis techniques will provide required information of the geographical variations/similarities in hydro-meteorological variables affecting Atlantic salmon juveniles.

Links to other hypotheses and life stages:
This research initiative forms the basis for addressing the link between the freshwater life stages, environment and subsequent survival at sea.

Consequences to atlantic salmon if hypothesis is correct:
If density independent factors are important in defining the quality of the smolt going to sea and the subsequent sea survival, then adult abundance may be negatively impacted by changes in environmental conditions associated with climate change.

Possibility of mitigation if hypothesis is correct:
Some environmental effects can be attributed to human activities (for example erosion and sedimentation). Although climate change cannot be mitigated, land use practices can modify the variance of climatic effects.

Sources:
Dempson, J. B., D. G. Reddin, M. F. O'Connell, J. Helbig, C. E. Bourgeois, C. Mullins, T. R. Porter, G. Lilly, J. Carscadden, G. B. Stenson, and D. Kulka. 1998. Spatial and temporal variation in Atlantic salmon abundance in the Newfoundland-Labrador region with emphasis on factors that may have contributed to low returns in 1997. . Canadian Stock Assess. Secretariat Res. Doc. 98/114, 161 p.

DFO Science Branch Maritimes and Gulf regions. in prep. An examination of possible causes of the decline of Atlantic salmon in New England, Quebec, and the Maritime Provinces. Can. Tech. Rep. Fish. Aquat. Sci.

PROJECT NUMBER: 3-F (Supplement)

Factor: Environmental: physical/biological

Title: Changes in UV exposure effect growth of juveniles and subsequent sea survival

Hypothesis:
Solar ultraviolet–B radiation (UVB; 280-320 nm) can penetrate the water column and has increased at the earth's surface due to ozone depletion (Kerr and McIroy 1993). "The metabolic impairment hypothesis is that increasing exposure to radiation during freshwater rearing first causes metabolic damage that results in increased mortality during the stressful period of smoltification, ocean migration, and adaptation to salt water. At higher dose levels, increasing metabolic effects should result in mortality in fresh water as well." (Walters and Ward 1998: p. 2536).

Background:
See description of hypothesis and evidence provided in Walters and Ward (1998). Evidence of effects of UV radiation on aquatic productivity, physiological effects including sunburn, suppression of immune responses and egg mortality (all summarized in Walters and Ward 1998). The effect is likely density independent although increasing

abundance of juveniles may force a proportion of the population into poorer habitats that are less shaded.

Research approach:

1. Dose-response test of UV metabolic impairment hypothesis.
   Why? Assess the UV effect on metabolic impairment of growth, disease-resistance, and seawater adaptability, and sea survival.

   Experimental design:

- Treatments include control (< 1 mJ/cm2 of UV-B radiation) and treatments of 10 mJ/cm2, 100 mJ/cm2, 500mJ/cm2, 1 J/cm2, 2 and 5 J/cm2 (high value is expected to produce severe sunburn and mortality within the first growing season). Treatments will be in replicate, with 100 fish per treatment (to obtain 50 fish per treatment replicate to go to sea-water challenge, thus seven treatments (including control) with replicate and 100 fish per treatment requires 1400 fish (14 aquaria). All other conditions will be standardized (water source, rate of flow, temperature, artificial photoperiod length, food type). Requires fourteen four-ft circular tanks with individual light sources. UV lights would be installed over each tank and UV-B radiation would be regulated by filters. Illumination would match the regular seasonal photoperiod regime.
- Sampling protocols: Fish will be sampled biweekly for length and weight. Mortalities will be sampled for length, weight, sex, and gonadal development.
- After the first season’s growth (early October), ten fish from each treatment (five per replicate) will be tested for disease resistance.
- Seawater adaptability: seawater challenge tests will be conducted in spring of the following year on 10 fish per treatment. Standard seawater challenge tests will be performed.
- Seawater grow-out and survival: seawater grow-out and survival tests will be conducted to address the short-term impairment of UV-B exposure on growth and sea survival. This experiment could be completed in test sea-cages in the Bay of Fundy. All fish would be individually marked prior to transfer to grow-out site or tanks. Replicate grow-out cages would be desirable. Experiment would end in September of first sea season and growth and survival determined.

Available databases to examine hypothesis:

1. Summarize available climate information related to the extent of UV-B penetration into the atmosphere and the depth of penetration relative to water quality characteristics. Measures and reporting of UV radiation have become more prevalent in recent years. This would provide an indication of the extent of the local effect within the Northwest Atlantic.
2. Time series of survival rates of hatchery-stocked smolts should be examined relative to type of and changes to rearing facilities. There are several multi-decade time series of survival rates in the eastern US and Maritimes Region of eastern Canada.

Time frame for completion:
One experiment could be conducted and completed within 22 months.
1. November to January (three months): spawning and egg incubation
2. February to March of next year (14 months): juvenile rearing, biweekly sampling
3. April: sea-water challenge tests, disease resistance test (or October previous year)
4. May to September (five months): grow-out in marine cages or in land-based facility

Resources required:

Facilities: hatchery with fourteen four-ft circular tanks within a building with ability to control lighting, temperature, flow for 18 months (facilities cost: $100 per month per tank = $25K)
grow-out site, two cages or alternatively grow-out tanks with flow through sea-water ($250 per site per month = $2.5K)

Materials: sufficient eggs from a wild spawning stock to produce 1400 feeding fry for rearing and growout (Inkind, available from DFO)

Personnel: hatchery personnel for spawning, incubation and rearing maintenance (one day per week equivalent for 18 months = $9K salary. *$600 per week*)
personnel for grow-out site maintenance and operation (one day per week for five months = $2.5K salary. *$600 per week equivalent*)
research assistant to oversee biweekly sampling and daily monitoring, data analysis and write-up (22 months @ 1.5K per month = $33K)

Likelihood that the proposed program will test the hypothesis:
The experiment is designed to test the dose response of UV radiation on growth, disease resistance, grow-out and survival of Atlantic salmon. Whether UV radiation is a plausible factor affecting Atlantic salmon survival and abundance will depend upon the dose response function derived from the experiment and the levels of UV radiation to which wild salmon in rivers of North America are exposed. For example, if the dose response function indicates measurable effects on survival and growth at UV radiation levels much greater than those experienced by Atlantic salmon in eastern North America, then the plausibility of this factor contributing to the decline in abundance of Atlantic salmon could be discounted.

Links to other hypotheses and life stages:
Addresses issues defined in IV.7.c (estuary), V.7.c (ocean life).

Consequences to atlantic salmon if hypothesis is correct:
As stated by Walters and Ward (1998), if the hypothesis is correct, “Marine survival rates may not recover even if ocean conditions return to normal."

Possibility of mitigation if hypothesis is correct:
Fish culture practices could be modified to ensure that UV-B radiation exposure is minimized. This may require simple to more expensive modifications to infrastructure (such as providing shade during rearing).

For wild populations, little can be done. Land use practices could be modified to increase the amount of overhanging vegetation in streams (to provide shade), especially the shallow areas used for rearing of juveniles.

Sources:

DFO Science Branch Maritimes and Gulf regions. in prep. An examination of possible causes of the decline of Atlantic salmon in New England, Quebec, and the Maritime Provinces. Can. Tech. Rep. Fish. Aquat. Sci.

Kerr, J.B.and C.T. Mclroy. 1993. Evidence for large upwards trends of Ultraviolet-B radiation linked to ozone depletion. Science 262:1032-1034.

Walters, C. and B. Ward. 1998. Is solar radiation responsible for declines in marine survival rates of anadromous salmonids that rear in small streams? Can. J. Fish. Aquat. Sci. 55: 253-2538.

ESTUARINE LIFE STAGES

PROJECT NUMBER: 4-E

Title: Temperature transitions (*changes in the hydrography of the transitional zone from freshwater to marine environment*)

Hypothesis:

Smolt survival is negatively associated with the magnitude of difference in temperature between freshwater and coastal marine environment at time of smolting.

Sub Hypothesis – For a given magnitude of temperature difference, smolt survival is negatively associated with the steepness of the temperature gradient between freshwater and marine environments. (This may interact synergistically with magnitude of gradient, if estuaries stratify more strongly when the temperature difference is greater. It also introduces a geographic component depending on size of the estuary and its location from north to south.)

Background:

Hatchery operators plan carefully to make temperature transitions fairly small when smolts are released. They observe higher mortality when the temperature transitions are “large’ (>three degrees?), and the mortality is delayed, not immediate. Aquaculture operators in Norway have noted smolt mortalities at temperatures less than 6^{o}C. With river temperatures increasing and cold ocean waters widespread through the Northwest Atlantic, this aspect of salmon biology has not been examined.

Research approach:

1. Relationship between size of temperature transition and physiological stress experienced by the smolts. (Laboratory studies)

2. Retrospective analyses of smolt survival rates relative to historic information on difference between freshwater and coastal temperatures. (Analyses of historic data – some reconstructed. Contrasts across estuary sizes/gradients and over years.)

Sources:

DFO Science Branch Maritimes and Gulf Regions. in prep. An examination of possible causes of the decline of Atlantic salmon in New England, Quebec, and the Maritime Provinces. Can. Tech. Rep. Fish. Aquat. Sci.

Dempson, J. B., D. G. Reddin, M. F. O'Connell, J. Helbig, C. E. Bourgeois, C. Mullins, T. R. Porter, G. Lilly, J. Carscadden, G. B. Stenson, and D. Kulka. 1998. Spatial and temporal variation in Atlantic salmon abundance in the Newfoundland-Labrador region with emphasis on factors that may have contributed to low returns in 1997. Canadian Stock Assess. Secretariat Res. Doc. 98/114, 161 p.

PROJECT NUMBER: 5-E

Title: Coastal migration routes and energetic costs (*migration routes and costs have changed*)

Hypothesis:

Changes (intensifications?) to the current patterns along the coastal areas and continental slope have changed both the distribution of post-smolts in space along the coast and the bio-energetics of making the outward migration to the Labrador Sea.

Background:

Post-smolts may spend some time in coastal areas preparing for their migration outward and northward, and during this period they may be seeking good conditions for growth and accumulating energy (except we don't know what those conditions are). Sooner or later they commence migrating generally northward and seaward against currents which are strong and cold. Moreover, they are migrating during a period of the year when capelin are inshore, the spring bloom has collapsed (?), and when we know of no highly abundant, energy-rich, and reliable food supplies for them if they are in the current streams. Furthermore, during the period of declining salmon populations the on-shore migration of capelin has been later than normal, some years as late as August. This presents some obvious bio-energetic challenges.

Research approach:

1. Bio-energetic model of the cost of post-smolts migrating upstream against the major currents and temperature fields, tied to estimates of the density of food they would have to encounter to grow and migrate.
   - Based on the model results, look at the quality of major potential prey (What is a *Paralepis* worth? What else is out there?) on the migration pathway.
   - Ask the model if there is a minimum size the post-smolts have to reach before they could expect to make progress against these currents.

- Once the model is developed, drive it with past annual patterns in strength and temperature of the currents, and see if the energetic demands become more or less bearable over time. Relate to temporal patterns of survivorship. Develop for a couple of areas of origins – to get contrast in the current regimes that they pass through.

2. Quantify the area (volume?) of water of various temperatures available in the coastal area during the post-smolt period for a number of years.

3. Couple with marine cruises fishing mid-water and surface trawls to learn more about the distribution and availability of food prey during migration and in areas where post-smolts may be found.

If post-smolts have to stay in coastal waters until they are of a size to succeed in their counter-current migration, the volume of suitable waters available may be important. There are many possible mechanisms linking variation in mortality to variation in availability of "suitable" waters, but the first-order relationship to some water masses/temperatures needs to be demonstrated. We may not know what the "preferred" temperatures are, but there may strong patterns in volume of water of various temperatures over time. Various pattern identification and pattern matching analyses could lead to more focused hypotheses, and much better targeted field programs for exploring variation in distribution in the coastal areas.

4. Active tracking of smolts in coastal areas could complement these analyses, and the analyses might help design more efficient field tracking programs in the coastal areas.

Sources:

DFO Science Branch Maritimes and Gulf regions. in prep. An examination of possible causes of the decline of Atlantic salmon in New England, Quebec, and the Maritime Provinces. Can. Tech. Rep. Fish. Aquat. Sci.

PROJECT NUMBER: 6-E

Factor: Life History

Title: Estimation of survival rates with technology (*identification of factors affecting survival rates of emigrating smolts, returning adults and post-spawning kelts in estuaries and coastal waters*).

Hypothesis:

Variation in estuarine survival is an important component of total marine survival from smolts to returning spawners.

Background:
Recent studies suggest that freshwater environmental factors (acid rain and endocrine disrupters) have contributed to low survival during the transition to marine life. Additionally, natural components of estuarine communities have undergone significant changes in abundance due to either natural (e.g. seabirds and marine mammals) or anthropogenic (sea lice, diseases) causes. These ecosystem changes are hypothesized to effect the survival of Atlantic salmon while migrating through the estuarine and nearshore environments.

Research approach:
Little historical data are available to measure changes in survival rates that may have resulted from these changes. Baseline data are needed that would measure these rates and monitor the effects on several systems across regional scales.

1. Track smolts through the estuaries and nearshore marine environment (dovetail studies with offshore arrays).
   - Develop index estuaries across the range of Atlantic salmon that take into account physical structure of estuaries and proximity to proposed marine migration routes;
   - Ultrasonic tags – focus on marine tagging and tracking for the first three months;
   - Radio tags to measure scale of bird and mammal predation;
   - Track an adequate number of smolts to determine survival rates and locations where mortality occurs.

2. Track adult salmon as they migrate through estuaries (capture wild smolts, raise in pens, tag and release as adults).
   - Replicate study in areas with and without aquaculture facilities;
   - Track an adequate number of adults to determine survival rates and locations where mortality occurs.

3. Examine the use of archival tags to study habitat preferences for larger salmon.

4. Examine presence of predators and overlaps in timing with Atlantic salmon presence.
   - See predation subgroup and outside sources for information on seabirds and marine mammals;
   - Utilize existing or develop new creel surveys for striped bass;
   - Determine the population status and spatial/temporal overlap of other alternate prey of similar size to smolt or adults (hydroacoustics).

Available databases to examine hypothesis:
Literature search of
- Quantitative survival of salmon in estuaries
- Densities and abundance of suspect predators

Time frame for completion:
Various aspects of these recommendations will take varying amounts of time for completion such as the literature review that could be completed within six months, or the smolt rearing to adult that could take two or more years.

Resources required:

Total: $100K annually per estuary

Facilities: smolt rearing to adult will require the use of offshore rearing pens; tracking will require the use of both fixed and mobile receivers, boats, aircraft, etc.

Materials: radio and ultrasonic tags (more than 100 of each), radio receivers, boat safety equipment, smolt traps

Personnel: aquaculture personnel for rearing smolts to adults, field crews to capture smolts, deploy fixed arrays of receivers, participate in tracking of smolts and/or adults, and data analysis personnel

Likelihood that the proposed program will test the hypothesis:
High.

Links to other hypotheses and life stages:
Yes.

Consequences to atlantic salmon if hypothesis is correct:
To paraphrase Walters and Ward (1998), if the hypothesis is correct, "Marine survival rates may not recover even if estuarine conditions return to normal."

Possibility of mitigation if hypothesis is correct:
Implement management measures designed to reduce known causes of mortality in estuaries.

Sources:
DFO Science Branch Maritimes and Gulf regions. in prep. An examination of possible causes of the decline of Atlantic salmon in New England, Quebec, and the Maritime Provinces. Can. Tech. Rep. Fish. Aquat. Sci.

Dempson, J. B., D. G. Reddin, M. F. O'Connell, J. Helbig, C. E. Bourgeois, C. Mullins, T. R. Porter, G. Lilly, J. Carscadden, G. B. Stenson, and D. Kulka. 1998. Spatial and temporal variation in Atlantic salmon abundance in the Newfoundland-Labrador region with emphasis on factors that may have contributed to low returns in 1997. Canadian Stock Assess. Secretariat Res. Doc. 98/114, 161 p.

Walters, C. and B. Ward. 1998. Is solar radiation responsible for declines in marine survival rates of anadromous salmonids that rear in small streams? Can. J. Fish. Aquat. Sci. 55: 253-2538.

PROJECT NUMBER: 7-E

Title: Marine fish predation (*predation by marine fish has increased*)

Hypothesis:
Predation of post-smolts by marine fishes in the estuaries or nearshore has increased, thereby reducing the marine survival rates from smolt to adult returns to rivers.

Background:
The spatial and temporal distribution and abundance of many prey species, such as capelin, has changed so much in recent years that the diet of other marine fishes, such as rock and Atlantic cod, may also have changed. There appears to also have been a shift in the distribution of cod and possibly other predator fishes to estuaries and nearshore areas frequented by smolts and post-smolts, suggestive of increased mortality on salmon. Salmon post-smolts have been found in the stomachs of Atlantic cod and rock cod in estuaries of several rivers in Newfoundland. Also, cod have been observed foraging in several other estuaries and in less that three meters of water nearshore. Although the spatial distribution of these fishes has changed, it is not known if the current observations of predation on post-smolts represent a change in the degree of predation.

Research approach:
Mark-recapture population estimates for predator fishes will be conducted in conjunction with stomach content analysis in the estuaries of rivers with smolt/adult enumeration facilities. This would determine the magnitude of predation and possible impact on sea survival and adult returns.

Acoustic tags will be applied to smolts, which would be subsequently tracked in the estuaries to determine the length of time that post-smolts spend in the estuary and nearshore areas.

Available databases to examine the hypothesis:
No complete data sets are available, although time series of information are available on marine survival rates of wild salmon at six enumeration facilities in Newfoundland, and three in Quebec. Survival rates on hatchery smolts are available at one site in Nova Scotia and one in New Brunswick.

Sources:

DFO Science Branch Maritimes and Gulf regions. in prep. An examination of possible causes of the decline of Atlantic salmon in New England, Quebec, and the Maritime Provinces. Can. Tech. Rep. Fish. Aquat. Sci.

Dempson, J. B., D. G. Reddin, M. F. O’Connell, J. Helbig, C. E. Bourgeois, C. Mullins, T. R. Porter, G. Lilly, J. Carscadden, G. B. Stenson, and D. Kulka. 1998. Spatial and temporal variation in Atlantic salmon abundance in the Newfoundland-Labrador region with emphasis on factors that may have contributed to low returns in 1997. Canadian Stock Assess. Secretariat Res. Doc. 98/114, 161 p.

PROJECT NUMBER: 8-E

Factor: Predation

Title: Seal and seabird predation (*bird and seal predation reduce survival of smolts and adults in estuaries*)

Hypothesis:
Bird and/or seal predation reduce the survival of outgoing smolts and/or incoming adults in estuaries.

Background:
Predation by birds and seals on outgoing smolts and by seals on returning adults has the potential to impact salmon populations. If predator harvest can be determined through diet studies and bioenergetic models (Cairns and Kerekes 2000, Hammill and Stenson 2000), and smolt output or adult returns can be measured through stock assessment programs, exploitation rate of local stocks can be calculated.

Double-crested cormorants breed colonially in coastal areas of Southern Quebec, the Maritime Provinces, and New England. Several major salmon rivers, including the Saint John and the Restigouche, have large cormorant colonies near their mouths. Although cormorants commonly aggregate during runs of anadromous fish to feed, cormorant diet has not been recorded at or near large salmon rivers during the smolt run in eastern Canada.

In Newfoundland, herring gulls and great-blacked backed gulls suffered a loss of food supply following the decrease of offal availability due to the cod moratorium. Subsequently, anecdotal reports suggested that gulls increased their visitation to river mouths in spring, presumably to prey on runs of anadromous fishes (W.A. Montevecchi, pers. comm. [1]).

Research approach:
Part A - Intensive studies

Research will take place in one estuary in each of Newfoundland, the Gulf of St. Lawrence, and the Bay of Fundy-Gulf of Maine area. Estuaries will be sought which have salmon runs that are monitored at the smolt and returning adult stages, and which have populations of seals and seabirds during the time of smolt and adult runs.

[1] W.A. Montevecchi. Biopsychology Program, Memorial University of Newfoundland, St. John's Newfoundland.

Cormorant diet will be determined from regurgitated boli (Johnstone et al. 1990) or, if necessary, from lethal stomach sampling. Diet of breeding gulls will be determined from regurgitations and from prey items dropped at colonies. Bird numbers will be derived from colony counts, or by estimating predator-days through air or vessel surveys, or counts from vantage points.

Seal diet will be determined by analysis of scats collected from hauling out areas (da Silva and Neilson 1985), or from lethal sampling. Numbers of animals will be obtained from surveys of predator-days, although such data are likely to be less reliable than those for cormorants and gulls because seals are more difficult to count than birds.

Total predator food consumption will be estimated from bioenergetics models, and salmon consumption will be estimated on the basis of salmon contribution to diet.

Temporal overlap of salmon with seals and birds will be determined. Overlap of predators with other prey, particularly runs of non-salmon diadromous fish, and biomass of alternate prey will be used to draw inferences regarding the relative importance of salmon and other prey in attracting seals to the area.

Bigg et al. (1990) were able to document seal and salmon behaviour during predatory attacks in a Vancouver Island estuary by direct visual observations. Such observations will be conducted in this study if conditions permit. Video or remote operated video equipment could also be used to document predation activity if the water is sufficiently clear.

Detailed observations of scars on returning adult salmon will be made. Through comparisons with other studies, and detailed comparisons of scar patterns with skulls of seals and other potential predators, criteria will be developed to identify the cause of surface scars on salmon. Timing of predator-induced scarring will be compared with temporal trends of predator presence. This will indicate to what extent scar incidence reflects predator activity in the estuary.

Part B - Extensive studies

Risk of predation from seals and birds in estuaries in North American rivers will be assessed. Bird predation potential will be assessed on the presence and size of cormorant and gull colonies in or close to the estuaries. Seal predation potential will be assessed from information on presence/absence or abundance and seasonal trends, of seals, as obtained from surveys of personal knowledge of field staff of DFO and other agencies. In some cases direct observations will be conducted by personnel of this project. Data on seal-induced scars on returning adults will be used to infer relative frequency of seal attacks during the salmon's journey to the river.

Available databases to examine hypothesis:
The locations of cormorant and gull colonies are given in published seabird atlases. The atlases also have population data available but these are often not up-to-date.

Time frame for completion:
Research would be conducted in spring-summer-fall 2001, 2002, and 2003.

Resources required:
Each study site will require one biologist (year-round), one technician (eight months), and one summer student (four months). Major expenses will be travel, field accommodations, and boating costs.

Salary:	$80,000 annually
Operating:	$20,000 annually
Total:	$100,000 annually, total $300,000

Likelihood that proposed program will test the hypothesis:
High for the intensively studied estuaries, moderate for other estuaries.

Links to other hypotheses and life stages:
Electronic tagging projects would greatly aid interpretation of the data obtained in this study, especially if tagging were conducted in this study's intensively studied area.

Consequences to atlantic salmon if hypothesis is correct:
If the hypothesis is true, salmon returns will continue to decline if predator numbers remain the same or increase.

Possibility of mitigation if hypothesis is correct:
Predation pressure could be reduced by predator culls or increased predator harvests. In some cases, predation could be averted by scaring predators from the area during salmon run.

Sources:
Bigg, M.A., G.M. Ellis, P. Cottrell, and L. Milette. 1990. Predation by harbour seals and sea lions on adult salmon in Comox Harbour and Cowichan Bay, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. No. 1769.

Cairns, D.K., and J.J. Kerekes. 2000. Fish harvest by common loons and common mergansers in Kejimkujik National Park, Nova Scotia, Canada, as estimated by bioenergetic modeling. Pp. 125-135 in F.A. Comin, J.A. Herrera and J. Ramirez (eds.). Limnology and aquatic birds: monitoring, modelling, and management. Universidad Autonoma de Yucatan, Mérida (Mexico).

da Silva, J. and J.D. Neilson. 1985. Limitations of using otoliths recovered in scats to estimate prey consumption in seals. Can. J. Fish. Aquat. Sci. 42: 1439-1442.

Dempson, J. B., D. G. Reddin, M. F. O'Connell, J. Helbig, C. E. Bourgeois, C. Mullins, T. R. Porter, G. Lilly, J. Carscadden, G. B. Stenson, and D. Kulka. 1998. Spatial and temporal variation in Atlantic salmon abundance in the Newfoundland-Labrador region with emphasis on factors that may have contributed to low returns in 1997. Canadian Stock Assess. Secretariat Res. Doc. 98/114, 161 p.

Hammill, M.O., and G.B. Stenson. 2000. Estimated prey consumption by harp seals (*Phoca groenlandica*), hooded seals (*Cystophora cristata*), grey seals (*Halichoerus grypus*), and harbour seals (*Phoca vitulina*) in Atlantic Canada. J. Northw. Atl. Fish. Sci. 26: 1-23.

Johnstone, I.G., M.P. Harris, S. Wanless, and J.A. Graves. 1990. The usefulness of pellets for assessing the diet of adult shags (*Phalacrocorax aristotelis*). Bird Study 37: 5-11.

PROJECT NUMBER: 9A-E and 9B-E

Factor: Aquaculture

Title: Aquaculture interactions (*aquaculture operations and escapees interact adversely with wild salmon*)
Aquacuture disease effects (*aquacuture fish are a vector for disease transmission to wild salmon*)

Hypothesis:

- Presence of salmon in sea-cages disorients outgoing smolts
- Presence of salmon in sea-cages disorients returning adults
- Captive and escaped aquaculture salmon transmit disease to outgoing smolts
- Captive and escaped aquaculture salmon transmit disease to returning adult
- Aquaculture sites attract predators, thereby increasing predation on ongoing smolts
- Aquaculture sites attract predators, thereby increasing predation on returning adults
- Aquaculture escapees increase competition for resources in the estuary
- Escaped fish provide a vector for disease transfer to wild fish

Background:
Background description for these hypotheses is provided in the DFO (in prep) document.

Potential for interaction:

LOCAL

Category	Smolts	Adults
Escaped	disease competition	disease
Captive	disease predator attraction disorientation	disease predator attraction disorientation

REGIONAL

Category	Smolts	Adults
Escaped	disease competition	disease
Captive	disease predator attraction disorientation	disease predator attraction disorientation

GLOBAL

Category	Smolts	Adults
Escaped	disease	disease
Captive	disease	disease

Research approach:

1. Identify and quantify the scope for interaction between farmed and wild salmon (either captive or caged fish):
   - Tracking wild post-smolts and returning maiden and repeat-spawning adults (address disorientation, predation); and
   - Tracking escaped farmed fish (time-structured release) (address competition, disease vector).

2. Conduct predator population census, behaviour and sampling in the area of the cages (seals and large predatory fish).

3. Conduct bioassays in cage culture embayments and in controls areas (disease and parasites).

4. Assay all escaped fish captured for disease and parasites.

5. Assay wild populations for disease and parasites.

Available databases to examine hypothesis:

- Predator population data (species and numbers);
- Fish health data from both wild and caged operations; and
- Aquaculture escapee numbers in the area of investigation.

Time frame for completion:

Two-year study conducted during the wild fish migration period through the estuary (May through October).

Resources required:
Costly (several hundred thousand dollars in each of two years) and not feasible without industry participation. Partnering essential to resource and to conduct investigations.

Likelihood that the proposed program will test the hypothesis:
High!

Links to other hypotheses and life stages:
- Other predation hypotheses;
- Freshwater interactions with escaped farmed fish and;
- Other disease hypotheses.

Consequences to atlantic salmon if hypothesis is correct:
May provide opportunity for mitigative measures and thereby reduce marine mortality.

Possibility of mitigation if hypothesis is correct:
High!

Sources:
Dempson, J. B., D. G. Reddin, M. F. O'Connell, J. Helbig, C. E. Bourgeois, C. Mullins, T. R. Porter, G. Lilly, J. Carscadden, G. B. Stenson, and D. Kulka. 1998. Spatial and temporal variation in Atlantic salmon abundance in the Newfoundland-Labrador region with emphasis on factors that may have contributed to low returns in 1997. Canadian Stock Assess. Secretariat Res. Doc. 98/114, 161 p.

DFO Science Branch Maritimes and Gulf Regions. in prep. An examination of possible causes of the decline of Atlantic salmon in New England, Quebec, and the Maritime Provinces. Can. Tech. Rep. Fish. Aquat. Sci.

MARINE LIFE STAGES

PROJECT NUMBER: 10-M

Factor: Marine Distribution

Title: Salmon distribution – models

Hypothesis:
1. Major changes in the oceanographic conditions of the North Atlantic have occurred since the 1980s. These conditions have altered the temporal and spatial distribution of preferred habitat for Atlantic salmon.

2. Lower temperatures in the Northwest Atlantic have reduced marine survival of Atlantic salmon.

3. Ocean productivity, or some other factor which affects survival of salmon, has been depressed in local areas of the Northwest Atlantic. Salmon stocks migrate to these areas or pass through them at critical stages due to fixed migration patterns. These salmon suffer lower marine survival.

4. The decline in North American Atlantic salmon has been caused by the synergistic effects of cold water and predation by marine endotherms, according to the following causation chain:
   a) water cools,
   b) endothermic predators increase in population because cold water gives them a relative advantage over ectothermic prey,
   c) predation on salmon increases because
      i) numbers of endothermic predators are higher,
      ii) cold water gives endothermic predators an increased advantage over salmon which are ectothermic, and
      iii) salmon must spend more time in the warm surface layer, where predation risk is high, in order to achieve target growth rates.

Background:
Routes and distribution of post-smolts in the marine environment is thought to be a function of origin, genetics, thermal preference, currents, foraging strategy and energenics. The weights and parameters for these variables are unknown. There is evidence that changes in the oceanographic and prey assemblages in the North Atlantic have undergone considerable change in recent decades. These changes may have resulted in considerable variation in the distribution and timing of salmon migrations. These changes in migration may have affected the marine survival of salmon through a number of mechanisms including growth, exposure to predators and loss due to climatic isolation. Conditions that aggregate post-smolts could account for exposure of a large portion of post-smolts to a common high mortality. Interpretation of marine survey catches requires an understanding of the processes that control post-smolt distributions. Postulating distribution rules and testing the output of these rules may be best accomplished through evaluating the output of migration models using historic and new research data.

Research approach:
The development of migration models to probe possible research directions. These would summarize the current level of understanding of the distribution of salmon post-smolts coupled with the physical oceanographic factors that affect their movements.

Available databases to examine hypotheses:
1. Survey published and on-going research for possible migration rules.
2. Assemble oceanographic data and models for possible input to models.
3. Design a computer program to test existing and new migration rules.
4. Use harvest and research catch records to test models.

Time frame for completion:
1. Two months.
2. Three months.
3. Six months.
4. Three months.

Resources required:

Total: 20K of operations and 70K of salary.

Facilities: Twelve months of office and meeting facilities.

Personnel: 0.5 person year for computer programming.
1.0 py of researcher time.

Likelihood that the proposed program will test the hypothesis:
The possibility that the model could be used to develop more efficient marine sampling designs is likely. Interpretation of the results of marine sampling virtually requires evaluation of distribution hypotheses. Interpreting the effects of changes in oceanographic conditions also requires a migration model.

Links to other hypotheses and life stages:
Models of salmon distribution in the marine environment are linked to all mortality hypotheses.

Consequences to Atlantic salmon if hypothesis is correct:
Inclusion of Atlantic salmon in harvest fishery rules, marine management areas or marine protected areas requires declaration of their temporal and spatial distribution.

Possible alternate methods:
Delineation of sensitive areas from chance, directed harvest and research catches.

Sources:
Dempson, J. B., D. G. Reddin, M. F. O'Connell, J. Helbig, C. E. Bourgeois, C. Mullins, T. R. Porter, G. Lilly, J. Carscadden, G. B. Stenson, and D. Kulka. 1998. Spatial and temporal variation in Atlantic salmon abundance in the Newfoundland-Labrador region with emphasis on factors that may have contributed to low returns in 1997. Canadian Stock Assess. Secretariat Res. Doc. 98/114, 161 p.

DFO Science Branch Maritimes and Gulf Regions. in prep. An examination of possible causes of the decline of Atlantic salmon in New England, Quebec, and the Maritime Provinces. Can. Tech. Rep. Fish. Aquat. Sci.

PROJECT NUMBER: 11-M

Factor: Marine Distribution

Title: Salmon distribution – coastal field studies

Hypothesis:
Same as project proposal 10-M

Background:
Marine migration routes are presumably adaptive, permitting smolts to meet their needs for food and predator avoidance while en route from home rivers to and from their principal oceanic feeding grounds. Past studies determined migration routes by tagging and recapturing fish. This work was conducted at a time when extensive commercial fisheries still existed, and there were reasonable expectations that sufficient numbers of tagged fish would be captured in the fisheries to document existing migration pathways.

Shifts in migration routes are presumably indicative of change in the marine environment. The fish should respond adaptively in order to best survive under the new environmental conditions. However, the new migration routes may force the fish into contact with new predators or to cross less productive areas than were previously used. This could decrease marine survival.

In coastal marine areas, projects would involve the *tracking* of salmon post-smolts as they leave the estuary and as they start to migrate toward open ocean areas; positioning of sensors to detect acoustic tags could be optimized at constricted points on the salmon's migration routes or at key geographic locations if routes are unknown. Also, recent developments and improvements in data storage tags (DSTs) would allow kelts to be tagged and recovered at some sites were smolts and adults are enumerated. The new generation of DSTs include measurements for temperature, depth and geolocation. Application of some radio tags would allow for predation to be detected and thus would link with predation field studies. Field trials currently being conducted in the Inner Bay of Fundy using pelagic trawls fishing on the surface, if successful, would allow for the direct capture of post-smolts in coastal areas. This project requires the collection of new data as previous salmon research has included little if any of these types of studies.

Research approach:
A knowledge of the present migration routes is necessary in order to help frame hypotheses about the mortality factors that any new migration route may be subjecting the smolts to. An approach to addressing this issue could be:

1. Data mining: A full understanding of past information on migration routes is required, if new patterns are to be documented. A reevaluation of the existing data needs to be done in order to assess its strengths and weaknesses. This should examine the similarities in migration routes among fish from different rivers and how the use of recaptures from commercial fisheries may have biased our understanding of past

routes. In addition, the data should be examined to see whether in the past there was any evidence for variability or shifts in the migration routes over time.

Available databases to examine hypotheses:
Because direct field studies have never been done before no databases are available to examine hypotheses. Projects would focus on new data collection and analysis.

Time frame for completion:
Six months from initiation of reevaluation. Should be finished within the next year.

2. Data updating: In the absence of commercial fisheries, new methods will have to be used in order to document present migration routes. These may be either direct (tracking of fish fitted with acoustical or data-storage tags (DST's), or indirect (Scale cesium contents, use of molecular biological techniques to document origins of fish caught at sea, scale patterns, etc.). At present, acoustical tracking is most feasible within confined spaces (Bay of Fundy, migration constrictions like the Straits of Belle Isles). DST's and the other methodologies may provide general indications of locations in the ocean, but may not provide precise enough positions to document migration route shifts. Certain techniques (Cesium analysis, river specific genetic origin) may take additional research development before they can provide reliable information.

Research approach:
Use acoustic receiver arrays to cover the exits from the Bay of Fundy, Cabot Strait, and Straits of Belle Isles to document the timing and origin of fish leaving respective home rivers. Couple this with experimental fishing transects during the migration period across putative migration routes, and leapfrogging of receiver arrays into promising areas. Collect and preserve samples from the fish caught for use in indirect evaluations of migration routes.

Time frame for completion:
Tracking and fishing work requires at least a one-year planning horizon in order to obtain equipment and/or work into the rotation for available ship time. Work could begin in the spring of 2001.

Resources required:
Material: Acoustic tags and tracking equipment: 1000 tags at 400$ each; 250 receivers at 1500$ each; mooring buoys and anchors for the 250 receivers at 150$ each; ship time for maintenance of arrays and downloading data: 1 day per week per array X 3 arrays X 12 weeks = 36 days; experimental fishing and leapfrogging of arrays into promising areas, 4 weeks of ship time per year; repeat field sampling for at least two years.
Personnel: Science and technical staff, including a project scientist and two technicians, full time, for 3 years

Likelihood that the program will test the hypotheses:
Data mining should provide useful information. Acoustic tracking should provide good information on timing and numbers of fish leaving through constricted areas. The other methodologies have promise, but the time frames for their development are uncertain.

Consequences to atlantic salmon if hypothesis is correct:
Will provide information that can help frame hypotheses for the causes of any observed migration shifts, and for reduced survival at sea.

Possibility of mitigation if hypothesis is correct:
None

Sources:
Dempson, J. B., D. G. Reddin, M. F. O'Connell, J. Helbig, C. E. Bourgeois, C. Mullins, T. R. Porter, G. Lilly, J. Carscadden, G. B. Stenson, and D. Kulka. 1998. Spatial and temporal variation in Atlantic salmon abundance in the Newfoundland-Labrador region with emphasis on factors that may have contributed to low returns in 1997. Canadian Stock Assess. Secretariat Res. Doc. 98/114, 161 p.

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Hvidsten, N.A., and P.I. Mokkelgjerd. 1987. Predation on salmon smolts, *Salmo salar* L., in the estuary of River Surna, Norway. J. Fish Biol. 30: 273-280.

Hvidsten, N.A., and R.A. Lund. 1988. Predation on hatchery-reared and wild smolts of Atlantic salmon, *Salmo salar* L., in the estuary of River Orkla, Norway. J. Fish Biol. 33: 121-126.

PROJECT NUMBER: 12A-M

Factor: Marine Distribution

Title: Salmon distribution – marine field studies

Hypothesis:
Same as project proposal 10-M

Background:
Clearly, the low returns to Atlantic North American rivers in recent years and an apparent lack of a causal explanation demonstrate the need for a better understanding of what is happening to Atlantic salmon in the sea. Much information has been published about the freshwater life of salmon but very little is known about life of salmon in the sea and most of what is known comes from studies related to commercial fisheries. What is known about the sea life of salmon in the Northwest Atlantic including migration patterns, food

resources, ocean distribution, and abundance of post-smolts, grilse, and multi-sea winter salmon has been summarized by Jensen and Lear (1980); Reddin (1985); Reddin and Shearer (1987); Reddin and Short (1991); Reddin and Friedland (1993); Friedland and Reddin (1993); Reddin and Friedland (1996). There are also several references to relationships between the environment and salmon abundance/distribution and climate change (Beamish and Bouillon 1993; Beamish et al. 1997; Narayanan et al. 1995).

The management of Atlantic salmon (*Salmo salar* L.) stocks and fisheries has the goal of achieving a suitable level of spawning escapement based on available freshwater parr-rearing habitat (Anon. 1991; Anon. 1997). In order for this approach to be successful, fisheries managers require forecasts of salmon abundance in advance of their return to fresh water. Accurate forecasts depend on knowledge of the mechanisms of salmon mortality at all stages in its life history but at sea mortality seems particularly important. Current forecasts of salmon for all North American salmon stocks producing two-sea winter (2SW) salmon are based on a relationship between the distribution in winter of sea surface water temperature in the Northwest Atlantic termed thermal habitat and the number of 2SW salmon. While the relationship between thermal habitat and salmon abundance has proven to be statistically robust, the underlying biological cause(s) of salmon mortalities and overall declining salmon abundance remains unknown (Friedland et al. 1993). These downturns in abundance have a number of possible causes including both biotic factors such as a reduction in the availability or abundance of food and an increase in the number of predators and abiotic ones such as climate. Climate change or climate variability could lead directly or indirectly to mortalities by reducing fitness or suitability to survive in a known environment.

In the Pacific, shifts in ocean climate have been detected on basin scale level (Beamish et al. 1997). In particular, it has been shown that Pacific salmon abundance trends were closely associated with changes in the climate-ocean environment and that these changes occurred throughout the distribution of Pacific salmon. Associated with these natural fluctuations is the concept of regimes and regime shifts, either towards higher productivity from low or the reverse (Beamish et al. 1997). For the Northwest Atlantic, there is evidence that a basin-scale shift in productivity may also have occurred for several species including Atlantic salmon. Basin-scale events may also be linked to downturns in salmon abundance in the North Atlantic similar to the Pacific through links to the North Atlantic Oscillation Index.

While we have concluded that the cause of the mortality lies in the ocean life of salmon, the actual cause of the mortality remains unknown. While tracking studies and data collection on ocean life using DSTs can help us understand more about salmon ocean life, the only method to learn more about the cause of mortality is through ship-board observations.

Research approach:
This approach would involve the use of *research vessel transects* in the ocean areas off the east and northeast coasts of Newfoundland and between Labrador and Greenland through the Labrador Sea. Coupled with the research cruises and tracking studies would be intensified oceanographic measurements where salmon are found and sighting and sampling surveys of potential predators. Stock identity determination will be done using results of new genetic studies.

A series of transects will be fished using surface set gillnets and trawls to catch post-smolt and other sea age salmon. Links to oceanographic conditions including fronts and major current systems can be made by collecting data during cruises compared to satellite SST data. Other studies can be conducted during cruises on diseases, numbers of fish farm escapees, presence and numbers of sea lice, predators and prey of salmon. By fishing midwater trawls available prey species for salmon can be determined compared to diet information in stomach contents. Origin of salmon will be estimated by river age and if possible DNA. Data storage tags can be applied to post-smolt and other sea age salmon to determine depth, water temperature and geoposition. Emerging technologies for tracking salmon at sea could also be used to determine behaviour along oceanographic fronts.

Available databases to examine hypotheses:
1. Results of marine cruises in 1970s and 1980s in Labrador Sea and Grand Banks.

2. Data on oceanographic conditions measured by research vessels during annual groundfish and other data collection cruises. Also, sea surface temperatures from NOAA polar orbiting satellites.

Time frame for completion:
A series of cruises conducted over a three-year period covering late summer/fall, winter and spring seasons of the year.

Resources required:
Total: 60 days of sea time per year
Materials: research trawl used by Marine Institute in Bergen, Norway and oceanographic equipment carried as standard gear on research vessels. Gillnets for occupying standard stations as fished in previous years. Access to satellite SST data and information on phytoplankton and zooplankton abundance collected by the Sir Allistair Hardy Institute, Plymouth, England. Approximately, $100,000 per year for the purchase of DSTs and acoustic tagging equipment if required.
Personnel: requires 1 PY for data collection, entry and analysis

Likelihood that the proposed program will test the hypothesis:
Goal of the proposed program is to collect baseline biological data on origin, distribution and abundance of salmon in the area from Labrador to the Atlantic coast of Nova Scotia. Throughout the program testable hypotheses may emerge on prey, predation, and

relationships to oceanographic conditions that can be tested. At the present time, the goal of the research program is to collect baseline data that is currently lacking on salmon life history in the sea.

Links to other hypotheses and life stages:
Various hypotheses related to predation, UV impairment of phyto and zooplankton production, and transfer of diseases to wild salmon from farm escapees.

Sources:

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PROJECT NUMBER: 12B-M and 13-M

Factor: Predation

Titles: Gannets as predators (*predation by gannets and indicators of ecosystem changes*)
Marine mammal predation (*marine mammal observations and biological sampling*)

Hypothesis:
Predation by gannets and marine mammals reduces marine survival of post-smolts and adult salmon.

Background:
The main potential avian predators in the marine environment are gannets, murres, kittiwakes, shearwater, gulls, and fulmars. Among marine mammals, potential predators include harp, harbour, and hooded seals and cetaceans, particularly toothed whales.

Seals and seabirds are, for the most part, opportunistic predators which take any prey within a given size range. Seals can take salmon of any size range, although it is unclear whether the large size of adult salmon reduces their vulnerability to seal predation. Seabirds take only post-smolt salmon, but the number of seabird species capable of harvesting post-smolts declines as the fish grow in their post-smolt year.

In general salmon appear only in trace amounts in the diets of seabirds and seals in the Northwest Atlantic. An exception is the northern gannet, a large plunge-diving seabird which breeds in eastern Newfoundland and in the Gulf of St. Lawerence. Because of their specialized feeding habits, salmon appear to be more vulnerable to gannets that to any other seabird or seal. Predation by birds and seals is likely density independent since salmon are rare in the sea and constitute only a minute fraction of finfish biomass in the Northwest Atlantic.

Research approach:
Monitoring gannet colonies:
Five colonies will be monitored monthly from June–September to document the contribution of post-smolts to the diet of gannets. The incidence pattern of smolts in the diet will be used to document timing of migrations. Scale analyses will also be conducted to determine the river age. Total current consumption of post-smolt salmon could be estimated via bioenergetic models, using dietary data with full spatial and temporal coverage of North American gannetries. Post-smolt sampling at gannet colonies will also increase knowledge of post-smolt migration timing and routes, at a cost that is much lower than directed research cruises.

Marine mammal observations:
Dedicated research cruises for marine salmonid research will include a systematic sighting program to document the distribution and relative abundance of marine mammals (seals and cetaceans). A marine mammal sampling program will be conducted to collect diet information throughout the duration of the project.

Available databases to examine hypotheses:
A considerable amount of salmon predation research has been completed at the Funk Island colony in Newfoundland. Very few observations have been made at any of the other colonies although there are unconfirmed reports of salmon tags being found at the Bonaventure colony in the Gulf of St. Lawerence. Information collected during this project would represent a significant temporal and spatial dimension to our existing database.

There is a large database and time series of diet information for harp seals (and to a lesser extent, hooded seals) in the Northwest Atlantic. However, most of the stomach samples for both species of seals were obtained from coastal waters. Relatively little is known about the diets of any seal species in off-shore areas, thus any new information would significantly contribute to the existing database and knowledge of any recent shifts in diets.

Time frame for completion:
Significant new data and contribution to existing knowledge could be made in three years.

Resources required:
Gannet project:
$50K/year for each of three years. Major costs are for travel to colonies and analysis time.

Marine mammal project:
$50K/year for each of three years. Most work would be in conjunction with other projects; e.g. a marine mammal observer would board salmon research cruises. Most of the remaining cost would be for analysis of historical and new data.

Likelihood that the proposed program will test the hypotheses:
Gannet predation: The relationship between gannets and the salmon decline cannot be directly evaluated because the diet of gannets has been continuously measured over the past 20 years at only one colony. However if gannets currently take a significant proportion of North American post-smolts, the hypothesis would become more plausible.

Marine mammals: For seals and cetaceans there is no direct test immediately available. The logistics of quantifying the impact of salmon predation when it is such a minor component of seal and cetacean diets are impossible to address with existing analysis techniques. The best short-term approaches may involve improvement of current diet studies, so that evidence of salmon predation is not overlooked and new research directions can be developed.

Consequences to atlantic salmon if hypothesis is correct:
Salmon returns will continue to decline if predator population remain at present levels or continue to rise.

Possible mitigation if hypothesis is correct:
Predation pressure could be reduced by increasing harvests of seals.
Reduction of gannets, while feasible, would elicit strong public opposition.

Sources:

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