



**A Proposal for an International Salmon Research Program Using Archival
Tags**

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Executive Summary

INPATE (the International North Pacific Archival Tag Evaluation Working Group) has evaluated the potential accuracy of archival (data storage) tags for estimating the daily position of tagged free-ranging animals such as salmon. We have also developed new algorithms to improve the accuracy of the tags. The archival tags we have tested are sufficiently accurate to justify an international effort to mount a cooperative high seas salmon tagging program. This working paper summarizes the results of our investigations, our current efforts to evaluate the best tag attachment methodology, and some of the issues that an archival tag research program on Pacific salmon can address.

We are proposing that NPAFC now strike a formal working group charged with planning a large scale field program to use these archival tags. A tentative budget to cover the cost of travel for the working group members and some of the remaining developmental costs is also included for discussion (*Appendix A*).

We propose that the NPAFC cover the initial costs of operating funds (including a small scale field program) for the working group out of existing financial resources, while the working group coordinates with each government and develops the specifications for a full scientific program. The initial tasks for the working group will be to:

- 1. Determine the primary scientific objectives to be addressed by the program;*
- 2. Identify the species to be tagged and the tagging locations;*
- 3. Develop a full budget including an estimate of the number of tags required;*
- 4. Establish a timetable;*
- 5. Obtain agreement for the full field program from the member governments; and*
- 6. Identify funding for the purchase of archival tags and ship time.*

1. Evaluation of Archival Tag Accuracy

Archival tags are capable of measuring and internally recording a wide range of environmental variables. Commercially available archival tags currently have a memory capacity of one megabyte, sufficient for continuous recording of environmental variables for 6-18 months at sea, depending upon the sampling frequency chosen. The Flash RAM used in the tags is capable of retaining the data for periods of >20 yrs.

The current generation of archival tags measures and records temperature, depth, and light level at programmable intervals. The light record is of particular interest because it is possible to calculate the position of a tagged animal every 12 hours using the data collected while the animal is at sea.

We have conducted several experimental trials to determine the accuracy of the tags for estimating geoposition, and the best algorithms for doing so.

Our results to date indicate that the archival tags are capable of estimating the daily position of a tagged animal to an average accuracy of approximately 150 kms based on the light record (Table 1; Figure 1). There are indications that appropriately placing “reference tags” at fixed locations in the ocean during a study on free ranging salmon might enable us to reduce the positional error to at least half its current value. A test of this possibility has yet to be implemented, but would be an important aspect of the field program.

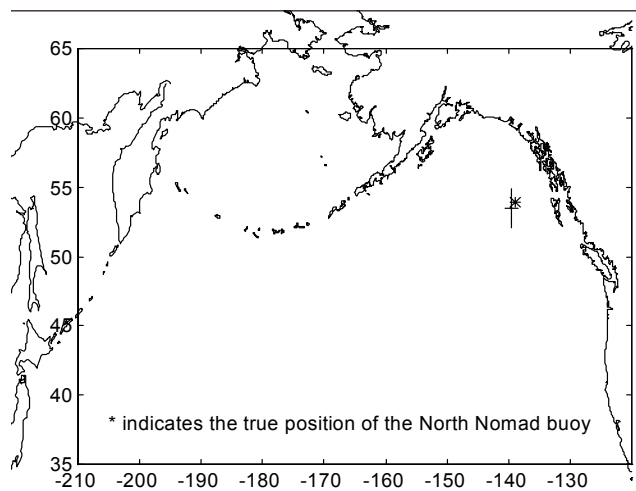


Figure 1. Comparison of the actual (*) and the estimated (+) position of an archival tag, based on the light measured and stored internally. The horizontal and vertical bars indicate ± 1 SD on the mean for the full length of the experiment (N=70 days). All tags from the same company gave similar estimates of position.

Table 1. Summary of best estimates of geoposition obtained to date from the archival tags. The best methodology for estimating geoposition is “DF”, which stands for filtering of the data and then differencing, a method we have developed. A method suggested in the literature (Hill 1994) for estimating geoposition from light data is to define the times that dawn and dusk occur as when light levels reach 5% of their daytime maximum (5F). This method provided inferior results in this experiment.

	DF	5F
a) Average Positional Error (kms)	159 kms	470 kms
b) SD Latitude	1.4°	3.9°
c) SD Longitude	1.0°	5.4°

2. Tag Attachment Methodologies

The methodology for attaching archival tags to free ranging salmon is critical to the success of a tagging program because tags must remain on the animal for many months at sea. We are currently evaluating tag attachment methodologies at the Pacific Biological Station in Nanaimo using 160 immature Atlantic salmon (ca. 40 cm T.L.). “Dummy” tags the size, shape, and weight of archival tags have been provided by the tag manufacturers. We will be evaluating the relative performance over time of tags either surgically implanted into the abdominal cavity or externally attached to the side of the animal. Rates of mortality and tag retention will be assessed relative to control animals held in the same tank using groups of 20 animals per tag type and attachment methodology.

The results from these experiments should be completed and reported in time for the Fall 1998 NPAFC meeting. Estimates of tag retention rates and mortality are necessary in order to assess probable rates of tag return for an individual tag, and will have a direct bearing on the number of tags that must be applied in a field program in order to ensure a reasonable probability of recovery of tagged animals at the end of their migration.

3. Scientific Issues for an Archival Tagging Program

An enormous quantity of information was generated through INPFC tagging programs in the 1950s and 1960s. This research demonstrated the remarkable extent of the distribution of Pacific salmon in the North Pacific Ocean, and that, for example, two sockeye tagged at the same location in the ocean would subsequently return to very distant river systems. In large part, our concept of the ocean migration and distribution of Pacific salmon was determined by these tags (Neave 1964; Royce *et al* 1968).

There are, however, significant limitations to our knowledge from “traditional” tagging programs. The primary difficulty is that only the release and recovery positions are known, and there is no direct evidence for how the fish moved between these points. Lacking detailed information of how salmon migrate in the sea, and what behavioural cues they respond to (e.g. their response to temperature or the direction and intensity of ocean currents), it has proven very difficult to establish where the fish are migrating from on their inshore spawning migrations. We provide three examples of still unresolved questions that an archival tagging program can resolve.

Example I

Issues concerning the interception of salmon by different countries are based on estimates of the proportional contribution of different stocks to each fishery. In large part, these estimates lack any mechanistic understanding of how (or why) the stocks move past different areas of the coast, or how oceanographic features such as currents or surface temperatures affect their migration paths.

As one specific example, the path migrating Fraser sockeye take around Vancouver Island is correlated with ocean temperature (Fig. 2). However, it is entirely unclear whether sockeye are

responding to temperatures while still far offshore, or only much closer in to the coastal zone. (Temperatures in both regions are highly correlated).

The migration route could be determined either in the offshore or coastal region. However, unless maturing salmon are tagged well offshore and their migration paths established for the several months prior to return it is impossible to establish which mechanism is correct. If, for example, migrating sockeye were tagged near or to the north of the Queen Charlotte Islands (52°N, 134°W; an experiment using conventional salmon tags that has previously been advocated), then only the component of the migrating sockeye moving along the continental shelf could be assessed. Any component of the migration moving directly towards Vancouver

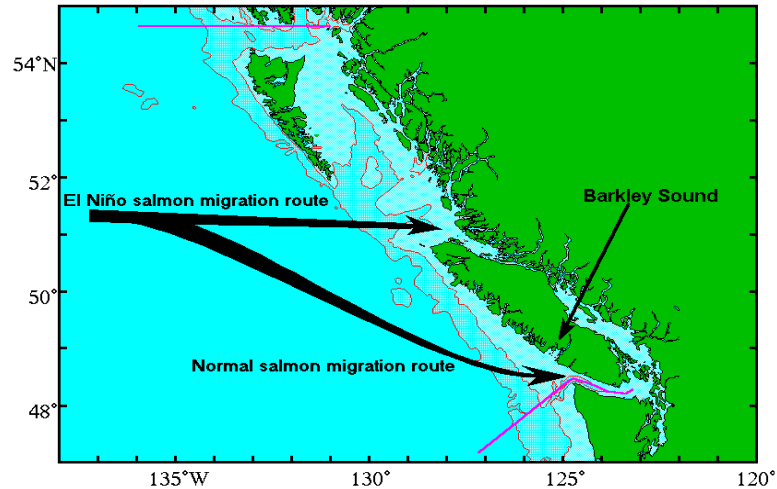


Figure 2. One possible migration assumption for how the northern diversion rate around Vancouver Island is determined. This diagram assumes that the sockeye diversion rate is determined offshore and is dependent on the latitude of landfall. In warm (El Niño) years landfall occurs farther north because offshore isotherms are displaced to the north. An equally plausible scenario is that the diversion rate is determined as the sockeye migrate south along the continental shelf, and the diversion rate is determined at the north end of the island, in coastal waters. Discrimination between these two possibilities, plus the actual response to temperature, requires determining the actual migration path.

Island from the west would not be identified in a coastal study, and the mechanism determining the diversion rate would not be established.

A similar issue exists off Japan, where Ueno (1992) has shown that at least a component of the chum returning to Japan undertake very deep water migrations (to 600m), apparently in an attempt to avoid the warm surface waters of the Kuroshio. In both the chum and sockeye cases, a critical aspect of understanding these homeward migrations is to understand the response to temperature and how salmon may move below the surface mixed layer to avoid high surface layer temperatures (see below for an additional example).

Example II

The migration of North American salmon has been described as a series of counterclockwise loops, either in the Gulf of Alaska for Canadian sockeye (Brett 1986; Furnell and Brett 1986), or in the central North Pacific Ocean for Alaskan stocks (Neave 1964; Royce *et al* 1968). Because salmon from widely varying areas of the North Pacific and Bering Sea can return to Bristol Bay at essentially the same time, it has been suggested that Pacific salmon must

be able to navigate based on an internal “map and compass”—that is, they must know both their current location and their ultimate destination (Groot and Quinn 1987; Quinn 1990; Quinn and Groot 1984; Quinn et al 1989). The migration paths of Asian salmon are less well known, but the results of a field study would provide an interesting contrast to the information obtained on North American salmon.

The best models of the surface circulation in the subarctic North Pacific have a resolution on the order of 100kms (LeBlond and Endoh 1996), very similar to the current accuracy of the archival tags that we have evaluated. A field study using archival tags would allow us to identify the migration path through the ocean, and by using numerical models of open ocean currents, remove the effect of surface currents on the observed movement of Pacific salmon and establish their actual heading and migration speeds.

Example III

Our third example of issues that can be addressed using archival tags involves the long-term response of Pacific salmon to global warming (Welch *et al* 1998*a,b*). Current projections of the amount of global warming place the isotherms defining the upper (southern) thermal limit on the distribution of most species of Pacific salmon well up in the Bering Sea if the amount of CO₂ in the atmosphere doubles. At current rates of emissions, these CO₂ levels could be reached within 50 yrs.

If the thermal limits are correct and the global warming projections are accurate, most species of Pacific salmon could be lost from the North Pacific Ocean in the next century (Fig. 3). Greenhouse gas models show a rapid increase in high latitude temperatures relative to baseline models beginning in the 1990s. The sharp declines in Bristol Bay sockeye in 1997, a year of record high ocean temperatures, are an example of why the effects of high temperatures in the ocean on Pacific salmon need to be established.

The most recently developed General Climate Models (GCMs) are by the United Kingdom’s Meteorological Office and the Max Planck Institute in Germany. These models have been developed in part to address scientific deficiencies in the previous models used in the IPCC (1992) report.

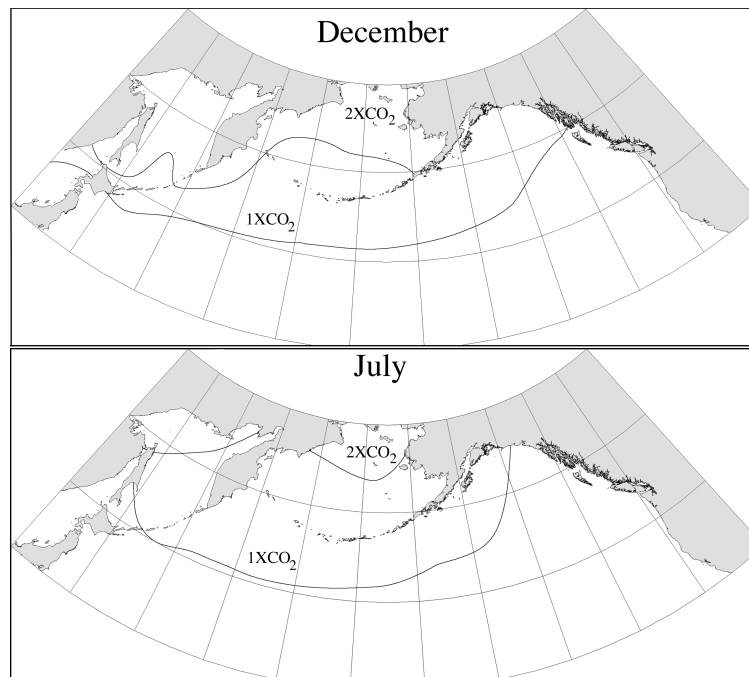


Figure 3. Comparison of the predicted winter (7 °C) and summer (12 °C) positions of the sockeye distribution under current and future climates (Albers equal area projection). Similar results hold for most species of other species of Pacific salmon. Under a doubling of atmospheric CO₂ most species of salmon could be excluded from the North Pacific Ocean.

Although substantially more sophisticated than the models used in the IPCC report of 5 years ago, these new models still indicate similar levels of warming for the North Pacific Ocean, and therefore similar future limitations on the ocean distribution of Pacific salmon (Fig. 4). The major source of uncertainty on the effect of global warming on Pacific salmon in the ocean is therefore the *biological reasons* for the existence of these thermal limits, not where current scientific efforts would place these limits.

The biological reasons for the sharp thermal limits for salmon are still unclear. They may indicate a biological compensation point—south of these limits salmon may be unable to gain sufficient energy from feeding to compensate for the added metabolic costs of higher temperatures. If true, then the thermal limits define the regions of the ocean where salmon can successfully grow. However, although there is currently only limited evidence for vertical migration of Pacific salmon in the ocean except under unusual circumstances, salmon might be able to compensate for warming of the surface mixed layer by spending significant periods of time at depth.

Again, a direct test of the hypothesis that salmon show sharp thermal limits is to follow the movement of salmon in the ocean, and show that they either avoid crossing the isotherms defining these thermal limits or begin to vertically migrate to maintain a lower average body temperature than would be possible by remaining solely in the surface mixed layer. The identification of *why* salmon apparently show such sharp avoidance behaviour to temperature is clearly an important issue that needs to be carefully validated, given the drastic loss of thermal habitat projected to arise from increases in greenhouse gas levels in the next few decades.

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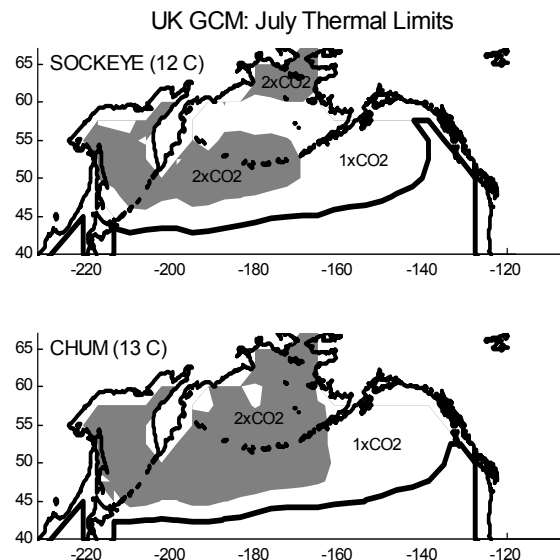


Figure 4. Recent work with the new generation of GCMs from the United Kingdom and Max Planck (Germany) lead to the same general projections as the IPCC (1992) scenarios used in creating the sockeye map in the previous figure. The GCMs indicate that a drastic decrease in the thermal habitat available to salmon in the North Pacific is possible.

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Appendix A. NPAFC Draft Budget Proposal for High Seas Archival Tagging Working Group (Year 1 Costs; All values calculated in Canadian Dollars).

Budget Item	Cost (\$Cdn)
Deployment of archival tags at Stn P and special purpose moorings; cost of consumables (batteries, acoustic releases, mounting gear).	\$5,000
Purchase of Archival Tags (15 tags @ \$1,600/tag)	\$24,000
Travel for WG members to planning meetings (least cost location)	\$10,000
Development of tagging tables and equipment, purchase of surgical instruments, and anaesthetic setup (two sets)	\$2,000
Travel to attend WG meetings for other archival tag Working Groups (Atlantic salmon or Bluefin Tuna)	\$2,000
Purchase of longline gear for tagging salmon at sea	\$2,000
Labour for assistance with tagging experiments and data evaluation	\$10,000
TOTAL PROJECTED COSTS:	\$55,000