Applications of the Pacific Ocean Shelf Tracking System (POST): A Permanent Continental-Scale Acoustic Tracking Array for Fisheries Research & Ocean Observation

David W. Welch
Chief Architect, Project POST, Kintama Research Corporation
4737 Vista View Crescent, Nanaimo, BC Canada V9V 1N8
Isabelle Gaboury
Kintama Research Corporation, 4737 Vista View Crescent, Nanaimo, BC Canada V9V 1N8
Michael C. Melnychuk
Fisheries Centre, 2202 Main Mall, University of British Columbia
Vancouver, BC Canada V6T 1Z4
Ron O’Dor
Census of Marine Life, Consortium for Oceanographic Research and Education,
Suite 420, 1201 New York Ave. NW, Washington, DC 20005 USA

Abstract- The Pacific Ocean Shelf Tracking (POST) array was initially conceived and planned as a single continental scale acoustic tracking system for direct measurement of the marine movements and survival of animals in the ocean. With the success of the demonstration phase, POST is now transitioning into a single integrated global system of compatible arrays distributed throughout the continental shelves of all continents. Field trials in 2004 and 2005 involved the deployment of 6 major listening lines, each about 20 km long, laid out to track the migration and survival of salmon smolts along >1,200 kms of the west coast of North America. Detection rates of individual 12-16 cm long salmon smolts was >90% for a single acoustic listening line. Precise measurements of migration timing, travel speeds and survival were obtained for the freshwater and early marine phases of various salmon stocks. The results demonstrate that it is possible to measure survival and movement directly in the ocean, and that the technology can be applied to a wide range of fish species. Although a key component of the array is the ability to provide a nearly complete census of the movements and survival of marine fish such as salmon, the array concept has much broader utility and can host a wide range of other ocean sensors. Such a system would yield revolutionary advances in our ability to study the oceans. Our current efforts on the Pacific coast involve developing a permanent year-round array whose operation is less labour-intensive, more reliable, and provides this wider range of ocean observations at lower per unit cost, which will allow the deployment of a much more extensive array.

I. INTRODUCTION

The oceans are largely opaque to man, making the study of their vast fisheries resources fraught with difficulties. To a large extent, our knowledge of fish stocks is based on the use of primitive tools (nets and hooks) that have changed little in thousands of years. The limitations of these tools mean that the scientific stock assessments that underlie fisheries management invariably must make assumptions about the basic biology of the fish. These assumptions are frequently little better than guess work, and are often made more for the simplicity they bring to computer models than because of their potential realism. However, these assumptions critically affect the interpretation of data from fish caught at sea. For example, the animals may be assumed to not make significant migrations between study regions, or to not show population specific behaviours that violate the assumption that all stocks of a given species are distributed similarly in the ocean. Failure of the fish to match these simplifying assumptions means that the scientific advice on which management decisions are made may be very misleading. Fishermen, whose livelihoods depend on the conclusions from these assessments, are often critical of modeling efforts because their experience gives them a deep appreciation for the complexity of fish movements, which they may feel is not reflected in the simplified models. However, this lore from the “school of hard knocks” is very difficult to incorporate in scientific assessments, and frequently sets the scene for unresolvable differences of opinion.

The Pacific Ocean Shelf Tracking project (POST) is intended to establish a permanent telemetry system to allow researchers an unprecedented ability to study the ocean biology of animals directly in the sea. The permanent system envisaged can also host sensors for long-term monitoring of...
physical ocean conditions. Its goals are simple but very ambitious: to develop a large-scale array for the continental shelf and slope regions of the world’s oceans, and to increase the amounts of information collected in these regions by many orders of magnitude over current levels.

Development of the POST array

In 2004 and 2005 we deployed a short-term array to demonstrate the feasibility of the concept and the potential value of the collected data. The overall array was made up of a series of listening lines, or “acoustic curtains”, each composed of a linear sub-array of independent nodes (Fig. 1). VEMCO VR-2 acoustic receivers were mounted on the hardware deployed on the seabed in a specific geometry to optimize the tracking of acoustically tagged fish. The final array geometry selected for use in the demonstration phase and the programming of the tags and equipment was based on a substantial body of experiments at sea and in rivers over several years starting in 2001. The results from these extensive field trials were used as the input for a formal optimization analysis to develop a strategy for the array design that balanced economic costs and high technical performance. Some of the simpler design considerations were sketched out in [1] Welch et al 2003. Parallel studies to develop a highly proficient surgical protocol and to establish a minimum size threshold for implanting tags in salmon smolts were also undertaken [2].

During this phase, the array was focused on demonstrating an ability to obtain a nearly complete census of migrating salmon smolts over several months or years at sea. Salmon were chosen as the primary target species group because of the public interest and value of the west coast salmon stocks. (The small size of the out-migrating smolts also meant that we were “pushing the envelope” on the surgical front as well as the many facets of developing the array technology).

The five main goals during this phase were to demonstrate: (1) the feasibility of building a continental-scale tracking array, (2) that the information is worth the effort, (3) that the array can operate in an economical fashion, (4) that our belief that survival over time can be measured directly in the sea is correct, and (5) That the theoretical prediction of array performance under the geometry and programming used was close to that actually observed.

POST operates in three parallel tracks. The POST Secretariat, hosted at the Vancouver Aquarium, is responsible for the education and outreach components, facilitating a better understanding of the fish tracking data by the public and scientific communities, and to act as a discussion forum for scientists interested in learning about the array. The operational side is the responsibility of Kintama Research., and involves designing, operating, and maintaining the physical array on the seabed (including securing permits for its emplacement), and surgically implanting the thousands of fish used on the system.

The basic VR-2 fish tracking receiver used in POST’s 2004-05 demonstration phase is a mature and stable instrument that will be the key sensor of the seabed array. It has a waterproof pressure casing housing the electronics (500m depth rating) and a low-power CPU and port for serial connections. Each receiver, running on lithium batteries, logs the date and time whenever a tag is detected in the vicinity of the receiver, alongside the unique ID transmitted by the tag. The acoustic tags (Vemco V9-6L) implanted in the abdomen of the individual salmon smolts are very long-lived (mean time to tag failure of 1-3 yrs, depending on tag type) by virtue of their low acoustic power and programmed transmission schedule. Each tag transmits at 69 kHz a unique acoustic pulse train that encodes both the tag serial number and checksum. The VR-2 receivers detect these transmissions, decode them, validate the checksum information, and then log the data and time of each tag’s detection to non-volatile memory if it passes the checksum test. If the transmission fails to pass this test it is not logged to memory but a false detection counter is incremented. The interaction of the array geometry and the tag programming partly comes in designing the longest lived tag possible (by reducing the frequency of tag transmission) while choosing an array geometry that maximizes the probability of detecting some of the transmissions. Constraints come in because of the need to economize both on the capital cost of the array (and its maintenance) and by minimizing the number of acoustic tags used while still ensuring high statistical reliability in the interpretation of the results.

![POST Array, 2006](image_url)
By physically recovering the array to the surface and downloading the data from the receiver, it would thus be possible to establish the movements and survival of each population across the array—assuming sufficient equipment was recovered and the array design and programming worked as predicted.

In 2006, POST moved to the deployment of a permanent array where the same fish detection data can be remotely uploaded to the surface via a wireless acoustic modem. This technology was tested in conjunction with the manufacturer, Vemco, in a series of experiments in 2004-05 operating in parallel to the operational array. The development of such an approach has the twin advantages that the most difficult aspect of the work—physically recovering the equipment to the boat from hundreds of meters down—is eliminated, while keeping the equipment on the bottom in deep water regions means that the rate of biological fouling is very slow (and the fouling is largely acoustically transparent). Because of the low power consumption of modern electronics, the projected lifespan of these bottom units is on the order of 6 to 7 years, and could be easily extended if loss rates from other causes (trawlers, electronic failures) are sufficiently low.

Further development of these nodes could make them capable of hosting a wide range of other instruments and long-term deployment on the seabed. Specifications for the POST receiver units that will be deployed in the future array require that they will be long-lived (5-10 year), permanent seabed units communicating data to the surface using an acoustic modem. These units will probably have a relatively low bandwidth (maximum speeds ≤38 Kb), low current drain, and low unit costs. Although power and bandwidth will be limited, they will be capable of very wide distribution over the continental shelf at relatively low cost.

Tracking along the continental shelf on the Pacific coast of North America

Off the west coast of North and South America, the shelf is frequently only 15-30 km wide. As one of the narrowest continental margins in the world, it is relatively simple to monitor the movements of animals remaining in the shelf or slope water regions using acoustic telemetry. Partly for this reason, POST is focusing on shelf tracking along the Pacific coast of North America. The migratory movements of all species of juvenile Pacific salmon (possibly excluding steelhead) are confined to the shelf-slope regions for many months, although some stocks eventually migrate to the open ocean after reaching the Aleutians, while other stocks appear to take up permanent residence on the shelf (Hart and Dell, 1986; Welch et al, in prep). After the first year of life in the ocean, some species of Pacific salmon (sockeye, pink, chum, steelhead) inhabit offshore, pelagic waters, while others (coho, chinook) appear to have both shelf-resident and off-shore variants (Groot and Margolis, 1991). The tracking array offers the opportunity to follow tagged fish and make major breakthroughs in understanding how salmon use the ocean. A permanent coastal tracking system which can gather positional information year round for many years would revolutionize the management of these species, many of whose abundances are in serious decline as a result of poor ocean survival. However, when and where in the marine phase of the life history this elevated mortality occurs is still a mystery. Coupling fish tracking data with long-term monitoring of the physical changes in ocean conditions would make the system an even more powerful science tool.

Test array for fish tracking

A test array centered around southern British Columbia was deployed in 2004 and 2005 to determine how effectively it could monitor the movements and fate of tagged salmon smolts entering the ocean. During 2004, most lines were about 20 km long with receivers sited on the seabed in depths of up to 280 m. Receiver units were also placed at river mouths where tagged fish would be entering the ocean in order to separately establish survival in the ocean and freshwater. The test array was physically recovered twice over a five month (April-September) deployment to download data and test array efficiency in 2004, and once (September-October) in 2005.

Tagging of salmon smolts

A total of 1,051 salmon smolts were tagged by Kintama in 2004, increasing to 1,600 in 2005 and slightly over 2,000 in 2006. (By 2006, total POST-coded tag sales by Vemco exceed 3,600, indicating the start of significant scientific buy-in by the research community). To tag the fish, each wild animal was captured during its migration down a river system to the sea, anesthetized, and then an acoustic tag surgically implanted into the body cavity, where it became a permanent implant. Hatchery-reared smolts were treated similarly, and all smolts were held until dusk of the day following surgery before being released, in order to allow full recovery from the anaesthetic. Overall, mortality to 24 hours post surgery was 3% in 2004, 2% 2005, and 0.6% in 2006, very low in comparison with most tagging programs.

II. Results

A key performance criterion for the array is the probability of detecting a tagged animal moving over each acoustic listening line. We calculated the average detection efficiency in 2004 and 2005 at a given listening line as (# of fish detected both on the line and downstream)/(total # of fish detected downstream), as this formula is not affected by mortality or residualization of tagged fish, between the two lines under consideration. The average detection rate for any given ocean listening line was 93\%±4\% (95\% CI) in both 2004 and 2005. Detection rates in 2005 were expected to have been nearly 100\% following some technical modifications to the array geometry in that year, but appear to have been reduced
because of the accidental recovery by a fisherman of two listening nodes on one line at the time when some stocks were migrating over it. In any event, as detection probabilities are high, survival at sea can be measured with relatively high precision. Speed of travel was also calculated for individual fish in each segment of their early ocean migration.

Detailed analyses of movement and survival data from the different stocks and species is beyond the scope of this paper. However, clear migratory patterns emerged for different salmon stocks. For example, most sockeye and steelhead from Strait of Georgia populations took the northern exit route through Queen Charlotte Strait rather than the southern route through the Strait of Juan de Fuca, while coho salmon stalled their migration after reaching the sea and did not leave the Strait of Georgia ecosystem. Striking differences were also observed in the distribution of some stocks of a given species over the listening lines, demonstrating that fine-scale differences in migration patterns between populations of the same species could be resolved.

An unexpected surprise occurred when substantial fractions of green sturgeon originally tagged in the Klamath and Rogue Rivers in California by other scientists were detected on POST’s outer shelf lines at Brooks Peninsula and Cape Elisabeth lines. Up to 50% of the animals originally tagged in northern California or southern Oregon rivers were detected by the array, and demonstrated both areas of prolonged residence (Brooks Peninsula) and transient presence (Cape Elisabeth). Very few were detected on the Strait of Juan de Fuca line and none on the northern Strait of Georgia line, demonstrating that this species as well had a preferred migration route. In some cases the animals also demonstrated a surprising capacity for rapid movement, with one sturgeon covering the 480 km distance from Brooks Peninsula to Cape Elisabeth in just 4 days.

Although the general performance of the array in 2004 in southern regions was very high, no detections of tagged fish were recorded on the southeast Alaskan line in 2004. This line was extended only half-way across the shelf in 2004 for logistical reasons. In 2005 additional equipment was moved to SE Alaska to extend the line across the shelf, and it was deployed for one full year, from June 2005 to June 2006. Only one POST-coded salmon smolt (a coho smolt from the West Coast of Vancouver Island) was detected moving over this line in 2005; in addition, two green sturgeon were recorded moving over the line in the winter and spring of 2006. (Both of these green sturgeon made round-trips over the SE Alaska listening line, with the two periods of detection of each fish separated by several weeks in one case and nearly six months in the other case). The failure to detect any tagged salmon smolts (or green sturgeon) almost 1,000 kms away from the rest of the array illustrates an important performance goal that needs to be kept in mind in future. Because the 2004 line only partially covered the width of the shelf, it was unclear whether the tagged smolts (or their batteries) failed to survive to this location, whether the fish slowed (or stalled) their migration before reaching the line, or whether they simply bypassed the listening line farther offshore. These multiple ambiguities gave us little guidance as to how to modify the array in such circumstances, and emphasize the importance of designing the array deployments to minimize ambiguities. The extension of the Alaskan line fully across the shelf in 2005 allowed us to clarify whether or not the POST tagged salmon smolts were reaching this line, and allows us to sharpen the scientific focus of future work as a result—but such results are only possible because we had ensured complete coverage of the shelf; the use of only a partial line (similar to that used in 2004) would have left significant unresolvable ambiguities.

**III. Future Developments**

With the increase in interest in using the POST array to answer fisheries management questions [3, 4, 5, 6], a wider range of fisheries agencies have begun to develop an interest in the types of data that POST can provide, and discussions have started on new and innovative ways to use the data. POST is thus beginning to prove its merits as a revolutionary fisheries tool. Thanks both to continued support from its long-time relationship with the Census of Marine Life and to growing interest from several funding agencies, POST is now in the process of “going global”, with interest expressed from all 7 continents in deploying POST-compatible listening lines.

As lithium chemistry is stable and has high energy density, usable lifetimes for the bottom nodes of over a decade are potentially possible. A most important addition to the POST array infrastructure will be the completion of design work to allow each of these fixed listening stations to also host a number of additional oceanographic sensors. Candidate sensors (in addition to the fish tracking sensors) would include the temperature-salinity module used in ARGO CTD floats. The addition of an upward looking ADCP, although more power hungry, would result in a complete seabed grid of water properties, describing how temperature, salinity, and bottom current speed and direction change over time as well as, perhaps, an index of zooplankton abundance from the intensity of the acoustic backscatter. This additional oceanographic information can be collected simultaneously with fish detection data, turning POST into a truly global ocean observation system for shelf-slope systems with revolutionary potential.
IV. CONCLUSIONS

In summary, POST has demonstrated that a large-scale system to track fish in the ocean is feasible. Equally important, the fates of multiple fish stocks (migration routes and speed of movement, plus survival) were simultaneously accounted for during their downstream and early ocean migrations, demonstrating that the system can be made economical because of its ability to support many studies at once. Having demonstrated the technical feasibility and biological importance of the data collected, POST’s near-term goals are to deploy units that can permanently stay on the seafloor for long-term monitoring along the continental-shelf and to increase the scientific understanding and need for the information that we will be collecting.

ACKNOWLEDGMENT

Many people have contributed to the development of the POST array technology, too many to individually acknowledge by name. We would like to particularly thank the many dedicated commercial fishermen who contributed their advice and boat handling skills to the critical aspect of allowing us to deploy and recover the acoustic array in its early stages. We learned a great deal from their practical knowledge! The Vancouver Aquarium has enthusiastically hosted the POST Secretariat and has played a key role in developing the education and outreach components of POST.

REFERENCES