“New maritime technologies: challenges and opportunities”

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In 2018-2022, the North Pacific Anadromous Fish Commission implemented the International Year of the Salmon (IYS) program to support the resilience of both salmon and the people who depend on them. The IYS had a number of research themes and initiated a series of signature projects including large-scale integrated marine expeditions that made noteworthy progress towards the outcomes. Expeditionary research program was enhanced by novel approaches and technology, some of them for the first time in a practice of marine expeditions. In October 2022, the IYS Synthesis Symposium summarized the program outcomes and reviewed perspectives with the goal of developing a Roadmap for the resilience of salmon and people through to 2030.

The level of effort required to monitor the entire North Pacific Ocean basin across four seasons is certainly beyond the capacity of existing research fleets and current monitoring approaches. Francisco Chavez, the Chief Scientist for the Monterey Bay Aquarium Research Institute (MBARI) eloquently notes that we need to “*greatly increase our ability to observe and quantify how and why life in the sea is changing*.” He argues that there are no systematic global efforts to observe life in the ocean because of a lack of scalable methods.

NPAFC scientists have widely applied innovative technologies in order to understand the state of the ocean and to refine the parameters of ocean ecosystem models over time. Fortunately, we are at a time of rapid technological change when the application of evolving remote sensing and emerging uncrewed technologies may provide a cost-effective solution. Modern technologies including but not limited to gliders, drones, buoys, satellites, fish tags, eDNA, and data systems could substantially supplement existing monitoring methods. The list of ocean parameters that can be monitored without immediate human involvement includes temperature, salinity, chemical composition, light, turbidity, chlorophyll fluorescence, dissolved organic matter concentration, eDNA and others. Platforms that can carry correspondent sensors are becoming increasingly capable. Uncrewed surface vessels (USVs) are ready to join the Global Ocean Observatory System. USVs have operated in hurricane strength winds, all latitudes, in strong currents, in high waves, and in semi-enclosed seas. Saildrones are wind-and-solar powered USVs which are capable of up to 12- month ocean data collection missions, monitoring the World Ocean in real time.

An example of a successful USV is Triton’s Ocean Aero, a hybrid ocean glider and sail drone which can operate in surface or underwater dive mode. Sail drones and ocean gliders now have the ability to carry hydroacoustic packages and conduct eDNA sampling, which, coupled together, have the potential to be the backbone for monitoring the biodiversity of open ocean ecosystems. In the open ocean, combining an acoustic profiler on a sail drone with Argo floats (sub-surface profiling floats which observe temperature, salinity, and currents) could help characterize dwelling conditions for salmon, their prey, and the environment. For coastal zones, more traditional methods of ocean mooring could be combined with novel glider and sail drone technology. Tracking the development and implementation of these technologies is important. The U.N. Decade of Ocean Science OASIS project (airseaobs.org) is proposing a community of practice under the GOOS for tracking the state of uncrewed ocean surface vehicle technology.

Remote sensing is an observational technique that allows scientists to use radiation measure properties on the ocean surface with sensors attached to aircrafts like satellites or planes. Remote sensing already has the capacity to measure Sea Surface Temperature (SST) and continues to advance in producing high resolution measurements of essential ocean variables which are increasingly capable of studying the mechanisms affecting fish productivity and distribution. Over the next few years, new satellites will be available and online which will increase resolution dramatically, and new altimetry sensors attached to these satellites will revolutionize hydrology. Remote sensing requires information provided by ground-truthing (direct observation) from *in situ* samples (measurements directly from the sea).

Tagging fish is a popular approach to determining the distribution and migratory patterns of fish. Learning where fish are in the ocean and assessing their condition across their life history will be a key requirement for determining how changes in the ocean will affect them. Tagging approaches range from simple physical tags, which provide information of movement when the fish is caught, to sophisticated electronic tags, which can archive or transmit information about the fish's position to satellites or broadcast unique radio signals. Acoustic tags are now small enough to be applied to fish ~6cm and can be used to study hypotheses of survival in discrete places and times. Because of their size, they can be applied to all salmon populations and used to study migration and survival in shelf or slope waters. A sampling design of arrays for the Northeast Pacific Ocean is proposed which could be used for salmon and potentially other marine species of fish and mammals.

Satellite pop–up tags, data logging tags which transmit the data through Argos satellite systems, are now much smaller and more effective. Combined with improved location algorithms, onboard computing capabilities, and rapidly evolving satellite constellations, they are a tool that should be considered for studying high seas distribution, migration, and behavior of salmon and other fishes. Fit chips are a genomic technology that allows non-invasive samples such as gill filament chips to tell us the physiological condition of a fish, as well as the presence of pathogens and environmental conditions that are affecting it. This will be a valuable tool as we continue to investigate the mechanisms impacting salmon survival. While not a physical tag, stable isotopes, elements and compounds stored in annual growth increments of hard parts can be used to reconstruct the location of fish in place and time. These techniques can be applied for most if not all marine species.

The IYS showed that an intense monitoring is needed to effectively address research and management issues in the marine resources' conservation. Meticulously organized data mobilization and data access are a key condition for further development of new research methods and techniques. Despite recent success in remote and uncrewed technologies, the ship-based monitoring and research will always remain an essential part of any ocean related program. Now, advanced capacity to deploy new platforms and sensors is held across multiple countries, agencies, universities, and the private sector. An effective partnership and an appropriate level of funding will be required to bring it together.

Synchronization of data and sample processing after the field research is also particularly important in fine scale studies of ecosystem dynamics. Methodology of integrated marine expedition requires near-real time data sharing between research teams to arrive at a complete picture of ecosystem functioning and dynamics. Collaborative high seas work has reaffirmed the need to establish standards and data sharing protocols to mobilize data associated with salmon and epipelagic ecosystems of the North Pacific Ocean that are consistent with the FAIR data principles (Findable, Accessible, Interoperable and Reusable) and create the data standards that define Essential Ocean and Essential Biological Variables for coastal areas and the open ocean. Expeditionary-based research project on *Basin Events to Coastal Impacts: An Ocean Intelligence System for Fish and People (BECI)*, which is particularly built on the IYS legacy, can help play a role in strengthening these needs. Currently, data collected in the IYS expeditions are available to research community via the IYS Data Mobilization Portal (https://international-year-of-the-salmon.github.io/about/). Data catalogue contains 113 datasets provided by thirty-one responsible organizations from the NPAFC member countries.

As any new technique, new platforms and sensors need continuous technical improvements and optimization of their deployment scheme. For bearing by fish devices, miniaturization and power consumption challenges remain important task for developers and designers.