FISHERIES AND MARINE MAMMAL OPPORTUNITIES IN OCEAN OBSERVATORIES

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Abstract: The fundamental difference between conventional biological surveys and stationary observing systems is the potential for unlimited spatial and temporal sampling from a suite of sensors in real time. This unprecedented sampling provides both opportunities and logistic challenges to the fisheries and marine mammal science communities. Strategic choice and placement of sensors should enable a suite of organisms to be continuously monitored over a broad range of spatial and temporal scales. Although, detection ranges of most active and passive sensors such as acoustic technologies, limits the feasibility of relying solely on a grid sampling design. Fisheries (i.e. fishes and invertebrates) research opportunities include: examining spatial and temporal fluxes of biomass; resource assessment with extended temporal sampling; quantifying distribution variability in space and time; and species-specific habitat use. Marine mammal research opportunities include: quantifying spatiotemporal distributions of animals; investigating biological responses to oceanographic variability; and monitoring behavioural responses to anthropogenic noise sources. Common elements to both groups include opportunities to monitor changes in densities, distributions, and fluxes of aquatic organisms over annual cycles and in response to variability in the ecosystem. The major challenge to both groups is processing voluminous data streams and the subsequent conversion to useable products within reasonable lag times. Despite the collection of many 'empty' data cells, observatories facilitate spatially and temporally scale-dependent observations of aquatic organisms that have not been possible using mobile platforms.

Keywords: acoustics, fisheries, marine mammals, ocean observatories

1. INTRODUCTION

Until recently, spatial and temporal sampling of the water column by acoustic and other remote sensing technologies was limited in range and duration. The combination of continuous power, data transmission, and long term deployments associated with ocean observatories provides both opportunities and logistic challenges to the fisheries and marine mammal science communities. Unlike other groups involved in planning ocean observatory experiments, fisheries and marine mammal science communities focus on mobile, apex predators that are located primarily on continental shelves. Predator-prey interactions among organisms that move independent of water motion (i.e. nekton) transfer energy (i.e. organic carbon) from the 'top down.' This perspective differs from the oceanographic view of 'bottom up' trophic transfer where biological-physical coupling facilitates the transfer of energy from physical structures such as upwelling that supplies nutrients to phytoplankton and the subsequent consumption by zooplankton, fish, and then marine mammals.

Primary science themes common to marine mammal and fisheries include biomass fluxes, population monitoring, and episodic physical events that initiate a biological response. Specific marine mammal science themes that can be exploited using an ocean observatory include seasonal distributions, ocean dynamics, and anthropogenic influences. Seasonal distribution research will map and monitor the timing and spatial variability of migration routes, feeding assemblages, and spawning aggregation areas. Ocean dynamics is characterized as the reaction of individual and groups of animals to environmental variability at small (e.g. fronts) and large (e.g. El Nino) scales. A fixed grid fitted with sensors provides the advantage of a large region simultaneously monitored over a wide range of spatial scales. Anthropogenic influences include the response by animals to noise (e.g. from vessels), and potential conflicts with shipping traffic and commercial fishing.

Dominant fisheries science themes include biomass fluxes, resource assessment with extended temporal sampling, distribution variability in space and time, and habitat use. The flux of biomass through space over time has not been traditionally quantified over large spatial and temporal scales [1,2]. Long term sensor deployments would facilitate investigations into the kinematic processes of migration, dispersal, and the coupling of biomass flux to environmental gradients. Assessment surveys of pelagic and demersal fish species are traditionally conducted using research vessels. Sample synopticity, resolution, and range of these Eularian (i.e. stationary grid) surveys are limited by vessel speed, time available, vessel manoeuvrability, gear restrictions, and surface conditions. Temporal surveys from a single location or surveys conducted by a suite of sensors have not been used in the management of harvestable resources. Tracking variability in fish distributions over time facilitates demographic (e.g. births, survival) investigations at the temporal scale of a generation and the spatial scale of a population. Habitat use by pelagic and demersal fish species is an emerging topic in resource management. Challenges associated with this theme are defining essential habitat, and quantifying the impacts of loss or damage to essential fish habitat.

The marine mammal and fisheries research communities will both benefit from the opportunity to monitor changes in densities and distributions of aquatic organisms in response to ecosystem variability. Many life history characteristics (e.g. timing and path of annual migrations) are not known for fish and mammal species. A continuous suite of sensors can provide a network to quantify and understand aquatic life cycles and over longer temporal scales, may be used to monitor biologic responses to climate change.

A combination of Eularian (i.e. fixed grid) and Lagrangian (i.e. mobile) sampling strategies are required to adequately sample fish and marine mammals through the range of ecological scales encompassed by an ocean observatory. Detection ranges of most active and passive sensors limit the feasibility of relying solely on a grid sampling design. Strategic choice and placement of sensors should enable a suite of organisms to be continuously monitored. This combined sampling approach can be used to detect high concentrations and strong gradients as indicators of biological or physical significant events. Detected changes in static or dynamic quantities such as biomass flux or temperature gradients can trigger intensive temporal and spatial sampling aimed at quantifying dominant processes that produced observed patterns. Given that the bulk of nektonic biomass is located on continental shelves, the availability of nodes and spur lines on the continental slope and shelf is imperative for a successful nekton sampling program. Location of sensor arrays should be oriented relative to species' migration routes and/or habitat types that exist within any region of interest.

2. EXAMPLE COMMUNITY EXPERIMENTS

To illustrate the potential for fisheries and marine mammal applications within an ocean observatory, two sampling approaches are described that address the question, "What is the distribution, relative abundance and movements of nekton within the monitored volume and how do these parameters vary with environmental conditions?" Nekton can be divided into three size categories: large pelagics (e.g. cetaceans, tunas), middle pelagics (e.g. dolphins, Pacific hake), and small pelagics (e.g. herring, sardines). Monitoring each category requires different sampling technologies.

2.1. Physical-biological Coupling

An experiment that combines physical-biological coupling across many tropic levels is the entrainment by and exploitation of dynamic features (e.g. eddies, jets) by aquatic organisms. The purpose is to examine the role of dynamic physical structures in the trophic organization, dynamics, and distribution of aquatic organisms. There are many examples of predators attracted to or keying on concentrations of prey items at high gradient areas (e.g. fronts). The survival and recruitment of zooplankton, some invertebrates, and larval fish species are influenced by the availability of food and conditions within water masses during transport to nursery areas [3]. Marine mammals, fish, and macro-zooplankton exploit patches of prey that are concentrated within or at boundaries of physical structures. These structures may be permanent (e.g. boundary currents, river plume) or ephemeral (e.g. wind-induced upwelling) features of an area.

The Juan de Fuca plate along the west coast of North America is proposed as a regional observatory (Fig. 1) and the Canadian portion has been funded (see http://www.neptunecanada.ca/). Several shelf locations are appropriate for fisheries and marine mammal sensor arrays: Cape Blanco, Heceta Bank, and southern Vancouver Island. Sensor arrays would be attached to three spur lines running from junction nodes onto the continental shelf. Sensor arrays on the spur lines would be spaced at sufficient resolution to detect eddy movements. Satellite detection of sea surface temperature, ocean color, and altimetry would be used in combination with acoustic tomography, local arrays and physical
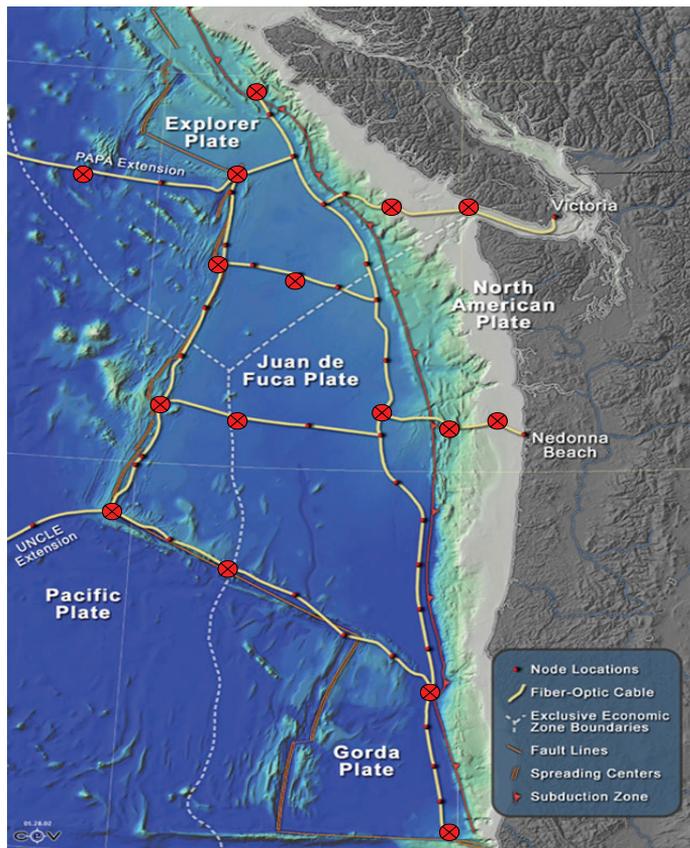
Fig. 1. Proposed NEPTUNE cable and node locations on the Juan de Fuca Plate

models to detect the formation and track movement of eddies as they propagate. The suite of sensors would potentially include winched CTDs, video plankton recorders (VPR), fluormeters, ADCP, dissolved oxygen, and active acoustics. Passive hydrophone arrays would be used to detect the presence of vocalizing marine mammals and could be used to detect acoustically tagged mammals or fish. Additional active acoustic systems would be used to monitor fluxes of fish.

As a propagating event approached or passed one of the spur lines, mobile samplers such as AUVs, gliders, or robotic fish would be deployed to run transects across the feature to map its boundaries, water properties, and its velocity. Sensors on these mobile platforms would include active and passive acoustics, optics, and collection systems to sample phytoplankton (e.g. fluorometry, optical plankton counter), zooplankton (e.g. VPR), and fish (e.g. nets or biosensors). Sampling would be used to assess biological constituents, collect samples for trophic transfer studies, and behavioral observations including predator-prey interactions.

2.2. Marine Mammal and Fisheries Long Term Observations

Monitoring distributions and movements of cetaceans and some fish populations would greatly improve the biological and ecological understanding of many species. The relevant science question is, "What are the movements of nekton within the monitored volume and their relationship to environmental conditions during those movements?" This question addresses the biological processes of migration and interaction with the environment. If constituents can be identified, then species-specific census counts can be used for population

monitoring and stock assessment. Specific studies that could be conducted during this monitoring include: distribution and migration patterns in relation to environmental variability and climate change, trophic dynamics, and comparing contributions by exploited and habitat reserves to density distributions and recruitment of aquatic populations.

A monitoring system at the scale of a tectonic plate (e.g. Neptune) is particularly appropriate for vocalizing cetaceans. Cetaceans produce sound ranging from subsonic to supersonic frequencies, which is the widest range of any class of organisms. Unlike humans, sound production and reception is the probably the most important sense to these animals. A current monitoring system has been constructed using autonomous hydrophone arrays in the Gulf of Alaska [4,5]. These deployed buoys contain recording systems that are limited in power, data storage, and must be relocated and retrieved before any data can be downloaded. Real-time access to the data is not currently possible.

Many strategies could be used to locate sensor arrays within an ocean observatory. For cetaceans, an ideal design would place vertical and horizontal hydrophone arrays on every node line that crosses the continental shelf. Regional coverage would ensure detection of all vocalizing animals since there are offshore (e.g. blue, fin, sperm whales) and nearshore (e.g. grey, humpback whales) forage areas and migration routes used by different species. Vocalizing cetaceans are best detected using arrays of multiple hydrophones (e.g. 20 to 40). Multiple, vertical hydrophone arrays permit beamforming and matched field processing, which increases the detection and two-dimensional tracking range of individual animals. A more restricted approach would place pairs of hydrophones and a compass in sound corridors along offshore and nearshore migration routes. A pair of horizontal hydrophones and a compass can be used to determine the direction from which calls arrive. A pair of vertical hydrophones allows the study of diving behavior of vocalizing animals. Satellite tags on individual animals could be used to augment identification and tracking movements of individuals or groups of whales. Additionally, passive tags could be placed on animals for tracking, using acoustic signals from tomography or navigational sources.

Hydrophones encompassing two frequency ranges would receive sound from a variety of cetacean and porpoise species. The first group is targeted to receive dolphin and porpoise whistles that contain harmonics as high as 100 kHz. Harmonics are often used in species identification. Since high frequency sounds attenuate quickly in water, these hydrophones should be located near the surface. Hydrophones used to receive vocalizations from large whales do not need comparable bandwidth due to the lower frequencies of their calls. Hydrophones that capture sounds up to 24 kHz combined with signal sampling at 48 kHz is sufficient to characterize low frequencies.

Large volume, long term passive monitoring is also appropriate for pelagic fish species. As an example, oceanic distributions, movements, and survival of anadromous salmon are not well known. In a demonstration project, horizontal arrays of hydrophones have been deployed straits surrounding Vancouver Island to detect acoustically tagged fish as they migrate from river mouths to marine habitats (see http://www.postcoml.org/intro.php). Acoustically tagged fish are detected as they pass within the range of hydrophones in an array. Migration and survival rates as fish return to natal rivers and streams can be estimated for different species and populations. This approach has been successfully used to track salmon species, sturgeon, rockfish, and herring. A permanent deployment of hydrophone 'fences' placed orthogonal to the coastline is envisioned to run from the Aleutian Islands in the Gulf of Alaska to southern Washington State (Fig. 2).

Fig. 2. Proposed placement of hydrophone 'fences' in POST project

Active acoustic systems could be used to examine seasonal fluxes of fish along continental shelves (e.g. annual Pacific hake migration in North America) and diel movements within the water column. Echosounders or multibeam sonar systems could be mounted on bottom or on platforms suspended in the water column. Mobile platforms such as AUVs could be used to survey transects along fixed paths from a single node or transit among regularly spaced docking stations. Once transects are completed, the AUV would dock to recharge batteries, download data, and receive instructions for the next deployment. A variety of sensors could be installed on the mobile platform depending on the fish species being tracked, and ancillary data needs.

In contrast to these Eularian sampling strategies, Lagrangian methods could be used to monitor specific fish populations or biological responses to physical events. Tracking platforms such as AUVs could be used to follow populations by focusing on a few tagged individuals during the migration. When an AUV is close to a satellite node, it could dock to recharge batteries and download data. A second AUV would assume tracking or once the original AUV was recharged, it would resume tracking. Recent developments in material science and robot kinematics potentially make the tracking platform less obtrusive to fish within an aggregation. The greatest challenge to Lagrangian tracking by mobile platforms is the ability to navigate and accurately log position while underwater. The capability to detect other acoustic signals broadcast for acoustic tomography will increase navigational accuracy.

Two additional challenges are associated with active acoustic sampling of fish populations. At this time, with the minor exception of high latitude ecosystems containing limited species diversity, acoustically identifying targets to species is not routinely possible based on acoustic signals alone. Two current solutions are available. Ship-based surveys using scientific echosounders and trawling can be used to identify constituent fish species, to sample length frequencies, and to compare temporal distribution patterns at any fixed location to those within the region. As a second option, fish tagged within large aggregations could be detected with hydrophones at fixed locations while fluxes of animals are monitored using active sonar systems. Since similar fish tend to travel together, the combination of passive and active acoustics could be used to monitor fish populations. The second large challenge when using active acoustic systems in cabled observatories is data processing and

management. Current data processing techniques are not automated. A person is still required to examine data for quality control and to discriminate acoustic target categories. Efforts are underway in several countries to automatic target recognition and to reduce non-informative data volumes. Active acoustic systems are notorious for producing large data volumes. A single system may acquire megabytes to gigabytes of raw data per minute depending on the sampling rate and range. The challenge of managing large data volumes will continue to diminish as data handling and storage clients continue to evolve.

3. SYNERGIES

Acoustic systems are essential and critical components of ocean observatories. Integration of instruments increases data acquisition efficiency, cost effectiveness, and should reduce logistic challenges for installation and maintenance. Sensors targeting fish and marine mammal populations can be used or integrated with other instruments to measure chemical, physical, and geological properties of the water column and substrate. A current challenges is to integrate existing or develop new acoustic sensors that are robust, long-lived, easily calibrated, and can provide data streams for multiple users. The potential for synergistic acoustic-based research exists within the ocean observatory community. Biologists are interested in how animals respond to and interact with their environment. The evolution of the 'ecosystem approach' as a new paradigm in resource management will encourage and ultimately force additional linkages between physically and biologically oriented investigators.

4. ACKNOWLEDGEMENTS

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