Ocean Tracking Network Canada: A Network Approach to Addressing Critical Issues in Fisheries and Resource Management with Implications for Ocean Governance

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ABSTRACT: *The Ocean Tracking Network (OTN) Canada is an integrative seven-year research program initiated in 2010 with academic, government, and industry partners. The team makes use of novel biotelemetry (primarily acoustic telemetry curtains), biologging, and oceanographic technologies to better understand changing ocean dynamics and their impact on ocean ecosystems, animal movements, and ecology and the dynamics of marine animal populations, many of which are commercially important. The network is organized around three ocean arenas (i.e., the Atlantic, Arctic, and Pacific) where specific research projects will occur. However, all projects will contribute toward addressing a single unifying national-scale question—what are the movements of continental shelf marine animals, how do these movements affect species interactions, and what are the consequences of environmental variability/change and human activities on these species' distributions and abundance? Taxa that will be tracked include diadromous (e.g., salmon, eels, sturgeon) and marine (e.g., sharks, capelin, cod) fishes and a variety of marine mammals (e.g., grey seals, killer whales). Some of the*

Red de Monitoreo Oceánico en Canadá: un enfoque de redes para el estudio de temas críticos en pesquerías y manejo de recursos con implicaciones de gobernanza de los océanos

RESUMEN: La Red de Monitoreo Oceánico (RMO) en Canadá, es un programa integral de investigación que inició en 2010 con la participación del sector académico, industrial y de gobierno. El equipo hace uso de tecnología de punta en cuanto a bio-telemetría (cortinas primarias de telemetría acústica), bio-marcado y oceanografía con el fin de comprender la dinámica del océano y su impacto sobre los ecosistemas marinos, el movimiento de los organismos y su ecología así como también la dinámica de las poblaciones de animales marinos, muchos de ellos de importancia comercial. La red se encuentra organizada en torno a tres dominios oceánicos (i.e. Atlántico, Ártico y Pacífico) donde se desarrollarán proyectos específicos de investigación. No obstante, todos estos proyectos abordarán un problema común de escala nacional ¿Cuáles son los movimientos de los animales marinos en la plataforma continental?, ¿Cómo estos movimientos afectan las relaciones entre especies?, ¿Cuáles son las consecuencias de la variabilidad/cambio ambiental y las actividades humanas en la distribución y abundancia de dichas especies? Los taxa que serán monitoreados incluyen peces diádromos (e.g. salmón, anguilas, esturión) y marinos (e.g. tiburón, capelines, bacalao) y una variedad de mamíferos marinos (e.g. focas, orcas). Algunas de las actividades comunes a los tres dominios incluyen la medición de características oceanográficas y su variabilidad en distintas escalas de tiempo y espacio, el movimiento de especies clave de distintos niveles tróficos así como también el uso de "biosondas" (animales que portan marcas que registran las localidades visitadas, las condiciones oceánicas y la interacción con otros animales marcados) y "robosondas" (vehículos a control remoto que miden las condiciones físicas, biológicas y químicas del océano) con el objetivo de complementar la información proveniente de RMO fijas, como las cortinas acústicas telemétricas. En última instancia, los datos generados se utilizarán para informar a los manejadores, para asistir en la formulación de nuevas políticas socioeconómicas y a brindar ímpetu a la reformas de prácticas de gobernanza y estándares legales.

common activities that occur in all arenas include measurements of oceanographic characteristics and variability at various spatial and temporal scales, movements of key species at several trophic levels, and use of key acoustic "bioprobes" (animals that carry tags that record locations visited, ocean conditions, and interactions with other tagged animals) and "roboprobes" (remotely controlled autonomous vehicles such as gliders that measure physical, biological, and chemical conditions) to complement measurements from fixed OTN acoustic telemetry curtains. Ultimately, scientific information generated will inform resource management, help formulate new socioeconomic policies, and provide some impetus to the reformulation of governance practices and legal standards.

Introduction

Globally, fish stocks have been vastly depleted, with many valuable species driven to commercial extinction (Pauly et al. 2002; Hilborn et al. 2003), leading to harvest efforts focused on organisms at lower trophic levels (Pauly et al. 1998). It is estimated that the world has seen a 90% decline in the population of large oceanic fish since the 1950s (Myers and Worm 2003). In addition, environmental variability and change can influence the productivity of marine systems (McGowan et al. 1998; Behrenfeld et al. 2006) and thus alter the distribution of animals in space and time, with unknown consequences. There are currently many knowledge gaps related to how animals move and interact with each other and with their environment in estuarine, coastal, and shelf habitats. These gaps pose many challenges for ocean governance, make sustainable management of fish populations difficult, and render rebuilding of fish stocks nearly impossible (Worm et al. 2009). Moreover, mobile animals that spend parts of their lives in multiple national jurisdictions pose enormous governance issues.

Studying animal–environment relationships in oceanic habitats presents a number of inherent challenges, related largely to the physical size of the systems, sometimes great depths, and severe seasonal environmental variations that preclude active study of species year-round in some regions. Over the past 40 years, there have been a number of innovations in biotelemetry, biologging, and oceanographic instrumentation that have helped to surmount the difficulties outlined above, advancing our understanding of marine life (e.g., Cooke et al. 2004; Block 2005; Ropert-Coudert and Wilson 2005; Rutz and Hays 2009). In the last 10 years in particular, there has been development and application of tools such as three-dimensional positioning systems (O'Dor et al. 1998; Espinoza et al., 2011),large continental-scale listening arrays (Welch et al. 2002), autonomous gliders (Webb et al. 2001), animal-borne oceanographic sensors (e.g., Biuw et al. 2007), and animal–animal interactive tags (i.e., "business card tags" [BCTs]; Holland et al. 2009). In addition, improvements in battery and tag technology are now allowing tagging of smaller taxa and life stages than could be studied previously. Collectively, this suite of tools and the data they can generate have the potential to provide knowledge needed to address key management and conservation problems that will ultimately benefit not only the world's biodiversity but also society and the economy.

The notion of a global Ocean Tracking Network (OTN Global), an international research and technology development consortium led by Dalhousie University, was developed in 2007 with the aims to revolutionize the way oceans were viewed and understood and thereby contribute to a more sustainable use of the oceans (reviewed in O'Dor and Stokesbury 2009; O'Dor et al. 2010). The OTN Global project is funded by the International Joint Venture Fund (IJVF) whose majority funding agency is the Canada Foundation for Innovation (CFI). Through the IJVF, CFI provides the infrastructure to establish a global network of acoustic detection stations for acoustically tagged animals. OTN Global is also deploying oceanographic sensors in association with the detection systems so that animal movements can be correlated with environmental variables and creating a data warehouse to compile the data from the network. Made-in-Canada technology will be installed in 14 oceans across seven continents to achieve these ends. In collaboration with the international scientific community and the host countries in which these deployments occur, the behaviors, movements, and interactions of hundreds of species of marine life will be tracked for up to 20 years.

CFI's mandate is infrastructure, and the OTN Global award did not include specific funds to support training of students, field research, and analysis. The telemetry infrastructure deployed by OTN Global provides maximum information when there are funds available to tag animals and release them to the wild. Data from the tagged animals can be used in interdisciplinary work coupling animal movements with oceanographic information, data on animal condition (e.g., physiology, genomics), or interactions with other animals including humans (e.g., Cooke et al. 2008).

In order to maximize the benefits of the OTN Global infrastructure components deployed in Canadian waters, an OTN Canada team was formed by S. J. Iverson, with 27 others, and its peer-reviewed proposal was awarded $10 M from the Natural Sciences and Engineering Research Council (NSERC), Canada, Strategic Network Program in late 2009. This award provides funding to undertake a 7-year integrative research program making use of OTN Global technologies. OTN Canada is a partnership primarily between NSERC-funded university faculty and the Department of Fisheries and Oceans (DFO) Canada but also draws on an extensive and wide-ranging collaborative effort with scientists and managers from other federal and provincial departments, conservation agencies, and industrial collaborators. Here we describe the objectives of OTN Canada and provide an overview of the ongoing and future research activity that will be conducted by the network. We also discuss how information generated by OTN Canada will be applied to address pressing management and conservation issues. This article is part of a series in *Fisheries* that is focused on NSERC strategic networks that are currently active in Canada and have specific relevance to fisheries and aquatic science (see Hasler et al. [2011] for introductory article).

OTN Canada Objectives

The OTN Canada Network is a large, integrative research program that aims to understand changing marine ecosystems across Canada. OTN Canada has three overarching questions:

1. What are the physical, chemical, and biological oceanographic linkages that determine the population structure, dynamics, movement, and critical habitat of marine organisms?
2. How will climate variability, environmental change, and anthropogenic activities affect the distribution and abundance of marine organisms?
3. What are the ocean governance implications, including social, economic, and legal dimensions, of OTN findings?

Under the umbrella of these larger issues, OTN Canada research will directly address one key, integrative question across the entire Canadian continent and its three ocean arenas (the Atlantic, Arctic, and Pacific; Figure 1): What are the movements of continental shelf marine animals, how do these movements affect species interactions, and what are the consequences of environmental variability/change and human activities on these species' distributions and abundance? Addressing this comprehensive question will encourage communication and collaboration among regions and investigators and allow maximum flexibility in conducting research. Much of the work of OTN Canada will be exploratory and occur in regions that have either been little studied or, in some cases, never studied before. We anticipate that many additional research questions will arise during the course of the network's activities (indeed, some already have in year 1—see Greenland halibut [*Reinhardtius hippoglossoides*] example below).

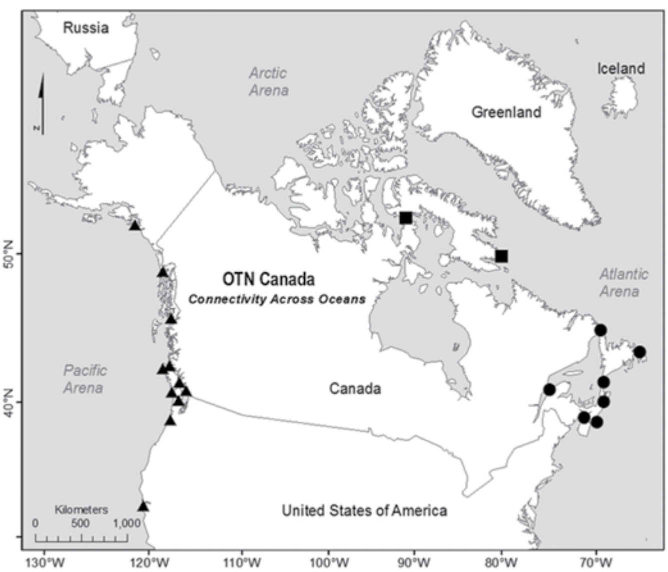

Figure 1. Map of Canada's three oceans (represented here as "arenas"), which are interconnected with respect to water mass exchange, migrating animals, and climate forcing. Symbols indicate many of the locations of proposed receiver lines/buoys representing acoustic curtains deployed in the Atlantic (circles), Arctic (squares), and Pacific (triangles).

Throughout the 7-year research program, there is a heavy focus on the training of students, postdoctoral fellows, and other highly qualified personnel. Though OTN Canada is focused on research within Canadian portions (arenas) of the Atlantic, Arctic, and Pacific oceans, it is important to remember that these Canadian waters are interconnected among themselves and to the vast expanses of the rest of these oceans through water mass exchange, migrating animals, and climate forcing. To assure direct comparison across the arenas, the following will be included within each arena: (1) measurements of oceanographic characteristics and variability at various spatial and temporal scales, (2) movements of key species at several trophic levels, (3) analysis of key acoustic "bioprobes" (animals that carry tags that record locations visited, ocean conditions, and interactions with other tagged animals; Holland et al. 2009), and (4) "roboprobes" (remotely controlled gliders that measure physical, biological, and chemical conditions) to complement measurements from fixed OTN curtains. Ultimately, information obtained will be offered to address socioeconomic and resource management issues by including a social science and legal component, partnering with investigators supported by the Social Sciences and Humanities Research Council, Canada, and other collaborators.

OTN Canada Research Themes

OTN Canada will address five key research themes to be integrated within and across its three arenas (Figures 1 and 2), all of which are interdisciplinary, interdependent, and complement one another:

Theme 1: Ocean Physics and Modeling

Migration patterns of marine animals are tuned to, and presumed to be affected by, the physical, chemical, and biological conditions in the ocean. As conditions change, so will patterns of movement, possibly with profound ecological consequences. A major challenge faced by OTN studies is the synthesis of physical, biological, and chemical measurements, along with other available data streams, to generate a dynamically consistent, time-varying, three-dimensional view of the ocean that can be used to help explain and predict the observed movements of the marine animals and thus answer the fundamental questions asked by OTN Canada. This theme's main objectives include developing a general-purpose observa-

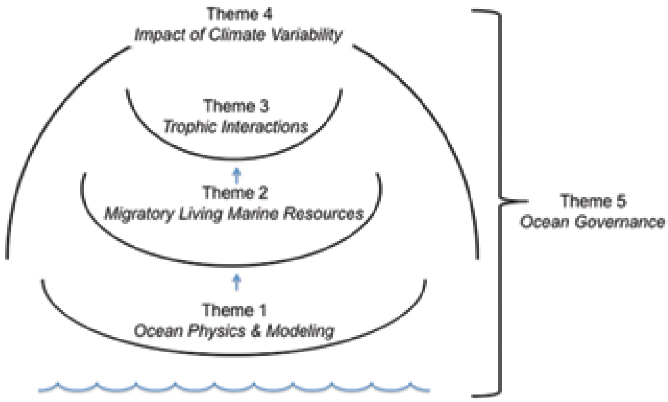

Figure 2. Schematic view of the interrelationships among OTN Canada's primary research themes.

tion and modeling platform that will provide integrated simulations of the marine environment and the movement of marine animals. It will do this by supplementing existing observational capabilities with new observation tools; developing advanced physical, biological, and chemical models; and generating effective methods for combining the models with observations. It is hoped that this will also lead to better prediction of past and future ocean states.

Theme 2: Biology and Behavior of Migratory Living Marine Resources

Many sea animals make extensive movements through the ocean, ranging from simple drifting or foraging patterns to large annual migrations in order to reach highly productive sites for feeding (growth) and reproduction. Understanding movements and migrations—and the physical conditions that drive them—is crucial to conservation, economic development, and prediction of how patterns will alter with climate variability and change. The main objectives under this theme aim to understand targeted species that are model or keystone species in their ecosystems or that include key species at risk and to understand these populations and movements in relation to oceanographic features and variability.

Theme 3: Trophic Interactions

The spatial and temporal characteristics of foraging by predators play important roles in structuring trophic interactions and understanding ecosystems. Because top predators are often large, long-lived, and geographically wide-ranging, their populations "integrate" the cumulative effects of changes in ecosystem structure and functioning over a range of spatial and temporal scales. Using novel acoustic technology newly developed for OTN, we will use predators themselves to act as bioprobes to sample their ecosystems and also provide information on interactions with other tagged organisms (Holland et al. 2009). The primary aim of this theme is to expand knowledge of predator and prey distributions in time and space in relation to ocean characteristics and to test hypotheses concerning predator and other impacts on prey populations, including economically important commercial fish stocks.

Theme 4: Impact of Climate Variability on Research Themes 2 and 3

Any significant climate change, whether long-lasting or episodic, will presumably alter oceanographic features, animal movements, and migrations and hence patterns of interaction, abundance, and distribution (Grebmeier et al. 2006). The main objectives of this theme are to predict the impacts of long-term climate change on (1) the movements, abundance, distribution, and interactions of the species studied under themes 2 and 3; (2) the physical, chemical, and biological ocean conditions measured and predicted under theme 1 (supplemented by other observations and modeling studies); and (3) the interrelationship between (2) and (3). Accompanying these predictions will be an evaluation of how future resource management must be approached.

Theme 5: Implications for Ocean Governance

Though themes 1–4 will increase understanding of the behavior and status of marine species and changes in ocean ecosystems, many legal and social issues will be raised not only by this new knowledge but also by the technological innovations themselves and by the ability of local, national, and international management systems to implement more effective and sustainable coastal and ocean governance. The objectives under this theme are to examine the adequacy of existing laws, management policies, socioeconomic patterns, and harvesting practices for protecting marine species, with a particular emphasis on those at risk in the three arenas, and to suggest ways to weave a stronger, more successful protective net in light of increasing scientific information.

Though social science research is expected to be an iterative process substantially guided by the OTN scientific information generated, a number of research components are envisaged. These will include undertaking Canadian case studies for the Atlantic, Arctic, and Pacific on how selected marine species at risk are faring, both in scientific understanding and management measures, and will focus on implementation of precautionary and ecosystem approaches. Because OTN acoustic curtains will be tracking many marine species (both marine mammals and fish stocks) that are transboundary in nature and shared with the United States, natural and social scientists from both Canada and the United States will also investigate the adequacy of existing scientific and governance arrangements and explore possible modifications. Another research component will address the social integration of OTN knowledge in policy and management. OTN science may result in alterations to management regimes, which will vary by region (Apostle 2009). The social and scientific meanings of uncertainty or risk and their communication in scientific fora will be explored (Callon 1986). The potential uses and users of knowledge produced by OTN will also be examined.

Example Case Studies of Ongoing Projects

Within each arena there are more than 10 projects that address the various themes and research questions of the SNG. Taxa that will be studied include diadromous (e.g., salmon, eels, sturgeon) and marine (e.g., sharks, capelin, cod) fishes and a variety of marine mammals (e.g., grey seals, killer whales). Space does not permit us to describe all projects in detail; here we present several of the studies that highlight ongoing research activity in each of the three arenas as part of the NSERC OTN Canada Network.

Atlantic Arena—Atlantic Sturgeon and Grey Seal Bioprobe Projects

Acoustic and archival tag technology will be used to study the behavior and habitat use of two large mobile predators, as well as information they can provide on other tagged marine organisms and their movements and interactions. Acoustic tags transmit globally unique acoustic signals (Voegeli et al. 1998) that are recorded and archived by submerged hydroacoustic receivers when the tag is within range (approximately 500 m depending on tag power and acoustic conditions of the water column). Data are collected only when the tag is in range of the hydroacoustic receiver (Lacroix and McCurdy 1996; Lacroix et al. 2005). Acoustic tags may be placed on animals as small as Atlantic salmon smolts (Lacroix et al. 2005). Archival tags store data measured by sensors (Cooke et al. 2004). Data from archival tags can be downloaded if the animal is captured and the tag is returned to the researcher (Block et al. 2001) or data can be transmitted directly to satellites if the animal is at the surface (James et al. 2006) or if the tag is set to disengage from the animal and float to the surface for data transmission (Block et al. 1998; Stokesbury et al. 2004). Archival tags are used to track larger animals because generally the tags are larger than acoustic tags. Both Atlantic sturgeon (*Acipenser oxyrinchus*) and grey seals (*Halichoerus grypus*) are physically large enough to carry the newest kind of electronic tags, the business card tag (BCT), which is a miniaturized receiver coupled with a coded pulse transmitter that combines both archival and acoustic tag technology and allows large animals to act as mobile receivers that record interactions with other tagged animals. Thus, information from many animals may be brought to shore by a few animals.

A collaborative OTN Canada research program between Acadia University and Mount Allison University that began in 2010 is focused on the Atlantic sturgeon, an iconic species of concern. These sturgeons feed seasonally in the Minas Basin, Bay of Fundy, Nova Scotia (Dadswell and Rulifson 1994), a region that supports Canada's first in-stream tidal power turbine. Atlantic sturgeon are common in the Minas Basin during summer, but details of their migration pathways, stock composition, and seasonal distribution are lacking (Dadswell 2006). Atlantic sturgeon also occur in the Saint John River, New Brunswick, and its estuary and use that habitat for spawning and as a nursery (Dadswell 2006). Two types of tags will be used to examine sturgeon habitat use, quantify mortality, and define areas of critical habitat in the Bay of Fundy. In 2010 sturgeon were tagged with coded acoustic transmitters (Figure 3a) in the Minas Basin ($N = 30$) and the St. John River ($N = 20$). Ten passive acoustic receivers moored in the Minas Basin, 13 spanning the Minas Passage, 10 in a dense array in the direct vicinity of the tidal power turbine, and 27 in the Saint John River and estuary will record and archive information on movement, environmental preferences, and mortality. To date 45 of the sturgeon have been logged on to passive acoustic receivers. This information will assist managers in determining areas that provide critical habitat for Atlantic sturgeon and help define mitigation measures that may be needed to protect this species

Figure 3. (a) Atlantic arena team member processing an Atlantic sturgeon prior to implantation with an acoustic telemetry transmitter for tracking off the coast of Nova Scotia. Fish are released in an area where they have the potential to interact with a tidal energy production facility. Photo courtesy of M. Stokesbury. (b) Adult male grey seal on Sable Island, Nova Scotia, fitted with a Vemco business card tag (BCT), VHF tag, and GPS-ARGOS satellite/temperature tag. Global Positioning System (GPS) and satellite data allow examination of fine-scale movements in the Atlantic, and BCTs act as mobile receivers, which reveal encounters with other tagged animals. Photo courtesy of W. D. Bowen.

from negative impacts of tidal power deployments in the near shore environment. In the future, BCTs will be deployed on sturgeon to help determine the extent of the coastal migrations of other tagged organisms, including various species of fishes and turtles, after first beta-testing the use of BCTs on grey seals.

In a collaboration between Dalhousie University and DFO, a series of studies are also being conducted to better understand the ecological function of large marine carnivores in continental-shelf ecosystems, using grey seals as the model species and the BCTs developed for OTN. Grey seals are an ideal testing ground for the BCTs because the tags can be deployed in the summer/fall and reliably recovered during the breeding season on Sable Island (on the Scotian Shelf) in January. These studies will examine the spatial and temporal patterns of prey encounters by a mobile, large marine predator and predator movements and foraging distribution in relation to fine- and mesoscale seasonal oceanography in eastern Canada. The first study will contribute to science advice on impacts of pinniped predation on the dynamics of prey populations of commercial or conservation importance (e.g., Atlantic cod, *Gadus morhua*). The second study seeks to understand the oceanographic features that grey seals may use to condition the way they search the environment for food and in turn predict how climate variability and long-term change may affect upper-trophic-level predators and alter their impact on continental-shelf ecosystems. In 2009–2010, Atlantic cod in the Gulf of St. Lawrence (n = 200) and Canso Bank on the Scotian Shelf (n = 100) were tagged with Vemco acoustic transmitters. In 2009 (n = 15) and 2010 (n = 20) grey seals were fitted with BCTs, VHF tags, and GPS-ARGOS satellite/temperature tags (Figure 3b), which recorded over 3,000 detections of other tagged animals (D. Lidgard, W. D. Bowen, I. D. Jonsen, and S. J. Iverson, personal comm.). All detections to date have documented encounters between tagged seals of the study group, providing insight into foraging patterns and potential hot spots, but as increasingly large numbers of cod, salmon (which are also being studied in the Atlantic arena), and other fish species are tagged, these interactions will also be measured.

Arctic Arena—Greenland Halibut Project

Cumberland Sound, on southern Baffin Island, Nunavut, supports a variety of arctic fish, seabird, and marine mammal species and a community of 1,400 people (Pangnirtung). Significant changes have occurred in this sound in the recent past, in particular, changes to the duration and extent of sea ice and the arrival of new species (e.g., capelin, *Mallotus villosus*). The sound is unique within the Canadian Arctic because it supports two commercial fisheries, for Arctic charr (*Salvelinus alpinus*) and Greenland halibut. The Greenland halibut fishery has traditionally taken place during the winter period, through the sea ice from February to May (Dennard et al. 2010). However, recent changes to ice conditions have disrupted this fishery, and efforts have begun to generate a ship-based, bottom longline summer fishery. At present, very little is known about the halibut population, its movements, and its ecological role in the Cumberland Sound ecosystem (Dennard et al. 2009).

In 2010, a 5-year study was initiated in collaboration with the University of Manitoba, University of Windsor, the Government of Nunavut, and DFO to understand the seasonal and annual movements of Greenland halibut in Cumberland Sound. An important goal of this research is to understand the biology of the halibut in relationship to other important marine fish (Greenland shark, *Somniosus microcephalus*; Arctic skate, *Amblyraja hyperborea*) and mammals (ringed seal, *Pusa hispida*; harp seal, *Pagophilus groenlandicus*; beluga, *Delphinapterus leucas*; narwhal, *Monodon monoceros*) within the ecosystem and to oceanographic characteristics of the sound. In August 2010, a 22.5-km acoustic curtain of two lines of 15 receivers each was established that span a shallow ridge (<200 m) with a deeper region in the middle (~350 m) that divides an area of deeper water (up to 1,400 m) to the south, where halibut are caught year-round, with a deeper area (~400 m) to the north where halibut are only caught in the winter. Acoustic tags were surgically implanted in 30 Greenland halibut (Figure 4a) and three Greenland sharks to assess when these fish move between shallow and deeper water within the sound. Many of these tags will last more than 10 years, providing data and potential insights on larger scale movements. Fifteen pop-off archive satellite tags (mini-PAT, Wildlife Computers, Redmond, WA) were also placed on nine Greenland halibut, three Greenland sharks, and three Arctic skates (Figure 4b) to generate high-resolution depth and temperature profiles at 30-s intervals over short (70 days) and long (1 year) periods. Four AURAL autonomous hydrophones (Multi-Electronique Inc., Rimouski, PQ, Canada), which passively record marine mammal vocalizations (see Delarue et al. 2009), and four C-PODs (Chelonia Limited, Cornwall, UK), which record clicks produced by odontocete whales (see Todd et al. 2009), were also placed in the north end of Cumberland Sound in 2010 to understand the movements, behaviors, and population structure of beluga and narwhal. The results of this research will be coupled with efforts to assess the population structure of commercially important fish in the Arctic to develop a sustainable conservation and management strategy for fisheries and ecosystem health in Cumberland Sound.

Pacific Arena—Pacific Salmon Project

Pacific salmon (*Oncorhynchus* spp.), and sockeye (*O. nerka*) in particular, are a focal group for the research activity in the Pacific arena in collaborative studies primarily between the University of British Columbia, Carleton University, and DFO. Starting in 2009, several studies were initiated to address issues associated with both ocean-bound smolts and homeward-migrating adults. One of the first studies examined the effects of different sizes of acoustic transmitters and fish sizes on sustained swim speeds, metabolic rate, feeding, and survival

Figure 4. (a) Arctic arena researchers implant intracoelomic acoustic transmitters in Greenland halibut in Cumberland Sound aboard a DFO research vessel. Photo courtesy of A. Fisk. (b) In addition to using acoustic telemetry, some fish (e.g., Arctic skate) are tagged with mini-PAT satellite archival tags. Photo courtesy of A. Fisk.

in smolting sockeye salmon in both freshwater and saltwater environments. This was a lab-based study intended to refine best practices in terms of sizes of transmitters that can be used in field telemetry studies on juvenile salmon that minimize the effects of tag size on behavior and survival and, in particular, to assess new tag sizes recently brought onto the commercial market and ensure that tagged fish are representative of untagged conspecifics. Such tagging validation studies are essential to ensure that data arising from tagged individuals are representative of untagged conspecifics (Cooke et al. 2011). Knowledge emanating from that project was used to support the start of a tagging study focused on outmigration of individual smolts from Chilko Lake, a population situated 600 km inland from the ocean, the highest elevation rearing lake for sockeye salmon in Canada. This is the first ever tagging project of its kind on juvenile wild sockeye salmon. In spring 2010, 200 2-year-old juveniles were captured as they initiated their smolt outmigration and surgically implanted with acoustic transmitters. Fish were tracked with acoustic curtains to determine travel rates and locales and levels of mortality. Preliminary results indicate that smolts are reaching the river mouth in about eight days with mortality rates of 70–80%. Movement and survival rates, as they migrated along the coast toward the open ocean, were assessed with acoustic receiver curtains (the Pacific Ocean Shelf Tracking [POST] project; Welch et al. 2002). Smolts reached the northern end of Vancouver Island in about 60 days, though suffering about 95% mortality since release. Studies planned for future years will involve examining the potential effects of tagging using even smaller transmitters, smaller fish, and experimental manipulation of release locale and fish condition to better identify the mechanisms associated with mortality.

In the summer of 2010, over 1,000 adult sockeye were tagged in marine waters during their coastal approach to examine the oceanographic and physiological (Figures 5a and 5b) correlates of behavior and survival of migrating fish. Oceanographic surveys conducted in parallel with the release of tagged fish were used to characterize oceanographic conditions where fish were migrating. Acoustic receiver curtains in the ocean associated with the POST and sentinel telemetry receivers situated throughout the Fraser River watershed were used to assess speeds of travel and fate of fish. Included in the study was an examination of how different handling techniques influenced the fate of fish, serving to both inform researcher handling protocols as well as provide some preliminary data for future projects that will be focused on Pacific salmon catch-and-release issues in the recreational and commercial fisheries. Data from studies of both smolts and adults are of direct relevance to management agencies that are struggling to understand the factors that influence the survival and behavior of wild salmon. Indeed, low returns of sockeye salmon in 2009 triggered a judicial inquiry (i.e., the Cohen Commission), and near record returns in 2010 emphasized how much there is to learn about the factors that influence survival of these wild fish both in freshwater and marine environments.

Application and Significance

The central and overarching component of OTN Canada will be the integration of research strategies, programs, and results across arenas with the fundamental aim of addressing critical issues in fisheries and resource management and implications for ocean governance. OTN Canada will serve as the research hub of OTN Global and will also act as a pilot demonstration and testing ground for field methods, technology development, data handling, modeling, analytical tools, training, and partnership models with industry, governments, and communities. Though the tracking of marine life is not necessarily new, the OTN Canada project is pioneering in its focus and its integration of many disciplines, as well as the geographical scale of its coverage. The research program of the network will use telemetry technology as a tool and integrate research across disciplines (e.g., physiological genomics, behavioral

a

b

Figure 5. (a) Physiological biopsy (nonlethal blood sample) being collected from adult sockeye salmon in Johnstone Strait, British Columbia (Pacific arena) prior to gastric transmitter implantation and release. Photo courtesy of J. Burt. (b) Information on fish physiology and behavior will be related to oceanographic conditions. Photo courtesy of J. Burt.

ecology, oceanography, statistics, and fisheries management) and between the laboratory and the field to advance our understanding of animal–environment–human interactions. OTN Canada will use new and innovative technologies, and these technological advances will provide information on key marine species relative to changing ocean dynamics within the Canadian Exclusive Economic Zone. In addition, researchers will develop new procedures for documenting and monitoring animal interactions at biodiversity hot spots in the open ocean.

Given the vast amount of data generated with such technology, data management, archiving, and analysis will present a number of challenges that must be overcome to realize the power of the data. Hence, OTN Global has also incorporated a large program specifically devoted to data compilation, secure storage, analysis, and design principles for all of OTN. Where possible, OTC Canada will collaborate with other groups such as the Global Ocean Observing System (GOOS), the ocean element of the Global Earth Observing System of Systems (GEOSS), the POST, the Victoria Experimental Network Under the Sea (VENUS), and the North-East Pacific Time-series Undersea Networked Experiments (NEPTUNE) Canada to contribute to other Canadian and global research and conservation efforts. To facilitate direct and rapid application of scientific data, OTN Global and OTN Canada have partnered with DFO with respect to both the installation of the physical network itself in Canadian waters and in aligning their departmental research across Canada with the NSERC-funded research network. In addition, extensive collaboration is already taking place with industrial manufacturers in terms of tag and receiver developments; that is, the scientific questions being asked by OTN Canada researchers are driving the industrial development of the equipment that is required to address and answer those questions.

Though OTN Canada's research will dramatically increase our knowledge of marine ecosystems and the animals that inhabit and move through them, another fundamentally important component of the network will be the extensive involvement of legal and social science researchers to help address international social and legal issues concerning ocean governance. On a global basis, the capacity of existing marine management bodies and arrangements, such as regional fisheries management organizations, to effectively use information generated by OTN is also open to question in light of common realities: politicized management structures, dominance of socioeconomic interests over marine biodiversity values, weak application of sustainability principles such as precaution and the ecosystem approach, and limited financing and human resources especially in developing countries (Russell and VanderZwaag 2010). Together with the Social Sciences and Humanities Research Council and OTN Canada researchers as well as other collaborators from various sectors, a social sciences research component will involve a program and series of workshops to compare and examine key issues affecting Canada, including endangered species, the precautionary approach and its uses; the social and scientific meanings of uncertainty or risk and their communication in scientific and policy fora; and potential uses and users of knowledge produced by OTN.

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