Developing a Mechanistic Understanding of Fish Migrations by Linking Telemetry with Physiology, Behavior, Genomics and Experimental Biology

The Value of Information in Fisheries Management
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Globalization, climate change, and new technologies challenge young people around the world, so AFS is working to continually refine and expand its services for students and young professionals.

Gus Rassam

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COVER: Close-up of micro-array slide (background) illustrating differentially regulated genes for sockeye salmon that die prior to reaching spawning grounds (foreground).

CREDIT: Steven J. Cooke
One of the benefits of a healthy and well-managed professional association is having a robust budget to support the recurring activities and services that members demand and have come to expect. Such activities include publications and meetings, but also reach beyond these traditional venues. Under the leadership of Executive Director Gus Rassam and the Governing Board, the annual budget has been managed to ensure a balanced budget by, more or less, limiting expenditures to equal revenues. In recent years, a series of unexpected windfalls occurred, revenues exceeded expenses, and AFS was faced with the enviable position of determining how best to apply these funds towards meeting the growing needs of our members.

In response to the windfall, a special committee composed of Past Presidents Christine Moffitt, Carl Burger, and Jack Wingate was appointed in 2005 to develop recommendations for AFS services and activities that could be accomplished under the increased financial security of AFS. The committee was called the “Enhancement of AFS Value Committee.” The following year, the committee guided the Governing Board in the development of a list of new services and activities to help achieve the major goals of the AFS Strategic Plan—member services, aquatic stewardship, and information transfer and outreach.

Last year, at their 2007 mid-year meeting in Atlanta, the Governing Board considered business plans for several initiatives and selected three for further pursuit and funding:

- Enhancement of public outreach by AFS staff,
- Support of AFS leadership development, and
- Development of an open-access, electronic journal dedicated to marine and coastal fisheries.

All three initiatives were pursued immediately thereafter:

- Elden Hawkes was hired as the AFS Policy and Outreach Coordinator,
- A special committee was appointed to administer the leadership development awards (i.e., small grants to support Governing Board members’ travel to the mid-year meeting), and
- The marine and coastal fisheries journal began to take shape under the guidance of the new editor, Don Noakes, and the AFS Publications Overview Committee led by Steve Cooke (see my President’s Hook column in the January 2008 issue of Fisheries). In addition, Donna Davis was hired at AFS to serve as the coordinator for the new journal.

Here, I introduce a proposed approach for funding new initiatives in the future. New initiatives are defined as strategic projects that enhance member and Unit services while advancing the major goals and mission of AFS. These projects may be one-time activities or may entail the creation of new services and activities that later become routine operations (such as leadership development grants and new journals).

Initiatives are identified from a variety of sources; some initiatives may generate funds for the Society, some will be revenue neutral, and some will entail continued costs. At the end of the budget year, the Executive Director, in concurrence with the AFS Officers, will identify the total amount of funds available to support each of two types of new initiatives—initiatives focused on Unit services or those addressing membership services. Below, I describe the proposed guidelines for the identification, selection, and implementation of both types of new initiatives.

UNIT SERVICES

Seed money will be made available for activities that assist Units in reaching their strategic goals and in carrying out their business. Any AFS Unit (Division, Section, Chapter, and Committee) may apply for funds, up to an upper limit which will be determined by the total funds available. Seed money will be returned to AFS after completion of the project or activity. Applications for seed money will include a brief narrative describing the strategic goal of the initiative, the need for the initiative, how the success of the initiative will be measured, the amount of funds requested, and a description of how and when funds will be generated to repay the seed money. Using a general screening process to ensure repayment and consistency of proposed activities with the AFS mission, the Governing Board will select initiatives and make awards prior to its mid-year meeting. Units funded through this process will submit brief progress reports to the Governing Board describing outcomes, challenges, and progress towards returning funds, and the list of funded initiatives will be posted on the AFS web site.

Continued on page 354
Aquaculture drug approval for Terramycin® 200 for Fish

Oxytetracycline dihydrate (Terramycin® 200 for fish) recently was approved in the United States for control of mortality in (1) all freshwater-reared salmonids due to coldwater disease associated *Flavobacterium psychrophilum* and (2) *Oncorhynchus mykiss* due to columnaris disease associated with *Flavobacterium columnare*. The limitation on treating salmonids in water temperatures below 9°C was removed (supplemental new animal drug application #038-439, 6 July 2008).

The sponsor is Phibro Animal Health (PAH, Ridgefield Park, New Jersey, www.phibroah.com). The approval marks the first new label claims approved for Terramycin® 200 for Fish for finfish in almost four decades, the first antimicrobial approved for controlling mortality due to columnaris disease in any aquatic species, the second antimicrobial approved for controlling mortality due to coldwater disease in freshwater-reared salmonids, and the first label claim for Terramycin® 200 for Fish to gain designation under the Minor Use and Minor Species (MUMS) Animal Health Act which entitles PAH to seven years of exclusivity for marketing rights. This approval will greatly benefit the commercial salmonid industry and public production of any salmonid reared in freshwater. Coldwater and columnaris organisms are serious pathogens that cause significant losses of hatchery-reared salmonids, including losses at state and federal hatcheries producing fish for native salmonid restoration programs.

The approval of Terramycin® 200 for Fish for controlling mortality due to coldwater disease in all freshwater-reared salmonids, for controlling columnaris disease in all *Oncorhynchus mykiss*, and for use below 9°C is the result of a cooperative effort among the sponsor, federal researchers, and the National Coordinator for Aquaculture New Animal Drug Applications. The Aquatic Animal Drug Approval Partnership Program (AADAP, U.S. Fish and Wildlife Service, Bozeman, Montana) (1) developed a document to evaluate the microbiological effects on bacteria of human health concern and (2) conducted and coordinated the pivotal and supportive efficacy studies. The U.S. Fish and Wildlife Service’s Coleman National Fish Hatchery, Quilcene National Fish Hatchery, Olympia Fish Health Center, and California/Nevada Fish Health Laboratory aided AADAP in conducting the effectiveness studies. The Upper Midwest Environmental Sciences Center (UMESC, U.S. Geological Survey, La Crosse, Wisconsin) (1) supported the effectiveness studies by providing feed analyses, (2) developed the environmental assessment based in part on its effluent survey on use in continuous-flow systems, (3) developed the robust analytical methods to detect oxytetracycline in fish tissue, (4) conducted the bridging studies between the official microbial inhibition assay and the high performance liquid chromatographic (HPLC) method, and (5) conducted the marker residue depletion studies in salmonids below 9°C.

AADAP and UMESC developed the data with financial support through base funds and the Federal-State Aquaculture Drug Approval Partnership Project that was under the auspices of the Association of Fish and Wildlife Agencies. The National Coordinator for Aquaculture New Animal Drug Applications provided (1) coordination of the approval-oriented activities with all involved partners including the Center for Veterinary Medicine, (2) provided input to PAH’s document that assessed the effect of residues in the human intestinal flora, (3) helped PAH in developing its labeling, All Other Information, and Administrative NADA submission, and (4) helped PAH gain MUMS designation for the newly approved label claims. For more information, see www.fda.gov/cvm/CVM_Updates/FDAantimicro071008.htm. —Roz Schnick

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2007 Status of U.S. Fisheries Report

On 28 June 2008, NOAA released its 2007 Status of U.S. Fisheries Report. The report provides the status determination for 528 stocks and highlights the following:

**Two hundred forty-four stocks or stock complexes** have overfishing determinations, 203 (83%) are not subject to overfishing, and 41 (17%) are subject to overfishing. According to the report, the number of stocks subject to overfishing has decreased from 47 to 45. Four stocks are no longer considered overfished (canary rockfish, Pacific ocean perch, blue king crab, and bigeye tuna) and two stocks have become overfished (winter skate and summer flounder).

**Twenty-three stocks** are both overfished and subject to overfishing. In 2006, 25 stocks were both overfished and subject to overfishing. For 2007, three stocks have rebuilt to 100% of their biomass that supports maximum sustainable yields ($B_{MSY}$) levels: silver hake, Gulf of Mexico red grouper, and Tanner crab. Four additional stocks have biomass levels of at least 80% of their $B_{MSY}$ levels: dolphin, Pacific whiting, shortbelly rockfish, and arrowtooth flounder.

**One hundred ninety stocks** are known with respect to their overfished determinations, of which 145 (76%) are not overfished and 45 (24%) are overfished. The percentages represent a slight improvement from last year's report. In 2006, 75% were not overfished and 25% were overfished.


Coastal Zone Reauthorization Act

On 4 June 2008, the House Natural Resources Committee, Fisheries, Wildlife and Oceans Subcommittee voted to move H.R. 5451 to the full committee. If passed, the Coastal Zone Reauthorization Act of 2008 would amend the Coastal Zone Management Act of 1972 by authorizing appropriations for grants under provisions relating to the administration of a state's coastal zone management program, resource management improvement, coastal zone enhancement, and national estuarine reserves. It would also increase amounts appropriated to states' coastal zone management program and resource management improvement to be retained for use in implementing coastal zone enhancement grant provisions.

Reauthorization of the Marine Sanctuaries Act

On 18 June 2008, the House Natural Resources Committee, Fisheries, Wildlife and Oceans Subcommittee conducted a hearing on the reauthorization of the National Marine Sanctuaries Act (NMSA). John Dunnigan of the National Oceanic and Atmospheric Administration (NOAA) stated that the system provides protection and management of almost 150,000 square miles of ocean and coastal habitats, and that it provides an ideal platform to test new conservation practices that can be applied in other coastal and marine areas. He continued by stating that NMSA has lacked an overarching mission statement since its passage in 1972 and concluded by stating that NOAA strongly supports the reauthorization of NMSA.

Leon Panetta of the Joint Ocean Commission Initiative commented NMSA needed the following improvements:

**Continued on page 354**
The notable features of this journal include:

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Developing a Mechanistic Understanding of Fish Migrations by Linking Telemetry with Physiology, Behavior, Genomics and Experimental Biology: an Interdisciplinary Case Study on Adult Fraser River Sockeye Salmon


ABSTRACT: Fish migration represents one of the most complex and intriguing biological phenomena in the animal kingdom. How do fish migrate such vast distances? What are the costs and benefits of migration? Some of these fundamental questions have been addressed through the use of telemetry. However, telemetry alone has not and will not yield a complete understanding of the migration biology of fish or provide solutions to problems such as identifying physical barriers to migration or understanding potential impacts of climate change. Telemetry can be coupled with other tools and techniques to yield new insights into animal biology. Using Fraser River sockeye salmon (Oncorhynchus nerka) as a model, we summarize the advances that we have made in understanding salmonid migration biology through the integration of disciplines (i.e., interdisciplinary research) including physiology, behavior, functional genomics, and experimental biology. We also discuss opportunities for using large-scale telemetry arrays and taking a more experimental approach to studies of fish migration that use telemetry (i.e., intervention studies involving endocrine implants, simulated migration studies) rather than simply focusing on descriptive or correlational techniques. Only through integrative and interdisciplinary research will it be possible to understand the mechanistic basis of fish migrations and to predict and possibly mitigate the consequences of anthropogenic impacts. Telemetry is a tool that has the potential to integrate research across disciplines and between the lab and the field to advance the science of fish migration biology. The techniques that we have applied to the study of Pacific salmon are equally relevant to other fish taxa in both marine and freshwater systems as well as migratory animals beyond ichthyofauna. The interdisciplinary approach used here was essential to address a pressing and complex conservation problem association with sockeye salmon migration.
Entendimiento Mecanístico de las Migraciones de Peces Relacionando Telemetría y Fisiología, Comportamiento, Genética y Biología Experimental: el Salmón Adulto del Río Fraser Como Caso de Estudio Interdisciplinario

RESUMEN: La migración de los peces representa uno de los fenómenos biológicos más complejos e intrigantes del reino animal. ¿Cómo es que los peces migran distancias tan grandes? ¿Cuáles es el costo/beneficio de la migración? Algunas de estas preguntas fundamentales han sido abordadas mediante el uso de la telemetría. Sin embargo, por sí misma, la telemetría no puede ni podrá ofrecer un entendimiento completo del origen de las migraciones de peces, no dará soluciones a problemas como la identificación de barreras físicas a la migración y tampoco permitirá entender los potenciales efectos del cambio climático. La telemetría, no obstante, puede complementarse con otras herramientas y técnicas para generar nuevos enfoques en la biología animal. Utilizando como modelo de estudio al salmón “sockeye” del Río Fraser (Oncorhynchus nerka) en el presente trabajo se resumen los avances logrados en cuanto al entendimiento de la biología de su migración mediante la integración del conocimiento de distintas disciplinas (i.e. investigación interdisciplinaria) como la fisiología, comportamiento, genética funcional y biología experimental. También se discute tanto la oportunidad de usar los diseños de telemetría a gran escala como el considerar análisis de carácter más experimental para estudiar la migración de los peces (i.e. estudios con implantes endócrinos, estudios de simulación de migraciones) en lugar de enfocarse sólo en técnicas descriptivas o de correlación. Solo mediante la investigación integrativa e interdisciplinaria será posible comprender las bases mecanísticas de la migración en los peces y predecir, y posiblemente mitigar, las consecuencias de los impactos de origen humano. La telemetría es una herramienta que tiene el potencial de integrar la investigación de diferentes disciplinas así como aquella proveniente del trabajo de campo y de laboratorio, con la finalidad de avanzar en la biología de la migración de los peces. Las técnicas que se han aplicado para el estudio del salmón del Pacífico son igualmente importantes para otros taxa de peces tanto marinones como dulceacuícolas, y para otros animales migratorios. El enfoque interdisciplinario que se usó en este trabajo demostró ser esencial para abordar una asociación de problemas crecientes de la conservación relacionados a la migración del salmón.

INTRODUCTION

Migration is one of the most complex and intriguing biological phenomena in the animal kingdom, and is observed in a wide variety of taxa including birds, mammals, insects, and fish (Dingle 1980). Ramenofsky and Wingfield (2007) characterized the changes in environmental conditions that regulate migration into three categories: (1) predictable seasonal changes in environment (e.g., temperature, photoperiod) which influence resources (e.g., food supply), (2) unpredictable changes associated with disturbance (e.g., weather, anthropogenic activity, predation), and (3) social relationships that tend to be life-stage related. In fish (Northcote 1984; Lucas and Baras 2000), and indeed most taxa, research efforts to date have focused primarily on the first category, where there are predictable movements between breeding and non-breeding areas. Irrespective of scale, migration is a remarkable activity that requires an understanding of both behavior (that is, what motivates a fish to migrate) and physiology (the capability for following through on its motivation; Hinch et al. 2006), and thus its study requires collaboration and integration between two or more distinct disciplines.

Early studies of fish migration relied on external marking to track individuals between different habitats in an effort to characterize timing and extent (Lucas and Baras 2000). However, spatio-temporal variation inherent to these kinds of studies can lead to biases against the detection of movement (i.e., the “restricted movement paradigm”; Gowen et al. 1994). Since the 1970s, a number of innovations in telemetry have enabled researchers to track individual organisms remotely in the wild using radio and acoustic platforms. Telemetry also includes devices that store data (archival data loggers—also called “biologging”; Block 2005; Ropert-Coudert and Wilson 2005) which are either downloaded upon recovery, or periodically transmitted to receivers, or some combination (Cooke et al. 2004a). Although telemetry devices can be expensive and cannot be used with all taxa or life stages (because the available tag sizes are inappropriate for the organism), they have provided biologists with unprecedented information on the spatial distribution and movement patterns of fish.

To date, the majority of telemetric studies examining migration have been either observational (describing patterns) or correlational (exploring relationships between environmental factors and migration timing or success). However, most of these approaches do not allow one to test hypotheses about mechanisms affecting migration. In fact, observational studies tend to generate more questions than answers, many of which cannot be addressed through telemetry alone. Nor does telemetry alone provide solutions to anthropogenic problems such as migration barriers and climate change impacts. Interestingly, migratory fish species are at twice the risk of extinction than non-migrating ones (Riede 2002) and are more susceptible to commercial and recreational exploitation (M.R. Donaldson, unpublished data). Given the complexity of migration and its role in a myriad of management and conservation situations, simply documenting...
migration timing and extent is insufficient. For example, we need to understand the fundamental processes that enable some fish to migrate vast distances, the causes of mortality during migrations, and the factors that cause some fish to migrate and others not to. Telemetry alone will never yield a complete understanding of the migration biology of fish, but as we will show, by integrating positional telemetry with other disciplines (e.g., stress physiology, functional genomics, oceanography, experimental biology) we can start to test hypotheses that until recently were not practical or within reach of fish ecologists.

The objective of this article is to highlight opportunities for enhancing the study of fish migration by adopting a more interdisciplinary (Box 1) approach to telemetry studies. To do so, we review our studies of adult Pacific salmonids (Oncorhynchus spp.) with a focus on the spawning migration of adult sockeye salmon (O. nerka) where we have adopted an interdisciplinary approach. The work we describe is a combination of basic and applied research and uses a number of novel techniques that were spatially and temporally organized around telemetry studies. Based on our experience and progress, we feel that our interdisciplinary and integrated approach, which couples telemetry with other techniques, has the ability to enhance future research on fish migration and ultimately provide fisheries managers with the knowledge to better manage and conserve migratory fishes globally. We also acknowledge that there is a rich historical literature on the topic of salmonid migration and complete coverage is beyond the scope of this paper (see Groot et al. 1995 for a starting point to the historical literature). Here we have focused on contemporary and forthcoming research that is focused on Fraser sockeye salmon.

### ADULT PACIFIC SALMON MIGRATIONS

The considerable information available on the migration of Pacific salmon, coupled with their importance to humans and ecosystem function, makes them a useful model organism to explore universal aspects of migration biology that extend well beyond salmonids. Pacific salmon life histories are varied, providing ample opportunity to explore inter- and intra-specific physiological and behavioral diversity (See Groot et al. 1995). Indeed, Hinch et al. (2006) recently used sockeye salmon as the model for the first life-history review of the behavioral physiology of fish migrations. Our research on sockeye salmon in the Fraser River, Canada's most productive salmon river, has focused primarily on adult spawning migrations in coastal and freshwater environments with a goal of gaining an improved understanding of physiological and energetic limitations. Adult salmon must transition from saltwater (where fish are hyposmotic) to freshwater environments (where fish are hyperosmotic), which creates significant physiological challenge. They often traverse long up-river distances (e.g., exceeding 1,200 km) which is challenging because they cease feeding a week or more before entering freshwater and must fuel the migration and gonad maturation by endogenous energy reserves (Brett 1995) and thus have enough remaining to spawn. Furthermore, river migration environments can be very inhospitable with fish facing variable, sometimes lethal temperatures and unpredictable flows, particularly now in our current era of climate warming. Because the coastal and up-river migration stages are naturally stressful, can involve high levels of mortality, and is when most fisheries on Pacific salmon occur, the need is great to understand movement and survival patterns. Not surprisingly, the majority of telemetry studies on salmon have focused on adult spawning migrations (reviewed in Hinch et al. 2006), but there is also a large body of work on outmigration of smolts with telemetry and PIT tagging (e.g., English et al. 2000; Venditti et al. 2000; Welch et al. 2004; Melnychuk et al. 2007), including several that couple different techniques from multiple disciplines to gain an improved insight into the mechanisms underlying out-migration biology (e.g., Martinelli-Liedtke et al. 1999; Aarestrup et al. 2000). Indeed, there are arguably more interdisciplinary studies on smolts than adults (see Hoar 1976; Høgåsen 1998). The focus of our article will be on the adult migratory phase.

A further important impetus behind the development of an interdisciplinary approach to studying salmon migrations was a fisheries crisis associated with the late-run Fraser River sockeye salmon, an economically important stock complex that includes the famed Adams River stocks. Unlike other run timing groups in the Fraser River (i.e., early Stuarts, early summer, and summer runs), late-run fish were known for their holding behavior in the Strait of Georgia (Fraser River Estuary), where they stopped their migration for periods of three to six weeks prior to re-initiating migration up-river (Cooke et al. 2004b). Beginning in 1995, segments of the run entered the river with little or no delay in the Strait of Georgia (Figure 1), and mortality rates for early-entry migrants exceeded 99% in some years (Cooke et al. 2004b). While developing a long list of hypotheses to explain both this early-entry behavior and the associated high mortality (Cooke et al. 2004b), it became apparent that there was surprisingly little known about the factors influencing migration behavior for adult Pacific salmon. This article summarizes the development of an interdisciplinary and interagency research program to examine mechanisms of mortality and behaviors of salmon migrations, and is intended to emphasize the opportunity available to telemetry practitioners worldwide interested in the study of fish migrations that utilize telemetry simply by being creative and reaching out to other disciplines. We conclude by discussing the benefits and challenges to interdisciplinarity.

### NOVEL OPPORTUNITIES FOR TELEMETRY IN FISH MIGRATION RESEARCH

Telemetry is revolutionizing how we study fish migration. However, by coupling telemetry with other tools and approaches,
it is possible to unravel some of the mysteries of migration biology (i.e., both proximate and ultimate questions) that would not be possible otherwise. For each subsection below we provide an overview of a specific methodological technique or approach and describe how each methodology has been implemented to advance an understanding of migrations. We begin with coverage of several topics that are central to our research program, specifically, the infrastructure needed to track migratory salmon across long distances (i.e., telemetry arrays), genetic tools needed for stock assignment of telemetered individuals, and non-lethal energetic and physiological biopsy techniques that enable us to collect tissues from telemetered fish.

**Large Scale Biotelemetry Arrays—Acoustic and Radio**

Technological developments associated with the advent of cell phones and the demand for other low power electronics have made it possible to deploy very-large scale and permanent acoustic (e.g., Welch et al. 2002; Heupel et al. 2006) and radio (e.g., English et
al. 2005) telemetry arrays. Instead of manually tracking individual fish, which is labor intensive and can only be done at irregular intervals, large-scale arrays enable the continuous monitoring of individuals across hundreds or even thousands of kilometers. In 2002 and 2003 a radio-telemetry array was established on the Fraser River that extended from Mission (~80 km from the ocean) to terminal spawning grounds (up to 1,200 km from ocean; Figure 1). Migration histories of coastal tagged sockeye were reconstructed from telemetry data (English et al. 2003, 2004) detailing the abnormal entry timing phenomenon of some late run sockeye (Figure 2). This receiver array has been deployed annually from 2005–2007. A pilot version of the Pacific Ocean Shelf Tracking (POST) acoustic telemetry array was deployed in 2003 to extend telemetric monitoring to marine areas (Crossin et al. 2007) and into deep lakes of the Fraser watershed. In 2006, large elements of this array were expanded (Figure 1) and some of it is presently used in a multi-year deployment with year-round coverage representing the world’s largest telemetry array. Coastal monitoring with this array has proven very effective at revealing how variable stocks and individuals are in the durations of estuarine holding periods prior to starting freshwater migration, and has revealed that once fish enter the river mouth, their migration becomes very directional (Crossin et al. 2007). Receivers (both radio and acoustic) have also been deployed in the vicinity of terminal spawning grounds (Figure 1) to determine migration success.

Figure 2. Representative migration history of two late run Fraser sockeye salmon (Adams stock) gastrically radio tagged on the same day in the ocean at Johnstone Strait (see Figure 1). Movement was monitored with an array of radio receivers (see Figure 1). One sockeye exhibits the typical holding period (2–3 weeks) in the estuary prior to entering the river. Conversely, the other individual enters the Fraser River within a few days of tagging and migrates upriver, however, this individual holds in their natal Shuswap Lake for two weeks prior to reaching the Adams River spawning ground such that the actual spawning date does not differ appreciably between these two very different migration strategies. See English et al. (2005) for more details on the radio telemetry study.

The information collected from the telemetry arrays provided an unparalleled opportunity to relate behavior and physiology of individual animals in the ocean with their subsequent migration survival and reproductive success. In addition, the data have proven very useful, when incorporated with a fisheries tag-recovery program, at identifying relative exploitation rates along migratory routes, and for the first time assessing natural mortality rates in coastal versus freshwater environments (e.g., Cooke et al. 2006a,b; Crossin et al. 2007). However, it is important to ascertain detection efficiency for any array to be certain that it is providing credible data on movements and survival. Detection efficiencies for radio-tagged sockeye in excess of 95% were common for most of the stations deployed along the Fraser River from 2002–2006 (English et al. 2003, 2004; Robichaud and English 2006, 2007). In only a few locations where the river was very wide and deep did the detection efficiencies drop below 90%. In 2006, we estimated that acoustic arrays deployed in the Strait of Georgia and Juan de Fuca Strait (Figure 1) detected 94–100% of the passing acoustic-tagged sockeye. In these studies, we thus interpret the numbers of tagged fish detected at a location as survival to that location. We caution that attrition between the monitoring locations (e.g., mortality) may also be caused by other processes other than “natural” mortality, such as tag loss, handling effects, or fishery removals. Tag retention for sockeye is believed to be high based on marine holding experiments (English et al. 2003, 2004) and high detection rates for in-river releases (Robichaud and English 2006). In 2006, 67% of acoustic-tagged sockeye released in Johnstone Strait survived to reach the SSGG listening line (Figure 1) and 49% released in Juan de Fuca Strait survived to the SSGG line (survival/day 91–92%; Table 1). Thus, in this example, large percentages of fish disappeared in coastal environments. Some were captured

Table 1. Number of acoustic tagged and released Fraser sockeye from Johnstone Strait (JS) and Juan de Fuca Strait (JdF), survival/day and mean travel time to the Southern Strait of Georgia acoustic line (SSOG, see Figure 1). Survival/day was estimated as S1/TMean, where TMean = mean travel time, and was adjusted for tag returns from the fishery.

<table>
<thead>
<tr>
<th>Release locale</th>
<th>Number of tagged sockeye</th>
<th>Number survived to SSOG</th>
<th>Tagged fish returned from marine fisheries</th>
<th>Tags returned (%)</th>
<th>Overall Survival (%)</th>
<th>Mean travel time (days)</th>
<th>Survival/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>JS</td>
<td>108</td>
<td>72</td>
<td>3</td>
<td>3%</td>
<td>67%</td>
<td>4.7</td>
<td>92%</td>
</tr>
<tr>
<td>JdF</td>
<td>39</td>
<td>19</td>
<td>3</td>
<td>8%</td>
<td>49%</td>
<td>6.6</td>
<td>91%</td>
</tr>
</tbody>
</table>
and our reported tag recoveries are undoubt-
edly an underestimate of actual exploitation
rates, and some likely perished from natural
causes. But these results beg the question of
what about these fish may have caused or
contributed to their specific fate? Such ques-
tions provide the general context for the
integrative work discussed below.

**Incorporation of Genetic Tools**

In order to gain the most from biote-
lemetry studies, researchers must know the
population origin of animals being tracked.
Animals are often tagged along a migration
route instead of within the home or natal
environment. Under these circumstances, it
may be possible to use genetic markers to pre-
dict their population of origin. This has been
done successfully in Fraser River sockeye
salmon, as large genetic databases used for
stock identification in fisheries management
already exist. Hence, in sockeye salmon,
which exhibit strong genetic structure due
to their high degree of fidelity in homing to
natal sites, small samples of tissues from the
operculum or adipose fin (collected so as to
avoid killing the fish) are sampled from fish
at time of tagging. Genetic analysis of micro-
orosatellite loci provides highly accurate and
rapid identification (in some cases 24 h) for
individual fish (Beacham et al. 2005). With
this information, researchers can determine
timing and location for tagging efforts and
rapidly identify if the targeted number of fish
from the populations of interest have been
tagged (English et al. 2005). Furthermore,
knowledge of the population of origin of
salmon allows researchers to determine the
fate of fish during river migration (English et
al. 2005; Robichaud and English 2006, 2007)
and examine associations between physi-
ological condition in the ocean and fate in
river on a population-specific basis (Cooke
et al. 2006a,b; Young et al. 2006; Crossin
et al. 2007). Knowing the population of
origin enables researchers to ask questions
regarding stock-specific migration routes
(e.g., distances and elevations of migration
routes, which are highly stock-specific) and
environmental conditions (e.g., migration
routes and duration of migration in relation
to water temperatures and flow conditions).
Given the important role of genetics in the
management and conservation of Pacific sal-
omids (Waples et al. 1990), the integration
telemetry and genetics has the potential
to yield major advances.

**Incorporation of Non-Lethal Physiological
and Energetic Biopsies**

Physiology and energetics are integral for
long distance fish migrations (Hinch et al.
2006), particularly those involving a transi-
tion between marine and freshwater systems
(Shrimpton et al. 2005) and reproductive
maturation. In addition to incorporating
physiological sensors into telemetry devices
(see below), non-lethal tissue biopsies or other
conditional assessments can be combined
with positional telemetry. Positional (e.g.,
standard) transmitters are relatively inex-
pensive compared to physiological telemetry
devices (e.g., electromyogram transmitters),
providing opportunity to achieve reason-
ably large "physiology-telemetry" sample
sizes with modest budgets. Although this
approach does not provide real-time data
on physiological or energetic status, it does
provide an indication of the status of the ani-
mal upon release. By coupling assessments of
animal position, movement, behavior, and
survival with non-invasive physiological
and energetic sampling, it becomes possible
to test hypotheses associated with animal
condition, behavior, and fate. The ability to
link individual behavior and fate with ener-
gy and physiology has eluded researchers
until recently (Altmann and Altmann 2003;
Goldstein and Pinshow 2006) and yet inter-
individual variation is recognized as an impor-
tant concept (Bennett 1987). Although the
concept of releasing transmitter-implanted
animals that have been biosampled for physi-
ological variables is simple and the poten-
tial insight invaluable, there are only a few
published examples where this approach
had been employed to study fish migration,
all within the last few years. Conventional
lethal physiological sampling (see McKeown
1984 for a summary of previous physiology
studies on fish migration) was ruled out as
the only sampling method in our studies
(although we did use it to complement non-
lethal telemetry sampling) because sampling
from a population that encounters natural
mortality during its migration provides little
insight into what happened to those that
were unsuccessful and/or died because the
sampling progressively becomes limited to
those fish that have succeeded in completing
a specific part of the migration. Assessments
of the physiological condition for individuals
with known fates and migration behavior are
clearly preferred.

It is possible to rapidly and non-lethally
collect a number of tissue samples includ-
ing blood (usually via caudal puncture), gill
tissue (using surgical tools), muscle (using
muscle biopsy punch), fin tissue, and scales.
Cooke et al. (2005) demonstrated that with
practice it is possible to rapidly sample mul-
tiple tissues from un-anesthetized, trans-
mitter-implanted (gastrically) fish without
deleteriously affecting animal condition or
post-release behavior. These tissue samples
can be analyzed for a variety of parameters
using a number of techniques including
blood and muscle biochemistry (e.g., metabo-
lates, ions, acid/base status), hematology
(e.g., hemoglobin, hematocrit), endocrinol-
ogy (e.g., hormone titres associated with
reproduction or stress), genetics (e.g., stock
identification; see above), genomics (e.g.,
gene expression; see below), and stable iso-
topes (see below). In addition, a number of
new tools enable the non-lethal measure-
ment of energy density using microwave sig-
nals (see Crossin and Hinch 2005) or total
body electrical conductivity measures (i.e.,
TOBEC). Typically, fish are anesthetized
prior to blood, muscle, and gill biopsies (e.g.,
McCormick 1993). However, in some cases
like migratory adult salmon) transmitter-
implanted fish could be caught in fisheries
and then processed for human consumption
which could put anesthetics into the human
food supply. Also, anesthesia may unneces-
sarily increase handling time, recovery, and
post-operative care, risk of predation, as well
as physiological disturbances arising from
the anesthesia. Thus, we have developed proto-
cols for physiological biopsy without the use
of anesthesia (Cooke et al. 2005).

We have used this biopsy technique to
sample fish in the Pacific Ocean and then
to evaluate the physiological and energetic
correlates of fate and behavior. One of our
hypotheses explaining why late-run sockeye
salmon were entering the river early was
that they had a different physiological status.
Specifically, we predicted that abnormally
early migrants would have advanced matura-
tion status (as assessed by reproductive hor-
mones), be prematurely prepared for entry
to freshwater, and/or have low energetic status.
Any of these physiological differences could
motivate the fish to enter the Fraser River
and reach spawning grounds as quickly as
possible (Cooke et al. 2004b). Indeed, our
first prediction was correct in that abnor-
ma1ly early migrants tended to have elevated
levels of reproductive hormones, including
testosterone, 11-ketotestosterone, and estradi-
ol (Cooke et al. 2008). However, since
gill Na,K+ ATPase was not significantly
different in early migrants, although more
variable from normal timed migrants, we
found limited evidence to support our second prediction regarding premature preparation for freshwater entry. Interestingly, converse to our prediction that early migrants had lower energy, motivating them to move more rapidly to spawning grounds, early migrants had higher energy densities than normal timed migrants. Using biopsies from fish tagged and released in the ocean, we found evidence that fish which failed to enter freshwater were characterized by elevated levels of stress indicators (e.g., elevated plasma lactate, glucose, and cortisol; Cooke et al. 2006a,b), whereas fish tagged during freshwater migrations (in the Thompson River; Figure 1) but failed to reach the spawning grounds had lower gross somatic energy and higher levels of plasma reproductive hormones than those that reached spawning grounds (Young et al. 2006). Recapturing previously biopsied individuals that are tagged with telemetry devices and evaluating temporal changes in physiological variables is an exciting approach that we have recently attempted. We captured, biopsied, and released acoustic-tagged Weaver Creek sockeye (Figure 1) during their migration, then re-captured some of these same individuals from spawning grounds several weeks later by using hand-held mobile acoustic receivers (Figure 3). Physiological measures evaluated included plasma lactate (an index of stress and recent anaerobic physical exertion) and plasma osmolality and gill Na+/K+ ATPase (indicators of ionic and osmoregulatory preparedness). The results reveal that some individuals physiologically respond to the migration in very different ways than the population trends. Such unique individuals may represent ones that perish before spawning or produce inferior offspring. Indeed, previous work by our group has revealed that sockeye salmon that tend to die en route in the freshwater migration phase are characterized by having higher levels of lactate (Young et al. 2006) and osmoregulatory dysfunction (Cooke et al. 2006b). This is potentially a very powerful assessment tool as it revealed just how individual-specific changes in physiological features can be and that average population-level changes are only a piece of the puzzle when trying to understand the mechanisms underlying behavior and fate.

**Incorporation of Genomic Tools**

Genetic studies generally are based on the variation at a small number of genes and gene families hypothesized a priori to be of importance, whereas genomic research typically encompasses thousands of genes, or even the entire genome, many with unknown connections to the traits of interest. Moreover, functional genomics research captures the interplay of genetic and environmental factors on the fate or behavior of an organism (Feder and Mitchell-Olds 2003), rather than viewing them as discrete processes. Gene arrays (also called microarrays) are a new functional genomics tool that can profile the expression of thousands of genes at once, enabling the assessment of response to environmental stressors on a genome-wide scale (Klaper and Thomas 2004; Thomas and Klaper 2004). In migration studies, microarrays can be used to determine the physiological switch points that occur en route, and to test hypotheses about the molecular pathways and regulatory elements involved in physiological change and maturation (Miller et al. 2007). Because gene arrays examine many more physiological pathways than is possible with conventional bioassays, gene arrays can also be a valuable data-mining tool to guide hypothesis development. For tissues sampled non-destructively, microarrays can be used in conjunction with biotelemetry studies to identify the physiological basis of behavior and/or fate. We used the salmonid GRASP microarray (i.e., 16,006 gene array; Von Schalburg et al. 2005), along with biotelemetry, to assess the genes associated with differential river entry timing.

![Salmonid GRASP microarray (with 16,006 genes) used to reveal patterns of gene expression. Gill and white muscle samples (for gene expression analysis) were collected from fish before they were tagged and released with telemetry transmitters. This approach enables the assessment of genes associated with differential behavior and survival.](image)
and in-river survival in adult sockeye. Using gill tissue collected from radio-tagged fish captured and released in the lower Fraser River (Figure 1) and tracked towards spawning grounds in 2005, we found a strong association between gene expression and freshwater fate. Statistical analysis revealed that 88 genes were expressed at a higher level in the fish that survived compared with fish that perished during migration (Figure 4, page 322). Profiles of survivors were more alike than that of mortalities (i.e., the dendrogram shows experimental condition clusters linking more tightly together among survivors) suggesting that fish die during migrations for several different physiological reasons but that fish survive because of a more common physiology. The gene clusters and physiological pathways that they regulate are presently being resolved, but regardless, these results demonstrate that some sockeye are physiologically predisposed at the start of river migration to survive and others to die—results consistent with our non-invasive biopsy results discussed above. The coupling of telemetry and genomics is going to yield unprecedented information on migration biology of fish. However, there will need to be re-engineering of scientific attitudes, training, and institutions, to achieve extensive interdisciplinarity and understanding of the promise of ecological functional genomics before this becomes a reality (Feder and Mitchell-Olks 2003).

**Incorporation of Physiological Sensors**

Researchers studying migration have used travel times from telemetered fish between two known points as well as other creative techniques to estimate swimming speeds, which are then used to predict energetic costs. Although such information is useful, it does not provide insight into the fine-scale behavior, swimming dynamics, or real energy expenditure as fish rarely swim in a straight line or at constant speeds and most telemetry devices operate with transmission rates that are significantly longer than burst swimming events. Failure to address such issues, particularly from short duration but high-intensity burst swimming activity can yield dramatic underestimates of migration costs (Rand and Hinch 1998). Innovation in physiological sensor technology that can be adapted into biotelemetry (or biologging) platforms means that researchers can obtain information on physiologically and energetically relevant activity through the measurement of heart rate, opercular rate, or some indicator of locomotion (e.g., electromyogram [EMG], accelerometer, tail beat). Although all of these technologies have been used on fish, only EMG telemetry has been widely embraced by fisheries scientists (Cooke et al. 2004c). Electromyogram telemetry tags are commercially available and can be implanted intraperitoneally, enabling long-term deployments without impeding individual migration performance. Although most often deployed with radio telemetry output modules, acoustic devices have been recently developed. Electrodes placed in the axial swimming musculature detect bioelectric activity (generated by the muscle contractions), which is then collected, integrated, and transmitted providing an indication of locomotory activity. Once calibrated (in respirometer), the transmitters can be used to reliably estimate energetic activity or swimming speeds.

For the study of migration biology, EMG transmitters have most frequently been used in the Fraser River watershed by members of our team. We have found that swimming speeds, swimming pattern, and energy use of upriver migrating salmon is clearly associated with local environment and varies with size, gender, and species. For example, river locales with turbulent flow patterns cause inefficient and energetically expensive swimming patterns (Hinch et al. 1996; Hinch and Rand 1998; Standen et al. 2004). Females tend to be more energetically efficient during migration than males, possibly because they have less reserve energy that can be used for swimming as much more is devoted to their gamete development than in males (Hinch and Rand 1998). Although they are closely related and share many of the same migratory routes, pink (O. gorbuscha) and sockeye salmon exhibit very different migratory behaviors, with pink generally swimming at more constant speeds, rarely exhibiting burst swimming (Hinch et al. 2002). Interestingly, on average, individual specific energy use was very similar between these species for a given reach of the migration (Standen et al. 2004). EMG telemetry has also been used to study energetic costs of migration in other Pacific salmon species including Chinook salmon (O. tshawetscha) and steelhead (O. mykiss) in the Columbia River watershed (USA; Geist et al. 2000; Brown et al. 2006) and in systems in Japan (e.g., Ueda et al. 2000). Because they can be used to help predict migration mortality resulting from energy depletion (e.g., Rand and Hinch 1998), EMG data can be very useful for habitat management in determining optimal water discharge regimes in regulated rivers during periods of migration to reduce energetic costs of migration, and for aiding the design of habitat modifications that affect flow (e.g., bank configurations, gravel bar management). They can also aid fisheries management in decisions regarding balancing allocations of fish between escapement and harvest in light of expectations of natural mortality caused by energy depletion (e.g., Rand et al. 2006).

**Incorporation of Environmental Sensors**

A number of animal-borne environmental sensors can be combined with biotelemetry devices that measure parameters such as water temperature, depth, dissolved oxygen, and salinity (see Cooke et al. 2004a). Our group has focused primarily on the use of thermal sensors because water temperature controls and limits almost all physiological and behavioral parameters of fish migrations, including energetics (Lee et al. 2003), physiological stress (reviewed in Hinch et al. 2006), migration timing (Cooke et al. 2004b; Hodgson et al. 2006), migration rate (Gonieu et al. 2006; Hodgson et al. 2006) and en route mortality (Gilhousen 1990; Macdonald et al. 2000). Migration studies that use telemetry often...
record environmental temperatures from a series of stationary temperature stations and then correlate these data with receiver detections of telemetry tagged fish to estimate thermal exposures (Goniea et al. 2006). However, this approach does not permit an understanding of changes in individual body temperatures throughout complete migration routes. Remote temperature data can be obtained from free-swimming migrants by using temperature-sensitive telemetry transmitters that send thermal and positional data to receivers in real-time (Berman and Quinn 1991; Azumaya and Ishida 2005; Clabough et al. 2006). The disadvantage of this approach is that data are only transmitted when detected by a receiver, which can reduce the temporal resolution of the data. These transmitters can also be very expensive. Alternatively, combining positional transmitters with archival temperature loggers can yield high-resolution temperature data throughout entire migrations, and be much less costly. Temperature loggers permit data to be collected continuously (e.g., minutes, hours), but must be retrieved in order to download temperature data to a computer (Tanaka et al. 2000) and recovery rates can be quite low (e.g., < 15%; Newell and Quinn 2005; ~13% by our group in 2006).

Because salmon home to specific natal areas, there is some opportunity for retrieving thermal loggers for fish that survive migrations and which can be located on spawning grounds using telemetry, although this can be a challenging task. When linked with detection data from telemetry arrays, temperature loggers permit the re-creation of complete migration thermal histories for individual migrants. Thermal histories allow

Figure 5. A representative thermal history figure for an adult migrating sockeye salmon (summer run, Horsefly stock) that was gastrically radio tagged (with an archival temperature logger attached to the transmitter) in the marine environment at Juan de Fuca Strait in 2006. Individuals were tracked from river entry to spawning grounds using a fixed telemetry array in the Fraser River. Labels refer to detection locations (i.e., fixed telemetry arrays) throughout the Fraser River watershed and correspond to inset map. Temperatures were logged at hourly intervals.
for a fundamental understanding of thermoregulatory behavior (e.g., use of thermal refugia, holding patterns, diel temperature fluctuations) during migrations and permit links to be made with multiple endpoints (e.g., linking physiological stress or energetic status with stressful temperatures or accumulated thermal units). In an example from 2006 (Figure 5), a marine-tagged adult sockeye experienced relatively cool coastal temperature for a few days after tagging then a highly variable thermal environment for a day as it entered the river mouth (+/- 8°C change; potentially related to tidal cycles). During its first week in the Fraser River, it experienced 17-19°C, though daily cycles and other anomalies were detected. Passage past cool water tributaries and through the hypolimnion of lakes seems to offer thermal refuge prior to reaching spawning grounds. The main disadvantage of using temperature loggers is that thermal histories of fish which perish during a migration cannot be assessed. For situations where temperature information is needed on fish that likely will not survive migrations, it is possible to estimate thermal experience from migration depth information through using depth-reporting acoustic transmitters. We have used this approach in several inland lakes and have found that sockeye which utilized thermal refugia (i.e., below the thermocline) were more likely to survive the migration than those that did not (Farrell et al. in press; see also Newell and Quinn 2005; Newell et al. 2007). Management agencies can use this information to inform decisions about reducing harvest rates to account for expected thermal-based migration mortality and thus aid in achieves pre-season escapement goals. Thermal history data also provides information on the actual environmental conditions encountered by migrating fish en route and, thus, allows for the validation of temperature-mortality models (e.g., Rand et al. 2006).

Integration with Oceanographic Data

The marine waters of British Columbia are a heterogeneous and complex biophysical system in which highly variable factors, such as temperature, salinity, dissolved oxygen, nutrient concentration, and currents generate a patchy distribution of marine animals. For anadromous migrating adult fish, oceanographic factors may not only influence travel distances and timing, but may also affect behavioral and physiological performances during up-river migration. Salmon migrations have been studied in coastal waters (e.g., Madison et al. 1972; Stasko et al. 1976; Quinn and terHart 1987; Quinn et al. 1989), but relatively less is known about salmon migration in the high seas. One example of how migratory behavior might be related to oceanographic conditions is the work conducted by Block et al. (2001) who found that Atlantic bluefin tuna (Thunnus thynnus) made trans-Atlantic migrations which could be linked directly to oceanographic processes such as productivity and sea surface temperature.

One hypothesis for unusually early spawning migrations in Fraser River late-run sockeye salmon is related to changes in coastal water properties. Changes in the marine environment, such as in surface water temperature, salinity, circulation, and mixed layer depth, may affect river entry timing by earlier “triggering” of certain physiological systems (e.g., accelerated maturation rates, freshwater preparedness). At present we are attempting to develop correlational links between the timing of up-river migration initiation of late-run Fraser River sockeye salmon and oceanic and meteorological measures from coastal waters of British Columbia (Thomson 2002). Preliminary results indicate that the proportion of late-run sockeye that enter freshwater early correlates with indices of coastal mixing (e.g., retention of freshwater layer). During homeward migration, Fraser River sockeye salmon encounter strong and fortnightly varying tidal currents in coastal areas and it is reasonable to believe that both the magnitude and the direction of the currents may also influence migratory behavior as has been documented for other salmonids (Metcalfe et al. 1990). Interestingly, Quinn et al. (1989) noted that Fraser sockeye did not exhibit behaviors indicative of selective tidal stream transport. Establishment of a clear cause-and-effect relationship between salmon river migration timing and their physical oceanic environment could provide a valuable tool for in-season management and conservation measures for Fraser River sockeye stocks. Although we have found strong correlations with several oceanic variables which make sense from a cause-and-effect perspective, we are not yet in a position to make definitive statements regarding the importance of the changing environment to fish response. Although there exist very few telemetry studies conducted with a focus on migratory fish ecology and the associated oceanography, such interdisciplinary studies could help us develop more suitable management plans for Fraser sockeye salmon (Hinch et al. 2006) and possibly other migratory fish species (Åkesson 2002).

Integrating Telemetry with Laboratory and Field-based Physiological Experiments

Swimming performance and oxygen consumption studies conducted in a laboratory setting could be relevant to field telemetry studies on fish migration. Such experiments provide an opportunity to determine ecologically relevant thresholds, such as the thermal optima (Topt) for aerobic scope which has recently been related to migration success of sockeye salmon. For example, Lee et al. (2003) used swimming performance trials to generate Tcrit values for Weaver Creek sockeye salmon. The laboratory-derived values from Lee et al. (2003) coincided with the most frequently encountered river migration temperature over the previous 60 years (Farrell et al. in press). The temperature when aerobic scope collapses to zero (Tcrit) above Topt has rarely been encountered but an important exception occurred in 2004 when 70% of a stock that entered the Fraser River failed to reach the spawning grounds (Farrell et al. in press). Using Tcrit as a cut off for failure to complete river migration, it was possible to explain over one-third of this disappearance (Farrell et al. in press). Unknown is the aerobic scope needed for up-river migration since zero aerobic scope simply allows to fish to rest and not migrate. Of course, the specific needs for aerobic scope will vary according to the migratory challenges faced by specific stocks of salmon. Given these findings, stock-specific characterization of Tcrit for aerobic scope provides promise to link stock-specific migration mortality (as assessed by telemetry) with their physiology.

It is also possible to integrate the findings from telemetry studies and laboratory swimming performance assessments to test hypotheses regarding energy use. Hanson et al. (2008) used energy assessments from fish at capture and travel rate data from radio telemetry to assess migration speeds (used as proxy for swimming speeds), and to estimate reach-specific energy use (from
Laboratory swim tunnel data; Lee et al. 2003) to reach sub-natal watersheds for summer run Fraser sockeye. The results revealed that fish generally displayed individually consistent swim speeds from reach to reach, and that those individuals that started with lower energy reserves did not swim proportionally faster or use proportionally different amounts of energy to reach spawning grounds than fish with higher initial energy reserves. These results suggest that energy reserve status may not be a primary determinant of migratory speed and highlights the value of linking field and laboratory results to broaden our understanding of fish migration behavioral energetics.

Laboratory studies have also validated findings from field telemetry studies where we documented high levels of mortality in late run sockeye salmon that entered the river several weeks earlier than normal. A laboratory study revealed that fish which accumulated more than 400 in-river degree-days (DD) tended to develop severe parasite infections (Parvicapsula minibicornis), which impaired swimming performance and led to significant physiological alterations (Wagner et al. 2005). Wagner et al. (2005) used data from telemetry studies (e.g., English et al. 2005) to calculate reach-specific degree-day accumulation of fish with different migratory behavior (i.e., early and normal timed migrants) and found that early migrants typically accumulated levels of degree-days that were consistent with severe Parvicapsula infections. Conversely, normal-timed migrants avoided the accumulation of sufficient degree days that would promote severe Parvicapsula infections by entering a cooler river and moving directly to spawning grounds.

Use of Intervention Experiments

Telemetry in and of itself generally leads to associations and not necessarily to a cause-effect resolution. Physiological intervention involves applying a treatment directly to the organism(s) of interest coupled with collecting pre- and post-treatment physiological samples followed by release. Tracking of the tagged organisms using biotelemetry then gives an understanding of how the treatment affects the animal, if the quality of the telemetry measurements is of sufficiently high quality. As such, it provides a powerful approach for testing hypotheses directly in the environment on the mechanisms underlying organismal behavior while avoiding the pitfalls which traditionally plague purely lab-based studies. Sensory impairment, endocrine manipulation, and exogenous treatment are three general classes of interventions that have been used as part of intervention-telemetry experiments, either alone or in combination with each other.

Sensory Impairment Interventions

Sensory impairment interventions involve blocking an organism’s use of its visual, olfactory, and/or geomagnetic sensory apparatus. This approach can be used to explore how migrating salmon navigate. Despite extensive use of sensory impairment from the 1960s thru 1990s, sensory deprivation has only recently been coupled with positional telemetry. Ueda et al. (1998) used a combination of blinding, magnetic disruption, and telemetry to demonstrate that fish with sight swim in a straight line through Lake Toya (Japan) to their natal area while visually impaired fish swim in random directions. The authors concluded that Lake Toya sockeye relied on visual cues for the open-water phase of their migration and then switched to olfaction once in close proximity to their natal water. Geo-magnetic orientation and rheotaxis were ruled out as navigation tools used by these sockeye.

Endocrine Interventions

Endocrine manipulation interventions seek to selectively activate or suppress neurosensory or endocrine pathways believed to be involved in migration timing and behavior. One of the primary questions that these approaches have been used for is to explore how maturation state relates to migration timing, energy use, and swimming performance. Research has demonstrated that accelerated sexual maturation, initiated by injections of gonadotropin releasing hormone (GnRH), promoted more rapid arrival at spawning grounds, that male migration timing is associated with serum testosterone and 11-ketotestosterone concentrations, and that female migration timing is driven by high serum DHP levels and declining estradiol-17B levels (Van Der Kraak et al. 1984; Sato et al. 1997). Our research team used endocrine manipulations as a test of our sexual maturation hypothesis for the maladaptive shift to earlier freshwater entry timing of the Fraser River’s late-run sockeye salmon. We intercepted migrating sockeye near the Queen Charlotte Islands (QCI; see Figure 1), approximately 700 km north of the Fraser mouth, and treated fish with GnRH, testosterone, or both hormones. Treated and control fish were fitted with acoustic transmitters, released back to the ocean and tracked to ultimate destination. Data analyses are underway and results are not yet available.

Exogenous Interventions

Exogenous treatment interventions implies subjecting test organisms to an altered environmental condition, such as warmer water temperatures or altered salinities, with the goal of eliciting a physiological and/or behavioral response which is then observed via positional telemetry. We examined the effect of high river temperature as an agent of migratory mortality in this fashion (Crossin et al. 2008). Specifically, adult late-run sockeye salmon were intercepted en route to spawning grounds and transported to large laboratory tanks where they were exposed to either a warm (18 °C) or a cool (10 °C) temperature treatment for ~3 weeks. The two holding temperatures simulated the effects of “early-timed” migrations which typically encounter warmer rivers and “normal-timed” migrations which encounter cooler rivers. At the end of the intervention, fish had accrued > 450 DD

Intramuscular injection of GnRH pellet into an adult sockeye salmon prior to releasing the fish and tracking it with the POST telemetry array.
in the warm treatment, and < 325 DD in the cool treatment, which led to high and low Parvicapsula disease expression, respectively (Wagner et al. 2005). Before being released back into the Fraser River to continue the migration, fish were non-lethally biopsied for blood plasma, gill Na+K+ ATPase activity, and somatic energy density. Migratory behavior and fate were then monitored in the second group of fish as they swam through an acoustic receiver array leading to the spawning grounds. The results of temperature treatment on migratory behavior and fate were striking, as warm-treated fish suffered twice the level of mortality as cool-treated fish, both during the laboratory holding phase and during the completion of river migration. Females exhibited much higher mortality rates than males. These findings were consistent with the hypothesis that elevated water temperatures during the freshwater migration period probably contributes to higher levels of en route mortality in later-run sockeye salmon, and that disease may play a significant role.

In 2006, we combined endocrine and exogenous interventions into a single experiment to test the hypothesis that late-run sockeye which migrate into freshwater earlier than normal do so because they are reproductively more advanced and/or more prepared osmoregulatory for freshwater than normal-timed migrants. We collected 300 migrating sockeye salmon from the Strait of Georgia (Figure 1), transported them to a lab, and held groups for 1 week in either 0 ppt (fresh), 14 ppt (iso-osmotic), or 28 ppt (coastal) salinity water crossed with and without GnRH injections. At the end of the holding period, we measured energy density, collected plasma, gill, muscle, and scale samples, implanted an acoustic transmitter to each fish, and returned fish to the Strait of Georgia for tracking and assessment of migratory behavior and fate. Data analyses are forthcoming.

**Integration with Otolith Microchemistry and Stable Isotope Analysis**

Stable isotopes provide the opportunity to evaluate nutritional status, feeding ecology, and trophic relationships, as well as inferring movement from the assimilation of site-specific isotopic signatures. Cunjak et al. (2005) suggested that isotopic studies could be strengthened by combining stable isotope analysis with telemetry techniques. Analyses conducted on radio-tagged downstream migrating Atlantic salmon smolts revealed different life-history strategies (Cunjak et al. 2005). Cunjak et al. (2005) also reported on remotely tracking fish with passive integrated transponders (PIT tags) and were able to distinguish between movements associated with foraging and seeking cool water refugia during high temperature periods. Stable isotope analysis can be conducted on scales, blood, or muscle tissue from non-lethal biopsies (see above) obtained from telemetered fish. Members of our team are currently analyzing scale samples collected from adult sockeye telemetered in the Pacific Ocean in an attempt to understand the influence of nutritional condition on migration behavior and fate.

An example of another recent synergy is the complimentary use of otolith microchemistry and radiotelemetry to examine life history variation in bull trout (Salvelinus confluentus) in the Hoh River, Washington (Brenkman et al. 2007). Data from tracking of radio-tagged individuals provided insight on the migratory behavior of the fish that helped to validate inferences drawn from variable strontium levels in otoliths. Obviously, otolith chemistry requires lethal sampling and is thus not possible on telemetered fish unless they are recaptured. However, coupling these two techniques, even in a complimentary manner, provided insight that would have not been possible had either of the two techniques been applied independently.

**ON INTERDISCIPLINARITY**

Our interdisciplinary research program arose out of necessity rather than a preconceived decision that we must adopt such an approach in an effort to understand the complex conservation crisis facing adult migratory Fraser River sockeye salmon (Cooke et al. 2004b). Interdisciplinary research is often motivated by a desire to tackle a complex problem, which demands knowledge and methods/tools from many disciplines (Rhoden and Parker 2004). Indeed, interdisciplinary research has been repeatedly identified as a promising strategy for addressing some of the most urgent environmental and conservation problems of today and tomorrow (Steele and Stier 2000; Sankar et al. 2007) and a prescriptive for complicated policy decisions (Metzger and Zare 1999). Based on our experience with this project, we would concur that many of our discoveries would not have occurred and our collective understanding would be more rudimentary had we not engaged in collaborative interdisciplinary research. One problem that often occurs with interdisciplinary projects is scoping of the research problems. However, in fisheries science a conservation crisis (e.g., Cooke et al. 2004b) can often provide the necessary focus and scope for an interdisciplinary project.

Numerous challenges can obstruct interdisciplinary research. For example, it is impossible for a single person or laboratory to possess the range of skills needed to conduct truly interdisciplinary research on fish migration. Hence, researchers need to embrace collaboration with colleagues in other disciplines. We have seen recent unlikely marriages of disciplines, such as functional genomics and ecology (Feder and Mitchell-Olds 2003) and conservation and physiology (Wikelski and Cooke 2006). We anticipate that such synergies as have been outlined above will stimulate advances in other areas of migration science, similar to what we have been able to accomplish on Fraser River sockeye salmon. Such interdisciplinary programs are difficult to launch because stakeholders often lack shared experiences and shared concepts (Sankar et al. 2007). Indeed, working with colleagues who are outside of one’s normal peer group can present challenges, particularly with respect to becoming fluent with the conceptual basis, language, and the scientific and technological limitations of the different disciplines. A mutual sense of trust and respect, as well as a high tolerance for different research cultures can be helpful. Obtaining funding for interdisciplinary research can also be challenging based on the organizational structure of granting/funding agencies as well as the institutional structure of a team that may undertake the research. For example, our team consists of academics from several institutions as well as several government agencies and industry. In our case, the conservation crisis and need for coordinated research yielded support from relevant natural resource agencies and flexibility in how funds could be disbursed to different team members. We are confident that the there is immense potential to make stunning discoveries about fish migration and enhance the management of fish populations, as well as to address other complex conservation or fisheries.
CONCLUSION

We hope to encourage scientists studying migration to move beyond simply documenting localized movement and assessing survival whenever opportunities for adopting a more interdisciplinary approach are available and necessary. Even if movement and survival remain the central goal of a study, additional effort or additional infrastructure can yield far more mechanistic information. There is growing recognition that individual variability is real (and not experimental noise or error) and that it is relevant to population biology (Bennett 1987). Combining telemetry with non-lethal biopsy or physiological sensors enables the researcher to focus on individual differences in behavior or physiology and ideally to evaluate the relationship between behavior and physiology (Hinch et al. 2006). One of the challenges involves reconciling such individual variability with management and conservation goals. For example, most of the novel techniques which we discussed in this article focus on individuals, yet the fundamental fisheries management unit is the stock or population and management should ideally occur at the ecosystem level (Link 2002). Given the complexity of fish migrations, all of the tools and approaches covered in this article will be needed to advance migration science. Already, some of these techniques are being applied to understand the biology of Pacific salmon on the spawning grounds (Hruska et al. 2007), as well as during their migration to reach these sites. We hope that the fish migration studies that use telemetry will become more mechanistic and experimental (i.e., hypothesis driven) and, as a consequence, illuminate the mysteries of fish migration and inform the management and conservation of these important resources. Indeed, the understanding of mechanisms should also allow for predictions of impacts of natural variability and anthropogenic climate change on salmon and other fishes.

ACKNOWLEDGEMENTS

This article represents a combination of ideas delivered in plenary presentations on migration at the 6th Fish Telemetry Conference Held in Europe (Portugal, 2005) by S. Hinch and the at the 7th Fish Telemetry Conference in Europe (Denmark, 2007) by S. Cooke. We thank the Southern Endowment Fund of the Pacific Salmon Commission, the Natural Sciences and Engineering Council of Canada, Fisheries and Oceans Canada, the Fraser River E-Watch Program, the Canada Foundation for Innovation, the Pacific Ocean Shelf Tracking Project (POST), and the Bridge Coastal Restoration Program of BC Hydro. We thank the Alfred P. Sloan Foundation, the Gordon and Betty Moore Foundation, and the Pacific Salmon Commission for financial support of components of the acoustic array described in the paper. This article is a contribution to the Census of Marine Life. A large number of individuals contributed to the work presented here. In particular, we would like to acknowledge Dave Robichaud, Mike Lapointe, Jeff Young, Simon Jones, Jim Cave, Brian Riddell, Al Cass, and Laura Richards. Lisa Thompson assisted with formatting the manuscript. Several anonymous reviewers and Tom Quinn kindly commented on an earlier version of this manuscript.

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The Value of Information in Fishery Management

ABSTRACT: Fishery management is often characterized by trade-offs among conflicting objectives. One important trade-off exists between investments in assessment (reducing uncertainty) and in implementation of management actions in a system. Resource-intensive assessment programs are often used to inform decision makers, and we argue that the value of these assessments should be measured not only in terms of the information they provide, but also relative to other management actions that could be funded in their place. In this article, we illustrate the importance of accounting for all aspects of the value of information using examples drawn from three critical areas of fishery management: invasive species control, commercial fisheries stock assessments, and marine protected area design. We discuss how experts have judged the value of assessment programs in the past, and provide suggestions as to how these methods could be expanded to examine the value of information in a more holistic manner.

INTRODUCTION

Uncertainty is pervasive in natural systems, and manifests itself in many forms (Morgan and Henrion 1990; Regan et al. 2002). The role of science in conservation and management of natural resources is generally to reduce uncertainty (Halpern et al. 2006), and to a lesser extent to allow managers to make decisions in the face of uncertainty. Belief is growing that traditional modes of research may not be able to resolve critical uncertainties at a reasonable cost, or perhaps not at all (Ludwig et al. 1993; Johannes 1998; Sala Á et al. 2002). However, experts in resource management continue to advocate for more resources for information gathering to support science-based decision-making (e.g., NRC 1998; NOAA 2001). We question this view, and suggest that an investment in information gathering should be valued based on its potential to improve management relative to other uses for that investment. Our purpose in writing this article is to urge a more holistic view of management in which assessment is seen as a part of an overall system. This view should facilitate consideration of trade-offs that exist between resources allocated to information gathering and those allocated to other management activities. We suggest that this trade-off has been largely ignored in the past, which can lead to inefficient use of available resources and a failure to meet management objectives.

Information gathering in natural resource management can include fundamental research, monitoring, and the analytical processing of data gathered from these tasks. Clearly, information gathering can help to reduce critical uncertainties and consequently ought to lead to better decisions about conservation and exploitation. However, the information gained through research and assessment comes at a cost, and it is reasonable to assume that a situation of diminishing returns exists, such that at some point further investments in information gathering become difficult to justify. At this point, the cost savings from reduced information gathering may outweigh the small potential loss in decision accuracy that results (Walters and Pearse 1996; deBruin and Hunter 2003; Ling et al. 2006). The challenge is thus to prioritize information needs, and to correctly identify and collect the optimal amount of information required to make good decisions. Additionally, when operating under a finite budget, resources allocated to one activity necessarily detract from those allocated to another. The costs of information gathering thus include not only direct assessment costs, but also opportunity costs: resources used to gather information could be used in some other way to improve the management of a system. Allocating resources to assessment and information gathering may increase certainty and provide economic and ecological benefits, but these benefits come at the expense of other actions that could help to achieve management objectives (Figure 1). Assessment decisions are
because larval sea lampreys prior to their metamorphosis into parasitic stream-dwelling larval sea lampreys prior to Great Lakes tributaries, which targets mainly through the chemical treatment of US. Control of sea lampreys is achieved with an annual budget of over $15 million. Focus of an intensive pest control program for fish species in the Great Lakes that is the trade-offs are less clear, such as commercial fisheries stock assessments, and marine protected area design. We first discuss our own experience in sea lamprey (Petromyzon marinus) control in the Great Lakes, a situation in which the trade-offs are readily apparent. We believe that the lessons learned from this system regarding the value of information can be applied to other managed ecosystems where the trade-offs are less clear, such as commercial fisheries stock assessments and the designation of marine protected areas. We discuss how experts have judged the value of information in the past, and provide suggestions as to how these methods could be expanded to examine the value of information in a more holistic manner.

SEA LAMPREY CONTROL IN THE NORTH AMERICAN GREAT LAKES

The sea lamprey is an invasive, parasitic fish species in the Great Lakes that is the focus of an intensive pest control program with an annual budget of over $15 million US. Control of sea lampreys is achieved mainly through the chemical treatment of Great Lakes tributaries, which targets stream-dwelling larval sea lampreys prior to their metamorphosis into parasitic juveniles. Because larval sea lampreys remain in their natal streams for several years before becoming parasitic, it is neither necessary nor cost-effective to treat every stream each year. However, natural variation in demographic rates of larval sea lampreys makes it impossible to predict with certainty when each stream will require treatment to prevent the downstream migration of parasitic juveniles. Therefore, each year a group of candidate streams is assessed to determine which streams should be prioritized for treatment (Christie et al. 2003; Slade et al. 2003). The current larval assessment methods are costly, using roughly one-third of the total chemical control budget, yet uncertainty remains in the population estimates produced by assessment and hence in the set of streams that should be treated each year (Hansen et al. 2003; Slade et al. 2003; Steeves et al. 2003). Resources allocated to assessment diminish those available to implement control strategies; therefore, any increase in assessment costs in an attempt to increase certainty about which streams to treat will result in a corresponding decrease in the resources available to actually treat streams. Here, the opportunity cost of assessment is very straightforward.

The optimal balance between assessment and control expenditures that will maximize the number of sea lampreys killed is unknown. Recently, we evaluated the effectiveness of an alternative assessment method that is less costly than the current method, under the assumption that resources saved on assessment would be used to fund the chemical treatment of additional streams (Hansen and Jones in press). We used an adaptive management approach, implementing both the experimental and the currently used assessment methods over a three-year period, and independently estimated the total population of sea lampreys that would be targeted by chemical treatments as a result of each method. Our results show that more sea lampreys are killed using the less resource-intensive assessment method than using the current assessment method. A reduction in assessment expenditures resulted in less precise, and possibly less accurate, population estimates, but the corresponding increase in resources available for stream treatments appeared to make up for the decrease in assessment accuracy, resulting in more sea lampreys killed overall.

This study provides a clear illustration of the importance of accounting for opportunity costs when evaluating any information gathering program. In sea lamprey management, our results suggest that the benefits of increased assessment accuracy are outweighed by the costs of forgoing additional lampricide treatments that could be paid for using assessment dollars. This case study provides a relatively simple, but important real-world example of the tradeoff illustrated in Figure 1. We

![Figure 1](image.png)

**Figure 1.** The relationship between resources allocated to information gathering, the resulting quality of information (solid line), and the resources consequently available for other uses (dashed line). The details of this trade-off vary depending on the context, and are explained for each example described in the text. For example, in sea lamprey management the x-axis represents resources allocated to larval assessment, and the solid line represents the increase in assessment accuracy and thus the ability to identify the most suitable set of streams to treat with lampricide in a given year. The dashed line represents resources available for the chemical treatment of streams, and thus the number of streams that can be treated in a single year.
data collection and stock assessments has that allocating considerable resources to worldwide during recent decades suggests (Hilborn and Walters 1992; NRC 1997; Regan et al. 2002 for discussions of factors that are derived from the data are frequently imprecise and subject to a variety of biases (Hilborn and Walters 1992; NRC 1998; Quinn and Deriso 1999).

Experience with commercial fisheries worldwide during recent decades suggests that allocating considerable resources to data collection and stock assessments has not prevented overexploitation and collapse (Walters and Maguire 1996; Fauly et al. 2002; Myers and Worm 2003). This failure of management has occurred in part because of high levels of uncertainty, which are for all practical purposes irreducible, that plague complex, exploited systems, and the inappropriate treatment of such uncertainty in population models (Sainsbury 1998; Schnute and Richards 2001; Kelly and Codling 2006). The failures of fisheries management in the past despite high levels of funding for stock assessments raise questions regarding the role that better-funded stock assessments might play in improving the management of commercial fisheries in the future, and the value of such costly stock assessments should be examined explicitly. This is not to suggest that the current fisheries management crisis is largely due to over-investment in stock assessments, but rather that these assessments should be viewed as components of the entire managed system.

Uncertainty in managed systems can be partitioned into many types (see Williams 1997; Regan et al. 2002 for discussions of types of uncertainty in natural resource management). Some types of uncertainty (e.g., observation error) can be reduced by allocating more resources to assessment, but others (e.g., environmental variation) cannot. We would therefore expect the relationship depicted in Figure 1 to apply to stock assessments for commercial fisheries in that more resources allocated to stock assessments (the x-axis) would result in better estimates of stock abundance and more certainty about management decisions (the solid line). At the same time, as assessment accuracy increases, an increasing proportion of the remaining uncertainty will be irreducible, resulting in diminishing returns from information gathering and the asymptote shown in Figure 1. In some cases, increased data collection to reduce uncertainty may be justified by the increased benefits in harvest or reduced risk of over-exploitation (Charles 1998). However, assessment, statistical analyses, and modeling are cost and labor intensive, and an excessive focus on these activities can detract from other important management procedures (Walters 1998; Schnute and Richards 2001; Kelly and Codling 2006).

The opportunity costs of allocating management resources to assessment of commercial fisheries (the dashed line in Figure 1) could take many forms, as resources currently used to fund intensive stock assessments could be used in a number of different ways. At a very broad level, the dashed line could represent the number of separate stocks assessed worldwide or within a nation’s waters: devoting more resources to individual assessments reduces the number of stocks for which assessments can be conducted (Kelly and Codling 2006), many of which are lacking data (Johannes 1998). Alternatively, the dashed line could represent funding available for research on fundamental uncertainties in biological processes and relationships that would serve to reduce process uncertainty about the exploited stock (Pereiro 1995; Charles 1998; Kelly and Codling 2006). The dashed line could also represent monitoring of the consequences of management actions, a key step of adaptive management which is often lacking (Walters 1997; Walters 2007). Such monitoring would improve future management as the consequences of various management actions became better understood. Finally, the dashed line could represent funds for the enforcement of regulations. Enforcement can reduce so-called “implementation uncertainty”: uncertainty in how regulations will play out in the real world due to illegal landings, bycatch and discards, unreported or underreported catches, and other factors (Rosenberg and Brault 1993).

Many authors have examined the value of reducing uncertainty or the value of increased surveys in commercial fisheries using operating models designed to maxi-

COMMERICAL FISHERY HARVEST MANAGEMENT

Worldwide declines in exploited fish populations have generated a great deal of concern among scientists, managers, and the public in recent years (e.g., Cochrane 2000; Jackson et al. 2001; Myers and Worm 2003). The concerns are multi-faceted, but in the end the major questions in fisheries management concern how to determine and implement sustainable harvest rates for economically valuable stocks. The traditional approach to management of large commercial fisheries has been characterized as an “absolutist approach,” in which large quantities of assessment data are collected and used to estimate population status and forecast the expected performance of alternative harvest strategies (Walters 1998; Parma 2002; Kelly and Codling 2006). Even when these assessments are well-funded and include fishery-independent data, the estimates of population parameters that are derived from the data are frequently imprecise and subject to a variety of biases (Hilborn and Walters 1992; NRC 1998; Quinn and Deriso 1999).

Experience with commercial fisheries worldwide during recent decades suggests that allocating considerable resources to data collection and stock assessments has
mize given objectives (e.g., McAllister et al. 1999; Punt and Smith 1999; Moxnes 2003) by using techniques including Monte Carlo simulations (e.g., Bergh and Butterworth 1987; Powers and Restrepo 1993; Punt et al. 2002) and Bayesian approaches (McAllister and Pikitch 1997; McDonald and Smith 1997). However, these studies did not include any analysis of the value of other management activities that could be funded in place of detailed assessments. Including such an analysis may change the value of increased survey intensity.

An explicit examination of the trade-off we describe may point towards a need to fundamentally restructure the assessment process of a given system. The initial costs of such a change in assessment will perhaps be high, as the new approach is implemented and debugged (e.g., Martell and Walters 2002; Walters and Martell 2002). However, if the long-term trade-offs between assessment costs and other uses for resources that will further management goals are accounted for, high initial investment in the development and implementation of alternative assessment methods may be justifiable. Alternatives exist to complex stock assessments. Rapid assessment techniques have been shown to be effective alternatives to detailed, resource-intensive surveys for a variety of natural systems (e.g., Oliver and Beattie 1993; Jones and Stockwell 1995; Metzeling et al. 2003), although these types of methods have enjoyed limited use in marine fisheries management. Fisheries population estimation techniques and harvest regulations that are effective in the absence of detailed stock data have also been developed (e.g., Walters and Pearse 1996; Hilborn 2002; Shotwell and Adkison 2004). In the end, the appropriate assessment procedure and the activities that could be funded in place of detailed assessments will vary depending on the specific characteristics of the fishery, and on the trade-offs involved.

**MARINE PROTECTED AREAS**

Marine protected areas (MPAs) are regions of marine habitat protected to varying degrees from exploitative uses. MPAs have received much attention in recent years as a means of preserving biodiversity and ecosystem processes, protecting vulnerable populations and habitats, and ensuring the sustainability of fisheries resources (e.g., Botsford et al. 1997; Roberts 1997; Halpern 2003). While some controversy exists regarding the efficacy of MPAs for enhancing populations of exploited fish species to support use outside of the reserve (Hilborn et al. 2004; Sale et al. 2005), they are generally believed to be effective conservation tools, and many countries and regions have established programs to create additional reserves in the future (Day and Roff 2000; Gladstone 2000; NRC 2001). Experts have suggested that if MPAs are to be successful at supporting fishery production and preserving biodiversity, protection of 20% or more of each type of marine habitat will be necessary (Roberts and Hawkins 2000; NRC 2001). Even if the long-term benefits of MPAs are sufficient to justify their establishment, the short-term costs associated with protecting this amount of ocean habitat are likely to be enormous. The cost of a global network of MPAs sufficient for biodiversity protection and fisheries sustainability has been estimated at $5–19 billion US, not including start-up or assessment costs (Balmford et al. 2004). With costs of this magnitude, evaluating the cost effectiveness of alternative marine reserve design is critical.

If costs of information were not an obstacle, MPA networks should be designed using detailed, spatially explicit data on species distributions and abundances throughout their range, ecological processes such as dispersal rates, and socioeconomic factors. However, such information is rarely available on the scale necessary to design MPA networks, especially in impoverished areas where reserves are most needed (Gaston and Rodrigues 2003), and the cost of gathering this information is very large relative to the resources typically available for assessment (Halpern et al. 2006). Furthermore, attempts to assemble a comprehensive database will inevitably divert resources from other important conservation goals (Roberts 2000; Halpern et al. 2006).

Protected areas are generally believed to be more effective when they are created with careful planning, following a systematic process (Pressey et al. 1993; Botsford et al. 2003; Roberts et al. 2003). Numerous criteria have been suggested as data inputs needed to guide the creation of MPAs (Table 1), and spatially-explicit algorithms have been created to assist in the delineation of MPAs which use selected criteria from Table 1 to maximize stated objectives (i.e., Worldmap, Williams 1999; BioSelect, Nichols and Margules 1993; MARXAN, Ball and Possingham 2000). However, there is no consensus on how to trade-off different criteria whose use might lead to different “optimal” configurations. Furthermore, there is good evidence that

### Table 1. Criteria identified as important for consideration in the design of marine reserves.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Selected References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species diversity and abundance</td>
<td>Pressey et al. 1993; Murray et al. 1999; Gladstone 2000, Margules and Pressey 2000; Sala et al. 2002; Roberts et al. 2003</td>
</tr>
<tr>
<td>Species ecology, movement, and dispersal distance at different life stages</td>
<td>Murray et al. 1999; Roberts 2000; Sala et al. 2002; Hilborn et al. 2004; Sale et al. 2005</td>
</tr>
<tr>
<td>Habitat types at relatively fine spatial scales</td>
<td>Pressey et al. 1993; Murray et al. 1999; Gladstone 2000; Roberts et al. 2003</td>
</tr>
<tr>
<td>Socioeconomic information</td>
<td>Murray et al. 1999; Sala et al. 2002; Hilborn et al. 2004; Gladstone 2000</td>
</tr>
<tr>
<td>Stakeholder input</td>
<td>Gladstone 2000; Sala et al. 2002; Hilborn et al. 2004; Sale et al. 2005</td>
</tr>
<tr>
<td>Fishing effort and impacts</td>
<td>Murray et al. 1999; Sala et al. 2002; Roberts et al. 2003a</td>
</tr>
<tr>
<td>Biogeographic regions</td>
<td>Sala et al. 2002; Murray et al. 1999; Roberts et al. 2003</td>
</tr>
<tr>
<td>Multi-species interactions and ecological functions</td>
<td>Pressey et al. 1993; Murray et al. 1999; Roberts et al. 2003</td>
</tr>
<tr>
<td>The effectiveness of other reserve designs</td>
<td>Pressey et al. 1993; Murray et al. 1999; Roberts et al. 2003</td>
</tr>
<tr>
<td>Past, present, and future uses and threats</td>
<td>Murray et al. 1999; Roberts et al. 2003</td>
</tr>
<tr>
<td>Likelihood of natural disasters</td>
<td>Murray et al. 1999; Roberts et al. 2003</td>
</tr>
<tr>
<td>Political considerations</td>
<td>Murray et al. 1999; Sale et al. 2005</td>
</tr>
<tr>
<td>Hydrodynamics and currents</td>
<td>Murray et al. 1999; Sale et al. 2005</td>
</tr>
</tbody>
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many alternative network configurations that allow for the realization of conservation objectives will emerge from a systematic process (Pressey et al. 1993; Gaston and Rodrigues 2003), which implies that the benefits from a reserve network may be quite robust to deviations from the particular network that emerges as “optimal” in some objective sense. This robustness alone raises questions about the value of the information sources that might be used to objectively guide MPA network design.

In recognition of the high costs of detailed assessments, many researchers have examined the performance of “surrogate” methods for delineating protected areas, motivated by interest in whether reserve networks can be created that protect species diversity without the costly acquisition of actual species distribution data (e.g., Vanderklift et al. 1998; Ward et al. 1999; Gladstone and Alexander 2005). These studies have yielded mixed results, likely due to differences among studies in spatial scale, study systems, levels of protection, and measures of success. Additionally, while surrogate methods have been demonstrated to be less costly than full biodiversity surveys in various systems (Balmford et al. 1996; Smith 2005; Marshall et al. 2006), there has been little effort to quantify differences in costs of different survey types for marine areas (but see Drummond and Connell 2005), how these differences in cost compare to losses in efficiency or effectiveness of reserves designed based on surrogates, or the benefits of other uses for the resources saved on assessment. Such analyses are critical in determining if surrogates provide an adequate means of delineating marine reserves.

In the MPA example, the x-axis of Figure 1 represents resources allocated to detailed ecological and socioeconomic surveys, and the solid line represents the degree of certainty with which the best (or one of the best) network configurations can be identified. The dashed line could represent a number of different options, for example, resources to assess a larger number of potential sites. Assessing more sites would increase the chances of identifying multiple candidate locations for a reserve, thereby allowing negotiations among stakeholders and increasing the likelihood of compliance (Pressey et al. 1993; Margules and Pressey 2000; Stewart et al. 2003). Alternatively, the dashed line could represent resources to acquire or protect additional areas. All else being equal, increasing the number of reserves in the network lowers the risk of failing to protect a critical location. Finally, the dashed line could also represent resources available to ensure compliance with regulations. In at least one set of reserves, there is evidence that individual reserves with the highest levels of compliance show the greatest level of success (Samoilys et al. 2007). Furthermore, an important temporal trade-off also occurs with detailed assessments of potential reserve networks. It takes time as well as money to assemble a complete biodiversity data set. A less time consuming, but also less thorough, assessment process could allow more rapid decisions about which areas to protect, resulting in a more rapid (but less certain) realization of benefits and lowering the risk of losing biodiversity in the interim between assessment and protection. A more extensive assessment process would result in a longer delay in realizing the benefits of protection.

Delineating MPAs differs from commercial stock assessments and sea lamprey control in that MPA placement is often a one-time decision, while harvest management of fisheries is a sequential decision-making problem in which managers have opportunities to learn from their past actions and adapt their future decisions accordingly (although a formal adaptive management process is rare in this context; Walters 1997, 2007). The fact that MPA placement decisions are to a certain extent irreversible will certainly influence the value of information used to direct their placement, as the cost of being wrong could be quite high. This does not, however, mean that a trade-off no longer exists between gathering this information and investing in other valuable areas of marine reserve management.

DISCUSSION

Our three examples illustrate what we believe to be an important and underappreciated challenge facing resource managers. We admit that it is often difficult to determine objectively the appropriate level of investment in information gathering to inform decisions about conservation and management. The starting point for the solution must come from taking a more holistic perspective on management. Most of the debate about how to assess systems such as commercial fisheries or marine reserves has concentrated on comparisons of alternative strategies for information gathering. We believe that more important questions arise at a higher level: what are alternative uses for these same resources, and would better management result from shifting effort from more refined assessments to these alternatives? The answer to such questions can only come from framing the resource management problem to make these trade-offs explicit; that is, treating assessment as part of a larger management system.

Viewing assessment as a component of a larger management regime requires a broad view of the entire interconnected management process. Sea lamprey management has benefited from an institutional arrangement in which a single decision-making body (the Great Lakes Fishery Commission) is centrally responsible for allocating resources between assessment and other management activities; in fact, this allocation is a critical element of their decision-making process. Elsewhere, management decisions are often not made with the benefit of this holistic perspective, but we do not see any obvious institutional impediments to adopting this view. We encourage fishery agencies, at the regional, national, and international level, to examine their management systems and identify opportunities to take a more holistic approach to resource allocation.

The technical challenges of confronting these trade-offs may seem daunting, but we believe examples exist that illustrate the approach towards which we are pointing. Specifically, fisheries scientists, especially in Australia and South Africa, have for several years been developing and applying methods referred to as “management procedures” or “Management Strategy Evaluation” (MSE) for simulating a complete fishery management system, including assessment (e.g., Butterworth and Punt 1999; Geromont et al. 1999; Punt and Smith 1999). These simulations have been used to evaluate the contribution of different levels of assessment to better decisions, and it is not difficult to imagine expanding these simulations to make explicit the trade-off between, for example, increased assessment and increased enforcement for capture fisheries. Similarly, an MSE-style simulation could be used to evaluate trade-offs for marine reserves such as the inter-temporal trade-off (act now or wait for better data) discussed above. We have, in fact, used an “operating model” of sea
lamprey control to examine the trade-offs discussed in our first example (M.L.J., unpublished data).

Balmford and Gaston (1999) provide another excellent example of explicitly examining the trade-off between resources used for detailed assessments and those used for land purchase in creating reserve networks in terrestrial systems. They concluded that detailed surveys allow the creation of more efficient reserve networks, and conducting such surveys will reduce the amount of land required to protect a given level of biodiversity. In their examples, the costs of conducting biodiversity surveys are more than offset by the reduction in land acquisition costs, and they conclude that biodiversity surveys are generally a good value for terrestrial systems. Their results demonstrate wide variations in the costs of land purchase, effective maintenance, and surveying, and they acknowledge that few data exist for the calibration of their model, even in terrestrial systems. Research of this type on marine systems would help to determine the value of biodiversity surveys relative to the loss of efficiency in marine reserve networks created using incomplete data.

Treating assessment as a component of a larger management process will doubtless raise questions that demand empirical evaluation, particularly when modeling provides equivocal answers. The most informative evaluations of the costs and benefits of different assessment strategies will come from adaptive management experiments, in which decisions are made based on different levels of information, implemented on the scale relevant to management, and monitored (Walters 1986). Despite the intuitive appeal of these types of large-scale management experiments, they are risky and difficult to implement, particularly in contentious systems such as commercial fisheries and MPAs (Walters 1997, 2007). Nonetheless, adaptive management studies may be the only way to truly understand the impacts of different assessment and resource allocation programs, particularly if modeling and past experience cannot resolve critical uncertainties (Walters 2007). Furthermore, as ecosystem management becomes more widely accepted as the goal of management (Pikitch et al. 2004), developing realistic parameter and variability estimates to be used in predictive models will become even more difficult, further necessitating the use of management-scale experiments to truly determine the outcomes of various assessment methods.

CONCLUSION

Our purpose here has not been to suggest that information gathering generally tends to be over-valued in resource management. In some cases, compelling arguments have been made in favor of more assessment: for example, increases in resources allocated to assessment and monitoring to assist in the prevention and early detection of invasive species is predicted to reduce the costs of often irreversible economic and ecological damages caused by invasions (Lodge et al. 2006). Instead, our goal is to argue that the funds to support all aspects of resource management are nearly always far less than managers would wish to have, and that limited resources create important, high-level challenges concerning their allocation. We maintain that the value of investing in information gathering should be explicitly considered in relation to the opportunity costs associated with other valuable areas of management. We urge decision makers to make these trade-offs an explicit part of their management systems. As well, research on the value of information across natural resource fields

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has not given enough attention to quantifying these trade-offs. We urge researchers to help fill this gap so as to ensure the most effective and efficient use of limited resources and aid progress towards achieving common conservation and management goals.

ACKNOWLEDGEMENTS

The Great Lakes Fishery Commission provided funding support for this research, particularly the sea lamprey case study. We thank Jim Bence, Tony Smith, and Carl Walters for their helpful comments on an earlier version of this manuscript. The second author would also like to thank the Project Seahorse Centre, UBC, Vancouver, Canada, and the Marine Ecosystems and Resources Group at CSIRO Marine and Atmospheric Research, Hobart, Australia, for illuminating discussions on this subject during his sabbatical leave. This is publication number 2008-18 of the Quantitative Fisheries Center at Michigan State University.

REFERENCE LIST


Summer is traditionally the season of leisure and no more so than for students. Schools let their captive audience free, students and teachers alike. They are able to recalibrate their life and look forward to new accomplishments in the fall to come.

Summer is also vacation time for most people. Having just come back from my annual sojourn to southern France, I am in a relaxed, open mood, what the French refer to as “décontracté.” While there, I talked to some high school students and their parents, just chatting idly. Even so, it quickly was apparent to me that the concerns we now face here in North America are shared in that part of Europe, and, likely, all over the globe.

For one thing, “globalization,” bad or good, is real and affects life universally in direct ways. So does climate change. And the young, with little memory of the world that existed 20 or 30 years ago—when “global warming” and the “ozone hole” were fashionable words among the elite and the Internet was a gleam in its father’s eye, the web was called “mosaic,” and the cell phone did not pervade our life so insistently, and, in some cases, so obnoxiously—are concerned about their future and their prospects.

While I was there, also, there was a leak from a nuclear center near Avignon. Uranium escaped in a local river. And France, which relies on nuclear energy for 75–80% of its electricity, had a moment of panic. When I left, the effects of that leak, both directly on fish in the river, and ultimately on people living nearby had not been fully assessed.

So, yes, globalization, ubiquitous information, changing weather (one of the coolest and wettest Mays and early Junes in southern Europe), rising cost of energy, increasing environmental stresses—all very familiar to all of us on both sides of the Atlantic, and all presenting a direct challenge to the youth who are beginning to assert their place in society.

AFS is not immune to these changes and challenges. Thinking of the Society as an organism that keeps changing and sometimes growing, we must pay constant attention to the forces that influence its metamorphoses. A few years ago, the AFS leadership decided to reduce the barriers for young professionals and students to join the Society. That effort has now borne fruit: the latest membership survey shows that the AFS membership is getting younger again, reversing a trend of the past 15 years.

That is just some of the data received from that survey. I and others will be discussing the survey and its implications in future columns. Other efforts to divine the future of AFS are also being undertaken: focus groups, a retreat of the Governing Board, and a survey by the Student Subsection. All will provide important feedback as AFS looks at formulating its next strategic plan.

The Montgomery County Historic Preservation Council recently voted to protect parts of the old Grosvenor estate, where AFS leases its headquarters. The estate was once the country home of National Geographic founding editor Gilbert Grosvenor. Nations Academy said this will delay their efforts to build a school on the property by at least another year. Although the school had planned to keep the Tudor-style Grosvenor mansion (now home to the Society of American Foresters), the council also recommended preserving the carriage house, caretaker’s house, and wide swaths of the surrounding grounds. The school designers are currently reworking their zoning exemption application.
Equal Opportunities Section Announces travel award winners

Joint Luncheon. The Equal Opportunities Section and Fish History Section will host a joint luncheon at the AFS Annual Meeting on Monday, 18 August at the Fairmont Chateau Laurier hotel. Our guest speakers will be presenting on the history of women and minorities in the fisheries profession. This will be an exciting opportunity to meet mentors and students from a wide variety of backgrounds and perspectives on the fisheries profession! There is no fee for students at the luncheon, due to generous contributions by mentors in the Society. However, all participants must RSVP by 1 August due to limited space and menu planning needs. We hope to see you there!

2008 Travel Awards. Out of 13 applicants, we were able to provide awards to 8 students this year, focusing primarily on students who have been involved in leadership positions in AFS Subunits or Sections and who are presenting a paper or poster at the meeting. This year’s recipients are

- Julie Harris, North Carolina State University (Ph.D.);
- Kristen Homel, Montana State University (Ph.D.);
- Heidi Lewis, Southern Illinois University (Ph.D.);
- Caitlin O’Brien, Oberlin College (B.S.);
- Ashlee Paver, University of Arkansas at Pine Bluff (M.S.);
- Kristen Pitts, Kansas State University (M.S.);
- Elizabeth Romero Hernandez, Universidad Autónoma de Baja California (M.S.); and
- Sara Seidel, Utah State University (M.S.).

In total, EOS has awarded $25,000 over the past 8 years to assist 48 students from 34 institutions in 6 countries!

Travel Award Contributors. The EOS Travel Award is entirely dependent on annual solicitations for funds from Units across the American Fisheries Society and to external organizations. We are very grateful to two Divisions, four Sections, and five Chapters for their contributions.

It’s not too late for additional contributions. Annual line items in Unit budgets are especially appreciated! Please contact Gwen White (gwhite@dnr.in.gov) with contributions or leads.

2009 Travel Awards. With your help next year, we hope to exceed our 2007 peak of 11 student awards at the San Francisco meeting. As an example of student response to receiving an award, we received the following from Lonnie Gonsalves, a student at University of Maryland Eastern Shore:

Not only am I thankful for this award because of its financial value; I also appreciate your recognition of my potential as a student, a scientist, and as a future colleague. I want to assure you and the section that with your continued support, whether it be financial or perhaps more importantly the moral support, that I as well as the students and faculty of the Living Marine Resources Cooperative Science Center will continue to perform quality research and provide valuable assistance in the recruiting and training of talented scientists from all demographics.

It’s not too early to start considering your contribution for student travel to the 2009 AFS Annual Meeting in Nashville, Tennessee! This support would enable us to continue ensuring that minority and female students will be able to participate in Annual Meetings and develop professionally through associations with AFS. Checks may be written to the “Equal Opportunities Section,” designated for the EOS Travel Award Fund. Units have typically sent $100 to $500, although any amount would be greatly appreciated. Contributions may be sent to: Julie Claussen, AFS-EOS Treasurer, Illinois Natural History Survey, 1816 S. Oak St., Champaign, IL 61820, 217/444-5113, juliec@uiuc.edu.

For more information, visit the EOS webpage at www.fisheries.org/units/eos or contact Gwen White, EOS Travel Award Chair, 317/234-4407, gwhite@dnr.in.gov.

—Gwen White
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<td>Aquaculture Europe 2008</td>
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<td>Sep 16-19</td>
<td>World Fishing Exhibition</td>
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<td>Sep 20</td>
<td>Ocean Conservancy’s International Coastal Cleanup</td>
<td>coastlines and waterways of 76 countries</td>
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<td>Sep 22-24</td>
<td>Oceania Chondrichthyan Society</td>
<td>Sydney, NSW, Australia</td>
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<td>Sep 28-Oct 2</td>
<td>Pathways to Success 2008 Conference: Integrating Human Dimensions into Fisheries and Wildlife Management</td>
<td>Estes Park, Colorado</td>
<td><a href="http://www.warnercnr.colostate.edu/nrt/hdfw/partners.html">www.warnercnr.colostate.edu/nrt/hdfw/partners.html</a>, <a href="mailto:eduke@warnercnr.colostate.edu">eduke@warnercnr.colostate.edu</a></td>
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<td>Oct 11-15</td>
<td>Fourth National Conference on Coastal and Estuarine Habitat Restoration</td>
<td>Providence, Rhode Island</td>
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<td>Oct 20-24</td>
<td>Fifth World Fisheries Congress 2008</td>
<td>Pacifco Yokohama, Japan</td>
<td><a href="http://www.5thwfc2008.com">www.5thwfc2008.com</a>, <a href="mailto:wfc2008@ics-inc.co.jp">wfc2008@ics-inc.co.jp</a>, +81-3-3219-3541</td>
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<td>Oct 22-23</td>
<td>State of the Lakes Ecosystem Conference</td>
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<td>Oct 28-29</td>
<td>Coastal Research Symposium</td>
<td>Biloxi, Mississippi</td>
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<td>Nov 7-8</td>
<td>Eighth Annual AFS Student Colloquium</td>
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<td>Nov 9-13</td>
<td>Integrating Biogeochemistry and Ecosystems in a Changing Ocean: Ecological and Biogeochemical Interactions in End to End Food Webs Workshop</td>
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<td>Nov 11-14</td>
<td>North American Lake Management Society Symposium</td>
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<td>Nov 14-16</td>
<td>Third International Bonefish and Tarpon Symposium: Research and Conservation for the Future</td>
<td>Dania Beach and Islamorada, Florida</td>
<td><a href="mailto:aadams@mote.org">aadams@mote.org</a></td>
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<td>Nov 19-22</td>
<td>11th International Conference on Shellfish Restoration</td>
<td>Charleston, South Carolina</td>
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<td>Dec 3-4</td>
<td>11th Flatfish Biology Conference</td>
<td>Westbrook, Connecticut</td>
<td><a href="http://mi.nefsc.noaa.gov/flatfishbiologyworkshop">http://mi.nefsc.noaa.gov/flatfishbiologyworkshop</a>, <a href="mailto:rmercald@clam.mi.nmfs.gov">rmercald@clam.mi.nmfs.gov</a>, 203/882-6549</td>
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**2009**

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<td>Jan 13-14</td>
<td>Lake Mead Science Symposium</td>
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<td>Jan 15-18</td>
<td>Spring Meeting of the Southern Division and Louisiana Chapter of the AFS</td>
<td>New Orleans, Louisiana</td>
<td><a href="http://www.sdafs.org/meetings">www.sdafs.org/meetings</a></td>
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<td>Jan 27-31</td>
<td>Texas Chapter of AFS and Texas Parks and Wildlife Department—Fisheries and Harmful Algae: Can They Co-Exist?</td>
<td>Fort Worth, Texas</td>
<td><a href="mailto:Fred.Janssen@tpwd.state.tx.us">Fred.Janssen@tpwd.state.tx.us</a></td>
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<td>Feb 15-18</td>
<td>Aquaculture America 2009</td>
<td>Seattle, Washington</td>
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<td>Mar 30-Apr 3</td>
<td>Improving the Ecological Status of Fish Communities in Inland Waters: International Symposium and EFI+ Workshop,</td>
<td>Hull, United Kingdom</td>
<td><a href="http://www.hull.ac.uk/hifi/events/index.html">www.hull.ac.uk/hifi/events/index.html</a></td>
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<td>May 22-26</td>
<td>Third and Last GLOBEC Open Science Meeting</td>
<td>Victoria, British Columbia, Canada</td>
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<td>May 25-29</td>
<td>World Aquaculture 2009</td>
<td>Veracruz, Mexico</td>
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<td>Jun 1-11</td>
<td>Indo Pacific Fish Conference and Australian Society for Fish Biology</td>
<td>Fremantle, Western Australia</td>
<td><a href="http://www.asfb.org.au/events">www.asfb.org.au/events</a></td>
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<td>Jun 14-19</td>
<td>Seventh International Conference on Molluscan Shellfish Safety</td>
<td>Nantes, France</td>
<td><a href="http://www.icmss09.com">www.icmss09.com</a></td>
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<td>Jun 23-26</td>
<td>International Paleolimnology Symposium</td>
<td>Guadalajara, Jalisco, Mexico</td>
<td><a href="http://www.paleolim.org">www.paleolim.org</a></td>
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<td>Aug 14-17</td>
<td>Aquaculture Europe 2009</td>
<td>Trondheim, Norway</td>
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MEMBERSHIP SERVICES

Initiatives for membership services may be identified through individual members, AFS Units, membership surveys, focus groups, or AFS staff. The desired outcomes of these services are the retention and recruitment of young professionals and students, and maintaining and enhancing AFS relevance. The Governing Board will establish guidelines for proposing new initiatives for membership services; these proposals will include a brief narrative describing the strategic goal of the initiative, the need for the initiative, and a description of how the initiative benefits AFS members. Other criteria may be established by the Governing Board. Proposals for new initiatives are submitted early in the calendar year to the New Initiatives Coordinator, who is a member of the Management Committee, appointed by the AFS president. The coordinator may request clarification or merging of two or more initiatives that are similar. A few weeks prior to the mid-year meeting, the coordinator presents the proposed initiatives to the Governing Board for review and selection. A small number of initiatives will be selected for further consideration based on the following criteria: (1) alignment with strategic goals and mission of the AFS, (2) ability to evaluate success of the outcome, and (3) cost considerations. Business plans for these initiatives are developed by the Executive Director working together with the originator(s) of the proposals. These plans typically require six months or more to develop. Upon completion, the Governing Board reviews the business plans, and as warranted, selects initiatives to support based on available funds. To ensure the long-term financial well-being of AFS, it is desirable to select at least one new initiative that will generate revenue (rather than being revenue-neutral or revenue-negative). Unfunded initiatives may be resubmitted in later years for consideration.

The process proposed for funding new initiatives seeks to improve the original approach used to identify and select initiatives. The improvement stems from the use of guidelines for preparation of applications and proposals, clearly-defined selection criteria, and the requirement of Units to co-invest in new activities (by stipulating the repayment of seed money). But, like the previous approach, the focus remains on activities and services that address strategic goals of AFS, and provides for oversight of the entire process by the AFS Governing Board. The Governing Board will deliberate and vote on this proposed process during our Annual Meeting in Ottawa. Assuming this process is adopted, expect to see exciting developments within AFS Units and all across the Society as we implement new activities and services to further enhance the value of AFS.

* Raise the stature of the National Marine Sanctuary Program, emphasize its mandate to protect sanctuary resources on an ecosystem-scale, and enhance its capacity to increase public awareness and appreciation of ocean ecosystems.
* Give sanctuary leadership express authority to use science-based tools, such as marine reserves, to accomplish their mission.
* Expedite the process for improving sanctuary management plans and amending regulations.
* Lift the current moratorium on the designation of new sanctuaries.
* Provide adequate and sustained funding for the sanctuary program.

Todd Zinser of the U.S. Department of Commerce stated that there are several actions that NOAA and the sanctuary program can take to strengthen the management of enforcement in the sanctuaries including:

* Finalizing the national sanctuary enforcement plan.
* Addressing the inherent management risks in having sanctuary regulations managed by one line office the National Ocean Service but enforced by another at the National Marine Fisheries Service.
* Ensuring that the Office of Law Enforcement continues tracking sanctuary violations and uses this data to manage enforcement resources and priorities.
* Considering broadening enforcement options by making greater use of summary settlement schedules.

John Dewitt of the National Academy of Public Administration stated the National Marine Sanctuary Program is designed and is working well. He further stated that the program embodies many of the recommendations of the two recent national commissions on ocean policy. Sanctuaries can play an important role in broader federal ocean policy as participants in and as models of effective ocean governance. He closed by stating that the sanctuary program deserves strong support from top officials in NOAA and the Department of Commerce and that action needs to be taken to reauthorize the sanctuary program so that it can continue to grow. NOAA should explore and report to the committee whether NOAA, its component agencies, and ocean governance in general would benefit from adopting the “civic,” multi-purpose approach that the sanctuary program utilizes.
Grenadiers or rattails are widely distributed in the oceans from the Arctic to the Antarctic. This is the first book to examine different aspects of the distribution, ecology, life history, stock assessment, and fisheries of different grenadier species in the oceans. The 25 chapters, written by 65 international experts, provide the most current data on the biology and fisheries of grenadiers. This volume will appeal to a wide spectrum of professionals, including fisheries scientists and managers, marine biologists and ecologists, and oceanographers.


The authors will clearly shave years off the learning curve for many heading into the field.

The book Salmonid Field Protocols Handbook is an ambitious and overdue undertaking. While there are several good recent texts that rigorously address the theory and analysis of field data, this is a text that is squarely aimed at those who regularly don waders and get their hands wet studying salmon. To this end, the 7 editors and 37 contributing authors should be commended and fisheries biologists should take note.

While the title does not reflect it, the book is shamelessly aimed at the Pacific Northwest and Pacific salmon. This can be perceived as either a “pro” or “con” depending on the reader. On one hand, the text could have served a much wider audience than the stated geographic area. On the other hand, much of the text still does. There are 18 methods described that cover a considerable range of technological complexity (from cast netting to electrofishing) and cost (foot surveys to hydroacoustics). Some topics, such as “Fish counting at large hydroelectric projects” are clearly of limited regional utility. The chapters on rotary screw traps and seining were particularly well crafted and will serve all readers regardless of locality and target species. Most chapters are well written and effectively draw on primary literature from many species and sources. In cases where theoretical discussions are limited due to the scope of the book, authors provide substantial direction for further investigation.

Each chapter is presented in a consistent format with Background, Sampling Design, Field and Office Methods, Data Handling, Personnel Requirements, Operational Requirements, and Literature Cited. Overall this approach works well and allows one to “shop” for the best approaches in a comprehensive and evenhanded manner. There is, however, some inevitable awkwardness in fitting a diversity of methods to the same format. In one chapter, readers are informed “Equipment needs” include duct tape, WD-40, rags, and toilet paper for carcass surveys. The equipment list for hydroacoustics differs significantly!

This is a book about field work. While approaches and chapter texts vary in detail, the information is the distillation of thousands upon thousands of hours of effort. I have no doubt that what may appear to be excessive thoroughness is born of experience and is worth passing on. Often I was struck with the thought “that’s a good idea” or “I wouldn’t have thought of that.” The authors will clearly shave years off the learning curve for many heading into the field.

The methods chapters are preceded by four essays that explain the rationale and the development of the book. These short works underscore the regional need in the Pacific Northwest for consistency, cooperation, and a common template. In one essay, the frustration of post hoc analysis is pitted against the logic and logistics of assessing need and designing rigorous and appropriate sampling designs. In another, a very detailed prescription for standardization and data forms is given. There is a palpable undercurrent through these sections that the enormous investments of time, money, and intellect have fallen short of the Pacific region’s collective potential. After all, that is the point of the book. The editors sum this up nicely in their dedication:

In the spirit of interdependence, we put forth the protocols in this book as we strive to create a common language of salmon knowledge for their survival and ours.

This is not a book one will sit down and read cover to cover. It is one that will serve as a reference for fisheries biologists well into the future to improve the design, implementation, analysis, and communication of findings from the field.

—Joseph Zydlewski
Maine Cooperative Fish and Wildlife Research Unit
U.S. Geological Survey, University of Maine—Orono

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Mandy Karnauskas is currently a Ph.D. student in marine biology and fisheries at the University of Miami. She received a B.S. in biology and a B.S. in animal science from the University of Massachusetts-Amherst. Before entering her Ph.D. program, Karnauskas worked with fishing communities and research teams in the Caribbean region. She spent two years in Haiti as a Peace Corps volunteer, working with fishing cooperatives and implementing sustainable development projects in multiple communities. She later spent two years in the Dominican Republic working as a high school science teacher, and collaborating with Dominican scientists on marine resource management issues. Karnauskas’s research interests include developing improved methods for fishery management in developing countries. Her dissertation research, based in Glover’s Reef in Belize, focuses on assessing the utility of different indicators used to measure the effectiveness of marine reserves to produce fishery benefits. This research should be useful for Belize Fisheries in evaluating their network of marine reserves, and will also inform the management of coral reef reserves worldwide. Karnauskas is also involved in community-based projects to improve marine resource management in the Dominican Republic.

Adam Peer received his bachelor of science degree in biology at Bowling Green State University, his master of science in fisheries science at Auburn University, and currently is a Ph.D. candidate at the University of Maryland Center for Environmental Science Chesapeake Biological Laboratory working under the direction of Thomas J. Miller. His Ph.D. dissertation is designed to investigate the importance of maternal characteristics on recruitment, sustainability, and conservation of fish populations—with particular emphasis on Atlantic coast striped bass. At the heart of this research is the idea that individual spawning striped bass contribute differentially to the next generation, and that identifying and promoting the conservation of females who contribute the most recruits will ensure long-term sustainability of this species. A rigorous exploration of this idea is being tested using traditional approaches to assess female demographics and reproductive potential in combination with novel molecular techniques to assess the influence of female condition and other maternal characteristics on reproductive success under natural conditions. Genetic markers are playing a key role in this research to match offspring with their mother’s genotype and phenotype and to track offspring through time to identify evidence for selection in the field and determine the role of maternal characteristics on recruitment.

Keith Dunton is a Ph.D. student in the School of Marine and Atmospheric Sciences at Stony Brook University. He obtained his masters degree in marine and atmospheric sciences from Stony Brook University in 2005, where his thesis research focused on growth variation in bluefish. Since then he has been working as a fisheries technician documenting the spatial and temporal marine habitat use of Atlantic sturgeon within New York waters. This study has led to a greater understanding of the spatial habitat use of Atlantic sturgeon within New York and the identification of essential habitat areas where Atlantic sturgeon concentrate. He is continuing this work within his dissertation research, which will aim to enhance the knowledge of the marine migrant stage of Atlantic sturgeon within the Atlantic Ocean and evaluate management alternatives to further protect them. Specifically, he will use acoustic telemetry to delineate essential aggregation areas and movement patterns, and evaluate timing and rates of dispersal within a hypothesized closed area in the Atlantic Ocean. Additional work will focus on assessing the current age and genetic structure, determining prey type, and modeling overall energetic consumption within identified aggregation areas.
Greening the AFS 2008 Conference

As the Greening Coordinator for the AFS 2008 Conference in Ottawa this summer, my main responsibility is to encourage that venues, events, activities, and participants use green alternatives whenever possible and practical.

We are working closely with the venues that are hosting the conference to ensure that green choices are practiced and that past efforts to make sustainable choices are recognized. Our local organizing committee members are reviewing details such as the use of reusable china, linens, and bulk condiments. We are investigating the possibility of providing a “litterless” dinner for the Wednesday evening social that will be held at the Canadian Museum of Civilization.

The Westin Ottawa was recognized in 2007 by Hydro Ottawa through a “Companies for Conservation” award; the hotel reaped an energy savings of $260,000 during that year through simple process changes and minor investments. Lighting retrofits included the replacement of existing fluorescent lamps with more energy efficient models and compact fluorescent light bulbs have replaced traditional pot lights and table lamps.

Other small changes that have effective results include: unoccupied rooms set at warmer temperatures in the summer/cooler temperatures in the winter, timer-based ventilation systems that give immediate control over convention room settings, and recently upgraded boilers. The Ottawa Congress Centre has employed similar energy-saving measures recently and also addressed water conservation by using a closed fluid cooler loop for refrigeration compressors and no longer using city water that, once used, was dumped down the drain. The Fairmont Chateau Laurier Green Partnership program received the designation as Best Corporate Social Responsibility Program in 2006. The award recognizes the best example of environmental and humanitarian activity, sustainable development, and the involvement of local populations by hotel groups throughout the world.

Electrical power that will be consumed by audio-visual services, provided for the Ottawa meeting by CCR Solutions, will have carbon offsets in place that are being arranged by the supplier with Zerofootprint™ (a registered Canadian not-for-profit organization whose goal is to empower groups worldwide to reduce their collective carbon and ecological footprint). CCR Solutions will also be providing digital signs to minimize the use of paper or foam-core signs and will use other energy-conserving approaches such as using LED lights whenever possible (e.g., for color blast lighting) instead of the more consumptive conventional alternatives.

The AFS Local Arrangements Committee is also looking into providing carbon offsets for other activities associated with the conference (e.g., related to accommodations, etc.) through initiatives such as tree planting. We are planning to facilitate carpooling through a dedicated page on the conference website where individuals can indicate pertinent information regarding their travel plans and contact each other.

There is a focus on using natural, sustainable or recycled materials wherever possible. T-shirts for volunteers and staff, Spawning Run participants, and for resale (as mementoes of the conference) have been selected with green principles in mind. Imagen Green Promo Products is the provider and 1% of their net sales will be donated to One Percent For The Planet, an alliance of businesses committed to leveraging their resources to create a healthier planet. The bags that will be used to hold materials provided at registration, ChicoBags™, are manufactured by a fair labour, fair wage manufacturing company; include a 1-year warranty; and are recyclable (through the ChicoBag™ company; they are repurposed into door mats and dog beds). Delegates at the conference will be provided with the abstracts for the presentations and other promotional material on a reusable (and multi-use) one-gigabyte flash drive (mass storage device).

If you have any ideas or suggestions about ways to “green” the conference, please contact Brenda Koenig at 705/755-1904 or brenda.koenig@ontario.ca.
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AFS Conference Booth 308

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Hydro-climate and Atmosphere-indexed Runoff Prediction (HARP)
Willingness to Pay: An Essential Component of a Cost-Benefit Analysis to Support Regulatory Decisions
Simplifying Barrier Culvert Determinations on Large-Scale Transportation Projects
Diversion Structure Consolidation: More Water for Fish?
How Did the Cable Get to the Other Side? Marine Resource Monitoring Requirements and Results at Submarine Cable Crossings

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Fisheries Biologist—Intermediate (2 positions) and Senior (2 positions), Golder Associates Ltd., Edmonton, Alberta, and Saskatoon, Saskatchewan, Canada.

Responsibilities: Initiate and manage projects. Supervise and train junior staff. Serve as liaison with clients. Make presentations and represent clients at meetings. Design and undertake fish and fish habitat field evaluations. Prepare proposals and reports. Apply advanced methods and techniques, solve problems, and perform data and statistical analysis assessments to develop fish habitat no net loss strategies and habitat compensation plans. Prepare fish and fish habitat environmental impact assessments for various types of developments including power, mines, oil and gas facilities, and pipelines. Organize and be responsible for health and safety in the workplace.

Qualifications: Senior level: M.S. or Ph.D. in aquatic biology, environmental sciences, or related discipline with 8 years experience or B.S. plus 10 years experience, preferably in the consulting industry. Intermediate level: M.S. or Ph.D. degree in aquatic biology or environmental sciences with 4 years experience or B.S. with 7 years experience. Strong working knowledge of freshwater aquatic ecosystems. Excellent technical writing, communication, and project management skills. Strong interpersonal, communication, and critical thinking skills. Project development, design, management, and implementation experience. Team oriented approach and attitude. Strong commitment to health and safety.

Salary (in Canadian dollars): Intermediate level: $66,000–$81,000. Senior level: $90,000–$110,000.

Closing date: Until filled.

Contact: Send CV and cover letter with preferred position and location to Chantal Richert, Human Development Representative, crichert@golder.com, or fax 780/483-1574. No phone calls.

California Recreational Fisheries Survey (CRFS) Sampler—Fisheries Technician, Pacific States Marine Fisheries Commission, California Department of Energy.

Responsibilities: Conduct field sampling of marine recreational anglers’ catch through the CRFS in coordination with California Department of Fish and Game. Conduct marine recreational angler interviews for catch, species composition, lengths and weights, and angler demographic and economic information. Contribute collected data to other agency data to estimate total marine recreational catch and effort for state and federal fisheries management. Work independently in the field and interview marine anglers at the completion of their fishing trip. Conduct sampling at launch ramps, piers, jetties, beaches, and aboard partyboats. Determine number of sampling forms used according to modes of fishing sampled.

Qualifications: See PSMFC website below.

Closing date: 30 September 2008.

Contact: www.psmfc.org/psmfc/employment-careers.

Marine Fisheries Observers, Marine Fisheries Observers AIS, Inc., out of ports from Maine to North Carolina.

Responsibilities: Work at sea collecting/recording data and biological samples for the National Marine Fisheries Service aboard commercial fishing vessels. Observers work on fishing vessels ranging from 40–100 ft. on trips ranging from 1–14 days collecting data on fish catch and discard.

Qualifications: B.S. in marine biology or biology. Able to commit to the program for at least a year. Other requirements include: a vehicle, U.S. or Canadian citizenship, CPR/First Aid certification, and passport.

Salary: $200 per sea day, $12 per hour land time with benefits.

Closing date: 18 August 2008.

Start date: Next three-week training session begins 8 September 2008 in Woods Hole, Massachusetts.

Contact: E-mail resume, references, list of biology courses and cover letter detailing sea and fish experience to 17478@aisobservers.hrmdirect.com. See www.aisobservers.com.

John P. Laborde Endowed Chair for Sea Grant Research and Technology Transfer and Visiting Professor, Office of Sea Grant Development, Louisiana State University.

Responsibilities: Perform work that directly supplements or complements activities being conducted by the program or other sponsored research, technology transfer, or education projects administered by OSGD. Scholarly work in either research or teaching would also be encouraged within appropriate discipline-based academic departments. See www.laseagrant.org/laborde/guidelines.htm. An offer of employment is contingent on a satisfactory pre-employment background check.

Qualifications: Nationally/internationally recognized in some area of marine/coastal research, technology.

To see more job listings go to www.fisheries.org and click on “Jobs.”
transfer, education, or business development. Academic candidates must hold the rank of full professor or its equivalent and will maintain similar rank during the appointment. Appointment duration can vary from a few months to one year. We particularly encourage nominations of individuals eligible for either one-half or full year sabbatical from their institutions.

**Salary:** Salary is commensurate with rank and qualifications.

**Closing date:** 29 August 2008 or until filled.

**Contact:** Those interested in applying or nominating an individual confirm a nominee’s interest should submit a nomination letter with the candidate’s curriculum vitae including e-mail address, summary of expertise/interests, proposed activity, preferred appointment dates, and salary requirements to Charles A. Chuck Wilson, Executive Director, Office of Sea Grant Development, 239 Sea Grant Building, Louisiana State University, Ref: 020577, Baton Rouge, Louisiana 70803. EO/EAE.

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**Responsibilities:** Work closely with project scientists to analyze data and prepare tables and charts.

**Qualifications:** M.S. in applied statistics, biostatistics, or closely related field. Minimum of 3 years experience, including environmental data analysis and SAS programming. Knowledge of GIS, MATLAB, and R programming language a plus.

**Salary:** Depends on experience.

**Closing date:** 31 August 2008.

**Contact:** Send cover letter and resume to: Normandeau Associates, Inc., Attn: Robyn Chadwick, 25 Nashua Road, Bedford, New Hampshire 03110; rchadwick@normandeau.com; fax 603/471-0874

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**Responsibilities:** Gather management data for the government. Live and work aboard U.S.-flagged commercial fishing vessels operating in the Bering Sea and North Pacific Oceans. Training in Anchorage, Alaska. Make 2 deployments of approximately 2 1/2 to 3 months each within 7 months of completion of training.

**Qualifications:** B.S. in fisheries biology, marine biology, general biology, zoology, or a related natural science.

**Salary:** $3,900–6,006 per month, depending on experience, plus room, board, and travel to and from job site. Subsequent deployment opportunities and salary advances available.

**Closing date:** 17 September 2008.

**Positions available year-round.**

**Contact:** David Edick, Alaskan Observers, Inc., 130 Nickerson, Suite 206, Seattle, Washington 98109; 800/483-7310; aoistaff@alaskanobservers.com; www.alaskanobservers.com.

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**Natural Resources Biologist I**, Maryland Department of Natural Resources, Fisheries Service, Annapolis.

**Responsibilities:** Provides technical and administrative support to Maryland’s striped bass harvest monitoring program. Assist the current biologist in net inspections and certifications, tag distribution, and data management. Assist with the distribution and collection of harvest permit cards and declarations of intent.

**Qualifications:** B.S. from an accredited college or university in biology,
natural science, natural resources management, botany, marine biology, fisheries management, zoology, or a natural resources management related field of study. Preference to candidates with up to one year experience working with Microsoft Access. 

**Salary:** $31,461–40,441, contractual, no benefits. 

**Closing date:** 26 October 2008. 

**Contact:** www.dnr.state.md.us/hr/jobs.asp. 

**Fisheries Biologist I**, Arkansas Game and Fish Commission, Fisheries Division, Mammoth Spring.

**Responsibilities:** Assist with all duties associated with a coldwater intensive culture trout hatchery including: spawning fish, monitoring development of eggs and fry, developing and implementing feeding schedules, administering chemical treatments for disease, monitoring water quality, maintaining hatchery production records, collecting and entering data and preparing reports on hatchery operations, assisting in the supervision of the hatchery staff, training workers in fish husbandry techniques, and assisting other personnel as needed with sampling and habitat improvement work. 

**Qualifications:** B.S. in biology, zoology, botany, or a related field, or equivalent. 

**Salary:** Grade 18, $26,415 per year. Salary above $26,415 requires exceptional qualifications as determined by the Office of Personnel Management. 

**Closing date:** 26 October 2007. 

**Contact:** See www.agfc.com/employment/. For additional information contact Melissa Jones, 877/625-7521.
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