Fisheries

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JULY 2013

AFS – Adapt or Perish!

Integrated Multi-Trophic Aquaculture

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Inherent Error in Fish Measurements

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Ecological Surveys and eDNA

The Imperative for Timely Action

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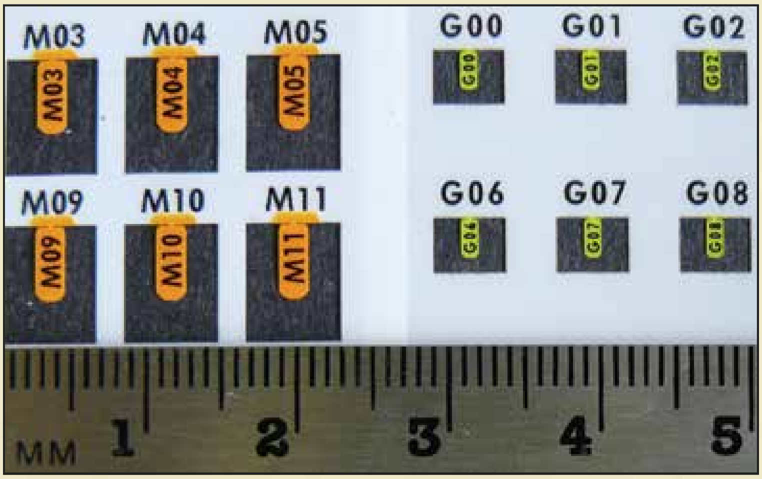

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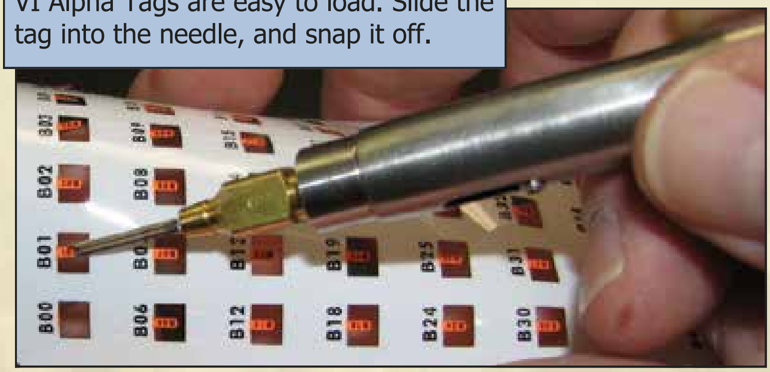

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Fisheries

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297 A sock of blue mussels, *Mytilus edulis*, with siphons wide open as they filter organic particles at an Integrated Multi-Trophic Aquaculture (IMTA) site in the Bay of Fundy, New Brunswick, Canada. Photo credit: S. Robinson.

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The World of Tomorrow

John Boreman, President

AFS President Boreman may be contacted at: John.Boreman@ncsu.edu

The other day I was rummaging through a trunk of old papers looking for a reprint requested by a colleague from Delaware. While doing so, I came across a certificate signed by Robert Moses thanking me for performing in the 1964–1965 New York World's Fair. More significant than my performance at the New York State pavilion, which will probably be entered in the annals of history as the most mediocre of all time, was the fact that the invitation to perform also included free admission to the fair. A highlight of the fair was a Disneyesque version of the world of the future, featuring 20th-century technology exhibited by corporate giants such as General Motors, General Electric, and IBM. I saw demonstrations of computer modems, picture phones, and computer-driven robots with human-like movements, which Disney dubbed "audio-animatronics." Many of the technological prognostications made then are now normal parts of our everyday lives.

What technological advances are in store in the next 50 years, or even the next 10 years? Computational technology that once filled a room, and now fits in the palm of our hand, will probably be reduced to the size of the head of a pin. Remote sensing of aquatic ecosystems, as well as their biota, will become more commonplace, as will remote sensing of fishery catches and discards. Communications at the speed of sound will be supplanted by communications at the speed of light, and we will wonder how we were able to survive without instantaneous video messaging with our fisheries colleagues around the world. Data collection and the capacity for data archiving and retrieval will increase by several orders of magnitude, likely leading to frustration as we attempt to move closer and closer to real-time management of fisheries. We will also be facing a growing set of bioethics issues as we delve further into genetic engineering and use of biodata implants; today's arguments related to stem cell research will pale in comparison. Finally, the increasing ease of communications will require us to become more vigilant in what scientific information gets posted and becomes available to everyone; we will need to find new and innovative means to ensure that our posted science still represents the best available and has undergone adequate peer review.

How will these advances affect our ability to monitor, assess, and provide management advice on fishery stocks and threatened or endangered aquatic species? This is the focus of the plenary session at the upcoming American Fisheries Society (AFS) annual meeting in Little Rock (September 8–12, 2013): Preparing for the Challenges Ahead. Our speakers are two visionaries in our field who will be looking to the future from the point of view of the field of fisheries science and the culture of fisheries scientists (see http://afs2013.com/plenary-speakers/). Pamela Mace, principal advisor for fisheries science in the New Zealand Ministry for Primary Industries, will present some plausible future scenarios to illustrate the potential state of marine fisheries. Dr. Mace will provide supporting arguments for the proposition that if the world's fisheries are to continue to provide food and livelihoods without compromising biodiversity conservation and other services, a concerted effort will be required to formulate, and develop the means to implement, a common vision that balances utilization and sustainability.

The second plenary speaker, Kelly Millenbah, associate dean and director for academic and student affairs in the College of Agriculture and Natural Resources at Michigan State University, will be characterizing fishery scientists of the future. Basing her talk on the *Fisheries* article she coauthored with Bjørn Wolter and Bill Taylor (Millenbah et al. 2011), Dean Millenbah will address the unique and difficult dynamics necessary for engaging the next generation in the stewardship of fish and wildlife resources. She will touch on the importance of understanding the characteristics of the next generation of natural resource leaders (Millenials and NextGens) and the individuals with whom they will interact in pursuit of conservation, which is key to ensuring that they can meet the challenges of a new era in resources management.

Our Society will also need to adapt to future technologies or perish. Currently, the two mainstays of income for AFS have been journal subscriptions and meeting attendance. Advances in communications technology will threaten both of these funding sources. We are seeing some of this happening now; online and open access journals are forcing the AFS to reconfigure its funding structure for authors as well as subscribers. Additionally, the push by our membership for increased capability to conduct the Society's scientific and business meetings electronically—which is a good thing—might mean a decrease in income obtained through meeting registrations—which is a bad thing. We will need to determine a fair charge for virtual registration, one that will not need to cover coffee breaks and banquets but one that will cover the costs of the webcast and provide a return to keep our Society afloat.

The world of tomorrow will present us with many opportunities and challenges that we cannot even conceive of today. Therefore, we must not lose sight of our purpose as a professional society, and we must task ourselves with diligently maintaining our high standard of scientific integrity as we prepare for the challenges ahead.

REFERENCE

Millenbah, K. F., H. K. Wolter, and W. W. Taylor. 2011. Education in the era of the millenials and implications for future fisheries professionals and conservation. Fisheries 36(6):300–304.

COLUMN
Fish Habitat Connections

The Imperative for Timely Action

Thomas E. Bigford

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Welcome to the third column in a series on fish habitat. In May we introduced plans to use this forum to elevate awareness of habitat across careers and roles. The June column explained how threats to fish habitat connect to research, management, policy, and to each American Fisheries Society (AFS) unit and member. This month we will focus on the temporal variable, as the full swath of fish habitat challenges demands our immediate and sustained attention.

This discussion is well timed. Fish habitats are being degraded or lost at rates that appear to be unsustainable and certainly that are not in the best interest of a world that values fish, recreational fishing, and commercial fisheries. There have been scattered successes (e.g., improved water quality, more concern about introduced species, greater awareness of the perils of river blockages, increased habitat restoration skills), but human-induced pressures alter the physical, geological, chemical, and biological underpinnings of fish habitats in ways that we still yearn to comprehend. And then there is climate change, which looms large and seems to be receiving increased attention. For both traditional and new stressors, the science is sparser than it should be and the degradation continues somewhat unabated.

It is important to be optimistic (the opposite is too depressing!), but signals from multiple indicators suggest that we are moving toward a tipping point where dwindling, healthy habitats cannot support robust and resilient fish populations and ecosystems. So let us look at how well our habitat-related rhetoric reflects the challenge to us as fisheries professionals. Are the parent AFS society, its units and members, and the organizations they represent focused sufficiently on priority fish habitat issues, or are we missing opportunities while our options decrease and funds dwindle?

The threats to fish habitat are legion. Just skim the list of AFS policy statements to gain an appreciation for the breadth of human-induced pressure on natural systems (fisheries.org/policy_statements). Most of those policies are more than a decade old, supported by science that—in most cases—needs updating. The AFS Resource Policy Committee—with help from experts in all AFS sections and divisions—faces the daunting chore of refreshing those policies to keep up with the best available knowledge. With 37 policies, the AFS will be busy updating the science and policies forever. Though scary, it is reassuring to know that our overall vigilance will continue over the cycles of AFS leadership. Let's hope for the same in public and private sectors, where we must also prepare for the long haul.

Climate change may help to elevate awareness and action. President Obama's mention of climate in his second inaugural speech (January 21, 2013) focused on action. AFS President John Boreman (2013) seized on the opportunity with his Letter to the President, wherein he connected climate to fish, water, and natural resources. The AFS, leading through its elected officials and influencing with solid science, can make a difference. We were engaged early, having hosted a special symposium on "Fisheries in a Changing Climate" in 2001 (McGinn 2002) and when the AFS Resource Policy Committee (under Colleen Caldwell's leadership) developed a summary of the issue and an AFS policy statement (Bigford et al. 2010). In May 2013, the AFS parent society and Potomac Chapter sponsored a congressional briefing on "Climate Change and Fisheries," where AFS President Boreman and other panelists reiterated the importance of action now. Our challenge as fish/fisheries professionals is to use that information to make a difference. Specifically, for traditional stressors—and now for climate change—we must focus on how habitat threats are affecting fish populations and human uses.

When combined, these local, regional, and global threats are unprecedented. Different timescales overlap to present truly scary scenarios. Some habitats like water column may shift uneventfully as climate and other threats materialize, with fish moving to new niches. Habitats such as canyons or cold gravel beds may not be as flexible, and dislocation could result. Though some traditional stressors took decades or even centuries to manifest themselves (for example, sediment contamination in our nation's waterways), climate change seems to be surging toward the top of our priority list more quickly. On the temporal scale, we are facing more threats than in recent memory. How long do we have to respond to protect some habitats, reduce threats elsewhere, and restore degraded habitats to the point of supporting healthier fish populations that provide greater ecosystem services? Should we expand our efforts to protect habitats since restoration requires more effort and extra years to regain lost services? Eventually we must restore what we could not protect, and then protect what we have restored, so our contributions from all fields represent a circle with multiple, interconnected challenges. These are uncomfortable choices that demand immediate attention.

The next column in this series will address another important scale—size. Habitat work, whether policy or science or management, can happen in a postage stamp of habitat on up to large ecosystems and regions. For any set of habitat threats,

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The Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN)—A Network for a New Era of Ecosystem Responsible Aquaculture

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La Red de Acuicultura Multi-Trófica Integrada en Canadá (RAMTIC) – la red para una nueva era de acuicultura ecológicamente responsable

RESUMEN: *La Red de Acuicultura Multi-Trófica Integrada en Canadá (RAMTIC) es una red estratégica del Consejo de Investigación en Ingeniería y Ciencias Naturales que dio inicio en el año 2010. Se concibió a partir del hecho de que la acuicultura, a pesar de ser el sector de producción de alimentos de más rápido crecimiento, está relacionada con temas de índole ambiental, económica y social. La acuicultura multi-trófica integrada (AMTI) ofrece una solución innovadora al problema de la sustentabilidad ambiental, estabilidad económica y aceptabilidad social de la acuicultura, ya que se fundamenta en un enfoque manejo basado en el ecosistema. El AMTI es el cultivo de especies propias de la acuicultura que provienen de distintos niveles tróficos, y es acompañado de funciones ecosistémicas complementarias de modo que el exceso de nutrientes de una especie es aprovechado por el lote de organismos del siguiente nivel trófico, propiciando así interacciones cinegéticas entre especies. La RAMTIC proporciona la investigación y desarrollo interdisciplinarios y personal altamente capacitado en: (1) diseño ecológico, interacciones a nivel ecosistema y eficiencia de bio-mitigación; (2) innovación de sistemas e ingeniería; (3) viabilidad económica y aceptación social; y (4) ciencia regulatoria. La RAMTIC debiera ser capaz de transformar las preocupaciones ambientales y socioeconómicas en ganancias y en alimento marino novedoso y de calidad, si se limitara el enriquecimiento orgánico e inorgánico que ocasionan las operaciones de alimentación en acuicultura, y se produjeran lotes adicionales de organismos cultivados para su extracción. La RAMTIC va más allá de atender temas de naturaleza científica y de ingeniería; está lidiando con los componentes socioeconómicos, políticos y de gobernanza.*

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ABSTRACT: *The Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN) is a Natural Sciences and Engineering Research Council strategic network that was initiated in 2010. It was triggered by the fact that aquaculture, though the world fastest growing food production sector, is associated with environmental, economic, and societal issues. Integrated multi-trophic aquaculture (IMTA) offers an innovative solution for the environmental sustainability, economic stability, and societal acceptability of aquaculture by taking an ecosystem-based management approach. IMTA is the farming, in proximity, of aquaculture species from different trophic levels, and with complementary ecosystem functions, so that one species' excess nutrients are recaptured by the other crops and synergistic interactions among species occur. CIMTAN is providing the interdisciplinary research and development and highly qualified personnel training in the following linked areas: (1) ecological design, ecosystem interactions, and biomitigative efficiency; (2) system innovation and engineering; (3) economic viability and societal acceptance; and (4) regulatory science. By mitigating organic and inorganic enrichment of fed aquaculture operations and producing additional extractive crops, IMTA should transform environmental and socioeconomic issues into benefits, trusted quality seafood, and novel seafood-based products. CIMTAN is going beyond addressing questions of a natural science and engineering nature and is addressing socioeconomic, policy, and regulatory governance components.*

Thus, understanding both the environmental impacts (Lotze et al. 2006) and the significance of aquaculture (Soto et al. 2008) is important if we want to design the responsible food production systems of tomorrow and make the Blue Revolution greener to enter the era of a more responsible Turquoise Revolution (Chopin 2012).

INTRODUCTION

As the human population continues to grow, we need to secure more and more of our food from aquatic environments (marine and freshwater; Food and Agriculture Organization [FAO] 2010). Capture fisheries, while continuing to have their role, will not fill the widening gap between the demand and the supply as their yields have remained stable or, in some cases, experienced declines. Aquaculture, which is already supplying around 50% of the aquatic food we eat, will increase that share of the production for our daily intake of proteins, carbohydrates, and lipids (FAO 2011). However, the development of intensive fed aquaculture (e.g., finfish and shrimp) at the amazing rate of 8.3% per year since 1970 (FAO 2011) has been associated with concerns about the environmental impacts of such monospecific practices, especially where activities are highly geographically concentrated or located in suboptimal sites whose assimilative capacity is poorly understood and, consequently, prone to being exceeded (Chopin et al. 2001; Naylor et al. 2003; Diana 2009).

As aquaculture production continues to expand, it is paramount that we avoid the same mistakes experienced with the increased intensification of agriculture during the Green Revolution. Thus, understanding both the environmental impacts (Lotze et al. 2006) and the significance of aquaculture (Soto et al. 2008) is important if we want to design the responsible food production systems of tomorrow and make the Blue Revolution greener to enter the era of a more responsible Turquoise Revolution (Chopin 2012).

For the aquaculture sector to continue to grow, it will need to develop innovative and responsible technologies and practices. Sustainable aquaculture should be ecologically efficient, environmentally benign, product diversified, profitable, and societally beneficial (Troell et al. 2003; Chopin et al. 2010). Integrated multi-trophic aquaculture (IMTA) has the potential to achieve these objectives by cultivating, in proximity, species from different trophic levels, and with complementary ecosystem functions, in a way that allows one species' uneaten feed and wastes, nutrients, and by-products to be recaptured and converted into fertilizer, feed, and energy for the other crops and to take advantage of synergistic interactions among species while biomitigation (partial removal of nutrients and CO_2 and supplying of oxygen) takes place. IMTA is the central and overarching theme; it can have many different variations, adapted to the local conditions (open-water or land-based systems, marine or freshwater systems, temperate or tropical systems). Proximity should be understood as not necessarily considering absolute distances but connectivity in terms of ecosystem functionalities, in which management at the bay area level is paramount (lease limits drawn on a map by humans do not always mirror the reality of nature).

Farmers combine the cultivation of fed species, such as finfish or shrimps fed sustainable commercial diets, with extractive species, such as seaweeds and aquatic plants, which recapture inorganic dissolved nutrients, and suspension and deposit feeders, which recapture organic particulate nutrients, for their growth. In this way, all of the cultivation components have an economic value (harvestable, healthy seafood and value-added marine bio-based products), as well as a key role in recycling processes and in providing biomitigative services for the surrounding ecosystem. The aim is to ecologically engineer systems for increased environmental sustainability (ecosystem services and green technologies for improved ecosystem health), economic stability (improved output, lower costs, product diversification, risk reduction, and job creation in coastal and rural communities), and societal acceptability (better management practices, improved regulatory governance, and appreciation of differentiated and safe products). In this way, some of the externalities of fed monoculture are internalized, hence increasing the overall sustainability, profitability, and resilience of aquaculture farms (Neori et al. 2007). A major rethinking is needed regarding the definition of an "aquaculture farm" (reinterpreting the notion of site-lease areas) and regarding how it works within an ecosystem in the context of a broader framework of integrated coastal zone management. The economic values of the environmental and societal services of extractive species should be recognized and accounted for in the evaluation of the whole value of these

IMTA components. This would create economic incentives to encourage aquaculturists to further develop and implement IMTA. Seaweeds and invertebrates produced in IMTA systems should be considered candidates for nutrient and carbon trading credits within the broader context of ecosystem goods and services. Long-term planning and zoning promoting biomitigative solutions, such as IMTA, should become an integral part of coastal regulatory and management frameworks (Chopin 2011).

Research and development on IMTA has been conducted on both the east and west coasts of Canada since 2001. Significant progress has been made over the last 10 years, but the need for a concerted and strategic approach became obvious and led to the early discussions on the need for a network approach in the spring of 2008. During 2009, the possibility of forming a Natural Sciences and Engineering Research Council of Canada (NSERC) strategic network was solidified among 26 scientists from eight universities, six federal government laboratories (Department of Fisheries and Oceans Canada, DFO), one provincial government laboratory (Research and Productivity Council of New Brunswick), and three industrial partners. A Research Network Agreement was signed by all members on January 6, 2010, making it the official starting date of the Canadian IMTA Network (CIMTAN), supported for 5 years by the NSERC, DFO, the University of New Brunswick, Cooke Aquaculture Inc., Kyuquot SEAfoods Ltd., and Marine Harvest Canada Ltd. to the amount of CAD$9.577 million. Grieg Seafood BC Ltd. joined the network in April 2012.

In this article, we describe the objectives of CIMTAN and provide an overview of the network and its ongoing and future research. We also discuss the benefits, applications, and significance of a network approach. This article is part of a series in *Fisheries* that is focused on NSERC strategic networks that are currently active in Canada and have specific relevance to fisheries, aquaculture, and aquatic science (see Hasler et al. [2011] for introductory article).

CIMTAN OBJECTIVES

CIMTAN is focused on developing a network of researchers, with complementary expertise, from across Canada to further develop IMTA approaches to strategically enhance economically sustainable food production systems. The ultimate goal of CIMTAN is to develop aquaculture systems that can be adopted by its industrial partners to efficiently mitigate organic and inorganic enrichment of fed aquaculture operations. By actively recapturing this material to turn it into the production of extractive crops of commercial value, environmental and socioeconomic issues are transformed into benefits, trusted quality seafood, and novel seafood-based products, not only for its industrial partners but also for coastal and rural communities and all Canadians.

With a strong pan-Canadian academic, government, and industry partnership, CIMTAN is providing the interdisciplinary research and development and highly qualified personnel training in the following linked areas of IMTA: (1) ecological design, ecosystem interactions, and biomitigative efficiency; (2) system innovation and engineering; (3) economic viability and societal acceptance; and (4) regulatory science, to facilitate the commercialization of IMTA in Canada.

Training of highly qualified personnel is a very high priority of CIMTAN, and the goal is to train 114 individuals, from undergraduate summer students, to master and doctoral graduate students, postdoctoral fellows, and technicians. Developing a versatile and interdisciplinary workforce is important if we want the scientists, policy influencers, decision makers, regulators, and industrialists of tomorrow to be innovative and build a more diversified and responsible aquaculture sector (deeply in need of expertise with appropriate interdisciplinary training) within the broader sector of sustainable and responsible coastal zone management.

The majority of the projects are conducted at commercial aquaculture sites, providing a direct opportunity for interactions with our industrial partners, who have been actively involved in the choice and development of the selected projects from the onset of the CIMTAN idea. They are actively involved in their implementations, are viewing the results firsthand, and will have the capacity to apply these results to their operations.

CIMTAN will generate new knowledge on alternative aquacultured species chosen based on their biomitigative functions and economic value. This will increase organic and inorganic biomitigation to develop even more efficient IMTA systems within an ecosystem approach and to diversify the Canadian aquaculture sector. New culture, technological, and engineering advancements and designs will strengthen the position of Canada as a responsible aquaculture production nation. The IMTA contribution to ecosystem health will need to be understood and quantified because ecosystem health generally means fish health and, ultimately, human health. In addition, CIMTAN is going beyond addressing questions of a natural science and engineering nature and is examining socioeconomic, policy, and regulatory governance components that are required for the full development of the sector. CIMTAN should create the conditions for increased economic opportunities in coastal and rural regions, including First Nations' communities, providing sustainable, quality seafood to Canadians, concomitant with increased societal acceptance of the aquaculture sector and public policy development for improved government decision making.

CIMTAN RESEARCH THEMES

The network is organized into three linked domains reflecting the four areas identified above: domain 1 is environmental, domain 2 is engineering, and both are linked by the cross-cutting domain 3 (economic and social), because biological, environmental, biotechnological, and engineering issues are always linked to economic aspects and social acceptability. Each domain is co-led by a scientist at an academic institution and one at a DFO laboratory, in recognition of the significant role played by this federal government department in this network.

Domain 1: Environmental System Performance and Species Interactions

Domain 1 is investigating how an IMTA system operates, its relative efficiency, and effects. The need for such a domain is driven by the fact that we are currently at a stage in the IMTA system development where a number of interested parties (regulators, nongovernmental organizations, and other scientists) are asking for more data on the degree of assimilation of IMTA sites. Therefore, one of the objectives of this domain is to generate more scientific data to enable a more detailed evaluation of the IMTA recycling and mitigation concept.

Domain 1 is essentially made up of two components: (1) an internal component that deals with how the system works and is efficient within the aquaculture operation and (2) an external component that deals with how the system works with pathways of effects and impacts on the surrounding environment with respect to dispersion of nutrients and the interactions with associated wild organisms. Domain 1 is made of eight projects, which are described below.

Quantifying the Capture and Conversion Efficiencies of Species Being Considered for Organic Extraction in Open-Water IMTA Systems

The potential of an organism as an organic extractive species within IMTA sites depends primarily on its ability to efficiently capture, absorb, and convert particulate waste into new production. On the east coast of Canada, the first organisms used for the organic extractive component have been the mussels *Mytilus edulis* and *M. trossulus* (Figure 1; Lander et al. 2004). Mussels ingest and efficiently absorb organic material from both fish food and feces (Reid et al. 2010; MacDonald et al. 2011). The sea cucumber *Cucumaria frondosa* is now being assessed for extraction efficiency because of its commercial value and possible complementary extraction of different particles not exploited by mussels (Figure 2). Sea cucumbers were exposed to experimental diets in the laboratory, where organic composition can be manipulated and controlled, and the natural assemblage of particles found at IMTA sites. Despite high individual variability in this species, a significant positive relationship was found between absorption efficiency and the quality of the food, thereby enabling the prediction of the response of the organisms for a variety of habitats. Several species are being considered for use as organic extractive organisms on the west coast of Canada, including the green sea urchin (*Strongylocentrotus droebachiensis*), the basket cockle (*Clinocardium nuttallii*), the blue mussel (*M. edulis*), the California sea cucumber (*Parastichopus californicus*), and the Pacific prawn (*Pandalus platyceros*). Ingestion rate, absorption efficiency, fecal production rate, energy budget, and biophysical properties of excreted feces are being determined in laboratory experiments for individuals fed either Sablefish (*Anoploloma fimbria*) aquaculture waste or "natural" diets.

Cultivation of Complementary Inorganic Extractive Species for Increased System Performance

Since 2001, the inorganic extractive component of the IMTA system on the east coast has been the two kelps *Saccharina latissima* and *Alaria esculenta* (Figure 3; Chopin et al. 2004). On the west coast, *S. latissima* has been cultivated since 2007. These two species are cultivated first in the laboratory,

Figure 1. A sock of blue mussels, *Mytilus edulis*, with siphons wide open as they filter organic particles at an Integrated Multi-Trophic Aquaculture (IMTA) site in the Bay of Fundy, New Brunswick, Canada. Photo credit: S. Robinson.

Figure 2. The sea cucumber, *Cucumaria frondosa*, held in individual flow-through containers in a laboratory absorption efficiency experiment. The sea cucumbers are exposed to various organic diets comprised of natural particles, supplemented with cultured microalgae or fish feed used at Integrated Multi-Trophic Aquaculture (IMTA) sites. Photo credit: L. Orr.

Figure 3. Harvesting of the kelp, *Saccharina latissima*, at an Integrated Multi-Trophic Aquaculture (IMTA) site in the Bay of Fundy, New Brunswick, Canada. Kelps remove dissolved inorganic nutrients from the ecosystem while providing diverse commercial products. Photo credit: T. Chopin.

from September to November, and then at the sites from November to June–July. They need to be harvested in late spring–early summer before natural erosion of the blades, and their fouling, compromise the harvest and quality of the derived products. Consequently, there is a period of the year (summer) when seaweeds are absent at the sites and inorganic biomitigation is not taking place. This project is investigating two new macroalgal candidates, *Palmaria palmata* (dulse) on the east coast and *Ulva* sp. (sea lettuce) on the west coast, whose cycles and characteristics allow growth of the macroscopic stages during the summer to provide biomitigative biomass during that time of the year and, consequently, an overall increase in the inorganic biomitigative capacity of the IMTA systems. Research is also underway to explore the use of seaweeds for partial substitution in fish feed formulations as alternate sources to fish meal and land plant proteins.

The Role of Microbes in the Nutrient Recycling of Organic Material from IMTA Sites

Understanding the various paths and processes by which energy flows through an IMTA site is one of the main objectives in the creation of sustainable aquaculture systems using ecosystem-based approaches. As food at one trophic level is recycled through another, the energy associated with organic particles is stripped out and converted to inorganic waste products such as ammonia, carbon dioxide, and heat. This transfer occurs right down to the lowest trophic levels where the bacteria reside. The objective of this project is to determine the role that bacteria play in nutrient recycling at a Salmon aquaculture site and to evaluate the relative scale of their ability to convert organic particles into inorganic components. Specifically, this project is enumerating bacteria and their respiration rates at and away from finfish aquaculture sites in both the water column as well as the benthos. This is done on a seasonal basis at IMTA sites on both the east and west coasts. This research is also identifying the bacterial communities associated with the aquaculture sites and how they evolve over the year. These results will fit into a model being prepared on energy flow through an IMTA system.

Quantifying Energy, Nutrient Dispersal, and Scales of Influence on Wild Species from Open-Water IMTA Sites

The project goal is to measure the abundance and distribution of wild species associated with IMTA cage sites and to learn how they are associated with nutrient availability in both the near and far fields. Current investigations include designing an appropriate field methodology with respect to feasibility and experimental design. The research thus far has quantified rates of biocolonization (biofouling) using standardized collectors that are similar to those used for monitoring invasive tunicates. Each collector consists of a series of polyvinyl chloride plates that serve as a substrate for native organisms such as bryozoans, hydrozoans, tunicates, and algae. These species colonize new substrates quickly and are suitable to measure early responses to nutrient availability (Chopin et al. 2012). Collectors are deployed at both finfish only and IMTA sites as well as at reference locations within the same geographic area but far from aquaculture activity. Upon retrieval, total accumulated biomass and surface area colonized are measured and compared among sites relative to other environmental variables. The next phase of investigation will be to deploy a full array of collectors around several IMTA and finfish only sites along with simultaneous measurement of environmental correlates such as temperature, salinity, current, chlorophyll, and oxygen.

Use of Blue Mussels as a Biological Means to Reduce the Horizontal Transmission of **Loma salmonae** *(Agent of Microsporidial Gill Disease of Salmon)*

As a general hypothesis, it is likely that the transmission of pathogens—and in particular the exchange of pathogens between the farm site and the "near-farm" environment—could be modified through IMTA practices. This may apply best or, alternatively, may be most successfully modeled for those organisms that possess methods of infection and transmission that allow extended periods of extracorporeal (off-host) survival and for which the severity of infection is quantifiable as a continuous outcome and directly (linearly) related to exposure to infectious dose. Given these considerations, the disease known as microsporidial gill disease of Salmon, a serious endemic gill disorder in farmed and wild Chinook Salmon (*Oncorhynchus tshawytscha*), and other Pacific Salmon, has potential as a model through which to better understand disease transmission in this modified aquaculture setting. The goal of this project is to develop a suitable laboratory in vivo branchial xenoma expression model for microsporidial gill disease of Salmon and to use it to explore our specific aims, which include determining to what extent blue mussels may remove, deactivate, or retain *Loma salmonae* spores released from infected fish (Figure 4). Additionally, the project is seeking a further understanding of the temporal kinetics of spore survival in marine environments and sediments, in addition to their survival within or on structures that may be used in IMTA settings.

The kinetics of horizontal transmission of fish pathogens is often poorly understood and limited by quantifiable disease models for realistic (low-dose) challenges of susceptible hosts. Such models are needed to fully characterize the role of a novel environmental variable, in this case the filtering and subsequent digestive activity of a bivalve. Recent work has led to the development of a repeatable low-dose horizontal transmission model for *L. salmonae* (Harkness and Speare 2011), and the effects of

Figure 4. Monoclonal antibody–stained spores of *Loma salmonae* within a xenoma developing within the gill microvasculature of an infected Chinook Salmon, *Oncorhynchus tshawytscha*. Photo credit: D. Speare.

immunostimulation and immunosuppression have been quantified within this in vivo model system (Speare et al. 2011).

Can Filter-Feeding Bivalves Ingest Planktonic Sea Lice, Leading to Reduced Lice Numbers on Cultivated Salmon?

A possible benefit of adding filter-feeding shellfish to the typical monoculture model of Salmon farming is the potential for reducing viral, bacterial, and parasitic diseases in the cultured fish as a result of the filtering of planktonic dispersal particles (e.g., bacteria, viruses, larvae, and nauplii) by the shellfish (Skår and Mortensen 2007; Molloy et al. 2011). This project is examining a number of filter-feeding shellfish species for their ability to ingest planktonic naupliar and copepodid stages of sea lice under laboratory conditions and assessing the effects of commercial scale quantities of shellfish on lice levels at a commercial Salmon farm site. The laboratory phase of the project, currently underway, is designed to determine which of four species of suspension-feeding bivalves (i.e., basket cockle [*C. nuttallii*], Pacific oyster [*Crassostrea gigas*], Pacific scallop [*Mizuhopecten yessoensis* × *Patinopecten caurinus*], and mussel [*Mytilus* spp.; a mix of *M. edulis*, *M. galloprovincialis*, and their hybrid]) consume lice larvae and their ingestion rates at various temperatures (5, 10, 15°C). If successful, bivalves grown by Salmon farms could potentially reduce the abundance of sea lice on caged Salmon using a biological control approach, possibly reducing the need for costly chemotherapeutants.

Presence, Effect, and Bioaccumulation of Therapeutants in Polychaetes

Coculture of the clam worm (*Nereis virens*), a sediment dweller commonly found in the Bay of Fundy, is being considered as a means to process the heavier organic solids that settle out from fish farms. This worm is often sold as bait. Ecto-parasites, commonly called sea lice, often affect cultured Salmon and require the use of drugs and pesticides to control the infestations. As a consequence of treatment regimes, these compounds are released to the surrounding environment (Haya et al. 2004; Burridge et al. 2010). The project goal is to determine the potential effects of two of the anti–sea lice therapeutants, the food-borne drug Slice® (active ingredient emamectin benzoate), and the pesticide AlphaMax (active ingredient deltamethrin). Ongoing toxicity studies are assessing acute and chronic effects of these therapeutants on the worms. Data emanating from these studies will be used to assess the feasibility of culturing worms under Salmon farms and may be considered by regulatory agencies when assessing risks associated with therapeutant use in finfish aquaculture.

Mathematical Modeling for Open-Water IMTA—Developing Tools to Support System Design and Measures of Sustainability

Matter and energy flux within open-water IMTA systems, and between IMTA systems and the environment, need to be qualified and quantified in order to assess farm design and develop measures of sustainability (Reid et al. 2009). Empirical measures of concentrations in open-water systems, as a means to assigning causality to a particular process or culture niche, have obvious challenges in such a highly variable and "leaky" environment. Some degree of modeling will, therefore, be essential to determine efficiencies and track delivery of nutrients to cocultured species (Reid 2011). Because most commercial-scale aquaculture in Canada occurs in open-water systems, IMTA will also be practiced in this context. IMTA system modeling must, therefore, be developed beyond the laboratory and small-scale pilot projects if it is to have real-world application. Consequently, the primary objectives of this project are to (1) reconcile existing ecological, animal, and seaweed husbandry efficiency measures; (2) continue the development of both a semistochastic nutrient transfer model to determine the overall IMTA system efficiency of nutrient and energy recovery and a mechanistic and deterministic model with time steps for better IMTA system understanding; and (3) determine methods to quantify system functions for open-water IMTA farm management, economics, and coastal zone policy development.

In September 2012, two new projects were added to domain 1: evaluating the performance of proposed and existing IMTA sites using an ecosystem modeling approach; and a variation on the IMTA theme for land-based, freshwater aquaculture operations: the development of freshwater IMTA for salmon and aquatic plants. These projects are not included in this article.

Domain 2: System Design and Engineering

Finfish aquaculture in Canada is largely based on salmonid production and concentrated in coastal British Columbia and New Brunswick. Despite a focus on the same salmonid species, the use of comparable feeds, employment of similar husbandry approaches, and provision of product to similar markets, both regional industries have evolved using distinctly different cage systems for their farm operations. In eastern Canada, the farms comprise independent circular plastic net-cages secured within an anchor grid. In western Canada, the industry uses primarily linked square or rectangular galvanized steel net-cages.

In terms of modifying these systems to support an IMTA approach, the logistical challenges are entirely different in the two regions. The circular cage grid system is considered an extensive infrastructure model, including space among the cages and within the anchor grid (Figures 5A and 6). IMTA development at these types of sites requires independent structures for the extractive species components, placed outside of the cage arrays. In this model, vessel access to all components would be maintained, but in fact the resulting IMTA system could be considered relatively leaky given the space around all of the individual component structures. Because IMTA components could be placed all around the fish cages, sites with bidirectional tidal flow could be considered for such development. The square, steel cage production system typical of the west coast is viewed as an intensive infrastructure model, with all containment structures in very close proximity (actually attached; Figures 5B and 7). Integration of extractive species within this type of system will require careful consideration of how access to fish cages will be maintained and how grow-out systems for the additional species can be designed and constructed without compromising the structural integrity and functionality of the original steel cage infrastructure.

The challenges resulting from adapting these systems to support IMTA integration are considerable. Domain 2 includes four projects designed to meet these challenges, providing critical information on ecological engineering (how new species can be effectively integrated into an existing finfish production system) that will allow future adoption by industry.

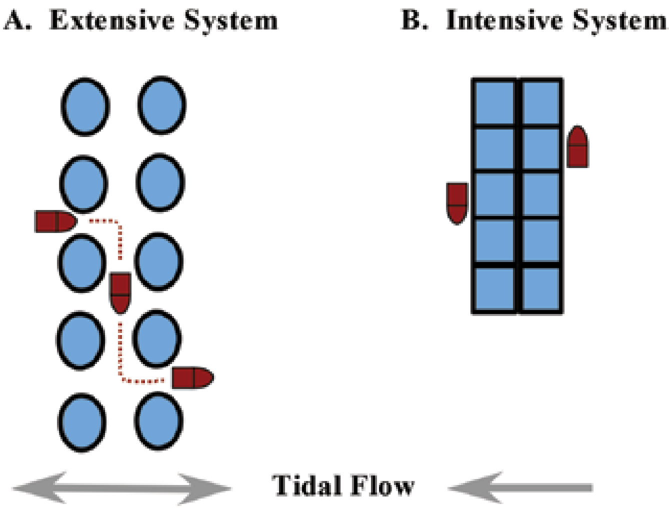

Figure 5. Current Canadian finfish aquaculture infrastructure, exemplified using a 10-cage configuration. (A) Circular cage system, typical of the east coast, will lend itself to extensive Integrated Multi-Trophic Aquaculture (IMTA) development. (B) Steel, square-cage intensive system, typical of the west coast, will require structural modification and innovation to support IMTA development.

Quantifying Temporal and Spatial Patterns of Nutrient and Organic Particle Plumes in IMTA Systems—The Basis for System Design

Delimitation of the spatial and temporal patterns and dynamics of the nutrient and particulate release, accumulation, and resuspension from different IMTA system configurations will provide critical information as to how leaky these approaches are and show how the extractive species components of these systems should be configured to maximize the ability to effectively intercept these waste streams. How these dispersion processes function within the natural fluctuations in nutrients, particulates, and inherent biotic assimilative capacity (e.g., phytoplankton) is also essential to understanding how IMTA systems should be designed and operated (Reid 2011). Results from this project will help develop an appropriate balance of species components of the IMTA system, as well as assist with production infrastructure design and engineering for effectively incorporating these species components into a multispecies design. Direct and indirect methods are being explored for delimiting the spatial extent of these waste plumes, comparing existing and new (optical) profiling techniques with indirect productivity measures of seaweed sentinels (kelps).

Extensive versus Intensive IMTA Systems—Hydrographic Influences and the Implications to Infrastructure Design and Operational Efficiency

Documentation of the dispersion and dilution pathways, specifically the near-field hydrographic flow properties, is being determined for both extensive and intensive IMTA production systems in order to provide for the most efficient ecological and structural design. This project supports a comprehensive evaluation of flow impedance by infrastructures, the effects of waste stream deflection (developed back-eddies, redirection of flows),

Figure 6. One of the Integrated Multi-Trophic Aquaculture (IMTA) sites in the Bay of Fundy, New Brunswick, Canada, operated by Cooke Aquaculture Inc.: Salmon cages on the left, mussel raft on the right foreground, and seaweed raft on the right background. Photo credit: T. Chopin.

Figure 7. The Integrated Multi-Trophic Aquaculture (IMTA) site of Kyuquot SEAfoods Ltd. on Vancouver Island, British Columbia, Canada. The right row of cages contains Sablefish; shellfish in the left row; and submerged kelp grid even more to the left (rectangle outlined by yellow buoys). The shellfish SEA-Tram system is visible across the first shellfish square. Photo credit: S. Cross.

the vertical entrainment of particles (potential persistence of nutrients), the effects of increased biomass on dissolved oxygen dynamics, the alteration of phytoplankton supply through the systems, and structural adaptation of IMTA to capitalize on the effect of flow on dissolved nutrient and particle movements.

Design and Pilot-Scale Testing of New Infrastructure Components, Including Integration of Energy Alternatives to Increase Operational Efficiencies

Aquaculture sites can be located remotely, far from the electrical grid. Because the intent of IMTA is to reduce the environmental impact of aquaculture operations, the provision of clean power to aquaculture sites is being investigated to avoid the need for diesel generators. Work to date has been focused on gathering resource data for the west coast IMTA demonstration site and performing initial component sizing. The use of on-site bioreactors to process seaweeds to produce biodiesel was explored but found to be unfeasible due to inefficiencies of scale. There were insufficient seaweeds available from target site operations with which to create the required quantity of biodiesel for energy self-sufficiency. An alternative approach is being pursued employing wind and solar energy sources to power aquaculture operations. An initial energy system model was assembled in HOMER that includes the net hoist power requirements, the source of the primary load, and power consumption (Hoevenaars and Crawford 2010). An energy audit has also been conducted on the on-site aquaculture staff residence. These data sets have been included in the custom energy usage model that is being developed to optimize the aquaculture power usage system, with particular consideration of proper simulation of the high power, low energy requirements of the site (Hoevenaars and Crawford 2012). As the custom power model is refined, it will be used to size renewable energy systems for current and future aquaculture sites.

Optimizing IMTA Species Component Stocking Densities and Infrastructure Orientation to Maximize Overall System Efficiency

Hydrographic processes will dictate how dissolved nutrient and particulate plumes flow among the different IMTA infrastructure components, defining how best the IMTA production systems should be designed and configured in order to fully capitalize on the dispersion pathways of these waste streams (Reid 2011). However, the interception of these streams by the various extractive species can, in itself (at commercial production levels), affect how efficient the resulting IMTA system will be. Proximity to the fed (fish) component, density of the grow-out structures (nets, cages, trays), vertical and horizontal orientation with respect to the flows, within-production unit densities, and spatial and temporal integration of multispecies and multiyear classes within each type of IMTA system are all issues being addressed by this project in order to ensure continual and optimal system performance.

Domain 3: Economic Analysis and Social Implications

There is growing recognition that the successful development of aquaculture is highly dependent upon the needs, capacities, and aspirations of people living in coastal communities (World Bank 2006). Though Canada's aquaculture industry is relatively small in comparison to that of other nations, its largely undeveloped coastline affords great potential for further growth.

In recent years, however, the expansion of coastal aquaculture has been overshadowed by a variety of environmental concerns and controversies. IMTA has the potential to address many of the environmental issues that confront Canada's aquaculture industry, but it also raises new challenges and research needs in the natural and social sciences. Domain 3 draws together social science researchers who investigate key issues associated with the wider adoption of IMTA in Canada. In particular, what is the economic and financial attractiveness of IMTA in comparison to competing aquaculture technologies and what are the implications of IMTA for coastal livelihoods?

It is important to recognize that IMTA is a food producing activity that relies on managed systems that are embedded within broader marine or freshwater ecosystems. A particularly useful concept that captures the two scales for analysis cited above is the "agro-ecosystem" (Conway 1993). This concept refers to biophysical impacts and interactions and to impacts involving the socioeconomic system, such as the effects that IMTA has on local communities in terms of social acceptability and sustainable livelihoods. An extended socioeconomic border is drawn around the biophysical system at the site level to include environmental impacts from production and the marketing and distribution system, both of which involve off-site concerns at a wider scale. For this network, it is this wider boundary and the inclusion of socioeconomic considerations at this scale that is of importance in defining the ecosystem of interest.

At the site level, domain 3 is primarily concerned with examining the management of an IMTA operation, addressing questions such as whether IMTA is financially viable (Whitmarsh et al. 2006; Ridler et al. 2006, 2007). It may also have a social or community dimension in that the operation must be—at minimum—supported by the community. In carrying out the analysis at the off-site or external level, one can draw on the concept of the agro-ecosystem to consider the extent to which IMTA mitigates the externalities associated with conventional practices. Externalities refer to the third-party effects of aquaculture, typically including nutrient enrichment and other downstream environmental impacts.

At the level of institutions and governance, the aquaculture industry is overseen in Canada by a combination of federal, provincial, and local authorities. In recent years, both the federal and provincial governments have been striving toward a more efficient regulatory framework, balancing the need to protect the environment, sustain fisheries, and enable a competitive industry to flourish. The existing regulatory environment, however, has been developed in the absence of IMTA. The current governance structures pertaining to coastal aquaculture in Canada may need to be reviewed with the aim of identifying changes in the policy and regulatory environment that are needed to facilitate the operation of IMTA sites.

Domain 3 consists of two projects. One project concentrates on the economic and financial dimensions of IMTA, and a second project considers the social and livelihood implications, primarily at the community level.

Economic and Financial Modeling of IMTA

Assuming that IMTA is an environmentally favorable means of food production for society, its adoption depends on the profitability of the system and whether the necessary economic incentives to promote adoption are in place. This project aims to (1) examine the net economic benefits of IMTA and compare them to those of conventional aquaculture systems, (2) assess the private financial incentives for IMTA production at the site level, and (3) investigate appropriate financial incentives for the wider promotion of IMTA. This project uses both financial and economic analysis tools, where financial analysis examines the business's revenues and costs and economic analysis examines the net effects of an activity, including its effects on external parties. Studies carried out under this project examine (1) the impacts of commercial-scale IMTA on the current British Columbia shellfish industry, (2) consumer attitudes and willingness to pay for IMTA, and (3) the comparative economics of nutrient dynamics in IMTA, closed containment systems, and conventional net-pen Salmon aquaculture.

Social Implications of IMTA

Canadian coastal communities are small, widely dispersed, and have a high degree of diversity, both economically and culturally. In recent years, many of these communities have experienced economic hardships due to downturns in the capture fishery and forestry sectors. One of the goals of this project is to investigate the potential that IMTA has for contributing to the development of sustainable coastal livelihoods in remote communities. This requires a consideration of the capacity and interest of people for participating in aquaculture, as well as the policies and training needed to facilitate their involvement. Developing a better understanding of the social and institutional aspects of implementing IMTA in coastal communities directly complements the natural science aspects and is an essential component in the overall process of helping IMTA reaches its full potential. Recognizing that the health of social, economic, and ecological systems are inextricably linked, this project has been developed with an explicit acknowledgement of the need to move across traditional academic disciplines and managerial "silos." Accordingly, this project is divided into three cross-cutting streams: (1) aquaculture governance, (2) the potential contribution of IMTA to Canada's coastal economy and social sustainability, and (3) First Nations and IMTA.

Linkages between Domains

The choice of IMTA species for potential commercial scale production will be based on combining the results from the biological domain 1 (their capabilities at delivering nutrients and their biological aptitude to capture these nutrients and convert them into biomass, feeding rates, growth, survival, and interactions), the engineering domain 2 (how easily can these species be held within an IMTA system, engineering design and placement of the various components, and stocking densities and temporal and spatial patterns of nutrient and organic particle plumes), and the economic and social domain 3 (value of the species [i.e., crops], marketability, profitability, viability, and acceptability). Moreover, for a full demonstration of the efficiency and value of IMTA systems, the biomitigative services and benefits provided by extractive species need to be identified, recognized, and valued. This will be another argument toward increased societal acceptance of IMTA as an aquacultural practice.

Domain 3 links to domains 1 and 2 because of the need to develop financial and economic analyses on the sound technical foundation provided. Moreover, the governance, social sustainability, and First Nations' issues are overarching; they define the social and political context within which IMTA initiatives must develop. As such, these issues are critical to the entire research program. If they are not suitably addressed and resolved, it will not be possible to successfully implement all the technical advances gained.

BENEFITS, APPLICATIONS, AND SIGNIFICANCE OF THE CIMTAN NETWORK APPROACH

After 9 years of relatively independent investigations on the east and west coasts of Canada, it was extremely judicious and timely to implement CIMTAN by combining academic knowledge and industrial know-how to create a formal network whose strategic approach, interdisciplinary, multi-institutional, and multisectoral strength—along with shared expertise—will be greater than the sum of the individual projects. Moreover, it is noteworthy that studies at the interfaces of fields of expertise often bring strength and validated solutions to resolve complex issues.

One of the incremental benefits of a network approach includes access to an enlarged equipment and tool inventory at academic institutions and government laboratories. Conducting experimental research on the east and west coasts in a concerted manner allows the acquisition of complementary and compatible information, hence increasing research outputs and outcomes and reducing redundancies in research efforts. Moreover, by gathering data on a wide geographical and temporal basis, with a wide range of environmental conditions, more generalized trends may be discerned, which will allow for the design of more robust systems and policies, taking into consideration both the universality of some aspects and the regional specificity of others.

By being the recipients of the knowledge and technology transfer generated under the network, the Canadian-based CIMTAN industrial partners will have a significant advantage in being the first to apply innovations in a targeted area of regional, national, and international relevance and competitiveness. It is important to underline that CIMTAN will not only address issues that are production based but will also look into aspects of improved ecosystem resilience, economic quantification of the environmental benefits of the IMTA practices, development of the nutrient trading credit concept for IMTA operations, and the anticipated increase in societal acceptance of the aquaculture sector when adopting IMTA practices supported by appropriate policies and enabling governance. CIMTAN is working closely with federal agencies such as DFO, the Canadian Food Inspection Agency, Environment Canada, Transport Canada, Agriculture and Agri-Food Canada, and their provincial counterparts, because their involvement in regulatory science will be required to enable IMTA to move from an experimental concept to a large commercial-scale reality.

The objectives of CIMTAN cover the full research and development and commercialization spectrum of investigations, conducting research at the experimental scale, developing precommercial practices, and transferring knowledge and technology to commercialize IMTA production systems and products. Because marine products are increasingly in demand, it appears very timely to invest financial and human resources in the aquaculture sector. Appropriate monitoring programs will be developed to ensure that IMTA provides diversified and trusted quality seafood. Healthy and novel IMTA-based bioproducts will also be developed. This will help in differentiating IMTA products, which, through better traceability and marketing, should command premium market prices.

Finally, it is hoped that the IMTA practice will bring new economic opportunities to coastal and rural communities in a manner that can be integrated with existing livelihoods and economic and social conditions in these areas. Increased revenue and employment should be generated in coastal and rural regions, which need stabilization of their workforce, including among First Nations.

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Detecting Temporal Trends in Freshwater Fisheries Surveys: Statistical Power and the Important Linkages between Management Questions and Monitoring Objectives

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ABSTRACT: *Monitoring to detect temporal trends in biological and habitat indices is a critical component of fisheries management. Thus, it is important that management objectives are linked to monitoring objectives. This linkage requires a definition of what constitutes a management-relevant "temporal trend." It is also important to develop expectations for the amount of time required to detect a trend (i.e., statistical power) and for choosing an appropriate statistical model for analysis. We provide an overview of temporal trends commonly encountered in fisheries management, review published studies that evaluated statistical power of long-term trend detection, and illustrate dynamic linear models in a Bayesian context, as an additional analytical approach focused on shorter term change. We show that monitoring programs generally have low statistical power for detecting linear temporal trends and argue that often management should be focused on different definitions of trends, some of which can be better addressed by alternative analytical approaches.*

Detección de tendencias temporales en muestreo de pesquerías continentales: poder estadístico y las relaciones entre temas de manejo y objetivos de monitoreo

RESUMEN: *el monitoreo que se realiza para detectar tendencias en el tiempo de índices biológicos y de hábitat es un componente crítico para el manejo de pesquerías. Por tanto, es crucial que los objetivos de manejo estén concertados con los objetivos de monitoreo. Estas relaciones requieren de la definición de los constituyentes de una "tendencia temporal" que sea relevante para el manejo. También es importante desarrollar expectativas acerca de la cantidad de tiempo necesaria para detectar una tendencia (i.e. poder estadístico) y elegir un modelo estadístico apropiado para el análisis. En este trabajo (1) se presenta un panorama de las tendencias temporales que comúnmente se encuentran en el manejo de pesquerías, (2) se revisa la literatura publicada sobre evaluación del poder estadístico en la detección de tendencias temporales y (3) se aplicaron modelos lineales dinámicos de contexto Bayesiano, como un enfoque analítico adicional enfocado en cambios de corto plazo. Se muestra que los programas de monitoreo generalmente tienen bajo poder estadístico para detectar tendencias lineales en el tiempo y se argumenta que el manejo debiera enfocarse en diferentes definiciones de tendencias, algunas de las cuales pudieran ser mejor estudiadas mediante enfoques analíticos alternativos.*

INTRODUCTION

Fisheries management agencies use a variety of methods to survey fish populations and their habitats. These surveys provide a wealth of information, including indices of relative abundance, descriptions of the size and age composition of the population, and assessment of habitat conditions (Murphy and Willis 1996; Roper et al. 2002). Although data obtained from these surveys are used to assess a variety of management and conservation objectives, a common theme is to monitor trends in biological or habitat indices over time (for conciseness, we use the term "trend" to include linear and nonlinear changes over time, including abrupt step changes). Detecting temporal trends has many implications in fisheries management. Some reasons why trend detection is important include (1) management actions often have time-oriented objectives (e.g., use stocking to restore fish populations within 10 years or stabilize eroding stream banks to immediately reduce sedimentation rates); (2) aquatic ecosystems may respond in complex and nonlinear ways to both natural and anthropogenic factors, resulting in unanticipated changes (Hayes et al. 2003a; Irwin et al. 2009; Rudstam et al. 2011); and (3) knowledge of previous system dynamics can inform structured decision-making processes by helping to identify what can realistically be considered acceptable or unacceptable outcomes of management (Irwin et al. 2011).

Although the concept of trend detection is not unique to fisheries assessment, the critical role that monitoring plays in fisheries management decision making emphasizes the importance of linking value-based management objectives to statistically based monitoring objectives. Establishing this linkage requires a definition of what constitutes a management-relevant trend. It is also important to develop expectations for the amount of time required to detect a management-relevant trend in a system indicator, with some level of confidence (i.e., statistical power), as well as choose an appropriate statistical model for analyzing survey data. Knowing the amount of time required to detect a temporal trend allows managers to identify cases where the time frame for management (e.g., stocking decisions that are made annually or every few years) differs from the time frame necessary to detect responses in the state of a system. Even when managers have access to long-term monitoring data, the reality is that many fishery management decisions are made in a "low statistical power environment" (see section Summary of Published Power Analyses). The negative consequences of this unfortunate reality may be at least partially alleviated by deliberate coordination of monitoring and management efforts. When properly designed, monitoring programs can provide a critical feedback loop for learning about system dynamics, which is fundamental to adaptive management (Lyons et al. 2008; Lindenmayer and Likens 2010). Thus, managers should be able to make more informed decisions when monitoring programs are designed to reduce key uncertainties. In turn, monitoring programs can also be used to evaluate how well observed outcomes correspond with anticipated responses to a management action.

In this article, we connect common fishery management questions to examples of monitoring objectives of detecting temporal trends. We discuss how different trend detection monitoring objectives can be translated into different statistical models and why this translation is critical for evaluating value-based management objectives. Within this context, we characterize several common issues that influence the statistical power of trend detection, and we discuss some advantages of Bayesian inference as an alternative to null hypothesis testing for making inferences about temporal trends. There are four major components to this article: (1) a brief overview of different types of temporal trends encountered in fisheries management, (2) a review of previously published studies that evaluated statistical power of long-term trend detection, (3) presentation of newly generated power analyses for detecting long-term trends using data from several fishery-independent surveys in the Great Lakes basin, and (4) an illustration of an additional, flexible analytical approach (i.e., dynamic linear modeling) geared toward alternative definitions of temporal trends. Our intent is that our literature review, illustrative examples, and discussion will better position resource managers to establish and communicate realistic expectations for temporal trend detection in freshwater fishery surveys.

Temporal Trend Detection in Fisheries Monitoring

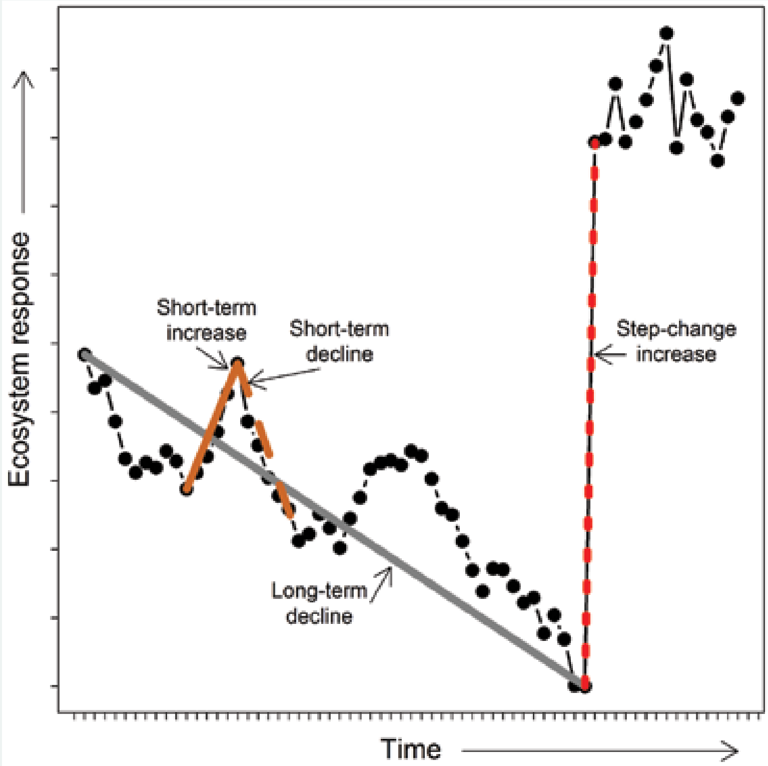
The degrees to which time-oriented *management objectives* are met are often assessed by (sometimes implicit) *monitoring objectives* that require detecting temporal trends. Simply put, fishery managers are often interested in whether important metrics have changed over time, particularly in response to management interventions (e.g., changes in fishing regulations). For example, consider a management action that has an objective of increasing the abundance of legal-size sport fish and a fishery-independent survey expected to assess the degree to which this management objective is being reached. In this case, a fishery manager may wish to "… detect an increase in the catch per effort (CPE) of legal-size fish within 5 years." When monitoring objectives are stated this way, they are often interpreted analytically as "… detect a statistically significant linear trend in in the logarithm of CPE of legal size fish within 5 years." Typically when assessing trends, a constant percentage change is estimated and hence an exponential trend is estimated using logarithms. Thus, to evaluate the management action, survey data are often examined for a statistically significant linear increase or decrease over time (Urquhart et al. 1998; Larsen et al. 2001), although the relative familiarity with statistical approaches that assume linearity may be partly responsible for the commonality of these types of analyses. Linear trend detection may often be sufficiently informative, even for nonlinear time series, as a long as a monotonic increase or decrease is present in the data (Urquhart and Kincaid 1999). However, this definition of temporal trend does not capture all of the important nuances of how aquatic systems can undergo temporal change, particularly when management actions are being frequently adjusted.

In addition to detecting short- or long-term trends persistent in monitoring data, fisheries managers are often interested in abrupt shifts to system conditions. Thus, detecting a long-term linear trend may not adequately represent monitoring objectives associated with large-scale management actions or system disturbance (e.g., establishment of invasive species). In this case, alternative statistical models must then be used to adequately address monitoring objectives. For instance, there are a variety of analytical approaches that can be used to detect thresholds in aquatic systems (e.g., Brenden et al. 2008; Baker and King 2010) that occur when the response of a system changes abruptly at some threshold value. For instance, Thomson et al. (2010) used a Bayesian change point analysis to identify periods of step changes in absolute abundance and in trends of change in abundance of four pelagic fish species in the upper San Francisco Estuary, California. In their case, identifying whether, and when, abrupt changes occurred helped to elucidate underlying causes and could help identify potential mitigation measures (Thomson et al. 2010): causes and management options that may not have been identified if statistical methods were used that only focused on detecting linear trends. Likewise, the detection and assessment of regime shifts in aquatic systems has been receiving increasing attention (Carpenter 2003; Carpenter et al. 2011). Thus, monitoring programs are often expected to provide answers to management questions about changes occurring over time, and frequently there can be multiple definitions (or interpretations) as to what these questions mean in terms of detecting temporal trends (Panel 1).

Statistical Power to Detect Long-Term Linear Trends

As reviewed above, detecting a temporal trend is often equated with finding a statistically significant long-term linear trend. This definition of temporal trend relies on linear models and null hypothesis testing as a means of making inferences about temporal dynamics, and thus the concept of statistical

PANEL 1. INTERPRETING TEMPORAL TRENDS.



Fisheries management objectives often specify a desire to detect temporal trends in an ecosystem response variable of interest. As a result, monitoring is included as part of the management process in an effort to evaluate whether or not a temporal trend has occurred. In this situation, translating management questions to monitoring objectives becomes a critical part of the overall management process. A key component to this translation is defining what is meant by "temporal trend." including both the duration of change sought to detect (a short- vs. long-term trend) and the anticipated form of the trend (e.g., linear, nonlinear, step change). The figure shows hypothetical nonmonotonic temporal dynamics of a fishery ecosystem response variable (solid black circles). The time series includes a long-term trend (grey line) describing an underlying long-term average decline over most of the time period. Within this period of long-term decline are shorter term trends, both increases and more severe declines compared to the long-term average (e.g., solid and dashed orange lines), illustrating that short-term trends may or may not be representative of long-term dynamics. The dashed red line indicates an abrupt step change (i.e., a threshold or "tipping point") in the time series. To translate management questions to monitoring objectives, we suggest that managers specify the anticipated rate, duration, and form of temporal trend to be detected. We have provided some illustrative examples in Table P1.

Table P1. Examples of common management questions related to temporal trends encountered in fisheries and descriptive characteristics related to translating these questions to monitoring objectives.

Example management question	Rate of temporal change	Duration of temporal change	Form of temporal trend	Example monitoring objective
Is the target population long-term average declining over time?	Usually gradual, sustained	Long-term cycles or permanent	Linear: Long-term trend[a]	Detect an underlying trend in the population over time
Is a strong year-class present?	Usually moderate	Short-term	Nonlinear: Short-term trend[a]	Detect a large recruitment event
How different are two time periods from one another (e.g., before and after a management action was implemented)	Rapid	Permanent over moderate to long-term time scales	Step change: Potentially a regime shift; steady-state conditions of meaningful duration	Detect a shift in system productivity
Has the target population increased each of the last 5 years	Moderate	Short-term to permanent	Linear: Short-term trend	Detect an increase/decrease in abundance due to a management action

[a]In practice, linear trends are often estimated on the natural logarithm scale.

power is used for evaluating trend detection capabilities. This approach also implies that whether or not a long-term (e.g., decades) linear trend is detected provides meaningful information on whether a system is responding to a management action as predicted. However, monitoring data may also be used to evaluate management actions over relatively short ecological time frames (e.g., 5–10 years). In this case, managers may not be interested in the long-term dynamics of a population but, rather, in whether conditions have changed from year to year or perhaps in the last 5 years. If traditional linear models are used to make inferences about the success of management actions under these circumstances, managers may be setting themselves up for failure because of the low statistical power to detect linear trends over relatively short, management-relevant time frames (<10 years). Failure can come in the form of not detecting a significant trend even though some biologically important change has occurred (although perhaps less likely in fisheries, failure could also come in the form of detecting a significant trend, due to relatively low total variability, that is not meaningful from a biological or management perspective; Wade 2000). To illustrate this point, we conducted a literature review on the power to detect statistically significant linear trends for freshwater biological and habitat indices.

Statistical power is the probability of rejecting the null hypothesis when it is, in fact, false (e.g., detecting a trend when a trend is present). Generally, power is a function of sample size, the choice of a type I error rate (usually represented as α; i.e., stating that a trend is present when, in fact, there is not a trend), effect size (i.e., trend magnitude), the underlying variance in the observations, and the statistical model used to evaluate power. When survey data are analyzed for temporal trends, sample size is often quantified as the number of years sampled and the number of sampling units sampled within a year. Common examples of fishery-related sampling units include the number of reaches surveyed within a stream, the number of sites visited within a lake, or the number of lakes sampled. In many power analyses, the significance level (α) is set at a conventional value of 0.05, but larger values are sometimes chosen if failing to detect a real trend in an index is deemed more important than detecting a false trend (e.g., Dauwalter et al. 2010). The magnitude of the effect size is generally stated as the desired amount of change over time that a management body is interested in detecting. Therefore, the desired detectable trend magnitude is often stated as a percentage change per year (e.g., detect a 3% per year decline in fish abundance) for power analyses evaluating the statistical power of detecting long-term linear trends. There are several sources of variability that affect statistical power to detect trends in fishery survey data (e.g., spatial, temporal, sampling [observation] error; Urquhart et al. 1998; Larsen et al. 2001), and previous work has also shown that how the total variability is partitioned among different sources is an important determinant of the statistical power associated with temporal trend detection (Wagner et al. 2007).

Summary of Published Power Analyses

Using previously published power analyses, we summarized the number of sampling years required to detect statistically significant linear trends, and we used statistical power as a means to compare across studies and biological and habitat indices. This review highlights the low statistical power of many fishery surveys that are evaluated in this manner as well as the nontrivial nature of explicitly defining temporal trend when developing management/monitoring objectives and, importantly, when deciding on the analytical method used for estimating temporal trend-related parameters.

We focused our literature review on recently published studies (from 1999 to 2011) that examined the statistical power to detect temporal trends in biological and aquatic habitat survey data. Specifically, we summarized the number of years needed to detect a trend of a given magnitude with a power ≥ 0.80. For fisheries survey data, power ≥ 0.80 is typically deemed as acceptable or "high" power. From the papers we reviewed, we report the stated temporal duration required for trend detection or we estimated the number of years from presented power curves when the number of years required to detect a trend was not directly indicated in the text. Although there are several factors that affect statistical power, we summarized the number of years required to detect a trend with respect to both the type I error rate and trend magnitude. We focused on these two influential factors because (1) they represent critical aspects of developing objectives for monitoring programs and (2) relative to other factors, such as within-year sample size, they have a large influence on power estimates. Although within-year sample size can influence statistical power for an individual study, we did not summarize the published power analyses based on sample size because for a given trend magnitude and sample duration, the range of sample sizes evaluated in the published literature did not often result in large changes in power. For example, the number of years required to detect a 1% per year trend in canopy cover with 80% likelihood ranged from 15 years when 10 sites were sampled each year to 13 years when 50 sites were sampled each year (Larsen et al. 2004). This small to moderate gain in power as a result of increasing within-year sample size is not unexpected because increasing sample size will not reduce all sources of variation affecting observations of fish populations and their habitat. Specifically, if coherent temporal variation is high (i.e., a strong year effect), neither increasing within-year sample size or within-year revisits to the same sites will have much influence on power (Urquhart et al. 1998; Larsen et al. 2001). Thus, plots of statistical power often display an asymptotic relationship with sample size in ecological studies. If a study did report the number of years to detect a trend for multiple sample sizes, however, we recorded and report all power estimates in an effort to capture some of the variability in power that is due to sample size. For studies that evaluated different sample designs (i.e., fixed site versus revisit monitoring designs), we report the average power across designs. This approach was used because survey sampling design tended to have a minimal impact on power estimates (e.g., Dauwalter et al. 2010) and relatively few designs were evaluated in most

Table 1. Summary of studies examining the statistical power to detect temporal trends in freshwater fishery survey data.

Indicator	System type	Design evaluated[a]/ scope of inference	Trend magnitude (percentage per year)[b]	Sampling duration (years)	Number of sites sampled per year[c]	α-Level	Reference
Biological							
Abundance and biomass for stream trout (*Salmo, Salvelinus*, and *Oncorhynchus* spp.[d])	Streams	Rotating panel/single site and network of sites	−2.5, −5	5–30	1–30	0.05, 0.10, 0.20	Dauwalter et al. (2009)
Trout biomass (Brook Trout *S. fontinalis*, Rainbow Trout *O. mykiss*, and Brown Trout *S. trutta*)	Streams	Rotating panel/ National Forest	−1, −2.5, −5	6–30	20–30	0.05, 0.10, 0.20	Dauwalter et al. (2010)
Bull Trout *S. confluentus* indices of abundance and population estimates	Streams	Fixed sites/ watershed	−25, −50, −75[e]	5, 15, 30	10–39	0.10	Al-Chokhachy et al. (2009)
Coho *O. kisutch* and Steelhead *O. mykiss* redd densities	Streams	Generalized random tesselation stratified design and stratified random design/regional	±5, ±10	3–18	8–40	0.05, 0.10	Gallagher et al. (2010)
Bull Trout *S. confluentus* redd counts	Streams	ND/state	0, ±10, ±20, ±50	3–30	1	0.05, 0.20	Maxell (1999)
Walleye *Sander vitreus* mean length at age	Inland lakes	Fixed sites/ regional	−0.5, −1.0, −1.5, −2.0	5–25	10–40	0.05	Wagner et al. (2007)
Walleye S. vitreus catch per effort	Great Lakes	Fixed sites/ single lake	−3, −5, −10, −20	5–25	10–100	0.05	Wagner et al. (2009)
Habitat							
Large wood volume (m^3/100 m)[f]	Streams	Rotating panel/coastal streams	1, 2	5, 10, 15	48	0.10	Anlauf et al. (2011)
Residual depth, riparian canopy cover, percentage of fine substrate (<2 mm in diameter), volume of large wood per unit length of channel	Streams	Fixed sites/ regional	1, 2	3–30	10–50	0.05	Larsen et al. (2004)

[a]For conciseness, we used “rotating panel” to include several types of revisit panel designs (see Urquhart and Kincaid 1999 for design details). ND = no design specified.
[b]Negative values indicate declines; positive values indicate increases over time; ± indicates that both increases and decreases for a given trend magnitude were evaluated.
[c]The definition of a “site” varies by study; see reference for details.
[d]Examined data from eight studies representing 22 streams.
[e]Statistical power was performed to detect a specified decline (e.g., 25, 50, or 75%) over a given time period, not on a per year basis.
[f]Variance structures for active channel width (in meters), percentage fine sediment, and percentage pool habitat were similar to large wood volume and assumed to have similar power.

published studies. For studies that reported power analyses based on actual variance estimates and alternative hypothetical variance structures (e.g., Wagner et al. 2007), we report power based on the actual variance estimates. Because we were interested in routine monitoring programs, we did not consider studies that examined the power to detect trends as a result of using management experiments (e.g., before–after–control–impact designs), although we comment on such management experiments in our discussion.

We found seven studies evaluating multiple biological indices (41 power analyses) and two studies evaluating habitat indices (43 power analyses) that met our criteria and were included in our summary of power. Biological indices included measures of fish abundance, biomass, density, CPE, redd counts, and mean length at age. In these studies, the biological indices were usually related to salmonids (*Salmo*, *Salvelinus*, and *Oncorhynchus* spp.), with the exception of two studies (Wagner et al. 2007, 2009) with Walleye *Sander vitreus* as the focal species. Habitat indices included measures of large wood volume, residual depth, riparian canopy cover, and percentage of fine substrate (Table 1). Not unexpectedly, on average, the number of years required to detect a trend decreased with increasing trend magnitude and the chosen significance level. Though there was moderate variation in the number of years required to detect a trend for the same significance level and trend magnitude (Figure 1), some generalizations emerged. The number of years required to detect trend magnitudes less than a 5% change per year (e.g., 0.5, 1, 1.5, or 2%) was ≥ 10 years (mean ± standard deviation [SD], 19 ± 5, n = 15) for biological indices. The number of years to detect a trend was < 10 years only when relatively large trend magnitudes were specified (e.g., a 10% or 20% change per year) or when moderate trend magnitudes (e.g., 5% change per year) and a type I error rate of 0.10 or 0.20 were adopted (see Figure 1). Although a smaller range of trend magnitudes was evaluated for habitat indices, similar patterns emerged. For instance, for a 2% per year change, the average number of years to detect a trend was 13 ± 4 (±SD, n = 22). Similar to biological indices, at the smallest trend magnitude evaluated (e.g., 1% change per year), it always required > 10 years to detect a trend (mean ± SD, 21 ± 6, n = 21; see Figure 1).

Great Lakes Basin Power Analysis Examples

To supplement the literature review, we performed power analyses based upon Walleye and Yellow Perch *Perca flavescens* fishery-independent gillnet surveys in three lakes in the Great Lakes basin. Specifically, we analyzed surveys from the Wisconsin waters of Lake Superior (Walleye and Yellow Perch); the Bay of Quinte, Lake Ontario (Walleye and Yellow Perch); and Oneida Lake, New York (Walleye only) to estimate variance structures. Catch per effort data were from fixed site gillnet surveys, where gillnets were fished at multiple sites within each lake each year, and the same sites were revisited each year. We then used a simulation approach for power analysis following the methods outlined in Wagner et al. (2007). Briefly, for each simulation for each lake, we used variance components estimated for each observed time series to simulate a hypothetical 30-year time series of catch data for 1,000 sites. These 1,000 sites were then treated as the total population of sites from which samples could be taken for that lake. A known population-average temporal trend (a 2% per year decline) was then imposed on each site-specific time series. However, each simulated site could deviate from this population-average trend; the magnitude of the deviation was dependent on the estimate of trend variation used in the simulation. We ran 250 simulations based on the survey estimates for each lake. For all data sets, at the start of each simulation 30 sites were randomly chosen and then treated as the fixed sites that were sampled throughout a 30-year sampling period. Although we observed minimal effect of within-year sample size on power through our literature review, we also performed simulations where 60 sites were sampled each year to further evaluate the influence of within-year sample size on power. These supporting sensitivity analyses using 60 sites were performed for Lake Superior Walleye and Lake Ontario Walleye and Yellow Perch. During 3-year intervals of each simulation (i.e., at years 3, 6, 9, etc.), we used a negative binomial mixed model to estimate the fixed slope parameter and test the null hypothesis that it was equal to zero by calculating a test statistic and comparing to a critical value (α = 0.05). Because the data were generated assuming a negative slope, the null hypothesis of a zero slope is false, and power was estimated as the percentage of simulations (out of 250) that rejected the null hypothesis.

These analyses demonstrated similar statistical power patterns to those reported in the literature we reviewed. We present detailed results for the 30 site simulations only, given that the number of sites sampled had a modest influence on the results, which supports findings in the literature review. For example, for Lake Superior Walleye, going from 30 to 60 sites resulted in an average percentage increase of power over the 30-year time period of 0.28%, and for Lake Ontario Walleye and Yellow Perch the average percentage increase in power was 6.4% and 1.3%, respectively. For the 30-site case approximately 15 years of sampling was required to detect a 2% per year decline in Walleye CPE (power ≥ 0.8) in Oneida Lake and Lake Superior, whereas >30 years of sampling was required to detect the same trend for Lake Ontario Walleye (Figure 2). The results were similar for Yellow Perch, with approximately 15 and 22 years of sampling required to detect a 2% decline per year in lakes Ontario and Superior, respectively (Figure 2). The aforementioned percentage increases in power as a result of sampling 60 sites per year had minimal to no influence on the number of years required to detect a 2% trend with power > 0.8 when compared to sampling 30 sites per year. Another way of saying this is that power approaches an asymptote well within the range of sample sizes typically considered in fisheries studies, and thus power for trend detection is dominated by the influence of among-year variation and number of years sampled, rather than only among-site variation and the number of sites samples.

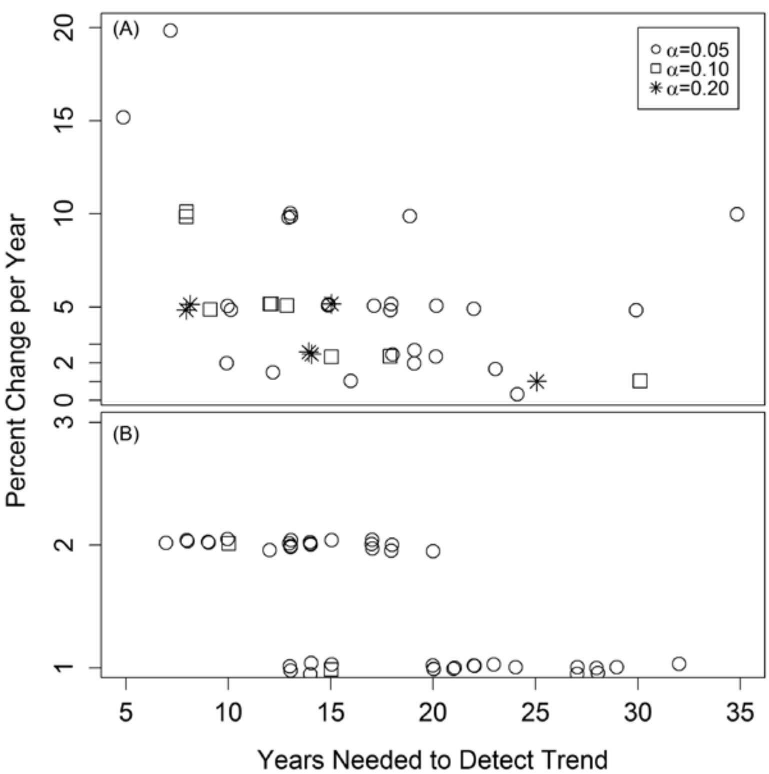


Figure 1. Summary of literature describing the years needed to detect a trend of a given magnitude with statistical power ≥ 0.80 for (A) biological and (B) habitat survey indices. Results are summarized by the significance level (α). Points have been jittered along the x- and y-axes to aid visualization. See Table 1 for studies used in the summary.

Dynamic Linear Modeling of Time Series Using Bayesian Estimation Techniques

Familiarity with standard linear regression techniques probably leads to their use even when management interest is not really in detecting a long-term overall trend across a time series. Rather, management interest often may center on what the rate of change is over a shorter term and how changes in this rate might coincide with management actions or other events. Estimates of the probability that the rate of change is less than some specified value (e.g., zero) can often be more useful than estimates of the probability that observed data arose in the absence of an underlying trend (the *P*-value from a hypothesis test). Given this, dynamic linear modeling in a Bayesian context is one tool that might better fit some management objectives. Dynamic linear models provide greater flexibility than linear regression by allowing the rate of change to also change over time. The use of Bayesian inference has grown in usage over time (e.g., Ellison 2004; Fabricius and De'ath 2004); however, it remains less commonly used than frequentist approaches for evaluating trends. One of the major advantages of Bayesian inference is that it emphasizes the relative probability of given rates of change, allowing for a more complete picture of the plausibility of different system dynamics.

Bayesian estimation can provide a flexible analytical framework for quantifying temporal trends, which also allows for probabilistic statements about outcomes that can facilitate communication of uncertainty to stakeholders. For instance, Bayesian analyses provide a probabilistic uncertainty estimate for all estimated parameters and derived quantities. Rather than relying on null hypothesis testing and with the resulting binary decision of a statistically significant or nonsignificant trend, Bayesian estimation allows for multiple decision possibilities and a more intuitive interpretation about the probability of a decline occurring in the time series (Wade 2000). As a result, trends can be evaluated and decisions made based on policy-relevant criteria that have been identified for any specific problem under consideration. In addition, although beyond the scope of this article, power analyses can be performed within a Bayesian context, providing estimates of the probability of achieving specific goals (rather than rejecting the null when the null is false) under different monitoring scenarios. Lastly, Bayesian analyses can take advantage of information that existed prior to a study to help inform inferences from the study (i.e., the use informative priors), whereas frequentist approaches assume that there is no relevant existing information (Ellison 2004). This may be useful in cases where information is available for the potential value of a parameter of interest.

To illustrate the concept of matching statistical models with monitoring objectives and the use of Bayesian inference, we further investigate the potential impacts of the establishment of an invasive species on Walleye in Oneida Lake, New York. Like many aquatic systems, Oneida Lake has been affected by many natural and anthropogenic stressors, including invasive species. Of notable importance was the invasion of zebra mussels *Dreissena polymorpha*, which were found in high abundance in the lake by 1992. Although the effects of zebra mussel establishment can cascade through trophic levels and vary among species and across life stages, for Walleye it was hypothesized that the establishment of zebra mussels would have a net negative impact, such that Walleye abundance was expected to decline (Irwin et al. in press). Specifically, it was predicted that declines in Walleye CPE would be evident post–zebra mussel invasion (i.e., post-1992), although double-crested cormorants also likely influenced Walleye abundance during this time period (Rudstam et al. 2004; Irwin et al. 2008).

For illustrative purposes, suppose that a monitoring objective related to Oneida Lake Walleye involved detecting temporal trends in CPE after zebra mussel invasion. The prediction that declines in Walleye CPE would occur after zebra mussels were abundant does not translate naturally to detecting a long-term linear decrease in Walleye CPE or its log. For this hypothetical monitoring objective, we are not interested in the long-term average trends in CPE; rather, we are interested in a potentially abrupt change in CPE connected to when zebra mussels became established. Specifically, we predict nonmonotonic trends in Walleye CPE over time, with a substantial decline occurring over a relatively short period after 1992, when zebra mussels were first observed at high densities in the lake. Further, it is likely that Walleye CPE would eventually level off at some lower but positive abundance (i.e., zebra mussels alone were not expected to drive any fish species to extinction).

To translate our prediction and monitoring objective for detecting nonmonotonic trends into a Bayesian statistical model, we fitted a dynamic linear model (DLM) to the time series

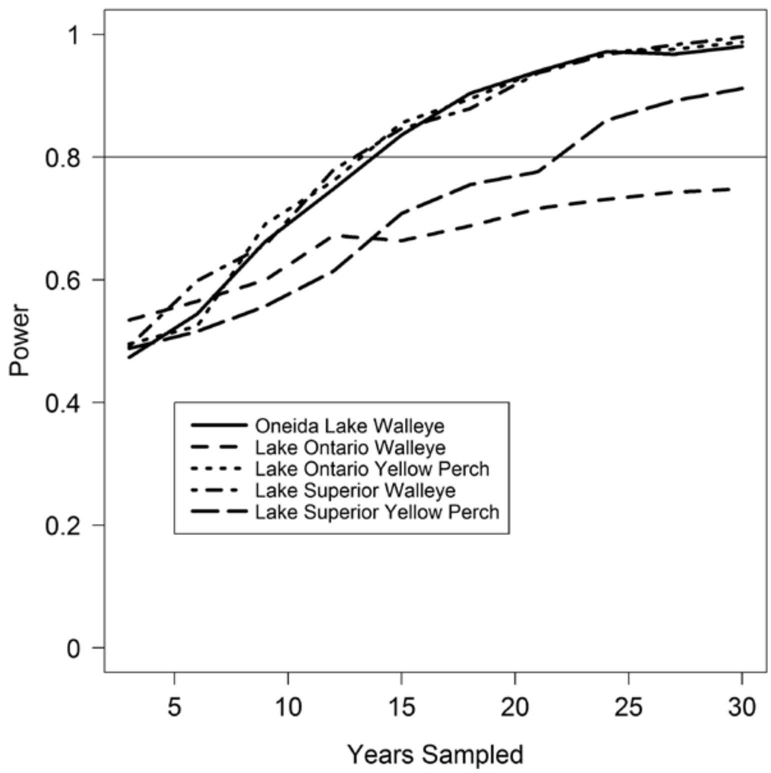


Figure 2. Power curves for detecting a 2% per year decline in species catch per effort for annual gillnet surveys in Oneida Lake, New York (Walleye only), the Wisconsin waters of Lake Superior (Walleye and Yellow Perch), and the Bay of Quinte in Lake Ontario (Walleye and Yellow Perch). Horizontal line at power = 0.8 was added as a reference.

of gillnet catches for Oneida Lake Walleye. The time series spanned the years 1957–2006 (except 1974 and 2005). Specifically, we fitted a DLM outlined in Panel 2. For this example, Bayesian estimation was performed using the program WinBUGS (WinBUGS 1.4; Spiegelhalter et al. 2003). An important feature of DLMs, which is relevant for addressing our monitoring objective, is that DLMs allow model coefficients (e.g., slope parameters) to change with time, enabling the elucidation of nonmonotonic trends.

The DLM considers both intra-annual (e.g., variation in CPE among sites within a year) and interannual (e.g., variation among years in average CPE) variability on Walleye CPE trends and captures the overall temporal dynamics of the Walleye CPE time series (Figure 3A). Note the increased uncertainty for the year 2006 (the final year of this time series), which is partly due to the missing data in 2005 and partly because the estimate is not constrained to be consistent with subsequent years of data. In addition, the Bayesian estimation allowed us to make inferences about changes to Walleye CPE relative to 1992. Specifically, negative annual rates of change occurred with a greater than 80% probability twice during the time series, one of which roughly overlaps with the period when the lake was experiencing zebra mussel establishment (Figure 3B, solid line). The results illustrate that the rate of temporal change likely changed over time.

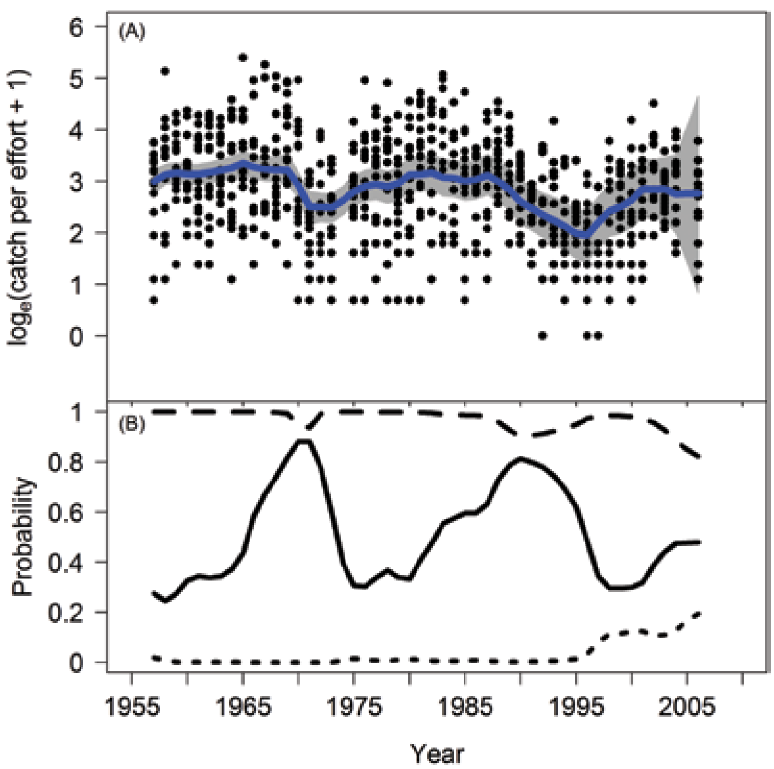


Figure 3. Posterior mean fitted values (curved solid line) and 95% credible intervals (shaded area) from a dynamic linear model fitted to $\log_e$-transformed Walleye CPE from annual gillnet surveys (solid circles) from Oneida Lake, New York (Panel A). Panel B summarizes the estimated probability of annual rates of change <0 (i.e., probability of annual declines in CPE; solid line), >−0.25 (large dashed line), or >0.25 (small dashed line) occurring throughout the time series.

Summaries and inferences from a Bayesian analysis are straightforward. In particular, the posterior distributions of estimated parameters are easily summarized and thus can be used to address specific management objectives. For instance, if it was important in the Oneida Lake example for a management agency to know the probabilities of annual rates of change being outside of a specified value, then such summaries can quickly be obtained (Figure 3B, dashed lines for >−0.25 or >0.25).

DISCUSSION

Monitoring for temporal trends is an integral component of many fisheries management programs. What constitutes a management-relevant trend is not trivial and should be addressed within the broader decision-making process that, ultimately, will result in the implementation and evaluation of specific management actions. Ideally, this process will take place within a formal decision-making framework that includes appropriately diverse stakeholder groups from the onset, thereby defining what the problem is and why management action is required in the first place (Irwin et al. 2011). A transparent and inclusive approach to decision making will help ensure that all participants are aware of relevant monitoring objectives, such as the anticipated trend (i.e., duration and anticipated form; Panel 1) that is desired to be detected or if multiple types of temporal changes are important. Such a process will also help ensure reasonable expectations for the amount of time that may be necessary to detect a management-relevant trend. As we have illustrated across several sources, the statistical power to detect relatively subtle changes over time is often quite low for many freshwater fishery indicators.

As a result of this low statistical power environment, it may take 10 years or more to detect a small to moderate trend, which may be unacceptable to managers or stakeholders. For example, waiting 20 years to evaluate the effects of experimental length limits on a fishery would likely not garner much political support. This low statistical power does not suggest that biologists must necessarily wait a significant portion of their entire career to determine whether indices of interest have changed over time. In fact, if the assessment of management actions is the primary objective (e.g., versus detecting a sustained trend related to long-term changes in influential environmental conditions), then in addition to well-defined objectives, management experiments represent an alternative approach to routine monitoring that will potentially decrease the amount of time required to detect temporal trends.

Designed management experiments often include the monitoring of a reference or control site, in addition to the monitoring of the manipulated system. The use of control and manipulated systems can increase the rate at which we are able to learn about a system by providing additional evidence of how the manipulated system would be expected to have responded in the absence of the management action. Although a vari-

PANEL 2. DYNAMIC LINEAR MODELING.

Dynamic linear models (DLMs) are a class of state-space models. DLMs have several features that make them desirable for modeling fisheries-independent survey time series data, including (1) the estimated CPE at each year is related to the CPE at earlier years (Stow et al. 2004), which is consistent with temporal dynamics of fish populations; (2) time-varying parameters most strongly influenced the current year's information and data from other years closest in time, as opposed to traditional linear regression where parameters (i.e., slope and intercept) are influenced directly by all observations; and (3) DLMs easily accommodate missing and unequally spaced and missing data, which is common for fishery-independent survey data.

Dynamic linear models consist of observation and systems equations. Briefly, a DLM can be parameterized as follows:

Observation equation:

$$\log_e(\text{CPE})_{ti} = \text{level}_t + \psi_{ti}, \quad \psi_{ti} \sim N(0,\Psi_t) \qquad (1)$$

Systems equations:

$$\text{level}_t = \text{level}_{t-1} + \text{rate}_t + \omega_{t1}, \quad \omega_{t1} \sim N(0,\Omega_{t1}) \qquad (2)$$

$$\text{rate}_t = \text{rate}_{t-1} + \omega_{t2}, \quad \omega_{t2} \sim N(0,\Omega_{t2}), \qquad (3)$$

where $\log_e(\text{CPE})_{ti}$ is the $\log_e$ of CPE (a small constant is typically added to accommodate zero catches) at site i in year t; level_t is the mean $\log_e$ (CPE) at time t; rate_t is the expected rate of change of mean $\log_e$ (CPE) and can be interpreted as the slope between consecutive time periods; and ψ_{ti} and ω_{tj} ($j = 1, 2$) are the error terms for year t sampled, which here are distributed as $N(0,\Psi_t)$ and $N(0,\Omega_{tj})$. In a Bayesian analysis, priors are needed for each estimated parameter, so to complete the model description we note that we assumed level_1, $\text{rate}_1 \sim N(0,1000)$; $1/\Omega^2_{tj} = \xi^{t-1} \cdot 1/\Omega^2_{1j}$, $1/\Psi^2_t = \xi^{t-1} \cdot 1/\Psi^2_1$ for $t > 1$ and $J = 1, 2$; and $1/\Omega^2_{1j}$, $1/\Psi^2_1 \sim \text{gamma}(0.001,0.001)$, where ξ is a discount factor (between zero and one) representing the fact that older information in the time series is not as useful for forecasting (Sadraddini et al. 2011). The priors used on the initial year parameters are considered noninformative. Because individual gillnet sets (i.e., sample sites) were used as the response variable, as opposed to using annual mean CPE, this model accounts for both intra-annual (Ψ_t) and interannual variation ([Ω_{tj}]; see Lamon et al. [1998]; Congdon [2010]; and Sadraddini et al. [2011] for details).

ety of experimental designs can be implemented, before–after, control–impact paired designs (BACIP; Stewart-Oaten et al. 1986; Stewart-Oaten and Bence 2001) are often used. Under a BACIP design, experimental (manipulated) and control (reference) systems are monitored before and after the impact, which could be the implementation of a management action. In such management experiments, the reference site acts like a covariate and functions in a different way than the control of a randomized experiment (Stewart-Oaten et al. 1992; Bence et al. 1996). Paired sampling of the manipulated and reference sites during the period before the management action allows such predictions and estimation of the effect of the action. The simplest form of BACIP is just one approach to evaluating management experiments. The nature of spatial and temporal variability and the extent to which "before" sampling is possible influence appropriate sampling designs (e.g., Hewitt et al. 2001; Underwood and Chapman 2003; Hayes et al. 2003b; Paul 2011). In some cases, the existence of other covariates can even alleviate the need for before sampling at reference sites (Bence et al. 1996; Paul 2011). Regardless of the specifics, the more general point is that use of data other than the response data from the manipulated site can be used to develop a statistical model predicting the manipulated site in the absence of the manipulation and greatly reduce the time required to detect ecologically meaningful trends.

We also stress that our review of power analyses and our analyses of data on Great Lakes Percids must be viewed within the specific context they were meant to address: detecting long-term average trends. If monitoring objectives pertain to detecting short-term and/or nonmonotonic trends, then a power analysis based on linear regression may not produce the most relevant information. As illustrated with the DLM example, alternative analytical tools, combined with Bayesian inference, may provide a better match to management and monitoring objectives than linear models and null hypothesis testing. Therefore, when it seems likely that the rate of change is changing over time, we might expect that managers and stakeholders will often be more interested in a local (in time) rate of change. Additionally, we might become interested in how frequently the sustained directionality (i.e., positive or negative) of the rate of change is changing. DLM is an approach better suited for such situations and allows for useful inferences, whereas repeatedly applying standard linear regression to subsets of the data would likely increasingly suffer from reduced power. Analytical approaches that are able to provide a more flexible framework for linking management and monitoring objectives should also be able to contribute to designing monitoring programs and evaluating management actions.

In summary, statistical power analysis is one tool that is useful for the design of monitoring programs and experiments; however, fisheries managers work in high-variability, low-statistical-power environments. Decisions about temporal trends and expected future trajectories will be made regardless of low statistical power, so the question is "In the light of low power, what can we do to ensure that we make the best decision possible, given the data in hand?" A critical step is the formulation of monitoring objectives that include a statement defining what is meant by detecting temporal trend. The definition must be translated to an appropriate statistical model that maximizes the utility of subsequent inferences for informing the decision-making process. If null hypothesis testing is used as the inferential framework, communicating results from power analyses to develop realistic expectations about the time required to detect trends is essential to ensure legitimate assessments of management actions. In many cases, Bayesian inference may provide a reasonable alternative to traditional null hypothesis testing. Although changing the inferential framework does not necessarily increase our ability to detect trends over a shorter time frame, it does remove the constraint of a temporal trend being interpreted as significant or not significant. Rather, Bayesian inference forces explicit consideration of the ecologically and management-relevant effect sizes to be detected in addition to acceptable levels of uncertainty while providing the ability to make probabilistic statements about estimated parameters describing temporal trends that may facilitate communications with stakeholders.

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FEATURE

Measurement Error in Fish Lengths: Evaluation and Management Implications

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ABSTRACT: *A fundamental aspect of fisheries science is measuring body length. Humans are inherently prone to error despite systems and provisions made to reduce it. We evaluated length measurement error (herein, referred to as "error") and digit preference from fish studies conducted on the Colorado River and Little Colorado River in Arizona. Empirical error estimates varied among fish species and generally increased with fish size. We identified a digit preference for numbers ending in zero and five, which was exacerbated with larger sizes. Error effects on growth estimates were largest for fish recaptured after a short time, and we suggest guarding against the error phenomenon by removing data from fish captured and recaptured within a minimum of 30 days. Human, situation, and specimen induced error factors are described. Fisheries professionals should be cognizant of error factors, especially in situations when high precision and accuracy are required and results have important management implications.*

Medición del error en la talla de los peces: evaluación e implicaciones para el manejo

RESUMEN: *un aspecto fundamental en las ciencias pesqueras es la medición de la talla corporal. Los humanos somos inherentemente propensos a cometer errores pese a los sistemas y medidas preventivas que se utilizan para reducirlos. En este trabajo se evalúa el error asociado a la medición de la talla (en lo sucesivo se le llamará "error") y la preferencia en el número de dígitos en los estudios ícticos llevados a cabo en el Río Colorado y el Río Coloradito, Arizona. Los estimados empíricos del error variaron entre especies de peces y en general se incrementaron conforme la aumenta la talla de los peces. Se identificaron preferencias en cuanto al número de dígitos para los números con terminación cero y cinco, lo cual se amplificó en los peces más grandes. Los efectos del error en las estimaciones de crecimiento fueron más grandes en el caso de los peces recién recapturados. Se sugiere tratar el fenómeno del error mediante la remoción de los datos provenientes de peces recapturados en los primeros 30 días después de su liberación. Se describen los factores de error humano, de medición y asociado al espécimen. Los profesionales de las pesquerías deben ser conscientes de los factores de error, especialmente en situaciones en las que se requieren precisión y exactitud y cuando hay implicaciones importantes para el manejo.*

INTRODUCTION

A fundamental aspect of fisheries science is measuring body length. Conventional measurements include total length (TL), standard length, and fork length (Anderson and Neumann 1996). Fish lengths can be measured with underwater cameras and laser-beam systems (Rochet et al. 2006), visual observation (Harvey et al. 2002), processing machines (White et al. 2006), and electronic measuring boards (Chaput et al. 1992). However, the most primitive and common method for measuring fish length is to use a board with a ruler adhered to the top surface and lengths are recited to a data recorder.

Humans are inherently prone to error despite systems and provisions made to reduce it (Reason 2000). Measurement error, defined here as the "inability to measure fisheries variables perfectly," is a type of uncertainty in fisheries population dynamics (Chen and Paloheimo 1998:9). Fisheries professionals should consider various factors that affect error rates and, more important, understand how error can influence the interpretation of fisheries data and, thus, management decisions.

Although studies comparing sport and commercial fishers' length measurements to those within the fisheries profession have been conducted (Ferguson et al. 1984; Page et al. 2004), few studies have evaluated length measurement error within the fisheries science profession. Our objectives were to (1) evaluate error for different fish species and size groups, (2) evaluate digit preference, and (3) demonstrate the necessity to remove data from fish captured and recaptured within a short time frame (e.g., 30 days) during growth studies.

METHODS

Length Measurement Error Evaluation

We evaluated a long-term fish monitoring database from various Colorado River and Little Colorado River studies conducted between Glen Canyon Dam (Lake Powell) and the inflow to Lake Mead in Arizona. The study area encompassed Glen, Marble, and Grand canyons and the Little Colorado River, which is a large tributary to the Colorado River. The Little Colorado River is the primary spawning and rearing grounds for the endangered Humpback Chub (*Gila cypha*) and other large-bodied native fish, including Flannelmouth Sucker (*Catostomus latippinis*) and Bluehead Sucker (*Catostomus discobolus*). The tailwater stretching 27 km below Glen Canyon Dam supports a recreational Rainbow Trout (*Oncorhynchus mykiss*) fishery.

The database contains over 750,000 individual fish records dating back to the late 1970s. More than 120,000 fish have been tagged with individually identifying marks (i.e., passive integrated transponder tags, numbered external anchor tags, and numbered coded wire tags). In addition to the species listed above, other species including Brown Trout (*Salmo trutta*) and Common Carp (*Cyprinus carpio*) have been tagged. Fish were captured using a variety of net types (e.g., hoop nets and trammel nets of various sizes and dimensions) and boat-mounted electrofishing (Coggins et al. 2006; Makinster et al. 2010, 2011). Total length (in millimeters) measurements were taken on measuring boards on shore or aboard research vessels during the day or night depending on the study requirements. Tagging protocols have varied across species and sizes, and generally fish less than 100 mm TL were not tagged with individual marks.

A portion of fish that received tags tended to get captured and recaptured within the same sampling event or soon thereafter. We only used data from fish that were marked or recaptured within a 3-day period of a subsequent recapture. We assumed that growth was negligible during this short time frame, which would not affect our estimates of error. The difference between the two independent measurements (i.e., the measurement at capture and the subsequent measurement at recapture) was used to estimate mean error. Our approach differed from that of Gutreuter and Krzoska (1994) because investigators in that study were aware of each other's measurements. Similar to Page et al. (2004), we eliminated error outliers greater than three standard deviations from the mean for each species. Fish were separated by species and grouped into 100-mm size intervals ranging between 100 and 300 mm TL, and a group for those greater than 300 mm TL was established. We did not include species and size groups with a sample size less than 30. We plotted error frequency by 1-mm increments.

Juvenile Chub Evaluation

To evaluate error for juvenile Humpback Chub that did not receive tags, we used a blind experimental design in which fish less than 100 mm TL were measured by two separate investigators. Fish were captured using hoop nets placed in the Little Colorado River during Arizona Game and Fish Department and U.S. Fish and Wildlife Service monitoring efforts in May–June 2012. Investigators were instructed to measure fish and record data with the same techniques they normally used during routine sampling. They were not aware of each other's measurements throughout the experiment.

Digit Preference

We evaluated digit preference (Beaman and Grenier 1998), otherwise known as "digit bias" (Sette 1941) or "response heaping" (Vaske and Beaman 2006), as a potential source of error. We plotted the frequency distribution of the last digit from all TL measurements available in the database and tested for significant differences using a chi-square goodness-of-fit test (significance level $\alpha = 0.001$) to evaluate the hypothesis that each digit was assigned with equal probability (Zar 2010). Additionally, we separated measurements into 10-mm length groups (i.e., 10–690 mm) and conducted a chi-square goodness-of-fit test for significance (same as above) for each length group independently.

Growth Rate Variability

We estimated absolute growth rate (millimeters per day) for Humpback Chub over a 23-year time series (1989–2011). The equation from Busacker et al. (1990) used to estimate absolute growth rate for individual fish is shown below:

$$\text{Absolute growth rate} = Y_2 - Y_1 \,/\, t_2 - t_1 \qquad (1)$$

where $Y_2 - Y_1$ is the difference in length between capture occasions, and $t_2 - t_1$ is the difference in time between capture occasions (i.e., days at liberty). The resulting data were plotted against days at liberty to highlight the variability in growth. Additionally, we plotted absolute growth rate as a function of fish length at initial capture for two groups: (1) fish with <30 days at liberty and (2) fish with ≥30 days at liberty.

RESULTS

A total of 8,909 fish were recaptured within 3 days of a previous capture event, which enabled us to obtain empirically based species- and size-specific error estimates. The frequency histogram showed that data were evenly distributed around zero

Photo 1. Photograph of an adult Humpback Chub collected during Little Colorado River monitoring. Length measurements were taken from a conventional wooden board with a measuring tape adhered to the top surface. Photo credit: Arizona Game and Fish Department.

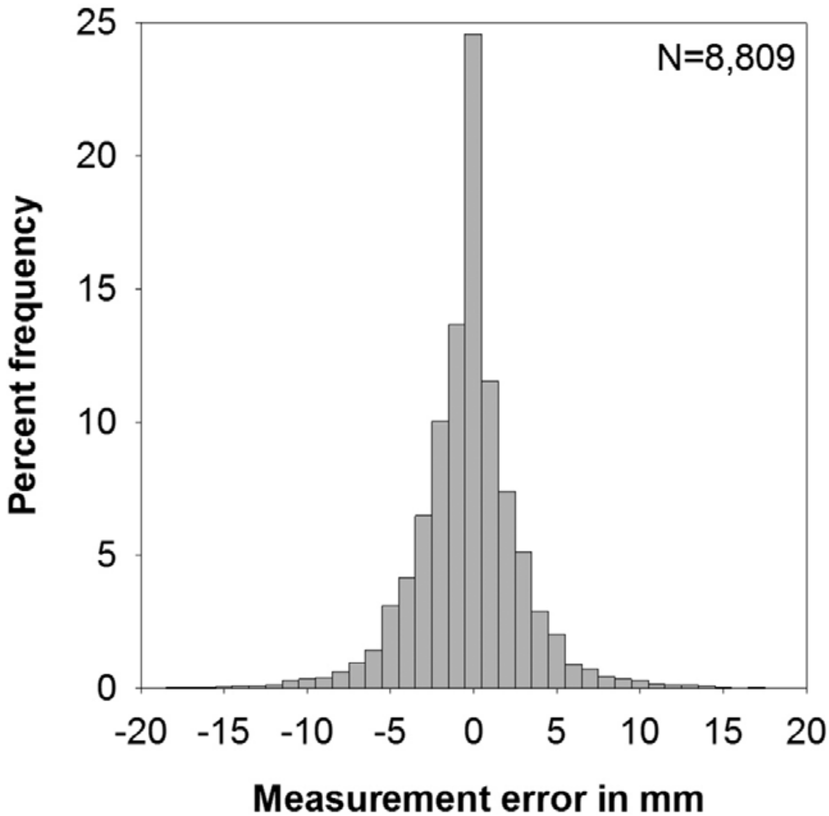

Figure 1. Length measurement error (total length in millimeters) frequency histogram in 1-mm increments. Negative numbers occurred due to shorter measurements taken during recapture event. Large outliers are not shown because the x-axis was bounded at −20 to 20.

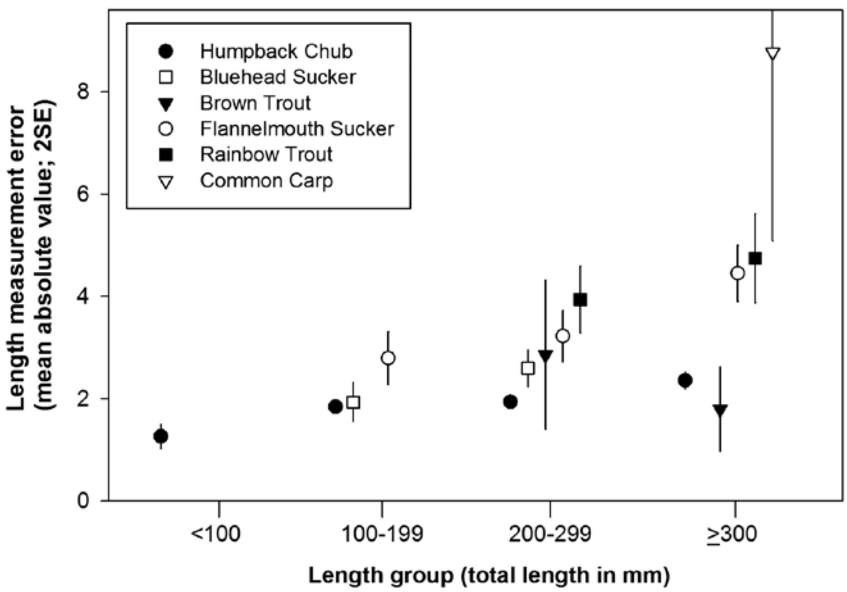

Figure 2. Mean ± 2 standard error length measurement error (absolute value; total length in millimeters) separated by fish species and size group. Humpback Chub (black circles), Bluehead Sucker (white squares), Brown Trout (black triangles), Flannelmouth Sucker (white circles), Rainbow Trout (black squares), and Common Carp (white triangles) were separated into four size groups (<100, 100–199, 200–299, and ≥300). Not all fish species met the sample size requirements (N > 30) for each size class.

with no error occurring 25% of the time (Figure 1). One hundred and twenty-two juvenile Humpback Chub were evaluated during the blind study. Humpback Chub error estimates from Figure 2 reflect those derived from the database, as well as those from the juvenile chub evaluation. Humpback Chub, Bluehead Sucker, and Brown Trout had the smallest mean error (Figure 2). Large Common Carp had the largest mean error (Figure 2). Several species showed increased pattern of error with size (Figure 2).

Empirical growth estimates from Humpback Chub showed that variability associated with error was reduced substantially

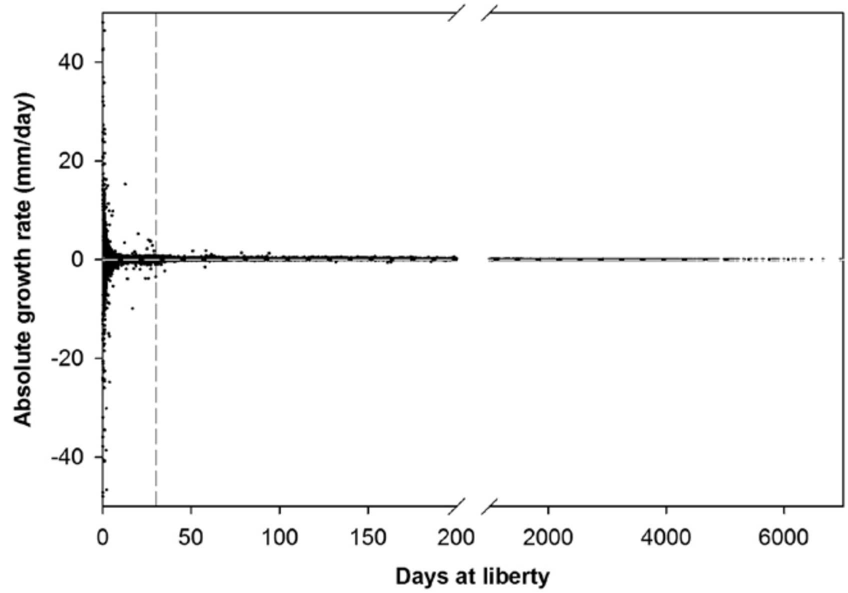

Figure 3. Empirically estimated mean absolute growth rate (millimeters per day) for Humpback Chub during long-term monitoring activities from 1989 to 2011 as a function of days at liberty. The horizontal white dashed line was set to zero for reference. The vertical black dashed line was set to 30, indicating the suggested number of days adequate for growth rate estimation.

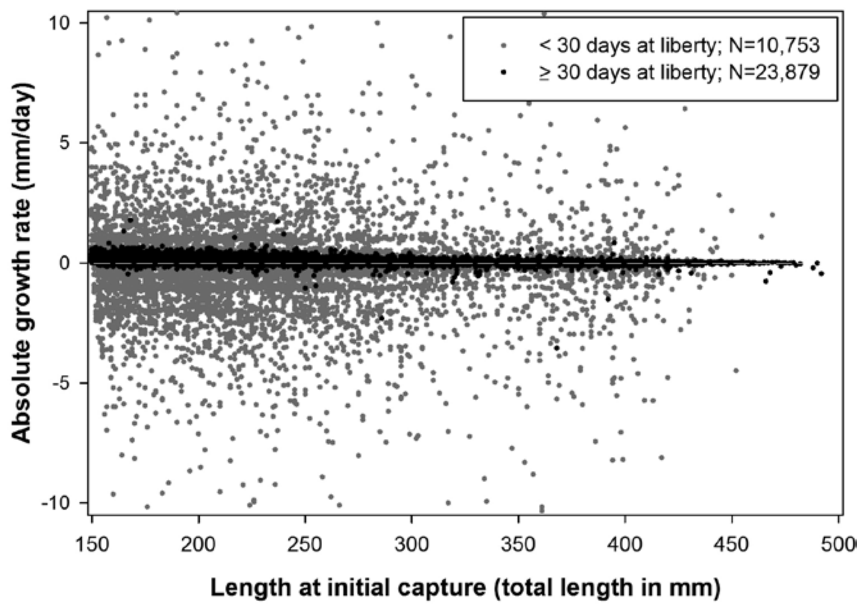

Figure 4. Empirically estimated mean absolute growth rate (millimeters per day) for Humpback Chub during long-term monitoring activities from 1989 to 2011 as a function of fish length at initial capture (total length in millimeters). Gray circles indicate data derived from growth rates attained with <30 days at liberty. Black circles indicate data derived from growth rates attained with ≥30 days at liberty.

over longer durations between capture events (Figures 3 and 4). The daily mean ± 2 standard error absolute growth rate for Humpback Chub recapture histories was lower (and negative) when using all data (−0.04 ± 0.25 mm/day; N = 34,632) compared to removing data for fish less than 30 days between captures (0.07 ± 0.01 mm/day; N = 23,879; Figure 4).

We identified a digit preference in the data set for numbers ending with zero or five (Figure 5; χ^2 = 28,098; df = 9; P < 0.001). This digit preference was evident across all length groups (χ^2 > critical value for all tests; df = 9; P < 0.001); however, preference was exacerbated with larger fish size (Figure 6).

Error Factors

Empirical error estimates varied among fish species and generally increased with fish size. Sources of error can be explained using an extension of the concepts introduced in Anderson and Neumann (1996). Error factors can be split into three categories: (1) human induced, (2) situation induced, and (3) specimen induced (Table 1). Most human-induced factors can be minimized if they are recognized and corrected (Phelps et al. 2012). For example, if incorrect fish snout placement on the measuring board is common for an investigator, this behavior could be altered to correct the bias. It could simply be an equipment problem where a gap is present between the board and the

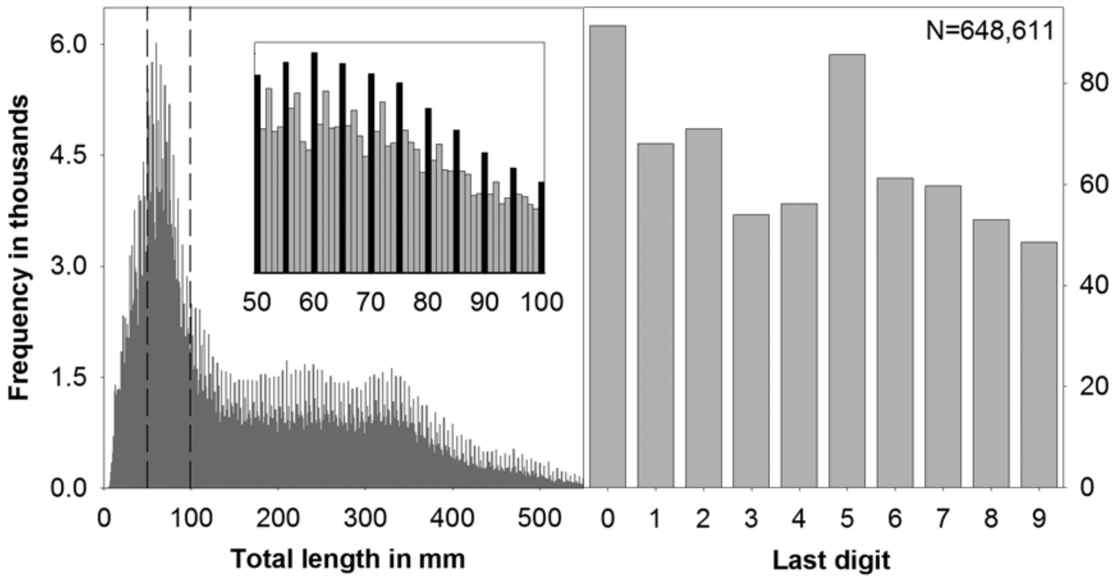

Figure 5. Total length measurements from a long-term fish monitoring database from various Colorado River and Little Colorado River studies conducted since the late 1970s. The dashed lines indicate the zoomed area (50–100 mm). The black bars (left plot) and gray bars (right plot) indicate a digit preference of numbers ending in zero and five.

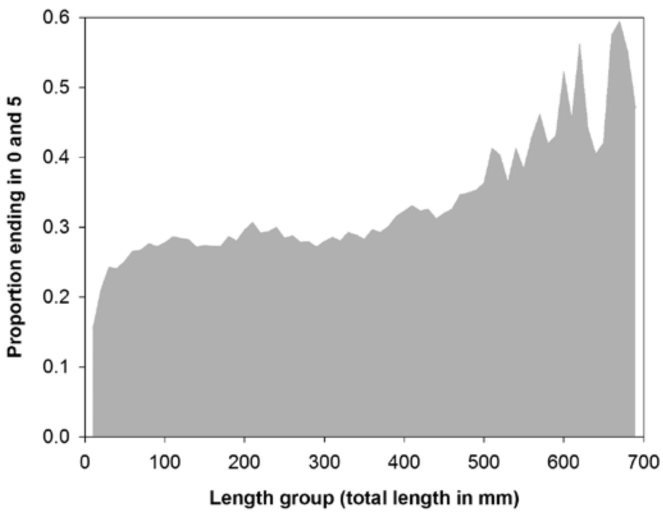

Figure 6. Investigators showed a proportionally higher digit preference for numbers ending in zero or five for larger fish. The proportion is shown for measurements ending in zero and five for each 10-mm length group (i.e., 10–690 mm).

start of the ruler. The pace of measurements likely influences precision, because a faster pace may yield higher error rates.

Digit preference is defined as consciously or inadvertently choosing certain patterns when reporting numerical values. Investigators showed a proportionally higher digit preference for numbers ending in zero or five, which was exacerbated with larger sized fish. Similarly, hunters and fishers tend to prefer numbers ending with a zero or five when reporting harvest (Vaske and Beaman 2006; Bailey 2007). Our inherent subconscious preference toward numbers ending with zero and five could influence error. According to Vaske and Beaman (2006), systematic digit preference can distort results. Digit preference (bias) has also been well established in the medical literature (e.g., blood pressure measurements; Wen et al. 1993; Thavarajah et al. 2003).

Situation induced factors are often uncontrollable (e.g., weather conditions), with the exception of a laboratory setting, which may facilitate fewer errors. Certain sampling situations make it more difficult to take precise measurements. For example, Harvey et al. (2002) found low precision (i.e., high standard deviation) in measurements obtained by experienced scientific divers. Field conditions vary widely across projects. Some projects are conducted during daylight hours on shore as opposed to nighttime work aboard boats. We found higher error in Rainbow Trout measurements than Humpback Chub measurements possibly because Rainbow Trout were sampled at night and processed aboard boats. Humpback Chub were primarily sampled during the day and processed on shore.

Fisheries professionals probably focus on relative error (error divided by length) rather than absolute error. One might assume (perhaps correctly) that the impact of a 5-mm error on a 300-mm fish differs from the same error on a 30-mm fish. Thus, measurement performance may be more related to minimizing relative rather than absolute error. Therefore, fish size is likely an important factor, because larger fish showed lower precision and higher digit preference for zero and five. We found that Common Carp, which are generally much larger than other fish in the Grand Canyon, had the largest error. Phelps et al. (2012) found a substantial amount of error in large Shovelnose Sturgeon (*Scaphirhynchus platorynchus*).

Morphological attributes and behavior vary across species. For example, snout morphology and size and placement of mouthparts could influence error. Flannelmouth Suckers have a blunt rounded snout and subterminal mouthparts. Without proper care when measuring Flannelmouth Suckers it is easy to apply too much pressure, causing the snout to turn downwards and, therefore, the body would not extend properly, causing an inaccurate measurement. Some fish species may exhibit stressed behavior while on the measuring board, whereas others may

Table 1. List of length measurement error factors and potential sources of bias.

Factor	Considerations
Human induced	Communication error between processor and data recorder Correct placement on measuring board Digit preference (bias) Equipment condition Misinterpretation Pace of measurements Skill level Vision problems
Situation induced	Setting (e.g., aboard research vessel, on shore, or in the laboratory) Time of day Weather conditions Visibility during diving surveys Distance of fish during diving surveys
Specimen induced	Disposition (e.g., live, preserved, frozen, or under anesthesia) Size Morphological attributes Behavior Movement during diving surveys

be calmer. Luiselli (2005) found that snake size and behavior influenced length measurements.

Generally, fish show unidirectional growth trajectories; however, Huusko et al. (2011) found that body length reduction can occur naturally in juvenile salmonids because of harsh winter conditions in small streams. Mabee et al. (1998) showed that clearing and staining of sacrificed specimens can cause 3%–5% shrinkage, and others have found length reduction post-preservation (Engel 1974) and without preservation or freezing (Morison et al. 2003). Therefore, it is important to consider fish disposition, especially if a live measurement at marking is compared to measurement postmortem (preserved or not). Fish body parts, especially caudal fins, can become damaged or disfigured between capture occasions. Biologists have observed caudal fin damage on Humpback Chub in the Little Colorado River, which would contribute to shorter measurement at recapture (D. Stone, U.S. Fish and Wildlife Service, personal communication).

Management Implications

Error effects on growth estimates were largest for fish recaptured after a short time, and those effects could bias von Bertalanffy parameters if growth estimates are used directly for parameter estimation. Therefore, time between capture and recapture events should be considered when assessing growth rates. A longer duration between capture and recapture events will lessen the potential for bias in growth rate estimates. Mean absolute growth rate from all Humpback Chub data was negative, indicating that dispersion associated with low days at liberty caused imprecise and erroneous estimates. In equation (1), when $t_2 - t_1$ is only a few days, error has a large impact on the numerator and the overall quotient is substantively influenced by the small denominator. Therefore, small errors in length could have a large effect on growth estimates. A negative growth rate value or one that is exorbitantly high will be a clear indication of error. The difficulty lies in understanding which positive growth rates are erroneous aside from extremely high values. In this study, the proportion of positive and negative errors was nearly equivalent, and thus only removing negatively biased numbers could positively bias mean estimates.

Although error was low in this study, large errors and systematic biases could influence interpretation of length data (Wetherall et al. 1987). The statistical methods required to analyze data will ultimately dictate the level of accuracy and precision needed. Harvey et al. (2002) explained a scenario in which small errors in fish lengths could produce inaccurate weight estimates. There are many other examples showing that other types of measurement errors can influence results, such as stock–recruit relationships (spawner biomass estimation error; Walters and Ludwig 1981), bioenergetics models (relative growth rate error; Bajer et al. 2004), age-structured calculations from otolith aging (aging error; Coggins and Quinn 1998; Campana 2001), and others (Zschokke and Ludin 2001; Hansen et al. 2005).

The error phenomenon described above has important management implications if growth rates are used to develop management goals. For example, Glen Canyon Dam Adaptive Management Program managers have considered options (e.g., temperature control device and flow treatments) to increase water temperatures to facilitate an increase in native fish growth rates (Grand Canyon Monitoring and Research Center 2007; Ralston 2011). As such, Coggins and Pine (2010) developed a temperature-dependent growth model for Humpback Chub in the Colorado River and guarded against the error phenomenon by removing fish observed within 30 days of initial capture. In future growth studies that use a mark–recapture framework, we suggest routinely plotting growth rate against days at liberty to identify bias associated with error. It is essential for fisheries professionals to be cognizant of error factors, especially those that contribute to systematic error.

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Stepping Up: Why You Should Consider Running for an AFS Office

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Looking for a good return on investment? Investing your time in AFS is the closest thing to a sure bet that there is: whether it's the new network connections you form or the skills you gain, serving in a leadership role in AFS always pays dividends. Every year, several months prior to annual meetings, leaders of the Society and its various units begin combing their memberships for those who are willing to serve the organization at a higher level—those who are willing to run for office or serve on a committee. We have served, and continue to serve, as unit officers and committee chairs, most recently on the AFS Nominating Committee, and the Fish Culture and Water Quality Sections, and we can attest to the fact that these searches are difficult at times. This is not to say AFS lacks worthy members with much to offer—far from it! But we are all BUSY! Many of our members are already serving their employers and the fisheries profession in a variety of capacities, and it can be difficult to find the time to also serve AFS. Striking a work/life balance is obviously important, but having reaped the benefits of serving our Society ourselves, we challenge you to consider finding the time to step up and serve at the Society or Unit level.

While being an AFS member opens doors and provides networking opportunities, serving as an officer or committee member puts you in an even better position to form new contacts and build your professional network. Serving in a leadership role means that you'll get to know other fisheries professionals by working alongside them. Whether it's a hectic schedule, social anxieties, or other reasons, it's easy to find excuses and avoid making a cold call to another office or introducing yourself to people at conferences. It's amazing how much easier it is to turn strangers into colleagues when you serve together on a committee or as officers—it clears all of those excuses aside. These new contacts may be the ones that help you get that next job or grant, point you in the direction of a great new hire, or help you find solutions to problems in an area outside of your primary field. As fisheries professionals, we often find ourselves in contentious situations with various stakeholders and partners; negotiations are friendlier and conflicts are easier to resolve when you know the person sitting on the other side of the table and share mutual respect because of your affiliation with the Society.

Still a student and don't think you can offer much? Joining a committee is a great way to start developing that network. It really is true about finding a job or graduate school position—yes, it's about what you know, but it's also very much about who you know. What better way to stand out from your peers, than by becoming active in leadership and getting to know those who may be able to offer you a job or research opportunity? It's also important for established AFS members to recognize potential in our student members, and help them find ways to take on leadership roles in our governance and in fulfilling our Society's mission.

Beyond networking, serving in a leadership role in AFS provides the opportunity to hone your communication and meeting management skills, become a better listener and public speaker, and learn to recognize and leverage strengths in yourself and others. The skills that AFS can help you develop are valuable in any professional setting, and can be just as handy outside the office. Serving in AFS also means that you're likely to interact with individuals working outside of your discipline and "comfort zone." Fisheries is a diverse field in which it is impossible to be an expert in everything; but there is definitely something to be said for learning a thing or two about areas outside your day-to-day work and area of expertise. Serving in a leadership role can help you to stay current and become a more well-rounded and aware fisheries professional.

Need another reason to join a committee or run for office? Consider the importance of life-long service. Many consider professional service to be something best put off until the twilight of one's career, arguing that in the future you'll have more time and will be in a better position to give back to your profession. There is some truth to this. We enjoy the benefits of AFS membership, and over time, a desire grows to repay these professional "debts" and, through professional service, give others the opportunities that we were afforded. That said, professional service is not something that should be strictly put off until later. Taking on leadership responsibilities within AFS is one of the best ways to build a professional network and get your professional life on the right track. The same can be said for reinvigorating a career—there is no better way to explore your "next step" options than to interact with a diverse spectrum of other fisheries professionals.

These are just a few reasons to consider stepping up and serving AFS at the Society, Division, Section, Chapter, or Subunit level. But don't forget the best reason of all—you have something to offer!

Meet Five of Our New Members!

The American Fisheries Society (AFS) has always been filled with movers and shakers—and this year the trend continues.

Daniel Aboagye

Presented at the World Aquaculture Society 2013 Meeting

Daniel Aboagye—originally from Ghana but now a resident of the United States (where he lives with his wife and children)—graduated from Auburn and is now working on his Ph.D. at Mississippi State University (and, yes, that's quite the commute). He hopes to wrap up his dissertation, entitled *Effects of Acute and Chronic Hypoxia on Respiratory Physiology of Paddlefish* by 2014. His studies will apply to both wildlife fisheries and aquaculture. Recently he gave a talk at a World Aquaculture Society meeting entitled "Effects of Hypocia and Temperature on Hypoxia Tolerance, Oxygen Consumption Rate and Swimming Performance in Juvenile Paddlefish *Polyodon spathula*." As his advisor, Peter Allen said, "Daniel is one of those people who never meets anyone who doesn't like him."

Mississippi State University assistant professor and aquatic scientist Peter Allen, left, and doctoral student Daniel Aboagye examine an Alligator Gar near the outdoor tank facilities at MSU's Aquaculture Facility. Photo credit: MSU Ag Communications/Kat Lawrence.

Felix Ayson

Endorsed by the President of the Philippines

Last June Dr. Felix Ayson—a career fisheries scientist specializing in biotechnology, marine fish hatchery, and climate change—became the new chief of the Southeast Asian Fisheries Development Center's (Bangkok, Thailand) Aquaculture Department (AQD). Dr. Ayson completed his postdoctoral fellowship at Kitasato University in Japan (2000) through a grant from the Japanese Society for the Promotion of Science; acquired his Ph.D. in zoology major in fish physiology and endocrinology from the Ocean Research Institute of the University of Tokyo (Japan) in 1994; and obtained his M.Sc. and B.Sc. in marine biology from the University of the Philippines Diliman (1987) and University of San Carlos (1981, cum laude), respectively. Dr. Ayson has so far published 16 science papers in peer-reviewed international journals as sole author or first author. He has received research grants on Rabbitfish from the U.S. Agency for International Development (USAID; 2001–2004) and AusAID (2004–2005); the latter was for an award-winning proposal on Siganid culture for a rural community. More recently, he has received a Milkfish grant from the USAID–AquaFish Cooperative Research Support Program (2007–2009) and is a current collaborator of a DOST-PCAAARD Milkfish project with the University of the Philippines Visayas. He has headed the AQD's programs on marine fish and climate change, which included research, training and information, and extension activities for aquaculture stakeholders. In between his stints at the AQD, he served as the chief technical advisor on aquaculture for the United Nations Food and Agriculture Organization in Rome, Italy (2007–2010); he was a visiting professor at the Tropical Biosphere Research Center of the University of Ryukyus in Okinawa, Japan (2005–2006); and he was a research fellow in Kitasato University (1997–1999). He was endorsed for his new position by Hon. Benigno Aquino III, Philippine President.

New AQD Chief Dr. Felix Ayson during the installation ceremony. Photo credit: SEAFDEC Philippines.

Konrad Hafen

Wins Researcher Assistant of the Year

When our new member—Konrad Hafen—is not busy being photographed kissing sucker fish in Idaho (by fellow member Cody Edwards—both also members of the Utah State University chapter), *and* winning the Quincy College Undergraduate Researcher Assistant of the Year, *and* serving up posters ("Effects of Impoundments on Brown Trout Source–Sink Dynamics in the Logan River, Utah: Conservation Implications for Endemic Bonneville Cutthroat Trout") *and* symposia ("Agonistic Behavior between Three Species of Commonly Stocked Salmonids in Utah Reservoirs") at the Western Division's Annual Meeting this past April, he is busy working with geographic information systems (DEMs, vector analyses, morphometric analyses, blimp and georeferencing, etc.), all while preparing to graduate in the spring of 2014 with a major in wildlife science, and minors in fisheries science and geographic information systems.

Konrad Hafen, relaxing with a sucker fish after a full year of being very successful! Photo credit: Cody Edwards.

Sarah Evelyn Moffitt

Invited to Blog for the Daily Kos

Sarah Evelyn Moffit was invited to join the *Daily Kos* Climate Change SOS Blogathon this past August. She was in good company, blogging alongside Richard Heinberg—senior fellow at the Post Carbon Institute; Michael Mann—director of the Penn State Earth System Science Center and cofounder of the award-winning climate science blog, RealClimate.org; Vermont Governor Peter Shumlin; Brian Kahn—from the International Research Institute at Columbia; Peter Erickson—Staff Scientist with the Stockholm Environment; Mark McCaffrey—Programs and Policy Director at the National Center for Science Education Institute; and more. Sarah's main contribution was her essay, entitled "Raspberries, Salmon, Hops: Personal Loss and Climate Change." Read a small portion of her essay below, and then head over to the *dailykos.com* to read her essay in its entirety:

Sarah Evelyn Moffitt reconstructs records of deep sea ecology through past and present events of rapid climate change. Sarah is an oceanographer, ecologist and paleoclimatologist, with expertise in climate communication. Photo credit: Jason Helyer.

> *Every human culture and regional environment is threatened by the impacts of climate change. The cycles of rain and dryness, the summer highs and winter lows, the snowmelt that becomes river water that becomes full aquifers—these are the climatic systems that are being altered. And these are the metrics that, when applied to our local and regional cultures, illustrate the vulnerability of our shared heritage. Crops like raspberries and hops are extremely sensitive to a tight envelope of precipitation and temperature. Salmon—the much maligned and disgraced behemoth of Northwestern ecosystems—is also acutely sensitive to rapid environmental change, in both marine and riverine settings. And, while you might argue that these crops and fisheries won't be eradicated on a 100-year timescale, they will undoubtedly become atrociously expensive. Functional absence in the market place is the same as real absence for us plebeians.*
>
> dailykos.com/story/2012/08/22/1123097/-Raspberries-Salmon-Hops-Personal-loss-and-climate-change

Sarah is expected to receive her Ph.D. in ecology this September from the University of California, Davis, with an emphasis on marine ecology. Her dissertation is entitled *The Paleoceanography and Paleoecology of the California Margin Oxygen Minimum Zone*.

Sarah Moffitt

Bringing Forensic Ecogeomorphological Analysis to Napa and Beyond

Sarah Moffit holding a Coho Salmon—for which she specializes in anadromous fisheries habitat assessments and stream inventories. Photo credit: U.S. Fish and Wildlife Service

Sarah Moffitt is a fisheries biologist specializing in surface water bio-assessments and aquatic biology. She has conducted stream bio-assessment protocols in over 100 stream reaches throughout California, Oregon, and Washington State. Ms. Moffitt specializes in anadromous fisheries habitat assessments and stream inventories for Coho Salmon (*Oncorhynchus kisutch*), Chinook Salmon (*Oncorhynchus tshawytscha*), and Steelhead Trout (*Oncorhynchus mykiss*), including both juveniles and adults. These standardized bio-assessment protocols focus heavily on the evaluation of ambient physical habitat and morphological conditions within aquatic systems such as riparian condition, fluvial processes, instream habitat complexity, as well as other various physical habitat and biological metrics. These assessments include forensic ecogeomorphological analysis as part of stream characterization and classification assessments performed throughout Napa, Sonoma, Marin, Lake, and Mendocino Counties. She has over five years of professional experience in biological field surveys, and special status species surveys including monitoring of water quality, vegetation, amphibian habitat restoration (including tadpole and adult surveys), and macroinvertebrate analysis, in addition to collaborating with numerous local interests to monitor the Suisun Marsh and Sacramento Delta as part of an ongoing effort that collectively spans over 30 years. Sarah has experience working in California Tiger Salamander habitat and has been trained in and performed Swainson 's hawk monitoring and nesting bird preconstruction surveys. She has collected data on microacoustic and other tagging systems which included graphical representation and analysis of data. She has nearly four years of experience with the U.S. Fish and Wildlife Service performing field stream assessments for anadromous species near Olympia and Redding. These surveys included the collection, extraction, organization, and evaluation of fisheries genetics and aquaculture material such tissue, scales, otoliths, and coded wire tags, and an analysis of material including a comparison of single nucleotide polymorphisms and microsatellites to temporally analyze patterns of anadromy as a strategy for evaluating restoration decisions.

IN MEMORIAM
Dr. Robert S. Campbell
1913–2012

Dr. Robert S. Campbell died at the age of 99 in Poplar Bluff (formerly of Columbia), Missouri, November 28, 2012.

Dr. Campbell was born September 9, 1913, in Saskatoon, Saskatchewan, and later became a naturalized citizen of the United States. In 1939 he obtained a Ph.D. in limnology from the University of Michigan. He taught at Central Michigan University until 1944, when he joined the Department of Zoology at the University of Missouri and later served eight years as chairman.

Dr. Campbell instituted a fishery research program in the Missouri Cooperative Wildlife Research Unit—one of the first units to do so. He maintained his interest and publications in fisheries as he continued his research in limnology. He is recognized for his definitive work on succession in strip-mine lakes and for his work on the effects of thermal effluents upon reservoir water quality. His research led to 40 publications.

Dr. Campbell was a member of seven national and international societies in the fields of limnology and fisheries. He served as president of the Midwest Benthological Society and was on the editorial staffs of the *Journal of Wildlife Management* and *Transactions of the American Fisheries Society*.

Dr. Campbell has been honored for his research and teaching, and was recipient of the Outstanding Professional Achievement Award, University of Missouri Wildlife Club, 1966–1967; the Educator of the Year Award, Conservation Federation of Missouri, 1970; the E. Sydney Stephens Wildlife Professional Award bestowed by the Missouri Chapter Wildlife Society, 1972; the Faculty Alumni Award, 1977; and the Missouri Chapters of the American Fisheries and Wildlife Societies, 1978.

Dr. Campbell was a dedicated teacher and counselor of undergraduate students. Many will remember him for introducing them to the field of fisheries and wildlife through his course, the Ecology of Wildlife and Man, in which he taught as many as 500 majors and nonmajors each year. His dedication to teaching was recognized as he was honored with the Alumni Association Distinguished Faculty Award, 1978.

Dr. Campbell always encouraged his students to become involved in the professional societies and two of his students later became presidents of the American Fisheries Society.

From the Archives

Now, if there is some influence brought to bear that will lift this state out of the hole or rut into which it has fallen, it will be a blessing, and this committee can certainly lay plans as to how it shall be done. If they cannot get the fish commissioner to do something, they can back up the people; and the people are ready at any time. There never was a time in the history of the state of Ohio when the laws were so good for the protection of fish as this year, there is no question about that. All that Ohio needs is a few good men right behind it, men of experience and men that have been educated in the American Fisheries society, that will push Ohio to the front. I am strongly in favor of Mr. Dickerson's motion.

The President: The chair is inclined to commend your energy in increasing the number of fish in Ohio by introducing the new method of raising them on trees.

Mr. Gunckel: I had to do it, and then they called me a liar. (Laughter and applause). So I started to raise boneless fish, and I have succeeded, I am happy to say, in that also.

John E. Gunckel and President E. E. Bryant (1902): Transactions of the American Fisheries Society, 31:1,17.

COLUMN
Guest Director's Line

Environmental DNA: Genetics Steps Forward When Traditional Ecological Surveys Fall Short

Marissa Jones

School of Aquatic and Fishery Sciences, University of Washington, Seattle, Washington. E-mail: marissa.h.jones@gmail.com

Ecologists go to tremendous lengths to determine whether species are present in an area, from visual surveys and traps to hidden cameras and expensive angling operations. But imagine the possibilities if you could census an aquatic ecosystem simply by collecting a bucket of water. After a bit of lab work, you would have in hand a survey of biological diversity: the microscopic algae in the water column, the bass in the depths, the minnows combing the shallows, even an endangered frog, cryptically hidden along the banks. *Voilà* —a survey of species richness without even having to get your boots wet.

As it turns out, this scenario is not far from reality. Sampling DNA from the environment (eDNA) rather than directly from an organism has emerged as a promising new tool for management and conservation in aquatic ecosystems. It is also an emerging topic at regional and national AFS meetings, including a symposium entitled "Environmental DNA (eDNA) Analysis—a New Genetic Tool for Monitoring, Managing, and Conserving Fishery Resources and Aquatic Habitat" sponsored by the Genetics Section at the September national meeting in Little Rock, Arkansas.

So, how does sampling eDNA work? Animals are continually sloughing off bits of skin and mucus that contain their DNA. Water carries these telltale molecular signatures from aquatic organisms. DNA can be collected by filtering water; only minute concentrations are needed since it can be amplified in the lab. The eDNA is then screened for species-specific molecular "barcodes" to determine whether a species' DNA is in the sample.

DNA barcodes are usually portions of genes that code for functions essential to life, such as those involved in cellular respiration. Genes that code for these vital functions accumulate minor mutations, keeping pace with speciation. The sequences are similar enough to be readily identified as a barcode, but different enough to indicate the species of origin. Scientists have been amassing databases of these diagnostic sequences, such as the Barcode of Life project (barcodeoflife.org). From repositories such as the Barcode of Life, researchers can design panels to screen for target species.

Environmental DNA is a burgeoning field with particular relevance to fisheries research. Noninvasive genetic approaches have been used for years to obtain genetic samples of mammals and birds from feathers, feces, or hair (Beja-Pereira et al. 2009). Ficetola et al. (2008) showed that these techniques could be used to detect the presence of invasive American bullfrogs in lakes, even at low densities. The ability to detect a species with no other physical evidence has captured the attention of freshwater ecologists, spawning a slew of papers with catchy titles such as "Conservation in a Cup of Water" and "Biodiversity Soup" (Lodge et al. 2012; Yu et al. 2012). The number of talks at the national AFS meetings has grown from several in Seattle, Washinton in 2011, to an entire session in Twin Cities, Minnesota in 2012, and another coming in up Little Rock, Arkansas this year.

Most authors agree that eDNA is useful for detecting rare or cryptic species, when the chances of finding animals by traditional means are very low even when they *are* present. This makes eDNA amenable to determining presence or absence of endangered species or monitoring the advancing front of a biological invasion. This work has already proven valuable for detecting the movements of invasive Asian Carps in the Great Lakes. Jerde et al. (2011) reported that "commercial fisherman caught an adult Bighead Carp within 13 km of Lake Michigan, only 4 km upstream of the nearest positive eDNA detection, further supporting what the eDNA evidence suggested 8 months earlier." Environmental DNA can be a useful tool for allocating resources where they are most needed, as invasive species move discreetly through waterways.

Sampling eDNA in the marine environment is more problematic. DNA breaks down over time, becoming fragmented into smaller and smaller pieces. The rate at which this occurs is strongly affected by the presence of heat and light, and varies widely between habitats. The vastness of the ocean makes it more difficult to predict where a snippet of DNA came from and how long it will persist. Foote et al. (2012) found that eDNA worked to detect marine mammals in controlled environments, but was less reliable in the wild. However, Thomsen et al. (2012a) noted that eDNA was as successful as traditional surveys for marine fish.

In addition to screening for target species, eDNA can be used to take a census of species richness, as in our hypothetical bucket of water. In this case, it's often called community DNA (cDNA) or metagenetics, terms coined by microbial ecologists that have since been applied to larger quarry. Thomsen et al. (2012b) targeted fish and amphibians, but reported DNA matches to numerous species, including deer and birds. It is also possible to screen gut contents for prey species in an organism's diet. These approaches expand the domain of detectable species to include rare passersby and those no longer identifiable by morphological criteria.

One important question lingers any time an expensive conservation or biological control effort hinges on detecting target species: *are you sure?* On this note, eDNA has some limitations. Without doing an in-depth calibration, eDNA speaks only of presence or absence of DNA, not animal presence or abundance, although the quantity of eDNA detected may be correlated with density (Thomsen et al. 2012b). A number of substances found in the environment can inhibit DNA amplification, leading to false negatives. The fact that the rate of DNA degradation varies so much between water bodies means that preliminary work is essential. Rigorous controls and validation are needed to exclude and eliminate possible sources of contamination or confusion. In short, eDNA trades the certainty that comes of having an animal in hand for the capacity for rapid and affordable species detection. Consider it another tool that managers and researcher have to help determine whether species may be present.

Despite some limitations, eDNA has tremendous potential to step in when traditional ecological surveys are not feasible. At the national AFS meeting in Little Rock, keep an eye out for the session "Environmental DNA (eDNA) Analysis—a New Genetic Tool for Monitoring, Managing, and Conserving Fishery Resources and Aquatic Habitat," sponsored by the Genetics Section. But while eDNA is an exciting and rapidly growing field, something tells me that it's not going to replace good old fashioned fish wrangling entirely. Sampling an animal without capturing, handling, or even seeing it… where's the fun in that?

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Forming New Partnerships... And Eating Hotdogs!

Joseph D. Conroy

Past-President, Ohio Chapter of the American Fisheries Society. Inland Fisheries Research Unit, Division of Wildlife, Ohio Department of Natural Resources, Hebron, Ohio 43025. E-mail: joseph.conroy@dnr.state.oh.us

David I. Wellman

Past-President, West Virginia Chapter of the American Fisheries Society. Wildlife Resources Section, West Virginia Division of Natural Resources, Farmington, West Virginia. E-mail: David.I.Wellman@wv.gov

What do fisheries biologists tend to do during the winter? Meetings, that's what! In true meeting fashion, members from the West Virginia and Ohio chapters of the American Fisheries Society met on the campus of Marshall University in Huntington, West Virginia during February 19–21 for a Joint Technical meeting titled, "Partnering Today for Challenges Tomorrow." The meeting commenced with a set of continuing education workshops to build knowledge of harmful algal blooms and early life stages of ichthyoplankton, and to explore acoustic methods in fisheries management. These workshops were presented by Dr. David A. Culver, Emeritus Professor at The Ohio State University, Dr. Edward F. Roseman, Research Fishery Biologist at the United States Geological Survey (USGS) Great Lakes Science Center, and fisheries biologists from the Ohio Division of Wildlife, respectively.

So what do the challenges of tomorrow include? The two most likely are Asian Carps (Silver, Bighead, and Black) which threaten invasion along with recurring harmful algal blooms in various aquatic ecosystems throughout West Virginia and Ohio. To learn more about these specific issues, plenary speakers tackled each topic. First, Duane Chapman, Research Fish Biologist at the USGS's Columbia Environmental Research Center, presented "A Pragmatic Discussion of the Asian Carp Invasion," which served to synthesize the current status of the carp invasion and to examine various risk assessments. The second plenary, titled "The Green Menace: Harmful Algae in the Great Lakes and Beyond," was presented by Dr. Tom Bridgeman, Associate Professor at the University of Toledo's Lake Erie Center, and outlined the various taxa that comprise the "menace" and then evaluated how changes in agricultural practices relate to increased occurrence of algal blooms in Lake Erie. These exceptional plenary presentations were followed by eight technical sessions over two days, which were comprised of 29 podium talks from participants representing 10 different organizations.

The meeting wasn't all work though! Camaraderie was built between chapter members through a packed welcome social at Hillbilly Hotdogs. A more formal dinner and social was held on campus the second night. Fourteen posters on topics ranging from Lake Erie stock identification using genetic or microchemical approaches to Ohio River phytoplankton abundance were presented during the second night's festivities. Additional interactions occurred during coffee breaks, one of which the Ohio Lake Management Society graciously sponsored.

For additional details, the conference program and abstract booklets can be found on the West Virginia Chapter website: www.sdafs.org/wvafs/Index.htm.

Clockwise, from upper left: Duane Chapman gives a pragmatic presentation on the Asian Carp's threat for the Great Lakes and the upper Ohio River; Pennsylvania chapter member Bob Ventorini tackles one mean hotdog during the welcome social at Hillbilly Hotdogs; chapter members fraternize during a coffee break; Ruth Briland focuses on finding just the right harmful alga to show workshop participants.

NEW AFS MEMBERS

Michael Cliff
Tristan Cooper
Brandye Freeland
Megan Highlen
Kenson Kanczuzewski
Steven Layman
Ashley Melancon
Erik Neatherlin
Lauren Overdyk
Zach Prause
David Reeves
Ralph Tingley
William Wait
Keith Waters
Kellie Whitton
Dillon Williams
Richard Wong

Continued from page 296

or (bringing back some optimism) opportunities, how do we identify the best mix of next steps in terms of size. Do we forego small efforts for work on watersheds or think globally but act locally? The size conundrum extends (loosely) into science—how do we balance research on basic, fine-scale understanding with our need for greater, large-scale understanding on how habitat relates to production or social benefits? To add to the challenge, these decisions have major financial implications. We will get to size in the August column. Until then, keep habitat in mind as you develop models, design sampling protocols, defend your budgets, and look to the future. And remember—we're doing this for the fish and our children.

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NEWLY CERTIFIED PROFESSIONALS

Associate Fisheries Professionals – FPA

Approved April 15, 2013

Jacob T. Westhoff
Tristan Widloe

Approved May 13, 2013

Zachary William Anglin
Brooks Fost

Certified Fisheries Professionals – FPC

Approved April 15, 2013

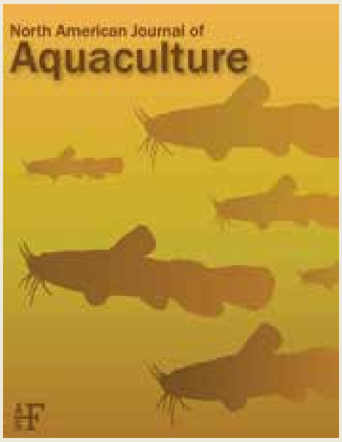
Matthew J. Breen
John E. Cooper
Demian Ebert
Keith B. Floyd
Thomas Michael Freeze
Paul Haywood
Scott E. LaPatra
Ben C. Neely
Patrick O'Rouke
Robin J. Reash
James H. Roberts
Dr. Christian Soucier

Approved May 13, 2013

Timothy F. Bonvechio
Timothy J Goeman
Cory R. Hamilton
Martin J. Jennings
Frank J. Leone
Lynn Noel
Jennifer Sampson
Jamison Wendel
David M. Wyffels

JOURNAL HIGHLIGHTS

North American Journal of Aquaculture
Volume 75, Number 2, April 2013



[Technical Note] Pumping Performance of a Slow-Rotating Paddlewheel for Split-Pond Aquaculture Systems. *Travis W. Brown and Craig S. Tucker*. 75: 153–158.

[Communication] Characterization of Bacteria Isolated from Landlocked Fall Chinook Salmon Eggs from Lake Oahe, South Dakota. *David J. Bergmann, Alicia Brakke, and Michael E. Barnes*. 75: 159–163.

Heat Shock Protein 70 (HSP70) Responses in Tissues of White Sturgeon and Green Sturgeon Exposed to Different Stressors. *Weifang Wang, Dong-Fang Deng, Nicola De Riu, Giuseppe Moniello, and Silas S. O. Hung*. 75: 164–169.

Refining Ammonia Treatments for Control of *Prymnesium parvum* in Striped Bass Fingerling Production Ponds. *Thomas A. Wyatt, Aaron Barkoh, and J. Warren Schlechte*. 75: 170–177.

Evaluation of Commercial Marine Fish Feeds for Production of Juvenile Cobia in Recirculating Aquaculture Systems. *Paul S. Wills, Charles R. Weirich, Richard M. Baptiste, and Marty A. Riche*. 75: 178–185.

Aquaculture Methods for a Genetically Managed Population of Endangered Delta Smelt. *Joan C. Lindberg, Galen Tigan, Luke Ellison, Theresa Rettinghouse, Meredith M. Nagel, and Kathleen M. Fisch*. 75: 186–196.

Comparison of Traditional and Fermented Soybean Meals as Alternatives to Fish Meal in Hybrid Striped Bass Feeds. *Artur Rombenso, Curtis Crouse, and Jesse Trushenski*. 75: 197–204.

Pretreating Channel Catfish with Copper Sulfate Affects Susceptibility to Columnaris Disease. *Bradley D. Farmer, Benjamin H. Beck, Andrew J. Mitchell, and David L. Straus*. 75: 205–211.

Safety of Feed Treated with 17α-Methyltestosterone (17MT) to Larval Nile Tilapia. *David L. Straus, James D. Bowker, Molly P. Bowman, Daniel G. Carty, Andrew J. Mitchell, Bradley D. Farmer, and Cynthia K. Ledbetter*. 75: 212–219.

[Communication] Ontogenetic Development of the Digestive Tract in Larvae of American Shad. *X. Y. Hong, X. P. Zhu, K. C. Chen, D. B. Pan, and K. B. Li*. 75: 220–227.

Effects of Water Temperature, Photoperiod, Eyestalk Ablation, and Non-Hormonal Treatments on Spawning of Ovary-Mature Red Swamp Crayfish. *Shengli Liu, Shiyuan Gong, Jinmei Li, and Wenhu Huang*. 75: 228–234.

Channel Catfish Hatchery Production Efficiency Using a Vertical-Lift Incubator (the See-Saw) at Various Egg Loading Rates. *Les Torrans, Brian Ott, Robert "Shorty" Jones, and Robert Jones Jr.* 75: 235–243.

[Communication] Decreased Hatchery Rearing Density Improves Poststocking Harvest and Return to Spawning of Landlocked Fall Chinook Salmon. *Michael E. Barnes, Matthew M. Wipf, Nola R. Domenici, Wendy M. Kummer, and Robert P. Hanten*. 75: 244–250.

Introduction to a Special Section: Lipids in Aquaculture Nutrition and Physiology II. *Jesse T. Trushenski and Rebecca T. Lochmann*. 75: 251.

The Effects of Diets Containing Standard Soybean Oil, Soybean Oil Enhanced with Conjugated Linoleic Acids, Menhaden Fish Oil, or an Algal Docosahexaenoic Acid Supplement on Channel Catfish Performance, Body Composition, Sensory Evaluation, and Storage Characteristics. *Jimmy Faukner, Steven D. Rawles, Andrew Proctor, Todd D. Sink, Ruguang Chen, Harold Philips, and Rebecca T. Lochmann*. 75: 252–265.

Alternative Feeding Strategies to Maximize Fish Oil and Fish Meal Sparing in Largemouth Bass Culture while Maintaining Production Performance and Product Value. *Andrew R. Coursey, Jesse T. Trushenski, and Christopher C. Kohler*. 75: 266–276.

Evaluation of the Effects of Menhaden Oil and Soybean Oil Levels in Purified Diets on Growth and Gonad Production in Adult Sea Urchin *Lytechinus variegates*. *Victoria K. Gibbs, Mickie L. Powell, Hugh S. Hammer, Warren T. Jones, Stephen A. Watts, Addison L. Lawrence, and John M. Lawrence*. 75: 277–284.

Effects of Increasing Docosahexaenoic Acid (DHA) and Arachidonic Acid (ARA) in Brood Diets of *Monodactylus sebae* on Fecundity, Egg and Larval Quality, and Egg Fatty Acid Composition. *C. L. Ohs, M. A. DiMaggio, S. W. Grabe, J. S. Broach, C. A. Watson, N. E. Breen, and F. T. Barrows*. 75: 285–294.

Traditional and Modified Soy Oils as Substitutes for Fish Oil in Feeds for Hybrid Striped Bass. *Jesse T. Trushenski and Kenson L. Kanczuzewski*. 75: 295–304.

Sparing Fish Oil with Soybean Oil in Feeds for White Seabass: Effects of Inclusion Rate and Soybean Oil Composition. *Jesse Trushenski, Bonnie Mulligan, David Jirsa, and Mark Drawbridge*. 75: 305–315.

Saturated Fatty Acids Limit the Effects of Replacing Fish Oil with Soybean Oil with or without Phospholipid Supplementation in Feeds for Juvenile Cobia. *Jesse Trushenski, Franklin Woitel, Michael Schwarz, and Fernando Yamamoto*. 75: 316–328.

CALENDAR
Fisheries Events

To submit upcoming events for inclusion on the AFS web site calendar, send event name, dates, city, state/province, web address, and contact information to sgilbertfox@fisheries.org.

(If space is available, events will also be printed in Fisheries magazine.)

More events listed at www.fisheries.org

DATE	EVENT	LOCATION	WEBSITE
July 14–20, 2013	2nd International Conference on Fish Telemetry	Grahamstown, South Africa	oceantrackingnetwork.org
July 15–19, 2013	The World Conference on Stock Assessment Methods for Sustainable Fisheries	Boston, MA	ices.dk/iceswork/symposia/wcsam.asp
July 21–25, 2013	7th International Symposium on Sturgeon	Nanaimo, Canada	iss7.viu.ca
August 9–12, 2013	Aquaculture Europe 13	Trondheim, Norway	easonline.org/images/stories/Meetings/AE2013/AE2013_Brochure_final.pdf
August 19–23, 2013	Aquatic Science at the Interface	Hamilton, New Zealand	aquascience.org.nz
August 26–27, 2013	Trout Unlimited's 2013 Utah Single Fly Event - To protect Utah's rivers and fight the spread of aquatic invasive species.	Green River, Dutch John, UT	tu.org/events/2013UTSF
September 8–12, 2013	AFS American Fisheries Society's 143rd Annual Meeting	Little Rock, AR	afs2013.com
September 23–25, 2013	2nd Annual World Congress of Mariculture and Fisheries-2013 (WCMF-2013)	Hangzhou, China	bitconferences.com/wcmf2013/default.asp
September 23–26, 2013	OCEANS '13 MTS/IEEE - The Largest Ocean Conference in U.S. History	San Diego, CA	oceans13mtsieeesandiego.org.
September 28–October 4, 2013	2013 World Seafood Conference	Newfoundland and Labrador, Canada	wsc2013.com
October 7–11, 2013	AFS 40th Annual Meeting of the Alaska Chapter of AFS	Fairbanks, AK	afs-alaska.org/annual-meetings/2011-2
October 21–27, 2013	3rd International Marine Protected Areas Congress	Marseille, France	impac3.org
August 3–7, 2014	International Congress on the Biology of Fish	Edinburgh, United Kingdom	icbf2014.sls.hw.ac.uk

From the Archives

It seems to me there is one matter which this association has always neglected and that is the matter of creating a public sentiment in favor of fish culture. We began in Michigan a year and a half ago in a systematic way to educate our people in the state in the interest of fish culture; we have already profited by it; it is a matter that has never been discussed by this association, a matter that has never been taken up, and we ought to devise some way of systematically educating the public in favor of fish culture. Every state where fish culture is carried on to any extent needs attention in that direction. When a farmer comes to the legislature, if fishing in his immediate vicinity is of no great importance, he looks on raising little fish as child's play; he votes against the appropriation because he does not see any need for the work in his own neighborhood; he takes no interest in the matter. The opposition in our legislature comes from those gentlemen who live in districts where there is no water in their immediate vicinity and where they derive no direct benefit near their homes from an appropriation in the interests of fish culture; and for that reason, to properly conduct the work (and we cannot conduct it properly unless we get sufficient appropriations with which to conduct it) it is necessary, in my judgment, to begin in a systematic manner to make public sentiment in the interests of fish culture; and I want to suggest that that matter be discussed here so far as it possibly can, and I will offer a motion that the chair appoint a committee to recommend at our next meeting the best method or methods of interesting the public and creating public sentiment in favor of fish culture.

F.B. Dickerson (1902): Transactions of the American Fisheries Society, 31:1,14.

AMERICAN FISHERIES SOCIETY
APPLICATION FOR COMMITTEE APPOINTMENT

As a small organization, AFS depends on volunteers for many tasks related to the science and the profession. Committees at all levels of the American Fisheries Society (AFS) provide many ideas that shape the future of the Society, and they are excellent avenues for members to begin or continue volunteer service to AFS. We encourage new members to contact their Chapter, Division, and Section officers to volunteer their services. We encourage experienced members, including students, to apply for AFS Committee appointments. (AFS committee terms are considered by the incoming AFS President for appointment starting in September) By volunteering at one or more of these levels, a member gains experience and leadership skills

Please number, in order of priority, no more than two (2) Committees on which you would like to serve:

____Associate Editor on a Journal
____ Awards
____Electronic Services Advisory
____Board of Professional Certification
____Continuing Education
____Endangered Species
____Ethics and Professional Conduct
____External Affairs
____Hutton Junior Fisheries Biology
____Investment
____Meetings Overview
____Membership
____Membership Concerns
____Names of Aquatic Invertebrates
____Names of Fishes
____Annual Meeting Program
____Publications Award
____Publications Overview
____Resolutions
____Resource Policy
____Task Force on Fishery Chemicals
____Time and Place
____ Vote Auditor
____Other
____

I AM NOW SERVING ON THE FOLLOWING COMMITTEE(S):
(Please indicate level--Chapter, Division, Section, Society)

....

....

I HAVE HAD EXPERIENCE ON THE FOLLOWING COMMITTEE(S):
(Please indicate level--Chapter, Division, Section, Society)

....

....

I can contribute to the committee(s) Indicated above because (optional):

....

....

(Continue on back if more space is needed)

NAME: .... **DAYTIME PHONE**: ....

ADDRESS: ....

CITY: .... **STATE, ZIP:** ....

COUNTRY:.. **FAX**:..

AFS MEMBERSHIP #: (optional) .... **E-MAIL**: ....

CURRENT EMPLOYER: ....

☐ Self-employed, ☐ retired, ☐ undergrad, ☐ M.S, ☐ Ph.D. student, or ☐ postdoc at the following university: ....

....

Please complete and return form for consideration to:
Unit Services Coordinator
E-mail: ggoldberg@fisheries.org

Juvenile Salmonid Courtesy: parks-conservancy.org