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135 An angler in Kerala, India. Photo credit: Antony Grossy.

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Cover: An everted intestine in Serrudo. Photo credit: Carlos Bernardo M. Alves, Bio-Ambiental Consultancy.

Fisheries

American Fisheries Society • www.fisheries.org

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The American Fisheries Society (AFS), founded in 1870, is the oldest and largest professional society representing fisheries scientists. The AFS promotes scientific research and enlightened management of aquatic resources for optimum use and enjoyment by the public. It also encourages comprehensive education of fisheries scientists and continuing on-the-job training.

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How Many People Are Enough (Too Many)?

Bob Hughes, AFS President

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In the 5 minutes that you take to read this commentary, approximately 8 million new human babies will be added to Earth's current 7.2 billion people. From the evolution of *Homo sapiens*, we did not reach our first billion until 1804, doubling again in 1930 to 2 billion, and again to 4 billion in 1974. At current population growth rates (around 1.2% per year) or about 200 million per day, global population will double again to 8 billion in 2024 (www.worldometers.info/world-population), a level that many feel exceeds Earth's carrying capacity (Pengra 2012). As biologists, we know that such growth rates cannot persist. Those of us who think ecologically see the effects of population growth multiplied by per capita resource consumption manifested in increased listings of threatened and endangered species (Figure 1), climate change, climate chaos, degraded ecosystem services (including water quality and availability, fisheries, and coral reef condition; Millennium Ecosystem Assessment 2005; Pengra 2012). Such global changes indicate that Earth's carrying capacity has already been exceeded (Pengra 2012). With the United States being the third most populous nation in the world and having an excessive ecological footprint (Ewing et al. 2010), it is important for us to stem our own population growth to demonstrate our concern with the issue. But four socioeconomic factors hinder progressive actions to attaining zero or negative population growth in the United States:

1. Population growth is a component of economic growth, determining its natural rate (Harrod 1939). In addition, neoclassical economists regard population growth as necessary for per capita growth in gross domestic product over the long term (Romer 1990; Jones 1998). That is, neoclassical economists believe that more people are needed to stimulate more consumption per person. And economics, regardless of the general ignorance of its practitioners in the laws of physics and ecology, has greater influence in governments than the natural sciences. Likewise, governments and the media pay greater attention to short-term economic indicators than multiple indicators of ecological status and trends that are reported with lower frequencies and have far greater long-term implications for Earth's biota (e.g., U.S. Environmental Protection Agency 2009, 2013; Stocker et al. 2013).

2. The United States has a fairly open and weakly enforced immigration policy. In the United States, the mean total fertility rate (births per woman) was 2.06 in 2013 (CIA 2013). Without immigrants, the U.S. total fertility rate would be 2.05 because 80% of births are to native mothers. However, legal and illegal immigrant mothers tend to have more children in the United States than in their native countries, 2.6 and 3.1, respectively (Camarota 2005). Likewise, native mothers have more children in the United States than in 124 other nations. Nonetheless, legal and illegal immigrants add about 2.3 million persons to the U.S. population annually, accounting for much of the U.S. population growth. Without those additions, the U.S. population would stabilize in the long run (Camarota 2005; Hurlbert 2011). Thus, resolving the human overpopulation problem in the United States must incorporate immigration policy as well as birth rates.

3. Reproductive rights are considered an inviolable human and religious right, regardless of family size or ecological or sociological impact. But because of the massive ecological footprint of each U.S. resident as well as the value of human life, one can make ethical arguments in favor of government support for family planning, health care, and greater economic and educational opportunities for women and the poor (Abernethy 1993; Limburg et al. 2011). Nonetheless, there is ample evidence that increased economic opportunity alone, or the perception thereof, stimulates population growth (Abernethy 1994; Camarota 2005).

In the 5 minutes that you take to read this commentary, approximately 8 million new human babies will be added to Earth's current 7.2 billion people.

4. Federal and state governments subsidize children through tax exemptions for dependent children, regardless of number, and cash assistance for needy families. It is unlikely that

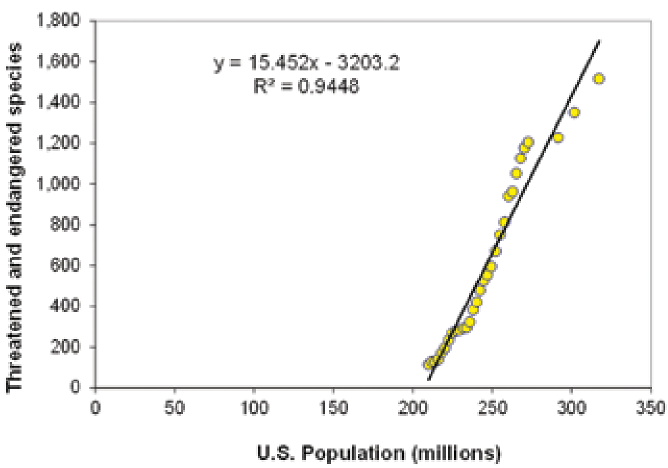

Figure 1. Number of threatened and endangered species as a function of population size in the United States (adapted from Limburg et al. 2011).

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COLUMN
Letter from the Executive Director

The Foundational Role of Chapters

Doug Austen, AFS Executive Director

It's not unreasonable to assert that the Chapters are the foundation of the American Fisheries Society (AFS), although the Sections might justifiably dispute this statement. I'll shine a well-deserved light on them in a future column. Most likely the vast majority of AFS members started their affiliation with the AFS through either a Chapter or a Student Subunit. We have 47 Chapters and about 60 Student Subunits or other university- or college-affiliated units (http://fisheries.org/chapters). Within these bodies lies much of the activity of the AFS through annual meetings, continuing education classes, professional development, field activities, and a rich history of engagement in conservation advocacy. This is also where the leadership of the AFS frequently has its beginning. For example, AFS President Bob Hughes was the Oregon Chapter president. Current AFS First Vice President Ron Essig was president of the Potomac Chapter and Southern New England Chapter. Second Vice President Joe Margraf was president of the Texas A&M Chapter and then the Ohio Chapter. Upon moving to West Virginia he helped start their Chapter and served as its first president. I had the privilege of being an Illinois Chapter president and consider the experience gained in multiple roles in Illinois while building up to Chapter leadership as foundational to my development as a professional. But these Chapters open other doors besides leadership.

The AFS as a corporate body—Chapters, Sections, Divisions—needs to show how the additive value of the Society to a prospective member's professional and conservation goals is worth the investment of his or her funds.

One of the key roles that Chapters play is to engage members and act as a gateway for them to join the Society. Everyone knows that getting a customer in the door is the biggest challenge in the effort to make them a client. The student or potential member needs to find a value in his or her membership, and frequently the first taste of that is the Chapter annual meeting. This is where they build professional friendships and personal relationships that last a career. So how will the AFS staff in Bethesda both support this effort and take advantage of this critical local level of organization? An emerging game plan of activities is being rolled out now and in the coming months. Of foremost importance is communication. We've started this by recently hosting the first conference call of all Chapters. Though only about two dozen of our Chapters were able to make the call, we accomplished a great deal through sharing information about topics such as taxes (all units need to file with the IRS), management of funds, insurance, our membership database upgrades that will allow for better tracking on unit members, web support, and sharing information about key Chapter activities that have been successful. We've supported this through a LinkedIn group specifically for Chapter and Division leadership where we'll regularly share information pertinent to the Chapters (search LinkedIn for "AFS Chapter, Student Subunit and Division Leadership Group").

Executive Director Doug Austen can be contacted at: dausten@fisheries.org

A second substantial challenge is making the transition from members joining just the Chapter to joining the Society. Most Chapters quite reasonably allow registrants to attend their meeting without becoming full AFS members. This doorway activity needs to be followed up with an active recruitment of these students and professionals to take the next step. Part of this is incumbent upon the AFS to make joining a value choice. We cannot simply rely upon AFS membership as a professional obligation to be the decision criteria for people to become members, although it certainly does address that role. The AFS as a corporate body—Chapters, Sections, Divisions—needs to show how the additive value of the Society to a prospective member's professional and conservation goals is worth the investment of his or her funds. More important, and certainly more so than their membership fee, is illustrating that one's commitment of time and talents to the organization will be a benefit that will provide members a value far beyond any monetary outlay. We encourage the Chapters and all of you—as you gather during these later winter months to convey this message—to work with us to better articulate the value of the AFS to those who are watching from the sidelines but who should be in the game.

COLUMN
Policy

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Ecosystem Modeling to Support Fishery Management

Thomas E. Bigford, AFS Policy Director

Since the 1980s, the fisheries world has witnessed a gradual transition from stock-based efforts (think of a genetically distinct portion of a species; e.g., Gulf of Maine cod) to the multispecies stock complex (all New England bottom fish species retained in the large-mesh trawl fishery; e.g., cod, haddock, flounders, redfish, hakes, and more) and more recently toward an ecosystem-based approach (for regional waters; e.g., the U.S. portion of the northwest Atlantic shelf). That progression reflects our increasing expectations for fishery management, including rebuilding plans for overfished stocks, greater opportunity for an embattled fishing industry, and ecosystems with sufficient forage, harvested species, and other components to sustain societal benefits for decades to come.

Ecosystem modeling is a helpful tool for fishery managers, yet models often elicit cautious reactions.

Ecosystem modeling is a helpful tool for fishery managers, yet models often elicit cautious reactions. We in the fish business need to engage with doubters on the rationales, applications, and benefits of various models. A successful model depends on solid data and clear expectations of how products will inform management decisions. So how can we make better use of models? What can we do with current tools and knowledge? How do we ease the angst of others?

Managing fisheries with improved success will rely on models that offer contextual, heuristic, tactical, and strategic advice, depending on their design and our needs. Perceptions that ecosystem models are all the same, are too complex, and lack sufficient rigor to be used in a fisheries management context are simply false. Despite fears, reality suggests that current constraints on staff and budgets will render ecosystem models even more appealing tools for scientists and managers alike. Models can fill gaps formerly occupied by more dollars for analysis, greater days-at-sea for research ventures, or larger staffs. Feel free to extrapolate wildly as you wonder how ecosystem modeling might unfold in waters near you.

We must also remember that successful fishery management will require us to model more than the fish or the management. The inherent complexity of fishery management often requires us to adjust our models and expectations over the course of a fish generation or when extrapolating from a fish to a population. Think about the many habitats, interspecies interactions, and other variables encountered by highly migratory species such as Atlantic Bluefin Tuna or anadromous species such as Chinook Salmon. That added complexity is important as our models expand to consider physical–chemical environmental change expressed in the wild by dead zones and the expressions of climate change.

The value and challenges of modeling are well established. In the relatively nascent field of ecosystem-based fisheries management, ecosystem modeling warrants our full attention. We must recite the time-honored mantras that models are only as powerful as their underlying data, one design will not cure all of our fish or environmental ills, and no one model will be suitable for all applications, but as budgets and staffs decline, models offer an efficient means to explore multiple variables and compare alternatives. Data remain the basic currency across designs and applications, as determined by our desired level of advice, so the ultimate power of any model hinges largely on information from the natural and social sciences. In fact, though each model depends on data, each application also helps to identify and prioritize information gaps and make difficult decisions on research funding.

Quite naturally, these many applications have encouraged modelers to develop tools from the simplest to the most complex. Sometimes our choice is limited by available data or perhaps our application, but there are usually viable options ranging from pithy and simple to everything including the kitchen sink.

For those of us who need some background (as I did before trying to cover a topic I have never studied), remedial assistance can be found in the proceedings from two National Ecosystem Modeling Workshops, which are leading to a third workshop in 2014. Those three "NEMoW" workshops organized by the National Oceanic and Atmospheric Administration (NOAA)/ National Marine Fisheries Service are now reflected by many regional fisheries management councils who have or are planning to develop an ecosystem-based fisheries management plan for their managed species. It is no coincidence that the NEMoW workshops and the regional fisheries management council decisions in the Atlantic and Pacific represent a convergence of ecosystem modeling efforts. The growing list of regional efforts reflects many ecosystem models, standards of use, and applications for living marine resources such as fish. The NEMoW

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Tablet Computers in Fisheries

Jeff Kopaska

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Tablet computers are currently one of the fastest growing segments in the technology sector. The Pew Research Center's American Life Project (www.pewinternet.org) indicates that ownership of these devices has increased from 3% of American adults in May 2010 to 34% in May 2013. The popular media indicate that this type of device was one of the hot buys for holiday giving, and I personally added to the craziness by purchasing two such devices for my children. So the percentage is likely much higher today.

Ruggedized tablet PCs have been used by Minnesota Department of Natural Resources (DNR) fisheries staff for field data collection for a decade. Devices such as Panasonic Toughbooks and various models from Xplore Technologies, the devices that the Minnesota DNR utilize, represent viable options for field data collection. When equipped with extra batteries, screen protection, and tethers, the total cost of one of these devices runs about $5,000. They work well in all conditions and are built to last. They can be a wise investment, but the up-front cost to outfit an entire agency can be a challenge.

The great thing about tablet computers is that they look like a sheet of paper—a field data sheet. You can set up the data entry screens on the device to emulate historic data collection processes. A few technology tweaks here and there and you can even make data entry easier than it used to be. Think of it—field data collection at a similar (or perhaps faster) rate as in the past and no time spent punching in numbers back in the office. This is the type of efficiency improvement that we are supposed to be after, allowing us to do more with less.

The Iowa DNR purchased four of these devices for test deployment to staff over the past 5 years. Acquiring the first two went off without a hitch, and the staff loved using them. The purchase of the second pair, however, kicked off a landslide of problems. New IT requirements came into play during the time between purchases, and the devices were held hostage by our IT department for over a year while they tried to determine how to encrypt and password protect a device with no keyboard. This was the watershed moment regarding my education about IT security, and it is the single most important issue that agencies face as they attempt to implement new technology solutions.

Last month, I mentioned that Lee Gutowsky observed that government agencies are hesitant to embrace new technologies. I think that internal policies within government agencies, specifically those related to IT security, are the real culprit. When you speak to IT security officers, they like to talk about data security. The first line of defense is confidential data, until you explain that we tend to give the public all the data we collect if they want it. Regardless of that, they say that the device must be encrypted, and all data transmitted from the device must be encrypted. They also say that because the device is capable of connecting to a "secure" network, there must be a way to prevent unauthorized access to the device if it is lost or stolen. Remember, because smartphones get their data from a cell phone data network rather than a hard-wired connection, they are somewhat exempt from these requirements.

The first line of defense is confidential data, until you explain that we tend to give the public all the data we collect if they want it.

These requirements may seem esoteric, but this is where the rub is between the technology we see in use in society and the technology we cannot use within agencies. Devices that operate on the Android and the iOS operating systems do not have robust enough encryption or password protection to deter hackers. For us, that meant no Apple iPads, Samsung Galaxy tabs, Lenovo IdeaTabs, etc. For the last few years, these have been the lower priced, attractive options that had me drooling to embark upon a new field data collection test. It took a while, but I finally figured out WHY we were not allowed to play with these devices.

There may be a light at the end of the tunnel. Microsoft has recently introduced the Surface line of tablet devices. These computers work on a Windows operating system, so the IT people seem to think that they might be able to clear a few more IT policy hurdles with these devices. My hope is that once we can start field-testing these computers, which cost as little as $300, we can find out whether it is more cost effective to deploy less expensive devices that may need to be replaced more frequently. If so, I believe that agencies will be willing to outfit field crews for $500 apiece, while they can't for $5,000 apiece. Stay tuned!

Join in the online discussion of this topic (and other interesting stuff) on the Fisheries Information and Technology Section web site at www.fishdata.org/blog/digital-revolution-tablet-computers.

Do you have suggestions for topics or questions that need answering? Please write to Jeff at Jeff.Kopaska@dnr.iowa.gov

COLUMN
The Communication Stream

What to Do With Your New Twitter Account (or Facebook, or …)

Jeremiah Osborne-Gowey, AFS Social Media Guru
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So you have taken the plunge and started up a social media account for your organization. Or perhaps you are considering it, still trying on the shoe in the store but haven't yet purchased it. Or maybe you are just shopping with friends and watching what they get/do with their "new shoes."

No problem. Take your time. You know the pace that works for you. Each of those approaches will work for getting you started in social media. What's important is that you are either considering adopting it as one of your communication strategies—or you have already adopted it. Because, let's be honest, nobody really sees electronic communications going the way of the eight-track tape or 3.5″ floppy disk any time soon. Quite the opposite, really. In fact, social media is becoming so popular that it recently surpassed radio, newspapers, and television as the primary source for where people get their news. That was no small feat.

But how do we balance this new foray into *online* communications with our current communication strategy/portfolio? What do we say on social media? How much time should we put into it? Who should do it?

1. Think of social media simply as an *extension* of the communication you already do. You may communicate more frequently and probably more rapidly with social media than you currently do (e.g., monthly newsletters, semimonthly e-mail splashes, the occasional press release, etc.). Maybe even in more sound bites than you are used to. But it is, at its core, still communication. To get started, set a fixed time (e.g., daily, semiweekly) to focus on developing your social media. Good communication—social media included—rarely happens by accident; it takes deliberate, strategic thought.

2. Make sure your topic is relevant to your target audience, is focused, and sticks to the key message(s) of your other communication strategies. You likely already take these steps in your other communiqués. The same needs to hold true for your social media interactions—with perhaps a splash of company culture thrown in (it personalizes you/your organization). In fact, your message is likely to be even more focused, given the relatively short amount of space that many social media providers allow (e.g., Twitter only allows 140 characters per message). You may even find that communicating via social media is a wonderful way to hone your brevity and editing skills. It sure has for me (and many others).

3. Social media is not a *replacement* for other forms of communication. E-mails still hold incredible importance for "one-to-one" or "one-to-several" types of conversations, as do more detailed forms of media like regular newsletters or press releases. Additionally, there simply is no substitute for face time. Think about the place where your most fruitful, question-answering, idea-generating interactions occur. Over late-evening drinks with colleagues during a conference? Maybe during a working lunch meeting or in the break room around the water cooler? Wherever it is, we spend an awful lot of time chatting face-to-face around the "campfire." But, as Chris Brogan says, someone has to build that campfire. That someone is you (or someone in your organization already passionate about social media or connecting with others). The campfire is the content you create and that your audience has already come to appreciate. Social media simply allows you to participate in the discussions *that are already occurring*. Put another way, it is the virtual water cooler.

Are you thirsty? They are. It's time to connect.

Water Quality Section Introduction and History

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RH Gray & Associates, Richland, WA

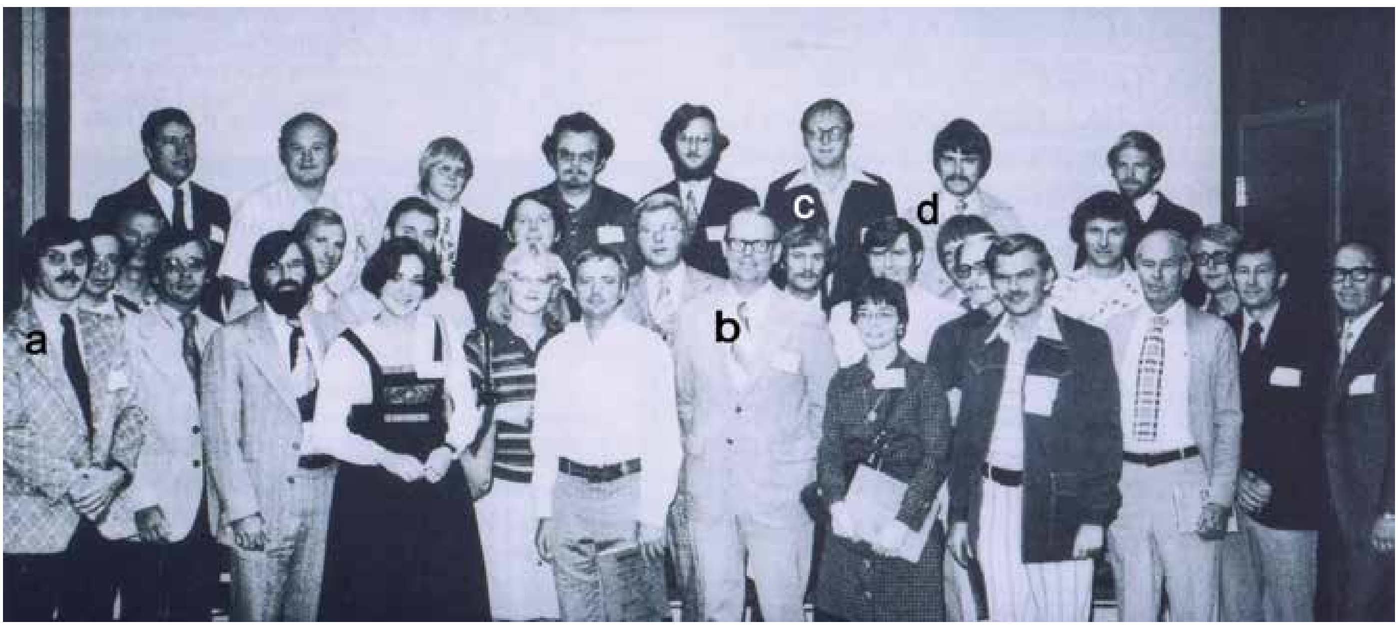
John W. Meldrim

First- and 30-Year WQS Secretary Treasurer, Glen Ellyn, IL

Water quality is integral to the work of a fisheries scientist, whether monitoring an aquaculture pond, measuring fine sediment in streams, or restoring a natural waterway. By the 1960s, deteriorating water quality conditions were evident across the landscape, and fishery biologists were tackling these issues to reduce water quality problems through focused research and informing management. At the federal level, legislation moved forward on a number of fronts. The Water Quality Act requiring state-set water quality standards became law in 1965. Public awareness and regulatory action found a common pursuit after 22 June, 1969, when Ohio's Cuyahoga River caught fire. The National Environmental Policy Act was set up by January 1970, and in 1972, the Federal Water Pollution Control Act amendments (33 U.S.C. 1251-1376; Chapter 758; P.L. 845, 30 June, 1948; 62 Stat. 1155), collectively known as the Clean Water Act (PL92-500; 33 U.S.C. §1251 et seq. (1972)), were enacted. The Clean Water Act focuses concern on aquatic life in addition to human health with an objective to restore and maintain chemical, physical, and biological integrity of U.S. waters, including the improvement of water quality for the protection and propagation of fish, shellfish, and wildlife.

THE WATER QUALITY SECTION (WQS) BEGAN IN 1977 AS THE FOURTH SOCIETY SECTION

The 1970s brought continued and increasingly complex environmental legislation that required the expertise of fisheries biologists in the area of water quality. American Fisheries Society (AFS) President Cam Stevenson, Executive Director Carl R. Sullivan, and Howard Johnson, the chair of the Standing Water Quality Committee, determined that it was time for the AFS to have a formal Section to address water quality issues, problems, and concerns. The organizational meeting occurred in 1976, at the AFS Annual Meeting in Dearborn, Michigan, and the WQS formed the following year as the fourth Section within the Society (see photo). Since inception, there have been numerous dedicated and outstanding members, with several section members having gone on to become AFS president; most recently the current president, Bob Hughes. Section membership grew rapidly to a maximum of 678 by 1981 (Gray and Meldrim 2000).



First meeting of the Water Quality Section, Vancouver, British Columbia, 1977. Future AFS WQS officers pictured include: Foster (Sonny) Mayer (a), John Meldrim (b), Bob Gray (c), and Jim Wiener (d). We invite readers to help us identify other folks in the photo. Photo credit: Water Quality Section.

SECTION MISSION

Though aquatic toxicology and the "development and use of standardized procedures and techniques" was certainly a focus of many initial members, our mission statement also emphasizes the "protection of watersheds, water quality and aquatic habitat in addition to the abatement of water pollution and aquatic habitat and watershed deterioration." Further, the WQS focuses attention "on watershed, aquatic habitat, and water quality concerns by conducting symposia, workshops and projects, collecting and assembling information for publication, and distributing results to Society members and the public." In meeting that objective, the Section provided a critical review of the EPA Red Book, which became a widely used publication (AFS 1979), and has continued to sponsor symposia, turning a number of them into published proceedings, including Mehrl et al. (1985), Becker and Neitzel (1992), Brown et al. (2005), Rinne et al. (2005), and Hughes et al. (2007). More recently, the Section has hosted short course webinars (2009–2010) on water quality standards, biological condition gradient, and tiered aquatic life uses.

RELEVANCE TODAY

The WQS is as vital to the Society now as it was at inception. The Section members continue to propose and provide comment on Society position papers and federal legislation covering issues relating to water quality and habitat. We've renewed focus on students/recruitment this year, are featuring students and their work on our website, have lined up several contributions for forthcoming editions of *Fisheries*, and have initiated and will sponsor a symposium on dams at the 2014 AFS Annual Meeting in Québec.

Additional information and photos concerning WQS can be found on the Section's webpage under Units on the American Fisheries Society website (www.fisheries.org). More information about the Section can also be obtained by contacting Margaret Murphy, current Section president. Those interested in joining the Section can do so by checking the appropriate box on their annual AFS renewal form or by contacting Eva Przygodzki (eprzygod@fisheries.org), AFS Membership coordinator, 301-897-8616, ext. 203; fax 301-897-8096.

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DON'T FORGET TO VOTE FOR 2ND VICE PRESIDENT

You still have a few weeks to put in your ballot. (If you did not receive instructions on how to vote online, please contact Eva at eprzygod@fisheries.org.)

AFS WANTS TO HELP YOU

Units: if you need help revamping your website, setting up a line of communication with your members, starting a newsletter, etc., please contact Sarah Fox: sgilbertfox@fisheries.org

If you need some help getting started with social media, contact Beth Beard: bbeard@fisheries.org

APRIL IS CALL FOR AWARD NOMINATIONS MONTH!

If you know someone deserving, now is the time to put your pen on paper and let the society know: afsmembers.org/award_nominations_2014

THE NEW *FISHERIES* GUIDE FOR AUTHORS IS OUT (AND IT HAS A NEW MISSION STATEMENT)

As the monthly membership publication of the American Fisheries Society (AFS) *Fisheries* magazine will be a key component of the Society's communication package and will provide timely, useful, and accurate information on fisheries science, management, policy, and the activities of the Society via peer-reviewed articles, essays, opinions, and popular articles that appeal to our members, fisheries professionals and students, policy makers, stakeholders, and the public in general. (Many thanks to our science editors for putting this together.) To find the new guidelines: afsmembers.org/fisheries-guides-for-authors-2014

AFS SEEKS CO-CHIEF SCIENCE EDITOR FOR *FISHERIES* MAGAZINE

The AFS seeks a scientist with a broad perspective on fisheries to act as Co-Chief Science Editor to work as part of a two-person leadership team to oversee the science content of *Fisheries*. The Editor must be committed to fast-paced deadlines and would be appointed for a 5-year renewable term that begins in early 2014. Duties include the following:

- Work in a highly collaborative manner with one other Chief Science Editor to manage the science component of *Fisheries*.
- Work with the Managing Editor, the Senior Editor, and others as part of the overall creative leadership of *Fisheries*.
- Assign an appropriate science editor for approximately half of the scientific manuscripts submitted to *Fisheries*.
- Make final publication decisions based on peer reviews orchestrated by science editors.
- Help to ensure the veracity of each issue's total scientific content.
- Help recruit and retain science editors and provide them with mentoring and guidance.
- Solicit cutting-edge submissions as well as ensuring broad coverage.
- Work with *Fisheries* Managing Editor and AFS Publications Director on the content, themes, and direction of the scientific aspects of *Fisheries*.

Qualifications: AFS seeks an established fisheries or aquatic science professional with substantial writing and editorial experience. As part of building an editorial leadership team, we seek skills and/or experience complementary to those of the current Co-Chief Science Editor, such as marine and coastal fisheries, but are not restricted by that desire. To be considered, send current curriculum vitae along with a letter of interest to alerner@fisheries.org by 19 April, 2014. Please also feel free to contact Jeff Schaeffer at jschaeffer@usgs.gov or 734-214-7250 for further information about the position.

Note: The Co-Chief Science Editor receives an honorarium and support to attend the AFS Annual Meeting.

BIGFORD RETIRES FROM NOAA

Thomas E. Bigford has retired after 36 years of dedicated federal service spent passionately protecting fish and their habitat. For the last 16 years, Bigford served as Chief of the Habitat Protection Division at NOAA Fisheries, where he directed marine, estuarine, and riverine programs related to essential fish habitat, fish passage, coastal wetlands, deep-sea and shallow coral, and habitat policy and science. He has helped open more than 1,300 miles of river habitat for diadromous fish and protected nearly one billion acres of habitat essential to our nation's fisheries. In his three years with the EPA and 33 years with the NOAA, Bigford helped launch the conservation careers of countless young people through mentoring our future natural resource professionals and leaders. He has held leadership positions with the Coastal Society and the American Fisheries Society and recently became the president-elect for the AFS Fish Habitat Section. Many thanks to him for his years of dedication in protecting the health of our nation's coastal and marine ecosystems and best wishes for a happy retirement! If you are interested in contributing to a gift, he has requested that donations be made to support habitat protection through the Land Conservancy of West Michigan (www.naturenearby.org/donate).

BIGFORD NAMED AFS POLICY DIRECTOR

And he wants to hear from you: tbigford@fisheries.org

FEATURE

Understanding Barotrauma in Fish Passing Hydro Structures: A Global Strategy for Sustainable Development of Water Resources

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ABSTRACT: *Freshwater fishes are one of the most imperiled groups of vertebrates, and population declines are alarming in terms of biodiversity and to communities that rely on fisheries for their livelihood and nutrition. One activity associated with declines in freshwater fish populations is water resource development, including dams, weirs, and hydropower facilities. Fish passing through irrigation and hydro infrastructures during downstream migration experience a rapid decrease in pressure, which can lead to injuries (barotrauma) that contribute to mortality. There is renewed initiative to expand hydropower and irrigation infrastructure to improve water security and increase low-carbon energy generation. The impact of barotrauma on fish must be understood and mitigated to ensure that development is sustainable for fisheries. This will involve taking steps to expand the knowledge of barotrauma-related injury from its current focus, mainly on seaward-migrating juvenile salmonids of the Pacific Northwest, to incorporate a greater diversity of fish species and life stages from many parts of the world. This article summarizes research that has examined barotrauma during fish passage and articulates a research framework to promote a standardized, global approach. The suggested approach provides clearly defined links to adaptive development of fish friendly technologies, aimed at mitigating the threats faced by global freshwater fisheries from the rapid expansion of water infrastructure.*

Sobre el barotrauma en peces durante su tránsito por hidro-estructuras: una estrategia global para el desarrollo sustentable de los recursos hídricos

RESUMEN: *los peces de agua dulce constituyen uno de los grupos más amenazados entre los vertebrados y las disminuciones poblacionales se consideran como alarmantes en términos de biodiversidad y suceden en perjuicio de las comunidades humanas cuyo bienestar y nutrición dependen de las pesquerías basadas en estos recursos. Una actividad que se asocia a la declinación de las poblaciones de peces de agua dulce es la construcción de infraestructura para el desarrollo de recursos hídricos, como presas, weirs e instalaciones hidroenergéticas. Los peces que transitan a través de la infraestructura hidráulica y de irrigación durante su migración hacia el mar, experimentan disminuciones de presión que producen lesiones (barotrauma), las cuales pueden contribuir a la mortalidad. Existe una nueva iniciativa para expandir la infraestructura para la hidroenergía e irrigación y aumentar así la seguridad de agua y la generación de energía de bajo costo en términos de producción de carbono. El efecto del barotrauma en los peces debe ser estudiado y mitigado para asegurar que el progreso sea sustentable para las pesquerías. Esto implicará expandir el conocimiento acerca de las lesiones relacionadas al barotrauma con respecto a como se encuentra ahora; sobre todo el conocimiento de la migración hacia el mar que realizan los juveniles de especies de salmón en el Pacífico noroeste, con el fin de incorporar una mayor diversidad de estadios de vida y especies de diferentes partes del mundo. En este artículo se resume la investigación concerniente al barotrauma en los peces durante su tránsito por hidro-estructuras y se plantea un marco investigativo para promover un enfoque estándarizado y global. El enfoque que se ofrece provee relaciones precisas para el desarrollo adaptativo de tecnologías amigables para los peces, diseñadas con la finalidad de mitigar las amenazas que enfrentan las pesquerías de agua dulce ante la rápida expansión de la infraestructura hídrica.*

INTRODUCTION

Freshwater fish are the second most endangered vertebrate group (Saunders et al. 2002), and many species currently face extinction (Ricciardi et al. 1999). Species declines are not abating, and in many parts of the world such declines have significant social and economic implications. Many of the world's developing nations rely heavily on freshwater fish for their livelihood, as both a source of income and food. For example, the Lower Mekong River basin (i.e., Cambodia, Laos, Thailand, Vietnam) supports the world's largest inland fishery, worth between US$4.3 and $7.8 billion annually (Hortle 2009). Fish and other aquatic organisms are essential for the livelihood, nutrition, and food security of citizens of the Lower Mekong River basin, accounting for 47%–80% of total animal protein consumed (Hortle 2007).

Many activities have had a role in freshwater fish declines throughout the world, including development of water infrastructure (Dudgeon et al. 2006). Water infrastructure, including dams, weirs, and hydropower facilities, can change natural flow regimes, degrade habitat and water quality, and interrupt or otherwise negatively impact important upstream and downstream fish migrations (Kingsford 2000; Agostinho et al. 2008). Though water infrastructure can create a complete barrier to fish movements, structures can also selectively injure or kill fish as they pass (Williams et al. 2001; Godinho and Kynard 2009). In such cases, barotrauma (trauma due to changes in barometric pressure) is of particular concern where hydropower facilities and irrigation structures create adverse hydraulic conditions that can injure and kill passing fish (Cada 1990; Baumgartner et al. 2006; Brown et al. 2012a).

Globally, the infrastructure associated with hydropower and other water resource development are extensive and expanding rapidly, especially in areas such as China, Brazil, and Africa (Geoscience Australia and ABARE 2010). Brazil is one example where hydropower generation is projected to increase 38% by 2020 (Ministério de Minas e Energia/Empresa de Pesquisa Energética [MME/EPE] 2011) through large hydropower projects, such as the Belo Monte Dam on the Xingu River of the Amazon Basin (the third largest [11,233 MW] hydropower production facility in the world; MME/EPE 2011; Castro et al. 2012) and the Santo Antônio (3,150 MW power potential) and Jirau (3,300 MW power potential) dams on the Madeira River. Worldwide, opportunities are being explored to install small-scale (typically less than 10 MW) hydroelectric facilities at water infrastructures built for other purposes, such as existing irrigation weirs (Bartle 2002; Paish 2002; Baumgartner et al. 2012).

The expansion of hydropower generation is in response to increasing demand for power in developing regions and a global desire for increased use of renewable energy in response to climate change. However, to maintain fish diversity and curb social and economic impacts in light of this development, research is needed to guide the design and management of hydropower facilities and other water infrastructure. In particular, minimizing barotrauma associated with passage through water infrastructure is a complex issue and of particular concern. In this article we review the science related to barotrauma with the objective of highlighting what is known and the knowledge gaps that exist in adaptively managing the threats faced by freshwater fisheries from the rapid expansion of water infrastructure. Though information covered may provide insight for barotrauma induced by angling, commercial fishery bycatch operations, or scientific sampling involving quickly bringing fish to the surface of a water body, the main focus of this article is furthering the understanding of barotrauma among fish passing downstream through dams, weirs, and hydropower facilities. In addition, this article does not provide an exhaustive review of all such water infrastructure passage related barotrauma (for further background information see Cada 1990) but focuses on the state of the science, provides insight for interpreting past research, and provides modeling and research frameworks for future endeavors in barotrauma research.

BAROTRAUMA DURING WATER INFRASTRUCTURE PASSAGE

It has long been acknowledged that fish can be killed or injured when passing through hydroturbines at hydroelectric facilities (Cramer and Oligher 1964). Similarly, it has been shown that fish can be harmed during passage through bypass systems or spillways at hydroelectric facilities (Muir et al. 2001). But the impact is not confined to structures specifically designed for the generation of hydropower, and considerable injury and mortality rates have also been reported for fish passing weirs primarily built to capture and divert river flows for irrigation (Baumgartner et al. 2006). This aside, research carried out to understand the mechanisms for injury during water infrastructure passage has been predominately focused around hydroelectric turbine passage (Coutant and Whitney 2000).

When fish pass through hydrostructures, such as hydroturbines, shear forces, blade strike, and pressure changes can lead to injury and death (Deng et al. 2005, 2007a, 2010; Cada et al. 2006; Brown et al. 2009, 2012b). Although one of the most apparent sources of injuries to fish may be strike from turbine blades, the likelihood of strike is low for small fish (Franke et al. 1997). Not all fish passing through hydroturbines are exposed to damaging levels of shear force or blade strike (Deng et al. 2007b), because this depends on the route taken by fish through the system and blade strike can vary to a large degree with fish size (Franke et al. 1997). All fish, however, are exposed to pressure changes, and the magnitude of change depends largely on turbine design, the path of the fish through the turbine, the operation of the turbine, the total operating head, the submergence of the turbine, and the rate of flow through the turbine (Carlson et al. 2008; Deng et al. 2010; Brown et al. 2012b).

As fish pass between turbine blades, they are typically exposed to a sudden (occurring in <1 s) decompression before returning to near surface pressure as they enter the downstream channel (Deng et al. 2007b, 2010). In hydroturbines, this can commonly involve decreases in pressure to levels between surface pressure (101 kPa) and half of surface pressure of approximately 50 kPa (Carlson et al. 2008). Fish passing through other types of hydrostructures are also exposed to rapid pressure changes (see Carlson et al. [2005] for an example of pressure fluctuations at a pump storage facility). Although little research has been done to quantify pressure changes outside of the hydroturbine realm, initial hydraulic investigations of irrigation weirs, where water is discharged under a gate (referred to as "undershot weirs"), show that passing fish would experience rapid decompression (in <1 s) to slightly below surface pressure as they are taken from depth in the upstream pool and discharged into surface waters downstream of a structure (C. A. Boys [New South Wales Department of Primary Industries] and Z. D. Deng [Pacific Northwest National Laboratory], personal communication).

The rapid decompression associated with infrastructure passage can lead to barotrauma arising from one of two major pathways. The first is governed by Boyle's law, where damage occurs due to the expansion of a preexisting gas phase within the body of the fish, such as contained in the swim bladder (Keniry et al. 1996; Brown et al. 2012e; Pflugrath et al. 2012). Boyle's law ($P_1V_1 = P_2V_2$ [where P_1 and V_1 are the initial pressure and gas volume and P_2 and V_2 are the resultant pressure and gas volume]) states that within a closed system (at constant temperature), the volume of a gas is inversely proportional to the pressure acting on the volume (Van Heuvelen 1982). For a fish passing through infrastructure, if the surrounding pressure is decreased by half, the volume of the preexisting gas in the body doubles. Injuries arising from this pathway typically include ruptured swim bladders and exopthalmia (Figure 1), everted stomach or intestine (Figures 2A and 2B), internal rupture of vasculature (hemorrhaging), and gas bubbles (emboli) in the vasculature, organs, gills, and fins (Tsvetkov et al. 1972; Rummer and Bennett 2005; Gravel and Cooke 2008; Brown et al. 2009, 2012b).

The second pathway is governed by Henry's law, where gas may come out of solution due to decompression-induced reduction in solubility, resulting in bubble formation (Brown et al. 2012e). Henry's law states that the amount of gas that can be dissolved in a fluid, such as blood plasma, is directly proportional to the partial pressure to which it is equilibrated. Thus, when the surrounding pressure is reduced, the dissolved gas may come out of solution, resulting in gas bubble formation, the basis for the bends in scuba divers who return to the surface too quickly. As fish pass through areas of low pressure, such as through hydroturbines, and experience decompression, their blood and other bodily fluids may become temporarily supersaturated and gas bubbles may form in the blood, organs, gills, or fins (emboli). As the gas bubbles grow, they can also lead to internal rupture of vasculature (hemorrhaging; Brown et al. 2012b; Colotelo et al. 2012).

Henry's and Boyle's laws may not be equally important in governing injury to fish during water infrastructure passage. Brown et al. (2012e) determined that, among juvenile Chinook Salmon (*Oncorhynchus tshawytscha*), injury and mortalities observed due to rapid decompression (simulating turbine passage) were largely caused by swim bladder expansion and rupture (as governed by Boyle's law), and the likelihood of mortality due to gases coming out of solution in the blood and tissue (as governed by Henry's law) was relatively low. They found that if juvenile Chinook Salmon were slowly decompressed to very low pressures (13.8 kPa; with 101 kPa representing surface pressure) over 2.9–3.6 min (median = 3.3 min), the fish could expel gas from their swim bladder via the pneumatic duct (a connection between the swim bladder and esophagus; Figure 3), preventing its rupture and subsequent barotraumas (e.g., emboli in the fins, gills, and blood vessels; exopthalmia; hemorrhaging). If fish were maintained at these low pressures, it took several

Figure 1. Exopthalmia (eyes popped outward) observed in (A) the Brazilian species Corvina captured downstream of a hydropower facility and (B) in juvenile Steelhead exposed to rapid decompression from depth (510.1 kPa, the equivalent to 40.7 m) to near surface pressure (117.2 kPa; Brown et al. 2012e). Photo credit: Carlos Bernardo M. Alves, Bio-Ambiental Consultancy.

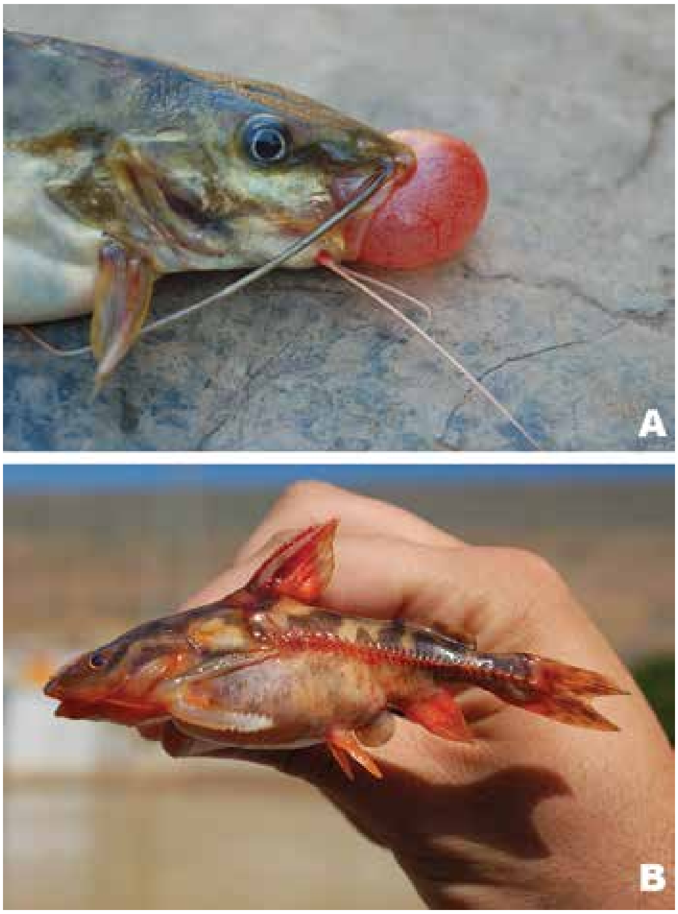

Figure 2. Images of an (A) everted stomach in the Brazilian species Mandi-amarelo and (B) an everted intestine in Serrudo. Photo credit: Carlos Bernardo M. Alves, Bio-Ambiental Consultancy.

minutes (mean = 3.0; range 2.2–7.0) before emboli and mortality were observed, presumably associated with Henry's law. In comparison, however, if juvenile Chinook Salmon were rapidly decompressed, the swim bladder often ruptured, expelling gas into the tissue and vasculature leading to hemorrhaging, emboli, and exopthalmia.

Though it appears that barotraumas governed by Henry's law are slow to develop relative to those linked to Boyle's law in juvenile Chinook Salmon, there are species-specific differences in damages that occur when fish are exposed to decompression. For instance, where Brown et al. (2012e) saw mortality due to Henry's law in juvenile Chinook Salmon exposed to 2.2–7.0 min of low pressure (13.8 kPa), Colotelo et al. (2012) found that juvenile Brook (*Lampetra richardonii*) and Pacific Lamprey (*Entosphenus tridentatus*) were uninjured when exposed to these same low pressures for over 17 min. Thus, the likelihood of emboli formation (and associated injuries such as hemorrhaging) may vary substantially among species. Though only a few species have been examined to date, it appears unlikely that gas coming out of suspension and forming emboli is the major cause of injury and mortality among fish passing hydrostructures because they are seldom if ever exposed to pressures below surface pressure for more than even a single second.

However, it should be kept in mind that supersaturation of gas is a large problem associated with dams. High levels of total dissolved gas (TDG) are associated with water routed over spillways. Water falling over spillways and into deep plunge basins of dams can cause gas to be entrained into the water (Ebel 1969). Prolonged exposure to elevated TDG can cause gas bubble disease (GBD) in fish. The difference between GBD and bubbles forming in the blood associated with barotrauma is that GBD involves gas moving from the surrounding supersaturated water into the tissues of the fish, leading to the formation of emboli (Beyer et al. 1976). Alternatively, when fish are decompressed during passage of a hydrostructure, the temporary supersaturation of the blood can cause bubbles to come out of suspension in the blood and tissues (Beyer et al. 1976). Thus, the source of the supersaturated gas is from within the fish instead of from the surrounding supersaturated water. Although a review of GBD is not within the scope of this article, it is possible that elevated TDG could lead to an increase of barotrauma. If fish with emboli present in their body due to GBD are decompressed during passage of hydrostructures, a higher amount of barotrauma may occur due to the expansion of those bubbles than may occur when the river water does not have elevated levels of TDG.

This leads to another factor that should be kept in mind when interpreting the barotrauma literature. Some researchers have had issues with confusing barotrauma with GBD when conducting decompression studies on fish. If the water the fish are held in while under pressure in test chambers is aerated or otherwise saturated with gas (similar to experiments by Bishai [1960] and D'Aoust and Smith [1974]), fish could experience GBD when decompressed, essentially the same condition as the bends in humans. This would lead to an extended period where the blood and tissues of the fish would be supersaturated instead of the very short period of supersaturation that fish would be exposed to during hydrostructure passage.

IMPLICATION OF SWIM BLADDER MORPHOLOGY

Barotrauma damage is frequently attributed to swim bladder expansion and rupture and, as such, the diversity in swim bladder form and function among fish may have significant implications for the relative susceptibility to injury. There are two broad groups, physoclists and physostomes. Physostomes, which are evolutionarily more basal fishes (e.g., lungfishes, sturgeons, and euteleosts), have a swim bladder that is connected to the esophagus via a pneumatic duct (often referred to as an open swim bladder). These fish gulp air at the surface and force it into their swim bladder. The second group is called physoclists, which are evolutionarily more derived fishes (neoteleosts), which have a swim bladder that is not connected to the esophagus (often referred to as a closed swim bladder; Figures 3 and 4) and the presence of a gas gland and countercurrent vasculature (called "retia") is used to regulate swim bladder volume and thus buoyancy (Pelster and Randall 1998). Physoclists may be much more likely to be injured during passage of hydrostructures than physostomes because they cannot quickly

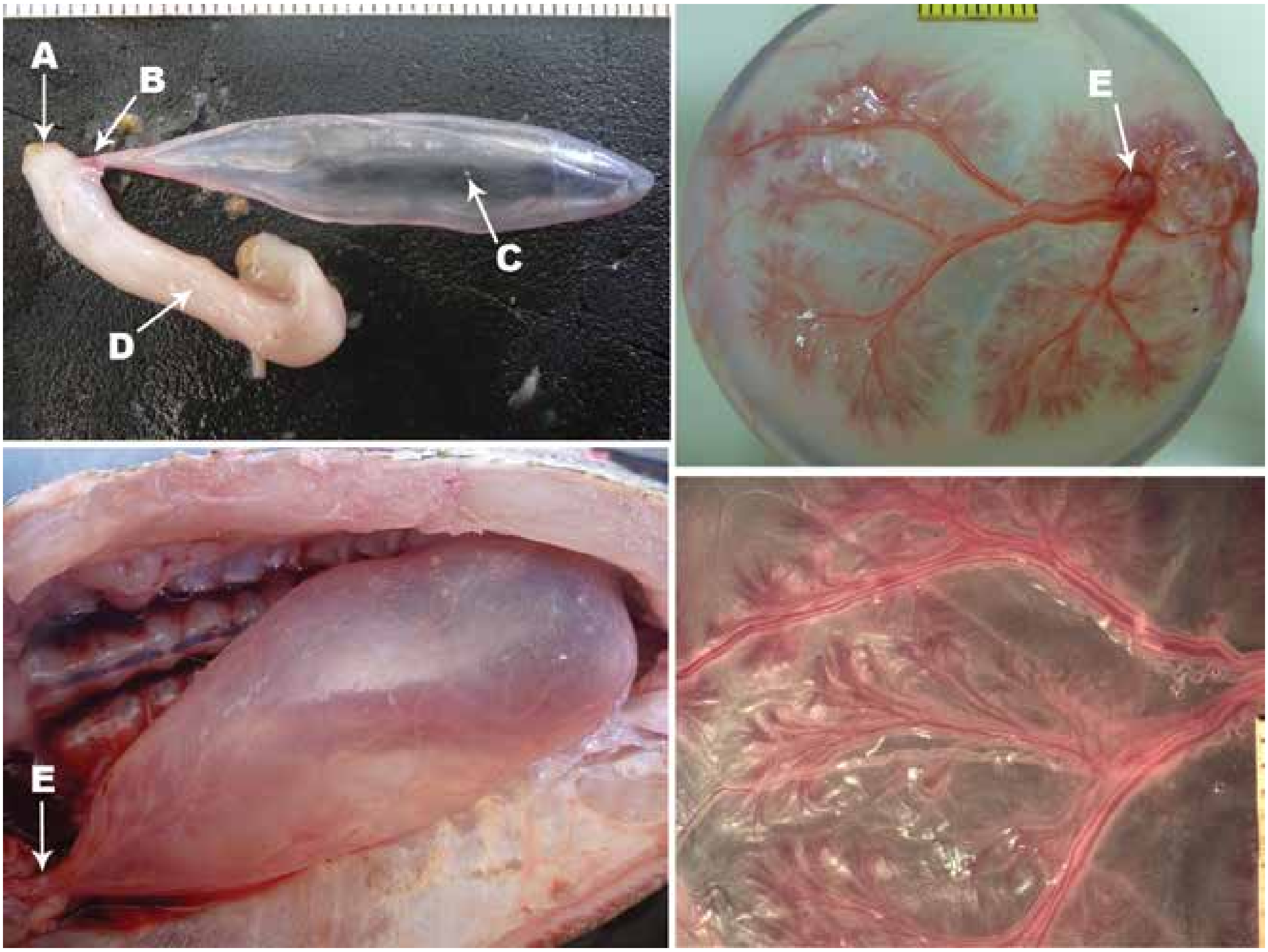

Figure 3. (A) Esophagus, (B) pneumatic duct, (C) physostomous swim bladder, and (D) stomach of a juvenile Chinook Salmon are shown in the upper left panel. The other three panels are photos of a physoclistous Smallmouth Bass swim bladder. The inflated swim bladder is shown in the lower left panel with the incoming vasculature source shown (E). The upper and lower right panels show a deflated swim bladder and the vascular rete (E also shows the incoming source of the vasculature). Photo credit: Ricardo W. Walker.

release gas as the swim bladder expands during rapid decompression (Brown et al. 2012e). To add to the complexity, most fish that are physoclistous as adults are physostomous as larvae, which enables initial swim bladder inflation by gulping air (e.g., Bailey and Doroshov 1995; Rieger and Summerfelt 1998; Trotter et al. 2003). Thus, the vulnerability to barotrauma may vary greatly within a species depending on its life stage (Tsvetkov et al. 1972). Another noteworthy variation in swim bladder morphology is found in the most diverse family of freshwater fishes, the cyprinids, which form a major component of the migratory fauna of Asian rivers. They have a physostomous swim bladder, but it has two chambers with an anterior projection closer to the Weberian apparatus to enhance hearing (Alexander 1962; Figure 5). The chambers are connected by an additional duct under autonomic muscular control (Dumbarton et al. 2010). Thus, during rapid decompression, excess gas would need to be voided through both chambers and two ducts simultaneously in order to prevent barotrauma due to swim bladder damage.

In order to predict the extent of inter- and intraspecific barotraumas that may be induced by hydrostructures within a given river system, it is crucial to understand how pressure changes affect fish with different types of swim bladders at different life stages. Physostomes are able to quickly expel gas via the pneumatic duct, using the *gass-puckreflex* (gas spitting reflex; Franz 1937), which is under autonomic control. The rate of this reflex is likely critical in reducing injury due to rapid decompression but appears to vary between—and even within—species (Harvey et al. 1968; Shrimpton et al. 1990). Shrimpton et al. (1990) determined that smaller Rainbow Trout had a higher gas pressure release threshold than larger fish (when examining fish in a range from less than 10 to ~250 g). Additionally, there have been observations of siluriform Catfish with everted stomachs (Figures 2A and 2B) downstream of hydroelectric facilities, which indicates that gas was not released fast enough from their physostomous swim bladder to avoid barotrauma during rapid decompression.

Unlike physostomes, physoclists can only regulate buoyancy through a relatively slow process of gas diffusion into and out of the swim bladder (see Figure 3). The physoclistous swim bladder is filled predominantly by oxygen that is released from a pH-sensitive hemoglobin as it is acidified within the retia of the swim bladder (Pelster and Randall 1998). The rate of swim bladder filling and the partial pressures that can be ultimately generated varies widely among physoclists, with some species able to attain neutral buoyancy at much deeper depths than others (Fange 1983). Some species, like Tench (*Tinca tinca*), can

- Class Myxini (hagfish)
- Class Cephalaspidomorphi (lampreys)
- Class Chondrichthyes (Elasmobranchii and Holocephali)
- Class Osteichthyes
  - Subclass Sarcopterygii (lobe-finned fishes; lungfishes)
  - Subclass Actinopterygii (ray-finned fishes)
    - Sub/Div. Cladistia (bichirs)
    - Sub/Div. Chondrostei (sturgeons)
    - Sub/Div. Neopterygii (gars)
    - Sub/Div. Teleostei
      - Infradiv. Osteoglossomorpha
      - Infradiv. Elopomorpha
      - Infradiv. Clupeomorpha
      - Infradiv. Euteleostei
        - Superorder Ostariophysi
          - Order Cypriniformes
          - Order Characiformes
          - Order Siluriformes
          - Order Gymnotiformes
        - Superorder Protacanthopterygii
          - Order Esociformes
          - Order Osmeriformes
          - Order Salmoniformes

PHYSOSTOMOUS (Subclass Sarcopterygii through Order Salmoniformes)

      - Infradiv. Neoteleostei
        - Superorder Stenopterygii
        - Superorder Scopelomorpha
        - Superorder Paracanthopterygii
          - Order Percopsiformes
          - Order Ophidiiformes
          - Order Gadiformes
          - Order Batrachoidiformes
          - Order Lophiiformes
        - Superorder Acanthopterygii
          - Series Atherinomorpha
            - Order Atheriniformes
            - Order Beloniformes
            - Order Cyprinodontiformes
          - Series Percomorpha
            - Order Beryciformes
            - Order Gasterosteiformes
            - Order Scorpaeniformes
            - Order Perciformes
            - Order Pleuronectiformes
            - Order Tetraodontiformes

PHYSOCLISTOUS (Superorder Stenopterygii through Order Tetraodontiformes)

Figure 4. The type of swim bladder present in different taxa of fish. Fish with an opening between the swim bladder and the esophagus (physostomes) and without this opening (physoclists) are shown, as well as fish without a swim bladder (the upper most three classes).

take weeks to fill their swim bladder (Jacobs 1934), whereas Bluefish (*Pomotomus saltatrix*) may be able to do so relatively rapidly (less than 4 h after puncture; Wittenberg et al. 1964) but still require hours to days. Presumably, these rates of swim bladder filling are indicative of rates of emptying, which are much too slow to prevent barotrauma due to the rapid (occurring in a fraction of a second) pressure changes that occur during water infrastructure passage. Thus, physoclistous species are likely very susceptible to barotraumas and likely much more sensitive than physostomous species; however, this remains to be investigated.

In addition to physoclists and physostomes, there is a third group of freshwater fishes that do not have a swim bladder and are therefore likely to have low susceptibility to barotrauma arising from Boyle's law. Juvenile Brook and Pacific Lamprey

Figure 5. Two-chambered swim bladder of the *Hypsibarbus lagleri*, a species endemic to the Mekong basin of South East Asia.

are two such species and were uninjured when rapidly decompressed in simulations of hydroturbine passage including exposure to pressures much lower (13.8 kPa) than commonly seen during turbine passage (Colotelo et al. 2012). Additionally, both species were held at this low pressure for an extended period of time (>17 min) without either immediate or delayed (>120 h) mortality (Colotelo et al. 2012). Together, these results suggest limited susceptibility to barotrauma via either the Boyle's or Henry's law pathways. In comparison to the Pacific Lamprey, when juvenile Chinook Salmon were rapidly decompressed to these same low pressures, more than 95% suffered mortal injuries (Brown et al. 2012b). Migratory fish species that reside in freshwater at least part of their lives and do not have swim bladders are not common but include Bull Shark (*Carcharhinus leucas*), freshwater Sawfish (*Pristis microdon*; a threatened species), and lampreys.

Other researchers have noted that fish without swim bladders had low susceptibility to barotrauma. For example, Bishai (1961) found larval Plaice (*Pleuronectes platessa* L.; 3.5–5.0 cm long) held at 202 kPa for 2–8 days were uninjured when decompressed over 5–10 min back to surface pressure (101 kPa). Similarly, Tsvetkov et al. (1972) found no damage to larval Atlantic Salmon (*Salmo salar*; 2–2.5 cm long; without a developed swim bladder) after being held at 101–606 kPa for 40 h or more and brought to surface pressure in less than 3 s. However, neither of these experiments involved reducing fish to pressures below surface pressure where barotrauma due to Henry's law (gas coming out of suspension in their blood and tissues) would have been anticipated.

IMPLICATION OF LIFE HISTORY AND BEHAVIOR

In addition to the physiological traits of fish, barotrauma research on freshwater species needs to be based on a template of ecology and behavior (Table 1). Understanding what life stages will be exposed to water infrastructure passage is critical to understanding the susceptibility of wild populations to barotrauma. The majority of research related to hydroturbine passage has been focused on seaward-migrating juvenile salmonids. Most salmonid species are semelparous (having a single reproductive episode before death) and, as such, the only life stage that may be affected by downstream passage is juveniles. There are, however, iteroparous (having multiple reproductive cycles over a lifetime) species that may pass through turbines as they migrate back to the ocean after spawning (e.g., Steelhead Trout [*Oncorhynchus mykiss*], Brown Trout [*Salmo trutta*], Atlantic Salmon, and Dolly Varden [*Salvelinus malma malma*]). Iteroparous species are also common in other bioregions such as South America, Asia, and Australia, where both adult and juvenile life stages may have to migrate downstream through hydropower and irrigation structures. In large floodplain rivers such as in South East Asia, South America, and Australia, egg and larval drift is a common life history trait (Baran et al. 2001; Humphries et al. 2002; Koehn and Harrington 2005; Godinho and Kynard 2009), and this mode of migration will increase the likelihood of encountering water infrastructure. Within North America, there are also many species (such as Paddlefish [*Polyodon spathula*], Walleye [*Sander vitreus*], and sturgeon [*Scaphirhynchus* spp.]) where eggs, larvae, or small juveniles can drift for long distances (Purkett 1961; Corbett and Powles 1986; Braaten et al. 2008). Early life stages are fragile and may be more susceptible to barotrauma than larger individuals because their bodies (swim bladder and other internal organs) are less robust (Tsvetkov et al. 1972), and the expansion of gas in the swim bladder may be more likely to cause damage relative to their body size. Understanding the ecology and timing of larval drift, as well as the time of first inflation of the swim bladder, will be critical in understanding their susceptibility to barotrauma. Additionally, more information is needed about physiological changes in larval physoclistous fish. They commonly have larvae with an open swim bladder but lose the connection between their swim bladder and esophagus as they develop. Identifying when this occurs may aid in understanding their increased susceptibility to barotrauma, important information for managing systems where these types of fish are present.

Larval drifting fish may also be susceptible to barotrauma due to expansion of metabolically produced gas. Brown et al. (2013a) noted barotrauma in the form of erratic swimming, death, and herniation-like abnormalities on the abdomen of larval White Sturgeon (*Acipenser transmontanus*) at the point when they first started feeding (8 days after hatching) but did not have an inflated swim bladder. They also noted gas in the intestines about 7 months after hatching that could also lead to barotrauma upon decompression.

Susceptibility to barotrauma is also likely to be influenced by the position fish occupy in the water column. Neutral buoyancy in fish is achieved by maintaining swim bladder volume constant, which is accomplished at deeper depths by having a higher gas pressure according to Boyle's law (see above). The depth and water pressure a fish has occupied prior to infrastructure passage (commonly referred to as "acclimation pressure") likely dictates the amount of gas a fish must have in its swim bladder to maintain neutral buoyancy because gases are compressible. If fish are benthic oriented, such as catfish, which are abundant riverine species in Asia and North and South America,

Table 1. Various traits that can influence the susceptibility of fish to barotrauma, along with example species.

Physiological, behavioral, or life history trait affecting susceptibility to barotrauma	Presence or absence	Susceptibility to barotrauma	Example species or project	References
The amount of free (undissolved) gas in the body				
Presence of a swim bladder	Yes	High	Chinook Salmon	Colotelo et al. (2012)
	No	Low	Pacific Lamprey	
Type of swim bladder	Open (physostomous)	Low	Chinook Salmon	Abernethy et al. (2001)
	Closed (physoclistous)	High	Bluegill	
Ability to expel gas out of the swim bladder through pneumatic duct	Better	Low	Large Rainbow Trout	Shrimpton et al. (1990)
	Poorer	High	Small Rainbow Trout	
Ability to fill the swim bladder with vasculature (rete)	Better	High	Bluegill	Harvey (1963); Fange (1983)
	Poorer	Low	Chinook Salmon	
Acclimation depth ability	Better	High	Burbot, Rainbow Trout	Fange (1983)
	Poorer	Low	Chinook Salmon	
Pressure exposure				
Acclimation depth	Deeper	High	Burbot	Stephenson et al. (2010); Fange (1983)
	Shallower	Low	Chinook Salmon	
Exposure pressure	Higher	Low	Irrigation weirs/spillways	Brown et al. (2012b)
	Lower	High	High-head dams	
Ratio of pressure change (acclimation pressure/ exposure pressure)	Higher	High	Hydroturbine	Brown et al. (2012a)
	Lower	Low	Bypass system	
Rate of ratio pressure change	Higher	High	Hydroturbine	Brown et al. (2012e)
	Lower	Low	Angling	
Life history				
Migrational patterns	More migratory	High	Murray Cod, Salmonids	
	More sedentary	Low	Trout Perch (*Percopsis omiscomaycus*)	
Larval or juvenile drift stage	Yes	High	Sturgeon, Murray Cod	Brown et al. (2013); Baumgartner et al. (2009)
	No	Low	Salmonids	
Structural integrity				
	High	Low	Adult fish	Baumgartner et al. (2009); Tsvetkov et al. (1972)
	Low	High	Larval or juvenile fish or eggs	

their initial acclimation pressure may be high and the lowest pressure (often referred to as "nadir") experienced during hydroturbine passage will likely have a greater impact on swim bladder expansion. The ratio of pressure change (acclimation pressure/hydroturbine nadir pressure) experienced by the fish during passage is therefore likely a major factor dictating the level of injury a fish may experience. In contrast, fish that typically occupy shallower depths (including those species with buoyant drifting larval stages) require less gas to achieve the same swim bladder volume needed for neutral buoyancy and therefore may be less susceptible to barotrauma due to rapid decompression. However, research is needed to determine whether benthic-oriented fish are neutrally or negatively buoyant, because this will have implications for the impact of the pressure change on barotrauma.

IMPLICATION OF THE RATIO OF PRESSURE CHANGE ON SWIM BLADDER INJURY

Fish injury following rapid pressure change is predominantly associated with expansion of preexisting gases, which often leads to rupture of the swim bladder (Brown et al. 2012e). Thus, prediction of barotraumas in fish passing through hydrostructures requires a firm understanding of the degree to which gas expands within fish when they are decompressed. Based upon Boyle's law (see above), one of the primary determinants of swim bladder volume change (and therefore likelihood of injury) will be the ratio of pressure change experienced by the fish during passage. This ratio may be as simple as dividing the pressure associated with the depth to which fish are acclimated and neutrally buoyant prior to passage with the nadir (lowest pressure) experienced during infrastructure passage. The following analogy acts to illustrate the importance of the ratio of pressure change rather than absolute pressure change to swim bladder volume and thus the potential for barotrauma. If a fish is brought to the surface (101 kPa) from an acclimation depth of 10 m (202 kPa) at which it is neutrally buoyant, it will experience a pressure change ratio of 2 (202 kPa/101 kPa), which implies that swim bladder volume would double (in the absence of body wall constraints). In this scenario, the absolute pressure change is 101 kPa (202 − 101 kPa; see Figure 6 for an example). The same doubling of swim bladder volume would also occur in a fish acclimated to surface water (101 kPa) that passes through a hydroturbine with a nadir pressure of 50.5 kPa because the ratio of pressure change is 2, even though the absolute pressure change is only 50.5 kPa, half the value of the example above. Understanding the significance of Boyle's law and its potential impacts on fish can inform the hydraulic design of hydroturbines and other water control structures to control the nadir pressure and minimize the ratio of pressure change. This approach is currently being used by the U.S. Army Corps of Engineers to design new turbines to replace aging turbines at Columbia and Snake River dams (Brown et al. 2012a; Trumbo

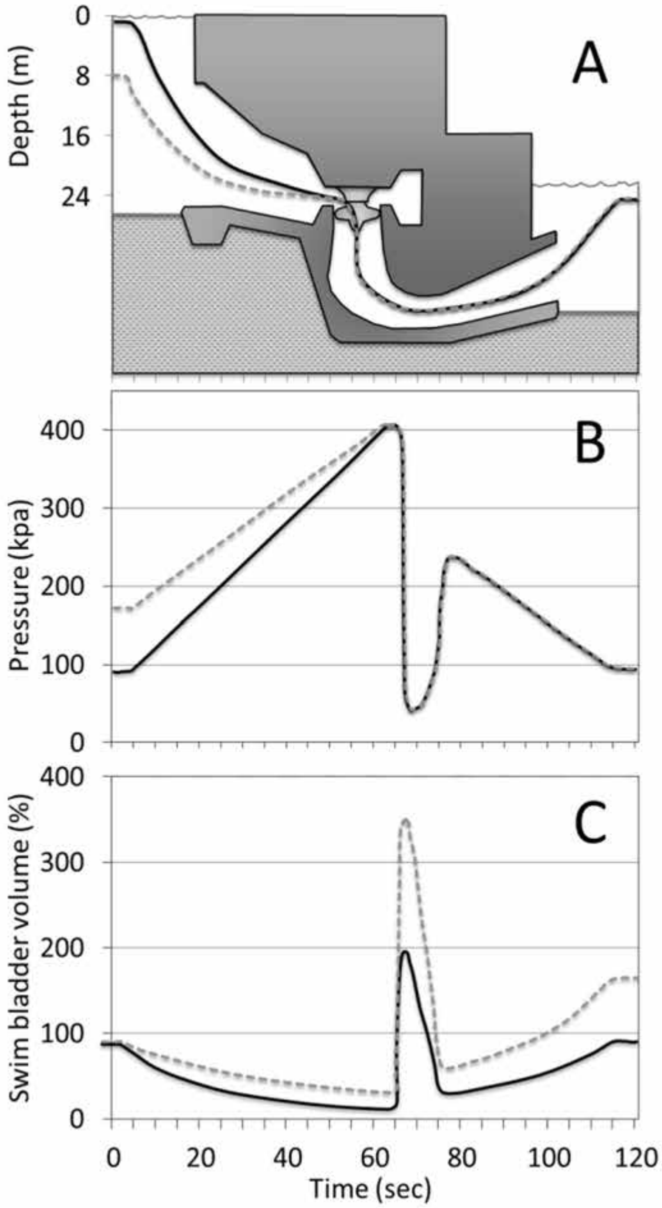

Figure 6. (A) Path through a hydroturbine, (B) an example of a pressure scenario that could be experienced, and (C) the swim bladder volume change (%) for fish neutrally buoyant at two different depths. The solid line represents a fish acclimated to near surface pressure, and the dotted line represents a fish acclimated to a depth of approximately 8 m (181.7 kPa).

et al. 2013). They recently contracted with industry to design and supply two new turbine runners for installation into Ice Harbor Lock and Dam.

DETERMINING ACCLIMATION PRESSURES AND CAPACITY FOR SWIM BLADDER INFLATION

Due to the importance of the ratio of pressure change in predicting the likelihood of barotrauma, it is necessary to determine the acclimation depth of fish as they approach hydrostructures and then determine the extent of the low pressures the fish will be exposed to during passage. Consideration must also be given to the swim bladder volume immediately prior to nadir exposure because some fish may expel gas from the bladder when exposed to pressure reductions associated with hydrostructure passage (Brown et al. 2012e) but before the nadir pressure exposure. Some different approaches can be used when trying to determine the acclimation depths of approaching fish, based upon the physiology of that particular species.

As a first approach, the depth from which fish are approaching structures should be known. Fish could be captured or monitored just upstream of dams or weirs under the assumption that this is the depth occupied during downstream migration. Identifying these migration depths could be facilitated by stratified sampling at different depths in the water column. Fish could then be captured and placed into a simple field hyperbaric chamber, where the pressure could be controlled and modified to determine the pressure or depth where the fish is neutrally buoyant. A neutrally buoyant fish appears level in the water column, instead of head down (positively buoyant) or head up (negatively buoyant; see Pflugrath et al. 2012). Another approach would be to move fish up and down in a water column (thus varying pressure) to determine at which depth they are neutrally buoyant. It may be necessary, depending on behavior, for some fish species to be sedated in order to determine buoyancy (Brown et al. 2005). Though these types of approaches have been used in laboratory research (Brown et al. 2005), field research into this area is needed.

The above methods may be fairly straightforward in fish with physoclistous swim bladders but more complicated in physostomes where gases can be expelled through a pneumatic duct. The latter may be minimized by sedating fish in a way to minimize stress such as slowly adding anesthetic to the water (similar to Brown et al. 2005); however, specific methods need to be developed.

Determining the maximum depth at which a fish species or life stage can attain neutral buoyancy is also very important information. This information can be used to predict susceptibility to barotraumas because it will influence the maximal ratio of pressure change that a fish may experience when passing through a specific hydroturbine or weir structure. Pflugrath et al. (2012) determined the maximum depth at which juvenile Chinook Salmon could maintain neutral buoyancy by attaching weights to the outside of the fish. As more mass was added, fish would gulp air at the water surface and fill their swim bladder until they were again neutrally buoyant. As more mass was added, the point at which fish could no longer attain neutral buoyancy was determined. Calculations of swim bladder volume and Boyle's law were then used to estimate the depth at which the determined maximum swim bladder volume resulted in neutral buoyancy (Pflugrath et al. 2012). This method is only useful for physostomous fish that only fill their swim bladder through gulping air at the water surface and forcing it through the pneumatic duct (such as Chinook and Sockeye Salmon; Harvey 1963; unlike fish like American Eels [*Anguilla rostrata*], which have an open swim bladder and an active retia).

Determining the maximum depth of neutral buoyancy in physoclistous fish or physostomous fish with a functioning rete

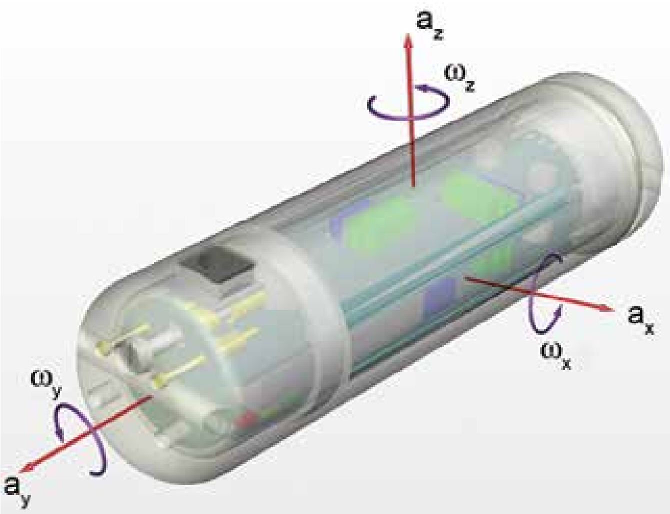

Figure 7. The mulitsensor fish surrogate showing the location of the measurement axes for the three rate gyros (that measure angular velocity, ω), three linear accelerometers (that measure the acceleration, a), and pressure transducers (Deng et al. 2007b).

could be conducted by slowly increasing the pressure in a hyperbaric chamber until neutral buoyancy can no longer be attained. The rate of swim bladder inflation in these fish is slow and variable among species and life stages (Fange 1983). This will have to be taken into account in experimental designs to assess maximum acclimation depths because some species may need to be held under pressure for long periods to determine the bounds of their buoyancy regulatory abilities. In addition, if pressures are increased too quickly, fish may not be able to attain neutral buoyancy at depths as great as those treated with slower increases in pressure. For physostomous fish, it may be necessary to remove all gas bubbles from the chamber to ensure that the swim bladder is inflated solely through the rete and not by gulping compressed gas bubbles inside the chamber, which could otherwise overestimate acclimation depths.

DETERMINING EXPOSURE PRESSURES DURING FISH PASSAGE

The nadir pressure is critical in determining the ratio of pressure change and is an essential parameter in predicting barotraumas as fish pass through hydro or irrigation structures. This pressure can be estimated using computational fluid dynamics models or can be determined in situ using a multiple sensor fish surrogate (Deng et al. 2007b). The latest generation 6-degree-of-freedom version of this device is an autonomous sensor package, consisting of three rate gyros, three acceleration sensors, a pressure sensor, and a temperature sensor (Deng et al. 2007b; Figure 7). It was developed at Pacific Northwest National Laboratory for the U.S. Department of Energy and U.S. Army Corps of Engineers to characterize the physical conditions and physical stressors to which fish are exposed as they pass through complex hydraulic environments. This device is currently 24.5 mm in diameter and 90 mm in length, weighs 42 g, and is nearly neutrally buoyant in freshwater. Although this makes it similar to the size and density of a migrating yearling Salmon smolt, this does not preclude its usefulness in systems where juvenile salmonids are not present. The multiple sensor fish surrogate provides actual measurements of pressure, the three components of linear acceleration (up–down, forward–back, and side-to-side), and the three components of rotational velocities (pitch, roll, and yaw) and internal temperature at a sampling frequency of 2,000 Hz, extending from its release location to the end of the particular passage.

For barotrauma research, the most important parameter to measure from a multiple sensor fish surrogate is pressure, which can be used to determine pressure profiles, estimate the depth of the fish during passage, and determine passage rates through different regions of a hydropower or weir structure. For example, the pressure profile of a typical turbine passage is characterized by an increase in pressure as fish pass downward toward and through the turbine intake, a rapid decompression (typically significantly below surface pressure in a fraction of a second) as the fish pass the turbine blade and a slow return to surface pressure through the draft tube (examples are provided in Brown et al. [2009] and Stephenson et al. [2010]). For passage through an undershot irrigation weir (where bypass water flows underneath the weir), the pressure profile reveals a slow increase in pressure upstream of the gate and a rapid decompression (<1 s) to slightly below surface pressure under the gate and a return to surface pressure in the tailwater.

The rate of decompression mentioned above is an important consideration when determining barotrauma susceptibility, because it can affect a physostomous species' ability to expel gas from the swim bladder. Brown et al. (2012e) found that when decompression occurred slowly (0.6–1.0 kPa/s), Chinook Salmon expelled gas more frequently and thus avoided barotrauma when compared to those decompressed at rapid rates (758.4 to 3,874.9 kPa/s; Brown et al. 2012b). Thus, clearly the rate of decompression associated with structure passage is crucial in predicting impacts; however, this information is often lacking and is needed.

Multiple sensor fish surrogates have been widely used to evaluate hydroturbine, spillway, and other fish bypass systems as well as pump storage and irrigation weir facilities. For example, it was deployed at different elevations and operation conditions to evaluate the biological performance of the advanced hydropower turbine (AHT) at Wanapum Dam (Washington State) to support its relicensing application. The AHT was designed to improve operational efficiency and increase power generation while improving the survival for fish passing through the turbines. The multiple sensor fish surrogate measurements confirmed that the AHT provided a better pressure and rate of pressure change environment for fish passage and improved the passage of juvenile salmon at Wanapum Dam (Deng et al. 2010). The multiple sensor fish surrogate is undergoing design changes such as the size, aspects of function, deployment and recovery, availability, and cost to extend its range of use and provide information for the development of fish-friendly hydrosystems internationally.

MODELING THE PROBABILITY OF MORTALITY OR INJURY

Once the range of natural acclimation pressures and the exposure pressures to be expected during passage through the hydraulic structures are determined, laboratory experiments can be conducted to relate the rate and magnitude of decompression to the expected mortality and injury of fish during infrastructure passage (Brown et al. 2009, 2012b, 2012e). These experiments involve exposing fish to pressure profiles that simulate passage through a hydroturbine or irrigation infrastructure under a range of ratios of pressure change. Such a laboratory approach for the simulation of infrastructure passage is being used to great effect to guide engineers when replacing turbines at dams in the Pacific Northwest of the United States (Brown et al. 2012a). However, a relationship between ratio pressure change and mortality and injury has only been determined for one species and life stage—juvenile Chinook Salmon (Brown et al. 2012b, 2012c)—and is likely to be species and life stage specific.

The type of equipment needed to simulate the different types of infrastructure passage can vary. Simulation of rapid decompression associated with hydroturbine passage requires sophisticated pressure chambers such as those described by Stephenson et al. (2010). These chambers are able to replicate the large ratio of pressure changes commonly observed during hydroturbine passage, which include nadirs well below atmospheric to pressures approaching 0 kPa. However, systems that only need to simulate smaller ratio pressure changes with nadirs of surface pressure (as may be characteristic of irrigation structures) or fairly slow pressure changes may be comparably simpler and inexpensive to construct. Simple systems could also be used in the laboratory to increase and decrease pressures to examine the capacity of fish to regulate their buoyancy.

The ultimate goal of this type of laboratory work should be to model the relationship between the ratio of pressure change fish are exposed to and the probability of injury or mortality. For all of the reasons previously mentioned, the ranges of ratio pressure change to be tested should be informed through careful consideration of the acclimation pressures prior to passage and the range of nadir pressures a fish is likely to be exposed to when it encounters various infrastructures throughout its life history. Once a relationship between mortality and pressure change is established with suitable statistical rigor, it is theoretically possible to predict the mortality of that species and life stage to any passage scenario, and it is only necessary to know the acclimation depth of the fish prior to passage and the nadir pressure expected at the hydropower or irrigation structure.

It is rarely practical to hold fish for extended periods following experimentation, and these holding conditions could vary widely and not represent field conditions. For these reasons, it may be possible to infer delayed mortality from the injuries immediately evident following rapid decompression during laboratory studies. McKinstry et al. (2007) combined the likelihood that fish had certain injuries present following simulated turbine passage with the likelihood of mortality to establish a mortal injury metric. Brown et al. (2012b, 2012c) subsequently determined that the likelihood a fish will be mortally injured relates to pressure exposure using the following equation:

$$\text{Probability of mortal injury} = \frac{e^{-5.56+3.85*LRP}}{1+e^{-5.56+3.85*LRP}},$$

where LRP is the natural log of the ratio of pressure change (acclimation/nadir pressures) to which the fish are exposed.

Techniques similar to those used by McKinstry et al. (2007) and Brown et al. (2012b) could be used to derive mortality metrics for other species. Brown et al. (2012e) determined that the ability of physostomes to expel gas from their swim bladder increases the variability in mortality when they are exposed to pressure changes. However, because physoclists cannot expel gas when rapidly decompressed, the anticipated level of variation is expected to be lower. Consequently, though Brown et al. (2012b) tested over 5,000 juvenile Chinook Salmon to determine the relationship between pressure change and fish damage, smaller sample sizes will likely suffice for physoclistous fish. However, to guide the international development of a broad range of sustainable hydro and irrigation structures, it is important to characterize the effect of pressure changes on a diverse range of physostomous and physoclistous species at different life history stages.

Laboratory experiments to determine the relationship between pressure changes and fish damage must take into consideration the depth to which fish are acclimated prior to water infrastructure contact, as well as the limits of fish buoyancy compensation. Researchers, managers, and turbine designers should be very careful when interpreting existing literature related to barotrauma in fish. Even 40 years ago, researchers like Tsvetkov et al. (1972) were concerned about the underestimation of fish injury associated with pressure changes due to methodological problems and inaccuracies. Examples provided by Tsvetkov et al. (1972) include tests where fish were not allowed to properly acclimate before being exposed to pressure reductions, such as placing physoclistous fish under high pressure and allowing them inadequate time to acclimate (just a few minutes, which is not adequate time for the swim bladder to be filled by the retia). They also highlighted studies of physostomous species where fish were acclimated to high pressures without access to air, thus not allowing fish to acclimate and fill their swim bladder.

These types of problems are not uncommon and also exist with a series of early experiments conducted by Abernethy et al. (2001, 2002, 2003). In these studies, juvenile Rainbow Trout and Chinook Salmon were placed into pressure chambers and held at surface pressure (101 kPa) or the pressures present at 19 m (191 kPa) of depth for 16–22 h. Fish were then exposed to rapid pressure reduction to pressures approximately in the range of 2–10 kPa (although the actual lowest pressures fish were exposed to during all tests were not noted). However, because the fish held at 191 kPa were not provided with an air surface, they could not fill their swim bladder and become neutrally buoyant. Thus, results indicated that fish approaching turbines at 19 m would have the damage similar to that of fish approaching at surface pressure. However, these unrealistic results were part of a chain of research that developed into the understanding of the importance of acclimation in barotrauma experiments (Stephenson et al. 2010).

Caution should also be taken when interpreting some field-based research and scale-model investigations of turbines. For many studies of turbine passage survival, balloons and radio transmitters are attached to fish to aid in their retrieval (see Mathur et al. [1996] for an example). Before release from the surface of a dam, the balloons are injected with a liquid, leading to a chemical reaction that creates gas. This allows fish to pass through the turbine while the balloons are deflated and then be recaptured in the tailwater of a dam after the balloons have inflated. Though these studies have provided a large amount of valuable data on the effects of turbine passage, the information they provide related to barotrauma is likely a best-case scenario because fish are typically injected into turbine entrances from surface pressure. In addition, some studies done on scaled models of turbines (Cook et al. 2003; Electric Power Research Institute and U.S. Department of Energy 2011), which hold promise for reducing strike and shear injuries to fish, were conducted by releasing fish into the scale turbine at surface pressure. Thus, these studies also likely provide a best-case scenario for barotrauma-related injuries.

FIELD VALIDATION OF MODELED MORTALITY RELATIONSHIPS

Any modeled data will benefit from ground-truthing to ensure that the predictions generated in the laboratory adequately reflect the complexities experienced in real-world systems. The mortality models described above are no exception. When possible, estimates made in the laboratory can be verified on existing or pilot hydroturbine or weir structures. The development of new designs is progressing at a rapid rate, particularly in the small-scale hydropower market (Baumgartner et al. 2012). Therefore, there are great opportunities for researchers to work with developers to validate the predictions made in the laboratory when assessing the suitability of pilot projects. In some parts of southeastern Australia, state fisheries management agencies are already requiring developers to initiate field validation of new small-scale hydro designs as a preferred intermediate step between laboratory studies and possible large-scale adoption of any technology (Baumgartner et al. 2012). Field validations may involve running live fish through facilities in parallel with multiple sensor fish surrogates, with the measured mortality rates and ratio of pressure changes compared with laboratory modeling. In the end, this will improve the confidence that developers and fisheries management agencies have in laboratory generated predictions.

Another factor that is critical for increasing the confidence in field results is to design experiments so that injury and mortality estimates are not biased. One important consideration is to ensure that all fish are acclimated to appropriate depths (corresponding to natural migration behavior) prior to being exposed to infrastructure passage. This has often not been the case in field examinations, as pointed out by Stephenson et al. (2010).

Another consideration involves the use of telemetry tags to estimate the route of passage and survival of fish. The mass of the tag relative to the mass of the fish (referred to as "tag burden") has been shown to influence growth, behavior, swimming performance, and survival for tagged fish when compared to untagged conspecifics (Zale et al. 2005; Brown et al. 2010), and is of particular importance for fish exposed to rapid changes in pressure. Carlson et al. (2012) demonstrated that for juvenile Chinook Salmon exposed to rapid decompression associated with simulated turbine passage, the probability of injury and mortality increased as tag burden increased. Fish carrying a negatively buoyant telemetry tag increase the amount of gas forced into the swim bladder to offset the additional mass and achieve neutral buoyancy, making them more susceptible to barotrauma (Gallepp and Magnuson 1972; Perry et al. 2001). In addition, having a telemetry transmitter inside the body cavity may limit the amount that a swim bladder can expand before it ruptures or causes compression-related injuries. Therefore, field estimates of mortality that are based upon tagged fish have the potential to overestimate the severity of barotrauma injury. To overcome this, we recommend using the smallest tag possible to minimize tag burden or a neutrally buoyant, externally attached tag (tag burden of 0%; Deng et al. 2012; Janak et al. 2012; Brown et al. 2012d, 2013b), when examining survival of fish exposed to rapid decompression associated with infrastructure passage.

AN ADAPTIVE APPROACH TO SUSTAINABLE DEVELOPMENT

Recently there have been renewed global efforts in the expansion of hydropower projects. The retrofitting of new hydro projects to existing structures has also been encouraged by the U.S. Department of Energy to increase the output of American hydropower capability (Hadjerioua et al. 2012). In some parts of the world, established irrigation networks are being explored for their potential to support new economies relating to power generation (Botto et al. 2010). In many other regions, new dams are being planned. As part of Brazil's decennial plan (MME/EPE 2011), 48 hydropower dams are proposed for construction by 2020. Most of these would be in the Amazon and Tocantins-Araguaia hydrographic regions. These dams are likely to threaten fish diversity of the Amazon (20% of the world's freshwater fishes, representing about 1,400 species) by regulating flows and disrupting important fish migrations (Rosa and Lima 2008). It is a similar story for the world's largest inland fishery in the Lower Mekong River, where it is predicted that construction of 11 mainstem dams will lead to a major decline in fish populations, significantly compromising food security (Halls and Kshatriya 2009). If these dire scenarios are to be avoided, it will be necessary to ensure safe fish passage at new and existing structures, with management decisions underpinned by rigorous science.

Based on the information provided in this review, we recommend a logical staged approach to conducting the barotrauma research that will be necessary for refining infrastructure design throughout the world (Figure 8).The first stage involves conducting the field or desktop investigations necessary to determine which species and life history stages are of interest. The majority of barotrauma research to date has focused on the susceptibility of juvenile Chinook Salmon, largely driven by the legislative need to protect this threatened species during its critical seaward-migration in the U.S. Pacific Northwest, where a large number of hydropower facilities could negatively influence their survival. In other large river systems of the world, including the Mekong River in Southeast Asia, the Amazon in South America, and the Murray-Darling River in Australia, a diverse range of species and life history stages undertake downstream migrations (Barthem et al. 1991; Araujo-Lima and Oliveira 1998; Humphries and King 2004; Lintermans and Phillips 2004; Baran and Myschowoda 2008) and are therefore at risk of injury and mortality at existing and proposed hydropower and irrigation operations. For fisheries scientists wishing to embark on barotrauma-related research in these regions, the decision regarding which species and size classes to prioritize for study is daunting. Such decisions could be aided by considering the many factors associated with the susceptibility to barotrauma (see Table 1), including both ecological and biological considerations. By assigning weighted scores corresponding to the factors for each species in an assemblage of fish, multivariate classification approaches could be used to identify key groupings of fish based upon similarity in barotrauma vulnerability (see Table 1). Choosing some fish and life history stages from the higher vulnerability groupings may provide a good starting point for experimentation.

Once the species of study have been selected, a combination of field and lab testing and modeling can both determine the depth of neutral buoyancy as fish approach structures during migration (or acclimation depth) and the expected range of exposure pressures during infrastructure passage (Figure 8). This will provide a range of ratio pressure changes that fish can be subjected to in experimental pressure chambers and, from this, injury or mortality relationships can be modeled. Care must be taken during this experimentation to ensure that fish are properly acclimated (acclimated to the range of pressures that reflect depths where fish are neutrally buoyant as they approach structures). Fish acclimated to surface pressures are likely to provide results that are not necessarily representative of fish in the natural environment because acclimation depth is a very important parameter (Tsvetkov et al. 1972; Stephenson et al. 2010).

The models generated by laboratory experiments can then be used to refine infrastructure design, with models and designs further validated during pilot field trials. This field validation and testing is seen as a critical link in the adaptive management loop that will ensure that fisheries scientists and engineers keep the research and development applied and ultimately targeted on the goal of promoting sustainable water resource development.

Minimizing fisheries losses at water infrastructure is a global problem, and major investment will be needed to promote innovative technology if the current fisheries losses throughout the world are to be abated. A global problem requires a global solution, and we therefore encourage international cooperation in future research efforts. There are many similarities in fish species among different regions of the world and, thus, international collaboration will greatly reduce redundancy. For example, catfish species are common throughout North and South America, Asia, and Europe, and sturgeons (a type of fish with drifting larval stages) are common in North America, Asia, and Europe.

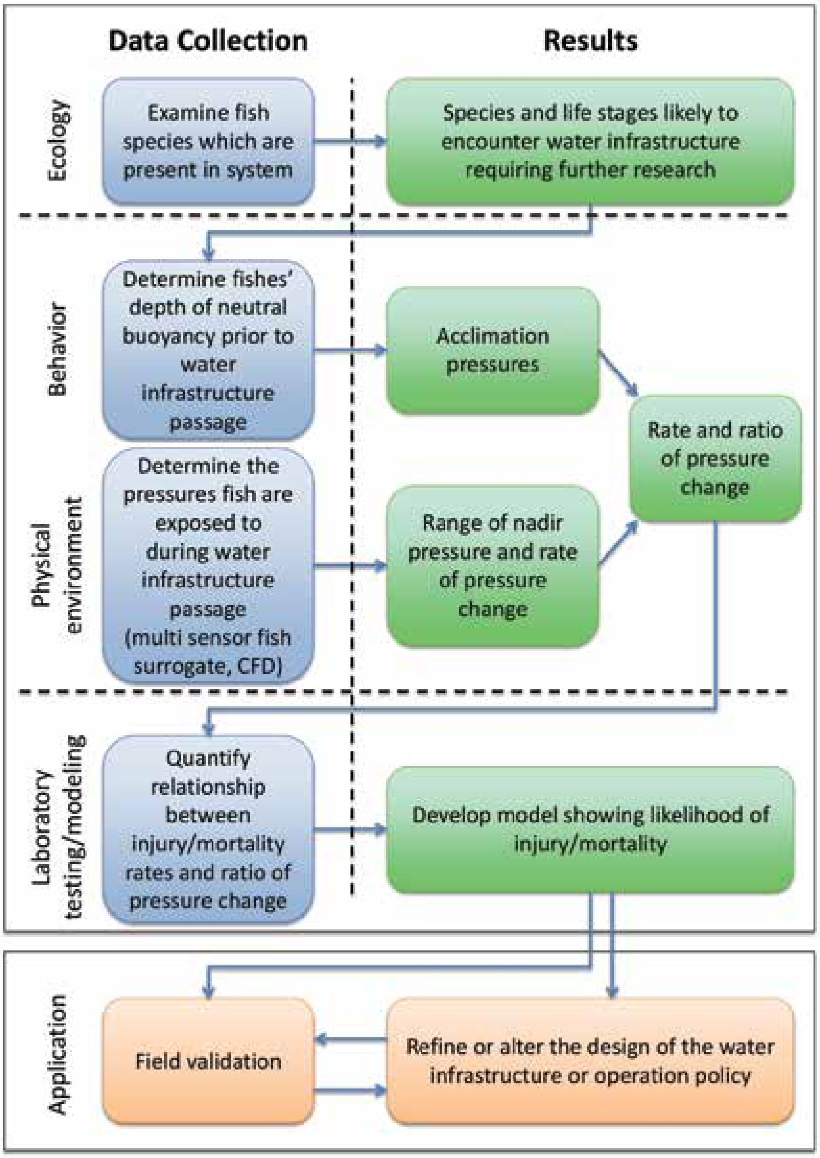

Figure 8. Recommended barotrauma research framework showing logical flow of activities and linkages with industry under an adaptive management model.

Similarly, larval drift will be a key consideration in many parts of Australia, Asia, and South America and also occurs among North American species. We are at a time where technology allows us to initiate downstream passage research among many species at a global scale using standardized approaches. Such a global approach could provide a more rapid advancement of science and engineering while minimizing duplication of effort.

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Response to Dettmers et al. (2012): Great Lakes Fisheries Managers Are Pursuing Appropriate Goals

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ABSTRACT: *After reading the article by Dettmers et al. in the November 2012 issue of* Fisheries *("Management of Alewife Using Pacific Salmon in the Great Lakes: Whether to Manage for Economics or the Ecosystem?"), we feel compelled to respond and to present a different perspective on this important management issue. Despite the generally positive contribution to Great Lakes literature made by this article, it contains several inaccuracies concerning the past and current state of Great Lakes ecosystems. Dettmers et al. present an oversimplification of options currently available to Great Lakes fisheries managers; a false dichotomy describing only two future options for management of these fisheries. We submit that managers could strive to "… maintain a diverse salmonid community, [while proceeding] (to the extent possible) with native species rehabilitation" and we conclude that, "… on each of the Great Lakes, managers are pursuing appropriate goals, managing the aquatic resources of the lakes for the greatest public good, given the variability in conditions and likelihood for success specific to each lake."*

Respuesta a Dettmers et al. (2012): los administradores pesqueros en los Grandes Lagos persiguen objetivos adecuados

RESUMEN: *después de leer el artículo de Dettmers et al. que apareció en el volumen de noviembre de 2012 de la revista* Fisheries *("Manejo de la alosa utilizando el salmón del Pacífico en los Grandes Lagos: manejo de la economía o el ecosistema") nos sentimos obligados a dar una respuesta y presentar una perspectiva distinta a este importante asunto de manejo. Pese a que la contribución del citado artículo a la literatura sobre los Grandes Lagos es positiva en términos generales, contiene numerosas imprecisiones en cuanto al estado pasado y presente de los ecosistemas de los Grandes Lagos. Dettmer et al. presentan una lista sobre-simplificada de opciones disponibles para los administradores pesqueros en los Grandes Lagos; una falsa dicotomía que describe sólo dos opciones futuras para el manejo de estas pesquerías. Sostenemos que los administradores pudiesen basarse en "...mantener una comunidad diversa de salmónidos [mientras se avanza] (en la medida de lo posible) hacia la rehabilitación de especies nativas" y concluimos que "...en cada uno de los Grandes Lagos, los administradores persiguen objetivos adecuados y, dada la variabilidad de condiciones y verosimilitud de éxito específicos de cada lago, gestionan los recursos acuáticos de los lagos en pos de un mayor bien público."*

THE PERSPECTIVE

After reading the article by Dettmers et al. in the November 2012 issue of *Fisheries* ("Management of Alewife Using Pacific Salmon in the Great Lakes: Whether to Manage for Economics or the Ecosystem?"), we feel compelled to respond and to present a different perspective on this important management issue. The authors are all highly respected Great Lakes biologists with whom we have worked closely on many Great Lakes issues and we agree with several of the points they present, particularly those related to the ongoing destructive effects of continued introduction of invasive species to these systems. However, despite the generally positive contribution to Great Lakes literature made by this article, it contains several inaccuracies concerning the past and current state of Great Lakes ecosystems, in several instances misrepresenting ongoing management processes and presenting an oversimplification and false dichotomy concerning options for managing Great Lakes fisheries.

In the section titled "Control of Sea Lamprey and Alewives," Dettmers et al. (2012), intentionally or not, seem to equate these two invasive species in terms of effects, control efforts, and control success. In the case of Sea Lamprey (*Petromyzon marinus*), the goal of managers was elimination of this organism from the lakes, targeting the vulnerable spawning life stage. Though we agree with the statement that "… lamprey numbers have been reduced to about 10% of previous highs in most lakes, …" (p. 496) the authors fail to point out that this is an expensive, ongoing battle and that in some areas of the lakes Sea Lamprey populations still represent the greatest source of mortality for native species such as Lake Trout (*Salvelinus namaycush*). On the other hand, again due to life history characteristics (i.e., broadcast spawning in widely distributed areas of the lakes), there was never an understanding that Alewife (*Alosa pseudoharengus*) could or would be completely eliminated. Rather, the goal of fisheries managers was to reduce alewife abundance and restore ecosystem function by converting an overabundance of prey fish to predator biomass. Today, depending on the lake in question, this predator biomass takes the form of reproducing natives, stocked natives, and stocked or naturalized nonnative predator species. For the nonnative salmonines, most have been stocked since the early to mid-1900s—including Chinook Salmon (*Oncorhynchus tschawytscha*), Coho Salmon (*O. kisutch*), and Steelhead (aka Rainbow Trout; *O. mykiss*); these salmonines are naturalized in many areas of the Great Lakes. Brown Trout (*Salmo trutta*) are also stocked, but naturalization of Brown Trout in the Great Lakes is extremely limited.

Dettmers et al. (2012) also argue, with little supporting documentation, that native fish "… may be better suited to the changing ecosystem, …" (p. 499) including the potential introduction of Asian carps to Great Lakes waters. Both native and naturalized nonnative predators are in the process of adapting to the constantly changing Great Lakes ecosystem; there is no evidence that native fish, such as coregonids and Lake Trout, are better suited to this changing system, especially given that we do not know what the future holds in terms of new perturbations. In fact, published accounts of Lake Trout life history traits suggest that they may be less suited to change (Evans and Oliver 1995; Shuter et al. 1998; Vander Zanden et al. 1999); they are a slow-growing species that thrive in cold, unproductive waters with simplistic (e.g., low number of species) food webs (Gunn and Pitblado 2004). In contrast, naturalized Pacific salmonines in the Great Lakes have relatively short life histories, have adapted relatively quickly to the Great Lakes ecosystem, and have naturally reproducing populations that fluctuate in concert with the changing prey conditions (Warner et al. 2008). These naturalized nonnative salmonines are also less susceptible to the ongoing threat of what is arguably the most devastating invasive species to become established in the Great Lakes—the Sea Lamprey. For example, Sea Lamprey wounding rates for Lake Trout are three to five times higher compared to Chinook Salmon in Lake Michigan (Wesander and Clapp 2012). Contrary to the authors' statements, Great Lakes Lake Trout populations are probably the most intensively and expensively managed fish populations in the world. There is little to no evidence that management solely focused on native predators will be less intensive, more certain, or better aligned with goals and objectives than that currently practiced in the majority of Great Lakes waters.

Dettmers et al. (2012) suggest that invasive Asian carps may drive a trend toward a benthic-dominated food web, to the benefit of native species. To suggest that an invasion of Bighead Carp (*Hypopthalmichthys nobilis*) and Silver Carp (*H. molitrix*) into the Great Lakes would benefit "coregonids and Lake Trout" via an indirect shift from a pelagic to benthic-oriented native fish community is entirely unsupported and misleading. The best currently available information suggests that Asian carp will not establish populations in the pelagic and deep benthic areas of the Great Lakes but rather threaten tributary, drowned river mouth, and shallow bay habitats supporting species such as Walleye (*Zander vitreum*) and Yellow Perch (*Perca flavescens*). Introduction of Asian carps in the Great Lakes will certainly be harmful to the fisheries, the ecosystem, and the people living in the region, but the contention that Lake Trout are better suited to respond to this potential introduction is entirely unsupported.

Throughout their article, Dettmers et al. (2012) misrepresent certain aspects of past and present Great Lakes fisheries management; the relative intensity of native versus naturalized nonnative predator management is one example already discussed. The statement that "… Lake Trout rehabilitation languished on in Lake Michigan for over a decade …" (p. 497) is an insult to the many dedicated state and federal biologists who have devoted significant time and resources to this issue in recent years. Great Lakes fish populations are managed jointly by state and federal agencies under the auspices of the Joint Strategic Plan for Great Lakes Fisheries Management (Great Lakes Fishery Commission 2007); this management is implemented through the actions of lake committees and lake technical committees on each of the Great Lakes. The dedicated efforts of Lake Michigan biologists to address the impediments to Lake Trout rehabilitation are fully documented in numerous peer-reviewed and agency publications (see, for example, Bronte et al. 2003). That rehabilitation has "languished" is not due to lack of effort on the part of those responsible but, rather, is due to the difficult nature of the problem, both economically and ecologically, as well as the multitude of stakeholder goals that it is the duty of state management agencies to consider. As described above, native predator management is not an unintensive undertaking.

In addition to the case of Lake Trout management, management of Pacific salmonids (in Lake Michigan at least) is misrepresented by the authors, in this instance by omission. Dettmers et al. (2012) state that "…fishery management agencies have collaboratively developed an indicator-based decision model …" (p. 497) but fail to provide citations for this management approach or for the science underlying this approach (see, for example, Claramunt et al. 2008, 2009, 2012). They also fail to acknowledge the fact that the approach has been shared and adopted, in part or fully, across management jurisdictions and lakes; for example, this approach received recognition from the American Fisheries Society Fisheries Administrators Section as the Outstanding Sport Fish Restoration Project in 2005. It has been intensively reviewed and regularly revised to include new information and modeling approaches and takes into account both nonnative and native predator species. It involves significant cross-agency data consolidation and analysis, as well as intensive efforts to develop common ground among managers with sometimes competing goals and objectives. Dettmers et al. (2012) treatment of this aspect of Great Lakes management implies a narrow focus on Great Lakes Pacific salmonine fisheries with little thought given to broader ecosystem consequences; this is certainly not the case.

In concluding their article, Dettmers et al. (2012) present an oversimplification of options currently available to Great Lakes fisheries managers, a false dichotomy describing only two future options for management of these fisheries. The authors suggest that Great Lakes managers must "… manage for economic returns …" by balancing Pacific salmon fisheries with the uncertainties surrounding Alewife production or "… manage for rehabilitation of native fishes" (p. 499). This either–or approach ignores fundamental cross-lake differences in productivity, habitat, and fisheries demand and implies that our current approach to management is flawed. We propose that there is, at least, a third option that needs to be acknowledged and discussed. As described in detail in a chapter in the recently published book, *Great Lakes Fisheries Policy and Management: A Binational*

Perspective (Taylor et al. 2013; to which one of the Dettmers et al. coauthors contributed a related chapter), managers could strive to "… maintain a diverse salmonid community, [while proceeding] (to the extent possible) with native species rehabilitation …" (Claramunt et al. 2013, p. 641). Though the risks inherent in this approach include a potentially longer trajectory to native species recovery goals, the benefits include not only improved economic outlooks for Great Lakes communities and fisheries but also maintenance of greater public support for Great Lakes protection, a greater ecosystem efficiency, and sustained ecosystem integrity. Nonnative Pacific salmonines are currently significant components of the Great Lakes ecosystem whose naturalized populations are changing relative to environmental conditions and ecosystem disturbances and whose management cannot be so easily written off. Claramunt et al. (2013) present an intermediate approach to managing Great Lakes fisheries whereby a diverse salmonine community is maintained concurrent with native species rehabilitation and conclude that "… on each of the Great Lakes, managers are pursuing appropriate goals, managing the aquatic resources of the lakes for the greatest public good, given the variability in conditions and likelihood for success specific to each lake" (p. 642).

In conclusion, we feel that the Dettmers et al. (2012) article presents an incomplete and possibly misleading perspective on current Great Lakes fisheries management. Though they should not be the sole deciding factor, social circumstances need to be taken into account in management of natural resources (Krueger et al. 1995). As outlined in the Joint Strategic Plan (Great Lakes Fishery Commission 2007), the shared goal for fisheries management in the Great Lakes is "… to secure fish communities, based on foundations of stable self-sustaining stocks, supplemented by judicious plantings of hatchery-reared fish, and provide from these communities an optimum contribution of fish, fishing opportunities, and associated benefits to meet needs identified by society for wholesome food, recreation, cultural heritage, employment and income, and a healthy aquatic ecosystem" (p. 4). The additional management approach outlined in Claramunt et al. (2013) does recognize the importance of these social factors, while also acknowledging the benefits accruing from incorporating native species restoration goals in an overall management strategy in the face of continued threats to the Great Lakes. By considering goals and objectives of all stakeholders in management decisions, managers are more likely to garner support from stakeholders for innovative solutions to current and future threats to the Great Lakes.

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FEATURE

Considerations When Determining Appropriate Management Goals: A Reply to Claramunt and Clapp

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We read with interest the response by Claramunt and Clapp (2014) to our article about management of Alewife (*Alosa pseudoharengus*) using Pacific salmon in the Great Lakes (Dettmers et al. 2012). Both authors are respected research biologists working for the State of Michigan, with whom we work regularly in a productive and respectful relationship, as part of the fishery management process in the Great Lakes. We understand some of the perspectives they bring forward in their response. At the same time, their viewpoints reinforce several perspectives we articulated in our original article and reinforce the difficulties facing management agencies when seeking to understand current science, account for uncertainties in the future state of ecosystems, and interact with increasingly knowledgeable and opinionated stakeholders.

We agree with Claramunt and Clapp that Sea Lamprey (*Petromyzon marinus*) control is an expensive, ongoing proposition. Canada and the United States established the Great Lakes Fishery Commission through the Convention on Great Lakes Fisheries, a treaty signed by the two nations in 1954 and ratified in 1955. The convention required the commission "… to formulate and implement a comprehensive program for the purpose of eradicating or minimizing the Sea Lamprey populations in the Convention Area. …" (U.S. Department of State 1956). The commission's Sea Lamprey control program is recognized worldwide as perhaps the only instance of ongoing effective control of an invasive species, and the commission's success is consistent with the purpose set out for the commission by the two countries. The commission's ability to control Sea Lamprey populations successfully is the cornerstone of the rehabilitation of Great Lakes fishery resources and allows fishery managers to undertake effective fisheries management activities (Dettmers et al. 2012). Nevertheless, Sea Lamprey do prey on the valued fishes that society seeks to manage. Whether fishery managers are managing for Lake Trout (*Salvelinus namaycush*), Pacific salmonines (O*ncorhychus* spp.), Lake Whitefish (*Coregonus clupeaformis*), or Lake Sturgeon (*Acipenser fulvescens*), their existing activities would be much less successful, if at all, without ongoing sea lamprey control, regardless of its cost. We submit that all salmonine fisheries in the Great Lakes, with the exception of Lake Superior, where Lake Trout have been successfully restored, are expensively managed fish populations, with heavy reliance on Sea Lamprey control and stocking.

The assertion by Claramunt and Clapp (2014) that there "… is no evidence that native fish, such as coregonids and Lake Trout, are better suited …" (p. 124) to changing Great Lakes ecosystems, particularly of the upper Great Lakes, is most curious. That native Lake Trout and coregonids are uniquely suited to the Great Lakes was well summarized by Eshenroder and Burnham-Curtis (1999). Further, consider what has happened in Lake Huron since 2004, when Chinook Salmon (*Oncorhynchus tshawytscha*) collapsed after consuming available Alewife in a changing ecosystem. By 2009, the estimated abundance of age-1 and older Chinook Salmon was 80% lower than their estimated abundance just 5 years before and 98% lower than their peak abundance levels (Johnson and Gonder 2013). The changing Lake Huron ecosystem can be traced to the lowest trophic levels, with reduced spring chlorophyll blooms since 2003 (Barbiero et al. 2013). Furthermore, cladoceran zooplankton declined substantially since 2003, largely being replaced by diaptomid copepods. These large-bodied copepods are typical of oligotrophic systems. As a result of these changes, Alewife and Rainbow Smelt (*Osmerus mordax*) populations have declined since 2004 (Riley and Roseman 2013). In the wake of these changes, peaks in wild Lake Trout recruitment were observed across Lake Huron between 2001 and 2007 (He et al. 2012), Bloater (*Coregonus hoyi*) populations continued to increase (Riley and Roseman 2013), and Cisco (*Coregonus artedi*) remain stable or are increasing in the North Channel and Georgian Bay (Ebener 2013). Quite clearly, Lake Trout and coregonids are well suited to the Great Lakes, especially in the near absence of Alewife and with oligotrophic conditions. Native nonsalmonid fishes such as Walleye and Yellow Perch also have enjoyed tremendously improved recruitment since the Alewife decline in Lake Huron.

Similar lower trophic level changes are occurring in Lake Michigan. The Lake Michigan Committee noted in its state-of-the-lake report that Lake Michigan is less productive now than when its Fish Community Objectives were published in 1995, leading to concern that the biological integrity of the lake is threatened (Robillard et al. 2013). Furthermore, soluble silica concentrations in spring have increased in lakes Huron and Michigan, indicating reduced productivity (Evans et al. 2011).

* **Retired.**

With limited spring chlorophyll blooms that are being replaced by fall maxima and dominance of *Limnocalanus* copepods, lakes Superior, Huron, and Michigan are exhibiting a strong convergence of trophic state and their lower food webs (Barbiero et al. 2012). To us, this body of evidence speaks quite clearly to changing ecosystem conditions favoring native fishes such as coregonids and Lake Trout.

Within this background, Claramunt and Clapp (2014) contend that there should be a third management option in addition to the two we proposed (Dettmers et al. 2012), namely, that managers should strive to "… maintain a diverse salmonid community, while proceeding, to the extent possible, with native species rehabilitation efforts …" (Claramunt et al. 2013, p. 641). The argument put forward by Claramunt and Clapp (2014) is that this approach is appropriate because it can maintain existing management of nonnative salmonid populations while simultaneously seeking to rehabilitate native fishes. We believe that though this approach is emotionally appealing and even desirable to many natural resource management agencies and their stakeholders, it may not achieve either goal effectively. Witness the thinking of Stockwell et al. (2009), who, based on an evaluation of 36 years of data from Lake Superior and other literature in the Great Lakes, concluded that near elimination of Alewife was needed to see substantial improvement in recruitment of native fishes. Additionally, Stockwell et al. (2009) concluded that management agencies may be stuck in the "paradox of the Alewife," whereby Alewife are essential for the management goals associated with Pacific salmonines but detrimental to rehabilitation of native fishes. Unless fishery management agencies are willing to specifically tackle the paradox, one or both of these management goals are likely to fail (Stockwell et al. 2009). We appreciate well that taking the hard action to directly address this paradox is very difficult, even though it is essential to do so.

To provide some perspective, we relate a scenario encountered by the senior author during his graduate education. The Ohio Division of Wildlife was interested in stocking hybrids of Striped Bass (*Morone saxatilis*) and White Bass (*M. chrysops*) into more of its reservoirs as a biocontrol agent for Gizzard Shad (*Dorosoma cepedianum*) to enhance production of other sport fish, while simultaneously enhancing a popular sport fishery for this predator. Before embarking on this proposed strategy, the division undertook the research to determine whether both of these goals could be achieved. Research indicated that the productivity of Gizzard Shad in most reservoirs was simply too great for even abundant hybrid Striped Bass populations to consume enough age-0 Gizzard Shad to reduce those populations (Dettmers et al. 1998). Based on these results, the division rethought its goals and decided that it would stock hybrid Striped Bass for sportfishing purposes only, while also considering watershed modification to reduce potential Gizzard Shad production. Though disappointing to the division, it appreciated that its goals were not possible based on the existing science.

With respect to the management of Alewife and Chinook Salmon, we believe that fishery management agencies should carefully evaluate all of the available science. The body of evidence is strong that alewife populations preclude native fish rehabilitation (Madenjian et al. 2008; Stockwell et al. 2009; Dettmers et al. 2012). We think that the following two questions about Lake Trout rehabilitation posed by Stockwell et al. (2009) to management agencies are well worth serious reflection, as Great Lakes lake committees decide how to manage their fisheries:

- Are management efforts to rehabilitate Lake Trout, Ciscoes, and other native fishes … practical if management agencies are simultaneously attempting to balance Alewife productivity with Pacific salmon abundance?
- Do short-term benefits of artificial predator–prey systems override the potential for long-term system stability and function afforded by fish communities dominated by native species?

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Robert J. Behnke, Ph.D.
1929–2013

Robert J. Behnke passed away 13 September 2013. He left a legacy as a true scholar, aquatic conservation champion, gifted communicator to the angling community and public, and colleague, mentor, friend, and family man. He was a professor in the truest sense of its Latin roots: "to declare publicly." He professed the value of conserving biological legacies, that there is room only for good science, and the beauty of scientific reason.

Born in Stamford, Connecticut, on 30 December 1929, Behnke developed a keen interest in fishing and nature as a youth. He earned a bachelor's degree in zoology from the University of Connecticut with an honors distinction for a published paper on the freshwater fishes of Connecticut. He established his reputation as the authority on the systematics of Salmonidae through his graduate research at the University of California. His M.S. thesis (1960) concerned the trouts of the Great Basin, and he expanded his studies to the entire family Salmonidae for his Ph.D. dissertation (1965). He then spent 10 months as an American Academy of Science exchange scholar in the Soviet Union to continue his systematics work on salmonids. In 1966, he was an instructor of ichthyology at the University of California at Berkeley before becoming the assistant unit leader of the U.S. Fish and Wildlife Service Colorado Cooperative Fishery Research Unit and a faculty member of Colorado State University (CSU), where he attained the rank of full professor. He left federal service in 1975 but continued to teach courses at CSU on ichthyology, ecological zoogeography, and conservation biology until 1999. During his career he traveled extensively to study salmonids and other fishes in North America as well as distant lands including Iran, Japan, Mongolia, Siberia, and several European countries.

Behnke was passionate about conserving native trout and salmon and argued persuasively that one had to preserve lineages of descent in order to do so. His first project in this regard was initiated in 1966—to raise awareness and help prevent extinction of the Greenback Cutthroat Trout (*Oncorhynchus clarkii stomias*) by isolating stream segments with barriers, removing nonnative trout, and reintroducing endemic greenbacks within its native range. It was a landmark effort in conservation biology, arguably the first of its kind in the aquatic realm and well before the Endangered Species Act. His conservation biology course was the first on this topic on the CSU campus. He was a polymath, fluent in three languages, and interested in history, philosophy, music, and poetry, each of which influenced his scholarly thinking. Self-taught in Russian, he became for many years the American editor and final translator of the Russian publication *Journal of Ichthyology.* His breadth was evidenced in his reading of classics in their original language. For example, he had read the poems of Alexander Pushkin and could discuss not only these but the man himself.

Although he authored over 200 scientific articles, he will be forever remembered for his unique ability to engage both academic and lay audiences in three books: *Native Trout of Western North America* (1992), *Trout and Salmon of North America* (2002) and *About Trout: The Best of Robert J. Behnke from Trout Magazine* (2007). He was especially proud of his discourse with laypeople, whom he viewed as important and powerful colleagues in the conservation arena. He understood the power of language and wrote elegantly. Tom McGuane, the great American novelist, said it well, "Biodiversity … reflects a millennial horizon of evolutionary development … the uninformed public has not looked closely or acknowledged the complexities of creation. ….Behnke and Tomelleri have looked closely, and their appreciative readers will find themselves capable of better citizenship than their predecessors in seeing to the well-being of this birthright." In the foreword to *About Trout*, Ted Williams remarked that these essays for *Trout* magazine were "Lyrical and yet scientifically precise." Williams wished he had Robert Behnke for a professor; anyone who read his writings, in fact, was his student. These were his "public declarations," and his books and columns were the classroom. Behnke's profound impact was recognized across an uncommonly broad spectrum of audiences. This is reflected in many honors, including him being the first professional recipient of the Aldo Starker Leopold Wild Trout Award in 1984 presented at the Wild Trout Symposium and the William F. Ricker Resource Conservation Award from the American Fisheries Society in 2000.

Despite his stellar scientific credentials, he was totally unpretentious and modest, being equally approachable by anyone. He loved fish, fun, and family and recalled every memorable experience, as well as the location and content of every worthy piece of literature, in his eidetic memory. He could catch fish on the most unlikely gear and his fishing rod was a most important scientific tool. He enjoyed bluegrass and even played the gut bucket in a band with his grad students. He was an amazing storyteller on multiple subjects, and all in earshot were held in rapt attention not only by the often hilarious content of his accounts but also by the contradictory traits of a commanding appearance set off by an uncharacteristically high and nasal voice. He was also a devoted husband and father. He was married to Sally for nearly 50 years, and he also loved and enjoyed his daughter Cynthia, son Robert Jr., and their families.

History shows that Behnke was prescient. As a scientist, conservationist, and humanist his contributions resemble a blending of *The Origin of Species*, *Sand County Almanac*, and *Walden Pond* and taken together are profound. He professed to his students that understanding evolutionary change and radiation of form is the basis of the "owner's manual" for those who are given the responsibility of stewardship of our native fishes. His gift was the ability to communicate this well, and his legacy is a message that awaits to inspire generations of anglers and conservation biologists who will become advocates for these beautiful fishes.

Carl B. Schreck, Hiram W. Li,
Kurt D. Fausch, and Kevin R. Bestgen

George Gordon Fleener 1923–2013

A longtime member of AFS and the Missouri Chapter (MOAFS), George Gordon Fleener, 90, died on 15 November 2013 after a long, courageous battle with cancer.

He was a founding member of MOAFS and a member of the AFS for over 60 years.

Fleener was born 23 March 1923, in Berlin, North Dakota. He met his future wife, Rosezella, in Springfield, Missouri, and they were married in 1946. She predeceased him and he is survived by two sons, six grandchildren, five great-grandchildren, and one great-great-grandchild.

Fleener served in the Army during WWII. After serving as a certified x-ray technician, he was deployed overseas to eastern Germany where he was involved in active combat for 5 months until the war ended in 1945. When he returned to the states, he worked as an x-ray technician for 6 months and was discharged in 1946. He then completed both his under graduate (1949) and graduate degrees (1950) at Utah State University.

Fleener was hired by the Missouri Department of Conservation in June 1950 and spent 39 years as a fisheries research biologist, retiring in 1989.

He conducted many different stream research projects but was the most proud of, and known for, his recreational use studies. The techniques he developed for probability sampling to measure the wide variety of recreational uses of streams was a highly significant contribution to the field of fishery science. In several instances his data were directly responsible for protecting streams from destruction by channelization or impoundment. The methods he developed were so important that they were adopted and used by other agencies around the country.

He received numerous awards, including MOAFS Award of Excellence, which recognized him for his many accomplishments as well as is innate ability to communicate effectively with landowners, agencies, and the public in general.

He served the AFS and MOAFS in various capacities and always encouraged others to become involved in the AFS as our professional society. Fleener was a certified fisheries scientist and was elected to membership of the American Institute of Fishery Research Biologists. In addition, he was a member of the VFW, the Utah State Alumni Association, the Timberwolves Association (104th Infantry Division), and the Masonic Lodge and Scottish Rite.

Fleener was an avid canoeist and made over 500 floats on various Missouri streams. He described himself as a "plain old simple country boy," but he was way more than that, as his record shows.

Joe G. Dillard

Curt Kerns

Curt Kerns, president and chief science officer of Wetlands Pacific Corp., passed away suddenly on 13 August 2013 in Nanaimo, British Columbia.

Kerns held an M.S. in fisheries science, with a minor in aquatic ecology. He was a registered professional biologist in British Columbia and Alberta, a certified fisheries scientist, and a former tenured associate professor with the Marine Advisory Program, University of Alaska, Anchorage and Juneau campuses. Kerns had a varied background in the fisheries industry. While in Alaska, he took leave for one year to act as operations manager for the Prince William Sound Aquaculture Association. He left academic work to found, develop, and operate Waterfour Industries Ltd., a saltwater salmon net pen grow-out site in British Columbia. Next, he moved to manage an EWOS Pacific Research Farm.

In later years, he established an onsite wastewater treatment, design, and management company using wetland technology as the basis for dealing with a wastewater originating from many sources. He was a founding member and served on the board for the Western Canada Onsite Wastewater Management Association, British Columbia chapter (WCOWMA-BC). As an innovator, his design for a new class of constructed wetland, the Vegetative Tertiary Filter, holds three patents and won the 2010 BCWWA Award of Excellence, the MISTIC Award for Environmental Technology, and the BCWWA Golden Shovel.

Kerns passed away in the Nanaimo Regional General Hospital palliative care unit with his wife Sheila by his side. He was an exuberant, passionate spirit who will be missed. Kerns will be remembered as a passionate supporter and advocate for the environment. Donations in his memory may be made to the Palliative Care Unit at the Nanaimo General Hospital.

Sheila Colbert-Kerns

Daniel Lluch Belda, Ph.D. 1942–2014

Daniel Lluch Belda was born in Uruapan, Michoacan, Mexico, and died at age 72 in La Paz, Baja California Sur, on 2 January 2014. In 1963, as a college student, he began working for the Instituto Nacional de Investigaciones Biológico Pesqueras (now known as Instituto Nacional de la Pesca-INAPESCA), where he later became vice director. He received his B.Sc. and Ph.D. degrees in biology from the Instituto Politécnico Nacional (IPN), where he worked as an academic from 1973 until his passing. He boosted the development of two of the most important scientific research centers in the Mexican Northwest region: the Centro Interdisciplinario de Ciencias Marinas-IPN (1978–1983) and the Centro de Investigaciones Biológicas del Noroeste (1984–1997). During a career lasting over 40 years, his scientific contributions helped to establish the foundation of contemporary fisheries oceanography and reshaped fisheries management in Mexico.

Daniel Lluch Belda was a versatile biologist. In the late 1960s he became one of the first marine mammalogists of Mexico. In the early 1970s, the Food and Agriculture Organization of the United Nations granted him a scholarship to study in the School of Fisheries of the University of Washington in Seattle. After his return, he concentrated on the assessment and management of the Mexican shrimp fishery, which comprised the core of his doctoral dissertation. By the late 1980s, he chaired the pioneer international working group on the "regime problem," for studying the covariation between large-scale sea surface temperature patterns and worldwide fluctuations of sardine and anchovy populations. He devoted his last years to investigating the ultimate origin of these environmental changes and the underlying mechanisms by which they relate to fish resources in the California Current system. Hopefully, his students will contribute further to this work.

In addition to his outstanding scientific trajectory, Daniel Lluch Belda was also a successful administrator and academic. In a period of 30 years, he was the CEO of three major scientific institutions in Mexico (INAPESCA, CICIMAR, and CIBNOR) and improved each one of them in such way that some considered him a sort of "King Midas." In the international arena, he actively negotiated in the United Nations to extend the Mexican Exclusive Economic Zone and recently led the certification process of the Baja Red Rock Lobster and Gulf of California Sardine fisheries. During this same period, countless B.Sc., M.Sc., and Ph.D. students were seduced by his overwhelming wisdom and natural charm, especially after attending his lectures on evolution, marine ecology, and fisheries management. The luckiest ones, myself among them, became part of his closest working team.

Daniel Lluch Belda had three requited loves in his life: his family and friends, his motherland, and his career. A pale reflection of his heritage is constituted by a school of thought regarding the management of natural renewable resources, an army of followers, more than 100 scientific publications, 40 postgraduate students who were under his guidance, and dozens of national and international prizes and recognitions.

Among the most significant recognitions to his professional labor are part of the 2007 Nobel Peace Prize (divided between the Intergovernmental Panel of Climate Change and Albert Arnold Gore Jr.), a scientific-life achievement award granted by the Mexican Fisheries Society and the Mexican Chapter of the American Fisheries Society, and at least six medals of honor bestowed by the National Secretary of Education, IPN, the Universidad Marista and the State of Baja California Sur for his life achievements in scientific research, professorship and public service.

He is survived by his beloved wife, four children, and six grandchildren, of whom he always was a devoted admirer. Undoubtedly, marine research in Mexico has lost one of its most valuable members. The entire fisheries science community will miss him dearly.

Pablo del Monte-Luna

Jacqueline F. Savino, Ph.D.
1955–2013

Jacqueline Frost Savino, known as Jaci to her friends and colleagues, was born and raised on a farm in the town of Olean in upstate New York. The eldest of the five Frost siblings, she learned early how to milk cows, ride ponies, and contribute to farm maintenance. During her early years exploring nearby streams and ponds, Savino was quite taken by nature and ecology. She did well in school and secured the title of Valedictorian for the 1973 graduating class at Portville High School. She earned her undergraduate degree in biology at Cornell University in 1977. During her sophomore year there, she met the man she would marry, Thomas Savino. Wed in August 1977, shortly after graduation, Jaci Savino and Tom made their way to Florida State University to continue their education. After a brief stay, they relocated to Columbus, Ohio, to complete their graduate studies at The Ohio State University. Tom joined the Ph.D. program in chemistry and Savino became Roy Stein's first Ph.D. student. She excelled in class work, research, and leadership, guiding undergraduates and junior graduate students through the complexities of the research process.

As a graduate student, she conducted stellar work in the arena of predator–prey interactions. She is most fondly remembered sitting at the top of a 15-foot step ladder, coding (with a behavioral recorder) the activities of Largemouth Bass and their Bluegill prey in large, outdoor pools with different densities of simulated vegetation. At that time, the community of inland fishery scientists working in the predator–prey realm intuitively knew that vegetation influenced behavioral interactions and rates of predation. Savino appreciated this perspective but sought to quantify and understand those interactions. Setting up an experimental protocol with simulated vegetation in outdoor pools allowed her to quantify predator–prey behaviors and thus test explicit hypotheses as part of her M.S. work. Published soon after earning her degree (Savino and Stein 1982, *Transactions of the American Fisheries Society* 111:255), her first paper became a citation classic (cited >460 times) because it quantified behavioral mechanisms underlying Largemouth Bass–Bluegill interactions across a range of vegetation densities, thereby providing insight into appropriate macrophyte densities to stabilize this interaction. Quickly moving through the program (M.S., 1981; Ph.D., 1985), she continued to conduct simply excellent work as recognized by her scientific peers.

Finding jobs for two Ph.D.s in the same location was a challenge, particularly in the 1980s, but Savino succeeded in landing an internship at the U.S. Fish and Wildlife Service lab in Ann Arbor, Michigan. Tom was employed as a chemist in Southfield, Michigan, and together they made a home in Novi. Even though USFWS was in a hiring slump, Savino's internship was soon converted to a permanent position, testament to her skills as a fledgling fishery biologist. This lab, now the USGS Great Lakes Science Center (GLSC), served as her professional home for her entire career. Here, Savino's expertise in behavioral ecology proved crucial to the research direction of the lab and to quantifying impacts of aquatic invasive species on Great Lakes biota. In 1989, she and Tom welcomed twins Cory and Justin into their lives. The family was happy, successful, and looking forward to a bright future.

Tragically, in 1992, at age 36, Savino was diagnosed with an incurable cancer, chronic lymphocytic leukemia. She immediately commenced chemotherapy, which allowed her to enjoy periods of good health, but she required repeated treatments. Throughout her fight with cancer, with Tom by her side, she maintained her dignity and grace, navigating her professional and personal life with strength, courage, and joy.

At the GLSC, Savino served as a fishery research biologist, initiating and conducting research on food web interactions, particularly with invasive species. More recently, she was involved in a large collaborative effort to investigate larval fish and invertebrate communities of nearshore areas of Lake Erie. Recognizing her scientific leadership and outstanding skills as a research manager, Savino was promoted in 1993 to leader of the Community Dynamics Section at the GLSC; she then became chief of the Ecosystem Dynamics Branch in 1996. As such, she oversaw research on a wide variety of topics including food web interactions, population genetics, and fish population dynamics. In 2002, Savino became chief of the Western Basin Branch, overseeing assessments of the status and trends of forage fish populations of the western Great Lakes (lakes Superior, Michigan, and Huron), evaluations of restoration efforts on native fishes such as Lake Trout and Lake Herring, and research on the ecology of invasive species. In 2008, she became deputy director of the Great Lakes Science Center, with her primary duties being personnel management, budget oversight, and science leadership at the center. Savino was instrumental in restoring the Deepwater Program at the center to meet the partner needs in managing salmonine fisheries in the Great Lakes. In addition to her center responsibilities, she served the AFS as president of the Michigan Chapter, chair of the Symposium Committee for the 1996 Annual Meeting, and chair of the Publications Overview Committee. Under her leadership, the Publications Overview Committee developed a strategic plan to guide the transition to a new model for AFS publications; in 2003, she received the Distinguished Service Award for her outstanding contributions to AFS. In spite of her health, Savino worked tirelessly for the benefit of the center and AFS, freely giving of her expertise, time, and insight.

Her scholarship and scientific accomplishments have contributed greatly to the understanding of Great Lakes ecosystems, but she will be equally remembered for the way she inspired others with her quiet, compassionate leadership and consummate professionalism. These qualities were evident early in her career, when as a Ph.D. student, Savino served as a mentor to younger students, as a leader in weekly lab meetings, and, quite importantly, as an inspirational role model for professional women in a male-dominated discipline. Her unassailable scientific standards led her to often argue for the best approach to a scientific problem, regardless of difficulty. In addition to fostering scientific excellence, she promoted dedication to the job at hand, with enjoyment an ongoing side benefit, as only an inspirational leader can. She was always ready with a smile, happy and contented to be doing the work she loved.

By 2010, her cancer had become more chemo-resistant and she decided to undergo a bone marrow transplant (BMT). Just prior to the BMT in August 2012, Tom Savino retired to be there for his wife. Following the procedure, Savino was upbeat, positive, and happy; she refused to succumb to the harsh reality of her disease, continuing to live her life fully. Sadly, graft-versus-host disease caused her hospitalization in December 2012, and its complications led to her passing away peacefully, with her husband of 35 years, Tom, at her side, on her 58th birthday, 26 April 2013. It is with sadness and a profound sense of loss that we mourn the passing of a selfless scientist who inspired good science, exemplified strong leadership, and exhibited courage, kindness, and compassion in her personal life and her professional career.

Jaci Savino lives on. She lives on through her husband, Tom, and their two sons and all those she touched in her personal life; she lives on through her science, her published papers, her model behavior as a science administrator, and all those that she touched in her scientific life. All who knew her took away what it means to be strong and joyful in the face of adversity, uncertainty, and, for want of a better phrase, the unfairness of cancer at an early age. Her courage and commitment to her family and her profession, even after her dire diagnosis, is to be admired and venerated. To say that she enriched the lives of those with whom she worked would be an understatement. She truly lives within us.

Mary C. Fabrizio and Roy A. Stein

David W. Willis, Ph.D. 1955–2014

David Wayne Willis, 58, of Brookings, South Dakota, passed away 13 January 2014, in Sioux Falls, South Dakota.

Willis was born 7 March 1955, in Ames, Iowa, to the late Dr. Wayne O. and Sally R. Willis. He is survived by his wife of 32 years, Susan, and his children and grandchildren.

At the time of his passing, Willis was a Distinguished Professor and head of the Department of Natural Resource Management at South Dakota State University in Brookings. He received his undergraduate degrees (B.S., M.S.) from the University of North Dakota and earned a Ph.D. in fishery biology from Colorado State University. Over the course of his postgraduate career, he worked at Pittsburg State University, the Kansas Fish and Game Commission, and Emporia State University, before beginning his long tenure on the faculty at SDSU that spanned 1987–2014.

Willis was well known as a scientist and educator. He stated that one of his greatest accomplishments was “the working relationships that I developed with students at all levels,” serving as thesis adviser for more than 50 graduate (M.S. and Ph.D.) students. He received numerous research and teaching awards from the American Fisheries Society and SDSU, among others, yet more important to him were the more than 90 awards received by his students.

Willis was an extraordinary scientist, teacher, and colleague, as well as a dedicated member of AFS. He coauthored and edited several AFS books; served on at least 41 committees; was president of the North Central Division, Fisheries Management Section, and Kansas Chapter; and served as an associate editor of the *North American Journal of Fisheries Management*. His many AFS honors include the President’s Fishery Conservation Award, Meritorious Service Award, Excellence in Fisheries Education Award, Excellence in Public Outreach Award, and induction into the Fisheries Management Hall of Excellence.

At SDSU, Willis secured grants in excess of $7 million to further the understanding of fisheries biology, education, conservation, and natural resource management. His scientific publications numbered more than 250 and included seminal papers and widely read textbooks on fisheries biology.

To know him was to understand that he was happiest with a fishing pole, a pond, and his family. He truly exemplified “do what you love, and love what you do,” all with a humble, kind, and ever-inquisitive nature. In addition to his family, Willis leaves behind valued friends and colleagues nationwide.

Memorial donations may be made to the David W. Willis Memorial Fund by visiting www.sdstatefoundation.org or SDSU Foundation, Lohr Building, 815 Medary Ave., Box 525, Brookings, SD 57007; 605-697-7475.

January has come and gone and spring is almost here, but the unnecessary deaths of Klumb and Spindler take us back:

- 7 January 1980—Three Duke field scientists died while conducting field work on a North Carolina reservoir.
- 17 January 1980—Two USFWS biologists died in a small plane crash returning home from a coastal Oregon aerial field survey.
- 30 November 2004—An assistant professor at Sheldon Jackson College, Alaska, died in a boating accident while responding to an EMS call.
- 17 September 2013—An Oregon Department of Fish and Wildlife biologist drowned while surveying the Umpqua River.
- 8 July 2013—A drunk driver kills Robert Klumb and Maegan Spindler while they were preparing for the next day of work, after having just completed a 12-hour day out in the field.

These are only nine of our colleagues who died while practicing our line of work. In their memory and with the hope of preventing future such incidents, the Society would like to establish January as AFS Safety Month. To do so, we are seeking the names and affiliations of other colleagues who died or were seriously injured while practicing our profession, as well as what could have been done to reduce the probability of such accidents. In other words, we want to honor them and prevent future accidents.

We are seeking the above information from each AFS Chapter.

Please send any information to news@afsmembers.org.

Thank you.

Bob Hughes, AFS President

Killed in the Line of Work

Robert Klumb, 46—the lead research biologist for the Great Plains Fish and Wildlife Conservation Office—and Maegan Spindler, 25—a fellow Fish and Wildlife researcher—had just returned from dinner with colleagues after a 12-hour day performing fieldwork along the Missouri River, in Pickstown, South Dakota, and were preparing their gear for the next day's research, when a drunk driver of a minivan blew a stop sign and killed them both. "In a boat, researching in the field, we prepare for life-threatening complications," said Dane Shuman, a fish and wildlife biologist who found his friends' bodies. "But you don't expect something like this in a motel parking lot."

Robert (Rob) A. Klumb, Ph.D.
1967–2013

Robert Klumb was an exceptional colleague and friend. A Wisconsin native, Klumb received his B.S. from the University of Wisconsin–Milwaukee in 1990. He attended the University of Wisconsin–Stevens Point where he evaluated fish growth models using oxytetracycline as a marker for age validation, receiving his M.S. degree in 1997. After leaving Steven's Point, Klumb spent several months working for the Idaho Department of Fish and Game, surveying native fishes in mountain lakes. He joined the Department of Natural Resources at Cornell University in 1997 where he studied bioenergetics and nearshore habitat use by larval and juvenile Alewife at the Cornell Biological Field Station, earning his Ph.D. in 2003. His work helped establish the importance of nearshore habitats to Alewife dynamics in Lake Ontario and continues to influence assessments there. His strong quantitative skills earned him an invitation to work cooperatively with American, Canadian, and Japanese scientists to evaluate the role of Pacific herring and Saury in the North Pacific Ocean ecosystem. In 2002, Klumb joined the U.S. Fish and Wildlife Service in Pierre, South Dakota, as a fisheries research biologist and was promoted to project leader of the Great Plains Fish and Wildlife Conservation Office in 2009.

Klumb was a talented biologist who led a variety of research projects on the federally endangered Pallid Sturgeon. He was also at the forefront of developing methods for assessing Asian carps in the Missouri River system, one of the largest river systems in North America. He authored or coauthored over 30 peer-reviewed publications—many of these focused on native or imperiled fishes. His dedication to fisheries conservation earned him a seat on many committees and workgroups where he led the charge for change.

In addition to his federal job duties, Klumb also served as an adjunct associate professor at South Dakota State University, where he played a fundamental role in coordinating federal research needs with graduate student education. He served as a mentor for over a dozen graduate students at both the master's and Ph.D. level. Colorful, energetic, and always positive, he was inspirational to students and colleagues. He always took the time to avail himself to other people to help them in their professional and personal endeavors.

Klumb approached all of his responsibilities with a keen eye for detail. His appreciation of the historical context of his work allowed him to learn from the past and make true advancements with his own work. He embraced the often frustrating realities of empirical science and contributed to advancements in assessment methodology as well as understanding the ecology of the species and systems he worked with. As a mentor, he led by example, and his hands-on approach to his work and his teaching efforts earned him a large and loyal group of colleagues. His legacy will live on in the example he set for students and future professionals.

Klumb's insatiable desire for and eclectic taste in music was well known among his friends. His extensive music collection represented a broad range of styles and artists from Roy Acuff to Warren Zevon and Frank Zappa and just about everything in between. Klumb had an affinity for singer-songwriters, including James McMurtry, Johnny Cash, Neil Young, Bob Dylan, Kristin Hersh, and Vic Chesnutt. He attended numerous live music concerts and frequented several music stores where he would often buy multiple copies of albums that he liked and give them to his friends. A night with him was often a tutorial in the musical output of obscure and underappreciated artists, and everyone who interacted extensively with him came away with a larger collection of music than they started with.

Klumb's passion for science, politics, and Milwaukee-made beer ran deep and wide. His inclusiveness and open-mindedness extended to both his work and his social life, and he will be remembered for the enthusiasm he exhibited in his approach to both. His knack for working across state, federal, and academic boundaries influenced a generation of young biologists. From the technicians who worked under his guidance to the students he mentored to the colleagues he left behind, he will truly be missed and his loss leaves a big void in the fisheries community. To honor his contributions to fisheries science, The Robert A. Klumb Memorial Award was established in memory of Robert Klumb, a life member of the Dakota Chapter of the American Fisheries Society (AFS). The award recognizes outstanding graduate student contributions in the areas of riverine fishes research, native species management, and/or the conservation of threatened and endangered fishes. Donations can be made to: Dakota AFS—Klumb Fund, USGS South Dakota Coop Unit, NPBL 2140B, South Dakota State University, Brookings SD 57007.

Steve Chipps, Randy Jackson, Mike Bozek, Ed Roseman, and Lars Rudstam

Maegan E. Spindler 1988–2013

Maegan Spindler was an outstanding young scientist and friend who grew up mostly in upstate New York and also lived for a time in Arizona. Her early love for plant and animal life led her to pursue and complete a degree in wildlife science from SUNY-ESF in 2010. Following completion of her B.S., her adventurous spirit took her to Vancouver Island University in British Columbia, Canada, to add a fisheries diploma in 2011, and the experience further developed her passion for native fishes. Her spirit and passion helped land her a job with the Wyoming Game and Fish Department in Pinedale, where the open landscapes of the arid West continued to shape her career goal: being a fisheries biologist. In the spring of 2013, Spindler accepted a position with the USFWS in Pierre to work on endangered Missouri River fishes and prepare for graduate school to study native fishes and the habitats that sustain them.

Spindler's passion for wildlife extended beyond the realms of fisheries biology; she enjoyed hiking, backpacking, camping, and traveling. She was also an avid fly angler and successfully completed Wyoming's Cutt Slam, by catching each of the subspecies of Cutthroat Trout in their native water. Her passion for native salmonids, and Cutthroat Trout in particular, was evident in the way she embraced her job duties or talked about her career aspirations.

When she was not out exploring the wild landscapes and the natural world's wonders, she was an accomplished artist. She enjoyed fly tying, print making, painting, and photography and had recently begun learning the banjo. Maegan loved to cook and kept impressive vegetable gardens in both Wyoming and South Dakota, two talents that often impressed guests.

Spindler was a talented young biologist whose work ethic and enthusiasm were unsurpassed—and she will be greatly missed by all those who knew her. Her family was proud of her career pursuit to become a fisheries biologist and she will be remembered as a great friend who would drop everything for people in need and was always up for doing something fun. We hope that her adventurous spirit will inspire future young fish biologists to pursue their passions. Spindlers's family has asked that donations in memory of her be made to the Center for Biological Diversity in Tucson, Arizona.

Gregg Spindler, Dane Shuman, Luke Schultz and Mike Bozek

Global Inland Fisheries Conference: Theme 1—Biological Assessment

The global conference "Freshwater, Fish, and the Future: A Cross-Sectoral Conference to Sustain Livelihoods, Food Security, and Aquatic Ecosystems" convening in Rome in January 2015 includes four main themes. The **Biological Assessment** theme will explore and develop new approaches to assess the production and status of inland fish stocks and their fisheries. The **Economic and Social Assessment** theme will explore and develop new approaches to provide monetary and nonmonetary value to fisheries, including importance to human health, personal well-being, and societal prosperity. The **Drivers and Synergies** theme will identify synergies between the services that can be made to increase societal gain while maintaining ecological integrity and allowing for the protection of aquatic biodiversity and fisheries production. Finally, the **Policy and Governance** theme will develop methods to assure that governance decisions take into account the contribution inland fisheries make to food security, human well-being, and ecosystem productivity. Each theme will conclude with a **Future of Fisheries** discussion forecasting various scenarios, along with recommendations for achieving the conference vision of a sustainable fisheries future.

The Biological Assessment theme panel chair is Rose Emma Mamaa Entsua-Mensah of the Council for Scientific and Industrial Research in Ghana. Ian Cowx of the University of Hull (UK) and Steve Cooke of Carleton University (Ottawa)

An angler in Kerala, India. Photo credit: Antony Grossy.

are acting as panel facilitators. Below, Cooke describes some of the questions that this theme will address.

THEME 1: BIOLOGICAL ASSESSMENT

Biological assessment is a fundamental component of contemporary science-based fisheries management. Or is it? In the developed world, routine biological assessment is taken for granted. However, it is still imperfect. Consider the massive number of lakes in Minnesota or northern Ontario relative to the limited resources available to devote to fisheries assessment and monitoring. In the developing world, there are inherent challenges with assessment, including lack of capacity, resources, and relevant natural history information (e.g., undescribed species). Fishery-dependent data can be difficult to generate because many freshwater fisheries are unregulated with no formal licensing schemes. Moreover, in small-scale fisheries many of the harvested fisheries products move rapidly into black market trading and bartering, which is difficult to quantify.

To inform fisheries management, we need to develop and validate a variety of biological assessment tools that are flexible and robust. For example, is there potential to develop remote-sensing based approaches for estimating fisheries productivity? Given that habitat is the foundation for healthy and productive fisheries, it may also be informative to develop proxies for productivity based on environmental metrics. And what are the best ways to track fisheries harvest in the recreational, commercial, and subsistence sectors? Is there a role for household surveys or fisher log books? And do the same techniques that work in rivers work in lakes?

These superficially simple questions plague fishery biologists and resource managers on a daily basis around the globe. There is dire need for creative discourse related to developing better tools for biological assessment of the diverse inland aquatic systems and fisheries that exist around the globe. Through a lively panel discussion, contributed papers, and breakout groups, the state of biological assessment in inland waters will be explored. The focus will be on developing solutions that are scalable and effective.

CALL FOR PAPERS—ABSTRACT SUBMITTAL NOW OPEN

Abstract submission is now open for the Global Inland Fisheries Conference. Please see the guidelines and instructions at www.inlandfisheries.org. All abstracts are due by 10 August 2014. Some travel support for young professionals and presenters from developing countries may be available; see the website for more information and updates.

Keep up with all of the conference news on Facebook, (www.facebook.com/inlandfisheries), LinkedIn (www.linkedin.com/groups/Global-Inland-Fisheries-Conference-7402542), and Twitter (@inlandfisheries).

From the Archives

I do not think it is wise to begin the discussion of papers on black bass until more members are present, and I do not like to appear on the floor too often, but as a little tribute to the scientists of the commission I want to read a little squib which I see comes from the *London Chronicle*:

THE LOBSTER HATCHERY.

Nature grim, in remorseless mood,
Undoes the work that she has done,
And out of every lobster brood
Slays ninety-nine and keeps but one.
Art stretches o'er the horrid scene
Her skillful and remedial sway—

And when I speak of "Art" I mean
The Fish Commission, U.S.A.
It takes the tender lobsterlet,
And gives him food and kind advice,
Changes his boots if they are wet,
Brushes his hair and makes him nice.

And lo, this baby of the sea
In gratitude begins to thrive;
Where one per cent it used to be,
Fifty, all fat, remain alive.
O noble work, heroic, grand,
That saves in scientific ways
Those little lisping lobsters, and
Keeps them for me and mayonnaise.

J.W. Titcomb (1902): Transactions of the American Fisheries Society, 31:1, 34.

DE LA RECHERCHE À LA GESTION DES PÊCHES:
PENSER ET AGIR LOCALEMENT ET GLOBALEMENT

FROM FISHERIES RESEARCH TO MANAGEMENT:
THINK AND ACT LOCALLY AND GLOBALLY

QUÉBEC 2014

144e RÉUNION ANNUELLE, 17 au 21 AOÛT 2014
144th ANNUAL MEETING, AUGUST 17-21 2014

AMERICAN FISHERIES SOCIETY

Meeting Update: Exploring Québec City

Immerse yourself in the unmatched charm of Québec, the only fortified city in North America, renowned for its dynamism, gastronomy, romanticism, and history. You'll find 400 years of history and a thousand and one things to experience. Marvel at the mighty Saint Lawrence, explore our rich history and heritage, day-trip on a theme tour, or enjoy your favorite sports and recreational activities—it's all here!

FOLLOW IN THE FOOTSTEPS OF THE COLONY'S FIRST SETTLERS!

Explore the Fortifications of Québec, which span close to 4.6 kilometers around Old Québec. Then wander over to Artillery Park, where characters in period costumes will welcome you to buildings dating back to the 17th and 18th centuries. Take in the history of a site where decisions that affected all of North America were made at Saint-Louis Forts and Châteaux, an archaeological crypt that was recently discovered beneath the Dufferin Terrace. Then round off your trip by learning about Jacques Cartier's first winter in Québec City in 1535 and hearing about the history of the Jesuits at Cartier-Brébeuf Park.

FINE DINING

One of the best reasons to visit the city is its food! Old Québec alone has over 100 restaurants, with a string of four-star dining experiences and some of the country's top chefs. Treat your tastebuds to fine French cuisine in 18th century surroundings, local specialties at our famous hotels and inns, market-fresh produce at our sidewalk cafés and European-style bistros, homestyle cooking and local beer at our pubs and microbreweries, and innovative global fare all around.

AGROTOURISM AND THE OLD PORT

Take the Gourmet Trail to sample delicious homespun flavors in authentic rural and urban settings. Maple groves, vineyards, cider mills, cheesemakers, chocolate stores, veal producers, and other artisans await. The colorful Old Port Market is bursting with all the goodness and flavor of local produce.

NIGHTLIFE

Get ready for Québec City's hopping club scene! Discos, pubs, and hip bars await on the ever-popular Grande Allée, along Rue Saint-Jean, and in the Nouvo Saint-Roch district. Chances are you'll want to while away the evening over a drink on one of the region's lovely sidewalk patios, before taking in a fabulous outdoor show at the Old Port or on the Plains of Abraham.

AN OUTDOOR PARADISE AT YOUR DOORSTEP

Recreation, relaxation, and excitement all beckon just kilometers from town. From Portneuf and Jacques-Cartier area to the Côte-de-Beaupré region and beautiful Île d'Orléans, have fun in our sensational outdoor playground.

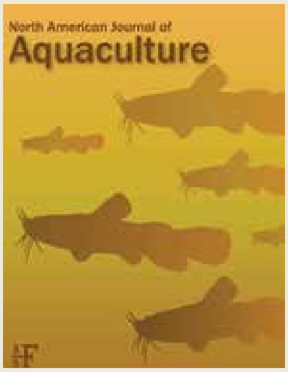
NATIVE TOURISM

Come meet a First Nations people, proud of their origin and witnesses to the history that shaped our country. The Huron-Wendat nation, which allied with the French in the time of New France, shares its culture and traditions with modern-day visitors at Musée Huron-Wendat, the traditional Huron site, the Interpretation Centre of Parc de la Falaise et de la chute Kabir Kouba, the Wendat flower gardens, and its craft stores.

Questions regarding AFS 2014 meeting and Québec City, please contact info.afs2014@gmail.com or visit www.afs2014.org and www.facebook.com/afs2014

JOURNAL HIGHLIGHTS

North American Journal of Aquaculture
Volume 76, Number 1, January 2014



CONSTITUTIONAL AMENDMENTS FOR MEMBERSHIP APPROVAL

Members of AFS were invited to vote on five proposed amendments to the AFS Constitution. Voting closed on 20 December 2013. The AFS Vote Auditor has reported that the results of the constitutional amendment vote are in good order and the vote was conducted in a proper manner. All five amendments were approved. The proposed amendments to the AFS Constitution, which were previously approved by the Governing Board, include:

- Updating the Constitution to reflect our recent journal (Marine and Coastal Fisheries)
- Addressing needs for membership on the board that certifies fisheries professionals
- Completing some much-needed updates to several AFS committees

More detailed information is also posted on the AFS website at http://fisheries.org/membership-vote.

Continued from page 99

many parents choose to have children because of tax exemptions or cash payments. However, nearly 4 million births per year in the United States (CDCP 2013) and a $3,900 tax exemption per child (for 2013) would equate to $15.6 million for newborns alone, assuming that those parents have sufficient taxable income. Regarding families lacking sufficient income, the United States spent over $16 billion per year (2006–2013) in Temporary Assistance for Needy Families, typically families with one unemployed parent and one or two children (Falk 2013). If subsidies to parents are deemed warranted for having children, why not tax credits or payments for childlessness or a limit of one exemption? Such policies would recognize an overpopulated world and nation as well as persons who elect childlessness or a single child for ecological, sociological, or ethical reasons.

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Continued from page 102

proceedings summarize primary models while addressing the uncertainty that accompanies models of all designs and affects their application in fisheries management (Townsend et al. 2008; Link et al. 2010). Together, these reports and the third NEMoW workshop in 2014 help to explain why NOAA/Fisheries, most of the eight regional fishery management councils, and their state partners have embarked on this regional ecosystem-based approach.

The models and applications discussed in those publications are examples and should not be interpreted as a monopoly. Indeed, the U.S. Fish and Wildlife Service, U.S. Geological Survey, and their inland fisheries partners have been very active in modeling habitat suitability and ecosystem services. Generally, NOAA may lean toward process models, whereas Department of the Interior uses statistical and geospatial analysis to select from models and applications. The Food and Agriculture Organization of the United Nations (2008) and others provide solid summaries of efforts across agencies and nations. Together, those efforts help to identify key data gaps including trophic ecology, spatially explicit data, implications for nontarget species, habitat connections of harvested or protected species, and socioeconomic data. Those variables promise to become more important as we invest more deeply in ecosystem-based approaches. Though there are options for dealing with uncertainty or credibility, the key is to apply model results carefully. That is absolutely essential when using models to delve into ecosystem-based approaches that carry their own uncertainty.

By its very nature, ecosystem modeling is a complex field, with doubt from all angles and across all model types and applications. In most models, a major challenge will be to extend beyond population attributes to include ecological factors such as habitat and food webs. The social sciences are another important complication. With solid data, and full awareness of our gaps, we should be able to estimate system-level biological reference points such as fishery production potential to establish sustainable harvest levels. In NOAA Fisheries, those needs and goals began to intersect in the mid-2000s, leading to the very first gathering of agency population dynamics experts and habitat experts in 2010 at the first ever joint National Habitat Assessment Workshop and National Stock Assessment Workshop (Blackhart 2010). The fish habitat and fish folks gathered for a second time in 2012 (Clarke 2013), that time moving beyond basic habitat–ecosystem–management connections to a more inclusive dialog about a shared path forward, including models.

We have shown the courage to impose serious rebuilding plans designed to bring back depleted stocks, imperiled fishermen, and struggling coastal communities, but our efforts must push beyond our best thinking of recent decades. We must be cautious about early models and approaches because some past fishery management proved not to be sustainable. New applications will bring new challenges for wider use of ecosystem models, but those hurdles are not insurmountable. Indeed, most of the newer models include a broader range of ecosystem facets than those earlier population-focused efforts.

To meet our needs, new models must account for social sciences and environmental factors. Improved ecosystem models will enable us to explore tradeoffs across species and fisheries and hopefully help to elucidate cumulative effects and unanticipated consequences associated with habitat dependence, gear impacts, bycatch, climate change, and other important factors.

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From the Archives

The culture of trout is also an American specialty.

In respect to the salmo fontinalis, or common brook trout, it is necessarily so, because this variety of trout is found in no other country. In Europe, however, there is the "salmo fario," or common trout, the salmo ferox, or bull trout, the salmo trutta, or lake trout, besides the char and grayling, which are closely allied to these; and there is nothing to prvent Europeans from cultivating these fish as Americans cultivate the salmo fontinalis, or American brook trout. But, in point of fact, this is not done. There is one trout-raising establishment in England, one in Wales, two or three in Ireland and Scotland, and these comprise all, in Great Britain, at least. Nowhere, except in America have the people entered, as they have here, with a universal accord and general interest, into the work of breeding and raising trout.

It seems to suit the American genius. There are, besides the excitement and novelty of it, a magnitude in the scale of operations, and a largeness of results, as well as an absorbing interest in the detail of it, that seems to commend it particularly to the American mind.

Livingston Stone (1872): Trout Culture, Transactions of the American Fisheries Society, 1:1, 46-56.

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
March 3–5, 2014	AFS Minnesota Chapter Meeting	Mankato, MN	mnafs.org
March 4–6, 2014	AFS Illinois Chapter Meeting	Bloomington, IL	illinoisamericanfisheriessociety.weebly.com/2014-annual-meeting.html
March 10–14, 2014	North American Wildlife and Natural Resources Conference	Denver, CO	wildlifemanagementinstitute.org
March 27–31, 2014	Japanese Society of Fisheries Science	Hakodate, Hokkaido, Japan	
April 7–12, 2014	AFS The Western Division Meeting's 2nd International Mangroves as Fish Habitat Symposium	Mazatlan, Mexico	fishconserve.org/email_messages/Mangrove_Symposium.html
May 19–23, 2014	AFS AFS Piscicide Class	Logan, UT	fisheriessociety.org/rotenone/Piscicide Classes.htm or sjohnston@fisheries.org
June 7–11, 2014	World Aquaculture Adelaide 2014	Adelaide, South Australia	www.was.org
June 24–27, 2014	Iberian Congress of Ichthyology	Lisbon, Portugal	sibic.org/jornadas/2014/inicio_en.html
July 7–10, 2014	Fisheries Society of the British Isles Meeting & Call for Papers-Integrated Perspectives on Fish Stock Enhancement	Hull, England	fsbi.org.uk
July 30–August 3, 2014	American Society of Ichthyologists and Herpetologists Annual Conference	Chattanooga, TN	asih.org/meetings
August 3–7, 2014	International Congress on the Biology of Fish	Edinburgh, United Kingdom	icbf2014.sls.hw.ac.uk
August 16–20, 2014	AFS AFS Annual Meeting 2014	Québec City, Canada	afs2014.org
August 16–20, 2014	AFS 38th Annual Larval Fish Conference (AFS Early Life History Section)	Québec City, Canada	larvalfishcon.org
August 31–September 4, 2014	AFS AFS-FHS – International Symposium on Aquatic Animal Health (ISAAH)	Portland, OR	afs-fhs.org/meetings/meetings.php
January 26–30, 2015	Global Inland Fisheries Conference	Rome, Italy	inlandfisheries.org
February 19–22, 2015	Aquaculture America 2015	New Orleans, LA	
May 26–30, 2015	World Aquaculture 2015	Jeju Island, Korea	
August 16–20, 2015	AFS AFS Annual Meeting	Portland, OR	
February 22–26, 2016	AFS Aquaculture 2016	Las Vegas, NV	
February 19–22, 2017	Aquaculture America 2017	San Antonio, TX	

NEW AFS MEMBERS

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Pushing the Limits: Using VIE to Identify Small Fish

Most tags just don't fit in small-bodied and early life stages of fish, but we still need to identify them, preferably without biasing our data. The options are further limited when many batches or individual identification is required. Visible Implant Elastomer™ (VIE) is internally injected but remains externally visible, and because the size of a tag is controlled by the tagger, it is easily adapted to very small fish. Colors and tag locations can be combined to create a coding scheme.

VIE has been used to tag newly settled coral reef fishes from 8—10 mm [1,2] with high tag visibility and little mortality. Marking success was influenced by tag depth, anatomical location of the tag, pigmentation of the skin, and investigator's experience with the technique. Long-bodied fish like eels and lamprey as small as 1 g are easily tagged with VIE[3, 4].

Very small salmonids are being identified with VIE. Trout ≤26 mm can be tagged at the base of the fins and have been recovered during stream surveys up to 83 days later[5]. This technique also worked well with Atlantic Salmon ≤30 mm, and has been used for monitoring in-stream movements through snorkel surveys[6]. The minimum size for tagging juvenile salmonids has been pushed down to 22 mm FL, and it is possible to tag alevins in the yolk sac[7], and fry in the fins[8].

VIE is well-suited for tagging juveniles of many other species and is used world wide. Please contact us if we can help with your project.

Photos: A syringe is used to inject VIE into the fin of a juvenile salmonid (top). VIE is available in 10 colors (left), of which six fluoresce under a VI Light for improved visibility and tag detection (center). Tagging rainbow trout fry as small as 22 mm is possible with VIE (below). Leblanc & Noakes[7] used this to identify fish originating from larger eggs (top) or smaller eggs (bottom).

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