



In this Issue: Fisheries in Gullah/Geechee Land Hard-Part Microchemistry Unlocks Fish Secrets Opportunistic Platforms for Telemetry Projects



Fisheries Techniques, 3rd Edition

Alexander V. Zale, Donna L. Parrish, and Trent M. Sutton, editors



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AFS Communications for the Ages

COLUMN President's Commentary

Donna Parrish, AFS President

Currently there is a debate among some AFS members pertaining to the topic of Society communications. Some members are proponents of AFS emphasizing the use of social media, but others are not. Some want informal content that profiles AFS members, but some want to limit content on members to highlighting their contributions to AFS and the profession. Based on these dichotomies, there is no mystery what drives much of the divide—age! Most of us more established fisheries biologists (i.e., the elderly) prefer to adhere to the media and style of communications that have been hallmarks during our careers. On the other hand, our younger members advocate for more social media and less structure of content that is broadcast under the AFS banner.

If we proceed in a typical process of making change in an organization of differing views on such topics, we will drift toward incorporating some of the newer media components and yet keep some of the long-ago-established aspects that have been the standards of professional societies. The divide will continue because the Society will not move fast enough for our younger members, but we will move too fast for older members.

The divide will continue because the Society will not move fast enough for our younger members, but we will move too fast for older members.

So, this month's bullets offer a few thoughts on effective AFS communications.

First, we all think that we have the answers on what and how AFS should communicate to its members and beyond. How is it that those answers are not the same? Well, we all have different perceptions and often those do not resemble reality. We have personal biases and we gain support for our ideas by listening to those who support our views. We can overstate conclusions, based on some inaccurate mental counting of how many have expressed opinions that agree with our own. One solution to this dilemma is to design and conduct a survey that asks the questions that will provide the answers needed. Oh, if it were only that simple! Even with the best designed survey, obtaining a high response rate may be the biggest hurdle in trying to distinguish perception and reality. Perhaps low response rates to surveys are because surveys represent "noise" to potential respondents, which leads to the next point.

AFS communications should be informative. Of course, what is information to one AFS member is noise to another. Most members do not have time to read magazines, blogs, or e-mails that do not interest them. What is the type of content that will attract attention and provide real information?



AFS President Donna Parrish can be contacted at: dparrish@uvm.edu

One measure of successful communication is whether a recipient learns something new and valuable. Possibly the worst result is reading something that in the end is considered a waste of time.

- Written content on any AFS medium should impress the reader that AFS is an organization of educated professionals. Magazines and other media are often written at a sixth-grade level to appeal to the majority of people. As a professional society we should keep our standards high on providing well-written content. Even for content aimed beyond AFS members, promoting the use of slang terms and substandard language will make AFS appear very unprofessional.
- In general, the content on AFS media needs to follow the guidelines of promoting science-based information. This is a president's commentary, which provides a different format from writing policy statements, for example. We need to be clear in what content is opinion rather than substantiated by peer-reviewed literature. Other organizations may choose persuasive prose to gain support for their positions. Some outlets can make unfounded statements as a strategy to draw attention to a problem. However, AFS cannot use those strategies and claim to be fisheries experts and professionals. AFS can be most effective in addressing fisheries issues by providing the science-based information that activists groups cannot. We should be very proud that we have the privilege of serving that role.

COLUMN Policy



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When Is Sublethal Deadly?

Thomas E. Bigford, AFS Policy Director

Much of our work touches on actions that affect individual fish or entire populations. As a science student, then a resource manager, and now a policy guy (a role that integrates science and management), I have often wondered about the ramifications of emphasizing body counts while minimizing other,

less quantifiable yet important impacts. In this column I challenge us to think more fully about how we factor adverse and beneficial effects of our actions into decisions, especially those sublethal effects that are often difficult to identify.

On this topic, I owe my curiosity to graduate school. I was a master's student of Stan Cobb's at the University of Rhode Island working on crab larval behavior after exposure to fuel oil distillates. I also held a part-time position at the U.S. Environmental Protection Agency's (EPA) Narragansett Laboratory, which sponsored my research as part of its focus on water quality. While most of Stan Cobb's students were investigating questions related to animal behavior and ecology, the EPA scientists were focused on lethal concentration 50 (LC50) and other measures of mortality. A few of the graduate students bridged the divide by adding behavioral questions to our experimental designs.

Fast forward 35 years. I wonder if we in the aquatic sciences/management/policy fields have progressed as much as is needed. I have contemplated that question often as I have observed fishery science and management decisions since graduate school. These worries popped to mind again as I read the May 2014 issue of ECO Magazine, a nice assembly of Environmental, Coastal, and Offshore material published by TSC (see www.eco-tsc.com/). A primary theme in that issue is underwater noise, which is known to have lethal and sublethal effects on fishes, marine mammals, and sea turtles. I was heartened to read about a balanced emphasis on lethal, physiological, and behavioral impacts based on sound intensity, distance, and animals affected. No single sample indicates progress but that observation was encouraging. Do we approach all issues with such breadth? Or, as I suspect based on my own career, is research on sublethal impacts progressing better than our efforts to apply knowledge in resource management decisions? For example, even when science reveals much about the effects of habitat gain or loss on shallow-water species, do fishery managers consider those variables when evaluating population health and setting harvest limits?

That difficult question extends beyond this column. And studying sublethal impacts of underwater sound on baleen whales in the open ocean is not the same as observing oiled crab larvae in a laboratory. But factoring sublethal impacts into population-level decisions seems too important to miss. I sense that our efforts to understand population trends fall short of our needs, in part because we often miss a key variable or two in the overall life history of valued species.

In fishery management, I have applauded work to consider sources of mortality other than those from fishing. That progression, more important for some species than others, was too slow for my patience. With habitat loss affecting many species it always seemed narrow to focus on fishing mortality. Too often, it took severe dips in population health followed by gut-wrenching debate and drastic harvest cuts before the conversation expanded to include all mortality sources. The expanded analysis is an easy leap where hydroelectric turbines kill most fish moving up- or downstream, for example, but what about nearshore species whose habitat is the shrinking band of aquatic vegetation? That ecological connection may be tenuous but still important.

I have often wondered how different our harvest debates would be if we in the fish world worked with others to exert greater control over nonharvest mortality, thereby enlarging the harvestable population to be shared by recreational and commercial interests, and then converted that success into larger allocations per sector. Without arguing about percentage shares per port, gear type, trip, or season each sector, everyone would emerge a winner from battles we've been waging for years.

You may wonder why I drifted from sublethal impacts to harvest shares. Those sublethal effects, often related more to habitat quality than quantity, can eventually have lethal consequences. Imagine a school of river herring migrating up Chesapeake Bay to the Susquehanna River, encountering an oxygen blockage prompted by a late summer algal bloom, a turbidity bloom triggered by unusual rainfall in the Pennsylvania agriculture belt, endocrine disrupters washing from feed lots, water flow obstacles at river's first blockage at Conowingo Dam, or a particularly noisy reach near a shore-side sand and gravel mining operation (all real obstacles in the first 5 miles above the river mouth). Any one of those events could convince a school of herring to change course, perhaps even to reverse direction. Although not lethal, the effects could be similar and the ramifications to fisheries managers could be significant. If the fish don't reach spawning waters, or their overall fitness is compromised by stops and starts, the population could be affected and harvests could dip.

Opportunistic Acoustic Telemetry Platforms: Benefits of Collaboration in the Gulf of Maine

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ABSTRACT: *Biologists monitor animal behavior, habitat use,* and survival through local telemetry projects. Migratory species cross these lines, connecting projects. Biologists can further these connections by expanding the area monitored, but this step is expensive. We evaluated three opportunistic platforms: (1) oceanographic buoys, (2) commercial fishing gear, and (3) drifters to test the feasibility of expanding coverage while minimizing costs. All Gulf of Maine platforms provided novel data, generating over 15,000 detections from animals released by 18 organizations. Performance was strong for buoys and commercial gear but low recovery hampered drifter utility, although advances in real-time drifter communication should improve future efficacy. Opportunistic platforms proved to be a low-cost method that can benefit researchers across aquatic systems. Animals from other studies connected us with researchers, fostered dialogue, and highlighted information gains from data sharing. Working with fishers and oceanographers also strengthens interdisciplinary and stakeholder communication and can increase overall public understanding and support.

INTRODUCTION

Telemetry is an established method used to track the movements, habitat use, and survival of animals using static receiver networks or active tracking in lakes, rivers, estuaries, and marine environments (Voegeli et al. 2001). For aquatic systems, two static telemetry study designs are common; gates (or curtains) monitor movement of tagged animals between lines of receivers (Kocik et al. 2009; O'Dor et al. 2009) and grids monitor movements within a designated habitat and often triangulate individual locations (Heupel et al. 2006; McDougall et al. 2013). These studies are usually initiated to monitor migration dynamics, survival, habitat use, and ecology of tagged animals. Initially, telemetry studies of marine or diadromous species fo-

Plataformas de oportunidad de telemetría acústica: beneficios de colaboración del Golfo de Maine

RESUMEN: los biólogos monitorean el comportamiento, uso de hábitat y supervivencia de los animales a través de proyectos locales de telemetría. Las especies migratorias traspasan estos límites y, por consecuencia, representan una oportunidad para conectar los proyectos. Los biólogos pueden llevar aún más allá estos proyectos, expandiendo las áreas monitoreadas, sin embargo dar este paso resulta costoso. En este trabajo, se evalúan tres plataformas de oportunidad: (1) boyas oceanográficas, (2) equipos de pesca comercial y (3) cuerpos de deriva para probar la viabilidad de expandir la cobertura de los proyectos, al mismo tiempo que se minimizan los costos. Todas estas las plataformas en el Golfo de Maine proveen datos nuevos, generando más de 15,000 detecciones de animales liberados por 18 organizaciones. El desempeño fue bueno en el caso de las boyas y del equipo de pesca comercial, pero los cuerpos de deriva redujeron las utilidades debido a su lenta recuperación; no obstante, los avances alcanzados en la comunicación en tiempo real con estos artefactos debieran mejorar su efectividad en el futuro. Las plataformas de oportunidad probaron ser un método de bajo costo que puede beneficiar a los investigadores que trabajan en distintos sistemas acuáticos. Los animales estudiados en otros trabajos, permitieron conectar a los investigadores entre sí, lo que propicia el diálogo y pone en relieve la ganancia de información e intercambio de datos. El trabajo conjunto entre pescadores y oceanógrafos fortalece la interdisciplinariedad y la comunicación con los interesados y, asimismo, puede incrementar el entendimiento y el soporte del público en general.

cused on the nearshore environment, but many study species are highly migratory and expanding the range of studies became necessary. Similar challenges for broad-scale monitoring occur in large and multijurisdictional freshwater systems such as the Great Lakes and Missouri–Mississippi River systems (Tripp et al. 2013). Linking these long-distance movement patterns to broader environmental conditions is a contemporary challenge for animal telemetry networks (Moustahfid et al. 2011). Though our case study is marine focused, any observing network could apply opportunistic techniques to expand geographically.

National ocean policy calls for strengthening the overall capacity to observe our oceans and Great Lakes (Malone and Cole 2000; Sullivan 2012). Physical and chemical data (e.g.,

temperature, currents, wind speeds, turbidity, color) are collected by sensors placed on platforms ranging from satellites to simple buoys. These data are used to generate weather and ocean forecasts, generate early tsunami warnings, monitor harmful algal blooms, etc. Key platforms for sensors include moored buoys, drogues, and remotely operated vehicles (Gazit et al. 2013). Concurrent to this monitoring, increasing numbers of aquatic animals are being studied using acoustic tags (transmitters) that can be detected in specialized receiver networks. The addition of acoustic receivers to fixed and mobile ocean data collection platforms provides a unique opportunity to merge animal movements and habitat use to environmental monitoring data streams (e.g., Manning et al. 2009; Moustahfid et al. 2011; Gazit et al. 2013). From an individual researcher perspective, these platforms can offer a cost-effective way to increase receiver coverage. By combining animal tracking with ocean observing platforms, scientists can now describe environmental conditions and habitat use of animals as never before (Oliver et al. 2013). Additionally, partners as varied as tugboat operators, dock owners, navigation authorities, or commercial fishers provide novel platform options not only in oceans but also in freshwater systems. There might not be gains in environmental data but new partnerships can form.

We explore the concept of opportunistic platforms through a case study of our experiences in the Gulf of Maine. In the region, acoustic telemetry studies began with Atlantic Salmon (Salmo salar) smolts and were limited to smaller rivers, estuaries, and bays (Lacroix and McCurdy 1996; Kocik et al. 2009). With expanding management needs, the focus shifted to investigate a larger ecosystem, Penobscot Bay. Simultaneously, needs expanded to evaluate multiple species of diadromous and coastal fish: Shortnose Sturgeon (Acipenser brevirostrum), Atlantic Sturgeon (A. oxyrhynchus), Striped Bass (Morone saxatilis), and Haddock (Melanogrammus aeglefinus; Fernandes et al. 2010; Zydlewski et al. 2011). Exploration and development of offshore wind and tidal power also increased the urgency to better understand habitat use of both exploited and protected species further offshore (Ritchie and Ellis 2010; Atlantic States Marine Fisheries Commission 2012).

Much has been accomplished through traditional acoustic arrays (Kocik et al. 2009; Fernandes et al. 2010), but expanding networks into deeper and offshore waters was needed yet resource intensive. We explored the integration of study networks with existing platforms to broaden coverage at minimal costs. There is a long history of using ships as opportunistic research platforms, back to at least 1726 when Benjamin Franklin studied the Gulf Stream while on trans-Atlantic crossings (De Vorsey 1976). We expand this concept to telemetry-focused platforms of opportunity (PlatOpus). PlatOpus assets act as an extension to traditional networks, providing information that can be used to strengthen and supplement research. We tested three platform types for their utility: (1) ocean observing buoys, (2) a fixed gear fishery, and (3) surface drifters. We chose these platforms due to initiatives to add biotelemetry assets to ocean observing (O'Dor et al. 2009; Moustahfid et al. 2011) and proven methods of collecting scientific data from a fixed-gear

fishery (Manning and Pelletier 2009). We believed that these platforms could provide effective offshore monitoring at minimal cost.

The goal of our case study was to compare and contrast different platforms to determine strengths and weaknesses of approaches, evaluate gear condition/persistence, and examine utility of these supplemental data streams. Specific objectives were to (1) use extant infrastructure to augment current telemetry projects, (2) maximize resources and minimize costs, and (3) foster collaborations with ocean scientists and fishers.

METHODS

University of Maine Ocean Observing System Buoys

The partnership between Northeast Fisheries Science Center biologists and the University of Maine Physical Oceanography Group began with deployment of acoustic receivers (model VR-2, Amirix VEMCO Ltd., Bedford, Nova Scotia, Canada) on oceanographic buoys starting in 2005 (Figure 1). Telemetry monitoring has been continuous since that time. Additionally, two short-term University of Maine Ocean Observing System (UMOOS) monitoring stations were part of this platform. Station E02 had two receivers placed at 6 m and 85 m depth at a proposed wind energy test site (June 2010 to August 2011) and a seasonal station at Linekin Bay began in June 2012 (Figure 1).

Prior to deployment, we performed laboratory tests to ensure that receivers and other electronics on buoys did not give or receive interference. We also developed custom hardware to attach receivers to anchor lines to maintain detection range and ensure effective retrieval. We attached receivers with the hydrophone oriented downward, 6–10 m below the surface from 2005 to 2011. Fisheries technicians prepared and tested the receivers following National Oceanic and Atmospheric Administration protocols prior to buoy attachment. Receivers were deployed and retrieved by oceanographers once or twice a year during routine buoy maintenance. When oceanographers retrieved a buoy, they redeployed new units. During 2012 buoy tending, all UMOOS-based receivers were repositioned to 50 m depth to simplify deployment and further improve detection effectiveness as noted through analysis of multidepth data at site E02.

Telemetry Monitoring on Lobster Traps

In 2010, we started the Telemetry Monitoring on Lobster Traps (tMOLT) project modeled after Manning and Pelletier's (2009) innovative environmental monitoring on lobster traps (e.g., eMOLT). We prepared receivers and distributed them to cooperating lobstermen who used their own commercial gear as deployment platforms. Lobstermen attached the receivers inside the trap using cable ties. The trap was deployed and location, date, and time of deployment were recorded by the lobsterman. If the trap was relocated during the season, they noted the date, time, and new location. Nine receivers were deployed in 2010



Figure 1. Locations of UMOOS buoys and tMOLT receivers. Permanent UMOOS buoys (labeled with letters A–N) are indicated by green circles and open stars represent short-term UMOOS buoys (E02, wind energy test site and LB, Linekin Bay); diamonds indicate tMOLT receiver location (black 2010, red 2011, open 2012). The inset represents the area between Casco Bay and Isle au Haut (courtesy of T. Trinko Lake).

between the Isle of Shoals and Cranberry Isles (Figure 1); eight receivers were deployed in 2011 and four in 2012. Most receivers were concentrated outside the headlands of Penobscot Bay or Merrymeeting Bay. Lobstermen retrieving their gear prior to winter returned receivers to our team and those that fished yearround swapped out receivers annually.

Drifters

In 2010 and 2011, we partnered with the Gulf of Maine Lobster Foundation and Southern Maine Community College to integrate acoustic receivers into drifter bodies (Figure 2). The Davis-style surface drifter is a drogue designed to monitor surface currents and is typically deployed in June and July (Manning et al. 2009). We deployed drifters in May to capture surface current data during the primary migration period of Atlantic Salmon smolts (Kocik et al. 2009).

The Davis-style surface drifter design (www.nefsc.noaa. gov/drifter) has four submerged fins that provide a surface to

catch the current so that no matter what angle the drifter faces, it will be driven by the current. Lobster floats are attached on the distal ends of the top spars to keep the drifter at the surface and are counterbalanced by lead ballast weights. To integrate acoustic receivers into the design, we replaced the lead ballast weight with a receiver that had been tested and prepared by our team (Figure 2). Each drifter was outfitted with a satellite transmitter (Comtech Mobile Datacom Corporation, Germantown, MD) placed on top of the primary mast and programmed to transmit location hourly. Location data were accessed at the Comtech website in real time and stored on their website. To aide recovery of stranded or intercepted receivers, each drifter had stickers affixed with contact information and instructions.

We deployed seven (2010) and six (2011) telemetry drifters at locations designed to target drifter paths toward potential salmon migration corridors. Deployment partners included a U.S. Fish and Wildlife Service Petite Manan National Wildlife Refuge boat (8 m) and a U.S. Coast Guard cutter (33 m). In 2010, four drifters were released in Penobscot Bay and three



Figure 2. (Left) Davis-style surface drifter about to be deployed by USCG Cutter *Jefferson Island* (Official U.S. Coast Guard photo). (Right) Attachment of a VR2 receiver on a drifter where the receiver acts as ballast in place of the normal weights. The metal bar alongside the receiver is normally used to attach it to an anchor line, but in this case it is used as protection for the hydrophone should the drifter wash ashore.

were released near Pleasant Bay. In 2011, all six drifters were deployed near Penobscot Bay. Drifters were recovered if they ran aground, became entangled in stationary gear, or were picked up by mariners. When circumstances allowed, drifters were redeployed. Receivers were usually recovered by commercial fishers and returned to our labs.

Data Processing, Management, and Distribution

We downloaded data from all UMOOS Buoy, tMOLT, and drifter platforms using VEMCO software. Data quality control and assurance were identical for each platform and most transmitters (87%) were detected more than once. We considered single detections at a station valid if corroborated by ancillary information (e.g., detections at neighboring sites or past track history). For transmitters that we had released, all detections were cross-referenced and entered in our database. If unassigned transmitters were noted, raw data files were sent to VEMCO for reconciling with researchers that released other transmitters. VEMCO then notified the researchers that we detected their transmitters. If researchers contacted us, we exchanged our detection and location data with their basic information such as the species tagged and entered information in our database. If a transmitter remained unassigned, we searched two databases: the Atlantic Cooperative Telemetry Network (www.theactnetwork.com/) and the Ocean Tracking Network (www.oceantrackingnetwork.org/). If no resolution was possible, these transmitters were designated as unassigned.

Once ownership was assigned, we imported and entered all data in a Microsoft Access relational database with four core tables: location, deployment, detections, and primary investigator. Transmitter codes are a primary key that link these tables and our format follows standard Ocean Tracking Network design and nomenclature.

RESULTS

All three platforms detected a total of 265 unique transmitters (258 individual fish, 7 unassigned) and 15,185 individual detections from 11 fish species (Table 1). Our target species, Atlantic Salmon, Atlantic Sturgeon, and Shortnose Sturgeon, were detected in 7, 5, and 1 year of the 8 years of study, respectively. Striped Bass, also common, were detected in 6 years. Fish release locations ranged from North Carolina northward to Nova Scotia (Figure 3). Annual transmitter detections ranged from a high of 99 in 2012 to a low of one in 2007 (Table 1). An overview of average annual receiver effort (2010-2011) illustrates the continuous monitoring of UMOOS buoys (365 days), seasonal nature of tMOLT (155 days), and shorter duration of drifters (45 days) in our study (Table 2). In 2010 to 2011 trials, the percentage of total annual detections by platform was highest for UMOOS buoys (51%), followed by tMOLT (45%) and drifters (4%). However, relative to effort measured in days per detection, tMOLT (3.3-3.5) was about twice as likely to detect transmitters as were UMOOS buoys (5.9-7.4) or drifters (6.1-7.7; Table 2).

Table 1. Individual transmitters and number of detections (in parentheses) by species on all PlatOpus platforms. Because individual transmitters were detected on multiple receivers or in multiple years, the total of 287 exceeds the overall total of 265.

Species	2005	2006	2007	2008	2009	2010	2011	2012
Alewife (Alosa pseudoharengus)	0	0	0	0	2 (4)	0	0	0
American Eel (Anguilla rostrata)	0	0	0	0	0	0	0	1 (21)
Atlantic Cod (Gadus morhua)	0	0	0	0	0	1 (9)	0	8 (1,512)
Atlantic Salmon (Salmo salar)	10 (9,761)	10 (58)	0	5 (63)	10 (16)	10 (37)	24 (372)	51 (995)
Atlantic Sturgeon (Acipenser oxyrinchus)	0	0	0	2 (17)	3 (11)	29 (424)	19 (232)	24 (530)
Bluefin Tuna (Thunnus thynnus)	0	0	0	0	0	0	0	1 (29)
Shortnose Sturgeon (Acipenser brevirostrum)	0	0	0	0	0	2 (22)	0	0
Spiny Dogfish (Squalus acanthius)	0	0	0	0	4 (8)	13 (210)	17 (302)	3 (201)
Striped Bass (Morone saxatilis)	0	1 (2)	1(3)	4 (25)	0	9 (175)	6 (22)	5 (61)
White shark (Carcharodon carcharias)	0	0	0	0	0	0	0	4 (44)
Winter Flounder (Pseudopleuronectes americanus)	0	0	0	0	1(2)	0	0	0
Unknown	0	0	0	0	1(1)	3 (10)	1 (1)	2 (5)
Subtotal	10 (9,761)	11 (60)	1(3)	11 (105)	21 (42)	67 (887)	67 (929)	99 (3, 398)



Figure 3. Location of research institutions that released fish detected in the Gulf of Maine (note: Stanford University location references general tagging site and Massachusetts Division of Marine Fisheries represents Gloucester and New Bedford Labs) with inset table summarizing assigned or unassigned (unknown) detections across platforms (courtesy of T. Trinko Lake).

Table 2. Relative effort and effectiveness of three platforms evaluated in the Gulf of Maine, indicating the number of stations, days deployed, overall effort, and success.

Platform		2010	2011	
UMOOS	Number of stations	9	9	
	Total detections	445	559	
	Total deployment days	365	365	
	Total effort (days)	3,285	3,285	
	Days per detection	7.4	5.9	
tMOLT	Number of stations	9	8	
	Total detections	417	358	
	Total deployment days	162	148	
	Total effort (days)	1,455	1,184	
	Days per detection	3.5	3.3	
Drifter	Number deployed	7	6	
	Total detections	25	9	
	Total deployment days	43	46	
	Total effort (days)	303	276	
	Days per detection	6.1	7.7	

UMOOS Buoys

From 2005 to 2012, receivers on UMOOS buoys recorded 14,101 detections from 214 transmitters belonging to research projects from 17 different organizations (Figure 3). We detected 11 species with release locations ranging from North Carolina to Nova Scotia and five unassigned transmitters on UMOOS buoys (Table 1). Species detected included Alewife (Alosa pseudoharengus), American Eel (Anguilla rostrata), Atlantic Cod (Gadus morhua), Atlantic Salmon, Atlantic and Shortnose Sturgeon, Bluefin Tuna (Thunnus thynnus), Spiny Dogfish (Squalus acanthius), Striped Bass, White Shark (Carcharodon carcharias), and Winter Flounder (Pseudopleuronectes americanus). Data from three UMOOS-based receivers were lost due to physical damage incurred in 2005 and 2006. The cause of the damage is unknown but may have been a vessel strike or damage caused during retrieval. Mounting adjustments have eliminated damage since 2007.

tMOLT

We recovered data from eight of nine receivers in 2010, seven of eight receivers in 2011, and all four receivers in 2012. To date, the tMOLT receivers have detected 75 individual transmitters belonging to 12 organizations, with a total of 1,050 detections (Figure 3). Five species (Atlantic Salmon, Atlantic Sturgeon, Spiny Dogfish, Striped Bass, and white shark) and one unassigned transmitter were detected on tMOLT. Some individuals were detected on multiple tMOLT stations: 10 transmitters were detected on two stations, three transmitters were detected on three stations, and one transmitter was detected on four stations. Because lobster gear is more dynamic and sometimes includes active movement of gear to track the resource, station movement ranged from negligible to 8,748 m with a median of 242 m. In 2011, a receiver failed due to mechanical problems.

Drifters

Drifter recovery rates varied from four of seven in 2010 to two of six in 2011. In 2010, we detected four tagged animals: two Atlantic Salmon, one Atlantic Sturgeon, and one Spiny Dogfish. Additionally, one unassigned transmitter was detected on three drifters. In 2011, drifters encountered one Striped Bass (Figure 4). The drifters took divergent paths and total distance traveled varied from 24 to 11,316 km (average 1,829 km; median 878 km) for units with complete tracking history (Figure 4).

Data Management and Distribution

Seven transmitters (2.6%) remain unassigned despite efforts to connect with researchers. The great majority of transmitters (97.4% or 258 out of 265) were assigned to their respective organizations after VEMCO notified them that our project detected their study animals or we assigned them to organizations after querying Atlantic Coastal Telemetry Network databases. We shared the detection data and receiver locations with the researchers who originally tagged the animals. All of our detection data will be archived on the web portal at www. oceantrackingnetwork.org.

DISCUSSION

Our case study indicated PlatOpus data were comparable to standard telemetry networks and provided valuable information. We detected our primary study animals at similar encounter rates to single receivers in nearby traditional arrays (Kocik et al. 2009; Fernandes et al. 2010; Zydlewski et al. 2011). As our network expanded in time and space, detections of additional individuals and species from other researchers increased. Experiences gained in our case study can be used in other marine areas, lakes, and rivers to enhance capacity and partnerships.

Utility and Potential of Platforms Evaluated

Though the potential of combining oceanography assets with monitoring of animals has been proposed (Moustahfid et al. 2011; Gazit et al. 2013), this case study demonstrates 8 years of operational success by continuous monitoring for acoustic transmitters on all UMOOS buoys. Detections of over 214 animals of 11 species from 17 research organizations demonstrated broad benefits. Deploying and maintaining large ocean buoys is costly, but adding independent telemetry equipment represents a minimal investment (receivers and specialized mounts). With hundreds of oceanographic buoys monitoring ocean conditions on the U.S. coastline and Great Lakes, further integration can significantly enhance fisheries research (Moustahfid et al. 2011).

The tMOLT results were productive, with animals detected at all but one location. Additionally, gear loss and receiver movement were minimal. Kocik et al. (2009) also used lobster trap moorings to secure receivers and found that they detected study animals effectively. The existing capacity of lobster traps was demonstrated by cooperative monitoring at 70 sites from



Figure 4. Drifter tracks (top panel 2010 and bottom panel 2011) with Penobscot and Pleasant Bay release areas indicated by arrows. Tracks that did not encounter animals are shaded grey to black in both panels. In the top panel, green, red, and blue paths detected 4 animals (circles) in 2010 (inset shows details for abbreviated tracks). In the bottom panel, the green drifter track detected one animal (circle) on two separate occasions in 2011 (maps courtesy of T. Trinko Lake).

Canada to Massachusetts that quantified seasonal temperature cycles, interannual temperature and tidal variability, and turnover rates (Manning and Pelletier 2009). Almost any fixed-gear fishery could be used to form a receiver network to monitor specific oceanographic features or fisheries. Such efforts can increase environmental education and stakeholder engagement.

Because of the risks, we evaluated the drifter platform using older receivers and limited trials. Recovery rates were the lowest of our three platforms but our 46% recovery rate was similar to other studies involving drifters (Manning et al. 2009). The risk of losing gear belies their usefulness; drifters detected two smolts in the open ocean and one was later recorded at an array near Halifax, Nova Scotia (Figure 4), providing novel information in open waters. Drifters are used to model localized currents and have provided data for oil spill cleanup, search and rescue missions, harmful algae blooms, and larval animal dispersal (Manning et al. 2009). Collecting ancillary fish observations in the course of these studies can provide useful ecological information. Manning et al. (2009) provide a glimpse of drifter potential through insights gained by releases of nearly 1,000 drifters. Drifter utility could be enhanced if receiver data were integrated into satellite data streaming. Costs would increase but would be balanced with real-time data collection. Efforts to develop low-cost robotic drifters would better balance costs for these platforms and provide real-time data over large seascapes (Jaffee and Schurgers 2006).

Use of PlatOpus Observations

Though the detection range is small and PlatOpus assets are broadly spaced, detections were valuable indicators of habitat use in areas with extensive ocean data or operational fisheries. Furthermore, detections have indicated the presence of animals that have traveled beyond their home arrays-sometimes unexpectedly. Collectively, PlatOpus detections have provided valuable information concerning anadromous fish ecology. For instance, Atlantic Sturgeon wintering areas in the Gulf of Maine are currently unknown (Atlantic Sturgeon Status Review Team 2007). However, detections of Atlantic Sturgeon on UMOOS buoys and tMOLT indicate winter use of a relatively well-defined area off the coast between the Penobscot and Kennebec rivers. Detections of four individuals between September and December 2010 were spatially consistent with detections of the same individuals (plus two more) in January and February 2011 detected on a UMOOS buoy. Though the short period of detection suggests that this is not an aggregation area but a migratory corridor, these data provide researchers and managers valuable information toward identifying coastal habitats that should be monitored more closely. Linking these detections with simultaneous oceanographic data can provide physical data useful in designating important habitat.

Detections of fish outside a local study area can also be beneficial. Mather et al. (2010) discovered novel subadult Striped Bass movements through PlatOpus detections. Though most movements are generally southerly, these Striped Bass moved northward from a Massachusetts estuary. Additional observations of Striped Bass in our data sets should help other researches better understand coastal movement dynamics in the Gulf of Maine. Additionally, observations of Atlantic Salmon smolts allowed calculation of swimming speeds in open ocean waters that assisted in parameterizing models to understand salmon movements at sea (Byron et al. 2014). These models have expanded our knowledge of probable migration routes beyond the range of PlatOpus data. Data collected in our case study are also being added to databases being used for publications for marine fish and more comprehensive analyses are forthcoming from other research partners.

Looking Ahead: Opportunity and Challenge

All three PlatOpus produced useful data and each have strong expansion potential. Equally important, they have fostered cooperation with new research partners, agencies, and stakeholders, leading to new projects and collaborations. These test projects reduced deployment costs, expanded our receiver coverage, and enhanced our understanding of habitat and occurrence of other species. Other platforms common in rivers, lakes, and estuaries could prove similarly successful. Attributes of a successful PlatOpus asset are communicative partners that provide known locations and safe platforms with high recovery rates. However, new platforms do create operational challenges as expanded networks detect animals from outside local studies. Challenges include increased data processing loads, research communication needs, and data sharing questions. We overcame these challenges and believe that our case study represents only a few potential platforms and partners.

Opportunities for partnership abound across two general categories of research partners: scientists and stakeholders. Collaborations with both groups benefited our research with broader spatial and temporal coverage. Each group brought unique collaborative prospects. Given increased use of our rivers, lakes, and oceans, the amount and variety of potential platforms is increasing, as is the need to understand fish habitat use and ecology.

Our collaborations with scientists have connected fish data with environmental monitoring, benefiting both biologists and oceanographers (Moustahfid et al. 2011; Gazit et al. 2013). Similarly, Oliver et al. (2013) used autonomous vehicles to monitor the ocean environment and fish simultaneously. Alternately, large animals with combined telemetry and environmental sensor tags can sample areas that are difficult to study, such as pack ice, beneath ice-covered waters, and at great depths in oceans and lakes (Moustahfid et al. 2011). Integrating animal and environmental monitoring complements both fields of study, informing fisheries science, place-based management, modeling/forecasting, and ecosystem management.

Our experiences with commercial lobstermen were likewise productive. The lobstermen demonstrated a keen interest in the science behind environmental monitoring and acoustic telemetry. We found that the habitats they targeted for fishing may be important to certain fish, fostering research ideas to expand coverage to other bottom types. It is through such discourse between scientists and commercial fishers that research can be augmented and redirected to the mutual benefit of both fish stocks and fishers (Anon. 2006). Other fisheries, both commercial and recreational, offer opportunities for partnership and, when established collaboratively, increase not only information gains but trust and communication between stakeholders and scientists. However, fishers represent only one potential stakeholder category. Offshore power interests have asked us to expand monitoring in support of their environmental assessments, forming a new collaboration. Freshwater systems offer similar options; Tripp et al. (2013) used navigation buoys and bridge piers in addition to their core platforms. They are also experimenting with mobile platforms on vessels. Potential stakeholder collaborators abound across aquatic ecosystemsnavigation buoys, tugboat and ferry services, offshore wind and tidal power, aquaculture sites, and privately/publicly owned docks. The potential for new networks is broad and the technology creates stakeholder excitement, resulting in partnerships that foster a stronger and shared understanding of fish ecology.

As studies expand beyond release sites, the identification of transmitters from outside local networks presents the initial challenge of locating biologists who released these animals and, secondarily, communicating clearly to resolve data sharing and ownership issues. In addition to working directly with the vendor, two databases can be used to identify unassigned transmitters, and they represent unique models. One model is a grassroots network that has designed a regional transmitter clearinghouse available online (www.theactnetwork.com). The other is centralized and has a more complex relational database structure, supporting online retrieval of both transmitter information and receiver locations (www.oceantrackingnetwork. org). Both models are successful in their goals and were essential to our efforts. However, the current systems are time consuming to navigate and do not contain all possible transmitters. A single repository or application that searches multiple sources would benefit researchers interested in documenting other transmitters and understanding regional or global receiver deployments (Haggan et al. 2009; Moustahfid et al. 2011; Gazit et al. 2013).

The second challenge to detecting unassigned transmitters is data ownership. Through our experience, we believe that dedicating resources to sharing these data is a scientific responsibility with reciprocal benefits. However, reasons for not sharing data are valid and varied: the workload needed to document unassigned transmitters, a tradition of not sharing data until results are published, and fear of potential misuse of data. These challenges are worth overcoming because information about study animals with overlapping habitats helps to better explain ecosystem dynamics and habitat use (Costello and Vanden Berghe 2006; Mather et al. 2010; Oliver et al. 2013).

Working with oceanographers, we used data structures that provided web access to real-time observations and archived data streams. Marine biology databases are evolving toward similar access models (Costello and Vanden Berghe 2006). Telemetry studies offer a nexus because ocean-observing data sets can serve as templates for biologists to develop standard data formats, protocols, and metadata to ensure quality control and assurance (Costello and Vanden Berghe 2006; Haggan et al. 2009; Moustahfid et al. 2011; Gazit et al. 2013). Establishing these standards would make the assignment of transmitters easier, clarify data sharing, and allow researchers to collaborate more effectively.

Working with biologists has helped us to improve array design, data storage, and analysis/visualization techniques. Working with ocean scientists and fishers has increased our understanding of the environment and stakeholder needs. Networks of receivers are good, but networks of researchers, stakeholders, and data are even more valuable. These opportunities are not restricted to our oceans; ongoing efforts in the Upper Mississippi River system (Tripp et al. 2013) and the Great Lakes Acoustic Telemetry Observation System (http:// data.glos.us/glatos) underscore the broader potential of PlatOpus. Across systems, biologists can reduce overall deployment costs or shift resources to gain additional receiver coverage and analysis capabilities. These gains can be leveraged further through regional consortiums and networks. Global telemetry networks will likely play an increasingly important role and potentially become the backbone of integrated animal telemetry studies. They also provide the vision to link biological data to marine and freshwater environmental monitoring (Gazit et al. 2013). However, overall monitoring effort is likely greatest in the combined assets of numerous unconnected local studies (e.g., on the Atlantic seaboard, dozens of estuaries sites are monitored independently). Combining local studies, grassroots initiatives, and global networks should form new research approaches across disciplines and species. The PlatOpus concept fosters integrative partnerships strengthening relevance to fishers and other stakeholders increasing overall public understanding and support.

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Using Hard-Part Microchemistry to Advance Conservation and Management of North American Freshwater Fishes

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ABSTRACT: Hard-part microchemistry offers a powerful tool for inferring the environmental history and stock assignment of individual fishes. However, despite the applicability of this technique to a wide range of fisheries conservation and management issues, its use has been restricted to only a small fraction of North American species and inland waters. In this article, we provide freshwater fisheries professionals with an accessible review of methods and applications of hard-part microchemistry techniques. Our objectives are to (1) summarize the science of hard-part microchemistry; (2) provide guidelines for designing hard-part microchemistry studies, including sample sizes, laboratory analyses, statistical techniques, and inferential limitations; and (3) identify conservation and management applications where these techniques may be particularly useful. We argue that strategic use of hard-part microchemistry methods (specifically when they are used in concert with other indirect tracer techniques such as stable isotope chemistry and genetics) can advance fish management and conservation across all stages of fish life history.

INTRODUCTION

Successful conservation and management of fishery resources requires understanding fish population structure and dynamics. Fisheries research in rivers and lakes often relies on telemetry and mark–recapture studies to assess individual movements and population processes within and between ecosystems (Pollock et al. 2004). They also rely on population genetics to reconstruct patterns of exchange and isolation among fish populations (Palumbi 2003). More recently, chemical tracers have proven useful for tracking individual fish across longer time periods, thereby complementing other direct and indirect methods (Cunjak et al. 2005; Cooke et al. 2013; Figure 1). This review focuses on hard-part microchemistry and stable isotope techniques; that is, techniques that rely on fine-scale but

Uso de la microquímica de partes duras en pro de la conservación y manejo de peces dulceacuícolas de Norte América

RESUMEN: la microquímica de partes duras representa una herramienta poderosa para inferir la historia ambiental y la asignación de stocks en peces. No obstante, a pesar de la aplicabilidad de esta técnica a un amplio rango de aspectos de conservación y manejo de pesquerías, su utilización se ha restringido a sólo una pequeña fracción de especies de aguas continentales en Norte América. En este trabajo, se presenta una revisión accesible de los métodos y aplicaciones de técnicas de microquímica de partes duras, dirigida a los profesionales en pesquerías de aguas interiores. Los objetivos son: (1) resumir la ciencia de la microquímica de partes duras, (2) proporcionar guías para el diseño de estudios de microquímica de partes duras, incluyendo tamaños de muestra, análisis de laboratorio, técnicas estadísticas y limitaciones de orden inferencial, y (3) identificar aplicaciones para la conservación y manejo en las cuales estas técnicas puedan ser particularmente útiles. Se argumenta que la utilización estratégica de métodos de microquímica de partes duras (específicamente cuando éstos son usados en conjunto con otras técnicas de rastreo indirecto como química de isótopos estables y genética) puede abonar a la conservación y manejo de los peces durante todos los estadios de vida.

discrete changes in hard-part (i.e., otolith, statolith, scale, and fin ray) elemental signatures that reflect changes in ambient water chemistry. These techniques have the ability to help fisheries biologists gain insight into lifelong patterns of fish movement and population linkages across chemically heterogeneous landscapes.

Microchemistry analyses of hard parts have proven useful in marine, diadromous, and freshwater fishes, yet in North American freshwaters, they have been applied in relatively few freshwater ecoregions to relatively few taxa (Box 1). These techniques have been used extensively in the Great Lakes, Upper Mississippi, and Colorado freshwater ecoregions but sparsely elsewhere, including the ecoregions with the highest fish richness (i.e., Teays-Old Ohio, Tennessee, and Lower Mississippi ecoregions; Figure 2c), where no studies on wildproduced fish have been conducted. Of the 53 microchemistry studies on North American freshwater fish we surveyed, 31 (60%) have focused on species in the family Percidae (exclusively Yellow Perch *Perca flavescens* and *Sander* spp.) and the family Salmonidae: a small fraction of North American species (Appendix A, Supplemental Material; Figure 2).



Figure 1. Depiction of techniques for inferring fish life history on population and individual bases ranging from genetics (can infer populationlevel metrics such as natal homing and stock structure or individual metrics like paternity or genotype) to muscle stable isotope chemistry (infers individual habitat use for last weeks to months). Genetics, markrecapture, and telemetry techniques all allow for individually based and population-based inferences to be drawn, but inferential power can be maximized by combining multiple techniques because each technique can provide different scales of resolution. For example, though genetics can be useful for inferring natal stock, it provides no insight into individual movements, insight that can be gained through mark-recapture, telemetry, and microchemistry. Investigating a population using multiple techniques in combination can thus increase inferential power.

Our experiences at state and regional fisheries meetings suggest that many freshwater fisheries biologists remain unfamiliar with microchemistry techniques, despite their widespread use in other aquatic systems. This unfamiliarity may stem from lack of access to information; studies utilizing hard-part microchemistry are generally published in specialized journals not commonly subscribed to by government agencies and small academic institutions. In response to this, we have constructed this article with the goal of providing an accessible summary of the methodological details, potential applications, and limitations of hard-part microchemistry approaches for fisheries scientists to facilitate their understanding and broader application in North American freshwaters. Specifically, our objectives in this article are to (1) provide scientific background detailing how and where microchemistry techniques have worked; (2) provide guidelines for designing and implementing hard-part microchemistry studies, including necessary sample sizes, laboratory considerations, data analysis, and key technical caveats; and (3) identify conservation and management applications where these techniques may be particularly useful.

SCIENTIFIC BACKGROUND

Hard-part microchemistry techniques involve a transfer of the elemental chemistry of water to calcified fish structures where they are retained for the life of the fish. The success of these techniques as a tracer of environmental history depends on two key factors: (1) habitats must differ consistently in water chemistry signatures—a function of geologic availability or an-

thropogenic inputs-and (2) these differences correlate to and are preserved in the calcium (Ca)-based molecular matrix of fish hard parts, including otoliths, statoliths, fin rays, and scales (Campana 1999). Fish hard parts typically used for age and growth studies have two qualities that enable them to be used for chemical analysis of environmental history: (1) they grow and lay down new material throughout the fish's life and (2) the material they are made of is not readily resorbed by metabolism of the animal (Campana 1999). If these requirements are met, elemental signatures can be linked to age and growth benchmarks on the hard structure and interpreted with respect to age or life history stages (Figure 3; Box 2). In this way, elemental signatures can be used as natural tags for reconstructing habitat use, migrations, and other fundamental aspects of fish life history that are beyond the spatial or temporal reach of most other approaches (Kalish 1989).

Hard-part microchemistry often focuses on elements that are found in minute amounts in the Ca-based matrix of the hard part to infer environmental history, but the relationship between the elemental abundance of water and that of hard parts is complex (Campana 1999) and genetically determined (Sollner et al. 2003; Limburg and Elfman 2010). For example, Ca is the major constituent by weight in the Ca carbonate (CaCO₃) matrix of hard parts, even though the relative weight of Ca in hard parts does not reflect the natural abundance of Ca relative to other elements in water. In fact, all other elements found in hard parts are present at very low concentrations (<1%; Campana 1999). The precise mechanisms by which freshwater fish take up elements from water are complex. In brief, elements are taken up from water as they pass over gills (as opposed to through intestines in marine fish that constantly drink water; Olsson et al. 1998), where they enter blood plasma. In otoliths, elements then cross into the endolymph fluid that surrounds the otolith where crystallization into otolith material occurs (Campana 1999).

STUDY CONSIDERATIONS

Selecting an Appropriate Study Area

For microchemistry techniques to be useful, it is critical that water chemistry differs at the spatial and temporal scale of interest. Given the fundamental role of water chemistry, it is wise to analyze water samples prior to sampling fish even when the spatial scale is large. Diverse geological makeup, dominant hydrological flow paths (e.g., groundwater versus runoff), habitat (floodplain versus channel in rivers), and water residence time can all contribute to differences in water chemistry. Similarly, anthropogenic signals such as lead (Pb) from mining (Friedrich and Halden 2008, 2010) or nitrogen-stable isotopes (¹⁵N) from land-cover differences (Vandermyde and Whitledge 2008) can be present in ambient water chemistry and may serve as a marker in fish hard parts. Water samples for metals (collected by submerging 500-mL polyethylene bottles and filtering water into new 500-mL polyethylene bottles containing 3 mL of trace metal-grade nitric acid in water; see Eaton and Franson 2005) can be sent to a laboratory and characterized using mass

Box 1. Geographic distribution of hard-part microchemistry studies relative to distribution of fish biodiversity.

Microchemical analyses may hold great promise in areas of high fish biodiversity. For example, the geology, soils, land use, and water sources that determine trace element concentrations in freshwaters are often heterogeneous in understudied North American ecoregions (particularly the Teays–Old Ohio), as indicated by designations of MLRAs (Figure 2c). Habitat needs throughout the life history of endemic fishes of special concern in these regions are poorly understood (Warren et al. 2000), and hard-part microchemistry methods could be especially useful for small-bodied fish such as darters and cyprinids that are too small for most markrecapture and telemetry methods for determining movements. One important note here is that ecoregions where studies are absent may indicate that studies have been attempted but water chemistry differences did not exist at a spatial or temporal scale to answer the question of interest. Because studies with inconclusive findings are generally not published, it is of primary importance that researchers verify that water chemistry differences exist at the spatial scale of interest exist prior to undertaking a hardpart microchemistry study.



Figure 2. Maps of the freshwater ecoregions of North America (Abell et al. 2008) showing the per ecoregion (a) total number of freshwater fish species, (b) number of studies listed in Appendix A using hard-part microchemistry, and (c) Natural Resource Conservation Service major land resource areas (MLRA) in freshwater ecoregions of the world (FEOW) of highest freshwater fish richness where different colors within each ecoregion represent distinct MLRAs. The MLRA spatial data available from NRCS, http://soils.usda.gov/survey/geography/mlra.

spectrometry for ~\$60 per sample. This is a practice that we recommend as pilot work to establish whether spatial differences in trace element concentrations exist in the focal area. An initial impression of potential water chemistry differences can be gained from examining basic geologic maps (Figure 4a) or the Natural Resource Conservation Service's Major Land use Resource Areas (MLRA; Figure 2c); areas grouped together based on characteristics such as geology and land use that may give an initial indication of water chemistry differences prior to running water analyses. Spatial heterogeneity of geological bedrock types may also be a good indicator of water chemistry differences (Newton et al. 1987). However, if spatial heterogeneity is too high or too low (i.e., over very small or very large areas) it may be difficult to determine movement of fishes among different habitats based solely on hard-part microchemistry (Figure 2c, Figure 4; see also Munro 2004; Dufour et al. 2005; Pangle et al. 2010; Oele 2013).

Characterization of hard-part microchemistry of resident (nonmigratory) fishes provides a convenient reference point for interpreting microchemical differences within or between more mobile species. For instance, to determine whether strontium (Sr) could be a useful tracer of migratory fish movements in the Wisconsin and Mississippi rivers, we mapped Sr concentrations from these systems reported in Garbarino et al. (1995) and compared them with otolith Sr:Ca ratios between resident Smallmouth Bass (*Micropterus dolomieu*), a species that has been widely shown as nonmigratory (Lyons 2011), from each



Figure 3. Western Sand Darter (Ammocrypta clara) otolith showing (1) laser transect on otolith, (2) laser spot on otolith, (3) two element transect output, (4) two element laser spot output, and (5) two element background concentrations. This output graph depicts uncorrected, raw count per second data (i.e., number of times the spectrometer encounters each element per second) from the LA-ICP-MS on the y-axis and the number of seconds since data recording began on the x-axis. In order to quantify the background concentrations of elements in the inert carrier gas and in the spectrometer chamber, the ICP-MS is allowed to collect data for ~30 s before the LA system is turned on. As a result, raw counts from the laser is turned on.



Shovelnose Sturgeon (Scaphirhynchus platorunchus) pectoral fin ray. Photo credit: Dan Walchak and Paul Kanehl, Wisconsin Department of Natural Resources.

river. Even with modest sample sizes (N = 18 Mississippi River, N = 20 Wisconsin River), these two rivers proved to have distinct Sr signatures (Figure 4). These differences set the stage for interpreting ontogenetic changes in Sr:Ca of migratory fish species in each river.

Choice of Instruments and Elements to Be Analyzed

Among the most important study considerations is deciding what elements will be analyzed because the target elements dictate laboratory needs and preparation methods (see Campana et al. 1997). The question being addressed and the geochemical setting for a study should guide these choices. To some degree, the elements selected for quantification may depend on proximity, availability, and cost of instrumentation (which routinely exceeds \$1,000 per day). Ideally, consideration should be given to likely predictors of water chemistry differences that may be caused by differences in geology or hydrologic connectivity.

Looking to literature on marine and diadromous fishes for guidance on element selection may not be especially useful due to large chemical differences between fresh- and saltwater and differences in metabolic functions of fish between systems. For example, Sr has been central to the work on diadromous fishes because saltwater has much higher Sr concentrations than freshwater, leading to a steep increase in hard-part Sr concentrations when a fish transitions between freshwater and saltwater. In freshwater, Sr is also commonly informative because, like barium (Ba), it replaces Ca in the CaCO₂ matrix, is stable over time (Hedges et al. 2004), and also has high spatial variability relative to other elements. On the other hand, manganese (Mn) proved useful in 96% of the studies we surveyed involving marine fishes and 100% involving diadromous fishes but has been much less useful in freshwater systems (Figure 5). The reduced utility of Mn in freshwater systems may be metabolic in nature; Gibson-Reinemer et al. (2009) found no relation between concentrations of water and otolith Mn in Rainbow Trout (Oncorhynchus mykiss) in addition to no relation between zinc (Zn), water, and otolith concentrations. Furthermore, the biogeochemistry of Mn in fishes is complex and appears to change with fish growth (Limburg et al. in press); we therefore recommend that caution be used if hard-part Mn is quantified.

Techniques exist to quantify a wide variety of elements and their isotopes. Elements should be ideally selected based on three criteria: (1) the element is incorporated into the hard parts in proportion to its concentration in the water (tested by fitting a regression line between water samples and fish collected at the same site; see Gibson-Reinemer et al. 2009; or through laboratory exposure of fish to varied elemental concentrations; see Collingsworth et al. 2010; Phelps et al. 2012); (2) elements should show spatial variability but temporal stability (at least over the spatial and temporal scales of the study); and (3) isotopes should have high relative abundance within the hard part or the portion of the hard part corresponding to the life history stage of interest such that concentration of these isotopes are routinely above the detection limits of the instrument used. Ele-

Box 2. Hard-part microchemistry analysis using laser ablation-inductively coupled plasma-mass spectrometry.

LA-ICP-MS is the most commonly used and preferred method of microchemistry quantification where possible (Ludsin et al. 2006). This technique is versatile because it can quantify a wide variety of elements, particularly heavy metals, including Ba and Sr, commonly used in movement studies (Appendix A). The LA-ICP-MS uses a laser to ablate a portion of the fish hard part (either a transect [Figure 3 part 1] or spot [Figure 3 part 2]). The ablated material is then carried via argon (Ar) or other inert carrier gas to a plasma torch inside the machine that ionizes the sample. The atomic mass of each ion is then recorded by a mass spectrometer based on mass to charge ratios and is quantified as the counts of each element recorded by the ICP-MS each second (counts per second; Figures 3 parts 3 and 4). These chemical signatures can then be linked to temporal landmarks on the hard structure (e.g., annuli). Other ICP-MS-based techniques also exist for quantifying heavy metals, the most commonly used of which is solution-based ICP-MS (SO-ICP-MS). This technique relies on the dissolution of the entire otolith in acid and is generally used when larval and young of year fishes are of interest (Ludsin et al. 2006; but see Schaffler and Winkelman [2008] for use on juvenile fish).

Determining whether to sample a spot or transect will depend on research objectives. Studies determining natal origin or homing or stock assignment, for instance, may use the laser to sample spots (Figures 3.2, 4) because these studies are interested in discrete points of life, generally the core (natal signature) and edge (recent signature). On the other hand, using the laser to sample a transect (Figures 3.1, 3.3) to give a more continuous depiction of environmental history may be better suited for studies of larval dispersal and migration history. We recommend the use of transect-based data collection for studies inferring movement from LA-ICP-MS data.

Transect data can present unique problems for analysis because calculations must be performed to interpret the data with respect to physical landmarks on the hard structure such as annuli. If the research objective requires understanding chemical signatures at specific ages, for example, annuli must first be enumerated and identified on the hard structure using standard age and growth techniques (Quist et al. 2012). However, before identifying chemical signatures by fish age, a link must be created between the time (in seconds since laser ablation was started) that a chemical signature was recorded by the mass spectrometer and the placement of each annulus on a hard part. We use this equation, which is based on the Fraser-Lee back-calculated length-at-age method (Quist et al. 2012):

$$T_{Li} = \left[\frac{A_i * T_{ttl}}{L_{ttl}}\right] + T_c, \tag{1}$$

where T_{Li} is the time in seconds (from LA-ICP-MS output) that laser transect crosses annulus *i*, A_i is the length of the hard structure from core to annulus *i*, L_{ul} is the total length of the laser transect on the fin ray, T_{ul} is the total time (s) elapsed over the laser transect, and T_c is the time the laser crossed the hard-part core.

Prior to data analysis, quantification of hard-part microchemistry requires postprocessing: calibration of data to known standard reference materials, correction for instrument drift, and subtraction of background concentrations of elements. These data processing tasks can be time-consuming, particularly when many elements are measured along a long sample transect, as is often the case in LA-ICP-MS studies. Postprocessing of LA-ICP-MS can be accomplished using free graphical user interface software like the Analysis Management System (Mutchler et al. 2008; www.geochem.geos.vt.edu/fluids/laicpms/ams.shtml) or the free download Fathom Toolbox for Matlab (Jones 2001; available at: www.marine.usf.edu/user/djones/matlab/matlab.html, although Matlab is not freeware). These software packages, as well as some proprietary alternatives, reduce the time required for the postprocessing step by accomplishing background and machine-drift correction of data, conversion of raw elemental counts into parts per million concentrations, and integration of elemental signals over a specified time period that corresponds to an age or life history stage into one step. These software packages require designation of an internal standard—that is, an element that is relatively invariant in concentration throughout the hard part—to quantify the relative abundance of the other elements. Generally, Ca is used as the internal standard due to its high concentration in hard parts relative to other elements. Software will require specification of concentrations of the internal standards either in parts per million or by weight. For these inputs, Ca makes up approximately 38% of the weight of the otolith weight (Campana 1999) and 23% of the weight of fin rays and scales (Clarke et al. 2007).

ments used in studies of freshwater fish that have been shown to display these traits include (but are not limited to) Sr, Ba, deuterium (²H—a stable isotope of hydrogen), ¹⁸O (stable isotope of oxygen), and ¹⁵N (but not for small fish; see Vandermyde and Whitledge 2008), although it is not commonly used (Figure 5). Other elements may be locally useful, such as magnesium (Mg), which has been used in a number of studies of freshwater fish (Figure 5), but researchers should ensure relationships between water and hard-part elemental signatures prior to their use because some elements may also be under physiological control. Utility of elements may also depend on the hard part examined. For example, commonly used trace metals such as Ba and pollutant heavy metals such as mercury (Hg), copper (Cu), Pb, or nickel (Ni) did not accumulate equally in both statoliths



Figure 4. (a) Map of geological units in the Mississippi River Basin (reds) upstream of the Wisconsin River Basin (blues). Shades and tints of colors in each watershed represent a different geological unit based on bedrock and surficial geology. Values on map indicate Sr values from water samples taken in the Mississippi and Wisconsin rivers reported from the October 1991 sample in Garbarino et al. (1995). Spatial data available from United States Geological Survey, http:// mrdata.usgs.gov/geology/us. (b) Bar charts of otolith Sr values from Smallmouth Bass (Micropterus salmoides) collected in the Mississippi River (N = 18) near the downstream-most point (red bar) and Wisconsin River (N = 20) approximately 80 km upstream of the Sr sampling point. Error bars represent standard error. Otoliths were analyzed using a CETAC Technologies LSX-213 LA system (CETAC Technologies, Omaha, NE) coupled to a Perkin-Elmer ELAN DRC II ICP-MS (Perkin-Elmer, Waltham, MA) located at the University of Massachusetts, Boston. In this procedure, the laser ablated a transect across otoliths extending from the core to edge (beam diameter: 25 μm; speed: 15 μm*s⁻¹, pulse rate: 20 Hz; energy level: 70%; nebulizer gas: 94%). United States Geological Survey solid standard MACS-3 was analyzed every 15 samples to correct for instrument drift. Each sample and standard run was preceded by a ~30 s gas blank measurement to enable calculation of background concentrations. We then used Analysis Management System (AMS) data reduction software (Mutchler et al. 2008) for integrating output across the entire otolith, background subtraction, machine drift correction, and conversion of LA-ICP-MS output from counts per second to $\mu g^* g^{-1}$.

(Brothers and Thresher 2004). In addition, though statolith iron (Fe), Cu, Pb, Mg, and Sr were found to be stable through metamorphosis from larvae to adult, rubidium (Rb) concentrations change after metamorphosis (Lochet et al. 2013). Considering the large number of freshwater studies that have found Sr to be useful for habitat discrimination coupled with its stability among hard parts, we recommend that this element should always be quantified in studies examining heavy metals. However, the utility of other elements will depend on the study area and hard structure examined.

Laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS; Box 2) is by far the most common technique currently used to assay hard-part microchemistry in freshwaters. This technique has been used in North American freshwaters for addressing a wide variety of research objectives (Appendix A) and is also among the most precise techniques available (Campana et al. 1997). LA-ICP-MS is used to quantify elements with high atomic weights (e.g., heavy metals), but other instruments are needed to quantify lighter elements that can be useful in investigations of fish habitat use such as hydrogen (H), carbon (C), nitrogen (N), oxygen (O), and their stable isotopes (²H, ¹³C, ¹⁵N, ¹⁸O). Use of lighter elements can provide different perspectives on fish environmental history and have been used to provide records of ambient water temperature (using ¹⁸O; Dufour et al. 2005; Weidel et al. 2007), river of origin (e.g., using ¹³C; Limburg et al. 2013), habitat type (e.g., river vs. floodplain lake using ²H, ¹³C, ¹⁸O; Zigler and Whitledge 2010, 2011), and watershed land cover (using ¹⁵N; Vandermyde and Whitledge 2008). Quantifying these elements requires use of high-resolution-inductively coupled plasma-mass spectrometry (HR-ICP-MS), high temperature conversion elemental analyzer-isotope ratio-mass spectrometry (TC/EA-IR-MS), or ion microprobe (secondary ion mass spectrometry). Like LA-ICP-MS, techniques used for quantifying low-atomic-weight elements can be linked to temporal landmarks on the hard structure because sample material is collected using a high-precision drill-a micromill-that can sample specific portions of life history, similar to using a laser to vaporize a spot (Box 2; Figure 3). Several other techniques



Figure 5. Number of published studies of North American obligate freshwater fish, and selected anadromous and marine fish from around the world (literature cited for this figure in Supplemental Material), that measured a particular element or isotope (dark bar) in a hard part (otolith, spine, fin ray, scale) in a fish hard part and used it in statistical analyses (light bar). For studies examining more than one element, each element is counted separately (i.e., one study can be counted for multiple elements).

are also available for quantifying hard-part microchemistry but are much less common. Examples of applications of these techniques and the elements they quantify are provided in Appendix A.

Hard-Part Selection and Preparation

Hard parts used in microchemistry analyses are typically the same ones used for age and growth studies for a given species. Otoliths, especially the large sagittal otoliths, have been the most commonly used. Lapilli otoliths have also been used in methodological tests (see Brazner et al. 2004) but are seldom studied. Fin rays and scales are generally thought to be comparable to otoliths and do not require lethal sampling, making them appealing alternatives for microchemistry studies (Clarke et al. 2007). Pectoral fin rays have been shown to provide a similarly permanent record of habitat use despite being composed of apatite (Ca phosphate mineral found in tooth enamel and bone material) rather than carbonate (Wells et al. 2003; Clarke et al. 2007; K. T. Smith and Whitledge 2010). However, the lumen of pectoral and fin rays can degrade, resulting in an incomplete record of early life history, especially in older fish (Davis-Foust et al. 2009). Similarly, scales are also associated

with incomplete environmental histories because they are often regrown following damage. Regrown scales will only contain information since scale regrowth (Wells et al. 2003; Clarke et al. 2007). Additionally, certain elements may not provide equally good records across all hard parts; for example, Pb concentrations in fish scales have been shown to be uncorrelated with that of otoliths from the same fish (Muhlfeld et al. 2005), although scale concentrations of Sr, cadmium (Cd), and Ba are correlated with water chemistry (Wells et al. 2003). Statoliths of lamprey (Brothers and Thresher 2004; Hand et al. 2008; Lochet et al. 2013), the only calcified structure for these fishes, are also though to be comparable to otoliths but require killing fish and may lose some elemental information after larval metamorphosis (Howe et al. 2013; Lochet et al. 2013).

Archived samples can be used in microchemistry analyses provided that hard parts were both immediately removed from the fish and stored dry, or whole fish samples can be preserved by freezing or storing in ethanol shortly after death (Proctor and Thresher 1998; Milton and Chenery 1998; Hedges et al. 2004). Large fish are commonly frozen—a preservation method that has similar results to hard parts that are immediately removed



Blue Sucker (Cycleptus elongatus) pectoral fin ray. Photo credit: Dan Walchak and Paul Kanehl, Wisconsin Department of Natural Resources.

from the fish and analyzed (Proctor and Thresher 1998), but small fish are frequently preserved in ethanol. In these cases, storage of fish in different grades of 95% ethanol (e.g., highperformance liquid chromatoraphy vs. American Chemical Society grade; Hand et al. 2008) or 70% ethanol (Milton and Chenery 1998) have all been shown to provide similar results to freezing samples. However, though elements that replace otolith Ca such as Sr, Mn, Ba, Mg, and Zn are not thought to be affected by storage of fish in ethanol, elements involved in biological regulation like sodium (Na), potassium (K), sulfur (S), chlorine (Cl; Proctor and Thresher 1998; Milton and Chenery 1998; Hedges et al. 2004), and ¹⁸O (Storm-Suke et al. 2007) may be altered by this preservative. Unfortunately, samples preserved with formalin cannot be used because the acidic properties of the preservation medium degrade otoliths (Morales-Nin 1992). Ideally, these preservation options could enable analysis of historical samples that could be valuable in reconstructing behavior and habitat use by fishes prior to shifts in management or restoration activities.

Careful handling of hard parts for analysis is essential for avoiding contamination, but the initial steps of sample preparation are similar to those used for analysis of age and growth. Secor et al. (1991) provided an excellent guide for preparing otoliths for microstructural analysis that can be a useful initial guide to microchemistry preparation. For statloiths, otoliths, and scales, sample preparation begins with removing hard parts using nonmetallic forceps (or metal forceps wrapped in Teflon tape to avoid contamination with metals) and then carefully cleaning structures of other biologic material. Hard structures are then stored dry or frozen inside clean glass, plastic, or paper containers, typically washed with trace metal–grade nitric acid, and dried before samples are placed in them. Fin rays may be removed with a metal blade because they must be sectioned prior to microchemical analyses. Preparation of samples after this point will depend on the analytical method chosen.

For LA-ICP-MS analysis (Box 2), whole or sectioned otoliths or statoliths are mounted on a petrographic glass slide with thermoplastic resin and polished. Polishing is accomplished with a lapping wheel using a series of alumina or diamond slurries or by hand using wet sandpaper (see Brothers and Thresher [2004] and Hand et al. [2008] for detailed statolith methods and Hamann and Kennedy [2012] for detailed otolith methods). Analysis of fin rays requires structures to be dried, mounted in epoxy, and sectioned using a low-speed saw before being mounted on glass petrographic slides, whereas scales

do not require sectioning after mounting. Fin rays and scales generally require little or no polishing to expose clean annuli. For all of these structures, it is important to triple rinse and even sonicate samples that have been sectioned and polished to remove residue from the saw blade and/or polishing step. Full preparation details are provided by Phelps et al. (2012) for fin rays and Clarke et al. (2007) for scales. In contrast, preparing samples for solution-based inductively coupled plasma–mass spectrometry (SO-ICP-MS) analysis involves dissolving entire otoliths in an acid solution for direct injection into the ICP-MS and there are no sectioning or polishing steps required.

The SO-ICP-MS method has been shown to provide results similar to the LA-ICP-MS, but the LA-ICP-MS has slightly higher precision and is the recommended method where available (Ludsin et al. 2006). Samples being analyzed by secondary ion mass spectrometry have a similar preparation, but it is of the utmost importance that the hard part surface is thoroughly polished to a very flat surface because ions can become trapped in even the tiniest pits in the surface. Once polished, the sample is rinsed of all impurities with ultrapure water and coated in a gold thin film prior to analysis (Weidel et al. 2007).

Sample Sizes of Fishes and Study Site Selection

As in other aspects of fishery science, sample sizes are a primary determinant of inferential power from microchemical analyses, and the minimum number of fish needed to reach robust conclusions will depend on the research question and chemical variation among study areas (Appendix A). Published studies of North American freshwater fishes have used sample sizes as small as two (Weidel et al. 2007) and as many as 138 fish per site (Whitledge et al. 2007), with a median of 16 (Appendix A, Supplemental Material). With respect to research objectives, studies seeking to conduct stock assessments or examine natal sites like Bronte et al. (1996; 26 fish per site) or Brazner et al. (2004; 34 fish per site) may require more fish to detect rare immigrants. Studies interested in lifetime environmental history may require fewer fish because they extract a large amount of temporal information from each fish (e.g., Weidel et al. 2007; n = 2).

The sample size per site appropriate for any given study depends on the variance in elemental composition within versus between sites and the number of distinct chemical histories present within each site (Hayden et al. 2013; Limburg et al. 2013). For instance, otolith microchemistry patterns can emerge with as few as five replicate individuals per site when locations have fixed chemical differences (Friedrich and



Walleye (Sander vitreus) otolith. Photo credit: Connie Isermann, Fisheries Analysis Center, University of Wisconsin-Stevens Point.

Halden 2010), but within-site temporal variation can sometimes swamp the variance between sites in highly seasonal environments. Moreover, microhabitat differences and short-term movements of fishes may enhance the variability in elemental signatures even among a resident population of fish. When movement between sites occurs, then larger sample sizes are required to robustly separate resident from immigrant microchemical profiles. In certain situations, investigators have limited control over within habitat signature variability. For instance, habitat signatures are frequently characterized using larval or young of year fish (i.e., Reichert et al. 2010; Oele 2013) that may drift to other locations. It is important to collect individuals prior to these movements in order to accurately characterize (and minimize variability) within-habitat signatures. Once within- and between-habitat variability is known, we also recommend using a power analysis constructed with variances of hard-part chemistries of resident fish or a small sample of the species of interest to determine the appropriate sample size for each system.

A second key aspect of study design is the number and spatial separation of sites being compared. Microchemical comparisons are most fruitful at the interface between water bodies with fundamental differences in chemistry because spatial distance and chemical differences are decoupled at geochemical borders. This often occurs near anthropogenic inputs or features (Palace et al. 2007; Murphy et al. 2012; Freidrich and Halden 2010) at confluence points in river networks (Freidrich and Halden 2008; Humston et al. 2010; Phelps et al. 2012) or where tributaries enter lakes (Hand et al. 2008; Schaffler and Winkelman 2008; Reichert et al. 2010). Longitudinal sampling along river channels, or comparisons within a large lake, is less likely to show distinct chemistries (Dufour et al. 2005; Oele 2013). We recommend using pilot analysis of water samples or nonmigratory fish species to identify sharp natural or anthropogenic chemical boundaries. Comparing a few sites on each side of such boundaries provides maximum inferential power for a given total sample size by focusing on replicate individuals from each site rather than a large number of sites. Regardless of the target number of sites and individuals to be analyzed, we also recommend collecting additional individuals as well as extra sites at the same time as resources allow. These collections provide backup options if unexpected patterns emerge, and they avoid complications from comparing samples collected at different times (and thus potentially different microchemical regimes).

Data Analysis

After deriving multi-element signatures from each sample, most studies use statistical assignment tests to determine source population, natal area, or environmental history. Linear discriminant function analysis (LDFA) is the most commonly used assignment technique for grouping individuals with similar microchemistry to elucidate which sites are distinctive (21 of 53 studies; Appendix A, Supplemental Material). Various types of regression analyses (analysis of variance, analysis of covariance, multivariate analysis of variance) are also widely used to test for differences among sites (Appendix A, Supplemental Material), but they lack the predictive modeling and validation steps of LDFA and its nonlinear counterpart, quadratic discriminant function analysis (QDFA). All of these statistics require that microchemical data meet normality assumptions, so log-transformation is common. LDFA and QDFA can use a



Walleye otolith. Photo credit: Connie Isermann, Fisheries Analysis Center, University of Wisconsin-Stevens Point.

training data set that usually involves young-of-year of focal species to characterize putative source populations—a step that can be used to present *a priori* characterizations of elemental signatures of source populations—although use of the training data set restricts assignment of fish of unknown origin to these source populations (e.g., a migrant from an uncharacterized source location will still be assigned to a characterized population). LDFA is the most commonly used technique, so we will restrict our discussion to comparisons between it and alternative methods of statistical assignment.

Researchers using otolith microchemistry in marine systems have addressed statistical limitations by employing assignment methods developed for population genetics (Cornuet et al. 1999) such as Bayesian, machine learning, or resampling techniques. These techniques are generally robust to deviations from multivariate normality and may also be able to assign individuals to unsampled sources. For example, Bayesian mixture models can allow for assignment of individuals to sampled or unsampled source populations (Standish et al. 2008; Neubauer et al. 2010; Pflugeisen and Calder 2013). In fact, the latest statistical models can estimate the likely number of unsampled source populations (Neubauer 2012; Hogan et al. 2014), an assessment that is not possible with LDFA, QDFA, or regressiontype analyses. As with any discrimination technique, successful application of Bayesian methods is predicated on the data havstable chemical differences among populations. Bayesian techniques have only been used in one study of obligate freshwater fishes of North America (Pflugeisen and Calder 2013), but use of these approaches will doubtless increase as Bayesian statistical methods become more common. Nonetheless, direct comparisons indicate that if there is a training data set, LDFA can provide results similar to those of computationally intensive approaches like Bayesian mixture models (Munch and Clarke 2008) when sample sizes are >30 or to artificial neural networks (machine learning) and random forests (resampling) when less than four elements are being used for discrimination (Mercier et al. 2011). A new technique, k-sample nearest-neighbor discriminant analysis, can assign individuals of unknown origin to groups and is also robust to deviations from normality, although its performance has not yet been compared against other statistical methods (Gao et al. 2013). Though these statistical approaches may seem daunting, they are increasingly accessible through

ing a high signal-to-noise ratio and

no-cost statistical packages (e.g., R package; R Development Core Team 2014) that can execute computationally intensive analyses using a standard personal computer. We recommend use of Bayesian techniques in concert with LDFA, QDFA, or *k*sampled discriminant analysis to ensure robustness to violations of multivariate normality and other statistical assumptions about otolith microchemistry data.

Technique Limitations

Hard-part microchemistry techniques also have a number of limitations that are important to consider prior to beginning a study, some of which are limitations for all studies and some that are particular to studies of adult fishes. For instance, all studies using hard-part microchemistry require distinct water chemistry among habitats for discrimination. If these differences do not exist at the scale of interest, then hard-part microchemistry techniques will not be of use, even at relatively large spatial scales (see Munro 2004; Dufour et al. 2005; Pangle et al. 2010; Oele 2013). Unfortunately, it may be difficult to ascertain where hard-part microchemistry may not be of use from the published literature because studies with negative results are seldom published (see Munro 2004; but see Howe et al. 2013). Temporal stability of water chemistry signatures is also an important limitation that all studies must consider. For instance, larval Yellow Perch showed unique Sr concentrations among tributaries of Lake Erie, yet interannual variability was sufficiently high that fish collected in one year could not be used to assign fish collected in a different year (Pangle et al. 2010). As a result, Pangle et al. (2010) recommended building a multiyear database of larval Yellow Perch signatures from several tributaries to help overcome this limitation. All studies must also consider analytical limitations, namely, that laboratory and statistical analyses required to conduct a hard-part microchemistry study have steep learning curves. Though we have made an attempt in this article to reduce this barrier, it is no replacement for a colleague or mentor who can help guide new investigators through this process. Additionally, equipment needed for laboratory analysis is common at large universities (often in found geology laboratories) but not elsewhere. As a result, access to



Young-of-year Northern Pike (Esox lucius) otolith. Photo credit: Dan Oele, University of Wisconsin-Madison.

both analytical expertise and instrumentation may be a limitation for fisheries biologists at government agencies and smaller academic institutions. Thus, in addition to using this and other papers to guide study design and inferences, we strongly recommend that new investigators seek advice or collaboration from colleagues with direct experience in chemical analyses of hard parts.

Several limitations to hard-part microchemistry techniques are particular to adult fishes. For example, brief sojourns into habitats with different chemistries will not be detected when residence is too short for sufficient new hard-part accretion to occur. This situation could be more likely to occur during time periods in a fish's life when the accretion rates are very slow; for instance, during spawning migrations when fish are devoting energy to reproduction rather than growth, movements during winter, or those of older fish that are growing very slowly. Difficulties may also exist in ageing and interpreting the hard parts of adult fishes because of uncertainty about how many annuli a fish has, what constitutes an annulus, or where annuli are placed. This limitation muddies how chemical changes recorded in the hard structure align with specific ages or life history events and can be partially overcome by averaging signals that correspond to a particular life history stage across parts of a hard structure for an individual fish.

CONSERVATION AND MANAGEMENT APPLICATIONS

Judicious use of hard-part microchemistry techniques has enormous potential to advance understanding of freshwater fish populations, just as it has for the marine and diadromous species where these methods have been pioneered (see reviews by Secor et al. 1995; Campana 1999; Secor and Rooker 2000; Campana and Thorrold 2001; Gillanders 2005a and 2005b; Elsdon et al. 2008; Brown and Severin 2009; Chang and Geffen 2012). The potential for hard-part microchemistry to provide insights into lifelong patterns of habitat use by fishes also makes this technique ripe for conservation and management application. In this section, we discuss how hard-part microchemistry techniques are suited to address some widespread conservation and management challenges.

Fisheries Law Enforcement

Hard-part microchemistry can provide a retrospective view of where a fish has been throughout its life and thus may provide evidence of illegal stocking or harvesting to law enforcement authorities. For example, otolith chemistry has been used to identify the source and estimate of date of illegal stocking of Lake Trout (Salvelinus namaycush) into Yellowstone Lake (Munro et al. 2005), as well as the source of invasive species in the Upper Colorado River (Whitledge et al. 2007). Microchemistry techniques may be especially powerful for law enforcement when used alongside other methods to identify the source of illegally harvested or imported fish. For instance, genetics can be a powerful tool for identifying the location of fish harvest (Ogden 2008), and coupling genotyping with microchemistry techniques can increase the resolution of stock assignments (Bradbury et al. 2008; Collins et al. 2013). In fact, freely available software now allows joint analysis of genetic and microchemical data (J. S. Smith and Campana 2010).

Merging hard-part microchemistry, genetics, and muscle stable isotopes—a technique that can provide insight into the last several weeks to months of habitat use (Cunjak et al.



Walleye otolith. Photo credit: Connie Isermann, Fisheries Analysis Center, University of Wisconsin-Stevens Point.

2005)— to provide several layers of resolution for pinpointing fish harvest location may be especially important in regulation of roe fisheries. Currently, it is difficult to regulate these fisheries because fish are highly mobile, harvest regulations vary from state to state, and commercial value of caviar-bearing species is sharply increasing as global sturgeon stocks collapse (Bettoli et al. 2009; Koch and Quist 2010; Pracheil et al. 2012). Combining multiple techniques may hold promise for enforcement of illegal harvest of fishes such as Lake Sturgeon (*Acipenser fulvescens*) that have genetically structured populations (DeHaan et al. 2006; Forsythe et al. 2011) and demonstrated utility for understanding movement and habitat use with fin-ray microchemistry (K. T. Smith and Whitledge 2011).

Designating and Prioritizing Conservation and Management Efforts

Fish often make use of different habitats in each major phase of their life history, and understanding how these habitats are connected through fish life cycles is essential for successful conservation (Wilcove and Wikelski 2008). Hard-part microchemistry offers a glimpse into the environmental conditions of spawning and nursery sites and provides a description of the environmental conditions that are encountered throughout fish life history. These conditions can be useful in pinpointing specific locations that can be protected to enhance conservation goals. For example, Yellow Perch declines coupled with their importance to sport fisheries in the Laurentian Great Lakes have prompted multiple studies focused on linking habitats to successful recruitment, such as Reichert et al. (2010), who used otolith microchemistry to show that larval Yellow Perch in Lake Erie tributary plumes have higher survival than those in open water. Similarly, in order to focus Bighead Carp (Hypopthalmichthys nobilis) and Silver Carp (H. molitrix) eradication efforts in the Upper Mississippi and Illinois rivers, Norman (2013) used otolith microchemistry to determine habitat use of these species throughout their life history. Results of this study indicated that control efforts focused on early life history should target floodplain lakes, whereas those focused on adults should target river channel habitats. In these cases, microchemistry provided insight into habitat use that could not have been derived from genetics (these sites are used by the same stock) or tagging studies (which cannot track larval fish effectively in large ecosystems). Accounting for such

complexity of habitat use through the life cycle is essential for improving local management and conservation efforts and can also contribute to prioritizing habitat restoration and threat alleviation at large spatial scales (e.g., Januchowski-Hartley et al. 2013; Pracheil et al. 2013; Martinuzzi et al. 2014).

Evaluating Recruitment and Stocking Contributions

In a system where fish populations are supplemented through stocking, determining long-term survival and dispersal of stocked fish after their release can be challenging. Hard-part microchemistry has proven effective in determining whether wild-caught adult fish are of hatchery or wild origin. Such studies take advantage of the fact that the chemistry of hatchery waters is often dramatically different from the water chemistry of the stocking location, yielding a distinctive hatchery signature of stocked fish during early life history. For example, Gibson-Reinemer et al. (2009) found that hatchery Rainbow Trout could be assigned back to their hatchery of origin based on otolith microchemistry signatures with a high degree of accuracy. Similarly, Bickford and Hannigan (2005) used elemental signatures from otolith cores to assign hatchery of origin of stocked Walleye (Sander vitreus). Hard-part microchemistry can thus facilitate insight into relative mortality and year-class

strength among different hatchery stocks for informing future stocking endeavors, as well as distinguishing the relative contributions of different hatchery stocks from wild-spawned fish.

Identifying per habitat contributions to recruitment of wild-produced fish is an important application of hard-part chemistry techniques for establishing targeted population management and conservation actions. Early studies demonstrating that hard-part microchemistry could be used to identify the river of natal origin examined Sr concentrations in otoliths of anadromous Atlantic Salmon (Salmo salar)-a fish that spends its early life history in freshwaters-to estimate contributions of Connecticut River tributaries to recruitment (Kennedy et al. 2000, 2002). More recent studies have used hard-part microchemistry techniques to determine the river of natal origin for obligate freshwater fish including Asian carps (Bighead Carp [Hypophthalmichthys nobilis] and Silver Carp [H. molitrix]) in the Illinois River (Norman 2013) using otolith Sr and Ba to identify river and otolith ¹³C and ¹⁵N to determine



Walleye scale. Photo credit: Connie Isermann, Fisheries Analysis Center, University of Wisconsin-Stevens Point.

natal habitat (e.g., floodplain, channel). In this case, understanding the source of fish recruitment both in terms of river and habitat within the river using microchemistry is helping to focus Asian carp control efforts in the study system and in other rivers as the range of these fishes expand.

CONCLUSIONS

There is a growing need for large-scale, progressive management of freshwater fisheries (Martin and Pope 2010; Post 2013; Pracheil et al. 2012) as habitat degradation, climate change, and land conversion continue to expand (Vörösmarty et al. 2010; Martinuzzi et al. 2013). Hard-part microchemistry techniques offer a valuable tool for understanding aspects of fish life history and habitat use that have been difficult to resolve using traditional techniques or even the latest genetic tools. In particular, microchemical approaches provide insight into movement patterns during early life history; a stage that has remained enigmatic despite advances in fish biology (Rose 2000).

Although there are questions that can be resolved using microchemical methods alone, they are the most powerful when used in combination with other techniques like mark–recapture, telemetry (Pollock et al. 2004; Cooke et al. 2013), and genetics (Collins et al. 2013). In that context, microchemistry can fill in information that cannot be gained during early life history, between encounters, when fish move outside of the search area, or within a single genetic stock. In additon, it is important to note that we are not advocating that microchemical methods are devoid of limitations and challenges but rather that the examples presented herein indicate ample opportunity to apply these techniques more widely across North American freshwaters. The resulting insights into fish movements, population dynamics, and life history are necessary for managing resilient freshwater fisheries now and into the future.

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SUPPLEMENTARY MATERIAL

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SYNOPSIS

A Roadmap for Science, Education, and Outreach for Natural Resources

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Sustainable management of natural resources poses critical issues for scientists, managers, public officials, and society at large. Successfully addressing these challenges will depend on concerted input from our academic and scientific institutions in order to develop pertinent new knowledge, train an educated workforce, and distribute the information to the public and decision-makers. The Science, Education and Outreach Roadmap for Natural Resources (APLU 2014), developed by 138 scientists from a wide range of disciplines, suggests where strategic public investments in research, education, and outreach could make significant impacts. The goals of the Roadmap for Natural Resources are to chart a path for natural resources research, education, and outreach for public universities for the next 5 to 10 years; identify major challenges, knowledge gaps, and priorities; provide guidance for policy makers in strategic planning and investment; support natural resources agencies, professional societies, and nongovernmental organizations advocating for use of sound science in natural resources decision-making; and facilitate interdisciplinary research, education, and outreach focused on natural resources challenges.

DEVELOPMENT OF THE ROADMAP

To initiate development of the roadmap, 78 participants completed five rounds of Delphi surveys to identify grand challenges facing natural resources science and management. Grand challenges are those that are difficult to solve, yet do have solutions or at least milestones that mark progress toward solutions. These grand challenges also pose significant social, environmental, and economic impacts. Grand challenges also stretch the limits of our collective research, extension, and teaching abilities and capacities. The Natural Resources Roadmap Advisory Panel invited scientists to lead the drafting of responses to each of the grand challenges; 35 scientists wrote the 6 sections of the roadmap. Each section frames the issue, examines current capacity and gaps in science, identifies research needs and priorities, and anticipates outcomes under the status quo and



following the roadmap's recommendations. Each section and the document as a whole underwent peer review and revision.

THREE TOP STRESSORS ON NATURAL RESOURCES

Natural resources face pressures from human activities including transportation, construction, and industrial production, although activities that are inherently extractive, such as agriculture and energy production, deeply stress natural resources when done poorly. Additionally, climate change complicates management of natural resources by imposing stressful impacts throughout ecosystems. To manage natural resources under such pressures, natural resource managers will need additional observational data, new tools and models, substantially increased social science research, and increased collaboration and partnerships with people in science and non-science fields well beyond natural resources management.

Among key issues posed by agriculture, we must determine the capacity of soil and water to meet current and future demands for agricultural, forest, and rangeland products. Sustaining agricultural and fisheries production will require more efficient use of land, water, energy, and chemicals. We must identify and implement methods to reduce nutrient loads in water while maintaining healthy economies. Regional and national water impacts of existing agriculture policies and subsidies, and potential solutions, will have to be identified. New insect, pathogen, and weed models are needed to project future species range-shifts, population dynamics, and epidemiology under different climate-change scenarios.

To address issues posed by energy production, we must improve understanding and public perception of the costs and benefits of energy development and use. To inform efforts for reducing the impacts of energy demands on natural resources, we will have to quantify the water demand of energy production, quantify biodiversity impacts of energy production, and identify sources of water and air pollution associated with energy production. We must develop technologies to reduce the ecological footprint for all types of energy production. And we must educate students, teachers, and consumers to better understand the consequences of their energy choices.

To respond to issues posed by climate change, we must determine species and ecosystem responses to multiple climatic, ecological, and social variables through both observational and experimental approaches. Achieving better understanding and management under different climate-change scenarios can be approached through use of improved models and simulations. Managers and local officials would better handle risk and uncertainty of managing natural resources under climate-change scenarios using improved tools and communication.

TOWARDS SUSTAINABLE MANAGEMENT OF NATURAL RESOURCES

Sustainable management of natural resources should be evaluated not only in relation to environmental quality standards, but also in terms of present and future social and economic expectations. Often, "sustainable" may be used synonymously to represent minimized inputs and idealized environmental quality. This vision of sustainability may, however, clash with economic issues, growing population and increasing living standards, and the necessity of adapting to climate extremes. Only with a mind towards the future can scientists analyze exiting patterns of resource use and assess alternative strategies for meeting increasing demands on natural resources.

Against this background, we must improve our knowledge of interactive processes between ecosystems and growing human populations and understand the influences of social and economic practices and policies on natural resources. Forest management and harvesting operations practices and technologies must be refined to sustainably meet the growing, and often conflicting needs of an expanding and more diverse society. We must advance knowledge of how rangeland ecosystems, socioeconomics, climate, and specific management practices change and interrelate over time. The distribution, abundance, and status of marine and coastal resources must be assessed in accurate and timely fashion, we must better understand interspecies and habitat-species relationships to improve predictions of sustainability, and patterns of human use upon sustainability must be better understood. We will have to develop and

implement adaptive and effective soil management strategies. Science must achieve a working understanding of the impacts of global climate change and demographic changes on crucial soil resources. We will have to advance our understanding of the responses and adaptation of biological diversity to changes in climate and land use. To better inform policy on water, we must improve our understanding of linkages among land uses, extractive consumption of water resources, and watershed resistance and resilience. Impacts on water supplies and associated risks from extractive uses and technologies, as well as carbon sequestration technologies, must be characterized and quantified. We must advance understanding of how policies and land uses impact water security, quantity, and quality over regional and national scales and assess how social and natural systems impact water security, quantity, and quality. We must advance and implement technologies for processing and distributing water to ensure sustainable, high-quality supply for human uses and maintenance of ecosystem services.

EDUCATION

The development of natural resource policy involves interactions among professional managers, the public, and elected officials. Public acceptance of natural resource plans and their effectiveness for achieving sustainable management depends upon the integration of scientific information and societal values. However, much of the American public has little understanding of the process by which scientific knowledge is gained. Hence, it is not surprising that citizens-and frequently their leaders-do not understand and often misconstrue scientific issues in discussions regarding the science and management of natural resources. Only by advances in popular understanding of scientific process, combined with more effective science communication, can discussion of natural resources issues be elevated. This goal may be achieved by including natural resources in K-12 education through incorporation into science, technology, engineering and mathematics curriculum and activities; strengthening natural resources curricula in higher education; improving the scientific literacy of our nation's citizens; effectively communicating scientific information to the general public; promoting natural resource stewardship and development of a conservation ethic; and promoting diversity in the natural resources professions.

The overall intent of the *Roadmap for Natural Resourc*es is to serve as a point of reference for discussions about these crucial resources. Further, the recommendations proposed in this roadmap should justify increased funding and collaboration for research, education, and outreach in the natural resources.

REFERENCE

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The Gullah/Geechee Fishing Association

Lonnie Gonsalves, Marybeth Brey, and Cecilia Lewis

The Executive Committee for the AFS Equal Opportunities Section

The AFS Equal Opportunities Section is dedicated to highlighting the value of diversity and increasing the participation of underrepresented groups within AFS and fisheries science. By sharing the stories of various groups, we are often able to see the common threads that link us as a multicultural society. Our section is working toward this goal by introducing a series of stories that showcase the value of fisheries, a common thread of interest among AFS members, to a diverse set of America's endemic cultural groups. This series will bring to you stories from multiple regions of the United States that focus on the social and economic roles that fisheries have traditionally held within these groups. By sharing these stories, we hope to further highlight the positive impact of fisheries science across the cultural spectrum of America. We also hope to call attention to issues and research questions that impact these groups and the United States as a whole.

The subject of our first excerpt is the Gullah/ Geechee Nation of the southeastern United States. Born from enslaved Africans brought to the United States predominantly from the region of West Africa, Gullah/Geechee people have cultivated the land and plied the waters of the Atlantic coast from southeastern North Carolina to northern Florida since the European colonization of North America. Throughout this time, the Gullah/ Geechee people have maintained many of the cultural facets of their African heritage. Their name refers to the African-based Creole language of Gullah, which was created by combining numerous African languages and Elizabethan English. It has an African syntax and phonetic structure. Dialogue between Gullah and English speakers on the Sea Islands resulted in the formation of a pidgin or dialect of Gullah called "Geechee." The people are also called both Gullah and Geechee. Their rich traditions, language, and customs have received greater acknowledgment among many coastal communities and historians over the last 20 years. This acknowledgment includes the passing of the Gullah/Geechee Cultural Heritage Act by the U.S. Congress in 2006 designating the "Gullah Geechee Cultural Heritage Corridor."

The establishment of the Gullah/Geechee Nation took place in July 2000 to protect the cultural



Queen Quet oyster replanting.



Captain Legree, the oldest GGFA member, at the Gullah/Geechee Seafood Festival.

legacy and rights of the Gullah/Geechee people. Similar to other coastal communities, this legacy includes a long-standing dependence upon fisheries, which play a major socioeconomic role for the Gullah/Geechee community. The fisheries that support the Gullah/Geechee people face a multitude of threats largely derived by man-made stressors in the form of urban, industrial, and agricultural development within coastal watersheds and overfishing. The Gullah/Geechee Fishing Association (GGFA) was founded in 2010 in order to strengthen advocacy and education efforts to protect fishing rights and the cultural heritage of the Gullah/Geechee people. The AFS Equal Opportunities Section was able to contact Queen Quet, Chieftess of the Gullah/Geechee Nation and a founding member and Secretary of the GGFA, to discuss the role of fisheries and the major fisheries-related issues impacting the Gullah/ Geechee Nation.

1. What is the mission of the Gullah/ Geechee Fishing Association?

- (a) To advocate for the rights of Gullah/Geechee and African American fishermen and fishery workers of the southeast.
- (b) To share traditional fishing methods with the next generation.
- (c) To restore access to the areas and factories needed to sustain the seafood industry in the Gullah/Geechee Nation and southeastern United States.

2. Can you provide us with a history of the Gullah/Geechee Nation (referred to henceforth as "the Nation") as well as the origins of GGFA?

That requires a *very* extensive answer. The best summary is that from 1999 to 2000 the Gullah/

Geechees came together from the Carolinas, Georgia, and Northeastern Florida to elect a "head pun de bodee," which means "Head of State" for their nation. They held a one-yearlong election, which resulted in Marquetta L. Goodwine being elected as the Head of State, global spokesperson, and liaison for Gullah/Geechees. The election was confirmed at a traditional African ceremony at Sullivan's Island, South Carolina, in Charleston County on U.S. federal property. A United Nations observer and U.S. federal employees were present to confirm this election and the official establishment of the Gullah/ Geechee Nation. The Gullah/Geechee Nation Declaration was presented at the enstoolment ceremony that now presented "Queen Quet" (www.QueenQuet.com), which became the official title name for the duly elected leader. One year later, they returned to this location to present their flag and constitution to the world and to have the 21-page constitution ratified and



Gullah/Geechee crab boil.



The Gullah/Geechee Fishing Association.

signed by the Wisdom Circle Council of Elders for the Gullah/ Geechee Nation. Go to www.gullahgeecheenation.com for more information.

3. Please explain the historical and current importance of coastal fisheries for the Nation, from both an economic and social standpoint.

Since the 1600s, Gullah/Geechees have historically harvested from the Intercoastal Waterway in the manner that their indigenous American ancestors did as well as their African ancestors did before their kidnapping along the west coast of Africa. Since that time, Gullah/Geechees continue to live from the land and the waterways. The top industries of the Gullah/Geechee Nation are agriculture, sea work (including harvesting, cast net making, and boat building), and tourism. Thus, the coastal fisheries are essential to the literal physical sustainability of Gullah/ Geechees and to the Gullah/Geechee Nation's economy.

4. What is the current state of the fishing industry in the Gullah/Geechee community? What are the major fisheries (shrimp, shellfish, sea trout, etc.)?

The Gullah/Geechee fishing industry has been in decline due to the harassment from the Departments of Natural Resources that fine Gullah/Geechee fishing families for harvesting in their historically traditional manner. They are fined for amounts and sizes instead of being recognized as a unique indigenous traditional group. In addition, harvesting is being done by fleets coming in from other areas. Climate change damage is taking place due to resort overbuilding as well. So, these threats have caused [declines in] blue crabs, oysters, shrimp, catfish, mullet, spot, croakers, etc., which are staples of the Gullah/Geechee fishing industry and diet.

5. What are the primary issues impacting Gullah/Geechee fishermen and the GGFA?

The primary issue for us at this point is getting special recognition established with the general assemblies so that Gullah/ Geechee traditional fishing can continue without jailing and fines taking place.

6. How do state and federal policies relating to fisheries regulations and environmental policy impact GGFA fishermen and the industries associated with fishing (distribution centers, markets and retail businesses, processors)?

They have priced Gullah/Geechees out of the creeks due to the numerous permit fees and fines. As a result, many stopped fishing altogether.

7. How can professional societies such as the American Fisheries Society assist with addressing issues that impact GGFA and the Nation?

They can work with us to help address the fact that Gullah/ Geechees are federally recognized as a national minority. Given that fishing is part of our Gullah/Geechee traditions that literally keep us alive, we need help getting our bill to the floor of general assemblies so that special IDs can be given to Gullah/ Geechee fishing families so that they can continue our traditions and pass these on to the next generation so that the culture will continue. We can also use your help with funding resources so that we can continue our work to educate others on ways to protect and restore our coastline and improve water quality and sustain the sea creatures that are necessary for us to have a healthy ecosystem and future harvests of seafood.



Ronald Goodwine of GGFA shows off his shrimp catch.



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UNIT NEWS

The Idaho Chapter of the American Fisheries Society would like to extend an invitation to members to join them for next year's annual meeting in Boise, Idaho, 3–6 March 2015 (www.idahoafs.org > 2015 Annual Meeting).

A Recap of This Year's Annual Meeting in Idaho Falls, Idaho

The meeting took place in February at the Shilo Inn with 233 attendees, of whom 33 were students-tremendous volunteers-from the Palouse and Portneuf student units. The topics of the meeting included passive integrated transponder tag detection systems, geospatial information using Google Earth, and hatchery innovations. President Elect Tom Curet organized the plenary session, under the theme: "Stream Connectivity in Fisheries Management: Fix It, Break It, or Leave It?" Plenary speakers included Jeff DiLuccia, Chris Beasley, Dave Moser, Dan Isaak, and Helen Neville, all of whom highlighted the fisheries management issues facing many western states, and the struggle to protect native species from nonnative invasions. Forty-two



Students and professionals mingle during the student mixer sponsored by the Palouse and the Portneuf student units and the Idaho Chapters Mentoring Committee.

technical presentations were made with two concurrent sessions, a poster session with 12 posters, a welcome social, a mentoring social, and student mixer pizza feed, and a sixth annual "Spawning Run." Despite threats of ice, snow, and rain, the sun came out long enough to provide excellent conditions for the Spawning Run and they had the best participation since this event started. A shorter walking route and some rather risqué outfits may have also contributed to the success.

The Chapter also recognized Dan Isaak and Brett High as Outstanding Fisheries Professionals. Paul Kline was awarded the R.L. Wallace Native Fish Conservation Award for his efforts in getting Sockeye Salmon back to Idaho. Paul Kline was not able to attend the meeting but was able to accept the award through Ed Shriever holding a cell phone to the microphone. Michael Quist received the award for Outstanding Mentor, and many others received awards and recognition for their distinguished service to the Idaho Chapter. In addition, several scholarships to both graduate and undergraduate students were awarded.

> Jim Chandler, President Elect Idaho Chapter E-mail: JChandler@idahopower.com



FRESHWATER, FISH, AND THE FUTURE

Global Conference on Inland Fisheries: Bringing a New International Focus

The Global Conference on Inland Fisheries was pleased to host a successful side event at the 31st Session of the Committee on Fisheries (COFI) at the Food and Agriculture Organization of the United Nations (FAO). The event featured several speakers who talked about the role of partnerships in inland fisheries sustainability. The side event culminated with the signing of a letter of intent by Michigan State University Provost June Pierce Youatt and FAO Assistant Director-General Árni M. Mathiesen to partner on several inland fisheries programs, including the Global Conference on Inland Fisheries, a new visiting scholar program named in honor of Robin Welcomme (former Chief of the FAO Inland Water Resources and Aquaculture Service), and an internship program matching promising MSU graduate students with FAO mentors.

• Read the press release here: www.fao.org/fishery/nems/40606/en

• photos of the event are available here: www.flickr.com/photos/americanfisheriessociety/ sets/72157645142832494/ and here: www.flickr.com/photos/faonews/sets/72157644693791117/.

During the official COFI meeting, 23 nations and 3 international non-governmental organizations made interventions in favor of having inland fisheries as a part of the COFI agenda and 9 nations and 1 NGO spoke in favor of holding an inland fisheries conference specifically.

REGISTRATION NOW OPEN

Registration is now open for the Global Conference on Inland Fisheries, 26–30 January 2015, at the headquarters of the Food and Agriculture Organization of the United Nations (FAO) in Rome, Italy. The registration rate has been set at US \$300 for all attendees, except for those receiving travel support to attend the conference. Registration is being hosted by the American Fisheries Society, so AFS members may use their saved log-in information to register. All others can quickly create a new account.



Due to FAO security requirements, all attendees must preregister for the conference by 23 January 2015. There will be no on-site registration. Register online at http://fisheries.org/ events-listing-registration and see the conference website at www.inlandfisheries.org for more information on hotels and logistics.

The Global Conference on Inland Fisheries is organized by Michigan State University and FAO. 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).

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AFS ANNUAL MEETING 2015

145th Annual Meeting of the American Fisheries Society: Second Call for Papers http://fisheries.org/meetings

Start planning a trip to Portland from 16 to 20 August 2015 for the 145th Annual Meeting of the American Fisheries Society, cohosted by the Society, the Western Division, and the Oregon Chapter in downtown Portland at the convention center. The Program Committee has decided to go "theme-less" for the 2015 meeting, in hopes of encouraging a more diverse submission pool of symposia, contributed papers, and posters, with an aim to gather proposals covering multidisciplinary and interdisciplinary topics—including aquatic resources—as well as those interesting our international and regional audiences.

SYMPOSIA

- Proposals for Symposia must be submitted by 16 January 2015.
- The list of accepted Symposia proposals will be posted on 13 February 2015.
- If accepted, organizers must submit a complete list of confirmed presentations and titles by 6 March 2015.
- Abstracts for Symposium oral presentations must be submitted by 13 March 2015.

CONTRIBUTED PAPERS AND POSTERS

- Those who wish to present in Contributed Papers or Poster sessions at the 2015 AFS meeting are required to submit abstracts by 13 February 2015. This includes Student Presentations.
- Confirmation of acceptance or refusal of abstracts will be communicated by 17 April 2015. (Student presentations will be considered for a "best presentation" award if the student fills out additional application paperwork available at www.fisheries society.org/education/BSP.htm.)

FOR MORE INFORMATION: VISIT FISHERIES.ORG > ANNOUNCEMENTS

AFS does not waive registration fees for presenters at symposia or contributed papers sessions or workshops. Registration forms will be available on the AFS website (http://fisheries.org/meetings) in May 2015; register early for cost savings.

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IN MEMORIAM

Billy Frank, Jr., passed away on 5 May 2014. He was so many things to us—a tribal leader, an advocate for tribal treaty and civil rights, a relentless champion for aquatic conservation and the environment, a great communicator and mentor, but, most important, a family man. He was able to communicate his ideas about conserving nature and the importance of traditional indigenous values to young children as well as politicians.

Born into the Nisqually Indian Tribe on 9 March 1931, Frank was raised on the Nisqually River. He was first arrested for exercising his right to fish in 1945 at the age of 14. In the 1950s Frank did a stint in the Marines and was a utility lineman in the 1960s. However, he always came back to the river to fish. He was instructed by his father to always go back to the river, even if under threat of arrest by state officers. By the time federal Judge Boldt made his decision in 1974, Frank had been arrested over 50 times along with other tribal members in what is now called the "Fish Wars" of the late 1960s and early 1970s.

A few years earlier, Richard Sohappy (of the Yakama Nation) was involved in a fishing rights case on the Columbia River. In 1969, federal Judge Belloni ruled in *United States v. Oregon* that the tribes were entitled to a fair share of the fish and the states could no longer use conservation to discriminate against tribal fisheries. A few years later, Frank and other tribal members were at the forefront of the "Fish Wars" on the Nisqually, Puyallup, and Green rivers. Finally, the federal government filed suit on behalf of the 20 western Washington treaty tribes against the state of Washington. In 1974, in the landmark case *United States v. Washington*, Federal Judge Boldt issued a decision with several important holdings, some of which are (1) that a fair share meant 50% of the harvestable fish as interpreted from the treaties; (2) that these tribes comanaged the fishery with the state of Washington; and (3) that no state regulation could be applied against tribal fishing unless a conservation need could be demonstrated. This decision was upheld first by the 9th Circuit Court of Appeals and then by the Supreme Court in 1979. Subsequently, the fundamental allocation principle was extended to other species of fish and shellfish in subproceedings of *United States v. Washington*.



Billy Frank, Jr.

Frank also had a positive effect on the younger generation of Native Americans who came after the "Fish Wars." Many, after learning about the struggle and oppression that our elders—including Frank—had been through, wanted to know why it was this way. Having a perspective of this struggle stimulated the younger generation to better understand our treaties with the federal government and how our past leaders ensured that our traditional foods would not be ceded to the United States. The past leaders agreed to allow settlement (statehood) of nonnatives into our

By the time federal Judge Boldt made his decision in 1974, Frank had been arrested over 50 times along with other tribal members in what is now called the "Fish Wars" of the late 1960s and early 1970s. areas, but our leaders refused to give up our inherent rights to the fish and other traditional foods. Frank understood this quite well, and he was willing to stand up for these inherent rights. Later, our younger tribal members realized that the treaties did not give us anything; these were inherent exclusive rights to fish that our forefathers had reserved in the treaties with the United States. In 2007 Frank wrote,

People forget that non-Indians in western Washington have treaty rights, too. Treaties opened the door to statehood. Without them, non-Indians would have no legal right to buy property, build homes, or even operate businesses on the millions of acres Tribes ceded to the federal government. Treaty rights should never be taken for granted—by anyone.

Frank never stopped fighting for the fish and the environment. He was the fisheries manager for the Nisqually Indian Tribe from 1975 to 1988. After the Boldt decision, the Northwest Indian Fisheries Commission was formed and he chaired the commission from 1977 to 1978 and from 1981 to 2014. Frank was passionate about the aquatic environment and everything that affected marine life. His energy and conviction about fighting for our brothers and sisters in the water positively influenced many Native and non-Native peoples to make a difference for our aquatic resources. Frank would not slow down; he was at many meetings this past spring: the 40th anniversary of the Boldt Decision at the Squaxin Island Tribe; his 83rd birthday party at the Swinomish Tribe; an intertribal hunting and wildlife policy meeting at the Tulalip Tribes; and a Tribal Leaders Summit with Secretary of Interior Sally Jewell and Representative Derek Kilmer at the Suquamish Tribe. At each gathering Frank would give you a hug and encouragement and a sense that all was good in the world. You always knew that you would be greeted with a sincere smile and a hug and a question, "How is everyone doing back home?" and you would begin by describing your most recent fishing matters and harvest conditions. And then he would ask about some of the people by name and you could give an update on how each was doing. He really was a giving and generous presence to be around.

Even after the Boldt decision in 1974, and affirmation of the U.S. Supreme Court in 1979, there were still problems. Even though the court case was positive in that it recognized the tribes had reserved their fishing rights in the Stevens treaties of 1855–1857 and that the state had to be comanagers with the tribes, there were still numerous disputes with the state of Washington in the early 1980s. Many continued to go to Frank for advice on what to do during those trying times. But Frank did not tell anyone what to do; instead, he encouraged everyone to do and be their best and to remember our people—the ones who we're fighting for. We are the salmon people. We will miss our friend but will not forget, and we will continue with what he has taught us: To respect ourselves and each other and be a warrior for the people and the natural world.

David Close, Mel Moon, and Colin Frank

Fish Have No Nationalities, But Harvest Does

Doug Austen, AFS Executive Director

"Fish have no nationalities, but harvest does," is the quote from Mr. Kostakopoulus, Director of Fisheries for Greece, used by former AFS President Larry Nielsen to introduce his article about the development of the first World Fisheries Congress (Nielsen and Wespestad 1993). Those words, according to Nielsen, simply and elegantly summarized the rationale for the development of the first World Fisheries Congress in Athens, Greece, in 1992. Those words have also been, at least in part, the philosophical basis for other key developments that have shaped the nature of the international fisheries activities of AFS. Winding the tape back six years to 1986, the characterization of fisheries by Kostakopoulus was likely also permeating the discussions of the representatives of the 22 fisheries societies convened at the initial Congress planning event, hosted in Manila by the Asian Fisheries Society. Fish stocks continue to move across geopolitical boundaries, disrespecting any demand for passports or visas. Harvest of freshwater and marine species continues to challenge our management systems. Greatly expanded aquaculture production in forms barely envisioned in 1992 have created immense food production capacity while also presenting challenging environmental and fisheries management impacts. Insert into the equation the impacts of climate change, the continual expansion of urban landscapes, hydropower developments, and other effects of the anthropocene and it is clear that the need for enhanced cooperation and collaboration among fisheries professionals is greater now than ever before.

The American Fisheries Society was a principal early leader of the move toward these international partnerships by proposing the World Fisheries Congress with the goal to "bring together fisheries scientists

and managers in a nongovernment, nonpolitical, academic setting devoted to the sharing of research findings and the application of collective knowledge in enhancing the scientific management of fisheries resources for sustained human benefits." After the 1986 Manila planning meeting, an international steering committee was formed in 1987, an Advisory Committee with an expanded membership of 26 societies was formed and convened in Tokyo in 1988, and the first event was held in Athens, Greece, in 1992. Out of that event emerged the concept of a World Council of Fisheries Societies (WCFS). The Council now provides oversight and is the central coordinating body for the quadrennial congresses. As part of the AFS co-evolution during this time period, the International Fisheries Section (IFS) was formed in 1997. The International Fisheries Section has an active set of gatherings at each AFS meeting, and a broad set of purposes: support and promote worldwide fishery educational, organizational, and research efforts; increase North American fishery scientists' awareness of the interests, needs, and contributions of their colleagues worldwide; increase awareness and cooperation of the American Fisheries Society and its members in international fisheries; and assist in the international exchange of information, including the provision of technical advice, among fishery workers of all nations (http://international.





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

fisheries.org). The Section has become one of the main supporters of the World Fisheries Congress since 1997. The upcoming 7th Congress, June 2016, in Busan, Korea, is taking shape (http://youtu.be/G9kgFNBeV11) and will undoubtedly have a significant AFS presence.

The World Council of Fisheries Societies (http://fisheries. org/about-the-wfc) was developed to, at least in part, institutionalize this Congress. The main aim of the Council is to promote international cooperation in fisheries science, conservation, and management. This includes sharing sustainable management practices, encouraging excellence in fisheries research, and

Insert into the equation the impacts of climate change, the continual expansion of urban landscapes, hydropower developments, and other effects of the anthropocene and it is clear that the need for enhanced cooperation and collaboration among fisheries professionals is greater now than ever before.



Experimental or Sampling Gill Nets - Trammel Nets - Seines - Trap/Fyke Nets

Continued from page 440 (Policy)

Those sublethal effects warrant our attention and deserve full consideration in decisions related to lethal take. Evaluating one without the other demands a broader research agenda, a more inclusive management construct, and strong policies to ensure that decisions are based on consistent applications of what I view as an ecosystem-based approach. In what might be a simplistic comparison, imagine if we only worried about the effects of climate change on ocean chemistry and acidification rather than the fuller sweep of changes from water temperature, relative sea levels, and new rainfall patterns across our continent. To me, that's as short-sighted as attempting to manage a habitat-dependent fish stock based solely on fishing mortality.

In my opening I mentioned both beneficial and adverse impacts. That was intentional. We need that breadth whether we're considering physiological or behavioral impacts from our decisions. If we restore a lake, let's evaluate success based on more than just fish counts. More robust adults should be celebrated just as we would welcome a strong year class. If we're restoring habitats, our goal should be a healthy roster of native species rather than opportunistic invaders.

Though I feel that our science is more robust on impacts, we may be better at recognizing incremental benefits than sublethal impacts. Perhaps that reflects the urgency to claim success. Hopefully that perceived gap will narrow as these subtle changes are important to us and society. These seemingly small messages can be valuable harbingers of the future, where we might choose to do less of one thing (as when Rachel Carson cautioned us not to use DDT indiscriminately) or more (such as the importance of physical shoreline features in creating successful mitigation projects). We'll all reap the benefits of a broader approach.

Continued from page 475 (Executive Director)

promoting the use of science in making decisions about the sustainable use of fishery resources. The principal activity of the Council has been to ensure that the Congress is hosted and successfully convened every four years. The Council solicits bids for the Congress and is responsible for the final selection of the host. In turn, the Congress acts as the venue for the only true gathering of the Council members. The current WCFS president is long-time AFS member Doug Beard, head of the U.S. Geological Survey National Climate Change and Wildlife Science Centers and the vice president is Shugo Watabe from the Japanese Society of Fisheries Science. Limited staff support is provided by AFS, with the lead being the Executive Director who is designated as Secretary General of the Council.

There is a great unrealized potential for the Council but like many such international organizations, the challenges of distance, language, and resources are substantial. In addition to the main goal of promoting cooperation on major challenges of science, conservation, and management, the charter

includes goals such as developing uniformity of nomenclature and standardization in matters such as information storage and retrieval, developing assistance for member organizations, and adoption of common practices and policies. With little funding and no dedicated staff, these are lofty challenges. Yet the need for such an organization as the Council persists and, in fact, is likely greater than ever as the world, like the fish and fisheries mentioned by Kostakopoulus, becomes increasingly interconnected. My intent as Secretary General is to explore ways to substantially increase the attention paid to the Council and re-energize its base. We've lost contact with many of the fisheries societies who were part of the early organization in the late 1980s. With the 7th Congress fewer than two years away, we have a great incentive and perfect opportunity to move the Council into a new phase of activity. If you have an interest in helping with the World Council or would like information on the 2016 World Fisheries Congress, please contact me at dausten@fisheries.org.

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JOURNAL HIGHLIGHTS

North American Journal of Fisheries Management Volume 34, Number 5, October 2014



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A Deckhand "Fester" Story

When I was a kid in the 1950s and 1960s, I lived in the Southern California seacoast town of Santa Monica. I had no life other than fishing (and unsuccessfully chasing girls) and lived much of every summer and every weekend on the sportfishing party boats. I occasionally helped out on the boats as a deckhand, and every deckhand I ever met had a storehouse of what I call "fester" stories. These usually involved some sort of awful accident that occurred while working on a party boat and usually involved hooks caught in various body parts or fish spines breaking off in these same parts. Almost inevitably, the wound became infected, swelled up, and festered. Rarely did the deckhand, poorly paid and uninsured, seek medical help. Rather, determined not to miss a day of work, the suppurating wound was cut open with a filleting knife and allowed to drain (perhaps down a boot?), while the gallant deckhand kept on gaffing fish and untangling lines.

Dr. Findlay Russell is one of the world's authorities on venomous animals, and here is his contribution to this folk art, with a story of his experiences with California Scorpionfish (*Scorpaena guttata*; Russell 1965):

As a "bait boy" on the Billings [sportfishing] Barge off Ocean Park, California during the 1930s, I received numerous stings from this fish. I recall that some of them were so painful that they caused me to vomit and on several occasions precipitate episodes of migraine. My fingers were often swollen for several days following an envenomation. I do not recall that I ever became immune to the pain produced by the venom, even though I suspect I must have been stung at least twenty times over a 4-year period. On some days, two of us cleaned as many as seventy-five of these fish during a single afternoon, and at least one person was stung every day or so while handling, or mishandling, Scorpaena guttata.

This is an excellent, and really quite subtle, fester story. Not only did young Russell actually throw up after being stung, he also got a migraine, and his fingers were swollen for days after. However, note that despite this he apparently just kept on working.

Excerpt from Milton Love's (AFS Member 2012) book: Certainly More Than You Want to Know about the Fishes of the Pacific Coast

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California Scorpionfish, Scorpaena guttata. Photo credit: Merit McCrea.

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

More events listed at www.fisheries.org

DATE	EVENT	LOCATION	WEBSITE
September 28– October 2, 2014	ICHE 2014 — 11th International Conference on Hydroscience & Engineering	Hamburg, Germany	http://iche2014.baw.de/why/index. html
October 1–3, 2014	EMSEA — The Second European Marine Science Educators Association Conference	Gothenburg, Sweden	www.emsea.eu/conference-2014-goth- enburg
October 12–16, 2014	WCMB-2014 — 3rd World Conference on Marine Biodiversity	Quingdao, China	http://wcmb2014.csp.escience.cn/dct/ page/1
October 14–17, 2014	Aquaculture Europe 2014	San Sebastian, Spain	www.marevent.com
October 20–24, 2014	$rac{\mathtt{A}}{\mathtt{S}}\mathbf{F}$ 41st Annual Meeting of the Alaska Chapter of the American Fisheries Society	Juneau, Alaska	www.afs-alaska.org/annual-meetings/ fall-2014
October 23–24, 2014	$rac{\mathbf{A}}{\mathbf{S}\mathbf{F}}$ National Workshop on Large Landscape Conservation	Washington, DC	www.largelandscapenetwork.org/2014- national-workshop/
October 26–30, 2014	Aquatic Resources Education Association Conference	Traverse City, MI	www.areanet.org/conferences.htm
October 26–31, 2014	Ocean Optics XXII	Portland, ME	www.tos.org/oceanopticsconference/
November 17–21, 2014	2nd International Ocean Research Conference	Barcelona, Spain	www.tos.org/2nd_ocean_research.pdf
December 3–4, 2014	$\frac{1}{S}$ 1 4th Flatfish Biology Conference	Westbrook, CT	http://nefsc.noaa.gov/nefsc/Milford/ flatfishbiologyworkshop.html
January 21–23, 2015	Texas Aquaculture Association-45th Annual Confer- ence & Trade Show	Kemah, TX	www.texasaquaculture.org
January 26–30, 2015	Global Conference on Inland Fisheries	Rome, Italy	inlandfisheries.org
February 16–19, 2015	$\frac{\mathtt{A}}{\mathtt{ST}}$ 2015 Annual General Meeting, WA-BC Chapter of AFS	Richmond, British Columbia	wabc-afs.org/2014/06/3530/
February 19–22, 2015	Aquaculture America 2015	New Orleans, LA	www.marevent.com
February 22–27, 2015	Aquatic Sciences Meeeting	Granada, Spain	http://aslo.org/meetings/
March 4–6, 2015	$\frac{1}{SF}$ 2015 Idaho Chapter Annual Meeting	Boise, ID	www.idahoafs.org/2015AnnualMeeting/
May 17-19, 2015	NPAFC International Symposium on Pacific Salmon and Steelhead Production in a Changing Climate: Past, Present, and Future	Kobe, Japan	www.npafc.org
May 26-30, 2015	World Aquaculture 2015	Jeju Island, Korea	www.was.org
June 22–24, 2015	Fish Passage 2015	Groningen, Netherlands	www.fishpassageconference.com
July 26-31, 2015	World of Trout	Bozeman, MT	www.troutcongress.org
August 16–20, 2015	$\frac{A}{ST}$ AFS Annual Meeting	Portland, OR	http://fisheries.org/meetings
February 22-26, 2016	Aquaculture 2016	Las Vegas, NV	www.marevent.com
September 19–22, 2016	OCEANS 2016	Monterey, CA	www.oceanicengineering.org
February 19–22, 2017	Aquaculture America 2017	San Antonio, TX	www.marevent.com

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