Linking Ecosystems, Food Webs, and Fish Production: Subsidies in Salmonid Watersheds

Implementation of Genetic Conservation Practices in a Muskellunge Propagation and Stocking Program
A Winter install of a pass-by antenna system on the East Fork South Fork of the Salmon River, Idaho.

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Inputs to salmonid stream food webs can include local production of benthic invertebrates, organic matter and invertebrates drifting down from fishless headwaters, marine subsidies from returning adult anadromous fishes, and terrestrial subsidies of invertebrates, nutrients, and plant matter.
Engaging Deeper Currents

I never had been more miserable in my life, standing in the aisle of a crowded “minibus,” wedged so tightly among fellow passengers that sweat mingled through our soaked clothing. Personal space ended at our skin. There was no air conditioner. We were caught in a traffic jam in the late afternoon rush hour of downtown Kuala Lumpur, Malaysia. Exhaust fumes burned our eyes and some among us started coughing. Then it started raining and persons fortunate enough to actually have seats and to be seated by windows closed the windows.

I was half a world away from the mountains, streams, and forests that had been my haunts prior to joining the U.S. Peace Corps. In that other world, my days had revolved around hunting, fishing, whitewater canoeing, backpacking, and my university studies. In that other world, I depended on my surroundings for inspiration and renewal. Wild and lonely places and the life that dwelled within those places made me happy and I pursued that happiness.

Joining the Peace Corps and coming to Malaysia had been with that intent—the pursuit of happiness. I understood the broader mission of my assignment but as a young man, my real purpose was to engage adventure and chase dreams. Now, here I was, caught in a traffic jam in the huge Southeast Asian city I’d called “home” for more than half of my two-year assignment, slowly cooking in a vehicle turned crock pot. I’d been caught in traffic jams before but never had I experienced misery to this degree. Aside from occasional trips into the countryside with my zoology students from the National University of Malaysia, the transient freshness and bird song of tropical mornings, and evenings spent with friends sampling wonderful Malaysian cuisine, the world that surrounded me was, for the most part, one of concrete, pavement, noise, congestion, and acrid air. I enjoyed my work at the university but otherwise I was not a happy man.

Mine was a shared misery on that minibus. We all sat or stood in stoic resolve. The absurdity of our condition pushed me deeper and deeper into myself. I missed my mountains. I missed solitude. I missed the quiet. I missed my hunting dog. Then, from those depths into which I’d pushed my thoughts a different sort of warmth emerged. Slowly it swelled within me until it finally erupted as laughter. I tried to suppress it but it would not be suppressed. The other passengers on that minibus quickly looked at me and I could see on their faces that most of them thought that the “European” in their midst had finally cracked. Those looks, however, were quickly and magically transformed when, speaking in the local language, I simply pointed out to those around me the absolutely ridiculous situation we’d all gotten ourselves into. A man beside me also started laughing quietly to himself. He was joined in laughter by a very elderly woman and within less than a minute that entire bus was rocking. Malaysians are wonderful people.

It was a transforming experience for me personally. I realized (admittedly late in life at age 28) that happiness is an individual’s personal responsibility and that I should not depend on my surroundings for it. It had to come from within. A half hour later, as I stepped off that bus and started walking to the little house in a residential suburb where I lived, a quieter realization enveloped me. Sharing that internally-derived happiness with others had transformed the world of my fellow travelers, even if only momentarily. This realization brought with it a profound sense of satisfaction, and that satisfaction overwhelmed the more transient happiness I’d experienced during the afternoon bus ride.

Those of us with professions grounded in the sciences can find ourselves in the pressure cooker of our own version of a Malaysian minibus. We voluntarily climb on board, usually in our youth, because we believe that it will take us where we want to go, into a world where we can be surrounded by scientific adventure and purposeful living. We are driven by passion for the mechanisms of science and for what the results of science can do for things, places, and people we care about. We pursue visions, dreams… and happiness. We commit ourselves to the journey and once on it discover that we are among fellow travelers, sometimes lots of them. It can become very crowded at times on that bus. Within our ranks, we discover people quietly enduring the ride with various degrees of engagement with the world beyond themselves. Some are obviously dwelling in a dimension of separate peace and we sense that they have very likely experienced transitions from the pursuit of happiness to deeper elements of satisfaction. However, some of the travelers sit or stand stoically and seem to be sad and lonely people. The surroundings apparently are not what they expected when they started the journey. The bus does not always take the scenic route.

Science can be a beautiful world, but science is also a deadly serious world that is sometimes unlovely and unloving. It is a world that thrives on passion, creativity, inspiration, revelation, and the wonderful
Freshwater fishing participation up in 2009

The Recreational Boating and Fishing Foundation (RBFF) released its “2010 Special Report on Fishing and Boating,” conducted by RBFF and The Outdoor Foundation. The report reveals 41 million U.S. anglers participated in freshwater fishing in 2009, an increase of 2% from 2008. In addition, anglers under 18 years of age made up more than 23% of all fishing participants. However, overall fishing participation was down slightly from 48.2 million participants in 2008 to 48 million in 2009, or 17% of the U.S. population aged 6 and up.

“Although overall participation is down slightly from 2008, we’re delighted to see that freshwater fishing, which is by far the most popular type of fishing in the United States, has been able to reverse a two-year downward trend into a one-year positive increase in participation,” said RBFF President and CEO Frank Peterson.

In 2009, fishing participants made 996 million outings (down slightly from 1 billion in 2008). More than 45% of fishing participants said the economy impacted how often they participated in outdoor activities and more than 85% of those fishing participants planned to spend more time participating in outdoor activities in 2010. The report also notes that 19.4% of U.S. fishing participants live in the South Atlantic region, a greater percentage than any other region.

Freshwater fishing was most popular among young people, with more than 22.5% participation under the age of 18 (down slightly from 24.6% in 2008). The largest age bracket of saltwater fishing participants was over the age of 45, making up 48.1% of all participants. There were 11.2 million fishing participants ages 6-17, unchanged from 2008. Youth participation in fishing drops from 25.4% among those ages 6–12 to 19% among those ages 13–17. Time, other sports/activities, schoolwork, TV, and video games were cited as barriers. Female participation in fishing fell significantly more than males through adolescence, down 44% as opposed to 12.9%.

The full report is available at the RBFF website at: www.rbff.org/uploads/Research_section/SpecialReportonFishingandBoatingWEBFINAL.pdf.
[Special Section: Data-Poor Fisheries]
A Case Study in Successful
Management of a Data-Poor Fishery
Using Simple Decision Rules: the
Queensland Spanner Crab Fishery.
Catherine M. Dichmont and Ian W.

[Special Section: Data-Poor Fisheries]
Management Strategy for Sedentary
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[Special Section: Data-Poor Fisheries]
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Rockfish Conservation Strategy.
K. Lynne Yamanaka and Gary Logan, pages
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[Special Section: Data-Poor Fisheries]
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Lessons from the New Zealand
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Climate change affecting walleye spawning timing

The possible effects of climate change on fish have been considered hypothetically, but where should one start looking for clues about whether they actually have begun? In a recent article in *Transactions of the American Fisheries Society*, Minnesota researchers examined historical records of the timing of walleye spawning and compared them to ice-out dates, the date when frozen lakes lose their ice cover each spring. Walleye spawning generally occurs soon after ice-out each year and the spawning dates have been recorded as part of hatchery egg collection programs since 1938. The researchers plotted walleye spawning dates at 12 locations against ice-out dates since 1970 and found that walleye spawning began one-half to one full day earlier for each day earlier that the ice-out moved forward in the calendar. Overall, both ice-out and walleye spawning are trending earlier in Minnesota, and the timing of walleye spawning may be a good indicator of climate change. Timing of Walleye Spawning as an Indicator of Climate Change, by Kristal N. Schneider, Raymond M. Newman, Virginia Card, Sanford Weisberg, and Donald L. Pereira. *Transactions of the American Fisheries Society* 139:1198-1210.

Seeing into Lake Ontario’s fishing future

Scientists often use computer models to simulate the effects of certain conditions on fish populations, often attempting to predict the consequences of human or natural events. In a recent article in the *North American Journal of Fisheries Management*, Cornell University scientists instead use a model to predict the future of recreational fishing on Lake Ontario. Lake Ontario is New York’s largest sport fishery, with anglers spending more than $54 million annually for charter services, bait and tackle, restaurants, lodging, etc. The lake’s recent history in recreational fisheries has been eventful, with introduced species and disease, varying levels of stocking, and changing fish productivity due to pollution control and zebra mussel establishment. The Cornell scientists narrowed down the main influences on the number of fishing boat trips on Lake Ontario to a few variables. First, time is a factor as interest in Pacific salmon fishing on the Great Lakes may be waning, and interest in fishing generally is declining as part of a long-term nationwide trend. Second, fishing boat trips show a pattern of following salmon stocking trends, increasing when fish stocking is higher and decreasing when stocking is lower. Finally, the number of fishing boat trips per year also was moderately correlated with the average number of black bass harvested per trip. Using this model to predict future trends, the researchers forecast a decline in fishing boat trips of 32% over the next five years. The authors suggest that New York’s lakeside communities may want to consider proactive programs to counteract the trend predicted in this model. *Sportfishing Participation on Lake Ontario: Modeling the Past, Predicting the Future*, by Nancy A. Connelly and Tommy L. Brown. *North American Journal of Fisheries Management* 30:821-830.

Revisiting discard reduction

Efforts are underway to reduce the number of discards—fish that are thrown back—in commercial trawl fisheries worldwide. Fish are often discarded because they are too small, low value, or the wrong species, or due to fisheries regulations. Most of the efforts to reduce discards have focused on technological solutions such as changing the fishing gear used. But how do fisheries managers know if these measures are really working? In a recent article in the *North American Journal of Fisheries Management*, scientists from the Universidad Nacional del Comahue in Argentina sought to examine whether a change to larger fishing net mesh sizes made 10 years ago to reduce the capture of juvenile hake in the San Matías Gulf was actually effective. The researchers studied fisheries observer and landing data, and also experimentally towed nets in the gulf. They found that the catch and discard of juvenile hake had not declined with the larger net mesh size and in fact had increased. Possible reasons include the limited data used when setting the new mesh size, the slow adoption of the new nets by fishermen, changes to the nets made by fishermen adding round straps, and the lack of monitoring and enforcement in the fishery. When Conventional Fisheries Management Fails to Reduce the Catch and Discard of Juvenile Fish: A Case Study of the Argentine Trawl Fishery in San Matías Gulf, by M. Alejandra Romero, Raúl A. González, and Matías Ocampo-Reinaldo. *North American Journal of Fisheries Management* 30: 702-712.
AFS Gulf Oil Spill Task Force

The American Fisheries Society has embarked on the creation of a Gulf Oil Spill Task Force as part of its overall initiative to address the current and future impacts of the Deepwater Horizon oil spill in the Gulf of Mexico. The mission of the proposed seven-member task force will be to provide direction and oversight for all AFS activities and initiatives addressing the impacts of the oil spill in the Gulf of Mexico on the region’s fishery resources and the economies that depend on them, short and long term.

The task force will have the following objectives:

1. Assist federal agencies, regional organizations, and states in the:
   a. Technical review of proposals, reports, and documents;
   b. Development of technically sound and equitable means for allocation of funds designated for research and restoration; and
   c. Identification of relevant data sets.
2. Coordinate with federal agencies, regional organizations, and states to ensure that timely and readily understandable information regarding the oil spill is made available via the AFS website and other AFS outlets.
3. Develop summary documents and handouts that clearly describe the:
   a. Status of the oil spill;
   b. Its current and projected impacts on regional fisheries resources and their dependent economies; and
   c. Agency and regional organization responses, in terms of addressing the impacts.
4. Ensure that the best scientific information is used to address the impacts on and restoration of fisheries resources affected by the oil spill.

The oil spill task force is just one part of an overall initiative proposed by AFS. The initiative also includes plans for coordination with federal and state agencies, briefings on the spill impacts, and information dissemination about the spill and its impacts to the public.

House hearing on Gulf oil spill

On 24 June 2010, the U.S. House Natural Resources Committee Subcommittee on Insular Affairs, Oceans and Wildlife held a hearing entitled “State Planning for Offshore Energy Development: Standards for Preparedness.” The hearing featured testimony from various state and non-governmental personnel, including William Walker of the Gulf of Mexico Alliance, Kristen Fletcher of the Coastal States Organization, Matt Menashes of the National Estuarine Research Reserve Association, and Dennis Takahashi-Kelso of the Ocean Conservancy.

During the hearing, witnesses expressed many viewpoints and recommendations on how the spill and the spill clean up itself are affecting the region’s aquatic organisms. Fletcher recommended that Congress provide for the evaluation of the impacts of dispersants on natural resources in the water column, at depth, offshore, nearshore, and the coast and how dispersants affect different life stages of finfish and shellfish. She stated that such an evaluation should include the impacts of dispersants on the persistence of oil in ecosystems due to oil settling and being re-suspended. Walker testified that the Mississippi Department of Marine Resources decided that their first priority was the protection of the critical marsh habitat that serves as nursery grounds and protective refuge for Mississippi’s juvenile shrimp, crab, and fish species.

Menashes testified that he believed that there are funding gaps for the biological inventory needs of reserves and other areas affected by the spill, and that an additional $2.5 million is needed to aid in these efforts. Takashashi-Kelso concluded the panel’s testimony by stating that decision making based on a detailed review of only one sector of the ocean and coasts is insufficient. He elaborated by stating that there is a need for a more complete approach to planning and risk management that prioritizes ecosystem health.

All participants acknowledged that if implemented the recommendations would not guarantee that another oil spill would never happen, but they would give a better understanding and accounting of the risks associated with such an event in the future.

Spiny dogfish stock recovered

The National Oceanic and Atmospheric Administration (NOAA) announced that the spiny dogfish stock has been rebuilt. This announcement will now allow catch levels for the dogfish fishery to increase from 12 million lbs. to 15 million lbs. this year. This catch level is consistent with the level set by the Atlantic States Marine Fisheries Commission for state waters. Vessel trip limits will remain at 3,000 lbs. for the fishing year, which runs from 1 May 2010 to 30 April 2011. The higher landing limit will allow a larger harvest while still accounting for concerns about relatively low numbers of mature females expected to enter the spawning population in the next few years.

New scientific information defining the size for a rebuilt dogfish stock became available in April, after catch level recommendations were made by the New England and Mid Atlantic Fishery Management Councils. The councils, which consist of fishing industry, state agency, and non-governmental organization representatives, develop management measures for this species that then must be approved by NOAA. The councils recommended NOAA Fisheries set a quota that would allow for more stability in future landings in this fishery.
Subsidies in Salmonid Watersheds

ABSTRACT: Physical characteristics of riverine habitats, such as large wood abundance, pool geometry and abundance, riparian vegetation cover, and surface flow conditions, have traditionally been thought to constrain fish production in these ecosystems. Conversely, the role of food resources (quantity and quality) in controlling fish production has received far less attention and consideration, though they can also be key productivity drivers. Traditional freshwater food web illustrations have typically conveyed the notion that most fish food is produced within the local aquatic habitat itself, but the concepts and model we synthesize in this article show that most fish food comes from external or very distant sources—including subsidies from marine systems borne from adult returns of anadromous fishes, from fishless headwater tributaries that transport prey to downstream fish, and from adjacent streamside vegetation and associated habitats. The model we propose further illustrates how key trophic pathways and food sources vary through time and space throughout watersheds. Insights into how food supplies affect fishes can help guide how we view riverine ecosystems, their structure and function, their interactions with marine and terrestrial systems, and how we manage natural resources, including fish, riparian habitats, and forests.

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Introduction

Freshwater fisheries management programs have traditionally focused on the maintenance or restoration of physical habitat, an approach that assumes local physical habitat structure and quality dictate fish production. In contrast, there has been less investigation on the role of food in sustaining fish populations. Evidence supports the notion that food limits fish production (Matthews 1998; Diana 2005), and is particularly compelling for stream salmonids (Chapman 1966; Mundie 1974; Mason 1976; Elliot 1994). When management programs are not successful it is often because they do not take a sufficiently broad view of watershed drivers (Meffe et al. 2002), including food webs and the processes that regulate food abundance for fishes. In this article, we expand conventional thought of physical controls on fish production, to look more broadly on food resources as a limiting factor on fish production in riverine ecosystems, and further present concepts and a model illustrating how fish food supplies vary through time and space throughout drainage networks.

As it is increasingly recognized that many stream fishes require a mosaic of habitat types throughout a riverine landscape to complete their life cycles (Schlosser 1995; Fausch et al. 2002; Stanford et al. 2005), there is a need to address the diverse array of prey sources that can be important to a fish population. Ecologists' growing focus on prey fluxes across habitat boundaries that "subsidize" recipient consumer populations (Polis et al. 2004) has drawn attention to the variable energy sources, both aquatic and terrestrial, that can fuel...
stream fish production (Bilby et al. 1996; Wipfli 1997; Wipfli et al. 2003; Baxter et al. 2005). In addition, there is growing awareness that the “resource sheds” of consumers often exhibit important variation dependent on spatial and temporal context (Power and Rainey 2000; Power and Dietrich 2007).

Here we propose a conceptual model of energy flow to stream fishes that incorporates the importance of multiple pathways and explicitly addresses how their relative contributions may change with season and spatial context within riverine networks. We develop and apply this model in the context of Pacific salmon and their watersheds, intending that it will be of general utility for understanding the array of food sources for other fishes and the processes and pathways that govern food supplies. Our intent in this article is to develop a model sufficiently applicable to ecosystems that contain other salmon species (e.g., Atlantic salmon), other non-salmon anadromous species (e.g., alewives), and systems lacking anadromous fishes across the globe.

Pacific salmon as a model

While most research and management dollars have gone towards understanding and mitigating the effects of habitat loss, hatchery stocks, dams, and salmon harvest in river systems in the Pacific Northwest (NRC 1996), relatively little has focused on the specific trophic processes and pathways that limit the productivity of riverine food webs that sustain production of salmon during their freshwater phase.

Pacific salmon are ideal for demonstrating an approach that explicitly addresses the diversity of energy sources for stream fishes. Though the emphasis of most past research has been on habitat as a limiting factor, there have been decades of research on the diets of salmonid fishes. In addition, our knowledge of energy pathways and function in the freshwater ecosystems they inhabit and the fluxes from adjacent terrestrial habitats has been improving. Many of these ecosystems also receive (or historically received) immense quantities of marine-derived biomass each year as adults migrate from the ocean to freshwater to spawn, a process whose importance is now better understood (Juday et al. 1932; Mathisen et al. 1988; Piorkowski 1995; Stockner 2003). Moreover, we now have increased information on the timing and spatial distribution of such fluxes in salmon streams, providing the basis for a model that addresses multiple cross-habitat subsidies whose importance varies through time and space.

Food sources for Pacific salmon in freshwater

Local production of benthic invertebrates

Fishes are often the top aquatic predators in riverine food webs and receive energy from multiple sources. For salmonid fishes, the most studied and widely recognized sources of prey in freshwater are benthic invertebrates that are produced locally, within the stream reach where fish occur (Allen 1951; Hynes 1970; Matthews 1998). In turn, the production of stream invertebrates is fueled by a combination of smaller prey (in the case of those that are predators) and organic matter synthesized by primary producers in streams, but also by small prey and organic matter which may be imported from ter-

Figure 1. Resource subsidies fueling fish-rearing food webs.
Terrestrial subsidies

Ecologists have long recognized the importance of terrestrial inputs of nutrients, dissolved organic carbon, and plant matter to basal productivity and invertebrate production in streams (Cummins 1974; Vannote et al. 1980). While these nutrients and energy may indirectly feed higher consumers such as fishes, terrestrial invertebrates that fall into streams are a relatively high-quality food source directly available to fish. Terrestrial invertebrate subsidies to streams can be substantial during the plant growing season, with annual inputs in forested temperate streams as high as 11 g/m²/y (see Baxter et al. 2005 for a review), dependent in part on the extent and composition of riparian vegetation (Mason and MacDonald 1982; Edwards and Huryn 1995; Romero et al. 2005). Terrestrial invertebrates can comprise more than half of energy ingested by stream fishes (Wipfli 1997; Allan et al. 2003) and are often the preferred prey of juvenile salmonids (see reviews by Hunt 1975; Baxter et al. 2005). Wipfli (1997) found terrestrial prey inputs averaged 10 mg dry mass/m²/d but at times were as high as 39 mg dry mass/m²/d. Further, in small streams in northern Japan, terrestrial invertebrates have been shown to comprise roughly half of the annual prey ingested by salmonids (Kawaguchi and Nakano 2001; Nakano and Murakami 2001), with significant consequences for fish growth and abundance (Kawaguchi et al. 2003; Baxter et al. 2007).

Marine subsidies

Marine inputs from adult anadromous fishes returning to freshwater habitats to spawn can be a major energy and nutrient subsidy to riverine ecosystems during parts of the year (Elliott 1997; Schmidt et al. 1998; Wipfli et al. 1998; Cederholm et al. 1999). Salmon typically range 2–25 kg each, depending upon species and gender, and often return by the millions in many of the large drainages around the Pacific Rim (Groot and Margolis 1991). Subsidy levels can range broadly from just a few spawners per stream to very high, local densities (Groot and Margolis 1991). Even very small watersheds can experience large returns of salmon. During and after salmon runs, marine carbon and nitrogen are sequestered at multiple trophic levels in freshwater and terrestrial systems (Kline et al. 1990; Chaloner et al. 2002a; Hicks et al. 2005), and these subsidies often dramatically influence community productivity and demographics. Wipfli et al. (1998, 1999) observed that biofilm mass and invertebrate density increased up to 25 times in Alaska stream systems with spawning salmon, and more salmon led to increased responses, up to a threshold. Aquatic invertebrates colonize and consume salmon carcasses (Piorkowski 1995) and can be found in high densities on and around dead salmon soon after the run (Minakawa and Gara 1999; Chaloner and Wipfli 2002; Claeson et al. 2006). Chaloner et al. (2002b) showed invertebrate growth rates increase in the presence of salmon carcasses in Alaska streams, although it remains unknown how much invertebrate biomass is produced from a given amount of salmon tissue. That will vary depending upon many factors, including invertebrate species present and whether carcasses remain reasonably intact and in place rather than flushing downstream or becoming buried or excessively fragmented (Chaloner and Wipfli 2002). Through invertebrate prey production, these increases can be translated to stream-resident salmonids, though fish also ingest salmon tissue and eggs directly (Bilby et al. 1996).
Wipfli et al. (2003) showed that stream-resident salmonids grew much faster and larger in southeastern Alaska streams enriched with salmon carcasses and eggs. Similarly, in selected Washington streams, juvenile salmonid growth increased in response to artificially-added salmon carcasses (Bilby et al. 1996, 1998). Responses to marine subsidies can vary though (Chaloner et al. 2004), with some stream communities showing no or even possible negative effects, possibly due to the lack of nutrient limitation in some streams (Wilzbach et al. 2005) or localized physical disturbance (Moore et al. 2004; Monaghan and Milner 2009). Nonetheless, the amount of adult salmon biomass actually available for ingestion by fish (directly via salmon eggs or fragmenting tissue, or indirectly through ingesting invertebrates that assimilate carcass tissue) is probably a very small fraction (est. 0.1–1%) of what enters freshwater systems, after accounting for removal by vertebrates (Cederholm et al. 1989; Gende et al. 2004) and other ‘losses’ from flushing, fragmentation, physical adsorption, or burial (Cederholm et al. 1989; Bilby et al. 1996; Gende et al. 2002; Moore et al. 2004).

A model incorporating multiple food sources for stream fishes

The importance of food from the four sources described above (local production, and tributary, terrestrial, and marine subsidies) can be better understood by addressing the relative contribution of each (Figure 3). The quantity and nutritional quality of these energy inputs can vary dramatically across time and space in riverine networks. A model incorporating these multiple food sources,
Incorporating annualized empirical data from typical salmonid-rearing streams (~2–5 m active channel width) in southeastern Alaska for these four independent variables:

- **L** = 2.7 mg prey dry mass/m²/d (Duncan et al. 1989),
- **H** = 1.2 mg prey dry mass/m²/d (Wipfli and Gregovich 2002),
- **T** = 5.8 mg prey dry mass/m²/d (Wipfli 1997), and
- **M** = 1.5 mg ingestible salmon dry mass/m²/d (derived from pink salmon (*O. gorbuscha*) adults at 1 spawner/m² at 0.1% availability described above; Groot and Margolis 1991; Wipfli et al. 2003)

Gives:

\[ F = L + H + T + M, \]
\[ = (2.7 \text{ mg prey dry mass/m}^2\text{/d}) + (1.2 \text{ mg prey dry mass/m}^2\text{/d}) + (5.8 \text{ mg prey dry mass/m}^2\text{/d}) + (1.5 \text{ mg ingestible salmon dry mass/m}^2\text{/d}), \]
\[ = 11.2 \text{ mg dry mass/m}^2\text{/d} \]

coming from all four sources on a mean annual basis.

**Figure 3.** Seasonal and temporal flux of food supplies in fish-rearing salmonid food webs.
This translates to roughly 25% of the total from local production, 10% from headwater inputs, 50% from terrestrial sources (immediately adjacent streamside), and 15% from marine sources during the summer (Figure 4). These proportions match closely with the diets (aquatic v. terrestrial prey) of salmonids in small salmonid-rearing streams in southeastern Alaska (Wipfli 1997), where cutthroat trout (O. clarkii) and juvenile coho salmon ingested about 50–60% terrestrial-derived prey, and Dolly Varden char (Salvelinus malma) in northern Japan (Kawaguchi and Nakano 2001; Nakano and Murakami 2001) ingested about half of that during the summer. At any point in time, food is delivered to a fish’s feeding space from some or all of these sources. Over time (e.g., one year), assuming salmonid-bearing habitats receive salmon or other anadromous runs, fish can acquire food from all four sources.

The conceptual model described above provides the basis for identifying and partitioning prey sources that serve as the trophic basis for production of salmonid and other fishes. To gain a more thorough perspective on fish demand for prey and the flow of resources that fuel production for a species or an assemblage of fishes, such information must be integrated into the framework of a bioenergetics model. The demand for prey by fish is frequently estimated using a bioenergetics model like that developed by Hanson et al. (1997) that incorporates information on prey energy content and is parameterized for the particular species and habitat of interest (e.g., Koehler et al. 2006, McCarthy et al. 2009). A somewhat coarser, “trophic basis of production” approach that has long been utilized by stream

**Figure 4.** Food subsidies incorporating both food quantity and its nutritional value.
invertebrate ecologists (e.g., Benke and Wallace 1980, 1997) may also be useful for fish in cases for which such a bioenergetic model may not be available. The approach requires estimates of production for each prey source and proportions of each prey type in fish diets as described above, but also assimilation efficiencies (commonly derived from the literature) for each prey type, and the production rate of the fish themselves. The method of Benke and Wallace (1980) calculates the trophic basis of production as follows:

1. Determine the fraction of production attributed to food type i \((B_i)\),
   \[ B_i = \frac{G_i \times AE_i}{\sum G_i} = 1, \ldots, n \]
2. Estimate the flow of organic matter via food type i to consumer j \((F_{ij})\),
   \[ F_{ij} = \frac{B_i \times P_j}{(AE_i / nPE)} \]

where \(G_i\) is the percent of each food type, \(AE_i\) assimilation efficiency (the fraction of the organic matter the consumer is able to assimilate) of food type i, \(P_j\) is the secondary production of consumer j (in this case fish) in g/m²/y, and nPE is the net production efficiency (the fraction of the organic matter the consumer is able to assimilate) of food type i. The approach requires estimates of the contribution of different prey sources to the production of fish that can be obtained, and actual flows from each prey type to the fish consumer can be calculated that provide the means for constructing a quantitative food web involving the fish and their prey. Incorporating temporal and spatial variation in prey source availability is the next step in developing a more comprehensive picture of the trophic basis for fish production.

### Incorporating temporal variation in food availability

Annual and seasonal fluctuations affect the amount of food delivered from any of the sources described above to fishes at any given time (Figure 3). Water and air temperature play a role in determining the amount of invertebrate prey supplied from either aquatic or terrestrial sources (Price 1997). Though benthic production is usually higher in the warmer seasons (Huryn and Wallace 2000), insect life histories often dictate that the standing crop biomass of benthic invertebrate prey is greatest during late winter and early spring (e.g., Nakano and Murakami 2001). Subsidies of invertebrate prey from headwater streams might be expected to follow similar seasonal patterns, but few studies have investigated their temporal variation. Wipfli and Gregovich (2002) showed they can be temporally variable but still a reliable source throughout the year.

Terrestrial invertebrate inputs and marine-derived fluxes are both markedly seasonal sources. Peaks in terrestrial prey inputs can occur any time during late spring, summer, or early autumn, and vary strongly in magnitude from year to year (Baxter et al. 2005). As described by Nakano and Murakami (2001), the seasonal asynchrony in availability of benthic vs. terrestrial invertebrate prey may be an important factor sustaining fish productivity and diversity in many streams inhabited by salmonids. Likewise, marine-derived subsidies exhibit dramatic seasonal variability, and usually occur during summer and fall when the standing crop of benthic invertebrates and fluxes of terrestrial invertebrate prey are at their lowest, thus providing fish a timely energy source prior to overwintering (Wipfli et al. 2003; Heintz et al. 2004; Wipfli et al. 2004). Salmon runs often last for several weeks, sometimes months (Groot and Margolis 1991). Though escapement peaks can be short-lived for given salmon species, the presence of multiple salmon species or stocks with variable run timings can increase the period over which this annual marine subsidy takes place, possibly stretching biomass flux out over half the year. Yet, regardless of the magnitude of this flux, its timing with respect to high flows can affect how much of this input is incorporated into freshwater production or is flushed out to the estuary (Cederholm et al. 1989; Wipfli et al. 1998; Chalonier et al. 2002).

Superimposed on the gross seasonal patterns described, the timing of food delivery relative to consumer physiology, movement patterns, and behavior are also important temporal considerations. Consumers must be positioned (e.g., physically, physiologically, behaviorally) to take advantage of prey resources when available. Fishes often exhibit movement whose purpose may be to occupy habitats with greater prey availability during different times of the year or stages of their life history. For instance, seasonal fish migrations between mainstem and tributary or floodplain habitats often appear to track availability of terrestrial prey sources and differences in timing of benthic invertebrate prey availability (e.g., Northcote 1997; Winemiller and Jepsen 1998; Lucas and Baras 2001). Likewise, they may move to upper reaches or tributary confluences in part to capitalize on headwater tributary subsidies of prey (Bramblett et al. 2002), or they may follow the spawning migrations of salmon to take advantage of opportunities to feed on their eggs or carcasses (Gende et al. 2002).

Yet, just because food is in a stream does not mean it is truly available. Being visual drift feeders, most salmonid fishes prey upon drifting invertebrates or emerging adult insects, whose availability is partially affected by drift timing and propensity to drift (Brittain and Eikeland 1988). Because invertebrates generally drift at higher densities at night (Waters 1962; Groot et al. 1995), and salmonids are generally believed to forage mostly during daylight, much of the prey that originates in headwaters may go uningested by these fishes (Brittain and Eikeland 1988; Groot and Margolis 1991; Allan 1995), a pattern that may also be induced by spikes in turbidity. The terrestrial food (T) category and total food (F) would both be lowered. Moreover, even if prey is available, it may not be used by fish. For example, extreme water temperatures can negatively affect the foraging rates of salmonid fishes (Matthews 1998), even if prey abundance is high. This would not affect the model, but would affect the amount of food assimilated.

### Incorporating spatial variation into food availability

The location of a given reach of fish habitat within a drainage will strongly influence the relative amount of prey that habitat receives from each of the four sources described above (Figures 3 and 4). The estimates of inputs from the four sources are those that might be expected throughout mid-watershed reaches (Figure 4). The relative contribution from each source should change predictably with position in a drainage network, though channel complexity in floodplain segments (Figure 5) would modify some of these expectations. This channel complex-
ity, particularly characteristic of natural floodplains, will greatly contribute to the amount of water-land boundary (Stanford et al. 2005), and in terms of prey exchange between land and water, make these highly complex habitats behave more like headwater channels with their high stream margin-to-water volume ratios relative to larger channels. Local, in-stream production of benthic invertebrates often varies predictably from headwaters to mouth (Grubaugh et al. 1997; Rosi-Marshall and Wallace 2002), but could be elevated in highly braided floodplains, relative to reaches with less complexity. However, such changes are likely to be smaller relative to spatial variation in marine, terrestrial, and tributary inputs, because these are more influenced by the extent of penetration of salmon into drainages and stream margin to stream volume ratios (Vannote et al. 1980; Polis et al. 2004). Thus, relative to other sources, the contribution of in-stream production to fish energy budgets is expected to be more consistent throughout the basin (Figure 4).

Subsidies of invertebrates from headwater tributaries likely would be greatest immediately downstream of the fishless-fish interface, because prey from this source have not yet been exposed to predation by fishes, and they are most proximal. As invertebrates are transported downstream through fish habitat, they may be consumed or leave the stream via adult emergence. Fish habitats downstream, farther from the highest density of fishless tributary sources, would be predicted to receive increasingly less prey from headwaters (Figure 4).

Regarding terrestrial invertebrate prey inputs, river continuum theory (Vannote et al. 1980) predicts that headwaters with their high stream margin-to-water volume ratios receive more allochthonous inputs than larger downstream reaches. Thus, small headwater streams should receive more riparian inputs of prey per stream surface area than larger streams nearer the coast (Figures 3 and 4). However, highly braided floodplains might have similar stream margin-to-water-volume effects, increasing prey inputs to streams per unit surface area (Baxter et al. 2005; and see Figure 5). In addition, inputs of terrestrial invertebrates can be affected by spatial patchiness in the type of riparian vegetation present (Wipfli 1997; Kawaguchi and Nakano

Figure 5. Floodplain habitat complexity increases amount of water-land interface in watersheds. Naturally functioning floodplains not impacted by human development provide immense off-channel habitats for rearing fishes and other freshwater-dependent species. Consumers in these complex off-channel habitats can benefit from high levels of both terrestrial subsidies and marine subsidies.
2001; Allan et al. 2003), with deciduous species generally housing more insects than conifers (Southwood 1961; Mason and MacDonald 1982; Ober and Hayes 2008).

In river systems with anadromous fish runs, habitats close to the ocean immediately upstream of saltwater often (but not always) receive the largest marine subsidy, simply because this area would usually receive the highest concentration of spawners, typical of those systems with strong chum (O. keta) and pink salmon runs that often spawn lower in drainages (Groot and Margolis 1991). Thus, in these areas and other reaches containing more concentrated aggregations of spawners, model inputs should shift towards a larger relative marine contribution (Figure 4). Progressing upstream, or other parts of the drainage where fewer spawners aggregate, marine subsidies would be expected to generally decline, dwindling to low spawner densities, and eventually becoming zero in headwaters (Figure 4). Sockeye (O. nerka), Chumook (O. tschawytscha), and coho salmon likely deliver the largest marine subsidies to fish habitats nearer the headwaters, as they generally swim farther up basins to spawn than chum and pink salmon and, though they usually exhibit lower spawner densities, at least Chinook salmon are also much larger sized (Groot and Margolis 1991). Exceptions to this general pattern clearly exist, as many spawning populations aggregate in drainage sections far from saltwater (Quinn 2004). For example, sockeye typically aggregate and spawn above and below lakes. Further, superimposed on general longitudinal patterns, spatial patchiness in carcass retention and nutrient storage mechanisms such as the amount of large wood or the size of floodplains and hyporheic zones may affect the extent to which this subsidy stays in streams and rivers versus being exported to saltwater (Cederholm et al. 1989).

**Food quality**

As is emphasized in the equations for calculating trophic basis of fish production and in models of bioenergetics in general, food quality is also an important consideration in the flow of energy to and assimilation by consumers. Quality is frequently expressed in terms of energy content of the food, but is also a function of a consumer's efficiency in digesting and assimilating a food resource. Caloric content of invertebrates varies, with consequences for energy assimilation (Cummins and Wuycheck 1971). Many invertebrates are highly sclerotized (e.g., bark beetles) or contain distasteful or poisonous biochemicals (e.g., rove beetles), which would be expected to affect digestibility and energy assimilation by fishes (Gerking 1994). In addition, prey size matters. Large prey are more profitable than small prey, all other factors being equal. Hence, both caloric content and digestibility will ultimately influence prey profitability.

Salmon eggs and certain other salmon tissues have a very high nutritional value, given their relatively high lipid content (Gende et al. 2004), and are often consumed by young salmonids (Wipfli et al. 2003; Bilby et al. 1996; Heintz et al. 2004). Juvenile salmon that consume salmon carcass tissues high in lipids sequester these in their own bodies, often resulting in increased freshwater and marine survival (Groot et al. 1995). Given the high nutritional quality of salmon eggs and other salmon tissues compared to the nutritional value of other food items (e.g., various species of insects), the relative trophic value of the marine subsidy would be much larger than predicted by the basic food quantity model. If food quality (e.g., measured as calories or assimilation efficiencies) is taken into account, relative inputs (weighted for quality) for the model shift towards a larger role for the marine subsidy (Figure 4). Balancing food nutritional quality, abundance, and seasonal availability will help put into perspective the true value of individual prey sources to fish production.

**Interactions among food sources and indirect trophic linkages**

It is also important to consider that the four prey sources we have described are often interactive, and can contribute to fish production through indirect as well as direct pathways. For example, as mentioned above, tributary, terrestrial, hyporheic, and marine sources of materials and organisms can all affect local production of benthic invertebrate prey for fishes. Perhaps the strongest illustration of such interactive effects may be via marine subsidies, which not only fuel fish production directly through consumption of eggs and tissue, but also through multiple indirect trophic pathways (Wipfli et al. 1998). Because much of the marine input is used by lower trophic levels (i.e., microbial production, and invertebrates), and fragmented and dissolved salmon tissue is stored within the hyporheic zone and released later, fishes may be benefiting indirectly as well as directly (Bilby et al. 1996; Stanford et al. 2002; Wipfli et al. 2003). Taking this marine storage and higher local secondary production into account, proportional inputs for the trophic model would shift towards an even larger marine influence (Figure 4), with some incremental increase in local production being an indirect result of marine subsidies (Wipfli et al. 1998; Minakawa and Gara 1999; Chaloner and Wipfli 2002). Moreover, these estimates do not take into account that terrestrial invertebrates may graze on riparian plants fertilized by salmon-derived nutrients (Wipfli 1997; Ben-David et al. 1998). Changes in plant growth and forage quality from fertilization by salmon could have profound effects on nutritional quality and abundance of terrestrial invertebrates (Slansky and Rodriguez 1987; Price 1997) that fall prey to fishes (Wipfli 1997; Allan et al. 2003; Baxter et al. 2005). Reciprocally, inputs of terrestrial invertebrates that feed juvenile salmon could affect their survival to adulthood, thus indirectly mediating the potential for return of marine-derived energy and nutrients to the system.

**Food, habitat, and their interactions**

A more comprehensive understanding of the ecological processes that regulate fish production in freshwater ecosystems will require a balanced consideration of food resources, physical habitat, and the interactions between them, as well as interactions with predators and competitors. Physical habitat structure may set the stage that constrains the extent to which food resources can regulate fish (or any consumer's) production in freshwater. A stream with ample prey resources, but with little suitable fish habitat, is not likely to support above average salmonid populations (Naiman and Bilby 1998). Alternatively, ideal salmonid habitat lacking ample food (i.e., oligotrophy, no marine subsidies, dense conifer young-growth riparian forest providing little riparian inputs and local productivity, and negligible headwater inputs) will also not sup-
port high salmonid production (Wipfli and Gregovich 2002; Allan et al. 2003). Freshwater ecosystems with reliable, suitable habitat and food supplies will undoubtedly support higher fish densities and in turn produce more fish biomass. Further, interactions between habitat and food are also important. For example, researchers have pointed out that wood in streams helps retain salmon carcasses, keeping this energy and nutrient subsidy available longer for assimilation by riverine food webs (Cederholm et al. 1989; Gregory et al. 1991; Gurnell et al. 1995). Also fish behavior itself may enhance retention, for example by salmonids seeking more quiescent waters (Piorkowski 1995). Likewise, the occurrence of optimal habitats (e.g., velocity refuges) and conditions (e.g., water clarity) for drift feeding influence the ability of fish to utilize prey resources that are present. Gaining a better understanding of the relative roles of food and habitat and their interactions in governing freshwater food webs will help us evaluate where and when fish populations are limited by food, habitat, or both.

**Effects of resource management on food resources**

Resource management activities at scales from local to global have the potential to strongly affect the quantity and quality of prey sources for stream fish such as Pacific salmon. Management practices that result in stressors such as habitat homogenization, pollution, or loss of water can drive reductions in local benthic invertebrate production (Rosenberg and Resh 1993; Carlisle and Clements 2005; Chadwick and Huryn 2005). Sedimentation in streams, from logging, road building, glacial melt, or other causes, will also impact local and headwater invertebrate prey sources (Waters 1995). Fish in food-limited habitats will probably be most vulnerable to the consequences of such prey loss. However, the assumption that high benthic invertebrate production follows from management for high quality trout and salmon habitat may lead to confounded efforts. For example, at the scale of channel units within stream reaches, pools are known to be sites of high salmonid abundance, whereas riffles are the locations that exhibit greatest invertebrate production. Drifting invertebrates originating in riffle habitats are thought to subsidize fish in pool habitats (e.g., Cooper et al. 1990). Consequently, attempts to manage for dramatic increases in pool density may come at the expense of prey availability for drift-feeding fish. Even where habitat restoration actions (e.g., large wood addition) may initially appear to increase fish numbers, these may be driven by redistribution of fish (e.g., Gowan and Fausch 1996) rather than increased local production of fish.

Likewise, management practices may directly or indirectly alter or reduce terrestrial or marine subsidies to stream fishes. Streamside forest management affects the amount and composition of riparian vegetation, with consequences for terrestrial subsidies of invertebrate prey (Wipfli 1997; LeSage et al. 2005; Richardson et al. 2005). Streams whose riparian forests have been removed or overgrazed will have reduced input of terrestrial invertebrate prey (Edwards and Huryn 1996; Kawaguchi and Nakano 2001) with likely consequences for salmonid populations (Mason and MacDonald 1982; Saunders and Fausch 2007). In contrast, headwater streams with riparian forest patches of red alder, often a consequence of past timber harvesting, can contribute more invertebrates to fish-bearing streams than those with conifer-dominated riparian forests (Piccolo and Wipfli 2002; Wipfli and Muslewhite 2004; Romero et al. 2005). Wildfires in headwater subcatchments can also dramatically alter the composition and increase the flux of insect prey from streams to surrounding habitats, for several years post-fire (Mellon et al. 2008; Malison and Baxter 2010). Regarding marine subsidies, commercial, sport, and subsistence fishing, as well as impediments to upstream salmon migration such as dams or road crossings, may block or severely reduce adult salmon returns into drainages. For instance, the Columbia River Basin presently receives a small fraction of its historical salmon runs, before resource management in the form of dams, urbanization, and fishing impacted returns, dramatically reducing marine nutrient and carbon subsidies to a vast landscape (Baker et al. 1996; NRC 1996; Lichatowich 1991).

**Implications for other food webs, consumers, ecoregions and geomorphologies**

Multi-prey source models such as the one we have developed here are likely to look different for other freshwater food webs that contain different fishes, are in other climatic regions, or are underlain by different geology, but the basic premises and processes will apply. For example, models for fishes that exhibit non-anadromous migrations or are herbivores, detritivores, or piscivores would focus on trophic pathways we have not emphasized here (e.g., Goulding 1980; Winemiller 1990; Taylor et al. 2006). Moreover, there is important variation in the prey sources we included even among stream systems occupied by invertivores like salmonids. Many streams outside of southeastern Alaska are substantially more productive for benthic invertebrates (Benke and Huryn 2006; Duncan et al. 1989; Huryn and Wallace 2000), and fish in these systems would likely depend more heavily on this food source, and proportionately less on the subsidies we have described. Fish in streams that are predominantly fed by ground water, with little runoff through stream networks, will undoubtedly rely very little if at all on invertebrate subsidies from headwater tributaries. It is also possible that in more arid landscapes fishless tributaries may be ephemeral and less reliable sources of invertebrate prey, assuming tributary hyporheic production is also minimal. Focused studies would help assess the contribution of this prey source to the trophic basis of production for stream fishes. Regarding marine subsidy, this component would not be included in the multi-source model for those systems that either never did receive marine subsidies, or no longer receive marine subsidies and are unlikely to be restored. Likewise, food webs that
are not nutrient or food-limited are likely to respond much differently to variation in prey subsidies. For example, salmon carcasses added to tributaries draining into Lake Ontario had little noticeable effect on stream food webs, likely a result of ample ambient levels of nutrients, carbon, and prey (Rand et al. 1992).

Actual vs. apparent food availability

Several critical assumptions are being made in our multi-prey source model, and certainly need to be recognized and researched, to help improve the accuracy, reliability, and applicability of the model. One major set of assumptions revolves around the 1 pink salmon spawner/m²/y used in the model, and how much material gets assimilated into the food web. Salmon densities can range from 0 to several fish per m² (and even higher immediately downstream of waterfalls and other barriers to upstream salmon migrations; Wipfli et al. 1998) and there are four other species of Pacific salmon that enter these watersheds (chum, sockeye, coho, and Chinook), all of which are larger, usually travel farther upstream, and occur at different densities than pink salmon (Groth and Margolis 1991; Quinn 2004). Also assumed is that all sources of food are available for consumption once they enter fish habitat (but clearly not all food items are eaten, due to low light, turbidity, predator avoidance tactics, etc.). While Bilby et al. (1996) found rearing salmonids consume salmon eggs and adult carcass tissue, how much of this biomass is ingested by young fish needs to be determined, relative to other sources. A very small fraction probably gets consumed by fishes, relative to what enters the system, with most “lost” to vertebrate predators, floods and flushing, physical fragmentation and chemical leaching, burial in stream sediments, and biological processing and uptake (Cederholm et al. 1989; Bilby et al. 1996; Wipfli et al. 1998; Gende et al. 2004). Watershed characteristics (e.g., vertebrate scavenger species present, gradient, woody debris and other physical structures, pool frequency and depth, stream flow) will dictate how much salmon tissue is actually available for consumption in streams. In addition to direct consumption, Wipfli et al. (1998) documented that aquatic invertebrate production apparently increases in streams with salmon, but it is unknown how much of the adult salmon biomass is actually converted into secondary invertebrate production, and how much of that gets ingested by fishes. Food quality (e.g., caloric content) also rapidly decreases from the time a salmon enters freshwater to post-spawning, which will also play an important role in energy uptake by consumers (Mathisen et al. 1988).

Current understanding, knowledge gaps, and research needs

This multi-prey source model helps illustrate what we know, what we think we know, and what we do not know about the sources of energy to stream food webs that support stream fish, especially salmonids. It also sheds light on the importance of broader ecosystem and watershed processes and connectivity. Although salmonid protection and restoration over the last few decades has largely focused on fish habitat, hatcheries, hydroelectric dams, and harvest (NRC 1996; Naiman and Bilby 1998), gains in understanding food web dynamics and trophic processes affecting salmonid production have been made (Richardson 1993; Nakano et al. 1999; Wilzbach et al. 2005). Our model helps synthesize and organize current understanding on this topic, and should also help stream ecologists further resolve the Allen paradox (Allen 1951; Hynes 1970; Huryn 1996). It points to three food sources (i.e., local, terrestrial, marine) as being most important, with headwater subsidies potentially less so, and highlights the need to incorporate food quality in food web analyses. However, the model represents only a step toward developing a more holistic understanding of the various prey fluxes to fish. Integrating knowledge of prey sources, fish diets, and prey assimilation efficiencies allows the trophic basis of fish production to be estimated, and when fish production is known as well, the trophic pathways that fuel it can be depicted in a quantitative food web. The seasonal and longitudinal models we have presented should serve as heuristic tools for attempts to more precisely describe how multiple prey fluxes vary in quantity and quality through time (daily, annual) and space (within and among drainages), under different riparian, headwater, local stream, and marine conditions. At larger spatial scales, modifying the model to fit other food webs characterized by different apex consumers (e.g., other fishes, amphibians, birds, etc.) will help expand the utility of the model and help us understand how such trophic pathways vary across regions. For example, how well does the model predict responses to other marine subsidies from species such as Atlantic salmon, smelt, or lamprey in other parts of the world? Also, are there other important sources of subsidies in other places? Undoubtedly so.

Informed management of stream fish populations will require that decision-making explicitly address the consequences of human actions for the complex trophic pathways that fuel fish production. To that end, ecosystem and food web studies are needed that directly assess the effects of management practices on these multiple trophic pathways, not simply their consequences for physical habitat characteristics. At present, relatively little is known about how multiple prey resources are affected by land management regimes or species invasions, either aquatic or terrestrial (but see Baxter et al. 2004; Baxter et al. 2007; Saunders and Fausch 2007). Our model was developed with data from a setting of relatively pristine, old-growth, temperate rainforests in southeastern Alaska. How do food pathways differ in a drainage like the Columbia River Basin that receives 6% of its historic salmon run, contains much more urbanization, irrigation, and agriculture, and has seen decades of fish habitat alteration (NRC 1996; Lichatowich 1999; McClure et al. 2003; Gresh et al. 2000)? The model should be expanded to predict effects of dominant agents of global environmental change, including aquatic and terrestrial habitat alteration, nonnative species introductions, and climate change. This will strengthen the model so that it can become an effective tool that provides insight and improves the way we study and manage fish, as well as riverine ecosystems and the land and seascapes to which they are connected.

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References


FEATURE:      
FISHERIES MANAGEMENT

Implementation of Genetic Conservation Practices in a Muskellunge Propagation and Stocking Program

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ABSTRACT: Conservation of genetic resources is a challenging issue for agencies managing popular sport fishes. To address the ongoing potential for genetic risks, we developed a comprehensive set of recommendations to conserve genetic diversity of muskellunge (Esox masquinongy) in Wisconsin, and evaluated the extent to which the recommendations can be implemented. Although some details are specific to Wisconsin’s muskellunge propagation program, many of the practical issues affecting implementation are applicable to other species and production systems. We developed guidelines to restrict future broodstock collection operations to lakes with natural reproduction and to develop a set of brood lakes to use on a rotational basis within regional stock boundaries, but implementation will require considering lakes with variable stocking histories. Maintaining an effective population size sufficient to minimize the risk of losing alleles requires limiting broodstock collection to large lakes. Recommendations to better approximate the temporal distribution of spawning in hatchery operations and randomize selection of brood fish are feasible. Guidelines to modify rearing and distribution procedures face some logistic constraints. An evaluation of genetic diversity of hatchery-produced fish during 2008 demonstrated variable success representing genetic variation of the source population. Continued evaluation of hatchery operations will optimize operational efficiency while moving toward genetic conservation goals.

IMPLEMENTACIÓN DE PRÁCTICAS GENÉTICAS DE CONSERVACIÓN DENTRO DE UN PROGRAMA DE CRIANZA Y PROPAGACIÓN DEL LUCIO RAYADO

RESUMEN: La conservación de recursos genéticos es un reto importante para las agencias que administran la pesca deportiva. Con el fin de estudiar el potencial actual de riesgos genéticos, en el presente trabajo se desarrolló una serie de recomendaciones para conservar la diversidad genética del lucio común (Esox masquinongy) en Wisconsin, y se evaluó hasta dónde las recomendaciones pueden ser implementadas. Si bien algunos detalles son específicos al programa de propagación del lucio en Wisconsin, muchos de los aspectos prácticos que afectan la implementación son también aplicables a otras especies y sistemas de producción. Se desarrollaron algunas directrices para restringir en el futuro las operaciones de recolección de reproductores hacia los lagos en donde la especie se propaga de manera natural y para desarrollar un grupo de lagos de crianza que podrán ser utilizados de forma rotativa, dentro de las fronteras regionales donde se distribuyen las poblaciones, sin obstante la implementación requerirá considerar lagos con historias distintas de crianza. El mantenimiento de un tamaño poblacional suficiente como para minimizar el riesgo de pérdida de alelos, requiere limitar la recolecta de reproductores hacia grandes lagos. Es posible emitir recomendaciones prácticas para contar con mejores enfoques de distribución espacial en operaciones de crianza y selección aleatoria de reproductores. Las pautas que ayudan en los procedimientos de estabulación y distribución implican algunos problemas logísticos. Una evaluación de la diversidad genética de peces producidos en criaderos durante 2008, demostró un éxito variable en cuanto a la representatividad de la población original. La evaluación continua de operaciones de crianza optimizará la eficiencia operativa mientras se avanza en el cumplimiento de objetivos genéticos de conservación.
Introduction

Conservation of genetic resources is a challenging issue for agencies managing popular sport fishes. Management objectives driven by public expectations often produce demands that conflict with obligations to conserve native genetic resources, particularly when artificial propagation and stocking are important management strategies (Philipp et al. 1993). The idea of genetic conservation is not new in Wisconsin or elsewhere, but implementation of management strategies based on genetic conservation principles has been sporadic. Genetic applications to management of some fishes, such as Pacific salmon (Oncorhynchus spp.), have been discussed and implemented for decades (Waples et al. 1990), but for many other species, a lack of guidelines has impeded management (George et al. 2009). To address the ongoing potential for genetic risks in the Wisconsin muskellunge (Esox masquinongy) propagation program, we developed a comprehensive set of recommendations to conserve genetic diversity, and evaluated the extent to which the recommendations can be implemented. In this article we describe these genetic conservation guidelines and discuss both progress and challenges to implementation. Whereas some of the details may be regionally relevant or specific to muskellunge, many of the issues will apply more broadly.

The state of Wisconsin contains waters with native, naturally reproducing muskellunge as well as numerous waters with introduced populations. Currently, about 800 waters, including over 700 inland lakes, are designated as muskellunge waters. Muskellunge are managed in Wisconsin with a variety of approaches, including a highly restrictive bag limit of 1 fish/angler on nearly all state waters, a variety of size limits based on growth potential, habitat protection, supplemental stocking, and maintenance stocking. Stocking has a long history in Wisconsin and is a highly visible component of the management program. Muskellunge stocking generally has wide public support, particularly among muskellunge anglers, and has been successful in achieving specific management objectives on many waters (Margenau 1999).

Propagation of muskellunge in Wisconsin begins with netting wild broodstock during the spring (Johnson 1958). Gametes are taken in the field and brood fish are immediately returned to the water from which they were netted. Fertilized eggs are disinfected and transported to the hatchery for subsequent incubation and hatching. Newly hatched muskellunge are transferred to hatchery ponds and raised to fall fingerlings—the primary product of WDNR muskellunge hatcheries (Margenau 1999).

Prior to widespread discussion or acceptance of genetic conservation principles in fisheries management, practices that increased efficiency in the propagation program led to variable levels of genetic risk. Social or political influences sometimes led to stocking lakes where it was not needed (Margenau 1999). Taking eggs from a small number of females reduced the number of fish that needed to be handled and the time required to achieve targets for egg take. The tradeoff with reduced labor and travel costs was reduced probabilities of sampling rare alleles and thus increased probability of genetic drift. Brood lakes were selected for efficiency in sampling fish, and included lakes with introduced muskellunge populations dependent on maintenance stocking, effectively eliminating natural selection for traits related to successful reproduction in the wild. Distribution of fish was done with little regard for existing stock structure and could result in stock transfers that could lead to outbreeding depression and loss of fitness. As a matter of efficiency, most lakes were stocked from the nearest hatchery, which was likely to be in the same basin; therefore, the extent to which individual waters were exposed to these risks was variable.

Guidelines for conserving genetic variation

Wisconsin’s native muskellunge are concentrated in the northern third of the state in the upper Wisconsin River, upper Chippewa River, and Lake Superior basins. These are the primary areas of concern for conservation genetic policy because most populations established elsewhere in the state through introduction of artificially propagated muskellunge do not sustain themselves through natural reproduction. Although performance issues related to potential genetic problems may be legitimate management concerns even in put-grow-take fisheries (Wingate and Younk 2007), the primary goal of these guidelines was the conservation of genetic diversity of native muskellunge. This goal was addressed with two broad objectives. The first objective was to conserve existing geographic patterns of diversity, or among-population genetic variation. Guidelines relevant to this objective (Table 1) focus on minimizing the potential for compromising stock structure

Table 1. Summary of guidelines recommended for Wisconsin muskellunge broodstock management. See text for discussion of implementation issues and feasibility of individual guidelines.

- Do not stock muskellunge waters sustained through natural reproduction.
- Adhere to use of regional broodstocks defined by spatial patterns of genetic variation.
- Only use lakes with self-sustaining populations as brood sources.
- Within the native range, stock only fish from the appropriate regional source.
- Use multiple brood lakes on annual rotation within stock boundaries.
- Base annual number of breeders on estimates of effective population size required to maintain existing within-population genetic variation.
- Restrict egg-take to lakes with populations sufficient to meet targets.
- Tag individual broodstock and maintain records to avoid repeat use.
- Randomly select healthy broodstock throughout the spawning season.
- Avoid selection for size or other physical trait.
- Approximate temporal distribution of spawning run with egg take.
- Collect broodstock in range of suitable spawning habitats.
- Minimize variance in number of eggs from each female.
- Modify hatching and rearing to maximize genetic variation represented within hatchery ponds.
- Modify distribution to maximize genetic variation represented within stocking events.
Among-population genetic variation

Two guidelines were critical to conserving the genetic variation that exists among populations. The first was the elimination of supplemental stocking in native muskellunge waters capable of sustaining healthy populations through natural reproduction (Category I waters; Table 2; WDNR 1996). The second guideline was to adhere to regional stocks so that any stocking within a basin containing native muskellunge was accomplished with a source based on geographic patterns of genetic variation. This guideline was relevant because many of Wisconsin’s lake systems are interconnected on a permanent or intermittent basis and some may contain a mix of categories (i.e., one lake is category I while another lake in the same system may be managed as category II or III; Table 2). Stocking of muskellunge into the category II or III system with exogenous sources could threaten the integrity of the category I water because of this connectivity. The working model for regional broodstock boundaries is based on the recommendations of Fields et al. (1997), and corresponds to two major river basins in the Mississippi River drainage, the Chippewa and the Wisconsin, as well as the Lake Superior basin. Regional broodstock boundaries may be adjusted based on ongoing microsatellite genetic analyses and will not be discussed in detail here. However, the framework established by designation of regional broodstocks applies to the implementation issues detailed below.

Consideration of potential broodstock sources was restricted to only native category I waters. The adherence to a genetic stock-based system provides for putative adaptive genetic differences among geographically distinct groups and reduces the subsequent risks associated with mixing distinct genetic groups, such as disruption of local adaptations and co-adapted gene complexes (Templeton 1986; Waser 1993). Adherence to the stock concept in Wisconsin’s muskellunge management was intended to ensure that stocked fish are well suited to the conditions of recipient waters and to minimize risk to any native populations that may occur in connected waters. All potential broodstock must demonstrate the ability to complete its entire life cycle in its current habitat; therefore, we did not consider the use of nonnative, non-recruiting (potentially low to no fitness) populations as regional brood sources.

Within-population genetic variation

The variation that occurs within populations is important to the population’s long-term health. The loss of variation through genetic drift can lead to loss of alleles, an increase in inbreeding, and the loss of fitness known as inbreeding depression (Allendorf and Luikart 2007). The loss of genetic variation within an artificially propagated population is primarily a consequence of using an insufficient number of broodstock. The probability of sampling rare alleles is determined by the effective population size ($N_e$) such that a low $N_e$ will result in less allelic diversity than a higher $N_e$.

To develop recommendations for broodstock numbers, we performed 1,000 simulations using known microsatellite allele frequencies (14 loci; Sloss et al. 2008) from two brood sources and determined the overall $N_e$ that would result in a ≥ 95% probability of maintaining all observed alleles (frequency ≥ 0.05 in source populations) over a generation. Generation time was defined as 7 years, which is the age at which a cohort will be mature in most Wisconsin populations, although some muskellunge mature at earlier ages, and some individuals will continue to reproduce for a decade or longer. The minimum $N_e$ for a generation was 350. The approach of considering multiple years of production to represent the genetic diversity of source populations also applies to other long-lived species such as lake sturgeon (Acipenser fulvescens; Drach and Rhodes 2007).

We based calculations and recommendations on an unequal sex ratio because Wisconsin muskellunge populations typically contain more males than females, meaning females were a limiting factor in developing a crossing strategy. Based on the target $N_e$ over a generation ($N_e = 350$), the annual effective number of breeders ($N_b$) should be ≥ 50. Precise calculations of $N_b$ depend on assumptions regarding the actual contribution of individual males, which will be affected by infertility rates and sperm competition; however, a strategy of targeting ≥ 20 females spawned with 3 males each (individual males used with a single female and then released) should achieve this target in most cases.

Within the native range of muskellunge, many natural populations are found in drainage lakes and rivers, and therefore have the potential for movement among systems within drainages. To sample the full diversity of native populations in spawning operations requires separation of stocks where appropriate, but also requires sampling from throughout waters within stock boundaries. To accomplish this, we recommended that egg-take opera-

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**Table 2. Muskellunge management classification system currently in use by the Wisconsin Department of Natural Resources.**

<table>
<thead>
<tr>
<th></th>
<th>Category I</th>
<th>Category II</th>
<th>Category III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recruitment</td>
<td>Natural</td>
<td>Natural + Stocked</td>
<td>Stocked Only</td>
</tr>
<tr>
<td>Stocking</td>
<td>None allowed</td>
<td>Supplemental</td>
<td>Maintenance</td>
</tr>
</tbody>
</table>

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tions for each regional stock should not focus on a single brood lake, but use several lakes on a rotating schedule. This ensures more sampling of the diversity within each regional stock, and also takes pressure off any one system that might be used for annual production.

Finally, an effort to represent the range of diversity present in brood populations is most effective when the distribution system can maximize the extent of variation represented in each delivery from a stocking truck. This issue can be overlooked but plays an important role in determining the amount of variation stocked into each lake. Nonrandom distribution of fertilized eggs was identified as a factor decreasing $N_d$ in lake trout (*Salvelinus namaycush*; Page et al. 2005), and is likely to apply across species. The ability to do this starts with stocking hatchery ponds with progeny of several different pairings, and representing more than a single pond’s production in deliveries of fingerlings.

### Artificial selection

Up to this point, we have discussed issues of stock boundaries, sampling adequacy, and loss of alleles through random drift. The other area of concern was imposing artificial selection, and thus propagating fish that may be well suited to culture but poorly suited to a natural environment. Because our muskellunge propagation is based on collection of wild broodstock, these issues are not as serious as those encountered with captive broodstocks. However, the potential for artificial selection still exists in the collection of wild broodstock as well as in the hatchery. Traits of concern may be physiological, morphological, or behavioral. As a practical matter, we cannot at this time measure heritability for every trait of concern, but we can assume that variability in many traits will have some genetic basis. Therefore, implementing guidelines to minimize the potential for inadvertent selection was appropriate.

Among the angling public, the muskellunge traits of greatest interest are growth rates and body size. However, a conservation genetics approach is based on retaining the range of variation present in natural populations and assumes that much of the variation is adaptive. Individual broodstock, assuming that they are otherwise healthy and lacking developmental abnormalities, should be chosen at random with respect to morphological traits such as size (Miller and Kapuscinski 2003). Propagation should include, but not exclusively target, the largest fish. Other traits that may be inadvertently selected out of convenience include run timing or preference for a particular spawning habitat. Some of the variation in spawning behavior is likely to be influenced by variation in water temperature or habitat availability, and is not necessarily heritable; however, as run timing has been shown to be heritable in other fish species (Stewart et al. 2002), representation from the temporal and spatial range of spawning within a brood lake remains desirable. Therefore, we recommended that spawning operations attempt to approximate the general temporal distribution of spawning activity.

### Relevance to waters with maintenance stocking

Maintenance stocking—stocking that is thought to exclusively account for year classes and the standing crop of muskellunge in a given water system—occurs both within the native range of muskellunge and beyond its borders. The use of an appropriate regional broodstock for production of any fish stocked within its native range is recommended because these fish are likely to be best adapted to local conditions, and because fish may move through connected systems. Stocking from the appropriate regional source minimizes genetic risk from fish movements, and is an important conservation practice in any water within the native range.

Beyond the native muskellunge range, local adaptation in a maintenance stocking situation is not a critical genetic conservation issue (stocking may be a community conservation issue, but that is beyond the scope of this discussion). Movements of fish to native waters in other basins are possible only through illegal
transport by people. However, guidelines to reduce genetic drift and inbreeding depression are relevant in any situation, because fish produced with these guidelines are likely to have better performance than fish displaying high levels of inbreeding.

**Implementation issues**

**Population size**

A successful broodstock management program requires populations that can be reliably sampled, and that contain a sufficient number of adults to support genetic conservation goals. These requirements impose an important constraint because muskellunge are present at low densities in natural populations. To determine the pool of populations meeting the minimum criteria for number of mature adults, we compiled records from 182 population estimates conducted in 92 lakes in northern Wisconsin. Population estimates were Peterson mark-recapture estimates conducted over two years (Margenau and Avelallemant 2000). Muskellunge were sampled with fyke nets and marked with a fin clip during the first year. The recapture run was conducted with fyke netting during the following year. Population estimates were used to calculate population density, sex ratio, and capture efficiency. These calculations were used to identify lakes likely to support populations sufficient to meet the guidelines.

The mean density of adult muskellunge reported by Hanson (1986) was 0.82/ha (0.33/acre) in a group of 8 Wisconsin lakes. Our expanded set of population estimates in 92 lakes revealed a slightly higher estimate of 0.99/ha, but most of the high estimates occurred in very small lakes (Figure 1). For lakes > 283 ha (700 acres), we found a mean density of 0.84 adult muskellunge/ha (0.34/acre). To provide an initial estimate of the number of muskellunge available for hatchery egg-take operations, we examined the size distribution of lakes within the native muskellunge range in northern Wisconsin (Figure 2). It was immediately obvious that many small lakes did not contain a sufficient number of adult muskellunge to meet numerical sampling objectives.

The feasibility of using many Wisconsin lakes to support hatchery production is dependent on sampling efficiency. Using the same data with which we generated the population estimates, we estimated that the average survey encountered approximately 28% of the adult muskellunge in a lake. Efficiency varied among lakes, and was dependent upon lake size and availability of spawning habitat. Furthermore, sex ratios were variable, and most lakes had a higher number of males than females. When we further considered that some of the females encountered may have already spawned, are not yet ready to spawn, or are not healthy (about 60% of netted females were usable in a recent egg-take effort on the Chippewa Flowage in Sawyer County), the pool of candidate lakes shrunk considerably. Using available figures for density, sampling efficiency, and proportion of females usable for spawning, we projected a minimum lake size of 356 ha (880 acres) to support hatchery operations. Given that abundance fluctuates over time within populations, lakes that provide the best chance of meeting conservation guidelines in the long term are > 405 ha (1,000 acres).

Within the pool of Wisconsin muskellunge lakes greater than 400 ha, most have received supplemental stocking at some point in their history. Choosing among them required consideration of several factors including the amount of known stocking and current ability of the population to sustain itself through natural reproduction. Some degree of uncertainty and

**Figure 1.** Muskellunge population estimates conducted in 92 Wisconsin lakes. Estimates are two year mark-recapture estimates of adults generated with fyke net capture data.

**Figure 2.** Size distribution of 578 lakes managed for muskellunge in the Upper Chippewa and Wisconsin River drainages in northern Wisconsin. Lakes larger than 400 ha are candidates for use as muskellunge brood lakes.
compromise is required to move forward with selection of brood lakes. Additional practical considerations include access for boat launching and spawning operations and reliable access to spawning locations when ice may still be present.

Although meeting the guidelines for number of brood fish is important for annual production, effective population size estimates were based on a generation, as described above. Therefore, brood lakes should have a population sufficient to ensure that annual targets can be met without reusing individuals in subsequent years. One of the implementation issues to consider if lake rotation options are limited is keeping adequate records of individual brood fish. PIT tags provide a feasible option for tracking individual muskellunge as part of a broodstock management program (Jennings et al. 2009). Alternatively, the number of brood lakes used in a rotation within a stock management area can be adjusted to minimize reuse of individuals.

Avoiding selection

Artificial selection involves either deliberate or inadvertent favoring of heritable morphological, physiological, or behavioral traits during spawning operations or production. Although any hatchery rearing environment will impose different selective pressures than a natural setting, the focus of the guidelines was on random selection of broodstock, because this is one area in which practical changes can be made. Although little can be done to change selective pressures within the hatching or rearing environments, by restricting egg-take to category 1 waters, we ensure that individuals in the source population are exposed to selection in the wild at all life stages. Because category 1 waters are not stocked, early life history stages of these source populations are not exposed to selection in the hatchery.

The issue of body size was discussed above, and random selection of available brood fish can be implemented on a daily basis during spawning operations to eliminate favoring fish with preferred morphological traits. The more challenging issue is sampling from throughout the run, so that inadvertent selection for early or late spawning does not occur. Here, the implementation challenges involve constraints imposed by the hatching system—the need to synchronize growth and harvest, and the costs of extended field operations. By sampling throughout the run, some days will result in obtaining small numbers of eggs, which can result in low hatch rates. Hatching jars work efficiently when full, but having many partial jars can be inefficient and limit capacity. Prolonging hatch over an extended period can result in size differences that result in cannibalization, which has the same ultimate effect (favoring early hatching fish) as early egg take. While some manipulation of incubation time can be accomplished by varying water temperature among banks of hatching jars, most hatcheries are limited in the extent to which they can synchronize hatch. Added staff time and transportation for extended egg take operations can stretch costs beyond current budget constraints. Success in meeting this objective will vary depending on the length of the run, but improvement over historic practices is feasible.

Other traits may be subject to artificial selection, and this will vary among propagated species. For example, walleye (Sander vitreus) may vary in spawning habitat preference (Jennings et al. 1996), and this may be an appropriate consideration in selecting locations to collect broodstock. For muskellunge, netting broodstock at different locations may decrease the probability of sampling the same fish among years, because individual fish may exhibit reproductive homing (Crossman 1990). In addition, muskellunge spawn at a range of depths (Pierce et al. 2007), and setting nets in a variety of habitats may help avoid selecting for habitat preferences if preferences are heritable. Even in established brood lakes, some test netting of previously unsampled areas is likely to minimize potential selection for spawning habitat preferences and increase the pool of individual fish vulnerable to netting.

Fish distribution

The primary goal of a conservation hatchery program is to ensure fish stocked into receiving waters are as close to a representative genetic sample of the regional stock as possible. Stocking in individual lakes, particularly those that may have connections to systems with natural reproduction, should attempt to represent the range of genetic variation that was sampled during egg-take operations. Although this sounds simple, only a subsample of eggs ends up in a single hatching jar, or even a bank of jars. Ponds are stocked as fish hatch, so that ponds contain fish of similar age and size. Losing uniformity in size in hatchery ponds can result in losses to cannibalism in the rearing ponds. As ponds are drained during fall, fingerlings are moved to stock trucks and delivered to the lake. To provide stocked waters with a representative sample of the annual production requires adjustments to harvest and/or delivery procedures, resulting in holding of fish and more handling, or increased delivery costs for multiple trips. This representative stocking posed one of the larger challenges in the current propagation program.

Genetic assessment of fish distribution and relative contribution assumptions

To assess the efficacy of providing a representative sample via this approach, we conducted a genetic analysis of brood fish and hatchery production from two hatcheries (Governor Tommy Thompson Hatchery in Spooner [GTH] and the Art Oehmcke Hatchery in Woodruff [AOH]) during the 2008 production year. We sampled all brood fish and at least 50 fish from each of 3 ponds per hatchery. All samples were genotyped for 14 previously described microsatellite loci following procedures described by Sloss et al. (2008). Adult and progeny diversity were compared using genic and genotypic diff-
ferentiation as implemented in GENEPOP 4 (Rousset 2008) using the default settings. These tests are comparisons of the allele frequency and genotypic frequencies between populations addressing a null hypothesis of no difference in allele (or genotype) frequency distributions among samples. These tests were performed to ask the question, “Does the observed data represent two samples from the same group?” We examined both global and locus-specific results of these analyses. Significance (alpha) values for all tests were corrected for multiple comparisons using a sequential Bonferroni correction (Rice 1989).

Results of these analyses showed mixing of the young in the hatchery ponds to be moderately effective in the initial year of implementation (Table 3). Significant differences were observed in the total diversity of GTH progeny versus brood fish; two of three production ponds were significantly different in global tests. However, individual locus tests showed only 2 of 42 tests were significant in the individual ponds and 4 of 14 tests were significant in the combined total GTH 2008 sample. Alternatively, AOH showed no significant deviation from the brood fish diversity in total and in all pairwise (pond-specific and total combined comparisons). Assuming that single receiving waters would receive progeny from only a single pond, four of six ponds met our expectation of representative samples of the original, brood fish diversity. More effective mixing and continued diligence in the effort will likely result in increased conformance to random expectations in subsequent production years.

Allelic diversity was mostly maintained in our samples (Table 3) with only one allele exhibiting a frequency > 2.5% in brood fish not being observed in the subsequent progeny (a single GTH allele had a frequency of 3.7% in brood fish but was not observed in 139 progeny). This allele was observed in five GTH brood fish (four heterozygotes and one homozygote) and not observed in any offspring. The probability of not sampling this allele if it was present in the combined GTH sample, given our sample size, was 0.0028% (Hedrick 2000). Two of the five individuals with this allele were females (one homozygote and one heterozygote). Although differential contribution among the male brood fish was expected, the data suggest differential contribution among the females. Further research into the parental contribution of brood fish in the stocked-out progeny could provide a better picture of what survival and family size variance occurs in hatchery ponds.

### Outlook for genetic conservation

The challenges to fully implementing a meaningful conservation genetics program are significant, but substantial progress has been made in the Wisconsin muskellunge propagation program during a relatively short time. Initially, we are likely to fall short of goals on certain aspects of the guidelines, such as those dealing with distribution. However, some of the more important elements of the plan, such as no stocking in category I waters and general guidelines for broodstock numbers and crossing procedures, were found to be feasible with continued commitment. Sustained implementation of these high priority guidelines alone will reduce future impacts to native populations.

Awareness of genetic issues is increasing among angler groups, and the general concept has support among representatives to an advisory Wisconsin muskellunge management team. Because a meaningful conservation genetics plan will restrict some stocking and increase costs, continued outreach with clearly communicated objectives will be essential to retaining support of the angling public and agency administrators. This project has required us to gloss over complexity and nuance in the field of genetics, but in the process, we have enhanced its relevance to coolwater fisheries management and provided the public with understandable goals and better appreciation of changes in the management of a valued sport fishery.

### Table 3. Summary of genetic diversity within 2008 brood fish and the three ponds for each of the two State hatcheries sampled. Combined refers to a combination of Ponds 1, 2, and 3 for each hatchery. Total number of sampled individuals (N), observed heterozygosity at the 14 surveyed microsatellite loci (H$_S$), total number of observed alleles across all 14 loci (A), p-value for genic differentiation tests (Genic p-value), and p-value for genotypic differentiation tests (Genotypic p-value) are presented. Hatchery ponds were only compared to the brood fish producing their respective cohorts.

<table>
<thead>
<tr>
<th>Sample</th>
<th>N</th>
<th>H$_S$</th>
<th>A</th>
<th>Genic p-value</th>
<th>Genotypic p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gov. Thompson Brood fish</td>
<td>81</td>
<td>0.6038</td>
<td>84</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Pond 1</td>
<td>46</td>
<td>0.5576</td>
<td>69</td>
<td>0.004</td>
<td>0.010</td>
</tr>
<tr>
<td>Pond 2</td>
<td>47</td>
<td>0.5586</td>
<td>70</td>
<td>0.231</td>
<td>0.293</td>
</tr>
<tr>
<td>Pond 3</td>
<td>46</td>
<td>0.5701</td>
<td>69</td>
<td>0.001</td>
<td>0.003</td>
</tr>
<tr>
<td>Combined</td>
<td>139</td>
<td>0.5619</td>
<td>79</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Oehmcke Brood fish</td>
<td>46</td>
<td>0.5392</td>
<td>82</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Pond 1</td>
<td>47</td>
<td>0.5583</td>
<td>71</td>
<td>0.981</td>
<td>0.990</td>
</tr>
<tr>
<td>Pond 2</td>
<td>47</td>
<td>0.5793</td>
<td>72</td>
<td>0.164</td>
<td>0.251</td>
</tr>
<tr>
<td>Pond 3</td>
<td>49</td>
<td>0.5366</td>
<td>72</td>
<td>0.276</td>
<td>0.489</td>
</tr>
<tr>
<td>Combined</td>
<td>143</td>
<td>0.5582</td>
<td>77</td>
<td>0.140</td>
<td>0.216</td>
</tr>
</tbody>
</table>
Acknowledgments

We thank the staff of the Gov. Thompson Hatchery and the Art Oehmcke Hatchery for their cooperation with implementation of new procedures. The state Muskellunge Management Advisory Team provided candid feedback through the process; we thank them for their input. Funding was provided by SFR Grant F-95-P to the Wisconsin Department of Natural Resources. Ed Murphy and Brandon Spude provided laboratory assistance. We thank Ryan Franckowiak, Al Kaas, Jen Hauxwell, and two anonymous reviewers for constructive and insightful suggestions that improved earlier drafts of the manuscript.

References


COLUMNS:
GUEST DIRECTOR’S LINE

A Behind-the-Scenes Look at the Dedicated Work of Our Members in Getting New Animal Drugs Approved for Use in Fisheries

Carl Burger
AFS Past President Burger can be contacted at cvburger@smith-root.com.

Ever wondered about the elaborate and intricate process involved in getting therapeutic drugs and treatments authorized for use by fisheries professionals? Have you considered the extent of research support behind this approval process for things like “immediate-release” anesthetics (that we hope to use in management-related sampling efforts), spawning hormones (used by our professionals to enhance restoration and recovery of imperiled fish populations), and antibiotics (often required by our hatchery-centric recovery programs)? I’ll bet that most of us are unaware of the considerable time, research, and costs involved in such approval efforts—many of which involve AFS members—and all of which directly affect our profession and our work in one way or another.

In early March, I had the good fortune to attend “Aquaculture 2010” in San Diego, a triennial meeting sponsored by our Fish Culture Section and two other partners, the World Aquaculture Society and the National Shellfisheries Association. I sat in on parts of two of their showcase sessions on fish therapeutics research and the drug approval process. I was amazed by the process and impressed by the substantial commitments of time and effort needed (in some cases decades) to get drugs approved for the fisheries community at large—for procedures and treatments we simply cannot do without.

The process goes something like this: the U.S. Food and Drug Administration’s Center for Veterinary Medicine (CVM) regulates the approval, manufacture, distribution, and use of animal drugs. In aquaculture and fisheries, CVM approves drugs based on data generated by a sponsor (a drug or chemical company) or a variety of “public data generating partners” (see below). The information generated by public-funded partners is critical because sales from aquaculture drugs in the United States are generally insufficient for most sponsors to recoup investments in the whole approval process. As a rule of thumb, it takes 10−15 years and $10−20 million to generate data sufficient to demonstrate that:

1. A drug is safe (to the fish or shellfish, the consumer, and the environment),
2. That its manufacture meets consistency standards, and
3. That it’s as effective as claimed.

It is this approval process that assures our domestic aquaculture production is safe and that it meets rigorous standards. Lack of adequate regulation can lead to problems and exposure risks. Drugs critical for use in aquaculture and fisheries on a global basis have included:

1. Oxidizing agents used as disinfectants (e.g., hydrogen peroxide and chloramine-T),
2. Antibiotics (e.g., florfenicol and oxytetracycline), and
3. Potential “immediate-release” fish sedatives (e.g., benzocaine and eugenol).

Currently, there are eight drugs approved and available for use in aquaculture and fisheries. Although this may seem like a sparsely equipped medicine chest, it’s important to recognize that this is almost double the number of drugs that were available to fisheries professionals in the mid-1990s. There were six new drugs approved from 1964 to 1994 (but two of those are no longer available) and four new drugs approved from 1995 to 2010. The progress in drug approvals over the past 15 years is attributable to a large degree to federal and state funding of the $30-million Federal-State Aquaculture Drug Approval Partnership Project and to the diligence of researchers and non-researchers associated with federal agencies, universities, and some of the drug companies, including those that helped coordinate or fund the approval activities. However, virtually no progress would have been made without the combined efforts of the sponsors and the

Note: Section President Jesse Trushenski summarized some of the recent activities and achievements of the AFS Fish Culture Section (recall that AFS was originally founded as the American Fish Culturists’ Association in 1870) in the Guest Director’s Line in the March issue of Fisheries. The present contribution delves a bit more deeply into an extremely vital role that FCS members and others play: the supportive research and reporting that assures us of having approved sedatives and therapeutics for virtually everything we do in fisheries, whether you are a field biologist, hatchery manager, research scientist, educator, consultant, or program administrator.—GNR

Continued on page 409
Tidewater Chapter

Presents awards at Annapolis meeting

The 2010 annual meeting of the Tidewater Chapter of the American Fisheries Society was held on 18–20 March in Annapolis, Maryland. The meeting was held at the Loews Annapolis Hotel, centrally located in historic downtown Annapolis. Several award winners were honored at the meeting.

One of the recipients of the 2009 NOAA Bronze Medal awards, Wes Patrick, has been a Tidewater Chapter member since 1999 and served for many years as secretary/treasurer. The Bronze Medal award is one of the highest honors that can be granted by the under secretary for oceans and atmosphere. The award was for leadership in developing a rigorous and flexible approach to end overfishing in U.S. fisheries via annual catch limits and accountability measures. The full project team was: Galen Tromble, Mark Millikin, Richard Methot, Caroline Park, Jennifer Ise, Debra Lambert, Wesley Patrick, Christopher Wright, and Theophilus Brainerd.

Student presentations once again carried a successful Tidewater annual meeting. A total of 24 presentations were evaluated and scored by six judges (10 posters and 14 oral papers). In the poster category, first place went to Jay T. Turnure (Rutgers University) for “Small-scale Movements and Site Fidelity in Weakfish (Cynoscion regalis): Diel and Seasonal Patterns in a Mid-Atlantic Bight Estuary,” second place went to Christian W. Conroy (University of Maryland) for “Migration and Habitat Use Patterns by Age 0 Striped Bass in the Patuxent River Estuary, Maryland, USA,” and third place was given to Marissa G. Brady (Delaware State University) for “Combining Mark-Recapture and Telemetry to Understand American Eel Population Dynamics.”

In the oral paper category, first place went to Cecilia S. Krahoff (East Carolina University) for “Using Passive Acoustics to Monitor Atlantic Croaker Populations in Pamlico Sound, NC,” and second place was a tie between Ryan J. Woodland (University of Maryland) for “Assessing Changes in Trophic Ecology of Juvenile Fish Across an Estuarine-Marine Boundary: Consequences of Natal Habitat Use” and Lonnie Gonsalves (University of Maryland Eastern Shore) for “Dietary Polyunsaturated Fatty Acids and Disease Progression in Striped Bass, Morone saxatilis.”

The Conservation Award is given periodically by the Tidewater Chapter to an individual, resource management agency, corporation, or non-profit organization that has distinguished themselves through notable fisheries or habitat conservation activities. This year the Chapter recognized two deserving individuals.

1. The first of two Conservation Award recipients was Karl Blankenship, long-time editor and principal staff writer for the Bay Journal. Launched in 1991 and published as a public service by the Alliance for the Chesapeake Bay for 20 years, and by Chesapeake Media Services beginning with the 20 March 2010 issue, the Bay Journal is the “newspaper of record” for bay happenings. Articles in this paper are frequently cited in reports, books, and other publications. The Bay Journal is one of the most dependable sources of accurate and also comprehensive coverage of often complicated scientific topics and usually controversial fisheries policy issues, thanks to Blankenship’s extraordinary analytical and writing skills. He can take on a formidable environmental issue and tell a story that is clear, concise, and easily understood. Blankenship can communicate science to a very broad audience in a way that makes most scientists and resources managers drool with envy. Respect for Blankenship and his writing skills extends far beyond the Bay Journal’s readership of over 40,000. He has won numerous awards for his work, including the Chesapeake Bay Foundation’s Lifetime Achievement Award in 2006.

Tidewater Chapter Awards Chairman Ron Klauda presents the Conservation Award to Karl Blankenship.
The second Conservation Award recipient was Jim Uphoff. Uphoff is with the Maryland Department of Natural Resources’ Fisheries Service and is a past president of the Tidewater Chapter. He has a long and distinguished record of applied science and advisory service in support of better land use, habitat protection, and fisheries management. His style of initiating discussion and debate in a sometimes self-deprecating and unassuming manner is well known. This approach usually launches Uphoff into a well thought out, critical comment or firmly-held view supported by his many years of experience as a field biologist and fisheries scientist. Uphoff does not demure when he holds unpopular beliefs. For example, he expressed the controversial view early in his career at Maryland Department of Natural Resources (early 1980s) that Chesapeake Bay striped bass were being over-exploited, a position that according to the recent book, Striper Wars, nearly cost him his job. Uphoff also insisted that scientists and managers did not completely understand what led to the recovery of striped bass in Chesapeake Bay, after the moratorium on fishing, and argued that the parable of recovery is far more complex than most believe. He forced the issue of predation effects into the Atlantic States Marine Fisheries Commission’s stock assessments for weakfish and Atlantic menhaden. Uphoff has also been an outspoken and effective promoter of the obvious, but often ignored or poorly understood, linkages among land-use planning, watershed development, and fisheries management in Chesapeake Bay. His initiative and problem-solving skills as a field biologist and fisheries scientist, coupled with his constant search for new ways to “skin a cat,” have led him to find answers to many key questions.

The Excellence in Fisheries Education Award is presented periodically to a Tidewater Chapter member who has achieved excellence in teaching and student advising in the field of fisheries science, and who also encourages student participation in the Tidewater Chapter, American Fisheries Society, and other fisheries-related meetings. This year’s Excellence in Fisheries Education award went to Ed Houde. Houde is a professor at the University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory. Houde’s research experience, publication record, and leadership on numerous review, advisory and planning committees for university, regional, state, federal, and international groups are noteworthy. These career contributions were recognized by the Tidewater Chapter in 2005, when Houde received a Conservation Award. But, his enthusiasm, energy, and commitment to quality education also are well known. “His method of teaching is very enjoyable, as he brings his passion for science...into the classroom,” said one of Houde’s students. He taught a graduate-level “Fisheries Science and Management” course at the Rosentiel School of Marine and Atmospheric Science and also later at the University of Maryland for more than 35 years. More recently, in collaboration with the late John Olney (Virginia Institute of Marine Science), Houde taught an “Early Life History of Marine Fishes” course that is internationally known. He gave an excellent lecture on fisheries management in a graduate-level “Ecosystem-based Resource Management” course that was collaboratively offered by the Maryland DNR and the University of Maryland (UMD) to DNR employees and UMD students. Houde’s colleagues, graduate students, and post-docs are inspired and humbled by his work ethic. He generously shares his wealth of scientific knowledge with all students who work under his guidance, and he offers abundant encouragement while setting an example of honesty and integrity. To date, Houde has mentored 11 Ph.D. and at least 28 master’s students who have taken (or soon will take) their places in the world of fisheries science and management.

The Eileen Setzler-Hamilton Memorial Scholarship is presented periodically to one or more outstanding graduate students who are currently enrolled in a fisheries science or closely-related curriculum and who have displayed a commitment to excellence in research, teaching, professional endeavors, and public education, outreach, and community. This award was created in 2003 to remember Eileen Setzler-Hamilton, a long-time member of the American Fisheries Society and fourth president (1989) of the Tidewater Chapter. This year the Chapter was able to offer the Eileen award to three deserving candidates. The first place award went to Cecilia Krahhorst, a M.S. candidate in biology at East Carolina University, who has been accepted to the Ph.D. program in coastal resource management at East Carolina. The two honorable mention awards were given to Ryan Woodland, a Ph.D. candidate in marine, estuarine, and environmental sciences at the University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory, and to Jacob Boyd, a M.S. candidate in biology at East Carolina University.

—Sara E. Mirabilio
Merging Our Deeper Currents

2009 ANNUAL REPORT

AMERICAN FISHERIES SOCIETY
WWW.FISHERIES.ORG
ADVANCING THE NATIONAL FISH HABITAT ACTION PLAN

AFS is represented on the National Fish Habitat Action Plan Board by Past President Stan Moberly. AFS hosted a Congressional briefing on this bill during early 2010. Additionally, AFS established a new Section in 2009, the Fish Habitat Section, within its organizational framework.

SUPPORTING EMERGING COHORTS OF NEW PROFESSIONALS

We continue to support the Hutton Junior Fisheries Biology Program, a summer mentoring program for high school students, particularly students underrepresented in the fisheries professions. This year, 24 students are out in the field working with mentors and learning new skills. Additionally, a new mentoring program was initiated by the AFS Governing Board this year to encourage emerging AFS leadership in our ranks. Through this program, young professionals who have expressed interest in AFS governance and leadership are invited to participate for one year in Governing Board activities. Finally, this year will be the first year of a new scholarship program for Native Peoples undergraduate students to attend an AFS Annual Meeting. These scholarships are sponsored by the U.S. Fish and Wildlife Service and administered by AFS.

ENCOURAGING FULL PARTICIPATION IN AFS MEETINGS

AFS recognizes that many members find it economically challenging to attend AFS meetings. Although nothing can fully replace physical attendance at meetings, technological advances make it possible for members to engage in virtual attendance. Accordingly, the Membership Concerns Committee, Meeting Oversight Committee, and Electronic Services Advisory Board initiated a pilot study during the joint AFS—The Wildlife Society (TWS) symposium on species introductions/re reintroductions to determine the best means for connecting AFS members to these meetings. The results of this exploratory initiative will be presented by the chair of the Meeting Oversight Committee during the Governing Board meeting at the 2010 Annual Meeting in Pittsburgh.

FORMALIZING AFS PERSPECTIVE AND POSITIONS

AFS finalized a policy statement on climate change and is currently working on a policy statement addressing the use of chemicals in fish culture. Additionally a new resolution is in development that addresses transparency and public participation in National Environmental Policy Act (NEPA) processes.

SPECIAL PROJECT AND A SPECIAL PARTNERSHIP

The AFS and The Wildlife Society (TWS) collaborated during 7–9 April 2010 to conduct the Joint AFS–TWS Symposium on Species Introductions-Reintroductions. This three-day meeting brought together participants from throughout North America and beyond. This symposium also served as an experiment to test the feasibility of

1. Conducting topic-oriented meetings (TOMs) as encouraged by the AFS Meeting Oversight Committee,
2. Working collaboratively with sister organizations in the newly-formed Coalition of Natural Resources Societies (CNRS), and
3. Ascertaining means for virtual attendance at AFS meetings.

CNRS was formed early this year to form a partnership among AFS, TWS, Society of American Foresters, and the Society of Range Management to work together on natural resources issues, particularly in the public policy arena.

SANTIAGO CRUZ 

Vice President
Gulf Oil Spill

Efforts to address the massive Deepwater Horizon oil spill in the Gulf of Mexico are already underway. As a professional scientific society, AFS will help ensure the timely exchange of science-based information. As part of that effort, a special briefing session has been arranged for the Pittsburgh Annual Meeting on Thursday afternoon, 16 September 2010. In addition, a proposed Gulf Oil Spill Task Force will help provide direction and oversight for all AFS activities and initiatives addressing the impacts of the oil spill in the Gulf of Mexico on the region’s fishery resources and the economies that depend on them. Potential objectives for that task force include assisting in the technical review of proposals, reports, and documents; helping in the development of technically sound and equitable means for allocation of funds designated for research and restoration; and identifying relevant data sets. Other possible activities include providing timely and readily understandable information regarding the oil spill such as summary documents, handouts, and web pages, as well as ensuring that the best scientific information is used to address the impacts on and restoration of fisheries resources affected by the oil spill.

National Fish Habitat Action Plan

Momentum for the National Fish Habitat Conservation Act (H.R. 2565 and S. 1214) continues to grow, with 25 co-sponsors in the House and 13 co-sponsors in the Senate. If passed, the National Fish Habitat Board will be formally established and given authority over funding of up to $75 million annually to directly support fish habitat work. This legislation recognizes the success and growth of NFHAP, with 17 regional partnerships working on the ground in aquatic conservation and 4 candidate partnerships waiting to be recognized.

In the third annual NFHAP awards ceremony, several partners were recognized for their active support of fish habitat efforts. The Outreach and Education Award was presented to Catherine Innan of the Wasilla Soil and Water Conservation District, and Scott Robinson, coordinator of the Southeast Aquatic Resources Partnership, received the Jim Range Conservation Vision Award. David Moe Nelson with the Biogeography Branch of NOAA was recognized with the Scientific Achievement Award while Kenda Flores of the Missouri Department of Conservation and Bob and Nicky Baker of the Lower Bourbeuse COA Landowner Committee shared the Extraordinary Action Award.

The National Fish Habitat Action Plan is the most comprehensive effort ever attempted to voluntarily conserve freshwater, estuarine, and marine waterways and habitat across the country. The Action Plan is a science-based investment strategy to conserve waterways and make conservation dollars stretch farther by combining federal and privately-raised funds to build regional partnerships. For more information, visit www.fishhabitat.org.

Due to the rising interest in fish habitat issues, the new AFS Fish Habitat Section was formed in 2009 and held its first formal meeting in Nashville. Joe Margraf serves at the Section’s first president.

World Council of Fisheries Societies

The World Council of Fisheries Societies is a nonprofit, nongovernmental membership organization established to promote international cooperation in fisheries science, conservation, and management. This includes encouraging sustainable management practices, encouraging excellence in fisheries research, and promoting the wise use of fishery resources. Planning is currently underway for the next World Fisheries Congress to be held in Edinburgh, Scotland, in May 2012. Also, a major symposium on “Fish and Climate Change” is being sponsored by WCFS member organizations such as the Fisheries Society of the British Isles, American Fisheries Society, and Japanese Society of Fisheries Science in Belfast, UK, in late July 2010.

Hutton Update

The Hutton Junior Fisheries Biology Program is a summer mentoring program for high school students. The principal goal of the Hutton Program is to stimulate interest in careers in fisheries science and management among groups underrepresented in the profession, including minorities and women. The Hutton Program provides students with a summer-long hands-on experience in fisheries research with a mentor who is working in some aspect of the field. A $3,000 scholarship and an AFS student membership are provided to each student accepted into the program. The Class of 2010 includes 24 outstanding students who are currently working with mentors in 16 states (Alabama, Alaska, Arizona, California, Colorado, Connecticut, Massachusetts, Michigan, Missouri, Montana, New Jersey, Oregon, South Dakota, Tennessee, Washington, and Wisconsin.) Of the exceptional students chosen for the Hutton Program this summer, nearly half are minorities and two-thirds are female.

The program is evaluated through the Annual Hutton Alumni Survey. The ultimate success of the program is determined by the number of students that enter the fisheries profession. According to the 2009 survey, 55% of Hutton alumni are studying or considering studying fisheries, biology, or environmental science; 20% have received undergraduate degrees in fisheries or biology; and of those students, 59% are pursuing advanced degrees in fisheries or biology.
Visit www.fisheries.org for the latest on fisheries science and the profession. Subscribe to the free Contents Alert e-mail service or search for your colleagues by using the membership directory online.

The Fisheries InfoBase now includes all AFS journals back to 1870, including the complete contents of all issues of Fisheries.

The AFS membership journal, Fisheries, offers up-to-date information on fisheries science, management, and research, as well as AFS and professional activities. Featuring peer-reviewed scientific articles, analysis of national and international policy, commentary, chapter news, and job listings, Fisheries gives AFS members the professional edge in their careers as researchers, regulators, and managers of local, national, and world fisheries. Fisheries is available to members online at www.fisheries.org.

Fisheries is available to members online at www.fisheries.org.

Recent and Upcoming Titles

Planning and Standard Operating Procedures for the Use of Rotenone in Fish Management
Community Ecology of Stream Fishes
Case Studies in Fisheries Conservation and Management: Applied Critical Thinking and Problem Solving
Inland Fisheries Management in North America, Third Edition
Pacific Salmon: Ecology and Management of Western Alaska’s Populations
Paddlefish Management, Propagation, and Conservation in the 21st Century
Biology, Management, and Conservation of Lampreys in North America
Pacific Salmon: Ecology and Management of Western Alaska’s Populations
SOCIETY AWARDS

AWARD OF EXCELLENCE
Carl B. Schreck

PRESIDENT’S FISHERY CONSERVATION AWARD
David W. Willis

THE HUDSON RIVER FOUNDATION WILLIAM E. RICKER RESOURCE CONSERVATION AWARD
David A. Fournier

CARL R. SULLIVAN FISHERY CONSERVATION AWARD
Ransom A. Myers, posthumous

MERITORIOUS SERVICE AWARD
F. Joseph Margraf

THE EMELINE MOORE PRIZE
Bradford E. Brown

DISTINGUISHED SERVICE AWARD
Steven Cooke
Melissa Wueellner

OUTSTANDING CHAPTER AWARD
Oregon Chapter

OUTSTANDING STUDENT SUBUNIT AWARD
Palouse Student Subunit of the Idaho Chapter
Lake Superior State University Student Subunit

EXCELLENCE IN FISHERIES EDUCATION
Michael Hansen

GOLDEN MEMBERSHIP AWARDS:
THE CLASS OF 1959

SKINNER AWARD
Winners: Marybeth Brej, Joe Gerken, Marie-Ange Gravel, Andrew Hafs, Caleb Hasler, Tarah Johnson, Cecilia Krahforst, Karen Murchie, Lora Tennant, Justin VanDeHey
Honorable Mentions: Allison Colotelo, Daniel Farrae, Connie O’Connor, James Thorson, Daniel Weaver

J. FRANCES ALLEN SCHOLARSHIP
Winner: Karen Mumche
Runner-up: Heidi Lewis

STUDENT WRITING CONTEST
Steven Gray

BEST PAPER AWARDS

MERCER PATRIARCHE AWARD FOR THE BEST PAPER IN THE NORTH-AMERICAN JOURNAL OF FISHERIES MANAGEMENT:
W. J. Overholtz, L. D. Jacobson, and J. S. Link

ROBERT L. KENDALL BEST PAPER IN TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY:
Kenneth A. Rose, Bernard A. Megrey, Douglas Hay, Francisco Werner, and Jake Schweigert.

BEST PAPER IN THE JOURNAL OF AQUATIC ANIMAL HEALTH:

BEST PAPER IN THE NORTH-AMERICAN JOURNAL OF AQUACULTURE:
David J. Wise, Terril R. Hanson, and Craig S. Tucker.

SECTION AWARDS

EQUAL OPPORTUNITIES SECTION
MENTOR AWARD: Benjamin Cuker

EDUCATION SECTION
2008 BEST STUDENT POSTER AWARD:
William R. Glass

2008 AFSSSEA GRANT OUTSTANDING STUDENT PAPER:
Winner: Ryan M. Utz
Honorable Mentions: Cassandra May, Heidi A. Lewis

ESTUARIES SECTION

STUDENT TRAVEL AWARD:
Bridgette Froschke, Jeanne-Marie Havrylkoff, Erik Lang, Edward McGinley

NANCY FOSTER HABITAT CONSERVATION AWARD:
Si Simenstad

FISHERIES MANAGEMENT SECTION
CONSERVATION ACHIEVEMENT AWARD:
Project SHARE
(Salmon Habitat and River Enhancement)

AWARD OF EXCELLENCE:
David Bennett

AWARD OF MERIT:
A. Lawrence “Larry” Kolz

HALL OF EXCELLENCE:
Wayne Tody, Dennis Unkenholz, Scott Van Horn

GENETICS SECTION

JAMES E. WRIGHT AWARD:
Yen Duong, Jamie Roberts

STEVAN PHELPS MEMORIAL AWARD:
Rachel Schwartz and Bernie May

MARINE FISHERIES SECTION

STEVEN BERKELEY MARINE CONSERVATION FELLOWSHIP:
Winner: Aleksandra Majkovic
Honorable Mentions: Jack Kittinger, Annie Schmidt

OSCAR E. SETTE AWARD: Bernard A. Megrey

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Northwest Marine Technology Inc.

### Official Members

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- Alabama Department of Conservation
- Alaska Department of Fish and Game
- Arkansas Game and Fish Commission
- Bureau of Land Management
- Colorado Division of Wildlife
- Delaware Division of Fish and Wildlife
- Florida Fish and Wildlife Conservation Commission
- Georgia Department of Natural Resources, Wildlife Resources Division
- Grand River Dam Authority
- Great Lakes Fishery Commission
- Hawaii Department of Land and Natural Resources
- Idaho Fish and Game Department
- Illinois Department of Natural Resources
- Indiana Department of Natural Resources, Division FWS
- Iowa Department of Natural Resources
- Kansas Department of Wildlife/Parks
- Kentucky Department of Fish and Wildlife Resources
- Maine Department of Inland Fish and Wildlife
- Massachusetts Division of Marine Fisheries
- Michigan Department of Natural Resources
- Minnesota Department of Natural Resources
- Mississippi Department of Wildlife, Fish and Parks
- Missouri Department of Conservation
- Montana Department of Fish, Wildlife and Parks
- Nebraska Game and Parks Commission
- New Jersey Department of Environmental Protection
- New Mexico Game and Fish, Department of Fish Management
- North Carolina Wildlife Resources Commission
- Ohio Department of Natural Resources
- Pennsylvania Fish and Boat Commission
- South Dakota Game Fish and Parks
- Tennessee Valley Authority
- Tennessee Wildlife Resources Agency
- Texas Parks and Wildlife Department
- U.S. Department of Agriculture, Forest Service
- U.S. Department of Agriculture, APHIS VS CEAH
- U.S. Fish and Wildlife Service
- Utah Department of Natural Resources/Division of Wildlife Resources
- Vermont Department of Fish and Wildlife
- Virginia Department of Game and Inland Fish
- Washington Department of Fish and Wildlife
- West Virginia Department of Natural Resources
- Wisconsin Department of Natural Resources
- Wyoming Game and Fish Department

### Sustaining Members

- Abernathy Fish Technology Center
- Advanced Technical Aquatic Control LLC
- Advanced Telemetry Systems Inc
- AIS Inc.
- Alaskan Observers Inc
- Alpha Mach Inc.
- Amirix Systems, Inc. (VEMCO)
- Arizona Cooperative Fish and Wildlife Research Unit
- BioSonics
- Columbia River Inter-Tribal Fish Commission
- Confederated Tribes of the Umatilla Indian Reservation
- Confederated Tribes of Warm Springs Reservation
- Douglas Island Pink and Chum
- Floy Tag and Manufacturing Co.
- Gomez and Sullivan Engineers PC
- Hallprint Pty Ltd.
- Halltech Aquatic Research Inc.
- HDR/SWRI
- Hubbs-SeaWorld Research Institute
- Hydroacoustic Technology, Inc.
- IAP World Services
- Illinois Natural History Survey
- Intake Screens, Inc
- Kodiak Regional Aquaculture Association
- Kootenai Tribe of Idaho
- Marel
- Miller Net Company, Inc.
- Mississippi Alabama Sea Grant
- Mora Fish Technology Center
- New England Fishery Management Council
- NOAA National Marine Fisheries Service
- Normandeau Associates Inc.
- Northern Southeast Regional Aquaculture Association
- Ohio State University
- Okanagan Nation Alliance
- Oregon RFID
- Oregon State University
- OSU Hatfield Marine Science Center
- Pacific States Marine Fish Commission
- Pentec Environmental
- Prentiss Incorporated
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- SCA
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- University of Arkansas—Pine Bluff
- University of Maryland
- Upper Columbia Salmon Recovery Board
- Virginia Polytechnic Institute
- Versar Incorporated
- Wildlife International Ltd.
- Yakama Indian Nation
**FINANCIALS**  
2009 ANNUAL REPORT

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**Change in Net Assets** 0

Although we attempted to list all 2009 donors, donations coming in through certain avenues may not have been completely captured in this list. Please contact Thollis@fisheries.org if your name was inadvertently omitted. We apologize for any errors and will run a list of any missed donors in a future issue of *Fisheries*. 
Some exciting events in Pittsburgh!

**MONDAY, 9/13**

8–12 Don’t miss the Plenary Session!
   —Ian Cowx, Univ. of Hull
   —Jane Lubchenco, NOAA
   —Larry Schweiger, National Wildlife Federation
   —Melissa Wuellner, SD State Univ.

(Spawning Run registration by Monday evening)

**TUESDAY, 9/14**

8–3 Climate Change Symposium
   Accounting for Climate Change through Vulnerability Assessments

9–5 Check out new products & books at the TRADE SHOW

**WEDNESDAY, 9/15**

6–9 Join colleagues for Early Morning Fun & Exercise at Spawning Run
   Cost—$25 includes colorful long-sleeved tech T-shirt

8–4 Influences of Natural Resources Extraction Activities on Fish Communities—Broad spectrum of viewpoints from industry, academia, state & federal regulatory agency perspectives. Timely with mining related issues raised before Water Quality Sec. & AFS Board

6–10 SOCIAL at Pittsburgh 200 & PPG Aquarium (4,000 animals & fish!)

**THURSDAY, 16**

1:20–3 Climate Change Issues Symposium

3:20–5 Science Perspectives on BP Oil Spill in Gulf of Mexico

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**NOTES**

We are one month away from hosting the 140th meeting of the American Fisheries Society in beautiful Pittsburgh. We have an exciting program lined up for the daily sessions and have set up wonderful venues for the evening socials, where you can relax and share stories with your colleagues. The meeting will be held downtown 12–16 September 2010, at the spectacular Westin Hotel and the David L. Lawrence Convention Center. If you haven’t done so yet, please visit the website to register and to book your hotel.

Visit Website for more Information: [www.fisheries.org](http://www.fisheries.org)

- Browse conference by day or by program, including contributed abstracts and symposium submissions
- Schedule a sightseeing trip or go fishing at Pittsburgh’s unique Three Rivers setting.

With fabulous dining, world-class museums, and innovative art galleries, Pittsburgh is one of the top travel destinations in the world. We look forward to seeing you in September 2010.
synergism of corporate endeavor. But it is also one that depends on skepticism, critique, and a generally negative orientation (think null hypotheses). We need to be careful. Our training, our discipline, and the extreme pressures that can be brought to bear on persons engaged in science, coupled with a propensity for us to blur professional and personal identities, can take a human toll. Broken relationships are all too common among scientists. These relationships are not all external either. We can break relationships within ourselves. Restoring these relationships can be tough. We must engage our deeper currents.

If you have written a thesis, a dissertation, a proposal for competitive funding, or a paper for a major international journal, you understand very clearly how deeply you must plunge within yourself in order to dig out the core elements of who and what you profess to be, and to express these elements in appropriate ways. If you have ever been on a desperate battlefield as a soldier or otherwise (think brown bear in the alders, storm at sea, Class I rapids transformed by overnight rain into Class V, a cottonmouth two steps from one of your students, or a student or colleague wedged under an overturned boat), you also have engaged in this aspect of the human experience. Those of us who have ever frozen during a major exam know that we have had to push beyond a threshold in order to have any hope for survival. (This happened to me on every statistics test during the first year of my doctoral studies!) You must move. You know that there is no place for compromise or mediocrity. There is no substitute for excellence. You must be successful. There is no other way. In that process, in those situations, you discover something about yourself. You discover the power to transcend...place, situation, certain individuals, politics...the pressure of an exam...self-imposed limitations or barriers. When this occurs, life takes on a strange sweetness and thoughts assume clarity unimaginable in the common realm. You act—decisively. You take charge. So much is at stake.

In this, my last “Hook” as president of the American Fisheries Society, I challenge you to take charge and to dredge deeply, engage those deeper currents, pull their essence into the light, and cover yourselves with the radiance of renewed professionalism and confirmed personal identity and purpose. Remember why you climbed on board the minibus. Those reasons are still valid. If the flames within you have cooled, fan them. You have the power to do that. Stay connected with fellow travelers on this pilgrimage. Inspire one another with your humanity as well as your professional disciplines. Keep in mind that science is a wonderful sacrament for the discernment of truth but that some things cannot be measured or counted. Don’t be afraid to engage them. Remember that the American Fisheries Society is a very human organization with a primary purpose of enhancing your professional pilgrimage. Support it. It is a treasure, but a treasure that requires constant polishing by its members to retain its luster. Don’t forget to charge your batteries from time to time; it makes a difference. AFS meetings are a good way to do all of the above.

It has been a profound privilege to serve you as president of the American Fisheries Society. Thank you for your trust. Thank you for your help along the way. This is a good journey. Keep the faith. Forge ahead.
researchers responsible for generating the data required for new approvals, and the CVM, which committed considerable resources towards clarifying the approval process and reviewing the study protocols and resulting data.

A major portion of the research conducted in the past 45 years in support of aquaculture drug approvals has been completed by the public sector—the research entities characterized as public data generating partners. Research groups such as the U.S. Geological Survey (USGS) Upper Midwest Environmental Sciences Center (UMESC; since 1964), U.S. Fish and Wildlife Service Aquatic Animal Drug Approval Partnership Program (AADAP; since 1994), U.S. Department of Agriculture (USDA) Stuttgart National Aquaculture Research Center (SNARC; since 1994), and Cornell University (funded through the USDA's National Research Support Project No. 7, or NRSP-7) have generated a tremendous amount of data that have or will lead to aquaculture drug approvals.

These entities and their researchers (AFS members like Mark Gaikowski and Jeff Meinertz at UMESC; Jim Bowker, Dan Carty, Molly Bowman, and Dave Erdahl with the USFWS AADAP facility; Paul Bowser at Cornell; Dave Strauss at USDA SNARC; Pat Gaunt at Mississippi State; and many others) have submitted countless reports and publications to CVM over the past two decades addressing issues such as effectiveness, residue depletion, and safety (to fish and the environment). Others, such as AFS Past Presidents Christopher Kohler (Southern Illinois University) and Christine Moffitt (USGS, University of Idaho), Roy Yanong (University of Florida), and Ron Phelps (Auburn) have provided the research results critical to the future approvals of drugs for fisheries and aquaculture. Still others (e.g., long-time AFS member Roz Schnick, who recently retired from her position as the national coordinator for Aquaculture New Animal Drug Applications, and Tom Bell, USFWS New Animal Drug Approval coordinator) have supported the approval process via their administrative capacities and regulatory roles.

It’s not possible to list all of those who contribute to the approval process for new animal drugs for use in fisheries. But their activities and their research support (conducted primarily with public funds) have affected and benefited all of us, whether we are fishery managers, research scientists, educators, consultants, or administrators. Where would we be today without these meaningful accomplishments in new drug approvals? Suffice it to say that there would have been no new fisheries-related drug approvals during the past two decades without the dedicated support of individuals like those mentioned above. They are critical to our profession...at all levels. And their long, hard work in the trenches is often overlooked and under-appreciated. Please think about giving them your sincere thanks for a job well done. From what I saw in San Diego, it’s much deserved!
### CALENDAR: FISHERIES EVENTS

To submit upcoming events for inclusion on the AFS Web site Calendar, send event name, dates, city/state/province, web address, and contact information to cworth@fisheries.org. (If space is available, events will also be printed in Fisheries magazine.)

More events listed at www.fisheries.org.

<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
<th>Location</th>
<th>Web Address</th>
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<tbody>
<tr>
<td>Aug 31-Sep 2</td>
<td>Third Annual Conference of the North American Chapter of World Sturgeon Conservation Society</td>
<td>Chico Spring, Montana</td>
<td><a href="http://www.wscs.info">www.wscs.info</a></td>
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<tr>
<td>Sep 5-9</td>
<td>Sixth International Symposium on Aquatic Animal Health: Global Strategies for a Changing Environment</td>
<td>Tampa, Florida</td>
<td>Andy Kane, <a href="mailto:Kane@ufl.edu">Kane@ufl.edu</a></td>
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<tr>
<td>Sep 8-11</td>
<td>Fish Sampling with Active Methods Meeting</td>
<td>Ceske Budejovice, Czech Republic</td>
<td><a href="http://www.fsam2010.wz.cz">www.fsam2010.wz.cz</a></td>
</tr>
<tr>
<td>Sep 12-16</td>
<td>American Fisheries Society 140th Annual Meeting</td>
<td>Pittsburgh, Pennsylvania</td>
<td><a href="http://www.fisheries.org/afs10/">www.fisheries.org/afs10/</a></td>
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<tr>
<td>Date</td>
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<td>Sep 22</td>
<td>World Ocean Council: Sustainable Ocean Summit</td>
<td>Honolulu, Hawaii</td>
<td><a href="http://www.ocean">www.ocean</a> council.org</td>
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<tr>
<td>Sep 22-23</td>
<td>Electrofishing Class</td>
<td>Vancouver, Washington</td>
<td><a href="http://www.smith-root.com">www.smith-root.com</a></td>
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<td>Sep 20-24</td>
<td>ICES Annual Science Conference 2010</td>
<td>Cite des Congres, Nantes, France</td>
<td><a href="http://www.ices.dk/iceswork/asc/2010/index.asp">www.ices.dk/iceswork/asc/2010/index.asp</a></td>
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<tr>
<td>Sep 28-30</td>
<td>Wild Trout Symposium</td>
<td>West Yellowstone, Montana</td>
<td><a href="http://www.wildtroutsymposium.com">www.wildtroutsymposium.com</a></td>
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<tr>
<td>Oct 3-8</td>
<td>Aquatic Resources Education Association Biennial Conference</td>
<td>Omaha, Nebraska</td>
<td><a href="http://www.arenanet.org">www.arenanet.org</a></td>
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<tr>
<td>Oct 19</td>
<td>Institute of Fisheries Management 41st Annual Conference: Fisheries in Transition from Source to Sea</td>
<td>Portsmouth, United Kingdom</td>
<td><a href="mailto:adrian.saunders@environment-agency.gov.uk">adrian.saunders@environment-agency.gov.uk</a></td>
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<tr>
<td>Nov 7-12</td>
<td>Eastern Marine Biology of Fisheries Research Institute</td>
<td>Taitung, Taiwan</td>
<td><a href="http://www.tfrin.gov.tw">www.tfrin.gov.tw</a></td>
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Fisheries Biologist I, AP World Services, NOAA, National Marine Fisheries Services, Panama City, Florida.

Salary: Competitive.
Closing: Until filled.
Responsibilities: Responsibilities include but are not limited to, data entry, data proofing, field support aboard small vessels, small boat operation, processing and archiving of biological samples, coordination with co-investigators across Florida, Louisiana, Mississippi, and Alabama to facilitate Gulf sturgeon research, and recruiting and training of field volunteers. Proficient operation of small boats and trailers, laboratory and field experience, computer literate and experienced with common word processing, database, statistical, and graphics programs, knowledge of basic biological statistics, experience making oral presentations, and scientific writing skills.

Qualifications: B.S. in biology or related science or 3 years experience in related field. Must be a natural U.S. citizen or a non-U.S. citizen with at least 5 years of continuous residency in the U.S. Ideal candidates meet these minimum requirements and are flexible and easy to get along with.

Contact: Apply through the IAP World Services website www.iapws.com for the fisheries biologist I position at the Panama City, FL lab location of NOAA Fisheries.

Ph.D. Graduate Student Research Assistantship,
Cooperative Fish and Wildlife Research Unit, Department of Biological Sciences, University of Arkansas.

Salary: Stipend will be $18,000 plus full tuition waiver.
Closing: 15 August 2010.
Responsibilities: Develop regional ecological-flow relationships that will form the scientific framework for setting
environmental flow standards and understanding impacts of global climate change. Work with a multidisciplinary team.

Starting date: Negotiable. Project is pending funding.

Qualifications: Applicants should have a B.S. and M.S. in fisheries, ecology, biology, or a related field and 3.0 GPA minimum and 1100 V Q minimum GRE. Previous research experience with fish and/or streams is preferred, but not essential.

Contact: Send a letter describing interests and career goals, resume including GPA and GRE scores, 3 names and telephone numbers of 3 references, and 4 transcripts to Dan Magoulick at danmag@uark.edu (preferred) or Cooperative Fish and Wildlife Research Unit, Department of Biological Sciences, University of Arkansas, Fayetteville, Arkansas 72701, 479/575-5449. See http://biology.uark.edu/1397.htm.

M.S. Graduate Research Assistantship, Cooperative Fish and Wildlife Research Unit, Department of Biological Sciences, University of Arkansas.

Salary: Stipend will be $15,000 plus full tuition waiver.

Closing: 15 August 2010.

Responsibilities: Examining population genetics and factors affecting distribution and decline of the imperiled coldwater crayfish Orconectes eupunctus in the Missouri and Arkansas Ozarks. Perform field work in the Ozark Mountains, experiments and observations in the lab, and ecological modelling.

Starting date: Negotiable.

Qualifications: B.S. in fisheries, ecology, biology, or a related field and 3.0 GPA minimum 1100 V Q minimum GRE. Previous research experience with crayfish and/or streams is preferred, but not essential.
**Contact:** Send a letter describing interests and career goals, resume including GPA and GRE scores, 3 names and telephone numbers of 3 references, and 4 transcripts to Dan Magoulick at danmag@uark.edu (preferred) or Cooperative Fish and Wildlife Research Unit, Department of Biological Sciences, University of Arkansas, Fayetteville, Arkansas 72701, 479/575-5449. See http://biology.uark.edu/1397.htm.

**Fisheries Conservation Manager,** Environmental Defense Fund, Austin, Texas.

**Salary:** Negotiable commensurate with experience.

**Closing:** 16 September 2010 or until filled.

**Responsibilities:** Oversee and coordinate catch shares projects in the Gulf of Mexico, including Texas, Louisiana, Mississippi, Alabama, and the west coast of Florida. Partner with federal, state, and other elected officials, fisheries managers and chief scientists, catch share program administrators, council members, and local fishermen to implement these and other projects. Research and analysis of project-related information.

**Qualifications:** Graduate degree in science, policy, economics, or law in areas related to environmental or marine resources policy or sciences OR a minimum of 5 to 7 years equivalent professional experience. Thorough understanding of state/federal policy and political processes. Good people and project management skills. Strong written/verbal communications skills.

**Contact:** See www.edf.org/jobs. Contact jobs@edf.org. EOE.
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