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Fisheries

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ufsh20

Full Issue PDF Volume 39, Issue 11

Published online: 20 Nov 2014.

To cite this article: (2014) Full Issue PDF Volume 39, Issue 11, Fisheries, 39:11, 481-572, DOI: 10.1080/03632415.2014.988555

To link to this article: http://dx.doi.org/10.1080/03632415.2014.988555

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Fisheries

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VOL 39 NO 11
NOV 2014

AFS and Aquaculture: A Themed Issue

Putting the Red Back in Redfish Lake

Fish In, Fish Out

Marine Net-Pen Aquaculture

Aquaponics in the Classroom

Infectious Salmon Anemia Virus Response

AFS Sections: Perspectives on Aquaculture

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Fisheries

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

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Fisheries (ISSN 0363-2415) is published monthly by the American Fisheries Society; 5410 Grosvenor Lane, Suite 110; Bethesda, MD 20814-2199 © copyright 2014. Periodicals postage paid at Bethesda, Maryland, and at an additional mailing office. A copy of Fisheries Guide for Authors is available from the editor or the AFS website, www.fisheries.org. If requesting from the managing editor, please enclose a stamped, self-addressed envelope with your request. Republication or systematic or multiple reproduction of material in this publication is permitted only under consent or license from the American Fisheries Society.

Postmaster: Send address changes to Fisheries, American Fisheries Society; 5410 Grosvenor Lane, Suite 110; Bethesda, MD 20814-2199.

Fisheries is printed on 10% post-consumer recycled paper with soy-based printing inks.

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Society by Committee

Donna Parrish, AFS President

AFS officers serve for five years, beginning in the role of second vice president and ending as immediate past president. The three years leading up to being president provide the opportunity to observe the officers in the next steps. As I now look at the immediate past president, I am impressed that he is alive and well. Last year he warned me of the amount of effort that is required to appoint AFS committee chairs and to provide the committees with their charge for the year. Thankfully, until recently I did not realize how correct he was.

At first glance, one would expect that the difficult part of appointing committee chairs is the arm-twisting, begging, and bribing with a free beverage that accompanies the request. Surprisingly, that is not the case. Most of those I have asked have responded affirmatively and indicate that they are happy or at least willing to serve. These responses have made such a positive impression on me because they come from very busy people. These chairs are some of the best examples of the committed professionals in our Society.

So, getting someone to serve as a chair or on a committee is not that difficult in most instances. What is overwhelming is appointing 40 chairs of committees and 17 liaisons to other professional groups. Just reading the long list is tiring and begs the question, Why do we have so many committees? Some plausible explanations are that very narrowly focused committees are more apt to complete the president's charge. Also, an individual is more likely to agree to be on a committee when the work load is not huge.

These committee chairs are some of the best examples of the committed professionals in our Society.

Over the last few years we have combined two AFS standing committees (Membership and Member Concerns) and the obligation of having a Time and Place Committee has been suspended for this year. With the increased complexity of meeting costs and budgets, the Management Committee is considered the more appropriate committee to make the Annual Meeting recommendation. We have also removed some of the officer responsibilities in chairing awards committees. The officers make a significant time commitment to the Society over a five-year period. However, it is clear that the officers do not have adequate time to actively solicit award nominations, which is an obligation of the position. For this reason, officers will no longer chair most of those committees.

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Also, we have changed the responsibilities of the Governing Board and the Management Committee. The Management Committee now has the responsibility of dealing with the standard motions regarding the Society budget, Unit bylaws amendments, etc., whereas the Governing Board focuses on larger issues of long-range value to AFS. Perhaps the time is here to modify more of our governance, especially regarding the types of committees that we need and how many. In the President's Plan of Work for 2014–2015, I indicated the importance of increased transparency of governance. Transparency will be easier to achieve by removing at least some of the opaqueness inherent in an organizational structure that has 40 committees.

Aquaculture and the Science–Policy Continuum

Thomas E. Bigford, AFS Policy Director

Aquaculture is a complex arena, complete with ever-expanding science, shifting management implications, and growing societal demands. How, then, do we create useful policy to guide our way? And how can AFS its members lead the way?

AFS proudly describes itself as the "oldest and largest professional society representing fishery scientists." Indeed, our history since 1870 is beyond reproach, and we started as a fish culturists' society. As our mission has expanded, our Society has developed a broader mandate, an organizational structure with Units spanning dozens of specialties, and membership interests that extend beyond fishery scientists practicing in the natural and social sciences. Scientific knowledge forms the basis of our toils, but we apply science in a management context, convert our collective wisdom into policy, and share all of that when we educate others. This approach is important in all AFS does and certainly is relevant to the aquaculture topics that dominate this *Fisheries* issue.

Aquaculture is a complex mix of issues ripe for attention by each AFS discipline. Culture techniques are constantly improving. Fish nutritionists continually search for non-fish-based feeds. Public perceptions are maturing as consumers track harvest techniques, country of origination, and factors related to humane and sterile handling. As with all crops, genetics are very important, and people worry whether genetically modified fish might someday be a part of our food supply. Engineers are designing pens, rafts, strings, and other devices to increase production, reduce escapement and predation, and control other problems like navigation hazards. The list is much longer. Some of that breadth is reflected in the articles and commentaries contributed by several AFS Section members for this issue. The discussion has major societal and economic implications as the world seeks protein to feed a burgeoning population, provide quality recreational fishing opportunities, and conserve imperiled fish populations.The policy implications of supplementing wild-caught fish with cultured fish are huge, and AFS is positioned perfectly to make a difference.

Like other fields, aquaculture offers many intriguing challenges. By using fish-based feeds and producing harvests that parallel wild catches, aquaculture is both a consumer of and contributor to aquatic natural resources. It is also a source of employment and financial gain and will define global food security—not just seafood security—for years to come.

Such a multifaceted activity has many implications regarding aquatic science, resource management, and policy. To contribute our personal expertise,we must balance the ethical and legal constraints of our day jobs with the opportunities to engage on the issue as active members of an AFS Chapter, Section, Division, or the Society. Whether in the context of aquaculture or any other aquatic resource arena, through our active participation in AFS we have the chance to satisfy our career ambitions, broaden our knowledge base, and please our supervisors. Not impossible, perhaps enticing to many, but a path that requires careful negotiation and the ability to engage in frank, open, and collegial discussion.

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How best to engage on all the aforementioned levels? AFS members have faced this professional conundrum for decades and are usually successful. Federal and state agency employees whose jobs are focused on research and education have served as lead authors for AFS on scientific reviews and policy statements. Academics with the same dual focus have also flourished in the policy realm. Those efforts have helped to inform ongoing AFS and agency decision-making and policy development on a number of topics. AFS applied that model for its own policies on climate change and the need for an immediate-release anesthetic or sedative. We've used a similar strategy to combine the expertise of a dozen AFS members into a Society position on future directions of the U.S. Fish and Wildlife Service's National Fish Hatchery System. These are mutually rewarding efforts. To the best of my knowledge, each effort resulted in accolades from the member's home institution and from AFS. We're all better off because of those members who have blazed a trail, and this trail now leads us to aquaculture.

> **We must balance the ethical and legal constraints of our day jobs with the opportunities to engage on the issue as active members.**

Another indicator of success is the recent effort by the AFS Special Committee on Hatcheries and Management of Aquatic Resources (HaMAR) to develop considerations for fish culture. Committee members Vincent Mudrak, Christine Moffitt, John A. Sweka, Scott F. Stuewe, Connie Young-Dubovsky, Kim Scribner, George Nardi, and Douglas Bradley designed a symposium for our 2013 Annual Meeting in Little Rock, with Jesse Trushenski as moderator. That effort led to AFS Governing Board action at the 2014 Annual Meeting in Québec City to

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Introduction to the Aquaculture-Themed Issue

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Jesse Trushenski

Jim Bowker

Welcome, readers, to the first in a series of themed issues for *Fisheries* magazine. Periodically, the Society will focus its attention on timely topics or subjects of special importance to the membership. In honor of our Society's history as an aquaculturists' organization and various ongoing initiatives related to the discipline, this issue is dedicated to all things aquaculture.

As you'll see, this issue is a bit of patchwork quilt; this is by design. Like our Society—and fisheries as a whole—aquaculture is diverse. Aquaculture can be described simply as the rearing of aquatic organisms, but this is no simple task: throughout the world, hundreds of species of finfish, shellfish, crustaceans, aquatic plants, and algae are reared in net-pens, rafts, ponds, raceways, and recirculating aquaculture systems. Aquaculture takes on additional complexity when one considers the context—not just *how* organisms are being raised but *why* we are raising them. Aquaculture is a critical source of animal protein: half of the seafood we eat comes from farms, meeting demand that would otherwise mean even greater harvest pressure on wild fisheries. But aquaculture is much more than farming fish for food: hatcheries raise fish for natural resource enhancement and imperiled species restoration. Fish are raised for ornamental purposes and as model species used in toxicological and biomedical research.

This issue highlights a bit of aquaculture's diversity, featuring many facets of fish culture. For example, one of the most contentious questions about modern aquaculture is whether it consumes more fish (in the form of fish meal and fish oil used as feed ingredients) than it produces. Byelashov and Griffin (this issue) answer this question and explain how "fish in/fish out" ratios should be calculated and what they really mean.

Another article in this issue discusses an important but infrequently mentioned aspect of aquaculture: its value as a teaching tool. Intensive aquaculture systems harness or simulate natural processes and ecosystem functionality, and Hart et al. (this issue) describe how aquaponic systems can be used to teach ecological and other principles in the classroom.

Aquaculture is much more than farming fish for food: hatcheries raise fish for natural resource enhancement and imperiled species restoration

We are particularly proud to feature an article by Kline and Flagg (this issue), detailing the substantial progress that has been made in applying conservation aquaculture to the restora. tion of Snake River Sockeye Salmon, arguably one of the most unique and endangered salmonid stocks in the world. Bringing these fish back from the brink of extinction is an incredible success and feel-good story. There is still work to be done, but more Snake River Sockeye have returned this year than in any year since 1956! These are just a few of the engaging, aquaculture-themed articles you will find in this issue.

You will also find numerous commentaries provided by AFS Sections relative to aquaculture. It seems that virtually all fisheries disciplines have a connection to aquaculture, and the outpouring of interest and support from the Sections for this themed issue was a welcome surprise.

Our aquaculture issue contains a lot of material that we think will interest those active in fish culture or allied fields. More important, we think that there is much here to interest and intrigue *all* fisheries professionals. We hope that you enjoy this themed issue and enjoy learning a little more about all things aquaculture.

AFS ANNUAL MEETING 2015

145th Annual Meeting of the American Fisheries Society: Third Call for Papers

2015.fisheries.org

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

SYMPOSIA

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

CONTRIBUTED PAPERS AND POSTERS

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

FOR MORE INFORMATION: VISIT FISHERIES.ORG > ANNOUNCEMENTS

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

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Fresh food at Portland Farmer's Market.
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Putting the Red Back in Redfish Lake, 20 Years of Progress Toward Saving the Pacific Northwest's Most Endangered Salmon Population

Paul A. Kline

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Thomas A. Flagg

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ABSTRACT: *In November 1991, the U.S. National Marine Fisheries Service listed Snake River Sockeye Salmon (*Oncorhynchus nerka*) as endangered under the U.S. Endangered Species Act (ESA). The last known remnants of the Snake River stock return to Redfish Lake in the Sawtooth Valley in central Idaho. In the ensuing two decades since the ESA listing, many actions have been taken to conserve the population, including the initiation of a hatchery-based gene rescue program. The chief aim of this article is to describe the development and implementation of hatchery-based gene rescue activities, review present-day release strategies and associated adult returns, and describe a new effort underway to expand program production to more effectively address recolonization and local adaptation objectives. In addition, we describe achievable population triggers to allow the transition from a hatchery-based effort to a habitat-based effort that should allow natural population recovery to proceed.*

Poniendo al lomo rojo de vuelta en el Lago Redfish, veinte años de progreso en el salvamento de la población de salmón más amenazada del noroeste

RESUMEN: *En noviembre de 1991, el Servicio Nacional de Pesquerías Marinas de los Estados Unidos de Norteamérica, ingresó al salmón (*Oncorhynchus nerka*) en el Acta de Especies Amenazadas de los Estados Unidos (AEA) bajo la categoría de amenazado. Los últimos remanentes conocidos del stock del Río Snake, regresaron al Lago Redfish, Valle Sawtooth, en la porción central de Idaho. Dos décadas después de haber ingresado esta especie al acta, se han llevado a cabo varias acciones tendientes a conservar a la población, entre las que se incluye el inicio de un programa de rescate genético. El objetivo del presente trabajo es describir el desarrollo e implementación de actividades de rescate genético basado en cultivos, revisar las estrategias actuales de liberación y posterior retorno de adultos y describir la nueva iniciativa de expandir el programa de producción para abordar de forma más efectiva la recolonización y los objetivos de adaptación local. Adicionalmente, se describe cómo se usarán detonantes poblacionales que permitan una transición entre esfuerzos basados en cultivos y esfuerzos basados en hábitats con el fin de facilitar la recuperación de las poblaciones.*

INTRODUCTION

Snake River Sockeye Salmon (*Oncorhynchus nerka*) from the Columbia River Basin are one of the most depleted stocks of salmonids in the world (Nehlsen et al. 1991; Waples and Johnson 1991; Flagg et al. 2004). In November 1991, the U.S. National Marine Fisheries Service (NMFS) listed Snake River Sockeye Salmon as endangered under the U.S. Endangered Species Act (ESA; Waples and Johnson 1991; 56 FR 58619 1991). The two other population groups of anadromous salmon that occur in the upper headwaters of the Salmon River are listed as threatened under ESA (spring/summer Chinook Salmon [*O. tshawytscha*] and steelhead [*O. mykiss*]). The last known remnants of this stock return to Redfish Lake in the Sawtooth Valley in Idaho (Figure 1). Sockeye Salmon returning to Redfish Lake travel a greater distance from the Pacific Ocean (1,448 km) and to a higher elevation (1,996 m) than any other Sockeye Salmon population in the world. Additionally, Redfish Lake supports the southernmost population of the species (Burgner 1991; Waples et al. 2011). Together these characteristics presented a strong argument for the ecological uniqueness of Redfish Lake Sockeye Salmon and subsequent designation as an Evolutionarily Significant Unit (ESU; Waples 1991). Five lakes in the Sawtooth Valley historically contained Sockeye Salmon: Redfish, Pettit, Alturas, Stanley, and Yellowbelly lakes (Bjornn et al. 1968). Reestablishment of natural returns of Sockeye Salmon in at least three of these lakes is considered necessary for maintenance and protection of the ESU (NMFS 2011).

Prior to modern settlement, Sockeye Salmon runs to the Snake River basin were estimated at about 150,000 fish, of which about 25,000–30,000 may have returned to the Sawtooth Valley in Idaho (Evermann 1896; Selbie et al. 2007). Paleolimnological data suggest that the onset of decline in Snake River Sockeye Salmon was concurrent with inception and intensification of commercial fisheries in the lower Columbia River in the mid- to late 1800s (Selbie et al. 2007). Within the upper

Salmon River basin, additional population stressors for Redfish Lake Sockeye Salmon have included mining and irrigation activities, non-game fish control efforts, *and* fish passage barriers constructed at lake outlets, harvest, predation, inadequate regulatory mechanisms (Bjornn et al. 1968; Flagg et al. 2004; Hebdon et al. 2004). From 1910 to 1934, a small hydroelectric project (Sunbeam Dam) blocked most or all returns to the upper Salmon River basin (Bjornn et al. 1968). From the 1930s on, a number of major hydroelectric dams were developed on the Columbia/Snake River system. Lower Granite Dam (Figure 1), at about 700 km from the Pacific Ocean, is the most upstream dam in the migration route of Snake River Sockeye Salmon.

The Salmon River enters the Snake/Columbia River system about 100 km upstream of Lower Granite Dam (Figure 1) and runs free-flowing for its entire 684 km length from its headwaters in the Sawtooth Mountains. The Salmon River portion of the migration route to Redfish Lake is sparsely developed. This migratory reach has some agriculture and irrigation impacts but also large stretches of wilderness. Almost 90% of the habitat in the Sawtooth Valley is within the U.S. Forest Service's Sawtooth National Recreational Area. The watersheds are in relatively pristine condition. The Sawtooth Valley lakes (and Redfish Lake in particular) are recreational destinations and are highly valued for their scenic qualities and clear water.

Since 1991, a group of agencies including the Idaho Department of Fish and Game (IDFG), NMFS, the Shoshone-Bannock Tribes, and the Bonneville Power Administration (BPA) have been collaboratively engaged in Snake River Sockeye Salmon recovery efforts. Actions have been coordinated through the multi-agency Stanley Basin Sockeye Technical Oversight Committee, the primary technical body associated with the recovery effort. Program goals were developed with input from management and federal action agencies. The near-term goal was to avoid extinction and to maintain remaining genetic diversity and population heterozygosity. The long-term goal is to rebuild populations to facilitate delisting and to increase abundance to levels sufficient to support sport and tribal harvest needs (Flagg et al. 2004; Hebdon et al. 2004; IDFG 2010). Numerous actions have been conducted and over 30 peer-reviewed articles have been published on various components of restoration ef-

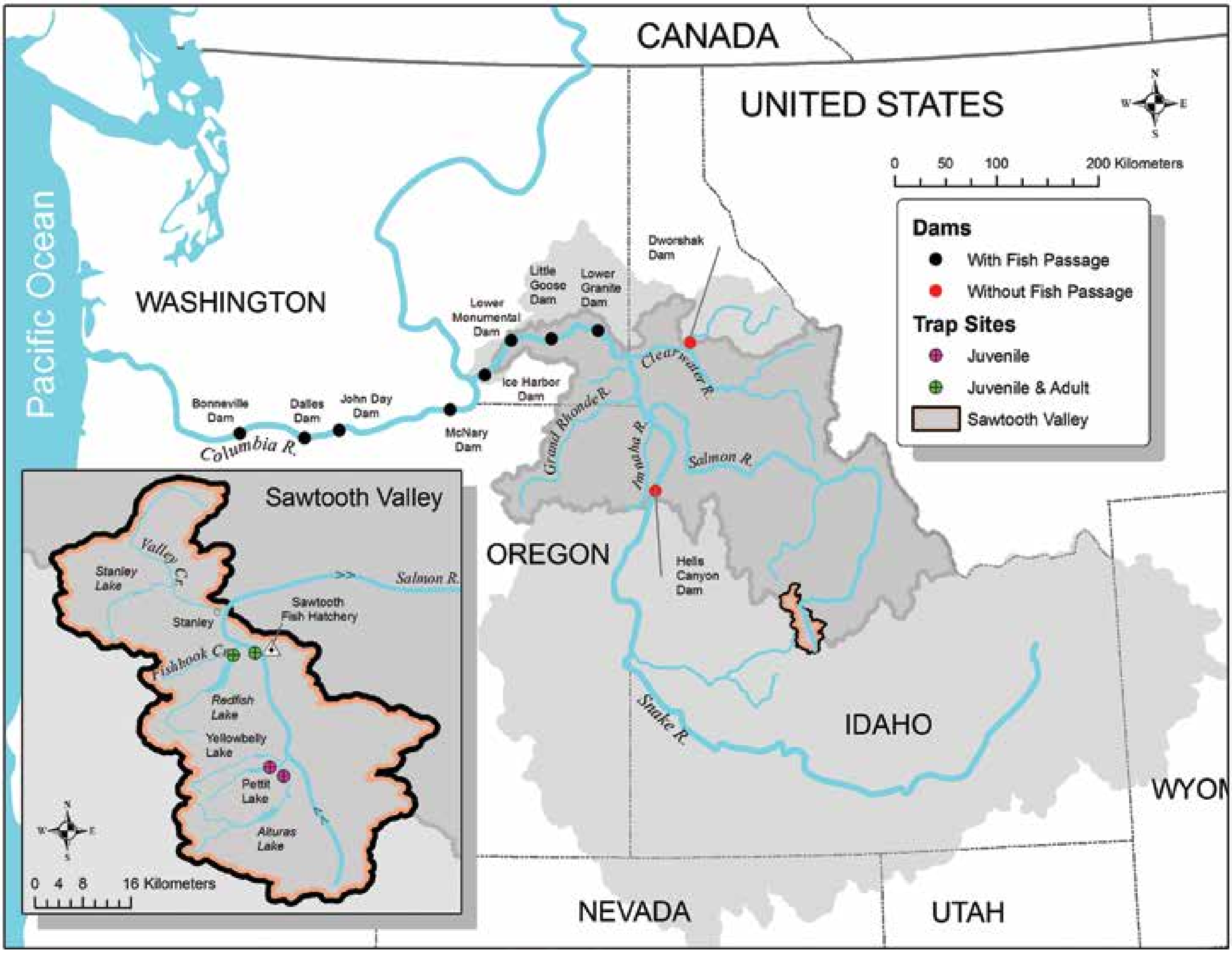


Figure 1. Map of the Columbia River basin, locations of mainstem and lower Snake River hydropower dams and Snake River Sockeye Salmon recovery habitat in the upper Salmon River basin, Idaho.

forts, including determination of lake carrying capacity and zooplankton dynamics; fish growth, survival, and migration dynamics; genetics; alterations of barriers and improvements in fish passage; and husbandry methodologies (Box 1).

Throughout this 20-year effort, the core of the Redfish Lake Sockeye Salmon program has been a hatchery-based captive broodstock program developed to preserve population genetics. In this article, we describe the results of this gene rescue effort that are helping stabilize population genetics and demographics and expand the abundance of wild fish. We also provide the methods we are using to develop achievable population triggers to allow the transition from a hatchery-based effort to a habitat-based effort that should allow natural population recovery to proceed. It is our hope that this summary will serve as a useful case history and blueprint for other fisheries professionals in need of an approach to combat an impending aquatic extinction event.

RESULTS AND DISCUSSION

Captive Broodstock Phase

Based on probable extinction scenarios and the pending ESA listing, in May 1991 a decision was made by IDFG, NMFS, and the Shoshone-Bannock Tribes to collect out-migrating smolts and to retain any anadromous adults that returned to Redfish Lake in the Sawtooth Valley in Idaho to begin a captive broodstock program (Flagg et al. 1995; Hebdon et al. 2004). This was controversial because in the early 1990s, the application of captive broodstock technology to Pacific salmon was considered highly experimental and success was uncertain (Flagg et al. 1995; Schiewe et al. 1997). Nonetheless, the only other alternative at the time appeared to be extinction (Flagg et al. 2004).

Broodstock Development

The present-day Redfish Lake Sockeye Salmon captive broodstocks were established from 16 anadromous adults, 26 residual Sockeye Salmon, and 886 out-migrating smolts collected during the early-mid 1990s from Redfish Lake and surrounding habitats (Table 1). Residual Sockeye Salmon are genetically similar to anadromous Sockeye Salmon but complete their life cycle in fresh water (see Burgner [1991] for a review). To avoid the risk of catastrophic loss of broodstocks, separate captive broodstocks were established in the beginning (see also Pollard and Flagg 2004). Annually, equal brood lots of eggs (about 500 each) from both captive-reared and ocean-return adults are developed at the IDFG Eagle Fish Hatchery near Boise, Idaho. One group is incubated and reared by IDFG and the other group is raised at NMFS facilities in Washington State (Manchester Research Station, Port Orchard, WA; Burley Creek Hatchery, Kitsap County, WA; see Baker et al. [2012]

BOX 1. Published articles by researchers involved with the Redfish Lake Sockeye Salmon recovery program.

SUBJECT	REFERENCE
Habitat/limnology evaluations	Budy et al. 1995; Luecke et al. 1996; Gross et al. 1998; Pilati and Wurtsbaugh 2003; Sawatzky et al. 2006; Selbie et al. 2007
Lake fertilization evaluations	Budy et al. 1998; Gross et al. 1997; Wurtsbaugh et al. 2001; Griswold et al. 2003
Predator/prey and life history evaluations	Beauchamp et al. 1997; Steinhart and Wurtsbaugh 1999; Massee et al. 2007; Kendall et al. 2010
Juvenile fish growth and survival evaluations	Steinhart and Wurtsbaugh 2003; Powell et al. 2010
Juvenile and adult migration studies	Hebdon et al. 2004; Keefer et al. 2008; Griswold, Koler, and Taki 2011
Genetics	Winans et al. 1996; Kozfkay et al. 2008; Waples et al. 2011; Kalinowski et al. 2012; O'Reilly and Kozfkay 2014
Gene rescue hatchery methodologies	Flagg et al. 1995, 2004; Schiewe et al. 1997; Flagg and Mahnken 2000; Berejikian et al. 2004; Pollard and Flagg 2004; Heindel et al. 2005; Swanson et al. 2008; Maynard et al. 2012

Table 1. Wild adult and juvenile Sockeye Salmon collected to develop the Redfish Lake captive broodstock program.

Collection year	Anadromous adults	Residual adults[a]	Out-migrating smolts
1991	4 (3 male, 1 female)		759
1992	1 male	5 (4 male, 1 female)	79
1993	8 (6 male, 2 female)	18 (16 male, 2 female)	48
1994	1 female		
1995		3 male	
1996	1 female		
1997			
1998	1 male		
TOTAL	16 (11 male, 5 female)	26 (23 male, 3 female)	886

[a] Residual Sockeye Salmon are genetically similar to anadromous Sockeye Salmon but complete their life-cycle in freshwater (see Burgner [1991] for a review).

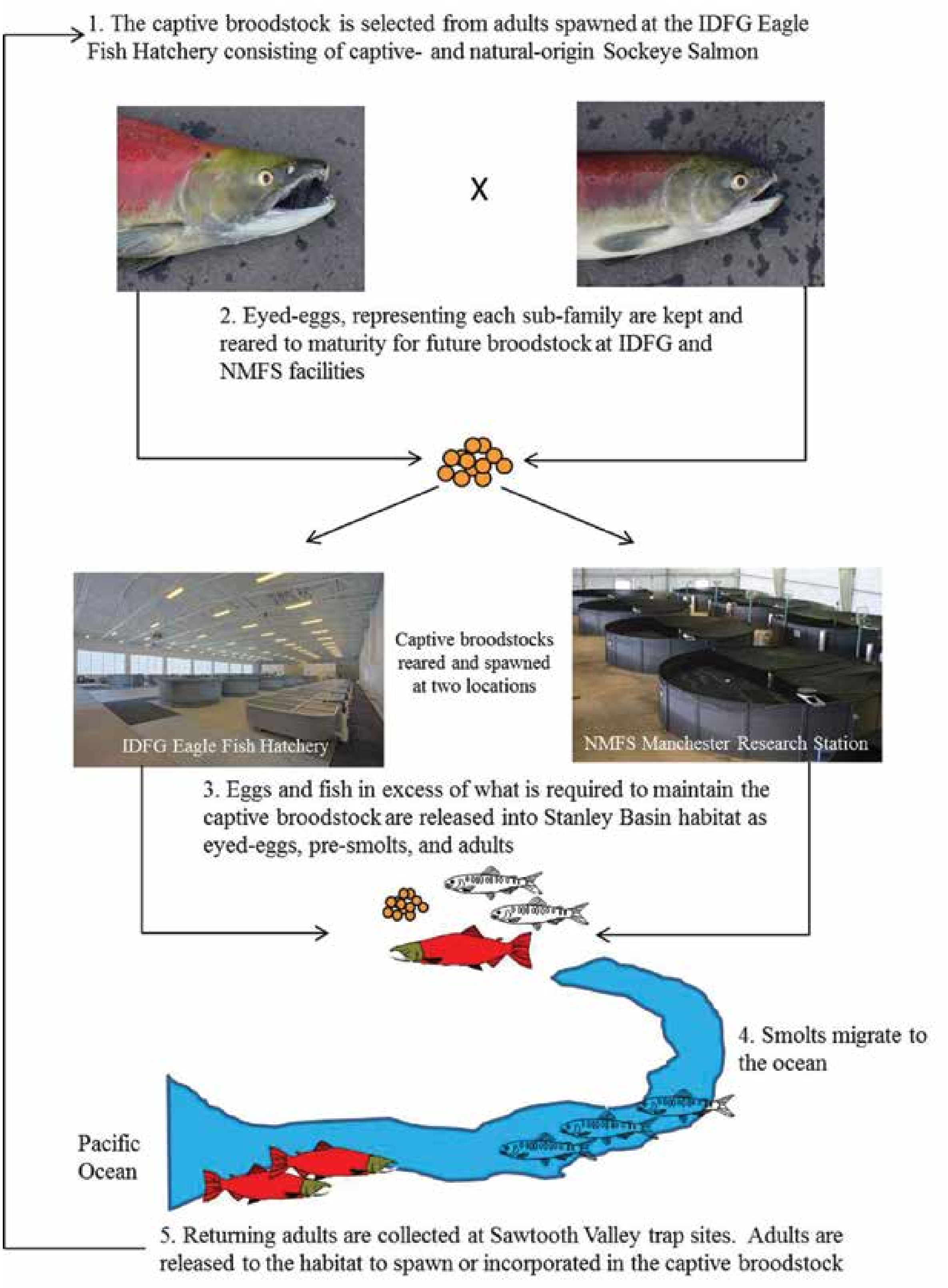
and Maynard et al. [2012] for facility and operational descriptions).

Two adult traps are installed annually to capture returning Sockeye Salmon. One trap is located on Redfish Lake Creek approximately 1.4 km downstream from the outlet of Redfish Lake and the second on the mainstem Salmon River at the IDFG Sawtooth Fish Hatchery (Figure 1). Trapped adults may be held at the IDFG Eagle Fish Hatchery (for spawning) or released to Redfish Lake to spawn naturally (see Figure 2 for a diagram that characterizes general program operations). The decision to “hold or release” specific adults is based on “real-time” genetic analyses conducted by IDFG (Kozfkay et al. 2008; O’Reilly and Kozfkay 2014). Such analyses take into account individual and family representation as well as relatedness of returning adults. Through 2005, pedigree information (e.g., known origin/lineage of individual members of the population) was used to develop annual spawning designs (Kozfkay et al. 2008; O’Reilly and Kozfkay 2014). From 2006 to present, a suite of 7–16 microsatellite loci have been used. This approach provides information on multiple population attributes, including (1) relative founder contribution, (2) the genetic importance of individuals, (3) genetic diversity and heterozygosity within and among individuals, and (4) relative relatedness among individuals (Kozfkay et al. 2008; O’Reilly and Kozfkay 2014). Annually, maximum avoidance of inbreeding matrices are developed to identify band sharing proportions (e.g., mean kinship information) among all possible mate combinations to minimize inbreeding (Ballou and Lacy 1995). Based on genetic distance, modified factorial mating schemes are developed to guide mate selection (Kozfkay et al. 2008). Eggs and fish destined for various reintroduction strategies are isolated to maximize the ability to track returning Sockeye Salmon back to release strategy and family (Heindel et al. 2005; Baker et al. 2012; Maynard and Flagg 2012). Performance metrics are monitored to document maturation and spawning processes for captive broodstocks, including rate of maturation, age of maturation, fecundity, gamete quality, and egg survival to the eyed stage of development.

Broodstock Outcomes

The fish culture program for Redfish Lake Sockeye Salmon has produced over 10,000 adult descendants from the 16 wild adults that returned to the Sawtooth Valley during the 1990s (Baker et al. 2012; Maynard and Flagg 2012; Maynard et al. 2012). The genetic focus of the program and adherence to principles of conservation aquaculture has enabled us to retain approximately 95% of the original founding genetic variability that remained in the population (Kalinowski et al. 2012). Although easily overlooked, a major program accomplishment was simply the development of fish culture protocols for rearing Sockeye Salmon full term to maturation. Earlier rearing attempts for various species of Pacific salmon and steelhead had suggested that captive broodstocks would have poor performance, with low egg survival, low egg-to-adult survival rates, and reduced size of captive-reared adults compared to wild fish (Flagg and Mahnken 1995; Schiewe et al. 1997). Overall, the Redfish Lake Sockeye Salmon captive broodstock effort has experienced much better production success than the earlier programs (Table 2). Egg survival to the eyed stage of development has improved to levels that usually exceed 80% and fry-to-maturation survival is now routinely around 80%. Size of fish in culture can now be manipulated to exceed that of wild fish. Average egg size of captive-reared females exceeds that of ocean-return females (11.4 compared to 17.0 eggs/g), although average fecundity of captive-reared females is still lower than that of ocean-return females (1,846 compared to 2,560 eggs/female).

The population amplification potential identified by Flagg et al. (1995) for captive broodstocks has been realized for the Redfish Lake Sockeye Salmon captive broodstock program. If the 16 returning adults (11 males and 5 females; Table 1) that were taken into captivity had been released to the Redfish Lake to spawn naturally, it is likely that the population would have gone extinct. According to data collected between 1955 and 1964, natural egg-to-smolt survival for Redfish Lake Sockeye Salmon was generally less than 6.0% and smolt-to-adult survival (from the Sawtooth Valley, through ocean residence, and upstream return; geometric mean) was 0.44% (Bjornn et al. 1968; Flagg et al. 1995; Hebdon et al. 2004). If the five female adults incorporated in the captive broodstock had each naturally spawned an average of about 2,500 eggs (Table 2), approximately 750 ocean-going smolts would have been produced. This, in turn, would have generated approximately three adult returns to the Sawtooth Valley equating to a survival rate of approximately 0.03% (i.e., 750 smolts * 0.0044). These fish would have been spread over a 4- to 10-year return window, or less than a fraction of an adult per year. Based on these figures, without intervention, extinction would have been all but certain. For groups of Redfish Lake Sockeye Salmon in captive



1. The captive broodstock is selected from adults spawned at the IDFG Eagle Fish Hatchery consisting of captive- and natural-origin Sockeye Salmon

2. Eyed-eggs, representing each sub-family are kept and reared to maturity for future broodstock at IDFG and NMFS facilities

3. Eggs and fish in excess of what is required to maintain the captive broodstock are released into Stanley Basin habitat as eyed-eggs, pre-smolts, and adults

4. Smolts migrate to the ocean

5. Returning adults are collected at Sawtooth Valley trap sites. Adults are released to the habitat to spawn or incorporated in the captive broodstock

Figure 2. Schematic depicting the general operations of the Redfish Lake Sockeye Salmon captive broodstock program.

Table 2. In-hatchery spawner information and associated egg and fry-to-maturation survival for Eagle Fish Hatchery captive broodstock and anadromous Redfish Lake Sockeye Salmon.

Spawn year	Female spawner weight (g)		Fecundity (n)		Egg size (eggs/g)		Eyed egg survival (%)		Fry-to-maturation survival (%)
	H[a]	W[b]	H	W	H	W	H	W	H
1991	NA[c]	1,100	NA[c]	2,177	NA[c]	NA[c]	NA[c]	90.86	NA[c]
1992	NA[c]	NA[c]	NA[c]	NA[c]	NA[c]	NA[c]	NA[c]	NA[c]	NA[c]
1993	1,801	1,160	2,182	3,160	12.25	15.63	46.58	58.53	70.82
1994	1,681	1,183	2,134	2,896	7.92	20.53	50.98	95.99	71.35
1995	2,630	NA[c]	1,576	NA[c]	21.61	NA[c]	68.06	NA[c]	NA[c]
1996	2,165	866	2,171	2,067	8.74	20.56	63.43	84.95	56.35
1997	2,093	NA[c]	2,206	NA[c]	10.03	NA[c]	60.22	NA[c]	88.39
1998	941	NA[c]	1,199	NA[c]	11.15	NA[c]	48.12	NA[c]	79.84
1999	1,990	635	1,981	1,619	9.686	21.56	38.52	93.26	83.78
2000	2,987	1,389	2,647	2,751	8.87	15.22	55.19	62.60	91.48
2001	1,517	1,223	2,148	2,687	10.74	13.46	41.13	60.52	80.16
2002	1,050	NA[c]	1,343	NA[c]	10.52	NA[c]	54.40	NA[c]	78.50
2003	1,246	1,282	1,627	2,578	10.65	19.32	88.77	98.00	89.63
2004	1,158	1,191	1,674	2,322	10.13	18.12	70.77	90.00	87.22
2005	1,094	1,404	1,707	2,450	11.90	18.29	69.55	82.00	86.61
2006	1,431	1,343	1,844	2,248	11.03	17.58	77.86	62.71	93.58
2007	1,077	1,424	1,618	2,828	12.26	17.1	74.29	80.18	80.04
2008	1,189	1,475	1,808	2,668	12.07	14.84	91.14	91.61	63.97
2009	1,137	1,486	1,616	2,749	12.34	14.86	90.10	88.16	70.17
2010	1,106	1,452	1,596	2,799	11.89	12.88	80.60	87.86	NA[d]
2011	1,557	1,484	1,994	2,749	12.21	14.86	76.47	82.84	NA[d]
2012	1,331	1,360	1,854	2,766	13.08	17.19	85.71	90.86	NA[d]
Mean	1,559	1,262	1,846	2,560	11.45	17.00	66.59	81.88	80.69
Geomean	1,476	1,237	1,816	2,531	11.21	16.81	64.49	80.76	79.96
sd	564	232	341	373	2.76	2.62	16.66	13.31	10.73

[a] Hatchery (H) captive broodstock adult data.
[b] Wild (W) anadromous adult data.
[c] Complete records not available.
[d] Life cycle incomplete.

broodstock culture, egg survival to the eyed stage and fry-to-adult survival have each averaged about 80% in recent years (Table 2), equating to an overall egg-to-adult survival rate of approximately 65%. For this endangered population, the survival advantage afforded by the captive broodstock program over natural production has been greater than 2,000% (i.e., 0.65/0.0003).

Initial Fish Reintroduction Phase

Although the initial focus of the captive broodstock program was gene rescue, excess eggs and fish were produced each year. Experimental reintroduction strategies were developed to take advantage of that production. These included release of captive-reared prespawning adults, eyed eggs, presmolts, and smolts, along with adults from these releases that returned from the ocean (Hebdon et al. 2004). Estimates of nursery lake carrying capacity and temporal limnological information have also been used to guide the development of annual reintroduction plans (Teuscher and Taki 1996; Griswold, Taki, and Letzing 2011; see also Box 1). Habitat evaluation and improvements actions include assessments of primary and secondary productivity, zooplankton species diversity and biomass assessment, O. nerka density and biomass assessment, and whole-lake fertilization (Griswold,Taki, and Letzing 2011; Box 1).

Through 2011, our efforts have produced over 3.8 million eggs and fish for reintroduction to Sawtooth Valley lakes and tributary streams. Of these, 1.6 million were released as presmolts, 1.1 million as smolts, 1.1 million as eyed eggs in egg boxes, and 8,000 as prespawning adults (Baker et al. 2012). With few exceptions, presmolt releases have occurred annually in the three primary Sockeye Salmon nursery lakes in the Sawtooth Valley (Alturas, Pettit, and Redfish lakes). Eyed egg releases have occurred primarily in Alturas and Pettit lakes, prespawning adult releases in Redfish Lake, and smolt releases in the outlet of Redfish Lake (i.e., Redfish Lake Creek) and in the main Salmon River near the IDFG Sawtooth Fish Hatchery (Figure 1).

Reintroduction Outcomes

The ability to evaluate reintroduction strategies by life stage at release and location of release (e.g., receiving water) has remained a top program priority since inception. We evaluated rigorously the relative success of different reintroduction strategies to help interpret which approaches are most successful (Hebdon et al. 2004; IDFG 2010; Griswold, Koler, and Taki 2011; see also Box 1).

Since 1998, adult returns and maturing adults reared full-term in captivity have been released annually to spawn naturally in Redfish Lake. The first fish from the captive breeding program released as juveniles returned to the Sawtooth Valley as adults in 1999 (Table 3). Numerous adults have been observed building redds and spawning (Table 3). Adult releases have been associated with increases in the out-migration of naturally hatched (in-lake) smolts from Redfish Lake (Hebdon et al. 2004). The largest adult returns to date occurred between 2008 and 2011, with over 3,900 fish returning during that period (Table 3). Most adult returns during the 2008–2011 time period were produced from a combination of 2004–2006 brood year juvenile releases. Through a combination of external, internal, and genetic marks, we were able to assign the majority of adult returns to a known combination of prespawning adult, presmolt, and smolt release options (Kozfkay et al. 2008; Baker et al. 2012). To compare relative benefits of each release strategy, we calculated each strategy's smolt-to-adult return rate for this as the ratio of adult returns divided by the corresponding out-migration estimate (Skalski 1998; Lady et al. 2001; Steinhorst et al. 2004; Tuomikoski et al. 2012). Calculated values represent "basin-to-basin" survival (i.e., Sawtooth Valley to Sawtooth Valley). Analyses were conducted by brood year, which allowed age-3, age-4, and age-5 adult returns to be aggregated and assessed relative to the estimated number of out-migrating smolts produced in a common spawn year.

For brood years 2004–2006, average smolt-to-adult return rates for Sockeye Salmon produced from juveniles released as smolts were over threefold greater than average rates for adults produced from Redfish Lake presmolt releases (i.e., 0.60% vs. 0.17%; Figure 3). Average smolt-to-adult return rates for Sockeye Salmon produced from natural spawning events in Redfish Lake were over threefold higher than results from smolt releases (i.e., 1.84% vs. 0.60%) and over 10-fold higher than rates for adults produced from presmolt releases (Figure 3). For these three brood years, over 83% of returning adults originated from smolt releases, whereas the presmolt release option accounted for only about 3% of all returning adults (Table 4). Importantly, the relatively small number of smolts produced from in-lake spawning events accounted for over 13% of the adult returns during this period (Table 4). Observed smolt-to-adult return rates for natural-origin fish have exceeded the minimum 2% rate we estimate is required for population self-sustainability (Figure 3; Flagg et al. 2004).

The results indicate that properly scaled smolt releases could be sufficient to produce enough adults (e.g., 5,000) from the ocean to recolonize Redfish Lake and that the juveniles produced from subsequent spawning events could have the increased fitness needed to substantially increase smolt-to-adult return rates to a point matching or exceeding self-sustainability. Our results also indicate that apparent "extinction vortex"–type scenarios (Soule 1986) could be reversable for this population. These results led managers to begin developing estimates of production levels necessary to eventually achieve population stablization and recovery.

Table 3. Anadromous Sockeye Salmon returns to the Sawtooth Valley, ID; numbers of anadromous and captive-reared adults released to spawn in Redfish Lake and numbers of subsequent redds (nest areas excavated by females) observed

Return year	Anadromous returns	Released to spawn in Redfish Lake[a]		Observed redds
		Anadromous	Captive-reared	
1999	7	3 (0)	18 (10)	8
2000	257	120 (41)	36 (NA)[b]	20 to 30
2001	26	14 (7)	65 (37)	12 to 15
2002	22	12 (7)	177 (62)	10
2003	3	0	309 (152)	42
2004	27	0	244 (135)	104
2005	6	0	176 (50)	78
2006	3	0	465 (247)	172
2007	4	0	498 (254)	195
2008	650	571 (207)[c]	396 (172)	338
2009	833	651 (169)	680 (331)	201
2010	1,355	1,209 (489)	367 (199)	155
2011	1,117	990 (414)	558 (277)	385
2012	257	173 (79)	622 (268)	306

[a] Total anadromous and captive-reared adults released to spawn in Redfish Lake (number of females in parentheses).
[b] Thirty-six captive-reared Sockeye Salmon released (sex unknown).
[c] An additional 51 anadromous Sockeye Salmon migrated upstream of the adult trap without handling (sex unknown).

BOX 2. Scenarios for sliding scale logistics for managing hatchery vs. wild escapements in high vs. low wild fish abundance years for Redfish Lake Sockeye Salmon (modified from HSRG 2009).

Variable sliding scales are useful for managing salmon abundance so that in low abundance years more hatchery-origin fish of the appropriate population component are allowed to reach the spawning grounds to reduce demographic risk to the respective populations. As an example:

- Each year, depending on NOR[a] run size, pNOB[b] and pHOS[c] are allowed to “float” or slide. Managers should establish an acceptable level of removal of NORs for use in the hatchery brood. This will be a fixed percentage of the total NOR return (say 40%) and will not change, regardless of NOR return.
- In years of high NOR abundance, this 40% could make up 100% of the needed hatchery brood (pNOB = 100%). In that case, no HORs[d] would be used in the hatchery brood. Hatchery fish can be allowed to reach the spawning ground (pHOS) if needed to achieve an appropriate number of fish spawning naturally (for demographic benefit and maximum use of available habitat). This, however, would not be required during years of very high NOR returns because both objectives (pNOB and natural spawning) may be met with NORs.
- In years of low NOR abundance, the same 40% of the NOR return would be removed for use in the hatchery brood (pNOB). However, in these years, that 40% may make up only a small part of the needed brood (i.e. pNOB 10%). In these years, enough HORs should be used to achieve needed hatchery brood and additional HORs should be allowed to spawn naturally (pHOS) to achieve the minimum acceptable level of naturally spawning.
- The goal of this sliding scale is to achieve an “average” PNI[e] over time of the desired level (0.67 or 0.5) depending on the population designation even though it may not be achieved in any one year. PNIs of >0.5 are required for the natural environment to influence evolutionary processes.
- A good way to determine the level of NORs that should be removed each year (see above) is to review the return of NORs over a long time frame and iterate what level (30%, 40%, 50%) is needed, on average, to achieve the desired PNI.

[a] NOR is the numerical natural-origin return in the watershed.

[b] pNOB is the proportion of natural-origin spawners taken into the broodstock.

[c] pHOS is the proportion of hatchery-origin spawners in the natural habitat.

[d] HOR is the numerical hatchery-origin return in the watershed.

[e] PNI = pNOB/(pNOB + pHOS) and is the proportional mean fitness of the integrated population relative to the natural population.

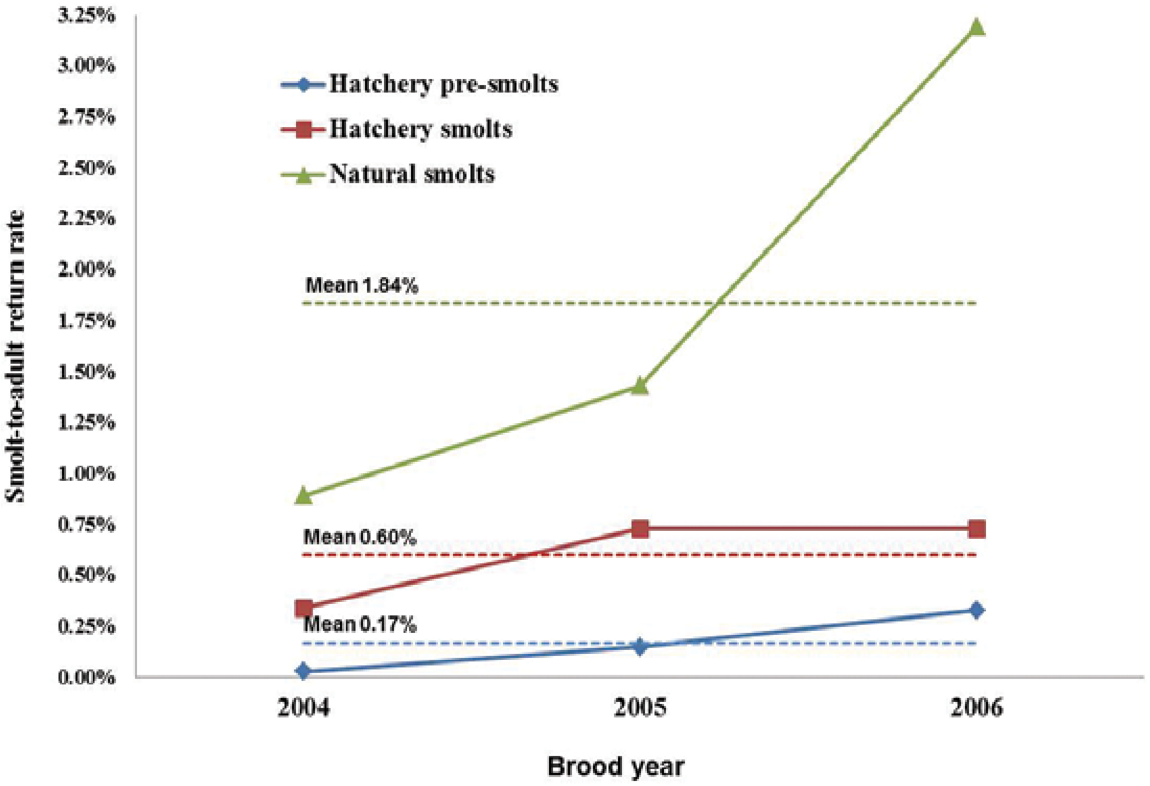


Figure 3. Smolt-to-adult survival rates for Redfish Lake natural-origin smolts, hatchery-origin smolts released as pre-smolts in Redfish Lake , and hatchery-origin smolts released in Redfish Lake Creek and the Salmon River at the Sawtooth Fish Hatchery. Dashed lines represent mean smolt-to-adult rates. Rates represent Sawtooth Valley to Sawtooth Valley survival.

Table 4. Contribution of juvenile Sockeye Salmon out-migrants from brood years 2004–2006 to adult returns back to Sawtooth Valley trap sites. Out-migrant groups include Redfish Lake natural-origin smolts, hatchery-origin smolts released as presmolts in Redfish Lake, and hatchery-origin smolts released in Redfish Lake Creek and the Salmon River at the Sawtooth Fish Hatchery.

Origin of juvenile out-migrants	Number of adult returns by juvenile origin[a]	Percentage of total return
Hatchery-origin presmolts released in Redfish Lake	83	3.2
Hatchery-origin smolts released in the Salmon River and Redfish Lake Creek	2,133	83.6
Natural-origin smolts produced in Redfish Lake	339	13.3
Total	2,555	

[a] Adult Sockeye Salmon linked to out-migrant origin using diagnostic marks and tags.

Planning for the Future

In an effort to advance the program's long-term goal of rebuilding and recovering the stock, project managers developed a tiered or phased approach that includes increasing the number of adult Redfish Lake Sockeye Salmon returns, incorporating more natural-origin returns in hatchery spawning designs and on spawning grounds, and moving toward the development of an integrated conservation program that takes advantage of local adaptation (IDFG 2010).

In their draft recovery planning process, NMFS identified biological goals of 1,000 naturally spawning Sockeye Salmon in Redfish Lake and 1,500 (combined) in two other Sawtooth Valley lakes (NMFS 2011). To estimate the number of smolts needed to return adequate adults to recolonize Redfish Lake, we modeled the population using the Columbia River Basin Hatchery Scientific Review Group's (HSRG) all-H analyzer (HSRG 2009; Michael et al. 2009; Paquet et al. 2011). We conservatively estimated full initial adult seeding for Redfish Lake at 2,000 spawning pairs and a subsequent natural smolt production potential of over 150,000 juveniles (IDFG 2010; see also limnology and population dynamic research papers listed in Box 1). We then used the smolt-to-adult return ratios from our evaluation of 2004–2006 brood returns to determine how returns from natural spawning events would fluctuate over time. Our calculations indicated that releasing 1 million hatchery-reared smolts could, under ideal circumstances, initially produce approximately 5,000 returning adult fish, which over time could result in the return of over 1,600 naturally produced adults. Juveniles produced from ocean-return adults would theoretically develop (through local adaptation) increased fitness necessary to increase smolt-to-adult return rates to levels that match or exceed self-sustainability (i.e., the 2% level shown for our test releases in the Reintroduction Outcomes section).

We used model results to adjust the proportion of natural-origin spawners taken into the broodstock (pNOB) and the proportion of hatchery-origin (pHOS) to natural-origin (pNOS) adult Sockeye Salmon released to the habitat for natural spawning. See Paquet et al. (2011) for a full review of pNOB, pHOS, pNOS, and other population metrics such as proportionate natural influence (PNI). Emphasis was placed on increasing the use of ocean-return adults and ensuring adequate numbers in the habitat for natural spawning. We used sliding scale logistics (Box 2) to develop rulemaking for managing abundance. In low abundance years, a higher ratio of pHOS of the appropriate population component would be allowed to reach the spawning grounds to reduce demographic risks. In high abundance years, pHOS would be greatly reduced and focus would be on allowing natural (wild) fish to dominate spawning.

We then structured two "next phases" of the project to (1) establish parameters for expanding the project and producing enough fish to recolonize the historic habitat and (2) provide for development of local adaption and the rebuilding of natural population structure. We also developed aggressive targets for phasing out both the captive broodstock and, ultimately, all hatchery intervention components of the program (Table 5).

We considered the capacity of Sawtooth Valley nursery lakes to support expansion efforts as well as freshwater competition among sympatric forms of *O. nerka* as potentially limiting factors in developing smolt production targets for the program. The strategy to release 1 million smolts during the recolonization phase of the program is consistent with estimates of lake carrying capacity developed by Stockner (2000, as cited by B. Griswold, Biolines Environmental Consulting, personal communication; NMFS 2014). Stockner estimated that Redfish Lake is capable of producing approximately 474,000 smolts per year as well as supporting an optimal escapement of 19,000 adult spawners. Under a program of whole-lake fertilization, these values increase to 1.1 million smolts and 46,700 adult spawners

Redfish Lake also supports a nonandromous Kokanee population founded from out-of-basin sources beginning in the 1920s and continuing through the 1980s (Bowler 1990). Kokanee and Sockeye Salmon compete for limited food resources. Several researchers have postulated that certain heritable traits associated with anadromy manifest themselves as outcomes that should prove advantageous when *O. nerka* conspecifics compete for food resources in freshwater (for a review, see Wood and Foote 1990; Taylor and Foote 1991; Wood 1995; Wood et al. 1999). Though encouraging, the resiliency of the food web to support program expansion is untested. Accordingly, Redfish Lake trophic dynamics will continue to be monitored by program cooperators and whole-lake fertilization will remain an option to be implemented as needed.

Recolonization Phase—Expanding the Program

The recolonization phase will focus on producing and releasing increased numbers of smolts, returning more adults from the ocean to Idaho collection sites, incorporating more ocean-return adults in hatchery spawning designs, and releasing more ocean-return adults to spawn naturally. Program managers have already begun implementing this phase of the program. Eggs for the expanded smolt program will be produced at IDFG and NMFS facilities. Spawning plans will be structured to include a minimum of 10% natural-origin adults in the broodstock (pNOB 10%). In the initial stages of the recolonization phase, an average of just under 5,000 ocean-return Sockeye Salmon (i.e., 637 and 4,347 natural- and hatchery-origin adults, respectively) are projected to return to the Sawtooth Valley annually (Table 5). Specific biological triggers are in place to guide the transition to the final (local adaptation) phase of the program including the ramp-down and ultimate discontinuation of captive broodstock efforts at NMFS and IDFG facilities (Table 5).

Releasing ocean-return adults in Pettit and Alturas Lakes could occur when adult escapement to Redfish Lake exceeds 5,000 fish (IDFG 2010). Allowing adult escapement to reach this level before allocating returning adults to other lakes will provide managers the opportunity to observe Redfish Lake fish habitat use and productivity over an appropriate range of adult spawning densities. Adult Sockeye Salmon that mature in the hatchery (i.e., captive broodstock) will continue to be released to Redfish, Pettit, and potentially Alturas lakes during the recolonization phase of the program. Adult Sockeye Salmon captured at the Sawtooth Hatchery weir and identified as Pettit or Alturas Lake origin will be transferred to their respective lake or origin and released to spawn (Table 5).

Local Adaptation Phase—Rebuilding Natural Populations

This phase of the program emphasizes the importance of local adaptation and the potential of natural-origin fish to in-

Table 5. Population outcomes, objectives and triggers for recolonization and local adaption recovery phases of the Redfish Lake Sockeye Salmon captive broodstock program.

Recolonization phase (smolt production target is one million)

Anticipated average outcomes and objectives:
- 637 natural-origin, anadromous adult returns to Redfish Lake
    - 522 released to spawn in Redfish Lake
    - 115 incorporated in captive broodstock
- 4,347 hatchery-origin, anadromous adult returns to Redfish Lake
    - 3,312 released to spawn in Redfish Lake
    - 1,035 incorporated in captive broodstock
- Option to release captive broodstock-origin, anadromous adults in Redfish Lake
- Option to release captive broodstock-origin, anadromous adults in Pettit Lake
- Option to release hatchery-origin, anadromous adults in Pettit Lake
- Option to release natural-origin, anadromous adults in Pettit Lake
- Redfish program pNOB[a] = 10%
- Redfish program pHOS[b] = not restricted
- Redfish program PNI[c] = not restricted

Trigger 1: Begin to phase out NOAA safety net program when 5-year geometric mean return of anadromous adults > 1,000.
Trigger 2: Terminate Eagle Hatchery captive broodstock program when 5-year geometric mean return of anadromous adults > 2,150.
Trigger 3: Initiate local adaptation phase when 5-year geometric mean return of natural-origin adults > 750.

Local adaptation phase (smolt production target is 600,000)

Anticipated average outcomes and objectives:
- 1,647 natural-origin, anadromous adult returns to Redfish Lake
    - 1,397 released to spawn in Redfish Lake
    - 250 incorporated in broodstock
- 5,072 hatchery-origin, anadromous adult returns to Redfish Lake
    - 600 released to spawn in Redfish Lake
    - 442 incorporated in broodstock
- Option to release hatchery-origin anadromous adults in Pettit Lake
- Option to release natural-origin, anadromous adults in Pettit Lake
- Redfish program pNOB = 36%
- Redfish program pHOS = objective: ≤ 30%
- Redfish program PNI = objective: ≥ 50%

Trigger 4: Begin to phase out Springfield Hatchery supplementation program when 5-year geometric mean of natural-origin, anadromous Sockeye Salmon returns meets NMFS's viability standards and associated delisting criteria.

ESA down-listing or delisting of Snake River Sockeye Salmon

Propose ESA down-listing when
- The 5-year geometric mean of natural-origin adult returns to Redfish lake and one additional recovery lake meets NMFS's ESA recovery standards (down-listing)

Propose ESA delisting when:
- The 5-year geometric mean of natural-origin adult returns to three recovery lakes meets NMFS' recovery standards

[a] pNOB is the proportion of natural-origin spawners taken into the broodstock.
[b] pHOS is the proportion of hatchery-origin spawners in the natural habitat.
[c] PNI = pNOB/(pNOB + pHOS) or proportionate natural influence is an estimate of the strength of selection in the natural environment relative to that of the hatchery environment.

crease program success toward achieving delisting criteria. The local adaptation phase of the program will be initiated after the three performance triggers for the recolonization phase have been satisfied (Table 5). As the number of ocean-return adults spawning naturally in Redfish Lake increases, the number of natural-origin adults returning to all Sawtooth Valley collection sites will increase. Sliding scale management will be used to determine the number of natural-origin adults spawned in the hatchery and released to the habitat for spawning (Table 5). Natural-origin adults should be sufficiently abundant to comprise at least 35% of the total number of fish spawned in the hatchery (i.e., pNOB ≥ 35%). The number of hatchery-origin adults released to spawn in the habitat (pHOS) will be managed to not exceed 30%. The resulting proportionate natural influence (PNI) will exceed 0.50, allowing the environment to drive the fitness of the composite population (HSRG 2009; Paquet et al. 2011). Once the local adaptation phase is fully initiated, both captive broodstock programs will have been terminated. IDFG hatcheries will be managed as traditional trap and spawn operations, releasing all juvenile production as first-generation smolts.

Ultimately, the desired end result will be ESA down-listing or delisting once local adaption and fitness increases have stabilized the population (Table 5). We recognize that the ability of the Redfish Lake Sockeye Salmon population to sustain levels of abundance and productivity consistent with NMFS delisting criteria is uncertain. Though it remains our hope that demographic and fitness gains associated with program implementation will be long-lasting, uncertainties related to ocean productivity and climate conditions may result in population downturns that demand attention. If a decision is made to reinitiate short-term protective culture, the tools and protocols we have developed in the present-day gene rescue program will help the next generation of managers, researchers, and fish culturists implement future actions.

CONCLUSIONS

Overall, the Redfish Lake Sockeye Salmon captive broodstock effort has experienced much better success than the earlier captive broodstock gene rescue programs described by Flagg and Mahnken (1995, 2000) and Schiewe et al. (1997). Since the first program-produced adults started returning from the ocean in 1999, over 4,500 adults have been collected at sites in the Sawtooth Valley, over 275 times the number that returned from wild spawners during the entire decade of the 1990s.

Smolt-to-adult return rates of naturally produced Sockeye Salmon have exceeded rates of adults produced from hatchery-reared smolts by greater than threefold. This is a critical program observation because it demonstrates the potential for the population to become self-sustaining and effectively address draft NMFS recovery objectives.

Increases in fitness for animals subjected to natural vs. artificial selection processes have been much theorized by conservationists. A large number of studies have suggested that long-term hatchery rearing of fish will reduce productivity and fitness through alterations in genetic, behavioral, and physiological patterns (Flagg et al. 2000; Fraser 2008; Naish et al. 2008). Many authors have suggested that reversal of hatchery-based reductions in fitness would take at best many generations to resolve (Lynch and O'Healy 2001; Ford 2002). Similar to findings developed by Galbreath et al. (2014) for Coho Salmon (*O. kisutch*), our data suggest that fitness recovery could be much more immediate. The survival advantages and apparent rapid increased fitness demonstrated by Sockeye Salmon hatched in Redfish Lake have allowed the development of realistic population triggers for the program's expansion effort. This type of natural rebuilding scenario is the hoped for result when conservationists intervene to rescue depleted populations.

The careful stepwise efforts carried out by the Redfish Lake Sockeye Salmon program in first containing the immediate extinction threat and then addressing multiple levels of gene rescue, habitat improvements, and carrying capacity issues can be seen as a model for future endeavors. As we noted in the Introduction, over 30 peer-reviewed scientific papers and countless reports have helped set the science-based stage for program advancement. Additionally, at the onset, we convened the Stanley Basin Sockeye Technical Oversight Committee, a working group of state, tribal, federal, and nongovernmental organization partners. This cohesive structure has been foundational in guiding science for the program and is requisite for projects of this kind. It seems highly likely that without the steps undertaken by the Redfish Lake Sockeye Salmon captive broodstock program, this ESA-listed endangered stock would currently be extinct. It also seems a virtual certainty that the steps described above have put the population on the road to recovery. To our knowledge, we are the first to report on the use of population integration standards developed by the HSRG (Paquet et al. 2011) to balance both hatchery and developing natural components of critically at-risk populations. It is our recommendation that these types of planning processes become standard operating procedures for all population interventions of this type.

ACKNOWLEDGMENTS

Dan Baker, Travis Brown, Ken Felty, and Brent Snider (IDFG); Carlin McAuley, Debbie Frost, and Bryon Kluver (NMFS); and Dwayne Banks (ODFG) maintained captive broodstocks, managed fish transportation and fish releases, and generated all fish culture information presented in the article. Mike Peterson and Kurtis Plaster (IDFG) implemented monitoring and evaluation programs and developed analytical products presented in the article. The Shoshone-Bannock Tribes provided habitat monitoring and assessment support. Jeff Heindel and Christine Kozfkay (IDFG) and Desmond Maynard (NMFS) coordinated program efforts and provided substantial input to the article. The authors thank Dan Schill for encouraging the development of the article.

FUNDING

Work was primarily funded by the Bonneville Power Administration and coordinated through the Northwest Power and Conservation Council's Fish and Wildlife Program.

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U.S. Response to a Report of Infectious Salmon Anemia Virus in Western North America

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ABSTRACT: *Federal, state, and tribal fishery managers, as well as the general public and their elected representatives in the United States, were concerned when infectious salmon anemia virus (ISAV) was suspected for the first time in free-ranging Pacific Salmon collected from the coastal areas of British Columbia, Canada. This article documents how national and regional fishery managers and fish health specialists of the U.S. worked together and planned and implemented actions in response to the reported finding of ISAV in British Columbia. To date, the reports by Simon Fraser University remain unconfirmed and preliminary results from collaborative U.S. surveillance indicate that there is no evidence of ISAV in U.S. populations of free-ranging or marine-farmed salmonids on the west coast of North America.*

Respuesta de los Estados Unidos de Norteamérica a un reporte de virus de anemia infecciosa en salmones en el oeste de Norteamérica

RESUMEN: *Los manejadores de pesquerías a nivel federal, estatal y tribal así como también el público en general y sus representantes electos en los Estados Unidos de Norteamérica (EE.UU.) manifestaron su preocupación ante la sospecha de la presencia del virus de anemia infecciosa (VAIS) cuando por primera vez se detectó en salmones del Pacífico colectados en su rango natural de distribución en áreas de la Columbia Británica (CB) en Canadá. En este artículo se documenta cómo administradores de pesquerías a nivel nacional y regional y especialistas en salud acuícola de los EE.UU. trabajaron, planearon e implementaron juntos acciones en respuesta a los hallazgos de VAIS en la CB. Hasta ahora, los reportes de la Universidad Simon Fraser permanecen sin confirmación y los resultados preliminares por parte de agencias de inspección y vigilancia en los EE.UU. indican que no existe evidencia del VAIS en poblaciones de salmón marino cultivado en sus rangos naturales de distribución dentro la costa noroeste de los EE.UU.*

INTRODUCTION

In October 2011, researchers from Simon Fraser University in British Columbia (BC), Canada, reported that genetic material suggestive of infectious salmon anemia virus (ISAV) had been detected in 2 of 48 free-ranging juvenile Sockeye Salmon (*Oncorhynchus nerka*) collected from marine waters near the central coast of BC (Simon Fraser University 2011). The researchers collected the salmon during the summer of 2011 and submitted them to the Atlantic Veterinary College, Prince Edward Island, where they were tested for ISAV genetic material using a real-time (quantitative) polymerase chain reaction (RT-PCR) assay. If confirmed, it would have been the first report of ISAV from western North America and also from free-ranging Pacific salmon and, consequently, could have commerce, economic, and resource management implications. Confirmation requires multiple lines of evidence that can include a combination of clinical signs consistent with the disease or positive results from multiple prescribed diagnostic tests (World Organization for Animal Health [OIE] 2012). Although confirmatory information beyond the reported PCR results was absent, the initial reports and concerns set additional investigation in motion.

Officials with the Canadian Food Inspection Agency (CFIA) quickly responded to investigate the reported finding of ISAV. They also contacted U.S. officials belonging to the National Aquatic Animal Health Task Force (Task Force). The Task Force is composed of aquatic animal health subject matter experts and senior leaders with the three federal agencies that share responsibility (U.S. Department of Agriculture, Animal and Plant Health Inspection Service [APHIS], U.S. Department of Commerce, National Oceanic and Atmospheric Administration [NOAA], and U.S. Department of Interior, Fish and Wildlife Service [FWS]) to protect the health of U.S. aquatic animals. Discussions were initiated between and within the Task Force and local fishery management entities including the State of Alaska (Alaska Department of Fish and Game, ADFG), the State of Washington (Washington Department of Fish and Wildlife, WDFW), the Northwest Indian Fisheries Commission (NWIFC), and Northwest representatives for APHIS, FWS, NOAA, and the U.S. Geological Survey (USGS) Western Fisheries Research Center as to the response to be made to the reported ISAV findings. This article describes how federal, state, and tribal management agencies are working together to investigate the potential presence of ISAV in salmon in the western U.S. waters, including (1) enhanced surveillance for ISAV; (2) research designed to detect viruses related but different than known ISAV strains, should a suspicious finding be made during surveillance; (3) a report to Congress; and (4) preliminary results of the first year of enhanced surveillance.

The Disease and Causative Pathogen

Infectious salmon anemia (ISA) is a serious disease of marine-cultured Atlantic Salmon (*Salmo salar*) that has caused significant mortality in Atlantic Salmon farms in Europe, eastern Canada, Maine, and Chile. Globally, economic losses due to ISA have been in the billions of dollars (Brun et al. 2009). The causative agent (ISAV) is a member of the family Orthomyxoviridae, which includes the influenza viruses, although ISAV does not infect or cause disease in humans or other mammals (OIE 2012). The ISAV genome is composed of eight segments of single-stranded RNA that, like those of the influenza virus, undergo mutation, reassortment, or recombination events that generate a large variety of strains (Plarre et al. 2012). Variants of ISAV causing disease in farmed Atlantic Salmon can typically be isolated in salmonid cell lines and are found to have deletions in a highly polymorphic region (HPR) of genome segment 6, whereas strains of ISAV that lack these deletions (commonly referred to as HPR0 type or wild-type strains; Mjaaland et al. 2003) are generally of low virulence for salmon and have proven resistant to cell culture. Such HPR0 strains can only be identified using a molecular assay targeting sequences in segment 6 and other segments of the virus genome. Whereas other fish species have been shown to carry the virus, clinical disease outbreaks of ISA have only been observed in farmed Atlantic Salmon (OIE 2012) and reported in one instance in farmed Coho Salmon *O. kisutch* in Chile (Kibenge et al. 2001). Indeed, previous research has shown that some Pacific salmon species are relatively resistant to ISA (Rolland and Winton 2003).

The reports from Canada of the suspected detection of ISAV in free-ranging Sockeye Salmon from the Pacific Coast of North America generated immediate and widespread concern in the United States because of the potential impact on farmed and wild/free-ranging salmon. Atlantic Salmon are farmed in marine settings in Washington State. Consequently, if a known pathogenic strain of ISAV were introduced to the Pacific Coast of North America, it is more likely to present in clinical form in farmed Atlantic Salmon rather than the less-susceptible Pacific salmonids. However, authorities could not rule out the possibility that the virus had evolved or mutated into a form capable of infecting and possibly causing disease in Pacific salmon or was a variant that had avoided detection during decades of routine surveillance for fish viruses based on cell culture screening.

Initial Communications and Surveillance Planning

Open and effective communications between the representatives of the Task Force and the local fishery management agencies, researchers, and fish health specialists in the relevant entities (WDFW, ADFG, NWIFC, APHIS, NOAA, FWS, and USGS) was essential to build a strong foundation for a response to the reported ISAV finding in British Columbia. Frequent phone calls were held from October to December 2011. A face-to-face meeting, hosted by APHIS, was held in Olympia, Washington, on 9 December 2011. At that meeting, discussions included the development of an ISAV surveillance plan, an interagency communication plan, and a response plan should a suspect finding of ISAV be made by any of the partners and subsequently confirmed by APHIS. Also discussed at the meeting was the report being prepared by the Task Force as directed by the U.S. Congress.

Congressional Report and Action Plan

In response to concerns about the potential impacts of ISAV in the Pacific Northwest, the U.S. Congress directed the Task Force in HR 2112, Amendment No. 893, to prepare a report that would assess the risk posed by ISAV to wild Pacific salmon and the coastal economies that rely on them. The Congressional report submitted by the Task Force in 2012 included the following:

- Background information on ISA and a review of current U.S. surveillance activities and response capabilities.
- A review of the confirmed and unconfirmed ISAV detections from Canada.
- Response to specific questions contained in HR 2112, Amendment No. 893

A copy of the Congressional report submitted by the Task Force can be accessed at www.nmfs.noaa.gov/aquaculture/docs/health/salmon_anemia_report.pdf.

Surveillance and Response Plan for ISAV

The surveillance and response plan envisioned by the cooperating entities was to include three parts: (1) an assessment of existing knowledge of ISAV status in the Pacific Northwest of the United States (derived from surveillance efforts that preceded the finding of ISAV in BC), (2) a proposed strategy for enhanced ISAV surveillance in wild/feral and commercial salmonid populations of the Pacific Northwest, and (3) agreements with state, tribal, and federal partners for enhanced surveillance, including response plans should ISAV be suspected or confirmed in the future. Here, we summarize aspects of each of these three objectives and also report the results of the enhanced 2012/2013 surveillance efforts.

Preexisting Knowledge

Atlantic Salmon hatcheries. Private Atlantic Salmon hatcheries raising Atlantic Salmon eggs, fry, and smolt in Washington State are visited regularly by a licensed veterinarian. Brood stock are lethally tested for viruses by cell culture using CHSE-214 and EPC cell lines (American Fisheries Society [AFS] 2012) at spawning, aiming to achieve 95% confidence that viral pathogens would be included in the sample if present at or above 5% assumed pathogen prevalence level (APPL). The smolt production facilities are land based and their water is sourced from wells. Currently, there is only one freshwater hatchery with Atlantic Salmon in Washington. The 30-year history with a lack of ISAV detections adds evidence of absence of this pathogen in the region.

Atlantic Salmon marine net-pens. The only Atlantic Salmon farms currently operating in Pacific waters of the United States are located in Washington State. The health status of these farmed fish is monitored on a routine basis by a company veterinarian and overseen by the WDFW for aquatic animal health in collaboration with APHIS-accredited veterinarians. Routine testing of fish in the marine grow-out stage is not required by state or federal regulations. However, fish mortalities are routinely collected by divers and unexplained morbidity or mortality initiate necropsy and diagnostic investigations. Federal and Washington State regulations require the reporting of any suspect ISA event or ISAV detection to WDFW, the Washington State Department of Agriculture, and federally to APHIS. Consequently, surveillance at the farms is a key mechanism by which new pathogens and clinical diseases are detected and reported. Given the clinical presentation of ISA in Atlantic Salmon in affected marine environments, the absence of disease reports in Washington's industry is strong evidence of the absence of pathogenic strains of ISAV in the region.

Pacific salmon hatcheries and returning fish. Since the early 1980s, WDFW, NWIFC, ADFG, and the FWS have conducted routine annual viral screening of fish from all hatcheries producing freshwater resident fish for recreational fishing or stock enhancement and restoration. Few of these facilities are entirely enclosed and therefore are likely to reflect the health status of the surrounding region. Juveniles reared on surface waters and destined for stocking in a different watershed are screened for specific viral, bacterial, and parasitic pathogens annually at 5% APPL (Salmonid Disease Control Policy of the Co-Managers of Washington State 2006).

Additionally, since the early 1980s, WDFW, ADFG, NWIFC, and the FWS have conducted annual surveillance for regulated viral pathogens on anadromous salmonid broodstock (salmon and steelhead *O. mykiss*) used for restoration and enhancement activities at a minimum of 5% APPL with some broodstocks screened at 100%. From July 2010 to June 2011 over 36,000 salmonids were sampled from 51 watersheds in Washington State. Samples were taken from Chinook Salmon *O. tshawytscha*, Coho Salmon, Sockeye Salmon, Chum Salmon *O. keta*, and steelhead. Virus isolation testing using CHSE-214 and EPC cell lines (AFS 2012) was conducted at state, NWIFC, and FWS laboratories. Alaska Department of Fish and Game conducts comparable testing of returning adult fish; that is, at least 60 adult brood per stock. No ISAV has ever been detected by these screenings in the Pacific Northwest or in Alaska.

If pathogenic ISAV strains were to occur in the Pacific Northwest, prevalence would likely be low across the native species because anadromous Pacific salmonids are generally of limited susceptibility to known genotypes (Rolland and Winton 2003). However, the historic large sample volume compensates for the possibility of low test sensitivity and prevalence in Pacific salmonids. Even presuming test sensitivities as low as 25% and infection prevalence as low as 1%, negative results from 36,000 fish (averaging 6,000 fish per species) provides strong evidence that pathogenic strains of ISAV would have been detected if present and well distributed across populations. In fact, for a sample size of 6,000 fish, the detection prevalence can be as low as 0.2% before the confidence starts to drop below 95% (AusVet Animal Health Services 2014), presuming that the pathogen is not confined to geographically isolated population segments.

International export facilities. Viral screening and APHIS-endorsed health certificates are required by some importing countries when receiving live eggs or fish from the United States. APHIS-accredited veterinarians inspect export facilities in Washington State and select fish for testing at 3- to 6-month intervals. Additionally, when required by the importing country, APHIS registers aquaculture establishments, which requires, in part, an annual inspection by an APHIS Veterinary Medical Officer. The Washington Animal Disease Diagnostic Laboratory (WADDL), associated with the Washington State University College of Veterinary Medicine, typically conducts this viral screening. The WADDL is one of the laboratories approved by APHIS to conduct testing for ISAV to support export health certification of aquatic species and is accredited by the American Association of Veterinary Laboratory Diagnosticians. Traditional ISAV screening for export certification includes culture of sampled tissues (kidney, spleen, pyloric ceca, and gill) on general and ISAV-susceptible cell lines including the EPC, CHSE-214, and SHK (OIE 2012). Over 15 years of surveillance supports ISAV freedom at these exporting facilities.

To conclude, preexisting surveillance efforts in Pacific and Atlantic salmonid populations in Washington and Alaska provide substantive evidence of historical absence of pathogenic strains of ISAV. However, because much of the preexisting surveillance is cell culture based, enhanced testing protocols using molecular assays will help to increase confidence of the absence of subclinical or novel ISAV genetic variants.

Strategy for Enhanced ISAV Surveillance:

The objectives for enhanced ISAV surveillance established by the Task Force and the state and tribal partners varied by sector to include natural and enhancement populations, stock restoration, and commercial Atlantic Salmon populations. Objectives include the following:

- Evaluate regional ISAV status to support zonation and/or movement decisions regarding fish, fertilized eggs, or gametes transferred for stock enhancement and restoration, rearing, or trade.
- Document regional ISAV freedom status to support facilities participating in domestic or international trade.
- Provide an evidence-based response to public and stakeholder concerns of new disease emergence.
- Provide early detection strategies in order to facilitate awareness and rapid response in the event of new pathogen introductions.

A key objective was to evaluate emergence of ISAV of any type (including HPR0 or previously undescribed genotypes of viruses) and provide direction for ongoing surveillance programs. The enhanced surveillance preferentially targets fish species of established susceptibility to known ISAV genotypes (e.g., marine-farmed Atlantic Salmon). Quarterly sampling at marine Atlantic Salmon farms commenced in 2013 and continues in 2014. Anadromous steelhead are also ideal candidates because they are broad-ranging, exposed to other salmonids in the open ocean, considered susceptible to ISAV (Biacchesi et al. 2007), and readily accessed at enhancement and stock restoration hatcheries. If ISAV of a known genotype were introduced to the Pacific Northwest, steelhead could be a likely reservoir population. However, because ISAV is an orthomyxovirus with strong evolutionary capacity, virus emergence could potentially occur in species of unknown or uncertain susceptibility. Accordingly, steelhead were sampled as an indicator species for known genotypes. Enhanced surveillance is also being conducted on other salmonids, namely, Pacific salmon (Chum, Chinook, Pink, Coho, and Sockeye Salmon), that are potentially susceptible to evolving or atypical strains of ISAV.

To further enhance detection of ISAV, sampling was focused on periods of high population susceptibility (e.g., stress) and potential exposure to the virus. Sampling for marine exposure targeted returning anadromous salmonid adults native to the Pacific Northwest. The testing methodology is designed to (1) improve the likelihood that we would find additional genotypes of ISAV if truly present, and (2) ensure the validity of a positive test.

Key to the strategy for ISAV surveillance in the Pacific Northwest was the selection of assays and laboratories appropriate for this purpose. The Task Force worked in conjunction with laboratory representatives from APHIS's National Veterinary Services Laboratories (NVSL), WADDL, and the FWS Idaho Fish Health Center in selection of surveillance assays and implementation of testing. From these discussions, a previously published real-time reverse transcription PCR assay for segment 8 was selected (Snow et al. 2006) and in this surveillance plan this assay was modified to a single-step reaction. This assay was selected based on its (1) ability to detect both European and North American strains of ISAV, (2) high sensitivity, (3) ability to detect both HPR-deleted and HPR0 ISAV, and (4) performance in a high-throughput testing system in order to evaluate large numbers of individual samples in a short period of time. It was decided that any detections by the initial screening assay would also be tested by two additional conventional reverse transcription assays, one evaluating for segment 8 (Blake et al. 1999) and a second evaluating the HPR of segment 6 of ISAV. Both of these assays produce larger amplicons allowing sequencing and genetic characterization of any detected ISAV strains. Prior to the initiation of testing, standard operating procedures and control reagents were created and distributed to all laboratories. NVSL evaluated the laboratories' limit of detection of the assay to multiple ISAV strains, reproducibility of the assay, and the satisfactory completion of a proficiency examination.

Agreements and Response Plans

APHIS, via cooperative agreements with ADFG, WDFW, and the NWIFC, is funding a significant portion of the enhanced surveillance being conducted in the Pacific Northwest. WDFW, ADFG, and the NWIFC provided in-kind support associated with collection and submission of samples to WADDL and NVSL. The FWS is funding collection of samples from the National Fish Hatcheries plus some nonhatchery stocks in the region and testing of those samples at the Idaho Fish Health Center.

To prepare for the event of a positive finding, states, NWIFC, USGS, and the FWS authored a contingency plan with input from the Task Force. The full response plan, including testing protocols, is available at the NWIFC web site (access.nwifc.org/enhance/documents/ISAV_Regional_Contingency_Plan_final_02-20-2013.pdf). The main elements of the response plan are as follows:

- If a suspect test result occurs using the validated ISAV RT-PCR assay, significant additional testing will be conducted to confirm that result and to determine the genotype of the viral sequence.

- If the additional testing identifies a presumptive positive sample but no disease is concomitant with the finding, biosecurity will be temporarily enhanced at the positive facility. If occurrence is either in a cultured or free-ranging population, additional testing will be conducted on that population if still available. No depopulation activity will occur in this situation.

- A confirmed finding of ISAV that is associated with disease and for which a virus has been isolated by cell culture will result in an emergency meeting of state, tribal, and federal fishery managers. Strong consideration will be given to quarantine of facility, destruction of infected stock, and disinfection of the facility. At the same time, ISAV surveillance will be increased in cultured and wild stocks in the immediate vicinity and nearby watersheds.

Results of 2012/2013 Surveillance

No ISAV was detected in either Washington (Table 1) or Alaska (Table 2) during surveillance in the first year. Additionally, extensive surveillance in Canada by the CFIA and the Department of Fisheries and Oceans on farmed and wild salmonids in British Columbia was unable to confirm the reported ISAV finding in western Canada (CFIA 2013). Surveillance data from 2013/2014 brood years and further analysis of disease status will be supplied in a subsequent report targeted for completion in 2015.

RESEARCH

As part of the U.S. response to Congress, a research plan led by the USGS Western Fisheries Research Center was proposed for integration with the enhanced ISAV surveillance plan. Because the results of the surveillance could not be known in advance, the research priorities were designed to be flexible and respond to new information as it became available. A tiered set of research priorities was identified with each stage of research being dependent on results from the previous work or from other information sources. The three proposed research stages are as follows:

1. Determine additional genetic information about the viral strain or strains present to provide epidemiological inferences about the distribution, origin, and biology of the agent(s) and inform the development of improved diagnostic tools.

2. Develop and test improved identification tools, including both molecular and cell culture–based approaches, that would provide better detection of new type(s).

3. If a positive finding of ISAV occurred, perform controlled laboratory infection studies to assess the risk of new type(s) to include evaluation of virus replication and persistence, histopathological changes, virus shedding, and development of a carrier state.

Any progress on research requires ISAV-positive material obtained from official U.S. or Canadian surveillance efforts. Thus, the research and surveillance plans are interdependent. The information from stage 1 of the research plan and the improved identification tools in stage 2 will require samples that test positive for ISAV or an ISAV-like agent to undergo additional testing to identify sequence or strain diversity. The results of the research plan could alter surveillance efforts if, for instance, a novel genotype is found in the region. Regional partner agencies agreed to collect a duplicate set of samples for the research plan during the enhanced surveillance effort. Initial research has focused on surveying a subset of the sampled fish with a flexible set of diagnostic tests for ISAV, with a goal of testing all Pacific salmon species, representing various habitats and geographic regions from Washington and Alaska.

CONCLUSIONS AND NEXT STEPS

Many lessons have been learned by the fishery management entities of Washington, Alaska, the NWIFC, the federal Task Force, and testing laboratories following the reported finding of ISAV in British Columbia. Perhaps most important is that close collaboration and effective communication between all parties is essential to ensure that we are making the best management decisions necessary to protect wild and cultured aquatic resources. We have found that it is critical to have consistent responses to inquiries from outside our respective agencies. The Task Force will continue to work with all partners, public, private, and tribal, to fulfill its role as outlined in the National Aquatic Animal Health Plan of protecting U.S. aquatic resources, both farmed and wild.

Although there is currently only one year of results of enhanced surveillance for ISAV, information from historic surveillance (active and passive) for fish viruses as well as the negative findings from the 2012–2013 effort provide a significant body of data indicating the nonpresence of ISAV in salmon stocks of the U.S. Pacific Northwest and Alaska. We recognize that ongoing surveillance with tools of appropriate sensitivity is important in order to have a high level of confidence in the status of all OIE reportable aquatic pathogens in U.S. waters. The completion of the enhanced surveillance project for 2013–2014 will increase our confidence as to the current status of ISAV in the marine waters of the Pacific Northwest.

FUNDING

The coauthors would like to recognize our respective agencies for their financial support to conduct the surveillance, research, and outreach/communication for this important topic. USDA/APHIS should be particularly recognized for their funding of laboratory testing of samples from Washington State, Alaska, and the NWIFC. The FWS should be commended for its support of these activities with both funding and regional staff involvement.

Table 1. Results from the 2012–2013 enhanced surveillance effort for infectious Salmon anemia virus (ISAV) RNA in fish sampled from Washington State. All 923 samples tested negative for ISAV RNA.

Species	Washington regions Sampled fish (number of stocks from which fish were sampled)			Total
	Greater Salish Sea	Washington Coast	Columbia River	
Sockeye Salmon *O. nerka*	85 (3)	40 (2)	50 (1)	175
Chinook Salmon *O. tshawytscha*	83 (5)	30 (2)	20 (2)	133
Coho Salmon *O. kisutch*	70 (4)	65 (4)	45 (3)	180
Chum Salmon *O. keta*	80 (4)	20 (1)		100
Steelhead *O. mykiss*	100 (2)	170 (4)	50 (1)	320
Atlantic Salmon *S. salar*	15 (1)			15
Total	433 (19)	325 (13)	165 (7)	923

[a] Adult Sockeye Salmon linked to out-migrant origin using diagnostic marks and tags.

Table 2. Results from the 2012–2013 enhanced surveillance effort for infectious salmon anemia virus (ISAV) RNA in fish sampled from Alaska. All 1,431 samples tested negative for ISAV RNA.

Species	Alaska regions Sampled fish (number of stocks from which fish were sampled)			Total
	Greater Salish Sea	Kodiak and Prince William Sound	Southeast	
Sockeye Salmon *O. nerka*	60 (1)	57 (1)	60 (1)	177
Chinook Salmon *O. tshawytscha*	60 (1)	60 (1)	180 (3)	300
Coho Salmon *O. kisutch*	58 (1)	120 (2)	179 (3)	357
Chum Salmon *O. keta*	58 (1)	60 (1)	179 (3)	297
Pink Salmon *O. gorbuscha*	60 (1)	120 (2)	120 (2)	300
Total	296 (5)	417 (7)	718 (12)	1,431

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Perspectives from the Fish Health Section

In Response – Peer Commentary on Infectious Salmon Anemia Virus Paper

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The previous article "U.S. Response to a Report of Infectious Salmon Anemia Virus in Western North America" by Amos and coauthors summarizes the response of federal, state and tribal agencies in the U.S. to the announcement in 2011 of the detection of infectious salmon anemia virus (ISAV) in samples of wild Sockeye Salmon (*Oncorhynchus nerka*) from British Columbia, Canada. The finding raised alarm among fisheries managers, fish culturists and fish health specialists because the virus, which has caused extensive losses in farmed Atlantic Salmon (*Salmo salar)* in Europe, Chile, and the east coast of North America, was thought to be exotic to the region. Soon followed by additional reports indicating the presence of the virus in other species of Pacific salmon in the province, the presence of ISAV on the West Coast of North America had potentially important implications for the health of the exceptionally valuable wild stocks of Pacific salmon as well as the large number of salmon reared by both public and private aquaculture in the western United States. As a result of significant media attention, concerns were also raised among the public and their elected representatives. In response to a U.S. Congressional mandate, various agencies rapidly constructed an enhanced surveillance and research plan to learn more about the possible distribution, source, and risk posed by the virus. Members of the Fish Health Section played a prominent role in these efforts, demonstrating the important interactions between fish health, fish culture, and fisheries management that represents one of the key strengths of the American Fisheries Society. Additionally, several participants in the surveillance and research efforts already had rapport and professional relationships through their membership in the AFS Fish Health Section. These relationships facilitated working through a scientifically challenging and politically charged issue. While early indications are that the virus is either absent or not widely distributed in the states of Washington and Alaska, this experience highlights the need for managers, fish culturists, and fish health specialists to work together to limit the introduction and spread of exotic pathogens and to better understand the drivers of emerging diseases affecting fish in aquaculture as well as in the marine and freshwater environments.

Perspectives from the Canadian Aquatic Resources Section

Canadian Aquaculture News: Grant to Study the Value of Incorporating Wild Salmon Genes into an Organic Aquaculture Industry Partner's Practice

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A research team led by University of Windsor's Daniel Heath, along with Yellow Island Aquaculture Ltd., recently received a strategic project grant from Canada's Natural Sciences and Engineering Research Council (NSERC) to study the value of incorporating wild salmon genes into an organic aquaculture industry partner's practice. Several of the team members were also recently honored with a Synergy Award from NSERC for their research collaboration with Yellow Island Aquaculture Ltd.

Capture fisheries alone are unable to sustain demand for seafood, and aquaculture is a growing source for that demand. Salmon farming is one of Canada's growing industries and is extremely valuable. However, salmon farming must balance production economics with environmental impacts. Farmed Chinook Salmon (*Oncorhynchus tshawytscha*) are a valuable niche market with substantial growth potential, coupled with lower perceived environmental concerns (being a native species); however, their performance has not been systematically assessed. The team will develop a performance-enhanced hybrid Chinook Salmon stock with higher survival and growth and reduced feed costs. The new stock will use less wild-sourced lipid and protein for feed and minimize drug and chemical use for disease control, thereby minimizing the environmental footprint. The project will generate data on Chinook Salmon production stocks that will serve to improve salmon farming efficiency which will help make Canada a global leader in Pacific salmon farming.

The proposal involves close collaboration among leading researchers at three universities, commercial salmon farms and related industries, and government and non-governmental organizations charged with fish management. Performance will be measured in offspring from crosses between inbred farmed and wild stocks; those offspring are expected to exhibit hybrid vigor, analogous to hybrid corn lines. Offspring will be reared in a range of environments (varying density and food type), and performance as measured by molecular, physiological, and behavioral aspects of growth, survival, and flesh quality will be compared. Specifically, the team will test for stock, environmental and interactions effects on growth, feeding and competitive ability, disease resistance, immune function, gene expression, and metabolic processes. The optimized commercial hybrid stocks, calibrated for variation in rearing conditions, will be marketed domestically and internationally, supporting the economic and environmental development of Canada's large and growing aquaculture industry.

Environmental Performance of Marine Net-Pen Aquaculture in the United States

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ABSTRACT: *The United States has a small net-pen salmon industry dating back over 40 years and a nascent net-pen industry for other marine fish. The United States net-pen aquaculture sector has improved its resource efficiency in terms of the amount of fish meal and fish oil used in feeds and reduced its environmental impacts in terms of the mass loading and impact of nutrient discharge on the receiving ecosystem, the incidence and treatment of fish diseases, the use of antibiotics, and the number and impact of fish escapes, while increasing production. These changes can be attributed to a combination of advances in science and technology, rising cost of fish meal/oil, improved management, and informed regulatory practices. Net-pen aquaculture has become an efficient food production system. Existing laws and regulations in the United States effectively address most of the potential adverse environmental effects of net-pen aquaculture.*

Desempeño ambiental de la acuacultura marina con jaulas de red en los Estados Unidos de Norteamérica

RESUMEN: *Los Estados Unidos de Norteamérica (EE.UU.) poseen una pequeña industria de acuacultura de salmones mediante jaulas de red que data desde hace cuatro décadas y una incipiente industria de cultivo con jaulas de otras especies de peces marinos. El sector de la acuacultura con jaulas de red en los EE.UU. ha mejorado la eficiencia de sus recursos en términos de cantidad de carne y aceite de pescado utilizados para la engorda y en cuanto a la reducción de sus impactos negativos: el aumento de la producción versus la carga de masa y el impacto de la descarga de nutrientes en los ecosistemas receptores, la incidencia y tratamiento de enfermedades de peces, uso de antibióticos y el impacto del escape de peces. Estos cambios son atribuibles a la combinación de avances científicos y tecnológicos, el incremento en el costo de la carne y aceite de pescado, un mejor manejo y prácticas regulatorias informadas. La acuacultura con jaulas de red se ha convertido en un sistema eficiente de producción de alimentos. Las leyes y regulaciones existentes en los EE.UU. abordan de forma efectiva los efectos adversos potenciales de la acuacultura con jaulas de red.*

INTRODUCTION

Aquaculture is likely to supply most of the projected increased need for seafood over the next few decades (United Nations 2011; Food and Agriculture Organization of the United Nations [FAO] 2012; World Bank 2013). With available land and freshwater becoming scarce, marine aquaculture (finfish, shellfish, and seaweeds) will be an increasingly important contributor to the world's future food supply (World Bank 2013; Organization for Economic Co-operation and Development [OECD]/FAO 2014). Aquaculture is well established in many countries and continues to grow worldwide (FAO 2012). The United States is a global leader in aquaculture technologies and scientific advances (Natale et al. 2012) but has a relatively small aquaculture industry (National Oceanic and Atmospheric Administration [NOAA] 2012; World Bank 2013), providing less than 5% of the seafood consumed nationally (NOAA 2012). We estimate that the U.S. net-pen salmon industry (Atlantic Salmon *Salmo salar* and steelhead *Oncorhynchus mykiss*) produced about 12,000 tons (live weight) in Maine (US$78 million) and around 8,000 tons in Washington State ($52 million) in 2010. In the same year, the United States also imported over 280,000 tons of farmed salmon (NOAA 2012). We estimate that another

500–1,000 tons of various marine species were produced in net-pens from the remaining states (Figure 1).

The last 40+ years have seen significant advances in fish farming technology and management practices focused on decreasing the environmental footprint and increasing economic performance.

Marine finfish aquaculture in the United States represents an opportunity to provide healthy, domestic seafood (Merino et al. 2012), create jobs, contribute to coastal economies, and help reduce the trade deficit (National Research Council [NRC] 1978; Rubino 2008; Kite-Powell et al. 2013). The United States has one of the largest areas of exclusive economic zone that is environmentally and economically suitable for net-pen culture (Kapetsky et al. 2013). Given this potential, why is the marine finfish aquaculture industry not expanding? The reasons may lie, in part, with environmental concerns expressed about the salmon net-pen aquaculture industry (Naylor et al. 1998, 2000; Naylor and Burke 2005). Specific issues include impacts on water quality (Boyd et al. 2007), degradation of the seafloor under net-pens (Bridger and Costa-Pierce 2003; Beveridge 2004), the effect of fish escapes on the genetic diversity of wild populations (Waples et al. 2012), the sustainability of using fish meal and fish oil for feeds (Naylor et al. 1998, 2000; Adler et al. 2008), the use of antibiotics (Smith and Samuelsen 1996), and the potential transfer of diseases from farmed to wild populations (Johansen et al. 2011). These concerns have been widely publicized beyond the scientific community (Knapp et al. 2007; Baron 2010; Knapp 2012) and generate negative public perceptions that, in turn, reduce social acceptance for many types of aquaculture (Moffitt 2006; Amberg and Hall 2008; Mazur and Curtis 2008). Once established, negative public preconceptions may overshadow recognition of the progress made in the net-pen fish farming industry and other forms of aquaculture. A lack of social acceptance hinders efforts to simplify a complex and uncertain regulatory process (Gibbs 2009; Chu et al. 2010). In turn, regulatory and economic barriers to entry (e.g., onerous, lengthy, and uncertain permitting; high costs of coastal land, labor, and other inputs) reduce the ability of the United States to compete in the global farmed seafood market (Kite-Powell et al. 2013).

The last 40+ years have seen significant advances in fish farming technology and management practices focused on decreasing the environmental footprint and increasing economic performance (Kaiser and Stead 2002; Tveterås 2002; Asche 2008). Regulations have been developed to set performance standards in all jurisdictions of the United States where net-pen aquaculture occurs (see Box 1 and Table 1). Numerous organizations have developed purchasing policies, standards, and labeling programs that promote responsible aquaculture, creating financial incentives for producers to improve practices and become part of the responsible aquaculture movement (Boyd et al. 2007). How do these pressures translate to impacts of net-pen farming?

This article examines the current resource efficiency and environmental performance of U.S. marine net-pen finfish farming, considering the roles that administrative controls (regulation, economic, and management) and structural controls (science and technology) play in shaping a sustainable industry (Boyd et al. 2007; Belle and Nash 2008). We discuss issues related to feed, water quality and benthic effects, animal health, and potential genetic effects of fish escapes.

FEED AND FEEDING

The use of fish meal and fish oil in aquaculture feeds has been highlighted as a major sustainability issue and a limitation to the growth of carnivorous species aquaculture (Naylor et al. 1998, 2000; Kristoffersson and Anderson 2006). Yet raising fish, including carnivores, has efficiency advantages over terrestrial animals (see Box 2), and no animal has a nutritional requirement for fish meal or fish oil (NRC 1983, 1984, 2011). Further, formulated feeds with no fish meal or fish oil have been used experimentally to feed farmed Atlantic Salmon, resulting in growth and survival similar to those obtained with feeds containing fish meal and fish oil (Torstensen et al. 2008; Burr et al. 2012). The same is true of Rainbow Trout *Oncorhynchus mykiss* (K. J. Lee et al. 2002; Barrows et al. 2007; Gaylord et al. 2007), Red Sea Bream *Pagrus major* (Takagi et al. 2000), Grouper *Cromileptes altivelis* (Shapawi et al. 2007), White Sea Bass *Atractoscion nobilis* (Trushenski et al. 2013), Cobia *Rachycentron canadum* (Watson et al. 2012, 2013), and Pacific Whiteleg Shrimp *Litopenaeus vannamei* (Sookying 2010; Olmos et al. 2011). Modern fish feeds are formulated from a variety of ingredients in carefully determined proportions to provide a balanced mix of essential nutrients and energy at the lowest practical cost (Hardy and Barrows 2002; NRC 2011). Sources for these nutrients and energy are not limited to fish meal and fish oil, nor are there essential nutrients unique to fish meal or fish oil (Gatlin et al. 2007; Barrows et al. 2008; NRC 2011).

Traditionally, fish feeds have contained a high percentage of fish meal and fish oil because these ingredients provided a cost-effective means to satisfy the nutritional requirements of fish (Hardy and Barrows 2002). The balance of nutrients in fish meal and fish oil closely resembles and fulfills most nutritional requirements of fish with very few antinutritional factors (compounds that negatively impact the nutritional value of the feed). Alternative nutrient sources typically need to be treated, blended, and/or supplemented to adjust for missing nutrients, improve palatability, or remove antinutrients (Gatlin et al. 2007; Barrows et al. 2008). Partial or total replacement of fish meal and fish oil in fish feeds is fast becoming the norm, but the research to develop and the effort to apply these modifications adds cost to the feed and requires investment in research, processing, and infrastructure (Gatlin et al. 2007; Barrows et al. 2008; Naylor et al. 2009).

Over the past several decades, the supply of fish meal and oil coming from targeted fisheries has been more or less constant, whereas fed aquaculture has increased (See Box 3). The

BOX 1. Regulatory Requirements for U.S. Net-Pen Aquaculture

Multiple U.S. federal, state, and tribal government agencies regulate marine fish farms. Although aquaculture permitting processes can be complex and lengthy, federal and state local laws and regulations provide a comprehensive suite of requirements to address the environmental effects of fish farms outlined in this article. Table 1 lists the federal laws that apply to environmental sustainability of marine net-pen aquaculture in the United States and the agencies responsible for their implementation. State governments often impose requirements that are more stringent than these federal requirements.

For net-pen aquaculture, the key federal permits related to the issues discussed in this article are issued by the U.S. Army Corps of Engineers (USACE) to authorize the placement of structures in navigable waters and by the U.S. Environmental Protection Agency (USEPA) to authorize discharges into the environment. These permits are typically issued in coordination with state agencies; however, in the case of National Pollutant Discharge Elimination System (NPDES) permits, the USEPA vests the states with the authority to issue permits in state waters in accordance with the Clean Water Act. Before issuing permits, the USACE and USEPA are required to consult with the National Marine Fisheries Service (NMFS) and/or with the U.S. Fish and Wildlife Service on issues related to protection of habitat, endangered species, and marine mammals. Aquaculture operations must also comply with permitting, monitoring, and reporting requirements for aquatic animal health under regulations of the U.S. Department of Agriculture's APHIS. Regulations pertaining to chemical application require permits from the USEPA, whereas aquatic animal drugs and feed manufacture require approvals from the U.S. Food and Drug Administration (USFDA 2014). Fish feeds and ingredients are regulated for safety by the USFDA under the Federal Food, Drug, and Cosmetic Act and the Food Safety Modernization Act. The USFDA requires animal feed to be "pure and wholesome, to be produced under sanitary conditions, to contain no harmful substances, and to be truthfully labeled." Only approved ingredients can be used in animal feeds, and feed mills have to follow quality control plans. To be approved by the USFDA for use in animal feeds, ingredients must demonstrate utility and safety to both the target animal (fish) and to the humans consuming them. Harvest levels of fish species used in making fish meal and fish oil in the United States are determined by fishery management regulations under the provisions of the Magnuson-Stevens Fishery Conservation and Management Act and state laws. Fact sheets on all of these federal laws as they relate to aquaculture can be found at websites run by the Fish Culture Section of the American Fisheries Society (2013) and the National Association of State Aquaculture Coordinators (2013).

Currently, all commercial net-pen aquaculture production takes place in state waters. Commercial salmon net-pen farming is well established in Maine and Washington, which have correspondingly well-developed regulatory programs to authorize and oversee these operations. For example, Washington State laws and regulations specific to marine aquaculture give the Washington Department of Ecology and Washington Department of Fish and Wildlife regulatory authority over marine net-pens, disease, fish transfer, escapement, and best management practices (Lori LeVander, Washington Department of Ecology, personal communication). Hawaii has been authorizing and overseeing commercial-scale operations using submerged net-pens for more than 10 years. New Hampshire has done the same with smaller-scale research facilities, and a commercial facility recently started operations in New York. As interest in commercial production of finfish in marine waters expands, it is likely that additional states will become more actively engaged in the regulation of the net-pen aquaculture industry. In addition, NOAA is preparing regulations for a Fishery Management Plan for offshore aquaculture in the Gulf of Mexico, designed to allow NOAA to issue permits for finfish aquaculture of managed species in federal waters. Other regional fishery management councils may adopt similar plans, which would result in additional federal rules to regulate fish farming in additional regions.

BOX 2. Relative Efficiency of Aquatic and Terrestrial Animals

Farmed fish are more efficient protein and energy converters than terrestrial livestock (Bartley et al. 2007; Brooks 2007). This is because fish generally do not use energy to maintain body temperature and they do not need to support their own weight against gravity (R. R. Smith et al. 1978; Talbot 1993). Fish also invest less energy and body mass in a skeletal system compared to terrestrial animals (Moffitt 2006). Smil (2002) compared the protein efficiencies (the amount of protein in the product/protein fed × 100) of different farmed animals and found that carp had higher protein conversion efficiency (30%) than land animals (5% for beef, 13% for pork, and 25% for chicken). Salmon, trout, and other carnivorous fish have protein conversion rates that can range between 30% and 50%, depending on diet and other conditions (Refstie et al. 2004; Soto et al. 2007).

U.S. consumers often prefer boneless meat and fish products. Because fish have relatively small skeletal systems, they have a higher percentage of edible portions than animals with larger skeletal systems. For example, as much as 68% of the weight of farmed salmon is edible compared to about 44% in cows, 52% in pigs, 46% in chicken, and 38% in sheep (Bjørkli 2002; Brooks 2007; Hall et al. 2011). Torrissen et al. (2011) suggested that Atlantic Salmon could be among the most efficient domesticated farm animals because 100 kg of dry feed yields 65 kg of boneless salmon fillets, compared to only 20 kg of edible product from poultry or 12 kg from pork.

Figure 1a. Submersible net-pen near Kona, Hawaii.

Figure 1b. Salmon farm in Washington State.

Figure 1c. Net-pens in Maine used for growing cod and salmon.

BOX 3. Fish Meal Supply and Demand

The world's annual supply of fish meal and fish oil has averaged 4 to 5 million metric tons of meal and around 1+ million metric tons of oil for the last 20 years (International Fish Meal and Fish Oil Organization 2013). Of these total quantities, currently, about 70% originates from "reduction" fisheries targeted at small, wild pelagic fish, such as sardine, anchovy, menhaden, and capelin. The remainder originates from processing wastes from both wild and farmed fish (Jackson 2012; FAO 2012; OECD/FAO 2014). Stocks historically used for reduction fisheries are more and more being used for human consumption, and processing wastes that were historically discarded are now being used for fish meal and oil production (Jackson 2012; World Bank 2013; OECD/FAO 2014).

Increased demand with fixed supply caused prices of fish meal (Figure 2) and fish oil to increase dramatically over the last decade (Adler et al. 2008; Jackson 2012; OECD/FAO 2014). This increasing cost differential relative to other protein and oil sources spurred development of replacements for fish meal and fish oil in aquaculture feeds (Gatlin et al. 2007; Tacon and Metian 2009; Tacon et al. 2011) and a greater recovery of fish trimmings from aquaculture and wild captured seafood (Shepard et al. 2005; Jackson 2012; OECD/FAO 2014). Prior to 2004, the price of fish meal was less than US$1,000/ton and was closely constrained by the prices of substitute proteins. After mid-2006, fish meal prices increased to $1,000–$1,500/ton, and by late 2009, they had further increased to $1,500–$1,800/ton. In 2012, for the first time, they peaked above $2,000/ton and were at $2,400/ton at the end of 2014. In comparison, during this same period, soybean meal, a leading substitute protein, increased from about $200 to a peak at $550/ton before settling down around $500/ton, widening the price gap between the two protein sources from less than $500/ton prior to 2004 to $1,000–$1,500/ton by 2009. Since 2002, the cost gap between soy protein and fish meal has increased almost fourfold. This provided the financial incentive to justify spending for the extra processing and supplementation needed to use increased amounts of alternative proteins and oils in fish feeds. Because feed accounts for more than 50% of the total operating costs in net-pen aquaculture and ingredients account for about 70% of the cost of making feed, there are strong economic incentives to use the most cost-effective mix of ingredients.

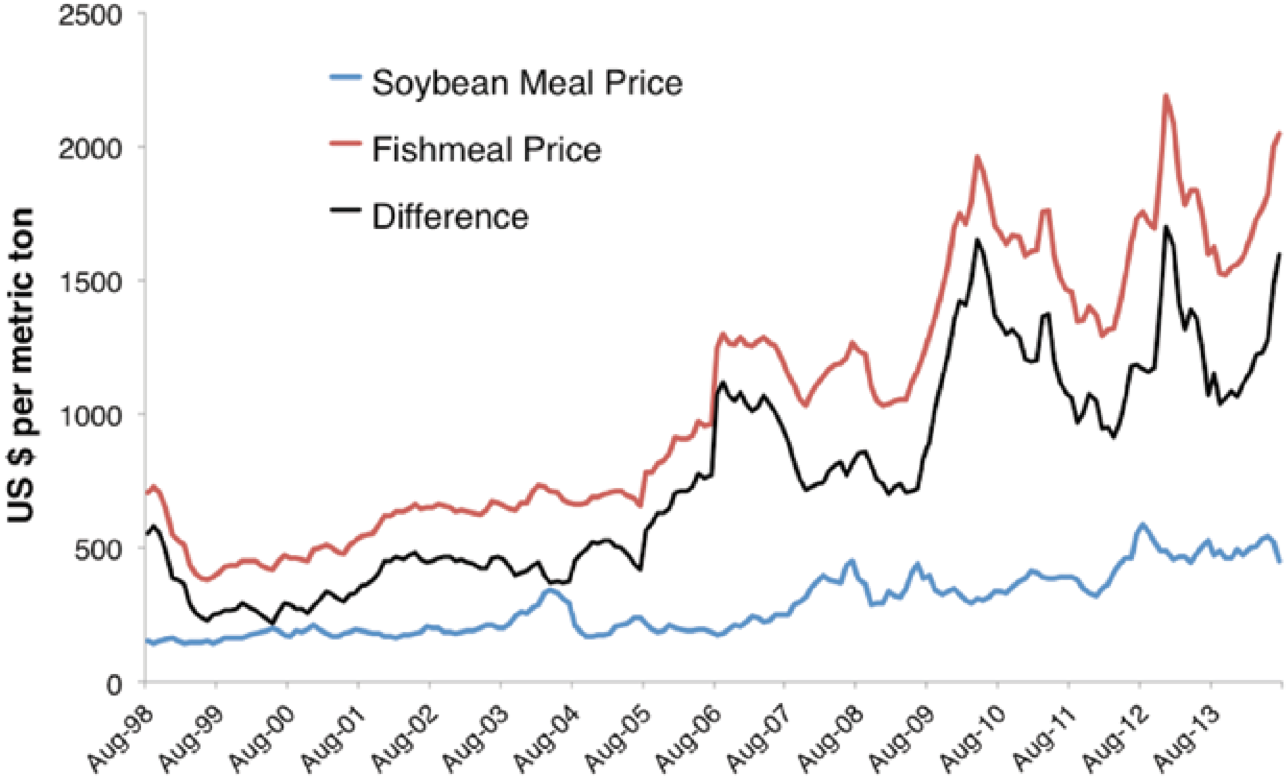

Figure 2. Cost in U.S. dollars per metric ton of 65% crude protein fish meal (Peru), 48% crude protein soybean meal (United States), and the difference between the two. Source: www.indexmundi.com (August 2014).

proportion of the world's supply of fish meal and fish oil going into aquaculture feeds increased by displacing use from terrestrial animal agriculture until it consumed an estimated 68% of world fish meal and 88% of world fish oil in 2005 (Tacon and Metian 2008, 2009; FAO 2011). However, by 2008, the amount of fish meal in aquaculture had fallen 13% from 2005 (FAO 2011; International Fish meal and Fish oil Organization 2013). Some stocks previously fished for producing fish meal and oil are increasingly being redirected toward human consumption (Jackson 2012; OECD/FAO 2014). Likewise, fish oil is increasingly being used as a human dietary supplement (Tacon and Metian 2009; FAO 2012; Jackson 2012). Tacon et al. (2011) and Jackson (2012) predicted that the percentage and the absolute amount of fish meal and fish oil consumed by aquaculture will continue to decrease as they become a smaller component of fish feeds, largely due to the development of lower cost alternative sources of protein (Gatlin et al. 2007; Barrows et al. 2008) and oil (Rust et al. 2011; Ruiz-Lopez et al. 2014). Similarly, Torrissen et al. (2011) reported that the Norwegian salmon farming industry has dramatically reduced the content of fish meal and fish oil in salmon feeds from >60% to <25% of the diet, largely by replacement with plant proteins and oils. Use of fish meal and fish oil in aquaculture has responded to the economic realities of the past few decades (see Box 3 and Figure 2), with increasing price differentials between fish meal/oil and other protein/oil sources leading to development of substitutes. Use of these substitutes is causing a decoupling of fed aquaculture and the harvest of stocks for fish meal and oil. Development of ingredient choice continues to be one of the most active areas of research in aquaculture nutrition.

NUTRIENT IMPACTS TO WATER QUALITY AND BENTHOS

Deleterious effects to water quality and the benthos around net-pen fish farms can occur when nutrient inputs exceed the physical, chemical, and biological capacity of the ecosystem to assimilate them (Pearson and Rosenberg 1978). Excess organic nutrients and suspended solids can lead to eutrophication and sedimentation in receiving waters (Boyd et al. 2007). Uneaten feed and fish wastes are the main sources of excess organic nutrients from net-pens. Because nutrients are discharged directly to the ocean, effluent treatment is not feasible. Instead, farms seek to manage nutrient waste with farm practices, efficient feeds and feeding (Figure 3), optimal pen configurations and farm orientation in order to optimize fish growth, waste distribution, and nutrient assimilation by the food web. Modeling interactions between farm production and environmental processes can guide decisions about sustainable farming (Aguilar-Manjarrez et al. 2010) and prevent exceeding the site's ecological carrying capacity.

Water Quality

Impacts to water quality at farm sites, including increased nitrogen, phosphorus, lipids, and turbidity, or oxygen depletion, have lessened significantly over the last 20 years (Soto and Norambuena 2004; McKinnon et al. 2008; Price and Morris 2013). These improvements are attributable to a combination of better understanding of siting requirements, improved feeding, better feed formulation, and better farm management practices. Good

Figure 3. Control room for a salmon farm in Washington State. Fish feeding, behavior, and health are monitored using underwater video and water quality data are collected and displayed on computer screens. Feeding is done based on a computer-controlled system, feedback from the video, and the operator's experience. Photo by Laura Hoberecht.

management practices include siting farms in well-flushed areas with adequate current (mean of >7 cm/s) and depth (Belle and Nash 2008). When net-pens are properly sited, water quality impacts are typically not detectable beyond 30 m from the pens (Mantzavrakos et al. 2005; Nash et al. 2005; Tlusty et al. 2005). Though a phytoplankton response to nutrient loading has been reported at some fish farms, this is generally considered low risk (Nordvarg and Hakanson 2002; Soto and Norambuena 2004; Apostolaki et al. 2007).

Causal linkages have not been established between fish farming and eutrophication (Pitta et al. 2005; Modica et al. 2006) or phytoplankton blooms (Silvert 2001; Anderson et al. 2008). In Maine and Washington, other factors besides nutrients, such as light availability and water temperature, often control natural variability in primary productivity. Naturally occurring nutrient fluxes from coastal ocean upwelling, or from land- and ocean-based sources, are often high relative to loads from aquaculture. Because nutrients may be flushed away from the immediate cage area and dispersed into the surrounding water body, it is difficult to assess whether far-field primary production is being affected over large areas and at longer timescales. The occurrence of many anthropogenically derived nutrients in coastal marine waters makes it difficult to attribute nutrification and phytoplankton response to any one source, including aquaculture.

Benthic Impacts

Benthic impacts result where organic nutrients in uneaten feed and fish waste accumulate on the seafloor (Pearson and Black 2001; Chamberlain and Stucchi 2007; Belle and Nash 2008) and do not decompose quickly enough by natural aerobic bacterial processes to keep up with the supply from the farm. In this case, sediments shift toward anaerobic conditions, and the benthic species diversity declines, with perturbation-tolerant generalists becoming dominant (Hargrave 2003; Holmer et al. 2005; Hargrave et al. 2008).

Benthic impacts from U.S. net-pens have reduced dramatically over the last few decades, due to improved siting and better management practices. Indicators to assess benthic condition include total organic carbon, redox potential, free sulfides, and abundance and diversity of marine organisms. Electrochemical and image analysis methods are also used (Schaaning and Hansen 2005; Wildish et al. 2003). These indicators inform site management decisions, such as when to fallow (leave a site empty of fish for a period of time) or to adjust feeding and harvest. Because feed typically accounts for more than half the operating costs, farmers have the financial incentive to use underwater cameras to monitor and regulate feeding to minimize wasted feed (Figure 3).

Accumulation of particulate waste is unlikely at farms over erosional seafloors (Kalantzi and Karakassis 2006). Under dispersive conditions, particulate wastes are spread away from the immediate farm footprint, aerobically decomposed, and assimilated by benthic organisms (Holmer et al. 2005; Phillips 2005; Giles 2008). Farm discharge can enhance productivity of macro-algae, invertebrates, and fish (Katz et al. 2002; Dempster et al. 2005; Rensel and Forster 2007). Conversely, depositional sites tend to accumulate organic waste. In this case, fallowing allows chemical and biological recovery of sediments (Wildish and Pohle 2005; Tucker and Hargreaves 2008; Borg and Massa 2011). Fallowing takes months to years for bottoms to return to pre-farm conditions depending on the site's flushing characteristics and level of accumulation (Brooks et al. 2003, 2004; Lin and Bailey-Brock 2008).

Modeling and Monitoring Water and Benthic Impacts

U.S. fish farms must monitor discharges to the benthos and water column to meet the standards of the Clean Water Act, which established the National Pollutant Discharge Elimination System (NPDES). In 2004, the U.S. Environmental Protection Agency (USEPA) developed a national effluent rule for net-pen aquaculture (USEPA 2004), establishing effluent limitations for aquaculture facilities into waters of the United States. Environmental impact models now allow regulators to assess the suitability of sites, understand the potential risks and benefits of proposed net-pen operations, and estimate the limits of acceptable farm biomass before they are permitted (Rensel et al. 2007; Black et al. 2008).

Monitoring data collected from U.S. marine fish farms (Alston et al. 2005; Lee et al. 2006; Langan 2007) and from other countries (Hargrave 2003; Wildish et al. 2004) often indicate few significant or persistent water quality or benthic issues (Price and Morris 2013). Such data help to validate and improve models to inform siting and management of current and future farms. In Maine and Washington, improved siting and pen configurations, better feeds, and improved feeding practices have decreased benthic deposition at salmon farms (Nash 2001; Langan 2007). Washington State regulations require no net increases in benthic nutrients (Lori LeVander, Washington Department of Ecology, personal communication). In Maine, the standard is "the habitat must be of sufficient quality to support all species of fish indigenous to the receiving waters and maintain the structure and function of the resident biological community" (Jon Lewis, Maine Department of Marine Resources, personal communication). Fish farms are required to have regular monitoring by independent third-party scientists with results reviewed by state agencies and made available to the public.

FISH HEALTH AND DISEASE TRANSFER

Disease is a fact of life in all animal populations and production systems. Water moves freely between net-pens and the open marine environment, allowing the transmission of pathogens between wild and farmed fish (Kent 2000). Fisheries managers are concerned about the risk of pathogen amplification on farms followed by transmission of pathogens from farmed to wild fish, as well as the introduction of nonnative pathogens and parasites when live fish are moved from region to region. Culturists have incentive to work with resource managers and regulators to ensure that fish health is optimized on the farm and not negatively affecting wild populations. Robust health of farmed fish is economically advantageous to fish farmers, who depend on high survival rates and marketing healthy fish.

Experience and observation of disease outbreaks in farmed salmon (Hastein and Lindstad 1991; Jones and Beamish 2011) and hatcheries (Amos and Thomas 2002) provide information on disease risks to wild populations. Fish diseases occur naturally in the wild, but their effects often go unnoticed because moribund or dead animals quickly become prey for other aquatic animals. Clinical disease occurs only when sufficient numbers of pathogens encounter susceptible fish under environmental conditions that are conducive to disease (Rose et al. 1989). Observable disease events may occur in net-pens because (1) fish are reared at higher densities than those found in nature, increasing rate of contact between individual fish within the pen; (2) infected fish are not removed from the farm population as they would be in nature by predators; and (3) the farm population is easily observed. Therefore, pathogens that normally exist in low numbers and do not cause disease in the wild may result in disease and observable mortality in farmed fish (Raynard et al. 2007).

Managers of aquaculture facilities prevent and control disease events with biosecurity measures, effective vaccines, appropriate nutrition, genetically improved lines of organisms, appropriate rearing densities and other proven aquatic animal health measures, and therapeutants. In addition, regulatory bodies have implemented rules to prevent introduction of exotic pathogens into new regions/zones and transmission of endemic pathogens among animals within an area. Common health risks for and from farmed salmon include bacterial and viral diseases and parasites. Principles to prevent and treat these health risks developed by the farmed salmon industry are also applicable for other species and are specified by the World Organization for Animal Health (OIE 2013) and the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (APHIS 2008).

Bacterial and Viral Diseases

Although bacterial infections are common in farmed salmon and caused significant mortality in the early years of salmon farming, a number of measures, including vaccines, probiotics, limiting culture density, high-quality diets, and judicious use of antibiotics are effective at preventing and controlling bacterial diseases. Antibiotics are considered a method of last resort and are being replaced by other aforementioned management approaches (see Box 4 and Table 2).

The management of viruses is focused on monitoring for diseases and maintaining culture conditions that provide for healthy fish able to resist disease through good nutrition, genetics, and low stress husbandry approaches. When a reportable virus is discovered, farms are typically depopulated (see Box 5).

Parasites

Much of what we understand about risks associated with parasites on farmed fish comes from work done to control sea lice on salmonids, and this is still an active area of research (see Box 6). Controlling the level of parasites on farms significantly reduces the potential for transfer to wild salmon and trout (D. Jackson et al. 2002; Jones and Beamish 2011; Rogers et al. 2013) and the health of the cultured stock. Significant in-

BOX 4. Antibiotic Use in Salmon Net-Pens

In the Norwegian salmon farming industry, antibiotic use has decreased by approximately 95% in the past 20 years due to the introduction and use of efficacious vaccines (Midtlyng et al. 2011). During that same period, salmon production in Norway has increased from about 180,000 to 1,000,000 metric tons (FAO 2013). Similar numbers are available for British Columbia (Department of Fisheries and Oceans, Canada 2014). In the United States, three antibiotics are approved and labeled to treat specific diseases in specific aquatic species. The majority of these labels are for freshwater applications. Any use by species, conditions, or diseases other than those listed on the label must be done via extra-label use that requires a licensed veterinarian to approve (USFDA 2012). As in Norway, effective vaccines have significantly reduced the use of antibiotics in U.S. salmon farming. In Maine, no antibiotic use was reported in net-pen salmon farms starting from 2007 (Table 2). This trend has continued and no antibiotic use has been reported for salmon net-pens in Maine from 2007 to 2012 (the last year records are available; Jon Lewis, MDMR, Aquaculture Environmental Coordinator, personal communication). This contrasts with approximately 13,500 metric tons of antibiotics being used in 2010 for all animals used for human consumption in the United States (USFDA 2011).

BOX 5. Dealing with IHN and ISA Viral Diseases

Infectious hematopoietic necrosis (IHN) is an acute disease of salmon caused by the virus of the same name (World Organization for Animal Health 2012). It occurs naturally in the Pacific Northwest and causes varying degrees of mortality in wild salmon (Traxler et al. 1997). Atlantic Salmon are farmed in the Pacific Northwest, but they have little resistance to IHN and are particularly sensitive to this virus. This has resulted in significant outbreaks of IHN in marine salmon pens in British Columbia (Saksida 2006) and a recent event in Washington State (J. Kerwin, Washington Department of Fish and Wildlife, personal communication). However, there is no evidence that historic IHN outbreaks in farmed Atlantic Salmon have impacted wild Pacific salmon in the Pacific Northwest. Returning adult wild salmon populations did not appear to be affected in years in which significant IHN outbreaks occurred in farmed salmon in British Columbia (Pacific Salmon Commission 1993). Furthermore, in controlled water-borne transmission studies with IHN virus, researchers were unable to cause an infection in Chinook Salmon *O. tshawytscha* or Sockeye Salmon *O. nerka* but caused infection leading to a 10% mortality rate in Atlantic Salmon (Traxler et al. 1993). There is an IHN vaccine that has been used in the Pacific Northwest on Atlantic Salmon but with variable success.

Likewise, infectious salmon anemia (ISA) is a serious viral disease of farmed Atlantic Salmon. Although ISA has been observed in Atlantic Salmon farms in Europe, Chile, New Brunswick, and Maine (Gustafson et al. 2007), the OIE reports that there are no confirmed cases of this disease or causative virus in the Pacific Northwest in wild or farmed salmon (OIE 2013). Nevertheless, agencies and industry in the United States and Canada carry on an active surveillance program for the ISA virus. Attempts to induce ISA disease in Pacific salmon using water-borne laboratory challenges have been unsuccessful, suggesting that Pacific salmon are resistant to the ISA virus (Rolland and Winton 2003). Recent reports in British Columbia suggest that the ISA virus, but not the ISA disease, was found in wild Pacific salmon (Simon Fraser University 2011). However, the Canadian Food Inspection Agency has been unable to confirm these findings (Canadian Food Inspection Agency 2012). Because ISA is a very serious disease for Atlantic Salmon, increased surveillance and research is currently being undertaken by Canadian and U.S. agencies to determine whether ISA virus is truly present in the Pacific Northwest. To date, this surveillance in 2012 and 2013 in the Northwest has failed to demonstrate the presence of ISA disease or the ISA virus (J. Whaley, USDA/APHIS, personal communication; J. Constantine, Canadian Food Inspection Agency, personal communication).

Management of viral diseases is focused on monitoring for the diseases and maintaining culture conditions that provide for healthy fish through good nutrition and low stress husbandry changes. When viral diseases are discovered, farms are depopulated. In the future, we may see vaccines for viral diseases, but so far they remain experimental.

tegrated lice management programs that have been instituted in Norway (Ministry of Fisheries and Coastal Affairs 2009) and Ireland include treatment of lice on farmed fish with approved therapeutants, fallowing of farm sites, and zonal single year-class management strategies. Cleaner wrasses and other species have been used commercially with success to reduce the lice load on salmon in pens and are an important part of integrated pest control programs there (Torrissen et al. 2013).

BOX 6. Sea Lice Impact Is Still an Active Area of Scientific Research

Sea lice have varying effects on wild and farmed fish depending on geographic location, ocean salinity, temperature, and infected fish populations in the vicinity (Jackson et al. 2012). Extensive studies conducted in Europe (Torrissen et al. 2013) showed that lice transmission initiates from wild to farmed fish and then can be transmitted back to wild fish (Raynard et al. 2007). Detrimental effects have been described for both wild and farmed hosts. The impact of sea lice from farmed salmon on wild fish has been reported to be substantial in some cases (e.g., wild Sea Trout in Ireland; Tully and Whelan 1993). Conversely, a 10-year study by D. Jackson et al. (2013) a decade later indicated that overall survival of out-migrating juvenile Atlantic Salmon in Ireland was only slightly impacted by sea lice, accounting for about 1% mortality compared to approximately 94% mortality for all other causes (5% survival to spawn). This study suggests that lice from salmon farms have a relatively small impact on wild Atlantic Salmon.

Observations by some researchers suggest that sea lice originating at salmon farms in British Columbia have caused infections and significant mortality in wild juvenile Pacific salmon (Krkosek et al. 2005; Morton and Routledge 2005). These authors postulated that marine salmon farms were responsible for depressions in wild Pacific salmon populations, including a low return of adult Pink Salmon *Oncorhynchus gorbuscha* to the Broughton Archipelago. In contrast, other research (Beamish et al. 2006; Jones et al. 2006; Jones and Beamish 2011) indicates that sea lice populations fluctuate due to climatic and water conditions and that wild Three-Spine Sticklebacks *Gasterosteus aculeatus* and wild salmon act as natural carriers and reservoirs of infection for other wild fish. After reviewing 20 years of data on sea lice in farmed Atlantic Salmon in British Columbia and its relationship with wild Pink Salmon survival (Pink Salmon are potentially the most impacted because of their relative small size upon entry to sea water as compared to other salmon species), Marty et al. (2010) concluded that wild salmon productivity was not associated with farmed fish production or prevalence of sea lice.

Researchers have investigated the use of vaccines and genetic resistance of hosts to combat lice. Although both approaches show promise in the laboratory, to date they have provided limited commercial success.

Similar approaches are used to manage sea lice on salmon farms in Maine and British Columbia, Canada (Rogers et al. 2013). In 2002, Maine salmon farmers and state resource agencies implemented an integrated pest management plan that includes monitoring, coordinated stocking of defined bay management areas, and a 3-year production cycle to include 8–12 months of fallowing between salmon harvest and restocking (Maine Department of Marine Resources [MDMR] 2007). A permit from the MDMR is required to stock a bay management area during the first year of the production cycle after fallow periods are met. The MDMR also monitors the movements and prevalence of sea lice on wild salmon smolts (MDMR 2007). Conversely, in Washington, significant sea lice infestation of farmed salmon has never been an issue because net-pens are located in areas where the salinity is too low for lice proliferation (Nash et al. 2005); therefore, treatment has not been necessary.

These approaches appear to have reduced the shedding and potential impacts of sea lice from salmon farms (D. Jackson et al. 2002; Torrissen et al. 2013). Common elements of successful lice control programs that are in use and are successful both in Europe and North America include treatment of severe infestations with appropriate and approved therapeutants (such as hydrogen peroxide and emamectin benzoate), rearing a single year-class of fish at a marine pen site or zone, fallowing sites between production cycles to minimize cross-infection between groups, and general management practices that ensure the health of aquatic animals (Torrissen et al. 2013). It is important that research continues to optimize and improve lice control on farmed salmon.

Prevention of Fish Disease Transfer

Most states have comprehensive aquatic animal health regulations that are prescriptive in preventing the introduction of diseased animals into the state and methods for managing disease events should they occur. In Maine, for example, laboratory fish health certification and a transfer permit from the MDMR are required prior to any movement of fish. Similar requirements are in place in other states. In addition, the federal agencies that have a role to play in fish health (U.S. Department of Agriculture [USDA], NOAA, and U.S. Fish and Wildlife Service) have developed a National Aquatic Animal Health Plan (APHIS 2008). Evidence from salmon farming indicates that operations that follow structured disease prevention programs and best management practices do not amplify pathogens sufficiently to cause disease in wild populations (D. Jackson et al. 2002). Effective programs include (1) routine health exams by aquatic animal health specialists; (2) health inspections prior to movement of fish between regions or health management zones; (3) accurate record keeping by the farmer to include mortalities, growth, and feed conversion; (4) implementation of a biosecurity plan for each farm site; and (5) use of preventive medicine such as vaccines and probiotics. Such programs are already in place for U.S. salmon farms.

Another concern is that escaped farmed fish could be vectors of disease transmission to wild stocks or produce other

Figure 4. Fingerling Yellowtail ready to stock.

demographic impacts, such as competition with or predation on wild stocks. Should escapees carry a disease agent, the risk of them being the source of an outbreak in wild fish is low because (1) native pathogens are already a part of the environment where wild fish are routinely exposed and have developed some natural immunity; (2) escapees are unlikely to generate an infectious dose (or infective pressure) sufficient to result in disease in a healthy, wild population; (3) the mere presence of a pathogen alone will not cause disease without environmental factors that play a large role in triggering disease events (McVicar 1997; Moffitt et al. 1998; Amos, Appeby et al. 2001); and (4) most escaped farmed fish have low fitness for the wild and quickly become easy victims of predators such as marine mammals, other fish, and birds (Amos, Thomas, and Stewart 2001). Nevertheless, escapes should be minimized, and cultured stock health should be maximized for both ecological and economic reasons.

Table 1. Main issues associated with marine net-pen aquaculture addressed by federal laws and the agencies responsible for their implementation.

Issues	Laws	Regulatory agencies
Fisheries management, protection of habitat, marine mammals, and endangered species	Magnuson-Stevens Fishery Conservation Management Act Marine Mammal Protection Act Endangered Species Act National Environmental Policy Act Coastal Zone Management Act National Marine Sanctuaries Act	NOAA (NMFS) NOAA (NMFS) NOAA (NMFS), FWS USEPA, NOAA (NMFS), USACE NOAA (National Ocean Service) NOAA (National Ocean Service)
Nutrient discharge	Clean Water Act, NPDES discharge permits Safe Drinking Water Act Marine Protection, Research, and Sanctuaries Act	USEPA, USACE USEPA USEPA, NOAA (NMFS), USACE
Siting, hazards to navigation, permitting and construction of structures, transporting product	Rivers and Harbors Act Lacey Act 14 U.S.C. 83 (marking structures in navigable waters) Outer Continental Shelf Lands Act	USACE FWS U.S. Coast Guard Bureau of Safety and Environmental Enforcement and Bureau of Ocean Energy Management
Seafood safety, feed ingredients, animal health, use of veterinary drugs	Federal Insecticide, Fungicide, and Rodenticide Act Federal Food, Drug, and Cosmetic Act Food Safety Modernization Act Hazard Analysis and Critical Control Points Program Surveillance and Monitoring Program	USEPA USFDA USFDA USFDA USFDA
Health management, best management practices	Animal Health Protection Act Virus Serum Toxin Act 9 CFR 101-124 (regulations on the spread of disease)	USDA (APHIS) USDA (APHIS) USDA (APHIS)
Escapes, broodstock management, monitoring and reporting	Magnuson-Stevens Fishery Conservation and Management Act State and local regulations with requirements for reporting and response	NOAA (NMFS) State and local agencies

Table 2. Annual use of therapeutants by Maine marine fish farms from 2001 to 2008. The use of trade names does not imply endorsement (reproduced from Maine Department of Marine Resources 2009).

Compound	2001	2002	2003	2004	2005	2006	2007	2008
Antibiotics								
Romet 30	None	None	None	None	None	None	None	None
Terramycin (kg)	349	6.7	1,229	316	313	None	None	None
Aquaflor (g)	None	None	None	None	None	0.13	None	None
Parasiticides								
Cypermethrin (L)	778	None	None	None	None	None	None	None
Slice (kg)	0.59	1.12	0.66	1.72	0.80	1.01	1.44	0.75

BOX 7. Understanding Genetic Risks and Benefits—Make Them Different or Keep Them the Same?

Understanding genetic risks from escaped fish to wild populations comes primarily from studies of farmed and wild populations of Atlantic Salmon (McGinnity et al. 1997, 2003; Hindar et al. 2006) and studies of hatchery released and wild populations of Pacific salmon (Ford 2002; Araki et al. 2008). Genetic and fitness risks from interbreeding of farmed and wild fish include loss of genetic diversity within and among populations and loss of fitness (Ford 2002; Naylor et al. 2005; Waples et al. 2012). Loss of diversity within a population or among populations may occur when cultured animals with low genetic diversity escape and interbreed at very high levels with locally adapted wild populations, making the next generation of the wild population more homogenous. Loss of fitness can occur when cultured fish genetically suited to survival in captivity interbreed with wild populations and the resulting offspring have reduced ability to survive and reproduce in the wild (Fleming et al. 2000; McGinnity et al. 2009; Araki et al. 2008).

Genetic selection in aquaculture is usually viewed in terms of increased profitability through gains in traits of commercial importance, such as growth rate, disease resistance, feed conversion, or product quality. However, genetic selection can also have implications on resource efficiency and environmental sustainability. Selected organisms may use less feed, produce less waste, pose less of a disease risk, and/or be more efficient at converting animal feed into human food than wild counterparts. Specific selection objectives in aquaculture that relate to environmental sustainability include better feed utilization to reduce waste and improved ability to utilize plant products to reduce dependency on fishmeal.

Managing for risks associated with loss of diversity and the benefits of selected breeding may involve trade-offs. For example, choosing unselected local wild broodstock, thereby keeping the genetic makeup of the cultured animals as similar as possible to that of the wild population, may minimize the impacts of escapes once they interbreed. However, this negates the ecological advantages of selective breeding for traits with commercial and environmental benefits (Gjoen and Bentsen 1997; Gjedrem et al. 2012). One approach could be to use highly domesticated animals with reduced survival and reproductive success in the wild. These fish may have low or no direct genetic impact on wild populations (Baskett et al. 2013) because such animals are less likely to breed and pass on genes to their wild counterparts and, therefore, less likely to influence the long-term genetic makeup of wild populations. Offspring from those that do breed successfully are also less likely to survive and so on as natural selection impacts future generations of wild fish. The loss of fitness in cultured animals for life in the wild generally increases with increasing number of captive-bred generations (Araki et al. 2008; Christie et al. 2011). Although domesticated organisms often have reduced reproductive success in the wild, when highly domesticated animals do breed successfully in the wild, the genetic impact on the natural populations could be greater than if undomesticated (wild-type) organisms were involved (Figure 4).

This dichotomy results in two opposite strategies to manage genetic risks: (1) strong domestication or make-them-different and (2) minimal or no domestication or keep-them-similar. Both strategies may have environmental merit depending on the specific situations and considerations.

GENETICS AND ESCAPES

Managing risks associated with escapes requires clear delineation of the risks, followed by measures to reduce escapes and their effects (Table 3) A variety of approaches based on analysis of risks and critical control points exist for reducing the number of escapes and their potential harm to wild stocks, including advances in infrastructure, veterinary science, and breeding (Naylor et al. 2005; Jensen et al. 2010; Laikre et al. 2010).

Fish may escape from net-pens in large numbers during singular events like severe storms, in small losses through damaged nets (Morris et al. 2008; Jensen et al. 2010), or during harvest operations (Dempster et al. 2002). Although catastrophic losses may be easily identified, more attention is needed to identify and prevent chronic, low-level escapes. Efforts to reduce escapes in salmon farming in Washington State and British Columbia, Canada, have been successful, as shown in Table 4. In the 10-year period from 1987 to 1996, the average annual escape rate was 3.7% of annual harvest, whereas more recently (2000–2009) escape rate averaged 0.3%. Similar trends are evident in Maine (unpublished) and in Chile (Sepulveda et al. 2013). Farm operators in the United States are required to develop best management practices for the prevention of escapes, have recovery plans if escapes should occur, mark all farmed salmon, and report any escapes.

Even with this improving trend, prevention of all escapes is unlikely; therefore, understanding the biological significance of escapes and dealing with the risks posed by escapes is necessary. The primary concern of escaped fish is the potential for them to interbreed with wild conspecifics and reduce the long-term fitness of the wild population (see Box 7).

Risks are typically species, site, and operation specific. The magnitude and type of genetic risk associated with the escape of farmed fish on wild counterparts is a function of (1) the number and survival of escapes relative to the population of wild conspecifics, (2) the difference in genetic makeup between the escaped farmed and wild fish, (3) the reproductive fitness of the escaped fish (Ford 2004; Waples et al. 2012), and (4) the opportunity for reproduction with wild fish. As domestication advances, survival and reproductive success in the wild decreases (items 1, 3, and 4) tending to reduce the risk, while genetic difference increases (item 2), which tends to increase the risk.

The approach used to deal with the trade-offs between selectively breeding cultured animals to be genetically different (make-them-different strategy) or maintaining wild broodstock (keep-them-similar strategy) may depend on the specific situation (Lorenzen et al. 2012). Comparison of alternate genetic strategies reveals varied degrees of consequences depending on the relative timing of natural selection, density dependence, and time of escape during the life cycle of the fish (Baskett and Waples 2013). For example, the make-them-different strategy can be a viable alternative to the keep-them-similar strategy, reducing risk if natural selection is significant between when escapes occur and reproduction happens. In addition, if selection in the captive environment is minimal, then demographic (e.g., competition and natural selection) effects outweigh fitness effects; if selection is significant, then fitness effects dominate (Baskett and Waples 2013).

Mitigation strategies to minimize the risk of genetic impacts include improved containment through better management and design of net-pen systems and antipredator nets; shore-based rearing for part of the grow-out period; improved fish handling practices during stocking, rearing, and harvesting; and use of sterile fish to eliminate reproduction (see Box 8). Maintaining large and healthy wild stocks, or choosing species for culture that have large, healthy populations, also decreases risk by decreasing the ratio of escapes to wild fish (Figure 4).

The trade-offs in genetic management and operational parameters of aquaculture can be complex, and one approach does not fit all species and locations. Models have been developed and are being refined to understand and manage risks to promote good management under a range of conditions (Tufto 2010; Baskett et al. 2013; NOAA 2014). Much of what we know about the underlying conservation genetics and mitigation strategies comes from modeling work done to understand and create genetic management plans for hatcheries producing fish for restocking programs (Ford 2002); that information is applicable to the management of escapes from commercial aquaculture operations (Hindar et al. 2006; Besnier et al. 2011). For example, salmon hatchery program managers can use models to simulate how changes in hatchery practices impact the genetics of enhanced populations (Paquet et al. 2011). Quantitative models provide insight for commercial operators and public hatchery managers to focus attention on risk reduction, for scientists to focus research efforts, and for resource managers to focus on monitoring and regulation.

CONCLUSIONS

Advances in technology and regulation over the last few decades now allow net-pen marine fish farms to produce significant amounts of seafood sustainably. Fish are very efficient converters of feed into human food, but as with other animal farming, care must be exercised to avoid harming the environment. In the United States, the Salmon farming industry and the government agencies that regulate aquaculture have had decades to develop the science, technology, management options, and regulations to successfully address key environmental concerns.

Table 3. General approaches for mitigating risks from aquaculture escapes.

Indentifying risks	Escape prevention	Reducing escape effects
Potential magnitude and route of escape (leakage, catastrophe, harvest, etc.)	Engineering, design, materials, anchoring	Siting, colonization potential
Life stage of escape (gametes, larval, juvenile, adult)	Management practices, monitoring, net repair, net replacement	Biological (sterilization, complete domestication, out-of-cycle reproduction)
Genetic effects (loss of diversity and fitness, domestication, drift)	Siting	Recapture plans and technologies Sterilization
Ecological effects (competition for space, food, predation, disease)		Domestication
Escape dispersal, geography		Genetic guidelines developed and followed
Site-specific risks		Maintain large and resilient natural populations Marking for recapture

BOX 8. Making Farmed Fish Sterile?

Research to produce sterile farmed fish may eliminate the direct genetic risks and reduce some of the demographic effects of escapes. Sterilization of cultured fish is more compelling as a risk reduction strategy and more effective when significant genetic differences exist between farmed and wild populations and escapees are still reproductively fit. Sterilization of fish may also benefit industry by allowing companies who invest in selective breeding some control over the use of proprietary high-performance domesticated lines. Sterilization of fish by inducing triploidy has been effective, with some triploids exhibiting survival and growth similar to diploids (Taylor et al. 2011). Research has also explored repressible sterile fish (fish that require dietary additives for maturation), which would be unable to reproduce if they escaped (Thresher et al. 2009). Even though these approaches are promising, much work remains to develop a cost-effective method of reliably producing sterile fish.

Progress over the last four decades has been significant. Research has produced feeds that contain reduced amounts of fish meal and fish oil, opening the door for carnivorous fish farming systems to become net producers of fish oil and fish meal. Vaccines, improved nutrition, and better health management have greatly reduced the need for antibiotics and the risks associated with diseases. Proper siting and feeding has greatly reduced negative impacts of nutrients on ecosystems. Escapement has been reduced by improved net-pen engineering and management, and our understanding of the genetic consequences of escaped fish has advanced to the point where models can be used to identify and manage the risks.

Table 4. Escaped farmed salmon in Washington State (WA), United States, and British Columbia (BC), Canada. BC salmon production levels in tons were used to estimate percentage of escapes for each year.

Year	WA Escapes[1]	BC Escapes[2]	BC Production (mt)[3]	Percentage BC Escapes[4]
1987	NA	54,998	1,936	11.36
1988	NA	2,000	6,553	0.12
1989	NA	390,165	11,883	13.13
1990	NA	165,000	13,512	4.88
1991	NA	236,150	24,362	3.88
1992	NA	69,178	19,814	1.40
1993	NA	21,113	25,555	0.33
1994	NA	65,109	23,657	1.10
1995	NA	57,883	27,275	0.85
1996	107,000	13,137	27,756	0.19
1997	369,000	46,428	36,465	0.51
1998	22,639	82,875	42,200	0.79
1999	115,000	35,954	49,700	0.29
2000	0	68,247	49,000	0.56
2001	0	55,414	68,000	0.33
2002	0	20,455	84,200	0.10
2003	0	40	65,411	0.00
2004	0	43,985	55,646	0.32
2005	24,552	64	63,370	0.00
2006	0	19,085	70,181	0.11
2007	0	19,246	70,998	0.11
2008	0	111,826	73,265	0.61
2009	0	72,745	68,662	0.42
2010	0	No data	70,831	NA
2011	0	12	74,880	0.00
2012	0	2,754	NA	NA

[1] Data for Atlantic Salmon escapes (number of fish) from Washington Department of Ecology. Reports of escapes of 1,000 or more fish began in 1996.

[2] Data for Chinook, Coho, and Atlantic Salmon and steelhead (number of fish) for 1987–2009 from British Columbia Ministry of Agriculture and Lands (www.al.gov.bc.ca/fisheries/cabinet/Escape_Stats.PDF). Data for 2011 and 2012 for Atlantic Salmon from the Department of Fisheries and Oceans Canada (www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/escape-evasion-eng.htm).

[3] Data for Chinook, Coho, and Atlantic Salmon and steelhead in metric tons from the Department of Fisheries and Oceans Canada (www.dfo-mpo.gc.ca/stats/aqua/aqua-prod-eng.htm).

[4] Calculated from number of fish estimated from production assuming harvest size of 4 kg.

Marine fish farms are required to comply with regulations similar to those of other food-producing and marine industries. Existing U.S. regulations address the environmental effects of net-pen aquaculture effectively. Technological progress, better monitoring, and adaptive oversight of the U.S. net-pen aquaculture industry have resulted in sustainable, affordable, and domestically produced seafood.

ACKNOWLEDGMENTS

The authors thank Dave Alves, Jess Beck, Susan Bunsick, Alan Everson, Brian Fredieu, John Hargreaves, Dennis Hedgecock, Laura Hoberecht, Nicole Kirchhoff, Lori LeVander, Jon Lewis, Patti Marraro, Jack Rensel, Jill Rolland, Paul Sandifer, Jeff Schaeffer, Jesse Trushenski, Diane Windham, and anonymous reviewers for valuable review and contributions.

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Managing Expectations for Aquaponics in the Classroom: Enhancing Academic Learning and Teaching an Appreciation for Aquatic Resources

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ABSTRACT: *Exposing the next generation to nature can foster a stronger appreciation for aquatic resources, yet it may not always be possible to allow students to experience natural aquatic environments. Aquaponics, the combination of aquaculture with hydroponics, can be an effective tool in schools and classrooms to reunite students with plants and animals, promote systems thinking, and encourage hands-on learning. In this article, we bring awareness to aquaponics in education, its potential as a novel platform for learning, and the realities of aquaponics in order to guide educators in managing their expectations for an aquaponics system. Specifically, running an aquaponics system requires diverse knowledge and skills, which makes it appealing as a teaching tool but may also present day-to-day technical challenges. Additionally, educational settings may affect long-term care, available space, and funding. We present strategies for addressing these realities of aquaponics in education and highlight two educational aquaponics programs.*

Gestionando las expectativas de la acuaponia en el salón de clases: mejorar la apreciación de los recursos acuáticos en el aprendizaje y docencia académica

RESUMEN: *Exponer a la siguiente generación a la naturaleza puede generar un fuerte apego a los recursos acuáticos, sin embargo no siempre podrá ser posible permitir a los estudiantes estar en contacto con ambientes acuáticos naturales. La acuaponia, que es una combinación de la acuacultura y la hidroponía, puede ser una poderosa herramienta en escuelas y salones de clase para reunir a los estudiantes con plantas y animales, para promover sistemas de pensamiento y alentar el aprendizaje práctico. En este artículo se llama la atención sobre la acuaponia en la educación, su potencial como nueva plataforma para el aprendizaje y sobre las realidades de la acuaponia, con el fin de guiar los educadores en cuanto al manejo de las expectativas que se tienen en los sistemas acuapónicos. En específico, echar a andar un sistema acuapónico demanda de distintos conocimientos y habilidades lo cual lo hace atractivo como herramienta de enseñanza, pero también puede presentar desafíos en el día a día. Adicionalmente, el contexto educativo puede afectar el cuidado en el largo plazo, el espacio disponible y el financiamiento. Se presentar estrategias para abordar estas realidades de la acuaponia en la educación y se resaltan dos programas de acuaponia educativa.*

INTRODUCTION

Richard Louv coined the term “nature-deficit disorder” in his 2005 book *Last Child in the Woods*. As Louv explained, children growing up in today’s world are increasingly disconnected from nature, which may have profound effects on their healthy development and their concern for natural resources, including aquatics. Because environmental conservation and sustainability are defining issues of the 21st century, it is critical for today’s children to be reunited with nature and to embrace pro-environmental behaviors (Louv 2005). Collaborations between families, schools, environmental education programs, and educators involved in fisheries, aquaculture, and aquatic sciences will be essential to instilling an appreciation for natural aquatic resources.

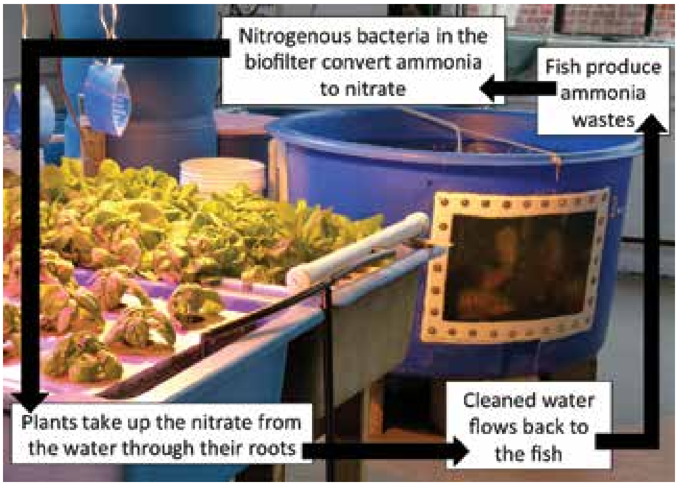
Authentic interactions with the natural world are important because such activities allow children to experience nature firsthand and gain practical skills and are more in line with how individuals learn (Kolb 1984). However, it may not always be possible for children to experience aquatic environments on a regular basis. In schools, logistical barriers such as transportation and safety, in addition to conceptual barriers like teacher attitudes, often limit the amount of time students spend in nature through formal educational systems (Ernst 2007). Furthermore, we also contemplate the broader question: Will a one-day field trip to a local farm or conservation area expose children to natural systems long enough to change their perceptions and enhance learning? To address these challenges and provide a complement to outdoor experiences, aquatic environments can be modeled in schools and informal educational settings to help reconnect children with natural processes, encourage hands-on learning, and cultivate systems thinking.

TEACHING AND LEARNING WITH AQUAPONICS

Aquaculture is the cultivation of aquatic organisms (Nash 2011), and hydroponics is a method of growing plants in water (Smith 2000). Aquaponics is another food production technology that combines both hydroponics and recirculating aquaculture (Figure 1). The naturally occurring process of nitrification is integral to biological filtration (i.e., biofiltration) in a recirculating aquaculture system, where toxic ammonia is oxidized to nitrite and then nitrate, a relatively harmless byproduct (Rakocy et al. 2006). In an aquaponics system, the plants absorb the nitrate byproduct as their preferred form of nitrogen (Bernstein 2011). In this way, it is possible to raise both fish and plants in a symbiotic relationship that closes the aquaculture waste stream and provides a second source of food from plant harvests.

Aquaponics can be used in educational settings to model natural aquatic systems and enhance academic learning. With an aquaponics system, students may explore biology through observations of animal and plant life cycles, investigate chemistry while analyzing water quality, employ math skills to calculate water flow rates, and practice finance by selling harvested products. For example, at an elementary school level, younger students can use aquaponics to observe organism life cycles and begin learning the fundamentals of the scientific method. At the postsecondary level, a small aquaponics system can provide a platform for analyzing system efficiency by measuring the flows of energy, water, and other resources, as well as the ongoing opportunity to use scientific methods of quantitative observation to manage system health. Although topics must vary with student age and ability, the continuing care required of aquaponics systems encourages responsibility, leadership, and teamwork at every level. Ultimately, using aquaponics in education allows students to have a tactile connection with living plants and animals, and hands-on learning through system care exposes them to the natural processes of ecosystems.

There has been an accelerated awareness of aquaponics in education over the past decade as more people learn of the technology. A *New York Times* article investigating the growing aquaponics phenomenon quoted Rebecca Nelson, of the aquaponics company Nelson and Pade, Inc., saying there “may be 800 to 1,200 aquaponics set-ups in American homes and yards and perhaps another 1,000 bubbling away in school science classrooms” (Tortorello 2010, D1). For example, teachers enrolled in the AgriScience Education Project at the University of Arkansas were loaned a small aquaponics system at no cost, plus an instruction manual and a set of student activities for using the system (Wardlow et al. 2002). Discussion of aquaponics in education is also occurring on the Internet, and an informal query of the Google search engine for “aquaponics in education” reveals approximately one million results with informational content on aquaponics, as well as ideas for lesson plans.



Aquaponics combines aquaculture and hydroponics in a symbiotic relationship where fish wastes provide nutrients for plant growth. UMass Amherst aquaponics system, photo by James Webb.

MOTIVATIONS

At the University of Massachusetts Amherst (UMass Amherst), we design and run small-scale, modular aquaponics systems.To raise awareness of aquaponics, we conduct public tours and workshops with interested students, educators, community members, and entrepreneurs. Our outreach work at UMass Amherst is linked to larger education projects that use aquaponics and aquaculture systems for agricultural development in Uganda and sustainability education in the United States. We have also collaborated with schools in New York, Hawaii, and Uganda to build versions of our modular aquaponics systems for educational use. These experiences have motivated us to further research aquaponics in education to assess challenges that educators may face (Hart et al. 2013).

We have witnessed growing excitement about aquaponics in education through our work on these projects. The number of schools with aquaponics systems appears to have increased, and there is a higher incidence of topics related to aquaponics in education on the Internet and in articles (Johnson and Wardlow 1997; Emmons 1998; Overbeck 2000; Nelson 2007; Lehner 2008; Johanson 2009; Milverton 2010). We have also heard many positive, as well as negative, anecdotes about classrooms and schools with aquaponics systems. However, there are few peer-reviewed articles about aquaponics in education (Nicol 1990; Emberger 1991; Wardlow et al. 2002; Hart et al. 2013), and the process of planning, building, maintaining, and using aquaponics in an educational setting has been unevenly documented and analyzed. Given this lack of information, this article brings awareness to aquaponics in education and its potential for connecting students with natural systems, promoting systems thinking, and encouraging hands-on learning. Although aquaponics is an artificial agricultural technology, the relationships among fish, plants, and nitrifying bacteria in an aquaponics system mimic a natural ecosystem. As a result, aquaponics allows for a more holistic system-like approach to aquatic education and active learning. Many of the ideas put forth in this article also apply to aquaculture education and other aquatic teaching tools. To this end, we have included information to consider and ideas for getting started with an aquaponics system, plus two examples of educational aquaponics programs. We encourage educators to address the potential benefits and challenges of aquaponics before embarking on a project and to adjust their expectations accordingly (Table 1).

EVERYDAY REALITIES OF AQUAPONICS

At first glance, growing fish and plants together may not seem difficult. However, the highly technical nature of aquaponics is often overlooked; to keep a system balanced, water levels, temperature, pH, and nutrients must match the physiological demands of all species, especially the nitrifying bacteria (Tyson et al. 2004; Rakocy et al. 2006). Nitrifying bacteria are essential to biofiltration in a healthy system and usually take between 4 and 8 weeks to become established, limiting initial ammonia remediation and the overall health of the system during that time. Crops and fish must also be managed at a ratio of nutrient inputs to outputs for optimum production, which varies according to species, system size, and cropping system (Rakocy et al. 2004). Aquaponics systems require daily care; even if automatic feeders and sensors are used, the system still needs to be checked for proper water flow and signs of poor species health. The reality is that aquaponics systems, even at small scales, are complex systems that rely on natural processes and require external care.

An educational setting also affects the logistics of building and running an aquaponics system (Hart et al. 2013). Space and location may be an issue; an aquaponics system requires a space that can get wet and the size may be limited by available classroom space. School hours may also limit access to the system, and existing infrastructure may affect access to necessary water, electricity, and heating or cooling technology. Many educational settings also require adherence to institutional policies for animal care and use to ensure animal health and safety. Furthermore, regulations may require permits for live animals, inspections of facilities, and precautions surrounding food safety. Building and maintaining a living system also requires ongoing inputs besides the initial construction materials: fish, feed, seeds, increased utilities, and miscellaneous incidentals. As a result, support is needed from administrators and other funding sources for initial project costs and for continued operating costs. Along the same lines, support from facilities and janitorial personnel may be helpful for installing, maintaining, and cleaning aquaponics systems. The living components of aquaponics systems also require regular care, including weekends, scheduled holidays, and extended school breaks. However, it is also these realities of aquaponics systems that challenge students to think critically and solve real-world problems, which makes aquaponics a valuable teaching tool.

Aquaponics systems present many details that need to be accounted for and success takes commitment, time, and sustained effort from everyone involved. In a survey of educators who use or have used aquaponics, participant responses indicated that passion for the process of building and using aquaponics in the long term is crucial given the need for a sustained effort (Hart et al. 2013). Similar to aquaponics, the literature on school gardens also reports that commitment to the garden from multiple parties is key to long-term success (Hazzard et al. 2011). These results suggest that educators who are excited about aquaponics and who recognize the realities are more

EXAMPLE 1. Aquaponics at Allegheny College, Meadville, Pennsylvania

www.foodforsustainability.com

In 2008, environmental science professor Thomas Eatmon, Ph.D. took his Allegheny College students to visit the Tom Ridge Environmental Center on Lake Erie. The students were so amazed by the aquaponics systems there that Eatmon was inspired to begin an aquaponics project at Allegheny College. In the five years since then, Eatmon has integrated aquaponics into his classes through service learning and as an interdisciplinary business, in addition to conducting his own aquaponics research. Eatmon and his students initially started with a 55-gallon tank and some plastic floating rafts along with the invaluable help of a local fish farmer. Currently, Eatmon and his students have a vertical system with about 600 gallons of water on one wall of their laboratory where they grow tilapia and lettuce, which they sell to their campus dining service. This system is used as a small-scale business so that students can explore economic and environmental efficiency. Work-study students are employed to care for the system by feeding fish, monitoring water quality, removing solid wastes, replacing lost water, breeding fish, germinating seeds, and harvesting the final products. In addition to managing their laboratory system and an ornamental system in their building lobby, Eatmon and his students are working with seven local classrooms in five area schools to help teachers and students learn about systems thinking with their own desktop aquaponics systems. The partnership allows Allegheny students to practice their skills as environmental educators by teaching students, as well as by providing curriculum support and weekly aquaponics maintenance that also benefits teachers. Through these partnerships and collaborations, Eatmon and his students hope to continue integrating aquaponics into their community to raise awareness of sustainable values, attitudes, and practices.

Table 1. Potential benefits and challenges of aquaponics in education presented to help educators manage their expectations.

Potential benefits	Potential challenges
Connect with nature, systems thinking, life cycle approach to learning	Time commitment spanning from planning, fundraising, construction, implementation to maintenance
Hands-on, active teaching and learning, production and product based	Technical difficulties, including plumbing, electronics, water chemistry
Multidisciplinary, including science, technology, engineering, and mathematics; business administration; sustainability	Space and resource limitations
Building community connections	Weekend/holiday/summer care, adequate training of support staff, and/or commitment from students
Growing trend in aquaponics as a food production system	Lack of readily available/accessible information

likely to have a positive and constructive experience. Furthermore, it is important to acknowledge that these realities offer many "teachable moments" in commitment, perseverance, and responsibility.

ADDRESSING THE REALITIES OF AQUAPONICS IN EDUCATION

A discussion of the realities and potential challenges facing aquaponics in education would not be complete without a subsequent discussion of workable solutions. To this end, we hope to provide educators who are interested in starting aquaponics projects with potential strategies to address the realities outlined above.

Aquaponics technology is complex and requires knowledge in a variety of fields: fish and plant health, water chemistry, physics, and construction. We recommend that educators who are interested in aquaponics research this information through articles, books, and the Internet. However, more importantly, we recommend that educators reach out to knowledgeable members of their community. Through connections with universities, schools, fish farms, community organizations, aquaponics hobbyists, state and federal fish hatcheries, businesses, and industry professionals, interested educators can learn new information and establish a supportive network that will be helpful throughout the project (Hart et al. 2013). Ideally, these community connections will grow into long-lasting, mutually supportive relationships.

It is also important to acknowledge that no two aquaponics systems are the same, making it especially challenging to prescribe concrete solutions for individual technical problems. However, this leaves room for the use of important critical thinking skills, by both educators and students, to develop creative strategies for addressing the everyday realities of aquaponics technology. For example, educators participating in a survey regarding aquaponics in education reported developing diverse solutions, including covering tanks with shower curtains, modifying pipe sizing from original designs, experimenting with different species, and using recycled materials such as plastic bottles (Hart et al. 2013). The development of these individualized solutions depends on a trial-and-error ethic, combined with expertise sourced from a supportive community, and is key for addressing the technical realities of aquaponics.

An aquaponics system must also match the situational realities and available resources in order for students to achieve maximum learning. For example, teachers in a traditional school setting may not have a classroom with a floor drain or the structural integrity to support 2 tons of water for a medium or large aquaponics system. In this situation, it is more realistic for a teacher to implement a tabletop system using a 20-gallon aquarium that grows plants in a floating raft above the fish. With a tabletop system, students are exposed to the principles of fish biology and basic water chemistry. After gaining confidence with a small system, interested educators and students who want to continue with aquaponics could develop a larger system in a more suitable location. Starting with a small system and tolerant species appropriate for the location will decrease the inherent learning curve.

An educational setting may also affect the logistics of building and maintaining an aquaponics system. Because of the academic schedule and potential bureaucratic constraints, we encourage educators who are interested in aquaponics to embark on a thorough planning process. In particular, educators should develop a clear vision for the project, tangible goals, a metric for measuring success, and a realistic timeline given academic schedules and potential technical limitations. As Hazzard et al. (2011) recommend for school gardens, stakeholders (e.g., teachers, administrators, students, and parents) should be involved in the planning process to delegate tasks, garner long-term commitment, and inspire enthusiasm. Reaching out to others in the school community, especially administrators, will also be essential for getting project funding and construction approval. We also encourage educators to develop contingency plans for unexpected outcomes. Though equipment failures, human error, and fish die-offs are expected events in the aquaponics industry, an educational setting can magnify these setbacks. However, contingency plans and an awareness of failure can turn these events into valuable learning opportunities for all involved.

Although small tabletop aquaponics systems may require less advanced planning than larger systems, educational aquaponics systems of every size still require care, resources, and plans for extended school breaks. Common summer break plans are to harvest and shut down an aquaponics system, to ask a student to bring a small system home to care for it, or to ask a year-round school employee to care for the system at the school (Hart et al. 2013). Many educators also assume full responsibility for system care over the summer, as well as winter breaks, weekends, and holidays. These plans are workable, although there may be unforeseen obstacles. For example, breaking down the system may require prematurely harvesting fish and plants, which may be an uncomfortable prospect for students. On the other hand, transportation of live fish and plants to a student's home may be logistically complicated. Though summer care for an aquaponics system may be challenging, advanced planning and contingency plans will be essential for a smooth transition between the school year and the summer. The challenge of daily care also presents opportunities for the development of creative, alternative models—for example, a mobile aquaponics system where teachers share the responsibility over school breaks. It may also be worthwhile to explore a model where systems are loaned out to schools by a central organization (e.g., nonprofit or university) that collects or manages them over the summer (Wardlow et al. 2002).

GETTING STARTED WITH AQUAPONICS IN EDUCATION

Armed with more information and the relevant language, we encourage educators to ask the questions necessary to plan for an aquaponics system because there is not one blueprint that

Table 2. Ten questions to guide educators in planning for aquaponics systems.

Questions to consider
Why do we want to use aquaponics in our classroom or school? What are our learning objectives for the system? (A specific answer to this question will help with project goals, timelines, and curriculum planning.)
What does success look like for this project (e.g., high number of students reached, a learning experience for all involved, systems used for 2 years, fish fry lunch, self-sustaining business)?
How does our vision of success translate into tangible goals for the system? What happens if we don't meet our goals or if they change along the way?
How can we get all stakeholders (e.g., schools, teachers, administrators, students, parents) on the same page about the project vision and goals? How will we clearly communicate at every stage of the project?
What is a realistic project timeline, given our goals, funding, personnel, and school year constraints? If this is a long-term project, how will resources and energy be maintained and refreshed? Keep in mind that biological filters take about 6 weeks to cycle and get established.
Given our goals for the system, our vision for success, and our realistic constraints, what is an ideal size for our system (e.g., tabletop aquarium versus small- to medium-scale versus commercial system)?
Is the space available properly equipped to meet our vision for success and accommodate the size of system we've chosen? Things to think about include climate and the need for heating and/or cooling, access during after hours, the availability of water and electricity, the structural integrity of the building and the weight of the water, and the probability of large water spills.
Who will be building the system? Will they have prior knowledge and training? Who else will be involved in building the system so that multiple individuals understand its functioning?
Who will be caring for the system on a daily basis? What training and support will they have or need? Will the system require care over short breaks (e.g., weekends and holidays)? How will system care be delegated?
Will the system require care over extended breaks (e.g., summer and winter)? If so, who will care for it? If it will be shut down, what happens to the plants and/or fish? Will they be moved or harvested and how?

EXAMPLE 2. Aquaponics at Cincinnati Hills Christian Academy, Cincinnati, Ohio

www.chca-oh.org | kevin.savage@chca-oh.org | gary.delanoy@chca-oh.org

At Cincinnati Hills Christian Academy (CHCA) in Ohio, high school teachers Kevin Savage, Ph.D. and Gary Delanoy teach biology, chemistry, environmental science, and sustainable agriculture through multiple classroom aquaponics systems. The teachers first started using aquaponics in 2011 when Savage's Environmental Science class built a five-column, vertical aquaponics system using a 65-gallon aquarium, recycled 2-liter soda bottles, and expanded shale media. Two individuals who had designed and built a similar system at a local restaurant used that system as a model to help the students understand the concepts behind aquaponics. Since then, the two teachers and their students have built other small aquaponics systems using different designs including floating rafts and media-filled beds in aquariums, deep water culture, nutrient film technology, and vertical tower systems. These systems have produced Channel Catfish *Ictalurus punctatus*, hybrid Bluegill *Lepomis macrochirus*, and Yellow Perch *Perca flavescens*, plus bell peppers, hot peppers, leafy greens, kale, basil, and lemon balm. Students are responsible for the aquaponics systems during the school year and have gained valuable experience in day-to-day aquaponics operations. Savage and Delanoy have fully integrated the aquaponics systems into the CHCA science curriculum, including a Research and Leadership program where upper-level students can pursue independent aquaponics projects. CHCA students are also involved in their community through aquaponics service learning projects. In 2013, Savage and Delanoy participated in building and maintaining aquaponics projects at the Cincinnati Park's Krohn Conservatory and the Cincinnati Zoo and Botanical Gardens. In the current school year, the teachers and their students are working with five local elementary and middle schools to help them establish and manage their own small aquaponics systems. Savage and Delanoy are also working to expand their aquaponics program with the installation of a large greenhouse, which will allow them to continue inspiring students toward environmental conservation and sustainable agriculture through aquaponics.

fits all situations (Table 2). It is important to keep in mind that programs and priorities will most likely grow and change over time. As a result, flexibility in planning will be helpful but a plan is still essential for a project of any scale. We recommend that educators who are interested in getting started with aquaponics begin by reaching out to form a supportive community to share knowledge and passion for aquaponics. From there, educators can work with other stakeholders and their community to develop a plan that fits their individual situation. With properly managed expectations, community connections, and a passion for the process, aquaponics can be an effective tool for inspiring appreciation for aquatic resources.

FUNDING

For financial and logistical support, we would like to thank the Allen Family Foundation, the Clarence and Ann Dillon Dunwalke Trust, the Western Massachusetts Center for Sustainable Aquaculture, the National Institute of Food & Agriculture, the U.S. Department of Agriculture, the Massachusetts Agricultural Experiment Station, the UMass Building Integrated Aquaculture Working Group, and the Department of Environmental Conservation (project number MAS00987).

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AFS SECTIONS: PERSPECTIVES ON AQUACULTURE

Perspectives from the Student Subsection and Education Section

In Response –The Use of Aquaponics in the Classroom

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Integration of aquaponics in educational curricula provides a valuable means of meeting the challenges of reconnecting younger generations with nature, renewing interest in fisheries and aquatic resources, and ultimately increasing recruitment of new Society members. The mission of the Society is to "improve the conservation and sustainability of fishery resources and aquatic ecosystems by advancing fisheries and aquatic sciences and promoting the development of fisheries professionals." Essential to this mission is education—continuing education of established and aspiring fisheries professionals and education of those who have yet to develop a full appreciation for fisheries and aquatic resources. Though the Society and its various factions typically focus their efforts on current and future fisheries professionals, the education of those who have yet to develop an appreciation for or interest in fisheries and aquatic resources is largely the responsibility of the primary, secondary, and postsecondary education communities. At its most basic level, integration of aquaponics in the classroom exposes students to and increases awareness of resources and ecological relationships that they may not otherwise be exposed to, providing the spark that may fuel the fire of lifelong interest in fisheries and aquatic resources, and complements other programs aimed at exposing students to aquatic resources (e.g., Trout in the Classroom; troutintheclassroom.org/). Because "nature-deficit disorder" is becoming increasingly prevalent among younger generations, creative strategies such as the integration of aquaponics in the classroom may be needed to bring younger generations back to nature, and we applaud those willing to take on these challenges.

Fish In, Fish Out: Perception of Sustainability and Contribution to Public Health

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ABSTRACT: *This article contributes to the ongoing debate regarding the sustainability of fishmeal and fish oil in aquaculture diets. It demonstrates why the "Fish In, Fish Out" metric, which is frequently used to show how many units of wild fish is needed to produce one unit of farmed fish, is not a valid tool for measuring the sustainability or efficiency of aquaculture production. Additionally, the metric diverts attention away from the human health implications of how we raise fish. It substitutes the mass of seafood for the arguably more important value-added dimension – the long chain omega-3 content per unit mass, which is low in fish raised on diets low in marine ingredients. Fishmeal and fish oil produced by sustainable fisheries remain some of the most ecologically efficient ingredients that contribute to the overall gain of seafood biomass. Because many aspects of our health and wellbeing depend on wild fisheries, we must insist on well-managed fish harvest for the health of the world's population*

Más pescado, menos pescado: percepción de la sustentabilidad y contribución a la salud pública

RESUMEN: *El presente artículo es una contribución al debate actual sobre la sustentabilidad y el aceite de pescado utilizado para elaborar dietas en acuacultura. Se demuestra cómo la métrica llamada "pez entra, pez sale", la cual es frecuentemente utilizada para calcular cuántas unidades de pescado extraído del medio natural se necesitan para producir una unidad de pescado cultivado, no es una herramienta válida para dimensionar la sustentabilidad o eficiencia de la producción acuícola. Adicionalmente, esta métrica desvía la atención de las implicaciones que tiene en la salud humana, la forma en la que se crían los peces. Se sustituye la masa de alimentos de origen marino con la supuestamente más importante dimensión con valor agregado –contenido del aceite omega 3 por unidad de masa– cuya concentración es poca en peces criados a base de dietas pobres en ingredientes marinos. La carne y el aceite de pescado producidos por pesquerías sustentables siguen siendo uno de los ingredientes ecológicamente más sustentables que contribuyen a la ganancia de biomasa marina. Ya que muchos aspectos de nuestra salud y bienestar dependen de las pesquerías, debemos insistir en promover una captura bien manejada en pos de la salud de la población mundial.*

INTRODUCTION

Cardiovascular diseases continue to be the most prevalent cause of death in the United States (Lichtenstein et al. 2006). Concurrently, farm-raised seafood is becoming less heart-healthy (Seierstad et al. 2005). Why? At least partially because demand for seafood and aquaculture production continues to increase, and the supply of omega-3-rich, marine aquafeed ingredients remains flat. As a result, these ingredients are being displaced by land-based ingredients (Torrissen et al. 2011). Not surprisingly, the long-term availability of marine resources became one of the most important and complex issues affecting environmental well-being and public health. But unfortunately, the "Fish In, Fish Out" concept, which intended to help make fish production more sustainable and is used as a guide for the environmentally conscious consumer (Tacon and Metian 2008), is fundamentally flawed. Those who popularize it may mislead the consumer.

FORAGE FISH PRODUCTS IN AQUAFEED

The metabolism of carnivorous marine species evolved on nutrients from natural marine sources, which cannot be economically replaced in total with land-based ingredients at this time. However, market forces and advancements in nutrition and genetics continue to facilitate partial and increased replacement of fish meal and fish oil in compound feeds for these species. Currently, marine ingredients often represent a minor fraction of feed formulations in diets for carnivorous fish. The rest of the ingredients come from terrestrial sources.

Since the mid-1990s (when comprehensive data first became available), fish meal and fish oil inclusion rates have substantially decreased (Tacon et al. 2011; Food and Agriculture Organization [FAO] 2014c). Concurrently, the diets became more nutrient dense and the feed conversion ratio has improved. This trend is projected to continue (Tacon et al. 2011; FAO 2014c). In 2013, diets of farm-raised salmon contained 15% fish meal and 8% to 9% fish oil (Marine Harvest 2014). Other ingredients of compound aquafeed for these groups of fish mostly come from terrestrial sources, such as soy, sunflower, wheat, corn, and rapeseed (Marine Harvest 2014; FAO 2014c). In addition, the use of animal by-product meals and fats continues to increase (Tacon et al. 2011). However, in the natural environment, salmon feed primarily on other fish and crustaceans (Jacobsen and Hansen 2001). When raised on entirely fish-based diets, some carnivorous species such as Yellowfin Tuna *Thunnus albacares* have been reported to consume up to

34 kg of feed fish to gain 1 kg of biomass (Wexler et al. 2003). As a general rule, only 10% of the energy from a trophic level is captured as biomass in the next higher trophic level (Welch et al. 2010). Therefore, most farmed carnivorous fish consume much less forage biomass than their wild counterparts.

Farm-raised omnivorous fish consume little fish meal and fish oil (Tacon et al. 2011). For example, in 2010, compound aquafeeds for carp and tilapia contained about 2% and 3% fish meal, respectively (Tacon et al. 2011). Diets of these species usually do not include fish oil (Tacon et al. 2011). Thus, on a global scale, considering quantities of fish meal, fish oil, and farmed fish and shrimp production, "feeding fish to fish" is part of a process that results in the overall gain of seafood biomass (FAO 2014a, 2014b).

MEETING TODAY'S NEEDS WITHOUT COMPROMISING NEEDS OF FUTURE GENERATIONS

Consumers increasingly demand that seafood products come from sustainable sources. The concept of sustainability has been defined in many ways, but one of the definitions possibly most relevant to this discussion is "the ability of an ecosystem to maintain ecological processes and functions, biological diversity, and productivity over time" (Draper 1998, 13).

Consistent with this definition, the menhaden *Brevoortia* spp. purse-seine fishery, for instance, produces fish meal and fish oil with minimal environmental impact. In fact, Pelletier et al. (2010) reported that menhaden meal and oil are among the least impact-intensive aquafeed ingredients, whereas crop-derived ingredients such as wheat gluten meal have the most impact on the environment, based on the cumulative energy use, biotic resource use, emissions, and other factors.With regard to the robustness of fish stocks used in production of fish meal and fish oil globally, there are valid concerns pertaining to Southeast Asian, Chinese, and some other fisheries. However, most fish meal and fish oil on the global market come from well-managed fisheries, like that of Peruvian Anchovy *Engraulis ringens*, the world's largest source of fish meal and fish oil (FAO 2014c).

An assessment of 53 maritime countries, which account for most of the global catch, ranked the United States among the top three with the most sustainable fisheries (Mondoux et al. 2008). Although small on a global scale, the menhaden fishery is the second largest and, perhaps, one of the most regulated fisheries (Everett 2008) in the United States.

Furthermore, many fish meal products do not rely on traditional fishmeal fisheries (FAO 2014c). In 2013, about 35% of the world's fishmeal was made from by-products of commercially processed food-grade fish (FAO 2014c). In addition, the amount of fish by-products used in production of meal and oil continues to increase (FAO 2014c). To summarize, the use of fish meal and fish oil, derived from well-managed and renewable fisheries, can be considered to be sustainable.

FISH IN, FISH OUT

In 2009, global production of farm-raised salmonids was 3.5% of total aquaculture production (FAO 2014b). Nonetheless, salmon has become a poster child of the inefficiency of "feeding fish to fish" and a victim of its own popularity among consumers. A few years ago, a peer reviewed paper laid a foundation to a popular belief that it takes five units of forage fish to produce one unit of salmon (Tacon and Metian 2008). Their argument was that typical salmon diets contained 20% fish oil and 30% fish meal, and one metric ton of unidentified small pelagic fish (forage fish) produces 50 kg of fish oil and 225 kg of fish meal. Thus, 150 kg of meal is wasted for each ton of forage fish used to make salmon feed, because 50 kg of fish oil makes 250 kg of salmon feed (i.e., 50 kg/0.2 = 250 kg), which then requires the addition of only 75 kg of fish meal (i.e., 250 kg × 0.3 = 75 kg). Under this scenario, 150 kg of fish meal (i.e., 225 kg − 75 kg = 150 kg) from each ton of forage fish is lost, and each ton of forage fish will only produce 250 kg of salmon feed. Furthermore, assuming a typical feed conversion ratio of 1.25, this amount of feed can produce only 200 kg of salmon biomass. So, according to Tacon and Metian (2008), the Fish In, Fish Out ratio of forage fish to salmon is 5:1 (i.e., 1,000 kg:200 kg). However, this model is grossly incomplete. As an example, in addition to fish oil, one metric ton of forage fish yields 225 kg of fish meal. In the scenario above, only 75 kg of fish meal is used for production of salmon feed, and the remaining 150 kg of fish meal is wasted. In actuality, market forces do not allow fish meal to go to waste. The conversion of forage fish into salmon does not occur in closed systems (Jackson 2009). The fish meal, which was unaccounted for in Tacon and Metian's (2008) calculations, is used in the formulation of feeds for other species that do not require high inclusion rates of fish oil. For example, farm-raised crustaceans constitute 7.1% of aquaculture production (FAO 2014b). In 2006, a typical shrimp feed contained 15% fish meal and only 1.5% fish oil (Tacon and Metian 2008). Because crustacean production is twice that of salmon, salmon diets could be argued to contain fish oil leftover from shrimp diet formulations, a scenario that was not contemplated by the authors.

MEDIA COVERAGE AND PUBLIC PERCEPTION

Shortly after the publication of Tacon and Metian (2008), Jackson (2009) published a rebuttal and explained why their approach was incorrect. He demonstrated that when the leftover fish meal was properly accounted for, and considering fish meal and fish oil that come from marine by-products, the actual Fish In, Fish Out ratio of forage fish to salmon was three times less than previously reported. He also demonstrated that on the global scale, one unit of forage fish supports the production of two units of farmed fish, shrimp, and freshwater crustaceans (Jackson 2009).

In 2010, Tacon coauthored another article and partially accepted the criticism, admitting that the metric was a "relatively narrow analytic tool" (Welch et al. 2010, 236). However, by that time, the Fish In, Fish Out concept had been picked up by the popular media and some retailers and producers. It continues to be quoted by some bloggers and op-ed writers, who make assumptions and claims based on inaccurate metrics. For instance, one author multiplied the numerator of Fish In, Fish Out by a factor of five and confused the Fish In, Fish Out described for salmon with a Fish In, Fish Out for most farm-raised fish. "It takes roughly five pounds of small fish to produce one pound of dry fishmeal, and for most farmed species of fish, it takes about five pounds of fishmeal to produce 1 pound of finished product" (Fish In, Fish Out of 25:1), wrote Charlie Levine, now former senior editor of *Marlin Magazine* (Levine 2009).

Unfortunately, but not surprisingly, Jackson's rebuttal that exposed some of the fundamental flaws of the Fish In, Fish Out concept did not receive the same level of media coverage and public attention as the original publication. Banobi et al. (2011) reported that high-profile environmentalist articles were cited 17 times more frequently than their peer-reviewed critiques, even when the originals were challenged by independent scientists on several different occasions. Furthermore, articles that did not cite the critiques almost always accepted the results of the original reports without adequate evaluation of the claims.

This was not the first time some environmentalists and nongovernmental organizations have taken advantage of their status as guardians of environmental sustainability and benefited from our cognitive bias, known as the "halo effect" (Balanson 2008). The halo effect often allows such reports to escape the critical examination by the media that occasionally repackages and recirculates erroneous information (Balanson 2008). As a result, the headline-driven research trickles down to producers and retailers, who sometimes find a way to benefit from dubious claims. For example, the president of a U.S. fish farming company that intends to market marine fish fed primarily plant-derived feed refers to a Fish In, Fish Out ratio of 1:1 as the "Holy Grail of marine fish feed research" (Coleman 2012). However, in nature, the Fish In, Fish Out ratio is very far from perfect (Welch et al. 2010). For example, Atlantic Salmon *Salmo salar*, at a trophic level of 4.4 ± 0.1, is more than one trophic level above the Atlantic Herring *Clupea harengus* (fishbase.mnhn.fr/Summary/SpeciesSummary.php?ID=236&genusname=Salmo&speciesname=salar&AT=Salmo+salar&lang=English and www.fishbase.org/summary/Clupea-harengus.html *in* Froese and Pauly 2013). Because the conversion efficiency between trophic levels is about 10% (Welch et al. 2010), the production of one unit of salmon biomass in nature requires more than 10 units of herring.

IMPLICATIONS FOR PUBLIC HEALTH

Large-scale epidemiologic investigations demonstrated that people at risk for coronary heart disease and ischemic stroke benefit from consumption of fish rich in omega-3 fatty acids (Mozaffarian et al. 2011). Consistent with these findings, the American Heart Association recommends the consumption of oily fish at least twice a week (Lichtenstein et al. 2006). Although fish consumption provides protein, selenium, magnesium, vitamin D, and other nutrients (Mozaffarian et al. 2011), the American Heart Association suggests that health benefits of fish consumption are primarily attributable to marine omega-3s (Lichtenstein et al. 2006). However, there are no standards for omega-3 content or for the omega-3 to omega-6 fatty acid ratio of farmed salmon. This ratio depends on the fish oil levels in salmon diets and ultimately determines the health benefits of seafood consumption (Seierstad et al. 2005). For example, in a double-blinded intervention study, patients with coronary heart disease were divided into three groups consuming Atlantic Salmon, which was raised on diets containing 100% fish oil, 100% rapeseed oil, or a blend containing equal quantities of these two oils (Seierstad et al. 2005). It is worth noting that all fish groups were raised on diets that satisfied their minimum requirement of omega-3 fatty acids for salmonids. Lipids extracted from fillets of salmon fed on 100% fish oil, rapeseed oil, or the equal-blend diets contained 30.2%, 11.7%, or 20.5% of total omega-3 fatty acids, respectively. The ratio of omega-3 to omega-6 lipids in salmon fed fish oil, rapeseed oil, or the equal-blend diet was 6.5, 0.6, and 1.7, respectively. As expected, patients who consumed salmon raised on the 100% fish oil diet exhibited reduced serum triglycerides and other improved indicators of health, whereas these effects were not significant in patients consuming salmon raised on 100% rapeseed or equal-blend diets (Seierstad et al. 2005).

An executive in the aquaculture industry publicly stated that consumers will not get the same benefits from salmon consumption if fish oil inclusion continues to decrease (Hage and Fiskaren 2012). According to the executive, consumers in the future may have to double their fish consumption in order to achieve the same intake of omega-3s. But simply increasing the consumption of vegetable-fed fish will not result in the same benefits as those derived from eating fish fed with fish oil. The decreased omega-3s are accompanied by increased omega-6s, which are already overly abundant in the typical Western diet and thought to be responsible for numerous inflammatory health issues that are prevalent in the Western world (Schmitz and Ecker 2008). Hence, standards based on incomplete science, media bias, and ill-defined sustainable aquaculture may lead consumers to accept seafood that is becoming less healthy.

THE NUMERATOR OF FISH IN, FISH OUT

Interestingly, no one seems to have questioned the numerator of the ratio, citing Fish In, Fish Out for salmon, tilapia, carp, shrimp, and other farmed species, while ignoring the "Fish In." Let's consider Fish In, Fish Out calculations by Welch et al. (2010). Like Tacon and Metian (2008), the authors considered a closed system, where forage fish were converted into salmon, and did not account for the unused fishmeal. Similar to Tacon and Metian (2008), these authors concluded that the Fish In, Fish Out ratio of an unidentified lean species, perhaps Peruvian Anchovy, to salmon was 4:1 (Welch et al. 2010). But now, let us use Gulf Menhaden *B. patronus*, the most common source of fish oil from the U.S. and a commonly used oil in salmon feeds, for the numerator. The fish oil yield of this species is reported to be 12% to 19%, and the fish meal yield is 19% to 23% (Parker and Tyedmers 2012). Let us use the 12% yield of oil and 23% yield for meal for this exercise.

So, one metric ton of Gulf Menhaden yielded 120 kg of fish oil and 230 kg of fish meal, which could produce 600 kg of salmon feed, because salmon feed contained 20% fish oil (i.e., 120 kg/0.2 = 600 kg). Under this scenario, because only 180 kg of fish meal is needed for 600 kg of salmon feed (i.e., 600 kg × 0.3 = 180 kg); 50 kg of fish meal (i.e., 230 kg − 180 kg) from each metric ton of fish is wasted. Using the feed conversion ratio of 1.25, 600 kg of feed can be converted into 480 kg of salmon. In other words, in this example, 2.1 units of forage fish produce one unit of salmon, which is one half the ratio reported by Welch et al. (2010).

In 2013 the inclusion rates of fish oil in diets of Atlantic Salmon declined to 8% (Chilean-raised fish), and the inclusion rate of fish meal declined to 15% (Marine Harvest 2014). The feed conversion ratio improved to 1.17 (Marine Harvest 2014).

Thus, in 2013 one metric ton of Gulf Menhaden could produce 1,500 kg of feed for Chilean salmon (i.e., 120 kg/0.08 = 1,500 kg). Because only 225 kg of fish meal is needed for 1,500 kg of salmon feed (i.e., 1,500 kg × 0.15 = 225 kg), 5 kg of fish meal (i.e., 230 kg − 225 kg) from each metric ton of fish is lost from the model. Using the feed conversion ratio of 1.17, 1,500 kg of feed can be converted into 1,282 kg of salmon. Thus, in 2013 the theoretical Gulf Menhaden-In:Atlantic Salmon-Out ratio has declined to 0.78:1, whereas excess and unaccounted for meal was used elsewhere. Nevertheless, some media sources still cite Fish In, Fish Out of 5:1.

THE DENOMINATOR

These examples assume a simplistic theoretical system, where forage fish is converted into salmon and the leftover fish meal is wasted. Our calculations are not meant to provide a meaningful or accurate metric but to point out that theoretic arithmetic exercises on forage fish conversion into farmed fish should be based on specific species for both the numerator and denominator; for example, menhaden/salmon or anchovy/tilapia. For a more realistic approach, collective terms should be used for the numerator and denominator. The estimates of conversion of wild-caught biomass to farmed biomass should consider all major sources of marine meal, oil, and all major farmed species to determine the efficiency of converting wild fish into farmed fish. In the interest of full disclosure, it is worth noting that little menhaden fish meal is currently being used in salmon diets. Instead, it is used in various animal diets, including but not limited to various non-salmonid fish, dogs, cats, baby pigs, shrimp, laboratory and zoo animals, and dairy cows. In fact, approximately 20% of the world's fish meal is used in diets of baby pigs before they grow to consume all-vegetable feed (Jackson 2009). In addition, some coproduct of fish meal processing, fish solubles, is a fertilizer for organic fruits and vegetables, and a significant amount of fish oil goes to direct human consumption, primarily in the form of fish oil supplements and pharmaceuticals. Thus, "Fish In" produces a variety of "Outs": "Fish Out," "Pets Out," "Plants Out," "Zoo Animals Out," "Laboratory Animals Out," "Fish Oil Supplements Out," "Pharmaceuticals Out," etc.

MASS BALANCE

Since the early 1950s, total aquaculture production has increased dramatically and reached about 89.6 million metric ton in 2012 (FAO 2014b). Neither fish meal nor fish oil is used in the production of approximately 39.0 million metric tons of this total, which consists mostly of molluscs (such as scallops, mussels, clams, and oysters) and seaweeds. However, both fish meal and fish oil are used in the production of the remaining farmed organisms, which mostly consist of crustaceans and fishes. Cyprinids (mostly carp) have been produced since the early 1950s, whereas salmonids (salmon and trout), cichlids (mostly tilapia), and crustaceans (mostly shrimp and prawn) were not produced in large quantities until the mid-1980s (FAO 2014c). Although feed for carp and tilapia contains relatively low levels of fish meal, because these fishes account for 67% of all farmed fishes, they consume relatively large quantities of fish meal on a global scale.

According to the FAO (2014b), the aquaculture sector produced approximately 27.2 and 50.6 million metric tons of fish and shrimp in 2003 and 2012, respectively. Concurrently, due to the increasing amount of forage fish going directly to human consumption (FAO 2014b) and improvements in fisheries management, the global quantities of fish harvested for fish meal and fish oil productions slightly decreased from over 19.3 million metric tons in 2003 to 16.3 million metric tons in 2012 (FAO 2014a). Thus, data from the FAO (2014a, 2014b) indicate that the ratio of fish harvested for fish meal and fish oil production to quantities of farm-raised fish and shrimp decreased steadily from 0.7 (Fish In, Fish Out ratio of 0.7:1) in year 2003 to 0.3 (Fish In, Fish Out ratio of 0.3:1) in 2012 (FAO 2014b). It is also worth noting that due to increasing utilization of marine by-products, the global supply of fish meal and fish oil has remained relatively stable. Over the last decade, the world's annual production of fish meal was about 5 million metric tons and the production of fish oil was about 1 million metric tons (FAO 2014b).

SUMMARY

Although some fisheries were poorly managed and as a result collapsed, many fisheries in the developed world have been well managed for decades (Hilborn 2007). These fisheries are sustained not only by government monitoring and regulations but also by long-term business decisions, ethical principles, and market forces (www.msc.org; www.friendofthesea.org). Some of the largest Salmon feed producers implement specific rules for purchase of fish meal and fish oil and follow guidelines and regulations from their national fisheries authorities. For example, Skretting, which produces approximately 1.5 million metric tons of feed annually for farmed fish and shrimp, has a strong commitment to sustainable fish feed production (Skretting 2014).

The use of forage fish in aquaculture production now results in the net gain of fish and crustacean biomass. Furthermore, other important products are also made from forage fish (for example, feed for conventional livestock, pets, and other captive animals; organic fertilizers; omega-3 oil for human consumption) but are not accounted for by the Fish In, Fish Out metric. Presently, feeding fish to fish is the only practical way to ensure that farmed seafood has health benefits comparable to those of fish harvested from the ocean. Thus, if the goal is to provide healthy, sustainable, good-quality nutrition for humans, fish farmers will choose to continue supplementing land-based fish diets with marine ingredients, at least until new cost-effective sources of omega-3s are developed, engineered, or discovered. Because many aspects of our economy and well-being depend on wild fisheries, ensuring their sustainability is one of the most important and complex issues today. Therefore, people's views regarding what is sustainable should not be manipulated through incomplete research and flawed metrics.

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Aquaculture and Louisiana Fisheries: Innovative Oil Spill Rehabilitation Efforts

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When the *Deepwater Horizon* drilling rig exploded and sank in the Gulf of Mexico, shockwaves were felt throughout the region and the country. The result was one of the nation's worst manmade disasters, with an estimated 4.9 million barrels of oil spilled into the Gulf and over 1 million gallons of dispersants applied to the waters of the spill area. The scope, nature, and magnitude of the spill caused widespread impacts to Gulf ecosystems, including the highly productive coastal estuaries, shorelines, and marsh habitats in Louisiana. The ripple effects of this event spread across the plants and animals that comprise these diverse environments to the Gulf Coast communities that rely on and cherish these important resources.

The Oil Pollution Act of 1990 provides for a scientific and legal process called a Natural Resource Damage Assessment (NRDA) to determine the size and scope of injuries to natural resources, as well as the services those resources provide, resulting from oil spills. Pursuant to the Oil Pollution Act, natural resource trustees assess the injuries and then develop and implement a plan to compensate the public for those injuries. The *Deepwater Horizon* NRDA trustees include representatives from the five Gulf states, along with a number of federal agencies including the National Oceanic and Atmospheric Administration and the Department of the Interior.

The assessment process alone can take many years even in a relatively small spill, and restoration typically does not begin until the assessment is complete. However, BP, a responsible party in the *Deepwater Horizon* spill, agreed to provide the trustees with up to $1 billion for restoration of injured resources prior to completion of the assessment (Early Restoration) due to the magnitude of the spill and the need to begin restoration more quickly than in a traditional NRDA. Once the trustees' assessment is complete, a final damage assessment and restoration plan will be developed to address injuries not fully addressed by the Early Restoration.

To date, Early Restoration for the *Deepwater Horizon* NRDA includes two projects that involve culture activities in Louisiana: the Louisiana Oyster Cultch Project and the Louisiana Marine Fisheries Enhancement, Research and Science Center (Deepwater Horizon Natural Resource Trustees 2012, 2014). For both of these projects, the Louisiana Department of Wildlife and Fisheries (LDWF) is the lead agency for planning, implementation, construction, operation, and monitoring. LDWF is responsible for managing Louisiana's aquatic resources and the habitats that support them, for the benefit of Louisiana's residents and visitors in perpetuity.

LOUISIANA OYSTER CULTCH PROJECT

Louisiana's Oyster resources (Eastern oyster *Crassostrea virginica*) are among the largest and most valuable in the United States. LDWF manages approximately 1.7 million acres of public oyster bottoms throughout coastal Louisiana and leases nearly 400,000 additional acres of water bottom to private individuals for traditional on-bottom cultivation. Louisiana's public oyster seed grounds are considered to be the backbone of the Louisiana oyster fishery, contributing directly to oyster landings and providing a source of seed oysters for transplanting to private leases.

Louisiana's oyster resources are among the largest and most valuable in the United States.

Louisiana's oysters were exposed to oil, dispersants, as well as response activities undertaken to prevent, minimize, or remediate oiling from the *Deepwater Horizon* oil spill. Since the spill, there have been severe declines in oyster abundance on the public seed grounds in both seed and sack size oysters compared to historical averages. Given the importance of the resource to the state, LDWF took a proactive approach to oyster rehabilitation and prioritized the Louisiana Oyster Cultch Project, which included placement of oyster cultch onto public oyster seed grounds and construction of an oyster hatchery facility.

Cultch plantings provide hard substrate on which free-swimming oyster larvae can attach and grow (Figure 1). The cultch planting approach utilized in this project has been employed by LDWF since 1917 and is a proven oyster management technique. Between the spring of 2012 and summer of 2013, over 170,000 cubic yards of cultch material was placed at six locations, both east and west of the Mississippi River (Figure 2). LDWF biologists continue to monitor these and other oyster reefs throughout coastal Louisiana as part of the LDWF Oyster Management Program.

The oyster hatchery portion of the project involves constructing a state-of-the-art facility to provide a supplemental

Figure 1. Cultch planting in Louisiana (above) and growth of oysters on cultch material (below).

source of oyster larvae and seed to help facilitate and expedite the success of cultch plants. This project builds on work pioneered by Louisiana Sea Grant, which has operated an oyster hatchery research facility for over 20 years. After being destroyed by Hurricane Gustav, hatchery functions moved to the LDWF Grand Isle Laboratory (Figure 3) in 2009. The new hatchery facility will greatly expand existing hatchery and remote setting capabilities that have already resulted in the deployment of over 1.25 billion larvae and approximately 52 million spat into coastal Louisiana waters since 2011.

Oyster hatchery operations will include broodstock maintenance, algal cultivation, larval production, and a nursery system with grow-out capacity. Larvae produced at the hatchery can be released into the water directly over cultch material or be remotely set on oyster cultch to create oyster seed. Remotely set oysters can then be deployed directly onto reefs or further developed in the nursery system prior to deployment in a suitable grow-out area (i.e., public seed grounds). Permitting and design have been completed, and construction is currently underway.

LOUISIANA MARINE FISHERIES ENHANCEMENT, RESEARCH, AND SCIENCE CENTER

Recreational fishing in Louisiana was adversely impacted by the spill, as widespread closures of areas for recreational fishing were necessary due to the presence of oil, cleanup ef-

Figure 2. Location of the six cultch plantings for the Louisiana Oyster Cultch Project.

Figure 3. Location of the oyster hatchery for the Louisiana Oyster Cultch Project on Grand Isle.

forts, and response activities. In addition to the closures, the lost opportunities caused recreational users to alter or cancel preferred activities, resulting in large reductions in coastal recreation in Louisiana. The objective of this restoration project is to help compensate for the loss of recreational fishing services resulting from the spill by constructing facilities to enhance recreational fishing experiences through aquaculture and promote environmental and cultural stewardship, education, and outreach.

This project will develop facilities at two sites with the shared goals of fostering collaborative, multidimensional research on marine sport fish (Red Drum *Sciaenops ocellatus*, Spotted Seatrout *Cynoscion nebulosus*, and Southern Flounder *Paralichthys lethostigma*) and bait fish species (Atlantic Croaker *Micropogonias undulatus* and Gulf Killifish *Fundulus grandis*). The facilities will also serve to enhance stakeholder involvement by providing fisheries extension, outreach, and education to the public. The primary facility will be located in Calcasieu Parish near the north end of Calcasieu Lake and south of the city of Lake Charles (Figure 4). The satellite facility will be located in Plaquemines Parish on the west bank of the Mississippi River, south of New Orleans (Figure 5).

The Calcasieu Parish facility plans include construction of a multipurpose building and pond complex to be used for marine fisheries research, production, education, and outreach. As currently planned, the building would contain a hatchery, visitor center, dormitory, administrative and staff offices, meeting rooms, crew support areas, two laboratories, covered access corridor, maintenance shop, and equipment storage rooms. The hatchery elements include indoor systems for broodfish maintenance, feed preparation and live food production, egg incubation and larviculture, and juvenile rearing. The production pond complex will consist of three half-acre rearing ponds, a saltwater reservoir pond, and two effluent treatment ponds. The public visitation and outreach portions of the facility will provide dedicated space for public education on fisheries management activities and restoration programs and will include a reception area, educational exhibits, display aquaria, a marine animal touch tank, visitor restrooms, and a youth fishing pond. The educational components of the project will also allow for opportunities to highlight the many different cultural and biological aspects of marine fisheries in Louisiana.

Plans for the Plaquemines Parish facility will involve constructing a new building and renovating existing onsite facilities. This location will serve as a research and demonstration facility for marine bait fish husbandry in support of recreational sport fishing. As currently proposed, the new building would house staff offices and a baitfish culture area with small-scale recirculating aquaculture systems for research and demonstration of technology for live bait husbandry. Existing onsite facilities that were previously used for plant propagation would be renovated or reconditioned, including a Mississippi River water intake structure and pumping station, ponds, and infrastructure components (e.g., water pipelines, access roads). The rehabilitation of existing ponds would be used for a combination of water storage, effluent treatment, and research projects on integrated multitrophic aquaculture for freshwater and low-salinity production of baitfish and coastal plants.

This project would allow LDWF to responsibly develop aquaculture-based techniques for marine fisheries management. At the same time, the creation of these living laboratories would enable a myriad of collaborative research possibilities while providing dedicated venues for outreach and education to the public. Hatchery fish would be utilized for a variety of research projects, including collaboration with academia and other stakeholders. The production and release of marked hatchery sport fish will be carried out in conjunction with LDWF's statewide Fishery Monitoring Program and be used for the long-term monitoring of Louisiana's fishery resources and the habitats that support them. Initial releases will be targeted experimental stockings to investigate ecological hypotheses and evaluate release strategies (e.g., spatial and temporal variation, fish size, marking techniques). This work would provide information on recruitment, survival, health, movements, and genetic structure of marine fish populations, which would be used to help develop and evaluate strategies for the management of Louisiana's saltwater sport fishery.

In the wake of the *Deepwater Horizon* oil spill, the Early Restoration projects represent just the first steps in a long journey to rectifying the damage caused by this disaster. The Louisiana Oyster Cultch Project and the Louisiana Marine Fisheries Enhancement, Research, and Science Center would support and improve Louisiana's ongoing efforts to conserve its fishery resources. The culture components of these projects would develop applied scientific methods as a novel tool for marine fisheries management in Louisiana. The outreach and educational aspects will deliver knowledge and information to the public on fisheries management topics and the importance of conserving valuable marine species and habitats. Overall, the elements coalesce with the overarching mission of LDWF to manage Louisiana's aquatic resources by maintaining healthy populations for current and future generations to enjoy.

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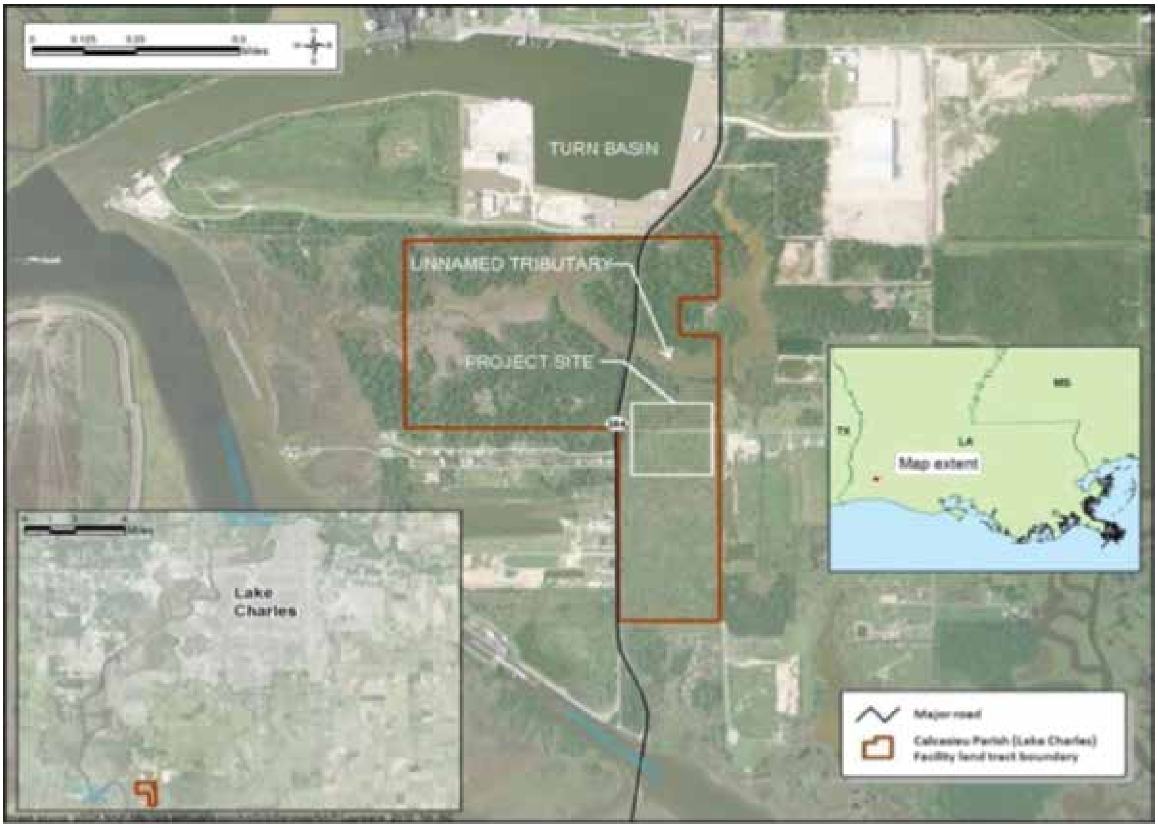

Figure 4. Location of Calcasieu Parish site for the Louisiana Marine Fisheries, Enhancement, Research, and Science Center project.

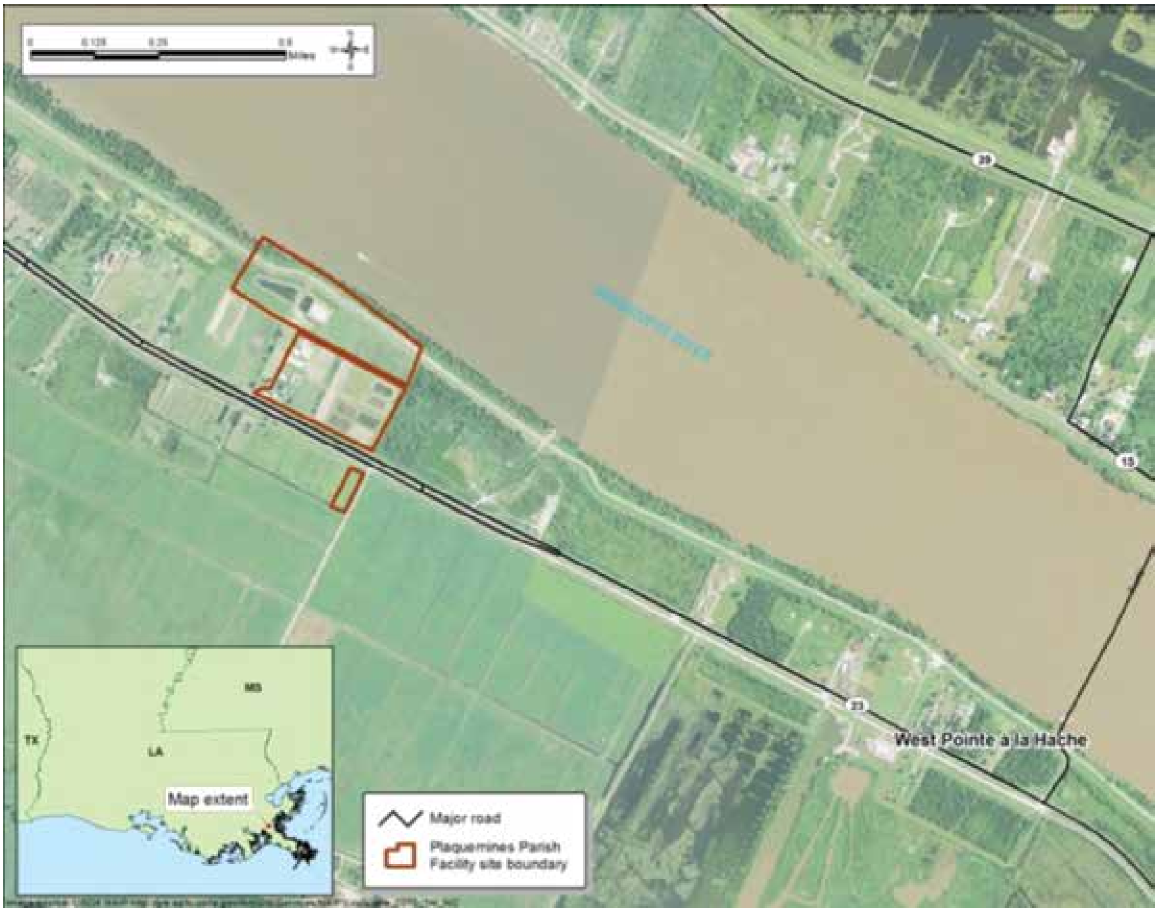

Figure 5. Location of Plaquemines Parish site for the Louisiana Marine Fisheries, Enhancement, Research, and Science Center project.

Hatcheries and Harvest: Meeting Treaty Obligations Through Artificial Propagation

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The Columbia River presents a formidable challenge that Pacific salmon must face twice in their lives. Salmon are challenged by environmental degradation, predators, numerous hydroelectric facilities, and fisheries.The juvenile salmon that reach the ocean and grow to adulthood finally return to the tribal communities that rely on them. Like countless generations before us, we wait for them to return to our families, our communities, and our longhouses.

We wait for the salmon because of their essential role in our cultures. Since time immemorial, Columbia River tribes have relied on salmon for our subsistence and ceremonial needs, as well as the foundation for a robust barter and trade economy. The tribes' relationship with salmon can be traced back to their creation stories. When the Creator asked each animal and plant for a gift to help the new people who would soon be created, Salmon offered his body to help feed them. In return, humans were instructed to respect and take care of salmon and his people. This bond flourished for the benefit of all.

The relationship between salmon and the tribes is so strong that tribal leaders were careful to reserve the right to fish at all usual and accustomed fishing places when negotiating the Stevens-Palmer Treaties of 1855 with the United States. The treaties established a federally protected tribal property right to the fish that was steadily eroded in succeeding decades by the growth of non-tribal fisheries and development. Though the tribes were first in right, they were often last in line for these salmon as they returned to their spawning grounds. The discriminatory fisheries management decisions of state agencies led to the tribes filing fishing rights litigation in federal court in 1969. The U.S. Supreme Court affirmed the treaty fishing right in *U.S. v. Oregon* and *U.S. v. Washington* on a number of occasions.

The tribal treaty right to harvest salmon at all usual and accustomed fishing places is an empty promise if there are no fish to catch. Development of the Columbia Basin brought overfishing, logging, ranching, mining, agriculture, hydropower development, and urban growth—all devastated salmon resources and diminished the treaty fishing right. The federal government was often complicit in the destruction of wild salmon and thus failed to make good on its promise to protect and maintain the salmon resource. At a minimum, the tribes continue to expect and demand the federal government to live up to the promises it made in the 1855 treaties.

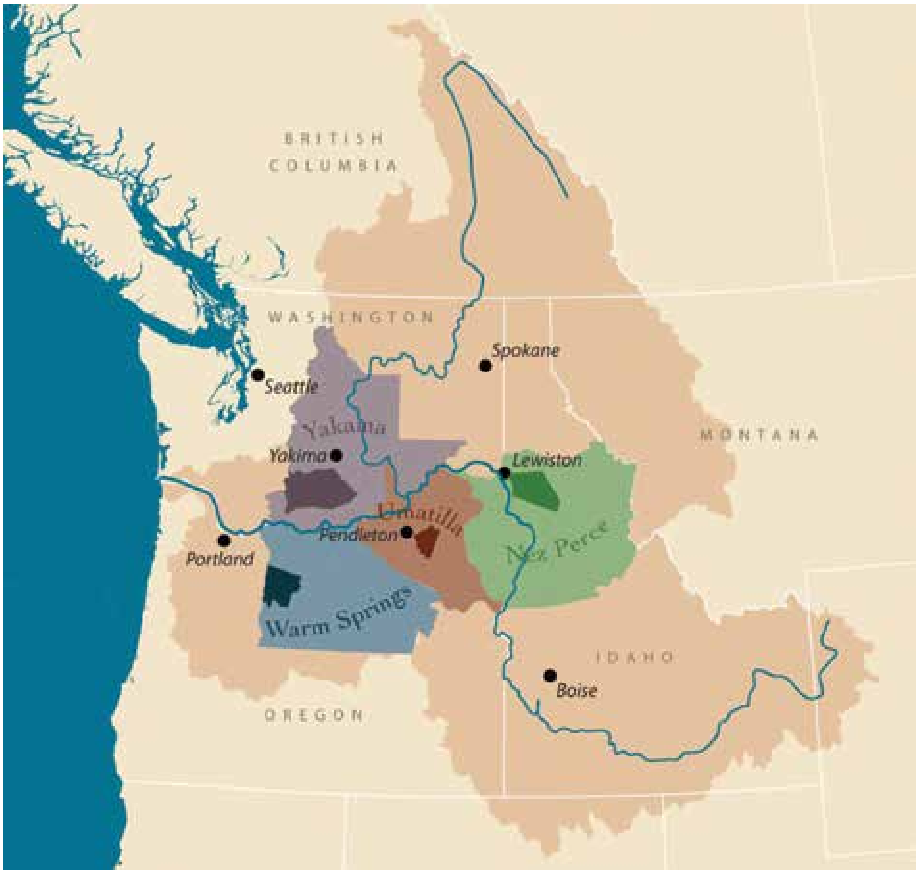
The government's answer to the destruction of salmon populations and their habitats was to construct hatcheries, but their placement did not follow the concept of in-place, in-kind mitigation. The majority of the hatcheries in the Columbia Basin were constructed downstream of the areas that suffered the largest impacts and downstream of the tribal fishing areas. The destruction of populations in the upper Columbia River and the placement of hatchery mitigation in the lower Columbia River downstream of Bonneville Dam further diminished the treaty fishing right because these mitigation fish would never swim past most of our usual and accustomed fishing places.

As the tribal treaty right diminished with each lackluster return and seeing little regional interest in restoring wild salmon, the tribes realized that hatcheries above Bonneville Dam were necessary to support the treaty right and cultural requirement to have fish present to catch. Recognizing that hatchery programs in the Columbia Basin can be designed to accommodate a variety of approaches and priorities, tribes argued that hatchery programs can and should be configured to support the production of wild salmon, rather than compete with it. Tribal scientists were instructed to look beyond conventional hatchery approaches to develop hatchery practices that enhance, mitigate, and sustain the wild salmon resource.

The success of this approach can be seen throughout the Columbia River Basin. Natural Snake River fall Chinook Salmon *Oncorhynchus tshawytscha* reached a low of 78 returning adults in 1990 and was listed for protection under the Endangered Species Act in 1994. The tribes worked with state and federal comanagers to establish a hatchery program that releases juveniles at key locations adjacent to natural spawning and rearing habitats. The result has been a steady increase in Snake River fall Chinook returns to the Snake River Basin. Twenty-three years later, over 56,000 fall Chinook adults crossed Lower Granite Dam, a third of which were of natural origin. All of these fish were allowed to return to the Snake and Clearwater Rivers to spawn and support tribal and nontribal fisheries.

Snake River fall Chinook is not the only success that the region can point to. The tribes have had significant success using innovative hatchery programs to reintroduce Coho Salmon *Oncorhynchus kisutch* throughout the upper Columbia Basin. Thanks to reintroduction programs led by the Nez Perce, Yakama, and Umatilla tribes, coho are now supporting tribal and recreational fisheries in parts of the Snake and Columbia Rivers where before they were declared functionally extinct in the 1990s.

Tribal scientists are active participants in the scientific scrutiny of the ecological and genetic effects of hatcheries. Recent research from Johnson Creek, Idaho, reported in the journal *Molecular Ecology,* found that using natural-origin spring Chinook as hatchery broodstock enhanced the spring Chinook population in Johnson Creek with little or no impact on the fitness of naturally spawning fish. Similar studies show that hatchery releases using naturally spawning spring Chinook for broodstock in the Yakima River of Washington produced substantial improvements in abundance and spatial distribution with no detrimental changes after three generations of the program. Tribal scientists are contributing to the growing body of scientific literature on hatcheries and tribal managers make decisions that carefully weigh biological risks and benefits of hatchery technology.



The ceded lands of the four treaty tribes make up a large portion of the central Columbia River Basin (darker tan). These ceded lands were transferred to the United States at treaty signing. Each tribe's ceded area is labeled, with the present-day reservation shown in a darker shade.

Dams in the Columbia Basin, such as Grand Coulee Dam on the Columbia and Hells Canyon Dam on the Snake River, blocked access to vast amounts of spawning habitat for the region's salmon and steelhead populations. Hatchery programs will continue to be necessary to aid in mitigating conditions for fish resources that were damaged or destroyed by the large and small blockages located throughout the basin. For instance, the Okanagan Nation Alliance is leading efforts to reintroduce Sockeye Salmon *Oncorhynchus nerka* into lake habitat previously blocked by small dams in the Okanagan Basin roughly 600 miles upstream from the Pacific Ocean. Hatchery outplants to Skaha Lake, combined with habitat and water management improvements, have produced dramatic results. The 2014 return of sockeye to the Columbia Basin was over 600,000 fish, by far the largest since the construction of Bonneville Dam in 1938. Approximately 80% of the return went to the Okanogan Basin. The Warm Springs, Yakama, and Nez Perce tribes are also working on sockeye restoration projects of their own.

Continued efforts to restore naturally spawning populations are vital to the long-term sustainability of salmon populations and for tribes to exercise treaty fishing rights now and for generations to come. The Endangered Species Act recognizes the potential for artificial propagation to enhance the abundance, distribution, diversity, and productivity of salmon populations listed under the act. Though an important restoration tool, limiting focus to hatcheries ignores the major contributions that are possible from the restoration of freshwater habitat and survival improvements in the pathway. Tribal actions are addressing all sources of mortality in the salmon life cycle, from egg in the gravel to adult on the spawning gravels. Hatcheries serve a necessary role in rebuilding and maintaining natural populations, providing fish for harvest, and fulfilling the treaty trust promises made over 150 years ago.

Pacific salmon populations face a variety of anthropogenic threats to their persistence and recovery, but "paralysis of analysis" in applying remedies should not be one of them. The nature and intensity of those threats vary across species' ranges, and tribes in their areas are utilizing hatcheries in ways that fit the specific restoration needs of local salmon populations. To be successful, regional comanagers must collaborate to meet common interests. Progress is being made. Population declines have been slowed or even reversed, but more work is needed if we are to leave a viable resource for future generations. As the late tribal leader Billy Frank often reminded non-tribal leaders: "We're not going away and you're not going away, so we need to figure this out together."

Carlos Smith is a member of the Warm Springs Tribe. He currently serves as chairman of the Columbia River Inter-Tribal Fish Commission and is a member of the Warm Springs Tribal Council.

About CRITFC: *The Portland-based Columbia River Inter-Tribal Fish Commission is the technical support and coordinating agency for fishery management policies of the Columbia River Basin's four treaty tribes: the Confederated Tribes of the Umatilla Indian Reservation, the Confederated Tribes of the Warm Springs Reservation of Oregon, the Confederated Tribes and Bands of the Yakama Nation, and the Nez Perce Tribe.*

AFS Completes Assessment, Issues New Guidance Regarding Hatchery Operation and the Use of Hatchery-Origin Fish

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BACKGROUND

The American Fisheries Society (AFS) is the oldest, largest, and most influential professional organization devoted to fisheries conservation and, in this capacity, the AFS has routinely assessed the contributions of hatcheries to natural resource management and issued recommendations to guide natural resource managers in best uses of hatchery-origin fish. For the past several decades, the Society has explored these issues in a formalized process conducted at approximately 10-year intervals to assess contemporary issues related to hatcheries and management of aquatic resources. Representatives of the Fish Culture and Fisheries Management Sections came together in 1985 to answer the question “Fish culture—fish management’s ally?” in a symposium entitled “The Role of Fish Culture in Fisheries Management.” In 1994, AFS reexamined the issues of fisheries enhancement in the context of emerging ecosystem-based approaches to resource management in a symposium and workshop entitled “Uses and Effects of Cultured Fishes in Aquatic Ecosystems.” A similar process was undertaken in 2003–2004 to once again review the uses of hatchery-origin fish and new scientific findings in the course of a symposium, web-based survey of fisheries professionals, and a facilitated workshop, collectively referred to as “Propagated Fishes in Resource Management (PFIRM).” Each of the previous cycles yielded a proceedings book (*Fish Culture in Fisheries Management* [Stroud 1986], *Uses and Effects of Cultured Fishes in Aquatic Ecosystems* [Schramm and Piper 1995], and *Propagated Fishes in Resource Management* [Nickum et al. 2004]), and most recently a guidance document, “Considerations for the Use of Propagated Fishes in Resource Management.” The so-called “PFIRM Considerations” guide, published by AFS in 2005 (Mudrak and Carmichael 2005), provided resource managers with general recommendations for decision making and successful implementation of fisheries supplementation, rehabilitation, and restoration programs.

In response to fisheries management policy changes that have occurred, newly available information on supplementation and rehabilitation, and fisheries issues that have arisen since the previous cycle, AFS President William Fisher established a steering committee in 2012 to reengage the Society in the next cycle of this iterative process. Dubbed “Hatcheries and Management of Aquatic Resources (HaMAR),” the process brought together Doug Bradley, Tom Flagg, Kurt Gamperl, Jeff Hill, Christine Moffitt, Vince Mudrak, George Nardi, Kim Scribner, Scott Stuewe, John Sweka, Gary Whelan, and Connie Young-Dubovsky under the leadership of Jesse Trushenski and Don MacKinlay to represent interested AFS Sections and the perspectives of state and federal agencies. They were subsequently joined by Jay Hesse and Ken Leber, Kai Lorenzen, and Lee Blankenship to represent tribal/First Nation perspectives and the Science Consortium for Replenishment of the Oceans, respectively. Collectively, this committee worked to develop, organize, and implement the HaMAR process.

The HaMAR committee's work began with a scoping survey to give voice to a diverse cross section of fisheries professionals in identifying contemporary issues of concern. The respondents highlighted a number of critical issues related to hatcheries, hatchery-origin fish, and fisheries management.

Based on these priority topics, presentations were solicited for symposia held at the AQUACULTURE 2013 conference (Nashville, Tennessee, February 21–25) and the AFS 2013 Annual Meeting (Little Rock, Arkansas, September 8–12). With assistance from organizers of the HaMAR special publication module, Des Maynard (see below), and Past President of the Fish Culture Section, Jim Bowker, the HaMAR steering committee worked to distill the symposia into a new guidance document, "Hatcheries and Management of Aquatic Resources (HaMAR) Considerations for Use of Hatcheries and Hatchery-Origin Fish." This process included multiple rounds of drafting and revision, followed by consideration and approval by the AFS Governing Board on 16 August 2014. The full text of the "HaMAR Considerations" guide will appear in forthcoming special issue of the *North American Journal of Aquaculture*, along with a series of papers derived from HaMAR-related symposia presentations. The "HaMAR Considerations," summarized below, represents an update and expansion of the previous "PFIRM Considerations" and is intended to provide aquatic resource managers with timely and comprehensive guidance regarding hatcheries and their products.

Executive Summary of "HaMAR Considerations"

Summary of Findings from PFIRM

The PFIRM process identified seven primary concepts that remain informative and should be considered when stocking fish:

1. Comprehensive fishery management plans. Comprehensive fishery management plans should guide resource managers through the choice to stock fish, evaluate stocking programs, and manage fisheries in an adaptive, responsive fashion. The comprehensive management planning process should recognize and consider alternatives to stocking and include inputs from various resource partners. When stocking is delineated, specific goals and objectives should be considered. Objectives should be specific, measurable, accountable, realistic, and time-fixed.

2. Biological and environmental feasibility. Decisions to stock propagated fishes should be predicated on science-based evaluations that indicate that the environment can support the stocked fish and stocking will achieve the identified management objective(s).

3. Risk and benefit analysis. Scientific evaluations should be conducted to determine what effects stocked fishes may have on the environment and native and naturalized biota (including humans) and what benefits and risks various approaches may yield.

4. Evaluate potential beneficial or harmful effects of increased and directed public use of aquatic environments on biotic (including human) communities. Particular caution should be exercised if introducing fish to an area where they did not occur previously.

5. Economic evaluation. Benefits and costs should be comprehensively evaluated and quantitatively described as accurately as possible.

6. Public involvement. Keep the public informed about pending changes in fisheries management, encourage dialogue on potential changes, and provide a forum for public input. Moreover, when appropriate, educate the public on legal and interjurisdictional issues, including tribal/First Nation treaty rights and responsibilities.

7. Interagency cooperation. Share technical science-based fisheries information to strengthen interagency coordination and interjurisdictional fisheries monitoring programs. Recognize regulatory and legal differences for the United States, Canada, Mexico, tribes, provinces, states, territories, and federal lands such as national parks and military reservations.

The "PFIRM Considerations" provided a good summary of issues considered important at the time for fisheries managers to use in their comprehensive planning process and subsequent decisions involving the potential use of stocked fishes. We consider these key issues to still be a primary need for resource managers in developing fisheries management plans that include stocking propagated fish.

Priority Shifts Identified during HaMAR

The HaMAR scoping survey respondents were asked to assess the current relevance of the major elements identified in the "PFIRM Considerations." More specifically, they were asked to identify which three of the seven elements they considered to be the most important in terms of contemporary stocking programs. The responses received made it clear that the "PFIRM Considerations" remain relevant, but there is now even more emphasis on integrated management and a need for greater specificity in considering the use of hatcheries and hatchery-origin fish. In particular, the following priority topics were identified during the HaMAR process as being particularly relevant.

Habitat Restoration and Management Efforts as Companions to Stocking

Whereas the focus of the "HaMAR Considerations" guide is the use of hatcheries and hatchery-origin fish, it is imperative to note that stocking is just one leg of the "three-legged stool" of fisheries management: stocking for supplementation is unlikely to be successful in the absence of complementary habitat rehabilitation and harvest management strategies.

Establishing Appropriate Uses for Hatchery-Origin Fish and Defining Expectations for Stocking Programs

Hatchery-origin fish are used to achieve a number of management objectives, and appropriate propagation and stocking methods vary based on the intended use of the fish. It is impossible to apply the principles of adaptive management if goals and objectives are not clearly articulated and agreed to by decision makers and stakeholders. Stocking may or may not be an effective management action, depending on the targets identified for the fishery and the current status of the receiving system. If quantitative assessments indicate stocking are advisable, species selection processes should take a broad range of biological, economic, and risk management criteria into consideration.

Understanding the Limitations of Hatchery-Origin Fish and Stocking Programs

Hatcheries and hatchery-origin fish are an essential component of many fishery management plans. However, there are limitations to stocking, and failure to recognize and address these limitations is likely to yield less than desired results and unintended consequences. Successful enhancement programs are closely connected to the fishery management process and are integrated with ongoing fishery monitoring programs. Flexible/adaptive management of hatcheries, conducted in concert with that of fisheries management plans, enables refinement, progress, and success in stocking programs.

Monitoring and Flexible/Adaptive Management of Stocking Programs

It is absolutely essential that fishery management plans include preestablished timelines and criteria for evaluating enhancement and deciding whether to continue, modify, or terminate the stocking program. The specific objectives and benchmarks of effectiveness will vary from one situation to another depending on the stakeholders involved and their values. The decision to continue or discontinue a long-standing stocking program can be fraught with political discord without agreed-upon criteria and quantitative measures to reference. Monitoring provides decision makers with the evidence needed to objectively evaluate enhancement effectiveness.

Hatchery Operation and Propagation Techniques

- Types of enhancements and complementary modes of hatchery operation. Not all fish tolerate the same environmental conditions, and husbandry methods vary substantially among the hundreds of finfish species that are reared throughout the world. Just as propagation techniques vary from fish to fish, what constitutes "best management practices" for a hatchery depends on the operation's requirements. Much progress has been made toward defining common stocking strategies; however, standardized terminology and definitions remain elusive. We encourage adoption of standardized terms to broadly characterize managers' expectations of the hatchery origin fish and help to frame the principles of hatchery operation and propagation methods. With this in mind, it is important to recognize that many hatcheries are functional hybrids, operating as harvest augmentation, supplementation, or conservation hatcheries by turns or simultaneously to produce various fishes in a manner consistent with their intended uses. Clear and well-documented objectives are essential for all hatchery programs, especially facilities rearing fish for different uses.

- Conflicting mandates. During development and operation of hatchery programs, managers are often faced with having to address competing and often conflicting objectives or mandates. Achieving a scientifically defensible but socially acceptable balance between harvest and conservation has proved to be challenging in many situations, both politically and biologically. To be considered successful, hatcheries should be used as part of a comprehensive strategy where habitat, hatchery management, and harvest are coordinated to best meet resource management goals that are defined for each population.

- Controlling the costs of hatchery operation. Feed cost and effluent management are increasingly critical constraints for hatcheries: flat or declining budgets and stricter oversight of water usage make the prospect of producing the same or greater numbers of fish a difficult, if not impossible, proposition. The costs of hatchery operation will continue to increase as a result of increasing feed prices and/or the need to implement more robust water treatment methods or transition to more intensive, water reuse–based rearing systems. Though reductions in effort or hatchery closures may offer short-term savings, it is important to recognize that curtailing hatchery programs will undoubtedly have broader economic consequences. In assessing their costs, the value of hatchery programs and their products must also be considered.

Culture of Imperiled Species and Conservation Hatcheries

The operational approaches and measures of success for a conservation hatchery may differ considerably from those of harvest augmentation/production or supplementation hatcheries. The mission of a modern conservation hatchery is twofold: gene pool preservation and recovery. Each conservation program will be site specific and depend on the physical and management limitations of each individual hatchery. The exact application of conservation hatchery strategies will depend on the particular stock of fish, its level of depletion, and the biodiversity of the ecosystem but will generally involve rearing protocols to maximize genetic diversity and the inherent fitness of the fish to survive and breed in its natural environment. In the future, creation of gene banks using cryopreservation and other biotechnological tools for reproduction may be increasingly important in the preservation or production of rare aquatic organisms.

Fish Health and Access to Disease Management Tools

Successful hatchery programs take a comprehensive approach to aquatic animal health, including use of biologics (i.e., vaccines and bacterins), biosecurity measures, and other preventative strategies; use of therapeutants and other disease management techniques; broodstock conditioning and spawning; marking progeny; and reducing handling stress. Many of these activities require administration of fish drugs, including antimicrobials, spawning aids, marking agents, and sedatives. To maximize the effectiveness of drug treatments and remain compliant with relevant regulations and aquatic animal health plans, hatcheries have a responsibility to ensure that staff know what drugs are legal and how to apply them correctly.

Biosecurity

“Biosecurity” refers to practices used to prevent the introduction and spread of disease-causing organisms and nuisance/invasive species. Biosecurity is commonly associated with disinfection, but comprehensive biosecurity plans can go well beyond simple disinfection procedures to include everything from facility layout and design, to livestock sourcing and quarantine, to record-keeping. Although many common fish pathogens and parasites are present in virtually all environments and are difficult or impossible to eradicate, others have a regional distribution or are easier to avoid or contain. In any event, biosecurity is an essential first line of defense against introduction or transmission of undesirable organisms.

Strategies to Maintain Genetic Integrity and Diversity in Hatchery-Origin Fish

Proper genetic management of and spawning strategies for hatchery-origin fish are critical to maintaining genetic diversity, minimizing inbreeding, maximizing effective population size, and reducing artificial selection. The degree to which these elements are intensively managed depends, in part, on the type of hatchery and intended use of the hatchery-origin fish. Various spawning strategies can be employed in hatcheries that can maintain genetic diversity, minimize inbreeding, maximize effective population size, and reduce adaptation in captivity and upon supplementation of these fish into wild populations.

Biological and Other Interactions between Wild and Hatchery Fish

Much of the concern over interactions between hatchery and wild fish has centered on genetic effects of hatchery fish on wild populations, and hatchery management strategies are often in place to minimize genetic risks. However, ecological effects may be just as important as genetic effects and should be considered when releasing hatchery origin fish into the wild.

Responsible use of hatchery fish in sympatry with wild fish should strive to minimize risk of negative interactions with wild populations, and a number of strategies may be applied to mitigate ecological risks from hatchery programs.

Risk Assessment and Decision Making

Risk assessment is the process by which the likelihood of an event occurring and the severity of its consequences are described. Risk itself is defined as the product of these two factors—likelihood of occurrence and negativity of consequences. Risks associated with hatchery operation and use of hatchery-origin fish should be delineated and integrated into the decision-making process in as quantitative a manner as possible, including the consequence of taking no action. Potential benefits should also be considered as a part of such an assessment. Benefits often relate to society, such as angling days, fish yield, and public access, but may also include ecosystem function, stability, cultural value, productivity, and others.

Depending on the elements of the scenario and the availability of quantitative information, risk assessment can be a straightforward assembling of facts and figures or it can be a challenging process involving considerable uncertainty. These challenges should not dissuade resource managers from attempting to assess the relative risk of proposed actions, including stock enhancement, with the caveat that decisions will still need to be made even when risks are not completely understood.

FINAL THOUGHTS

- Effective communication. Though the need for cooperative management, inclusive planning, and interdisciplinary approaches to fisheries management may seem self-evident today, this was not always the case. Those participating in HaMAR exemplified a willingness to engage those with differing views and focus on science-based decision making, both of which are essential to the creation of effective fisheries management plans, including the use of hatcheries and hatchery-origin fish.

- Issues yet to be resolved. Like any scientific endeavor, HaMAR effectively addressed many questions but raised others. What progress has there been in quantifying the socioeconomic impact of fisheries enhancement? Why are state fisheries managers reluctant to resist stakeholder demands to judge stocking programs simply by the numbers of organisms stocked? Is there an urgent need to increase seafood production? Whereas some of these questions may find quantitative responses or solutions in the future, it may not be possible to address all of them in the context of traditional fisheries science.

To be fully successful, every hatchery program must be scientifically defensible, have well-defined and documented goals, and be flexible and respond adaptively to new information. Proper forethought and documentation will go a long way to strengthening the scientific foundation of hatchery operation and the use of hatchery-origin fish.

For more information about the HaMAR process or its deliverables, please contact the authors.

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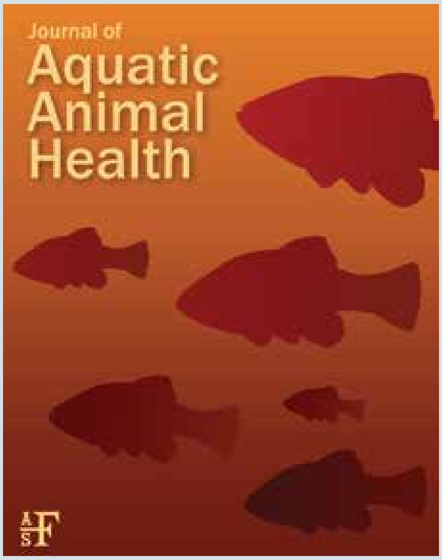

HSRG Issues New Report, “On the Science of Hatcheries …”

In 2014, the Hatchery Scientific Review Group (HSRG) completed a comprehensive review of scientific advancements in hatchery management. The purposes of the review were to

- Provide an updated perspective on the role of hatcheries in salmon and steelhead management in the Pacific Northwest.
- Evaluate the impact of the HSRG’s work on hatchery management in the Pacific Northwest.
- Review new information and consider whether the HSRG’s principles, broad recommendations, and analytical framework are still consistent with the best available science.

The resulting report, titled “On the Science of Hatcheries: An updated perspective on the role of hatcheries in salmon and steelhead management in the Pacific Northwest,” (HSRG 2014) provides an update from the HSRG on the progress being made toward science-based hatchery reform and related changes in harvest management. The report reviews recent advancements in the science and understanding of the effects of hatchery operations on the conservation and sustainable fisheries goals of tribal, state, and federal managers. An executive summary of the report follows; the full text of “On the Science of Hatcheries” can be accessed at www.hatcheryreform.us.

EXECUTIVE SUMMARY

Hatcheries have long played a necessary role in meeting harvest and conservation goals for Pacific Northwest salmon and steelhead. However, a need to reform the hatchery system has been identified by scientists and policymakers based on growing concerns about the potential effects of artificial propagation on the viability of salmon and steelhead in their natural habitats. The U.S. Congress established the Hatchery Reform Project in 2000 as part of a comprehensive effort to conserve indigenous salmonid populations, assist with the recovery of naturally spawning populations, provide sustainable fisheries, and improve the quality and cost-effectiveness of hatchery programs. The HSRG was charged with reviewing all state, tribal, and federal hatchery programs in Puget Sound and coastal Washington. The review used an ecosystem-based approach founded on two central premises: that harvest goals are sustainable only if they are compatible with conservation goals and that artificially propagated fish affect the fitness and productivity of natural populations with which they interact. The intent of the project is for science to direct the process of reform. Reforms should ensure that the hatchery system matches current circumstances and management goals.

Since 2000, the HSRG—an independent scientific review panel—has carried out its mission of incorporating the most up-to-date science into hatchery management, with financial support from state and federal sources.

Hundreds of hatchery facilities in the Pacific Northwest are operated by federal, state, tribal, and local governments. Some of these hatcheries have been operating for more than 100 years. Most were built to produce fish for harvest when wild populations declined from habitat loss, overfishing, and the construction of hydroelectric dams. Hatcheries have generally been successful at producing fish for harvest. However, the traditional mitigation policy of replacing wild populations with hatchery fish is not consistent with today’s conservation goals, environmental values, and scientific theories. Hatcheries cannot replace lost habitat and the natural populations that rely on it. It is now clear that the widespread use of traditional hatchery programs has actually contributed to the overall decline of wild populations. The historical use of artificial propagation for harvest mitigation has frustrated the successful integration of management directives and created regional economic inefficiencies. Today, it is clear that hatchery programs must be seen as just one tool to be used as part of a broader, balanced strategy for meeting watershed or regional resource goals. Such a strategy also incorporates actions affecting habitat, harvest rates, water allocation, and other important components of the human environment.

Pursuant to the Hatchery Reform Project, comprehensive reviews of over 200 propagation programs at more than 100 hatcheries across western Washington were completed in 2004. Based on those reviews, analytical tools were developed in 2005 to support application of the HSRG’s principles (HSRG 2009; Paquet et al. 2011). Also in 2005, Congress directed the National Oceanic and Atmospheric Administration–National Marine Fisheries Service to replicate the project in the Lower Columbia River Basin. Ultimately, that scope was expanded to include the entire Columbia River Basin, and the resultsof this hatchery assessment were reported soon thereafter (HSRG 2009). Three principles (listed below) emerged early in the HSRG’s review and served as guidance for the development of recommendations for hatchery reform. The principles provide a method of incorporating the best available science into policy decisions about the design and operation of hatcheries.

- Principle 1: Develop clear, specific, quantifiable harvest and conservation goals for natural and hatchery populations within an "All H" context. Habitat, hatcheries, harvest, and hydropower (dams) constitute the "All H." Hatcheries should be used as part of a comprehensive strategy where habitat, hatchery management, hydropower operations, and harvest are coordinated to best meet resource management goals that are defined for each fish population in the watershed.

- Principle 2: Design and operate hatchery programs in a scientifically defensible manner. The scientific rationale for a hatchery program in terms of benefits and risks must be formulated to explain how the program expects to achieve its goals. The strategy chosen must be consistent with current scientific knowledge.

- Principle 3: Monitor, evaluate, and adaptively manage hatchery programs. Ecosystems affected by hatchery programs are dynamic and complex; therefore, uncertainty is unavoidable. New data will change our understanding of the ecological and genetic impacts of hatchery programs, and this should lead directly to changes in hatchery operations.

Important HSRG Conclusions

The HSRG (2009) provided many specific and regional recommendations for each hatchery program evaluated. Important conclusions emerged that need to be addressed through policy, management, and research and monitoring as part of the hatchery reform implementation process.

- Identify the purpose of the hatchery program in the context of an All H strategy to meet resource goals over time. Hatchery programs may contribute to harvest, conservation, or both. To be successful, hatchery programs should be managed in concert with harvest and within an integrated long-term plan that also incorporates present and future habitat and hydropower scenarios. A hatchery should be the strategy of choice only to the extent that it is better in a benefit–risk sense than other alternatives to meet similar goals.

- For hatchery programs with a harvest purpose, manage broodstocks to achieve proper genetic integration with, or segregation from, natural populations. In an ideal integrated program, natural-origin and hatchery-origin fish represent two components of a single gene pool that is locally adapted to the natural habitat. A population that supports an integrated program would make a greater contribution to harvest than the existing natural habitat can sustain on its own. The intent of a segregated hatchery program for harvest mitigation is to maintain a genetically distinct hatchery population. The segregated approach uses only hatchery-origin fish for broodstock and results in a population that is adapted to the hatchery environment and can maximize the efficiency of hatchery propagation. The management of hatchery programs for harvest augmentation is a matter of balancing harvest benefits versus risks to affected naturally spawning populations.

- The role of a hatchery program in the conservation of naturally spawning populations should be determined by the status of the population. The use of hatcheries in population recovery should be informed by the science and principles of conservation biology. The management of conservation programs is a matter of balancing short-term demographic benefits versus long-term fitness goals. Conservation programs should be temporary and associated with biologically defined triggers to modify or terminate the hatchery programs.

- Promote local adaptation of natural and hatchery populations. Local adaptation is important because it maximizes the viability and productivity of the population, maintains biological diversity within and between populations, and enables populations to adjust to changing environmental conditions (e.g., through climate change). Many hatchery programs have disrupted the natural selection of population characteristics that are tailored to local conditions. Proper integration or segregation of hatchery programs is the HSRG's recommended means for minimizing the adverse effects of hatcheries on local adaptation of naturally spawning populations. Local adaptation of hatchery populations is achieved by using local broodstock and avoiding transfer of hatchery fish among watersheds.

- Minimize adverse ecological interactions between hatchery- and natural-origin fish. Ecological interactions include competition for food and space, predation of hatchery fish upon natural-origin fish, and the potential transfer of disease from hatchery- to natural-origin fish. One way to minimize these interactions is for hatchery programs to be operated so that reared and released fish are as similar biologically to their natural counterparts as possible. Alternatively, hatchery programs can be operated so that hatchery fish are segregated from their natural counterparts in time and space. In this context, it is also important that the rearing facilities meet all applicable environmental compliance requirements (e.g., water withdrawal, discharge, screening, etc.).

- Maximize survival of hatchery fish, consistent with conservation goals. For hatchery programs to effectively contribute to harvest and/or conservation, the survival and reproductive success of hatchery releases must be high relative to those of naturally spawning populations. The primary performance measure for hatchery programs should be the total number of adults produced (those caught in fisheries plus those that escape to the hatchery or natural environment) per adult spawned at the hatchery. This measurement should be greater than that achieved in the wild. This is particularly important for integrated programs to avoid broodstock "mining" from the natural population. It also ensures that the fewest number of hatchery fish will be released to accomplish the desired goal.

- Hatchery reforms increase the value of habitat improvements. Measures that restore the fitness (and therefore productivity) of naturally spawning salmon and steelhead populations are necessary to realize the benefits from investments in habitat improvements. Conversely, when habitat improvements are made without hatchery and harvest reforms, the resulting benefits will not be fully realized. Productivity benefits are also likely to be realized on a shorter timescale from hatchery reform than improvements in habitat. Given these factors, there is no apparent biological reason to wait for future habitat improvements to take full effect before implementing hatchery and harvest reforms.

- The role of science is to inform policy decisions. Science should provide a working hypothesis for how management actions will affect resource outcomes. The HSRG has proposed its recommendations as one solution to increase the benefits and reduce the risks associated with operating hatcheries. The HSRG's framework provides an alternative to the century-old paradigm that guided hatchery policy in the past, in which hatcheries were the simple and ubiquitous solution to mitigate for habitat loss and overharvest. The HSRG framework is more consistent with currently available science than the old paradigm. As new information becomes available, the HSRG framework should continue to be challenged and revised. Science thus informs policy decisions by evaluating potential biological benefits and risks associated with alternative management actions. Research that addresses specific questions related to hatchery reform can lead to more efficient policy adaptation.

- Harvest reforms can complement hatchery reforms to improve harvest and better achieve conservation objectives. The HSRG found that harvest reforms, in combination with hatchery reforms, can both increase harvest and help achieve conservation objectives. For example, mark-selective sport and commercial fisheries allow greater catches of hatchery-origin fish while reducing mortality to natural-origin fish needed for escapement and broodstocks. Mark-selective fisheries have the potential to improve the ability of managers to meet management targets for natural production, reduce straying, and decrease the number of hatchery-origin fish on the spawning grounds. Without increases in selective fisheries, solutions to meet conservation goals will require reduced hatchery production and catch. Similarly, opportunities were noted where more hatchery fish could be acclimated and released from specific locales (e.g., bays and tributaries). This would allow more intensive fisheries on the returning hatchery-origin adults near the point of release with fewer impacts on natural-origin fish than currently occur in more mixed-stock waters.

Detailed reports on all of the HSRG's reviews, analytical tools, and framework are available online at www.hatcheryreform.us. The HSRG understood that the scientific framework it proposed in 2009, along with its specific recommendations for hatchery reform, would require constant review and revision. The HSRG's framework recognized that there are significant uncertainties in assessing the effects and roles of hatcheries, including the future condition of habitat, climate change, and the ecological and genetic effects of hatchery fish on the viability of naturally spawning populations. Since the last HSRG publication in 2009, research and monitoring of hatchery programs have brought forward new information and insights on hatchery science. These advancements are the focus of the HSRG's 2014 report.

Implementation and Status of Hatchery Reform

The HSRG's hatchery reform recommendations have become a pervasive set of standards for developing new hatchery programs and making existing programs consistent with resource goals and 21st-century science in the Columbia Basin, Puget Sound, and along the Washington coast. The hatchery management principles developed by the HSRG are being institutionalized in several agency policies (e.g., Washington Department of Fish and Wildlife's Hatchery and Fishery Reform Policy adopted in 2009) and many hatchery management plans and are widely cited in scientific reviews (e.g., Northwest Power and Conservation Council's Independent Science Review Panel's 2011 programmatic reviews and various reports available at www.nwcouncil.org/fw/isrp/). The HSRG has increased understanding of the potential conservation benefits of hatchery reform by emphasizing the importance of using models and the best available science. In addition, combining the HSRG hatchery reform framework with thoughtful designations of populations based on biological importance can lead to realignment of propagation programs to provide more sustainable harvest in the future.

Hatchery reform has been implemented across the region in a wide range of programs including treaty, state, federal, harvest, and conservation programs. The most frequently implemented program changes include installing weirs (allows better management of hatchery broodstocks and natural spawning populations), developing locally adapted broodstocks (improves survival and productivity of hatcheryand wild populations), marking all hatchery releases (promotes effective broodstock management, wildstock assessment, and selective fisheries), and establishing new and more intensive selective fisheries (increases catch of hatchery-origin fish and survival of natural-origin fish). Some programs have developed comprehensive monitoring and evaluation plans that incorporate an adaptive management process.

However, more work is needed to align hatchery programs as part of an All H strategy coordinating the management of habitat, hatcheries, harvest, and hydropower to meet population goals. Many hatchery management plans do not contain quantitative harvest or conservation goals that are linked to population recovery goals. In addition, many hatchery plans still do not state explicit assumptions about population status and biological importance (population designations) or biological metrics that are critical to effectively achieve harvest and conservation goals. Long-existing institutional divisions of responsibilities have been cited as impediments to collaboration and coordination among habitat, hatchery, harvest, and hydropower managers. In addition, managers often face logistical, stakeholder, regulatory, and fiscal challenges in meeting population management objectives. The following are some key conclusions, findings, and scientific advances from this report that address habitat, hatchery, harvest, and hydropower management:

- Managing hatchery effects on the viability of naturally spawning populations is critical. Maximizing fitness and local adaptation is especially important to the viability of salmon and steelhead in the face of changing environmental conditions due to climate change.

- Managing hatchery effects on population fitness and local adaptation is necessary to realize the production potential of existing habitats and to realize benefits from investments in habitat improvements.

- Cultural and economic benefits of harvest are still important, and hatcheries are a necessary tool for the foreseeable future. Solutions exist that meet harvest goals while protecting the long-term viability of naturally spawning populations. However, this can only be achieved through scientifically informed decision making and accountability for trade-offs between near-term benefits and long-term costs in population viability.

- The HSRG recommendations and working hypothesis have been criticized, but better, scientifically supported alternatives have not been proposed. The HSRG standards should be challenged with better alternatives but not discarded because of imperfections or uncertainty. The existing paradigm has always contained imperfections and uncertainties. Though findings of recent scientific studies are consistent with the HSRG framework and assumptions, results will help refine parameter values in the future.

- The biological principle behind the broodstock standards for both integrated and segregated populations is to promote local adaptation and restore productivity and viability. A major concern with many current hatchery programs is that they have been operated in a manner that disrupts natural selection for population characteristics that are tailored to local environmental conditions. Proper integration or segregation of harvest augmentation programs is the recommended means to minimize the adverse effects of hatcheries on local adaptation of natural populations. Recent studies and analyses suggest that segregated hatchery programs should be used with even greater caution than originally suggested by the HSRG, because of their potential to harm viability of natural-origin fish.

- Research priorities for harvest augmentation programs should include studies on the relative reproductive success of hatchery fish spawning in the wild and the long-term fitness effects on naturally spawning populations caused as a result.

- Avoiding negative ecological interactions between hatchery- and natural-origin fish should be a primary concern for recovery efforts and fisheries management. However, to date HSRG has found no new information that might provide useful standards to estimate the size or scope of the effects of ecological interactions. The type, direction, and extent of ecological interactions should be assessed on a case-by-case basis.

- The scientific literature indicates that artificial enhancement can be of great benefit in raising the level of nutrients in freshwater systems. The methods endorsed by the HSRG are distribution of adult carcasses (where disease issues are not a concern) or carcass analogs. Nutrification projects require careful planning and evaluation to ensure that resources are used wisely and risks are understood.

- The HSRG recommends that monitoring plans be implemented as part of a structured annual adaptive management decision process for hatcheries. This process should specify roles and responsibilities, schedules, and data and information sharing and coordination.

- The need for regional consistency and coordination is well recognized but remains elusive. Improvements in this area would result in better use of resources and more reliable information. Standards for estimating population viability would help decision making at local and regional levels.

- Research programs, which tend to have global value, should be regionally designed, cost-effective, and coordinated to avoid misinterpretation and misapplication of results.

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Perspectives from International Fisheries Section Members

Blue Growth: The 2014 FAO State of World Fisheries and Aquaculture

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The latest United Nations Food and Agriculture Organization report (FAO 2014) addresses the prospect of feeding a human population set to rise to 9.6 billion by 2050. Aquaculture products now provide approximately one-half of all food fish consumed, and fish also provide important food security and economic growth. In the FAO analyses, food fish included finfish, crustaceans, mollusks, amphibians, freshwater turtles, and other aquatic animals (such as sea cucumbers, sea urchins, sea squirts, and edible jellyfish) produced for human consumption. At the present time, food fish provides the world population of nearly 7.3 billion people with an average of one-fifth of total animal protein intake.

In the 2014 report, the FAO promotes “Blue Growth” as a cohesive approach for environmentally compatible, integrated and socioeconomically sensitive management of aquatic resources including marine, freshwater, and brackish water environments. The report is divided into four parts: (1) world statistics of capture and aquaculture systems and sectors, (2) selected issues in fisheries and aquaculture, (3) highlights of special studies that help to interpret the statistics, and (4) the outlook for the future goals of meeting fish demand. Among the selected issues in part 3 are the role of aquaculture in meeting increasing nutritional needs and a discussion of the challenges in the management of inland waters and water development. The highlights of special studies include a summary of FAO voluntary guidelines on tenure rights and governance and a study of vulnerability to climate change.

According to the report, annual world food fish production from aquaculture rose annually by 5.8% in 2013 to 70.5 million metric tons. Production of farmed aquatic plants (mostly seaweeds) was estimated at 26.1 million metric tons. In 2013, China alone produced 43.5 million metric tons of food fish and 13.5 million tons of farmed plants. Statistics and comparisons including data for 2012 were provided in detail, organized by sectors and regions.

North American aquaculture development has not kept pace with the growth of production in other regions, especially Asia. Farmed fish production in the United States has declined over the past several years, whereas production in Asia has grown substantially. Domestic fish and shellfish production are challenged by several economic and social factors, including competition from cheaper imported products and an array of regulatory constraints. The State of World Fisheries and Aquaculture report for 2014 shows that production for North America (Canada, the U.S., and Mexico combined) dropped from 668,507 metric tons in 2005 to 593,476 metric tons in 2012. This production accounts for less than 0.9% of the total world production, exclusive of aquatic plants and nonfood products.

The U.S. ranks as number 15 among worldwide producers of farmed species, with a national total of 420,024 metric tons; however, this accounts for only 0.6% of world production. U.S. production remained dominated by finfish, primarily indigenous species such as Channel Catfish (*Ictalurus punctatus*) and Rainbow Trout (*Oncorhynchus mykiss*), produced in inland waters (44% of total). Finfish produced in mariculture operations including ocean and intertidal zones, as well as onshore land-based operations, accounted for 5% of the U.S. total. Shellfish production (e.g., mollusks) accounted for 40% of U.S. production and consisted of indigenous species and introduced species. The remaining 10% was crustaceans.

FAO promotes “Blue Growth” as a cohesive approach for environmentally compatible, integrated and socioeconomically sensitive management of aquatic resources including marine, freshwater, and brackish water environments.

Worldwide, the growth of inland aquaculture has outpaced mariculture and accounts for nearly 58% of aquaculture food fish production, likely reflecting its ease in development without a complex infrastructure. Crustacean aquaculture occurs in inland and mariculture environments. Crustaceans account for less than 10% of production by weight; however, their proportion of total by economic value is more than twice that amount, at 22.4% of the total. The economic value of world aquaculture was estimated at U.S. $138 billion.

The report voiced concern for the future growth of inland aquaculture, given increasing demands on land availability, freshwater resources, urbanization, and water development for energy, irrigation, navigation, and municipal and industrial uses. The role of reservoirs in aquaculture production is likely to increase, but there will be tremendous challenges with that due to water quality issues and even rural distribution networks. The report includes a discussion of the value of inland aquatic ecosystems for environmental/ecological services such as hydrological cycles, riparian communities, carbon sequestration, and cultural and recreational values. The estimated value of these services is U.S.$4.9 trillion. A more in-depth understanding of the value of ecosystem services would likely highlight the importance of functional fresh, brackish, and marine ecosystems, and the potential for integrated aquaculture combining fed with nonfed animals (e.g., mollusks) and opportunities for aquatic plants and algae (e.g., seaweeds).

References to the Blue Growth initiative are interspersed throughout the report. The Blue Growth initiative was developed from the United Nations Conference on Sustainable Development in Brazil (Rio+20) as a way to better address the need for sustainable, integrated, and socioeconomically sensitive management of seas, lakes, rivers, and reservoirs. Ecosystem approaches to fisheries and aquaculture, climate change, habitat restoration, protected areas, and regulation and control of invasive species are all part of the Blue Growth initiative. FAO-hosted workshops are scheduled for this fall at several locations around the world, including Bangladesh, Oman, Barbados, and Rome.

A disconcerting trend noted in the report was that the proportion of nonfed species (those feeding on natural feeds from the water) in farmed food fish production declined from 33.5% in 2010 to 30.8% in 2012. The growth of species reared on formulated feeds (manufactured feeds) has consequences for water quality, including nitrogenous wastes, feces disposal, and oxygen depletion. Production of formulated feeds also increases demands for fish oils and fish meals, as well as land-based plant proteins. The report indicates that Africa, Latin America, and Caribbean countries have pursued development of species fed on formulated feeds, and increased production with nonfed species could help these regions use the natural ecosystem services for production systems. Less carnivorous species, such as tilapia (family Cichlidae), continue to be used more commonly in aquaculture systems in 135 countries and territories on all continents.

The United States and Japan are the largest single importers of fishand fishery products. Both countries are highly dependent on imports for their fish consumption (at about 60% and 54%, respectively, of their total fish supply). Japan was the largest importer in 2012 at US$18.0 billion. Much of the product imported in both countries is high-value product. Worldwide, shrimp continued as the most valuable single commodity, constituting 15% of the total value of internationally traded fishery products in 2012.

Food safety and environmental compliance were reviewed in the report through discussion of the results of a questionnaire. The self-assessment questionnaire was provided to all governments, but fewer than 65 reported. Of the safety and compliance measures reported, escapes and carrying capacity were the least regulated, whereas regulation of nonnative species and food safety were the most regulated areas of aquaculture.

This new FAO report frames the theme of Blue Growth to move assessments and communications about aquaculture into an integrated framework that promotes responsible and sustainable fisheries and aquaculture. Will this be possible? How engaged are we as biologists in following and supporting this process? The FAO also provides technical guidelines on aquaculture certification and an evaluation framework for assessing such schemes. Overall, the major challenge for aquaculture governance is to ensure that the effective measures are in place to guarantee environmental sustainabilitywithout destroying entrepreneurial initiative and social harmony.

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Perspectives from International Fisheries Section Members

Current State of Aquaculture in México

Felipe Amezcua and Martin F. Soto

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México has an abundance of aquatic habitats, varied climates, and geological diversity; consequently, there are freshwater, brackish, and marine ecosystems that are suitable for the cultivation of various species of fishes, mollusks, crustaceans, and other species. At present, aquaculture activities in México are regarded as an important source of food and employment. Mean annual aquaculture production is 224,249 metric tons and continues to grow (CONAPESCA 2008). In terms of its contribution to global aquaculture production, México ranks third for tilapia (65,000 metric tons/year; CONAPESCA 2007) and sixth in marine shrimp (126,000 metric tons/year in 2009; FAO 2012). These production volumes are substantial; however, considering its size, the area occupied by the inland water bodies, and the number of aquatic species inhabiting its waters, México may be considered an "underachieving" country in aquaculture production (Villaseñor and Amezcua 2014). Other smaller countries with fewer inland water bodies such as Vietnam, Indonesia, Thailand, Bangladesh, Chile, and the Philippines rank higher in production; in 2006, these countries were among the top 10 aquaculture producers, whereas in the same year, México ranked 25th (FAO 2012). There are several reasons why aquaculture is underdeveloped in México.

Freshwater aquaculture dominates the industry in México, accounting for 80% of all operations and producing the greatest amount of biomass (Norzagaray-Campos et al. 2012). One of the main issues with freshwater production is that almost all the cultured species—tilapia, carp, trout, and crayfish—are nonnative. Native species are not widely cultivated because their biology and culture methods are poorly understood, there is a general lack of interest in them among culturists and also agencies who might fund native species aquaculture research, and their market value is usually low compared with exotic species (Norzagaray-Campos et al. 2012). It is known that some native species are threated with extinction due to habitat degradation and destruction, including the presence of invasive and exotic species (Miller et al. 2005; Torres-Orozco 2011); however, little is being done to prevent this from happening. Another challenge with freshwater aquaculture is the lack of studies of the inland waters in which it occurs. Most farming occurs in reservoirs, but there is little to no information available about the carrying capacity of these systems. This can result in eutrophication of water bodies due to aquaculture production throughout the year in addition to nutrient inputs from human activities and flooding during rainy season (Olvera-Viascán 1992; Muro-Torres 2009); as a result, high mortality rates are common. The former two problems are compounded by the lack of aquaculture research activity and aquaculture professionals that might resolve these issues.

For marine and brackish aquaculture in México, shrimp is the most important aquaculture industry, representing profit sales of approximately US$700 million. Because of shrimp aquaculture's economic importance and industry growth over the last two decades (FAO 2012), large amounts of effort and resources are dedicated to this activity. Major areas of research are nutrition and development of improved feeds, determination of the optimal conditions for each cultured species, improving larval survival, genetic improvement (Norzagaray-Campos et al. 2012), and more recently, pathology, specifically focused on viral and bacterial diseases of shrimp (Guzmán et al. 2009). However, shrimp aquaculture is criticized for its unsustainable practices. These include pollution by discharge of effluents rich in nutrient and organic matter, causing eutrophication and frequent harmful algal blooms in coastal waters; destruction of sensitive coastal habitats, including mangrove forests; threats to aquatic biodiversity; and depletion of fishing stocks (Páez-Osuna et al. 2003). Major challenges to shrimp farm success include the proper management of diseases, as adequate protocols are required to avoid the spread of diseases to wild populations, and the effect of this activity on stocks of sardines and anchovies, as these are used for the production of formulated food (FAO 2013). Future plans to move the shrimp industry inland might also cause problems with saline intrusion into agricultural soils.

Another challenge for marine aquaculture in México is that it is focused on a small number of species. At the moment, only shrimp and few species of mollusk and finfish are being farmed, but México has a large diversity of other species that are suitable for aquaculture. Although some research is being done to investigate these species, more research is needed in order to diversify marine aquaculture in México (Norzagaray-Campos et al 2012).

The Mexican government, together with FAO, producers, and academia, is addressing these issues through the National Program of Fisheries and Aquaculture 2014-2018 (SAGARPA 2014). The goal of this program is to identify the limiting factors that preclude the development of aquaculture in México and look for solutions to problems in six main areas: 1) legal framework for aquaculture development; 2) markets and production; 3) current state of natural resources; 4) technology development; 5) research; and 6) obtaining food security and rural employment through aquaculture. This program is now at the end of the first stage, which was the establishment of the program's action plans to further the development of sustainable, profitable aquafarms in México.

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ANNOUNCEMENT

Renewable Natural Resources Foundation
Congress on Adapting Food Production to a Changing Climate: Identifying Tactics and Establishing Priorities
December 9–10, 2014
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Agricultural systems are extremely sensitive to climatic variability. Deviations from historical patterns of temperature and precipitation cause agricultural areas to shift, affecting crop production cycles and yield, and the proliferation of disease, insect pests, and weeds. Extreme weather patterns, especially drought, pose an increasing risk to food supplies as the planet warms. The consequences of a changing climate will vary from region to region and will be alleviated or exacerbated by each region's respective social, economic, and political environment.

Elements of sustainable domestic agricultural production include water allocation, crop selection, adjusted production and harvesting strategies, and policies prioritizing resilience. The international community faces similar issues. The situation is more complicated in some regions because of economic and social pressures. Food shortages can pose humanitarian crises and national security concerns.

RNRF congress delegates will discuss the consequences of a changing climate on agricultural production and identify tactics and priorities for sustaining global productivity. The congress will feature discussions on domestic and international policies, agronomic and technical solutions, economics, food security, and distribution. It will conclude with a discussion of the future of international agricultural and food institutions. The primary goals of this meeting are to identify specific strategies and tactics to sustainably adapt food production to a changing climate and explore the multi-disciplinary and global scale of this challenge.

For more information contact Melissa Goodwin, Program Director, E-mail: melissa.goodwin@rnrf.org

Perspectives from the Socioeconomics Section

The Role of Hatcheries in Ensuring Social and Economic Benefits of Fisheries in the United States

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Fish and fishing are woven into the fabric of American culture and deliver numerous social and economic benefits. Natural fisheries are the foundation for providing fish and fishing benefits,but angling exploitation, habitat degradation, and human population increase strain these natural systems. State and federal hatcheries ensure the quality of these fisheries by supplementing natural recruitment.

The story of a father taking a son fishing has been lived so many times in our country that it has become a rite of passage. It is a rite of passage that was romanticized in the iconic opening segment of *The Andy Griffith Show* and many other areas of popular culture. It has evolved from father–son trips, to mother–son trips, to father–daughter trips, to whole family fishing trips (including every definition of today's modern family).

Fishing is a leading recreational activity in the United States. In 2011, over 33 million U.S. residents over the age of 15 went fishing on over 455 million fishing trips (U.S. Department of the Interior 2011). These trips facilitate the strengthening of family and friendship bonds, and for many anglers, fishing is as much about interpersonal relationships as it is about the fish. Many other anglers seek solitude and mental health benefits when they take to the water. Paul Quinnett, in his book *Pavlov's Trout*, expresses that those who fish are less likely to commit suicide because fishing is essentially the practice of having hope.

Fish and fishing are also essential to many indigenous peoples' cultures as well, typically serving both ceremonial and subsistence roles. Hatcheries play a vital role in fulfilling various treaty and statutory commitments between the U.S. and tribal nations.

Social and cultural values of recreational fishing also translate into economic benefits. In 2011, recreational fishing trip and equipment expenditures totaled greater than $41 billion (U.S. Department of the Interior 2011), and total gross domestic product contributions were approximately $62 billion (Southwick Associates 2013). Commercial and recreational fishing combined sales impacts reached nearly $200 billion in 2012 and supported 1.7 million jobs (National Marine Fisheries Service 2014). Fishing equipment and motorboat fuel sales support fishing conservation through the utilization of the North American Model of Fish and Wildlife Conservation, whereas excise taxes go to support state fisheries agencies efforts to manage, conserve, and research our fisheries resources.

Quality fishing increases property values as well. In Wyoming, it was estimated that the statewide value of agricultural land increased by almost 10% with increased angling quality (Wasson et al. 2013). Obviously, fishing quality can be greatly influenced by the work conducted in our nation's hatcheries and thus indirectly can effect property values.

Recreational, commercial, and subsistence fisheries are all benefited by hatchery production and in turn provide enhanced cultural, social, and economic benefits to our nation. However, hatchery operations alone are major economic drivers. In 2006, the federal fish hatchery system supported over 8,000 jobs, $903 million in economic output, and 13.5 million angler days (Charbonneau and Caudill 2010).

In response to potential closures of federal hatcheries earlier this year, witnesses testified to the House of Representatives Committee on Natural Resources as to the importance of a robust national fish hatchery system. Congressman Collins of Georgia testified to the importance of the Chattahoochee Forest National Fish Hatchery saying, "It is beloved by the community, it shows great return on investment, and it is an economic engine of this part of rural Georgia … having generated just over $30 million of total economic output on just a $747,000 investment." Arkansas Congressman Crawford's district includes both Greer's Ferry and Norfork National Fish Hatcheries (two of the largest mitigation hatcheries in the United States). He testified that these two hatcheries were responsible for $150 million in annual economic output and over 1,700 jobs.

Hatchery impacts on fishing success and the economy are readily apparent, but they still only represent a portion of the services provided by hatcheries. Hatcheries also produce a plethora of non–sport fish to restore imperiled populations and maintain biodiversity. Such ecosystem services provide value to our environment but can be difficult to translate into dollars and cents. However, research has demonstrated that the public's willingness to pay typically well exceeds the cost of recovery and restoration of imperiled species (Loomis and White 1996). Even though existence value can be difficult to quantify, it is still an intangible benefit provided by hatcheries through the raising and restocking of imperiled fishes.

Without a doubt, the benefits provided by our nation's state and federal hatcheries are substantial on many levels. Ensuring quality recreational fishing, preserving our natural heritage, supporting commercial stocks, and facilitating the continuation of portions of native culture are all occurring thanks to hatcheries. Much of this work is easily overlooked, but I for one am grateful for our robust system of public fish hatcheries and the important work that they conduct.

ACKNOWLEDGMENTS

I would like to thank Jesse Trushenski for her vision to have a hatchery-centric edition of *Fisheries* and her leadership to make it a reality. Most of all, I want to thank the hardworking and often overlooked staff of the state and federal hatcheries, who every day are on the front lines conducting research, checking water quality, treating disease, hatching, feeding, harvesting, hauling, and stocking fish. Without your dedication and efforts, the previously described benefits to our nation would not be realized.

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Perspectives from the Water Quality Section

Aquaculture and Water Quality Management in the United States

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INTRODUCTION

Aquaculture is a diverse enterprise, involving controlled or semicontrolled rearing of aquatic organisms for food, natural resource management and imperiled species restoration, ornamental enjoyment, research, and educational purposes. Human population growth will continue, as will anthropogenic disturbances on aquatic ecosystems; therefore, the need for aquaculture's services and functions will continue to increase in the coming decades. Although use patterns vary depending on the culture system involved, raising fish requires water and can have downstream effects. Here, we present a brief synopsis of aquaculture and its relationships to water quality, especially in the United States. By no means do we present a comprehensive assessment of this topic, but we hope that the information below can help fishery professionals and the public better understand these issues, engage in informed discussion, and encourage the use of practices that reflect stewardship of aquatic resources, including water, and allow aquaculture to provide its many benefits to the public.

WATER QUALITY WITHIN AND OUTSIDE AQUACULTURE SYSTEMS

Water quality management is fundamental to all forms of aquaculture and involves monitoring and adjustment of physical (e.g., temperature) and chemical (e.g., pH, alkalinity, salinity) parameters, as well as related biological variables (e.g., biological oxygen demand, chlorophyll *a*) that can affect the physical and chemical condition of water. This broad definition of water quality is accepted not only in aquaculture (e.g., Boyd and Tucker 1998) but also in natural ecosystem management (e.g., Novotny 2003; Brown et al. 2005). Fisheries professionals engaged in aquaculture have strong interests in source water quality and water quality management within the culture systems, whereas fisheries professionals engaged in management of wild fish and natural systems may have greater interests in water quality outside the culture systems and the potential effect of aquaculture effluent on receiving ecosystems. We divided the discussion on this topic into these two perspectives.

Water Quality within Aquaculture Systems

All aquaculture operations require water, and both the quantity and quality of water available will determine the species and densities that can be raised, as well as what culture systems can be used. Though aquaculture is a consumer of freshwater, the volumes used are minor compared to uses for other agricultural purposes and, unlike these other uses, water use in aquaculture is largely nonconsumptive. Virtually every aspect of water quality will influence culture practices, including water temperature, salinity, dissolved oxygen, pH, alkalinity, and suspended solids/turbidity. However, in the present work, we will focus on those parameters for which it is most likely that natural environments and culture systems will interact.

Within a specific aquaculture system in a certain location, water quality is primarily driven by standing biomass (i.e., the density of aquatic organisms in the culture system), feed and/or fertilizer inputs (e.g., amount and type), and various technologies used to amend or adjust water quality prior to use or discharge (e.g., degassing, aeration, physical and biological filtration). Key water quality parameters within an aquaculture system are dissolved oxygen (DO), ammonia, and pH. To provide sufficient DO for growth of fish and other cultured aquatic animals, an aeration system is most commonly used. For example, electric paddle wheel aerators (Figure 1) are common in aquaculture ponds for culturing Channel Catfish (*Ictalurus punctatus)* or other species (e.g., Torrans 2008). Ammonia is usually monitored in the form of total ammonia nitrogen (TAN), which includes the less toxic ionized form, NH_4^+, and the unionized form or more toxic form, NH_3. High concentrations of ammonia (e.g., TAN > 1.0 mg/L) can cause stress or even have lethal effects on cultured aquatic organisms. The effects of pH on cultured aquatic organism are mainly indirect, whereby pH affects other water quality parameters such as the toxicity of

Figure 1. Electric paddle wheel aerators provide dissolved oxygen (DO) for cultured Channel Catfish in a commercial pond, east Arkansas. Photo credit: Sagar Shrestha.

ammonia (i.e., the NH_4^+:NH_3 ratio is influenced by pH; Boyd and Tucker 1998). The optimum pH range for aquatic animals is between 6.5 and 9.0. When pH goes above or below this range, sublethal and lethal effects can be seen on cultured organisms, especially during the early life history (e.g., Mischke and Chatakondi 2012; Chen et al. 2014).

For intensive aquaculture systems to be operated effectively and efficiently, these water quality parameters must be monitored closely (Figure 2). In addition to the above-mentioned water quality parameters, depending on the culture system, turbidity and Secchi disk visibility, nitrite, hardness, and hydrogen sulfide are also routinely monitored in aquaculture systems. Clearly, there is a role for water quality scientists in helping to optimally manage aquaculture systems.

Water Quality Outside Aquaculture Systems

Discharges or effluents from the aquaculture systems are often a primary concern of natural fishery professionals and the public. However, aquaculture systems range from essentially closed (e.g., ponds and tanks), to partially open (e.g., raceways), or fully open (e.g., net pens, cages) systems, to natural aquatic ecosystems (e.g., so-called ranching operations). Effluents can be discharged passively, such as from net-pens/cages, or actively, as in the case of continuous flow-through systems or periodic discharges from recirculation/reuse systems. These different types of discharges affect the magnitude of interactions between the culture system water quality and the receiving water quality. Major effluent constituents of concern are total suspended solids (TSS), nutrients (i.e., nitrogenous wastes and phosphorus), and biodegradable organic materials. For instance, when a natural aquatic ecosystem (a stream or a coastal shore) receives large amounts of TSS, nutrients, and organic materials (from any source) that exceed the system's capacity to process and integrate these materials (i.e., the amount the receiving water body can use and recycle), the excess may increase aerobic respiration (by stimulating microbial activity), which may contribute to hypoxic conditions (e.g., DO < 2.0 mg/L) in the receiving aquatic ecosystem. Additionally, the extra nutrients may stimulate growth of algae and aquatic plants, potentially causing water quality degradation (i.e., eutrophication) of the receiving aquatic ecosystem. Without treatment controls in place, continued water quality degradation could result in mortality of sensitive aquatic organisms, shift aquatic communities to more environmentally tolerant species, and, in extremely rare cases, ecosystem collapse.

To meet the objectives of the United States Clean Water Act, the United States Environmental Protection Agency (USEPA) finalized a new rule establishing effluent limitation guidelines for concentrated aquatic animal production (CAAP), or aquaculture, facilities on 30 June 2004 (USEPA 2004). The regulation applies to CAAP facilities that generate wastewater from their operations and discharge that wastewater directly

Figure 2. Graduate students John Farrelly (left) and Christopher Laskodi (right) at the Aquaculture and Fisheries Center, University of Arkansas–Pine Bluff, put a data sonde in a commercial Channel Catfish pond to monitor DO and related water quality in eastern Arkansas. Photo credit: Yushun Chen.

into waters of the United States. The CAAP effluent limitation guidelines will help reduce discharges of TSS, nutrients, aquaculture drugs, and chemicals (USEPA 2004). However, the target CAAP facilities should have the following characteristics: (1) use flow-through, recirculating, or net-pen systems; (2) directly discharge wastewater; and (3) produce at least 100,000 pounds of fish a year (USEPA 2004). The use of drugs and chemicals in U.S. aquaculture is also strictly regulated by the U.S. Food and Drug Administration, which requires extensive proof of the environmental safety of drugs prior to approving their use.

Many aquaculture ponds are closed aquaculture systems without direct connections to adjacent natural streams. For instance, the Mississippi River Delta catfish and bait fish ponds in states of Mississippi and Arkansas that we have worked on in the past several years are within this category. The ponds are harvested by seines every year and usually not drained for 10–15 years. During the draining, the pond water is often pumped from one pond to another pond (Figure 3) instead of draining the pond water to an adjacent natural stream to (1) save scarce water resources and (2) avoid negative impacts on adjacent natural streams. Compared with ponds, partially and fully open aquaculture systems have a greater chance to connect with the adjacent natural aquatic ecosystems. For instance, by design, cages have frequent water exchange with outside open environment (e.g., a lake or a coastal shore). However, cultured species also play an important role in mitigating environmental effects from aquaculture. For instance, some filter-feeding organisms (e.g., shellfish) can have positive environmental effects as they remove algae and suspended particles from the water column (Rice 2008).

Aquaculture facilities (fish farms, hatcheries, etc.) within the United States are under a great amount of regulatory scrutiny from the USEPA and state and local environmental agencies. Similar to other dischargers, they must operate under National Pollutant Discharge Elimination System permits and stay within strict discharge limits or face steep fines if these limits are exceeded. In addition, aquaculture facilities are regulated strictly by the U.S. Food and Drug Administration, U.S. Fish and Wildlife Service, U.S. Department of Agriculture and U.S. Department of Agriculture Animal and Plant Health Inspection Service, and National Oceanic and Atmospheric Administration. To develop sustainable aquaculture, the aquaculture community has been very proactive in promoting environmental conservation. For instance, guidelines are available for aquaculture effluent management for producers (e.g., Boyd 2003). To minimize the

Figure 3. Draining a bait fish pond by pumping the pond water from one pond to another pond in a fish farm in east Arkansas. Photo credit: Yushun Chen.

environmental impacts from aquaculture, a series of environmental best management practices (BMPs) has been developed and proposed for individual aquaculture systems (e.g., Tucker and Hargreaves 2008). For aquaculture systems having direct effluents into adjacent natural aquatic ecosystems, whether with or without BMPs implemented, the receiving aquatic ecosystem may need to be monitored regularly with respect to TSS, nutrients, DO, aquaculture related chemicals and/or biological metrics, to either detect impacts of the aquaculture operation or ensure the effectiveness of implemented BMPs on mitigating environmental impacts from the aquaculture operation.

CONCLUSIONS

In summary, aquaculture has been and will continue to play a large role in water quality and natural resources conservation. We conclude with the following points: (1) aquaculture will further develop all over the world in the coming decades to meet increasing human and society demands and to aid in management and restoration of aquatic resources; (2) water quality is involved in almost every aspect of aquaculture; and (3) aquaculture professionals in the United States need to maintain good water quality within aquaculture systems to achieve production goals and to meet federal, state, and local requirements regarding water use and discharge. In this context, there is a natural partnership between water quality scientists and aquaculturists to ensure that the aquaculture operations and natural aquatic ecosystems continue to coexist in balance.

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Perspectives from an AFS Marine Fisheries Section Member

Offshore Aquaculture Regulations Under the Magnuson-Stevens Fishery Conservation and Management Act

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Disclaimer: The views and opinions expressed in this article are those of the author and do not necessarily reflect the official policy or position of the Mid-Atlantic Fishery Management Council.

STATE OF WORLD FISHERIES

Worldwide, the percentage of assessed fish stocks that are overexploited or fully exploited is 87% (FAO 2011). The possibility of future expansion in wild catch is questionable and the risk of decline if not properly managed is real. However, aquaculture production has allowed global fish production to outpace world population growth (FAO 2014). There is no doubt that aquaculture plays an important role in the world food supply. In 2012, aquaculture contributed about 50% of all fish for human food worldwide. Projections indicate that this share will increase to 62% by 2030 as wild capture fisheries production stabilize and seafood demand continues to increase (FAO 2014).

While aquaculture is an important component of global and U.S. food systems, the U.S. aquaculture sector has not shared the global growth of the aquaculture industry (FAO 2014). In order to satisfy consumer seafood demand, the U.S. heavily relies on imports, with over 90% of the seafood consumed (in edible weight) in the U.S. is imported (Fisheries of the United States 2012). However, a portion of the imported food is caught in the U.S., exported overseas for processing, and then reimported to the United States. The U.S. aquaculture industry presently contributes 5% to the seafood demand in the country, producing primarily oysters, clams, and some finfish (Fisheries of the United States 2012). In the future, orderly increases in the domestic growth of the marine aquaculture sector will alleviate the dependence on foreign imports to meet domestic seafood demand, reduce trade deficit, create domestic jobs, create products/services, and keep working waterfronts viable, while protecting the marine ecosystem.

NOAA/MSA CONNECTION

In order to foster the domestic growth of the aquaculture industry in the United States, the National Oceanic and Atmospheric Administration (NOAA) has implemented a marine aquaculture policy within their broader stewardship mission that includes social and economic goals (Available: www.nmfs.noaa.gov/aquaculture/docs/policy/noaa_aquaculture_policy_2011.pdf). NOAA regulates fishing in federal waters, including aquaculture, under the Magnuson-Stevens Fishery Conservation and Management Act (MSA). The act created eight regional fishery management councils to manage fisheries in federal waters and promote conservation. Regional fishery management councils are responsible for preparing Fishery Management Plans (FMPs) for fisheries within their areas of geographic authority. An FMP includes data, analysis, and management measures required to meet the goals and objectives of the specific plan. The FMPs are based on national standards for fishery conservation and management set forth in the MSA, and contain an environmental assessment or an environmental impact statement. FMPs are submitted to the Secretary of Commerce for approval and implementation.

The applicability of MSA depends on whether the species being cultured is federally managed and therefore subject to an FMP (National Sea Grant Law Center 2014). For proposed aquaculture operations that involve the culture of a federally managed species, special permits may be required to use aquaculture gear, and harvesting of the species may be subject to other management regulations in place (e.g., minimum size limit, seasons, daily harvest limits). For proposed aquaculture operations that do not involve the culture of a federally managed species, a permit from the National Marine Fisheries Service (NMFS) would not be required. Nevertheless, NMFS would still consult with other federal agencies to ascertain that other laws and responsibilities such as the Endangered Species Act are met (National Sea Grant Law Center 2014).

Currently, only the Gulf of Mexico Fishery Management Council (GMFMC) has implemented a comprehensive aquaculture FMP that covers aquaculture for all managed species (except shrimp and corals). The GMFMC developed the aquaculture FMP to provide a programmatic approach to evaluating the impacts of aquaculture proposals in the Gulf of Mexico and a comprehensive framework for regulating such activities. The primary goal of this aquaculture permitting program is "to increase the maximum sustainable yield and optimum yield of federal fisheries in the Gulf of Mexico by supplementing the harvest of wild caught species with cultured product" (GMFMC 2009). The aquaculture FMP provides an instrument by which the GMFMC and NOAA/NMFS can authorize aquaculture operations for federally managed species in federal waters in the GMFMC jurisdiction under the MSA.

In 1998 the New England Fishery Management Council (NEFMC 1998) developed a framework adjustment process in all the councils' FMPs to include aquaculture of managed species in the Exclusive Economic Zone. This process operates in conjunction with the existing federal regulatory roles of the Environmental Protection Agency (EPA), NMFS, U.S. Coast Guard (USCG), etc.

OTHER FEDERAL REGULATORY ELEMENTS

It is important to mention that the current regulatory process for offshore aquaculture is extensive. Authority for offshore aquaculture falls primarily within the Army Corps of Engineers (Corps) and the EPA. The Corps, under the Harbor and Rivers Act, is responsible for issuing permits for structures located in navigable waters. EPA asserts regulatory authority over discharges of aquaculture facilities (as Concentrated Aquatic Animal Production [CAAP] facilities) under the Clean Water Act (Rieser and Bunsick 1999).

When permitting unmanaged species for culture, the role of NMFS is limited to consultation with the Corps under Section 7 of the Rivers and Harbors Act and Essential Fish Habitat under MSA. However, active participation of the regional fishery management councils is not strictly required. The Corps process does include having all proposed projects out for a public comment period.

EXAMPLES OF HOW THE CURRENT REGULATORY PROCESS HAS WORKED

Currently marine aquaculture production in the U.S. involves the culture of unmanaged species in state waters. This is slowly changing as entrepreneurs, using mature technology from the rest of the world, sense an opportunity in federal waters. In the past year, there have been multiple applications for shellfish culture in federal waters off of Southern California and Massachusetts, and for finfish culture off of Hawaii. All of the shellfish farms are for unmanaged species, thus no council participation was required.

In the case of the Massachusetts proposals, a presentation was made to the NEFMC as a courtesy to apprise them of one of the projects. However, while in federal waters, a second project was also under the fisheries jurisdiction of the state. In the latter project, a notice was given to the state and council by the applicants. In these cases, local fishing industry participants were principals and active participants in the projects, and the lead federal agency for these applications was the Corps. These proposals were reviewed by multiple federal agencies (NMFS, USCG, EPA, etc.).

For the finfish farms in Hawaii, all farms were permitted in federal waters under a one year Exempted Fishing Permit (EFP). One was not anchored so it did not require a Corps permit, the other was permitted by the Corps. For one project, NMFS authorized a demonstration project through permits issued under regulations implementing the Western Pacific Regional Fishery Management Council's Fishery Ecosystem Plan (a broad ecosystem-based approach that addresses all managed species in the ecosystem) for the Hawaiian Archipelago (National Sea Grant Law Center 2014). As such, aquaculture operations for federally managed species under an existing FMP can be authorized or restricted by NOAA/NMFS even if the FMP for such species does not directly address aquaculture.

Currently there are two other projects for finfish culture in federal waters that the author is aware of. One is off the coast of Southern California and the other off of Hawaii. There is also considerable interest in mussel culture in New England waters and finfish culture in the Gulf of Mexico. Regulations for the Gulf of Mexico FMP have been in the development process since 2009 with the release of the FMP. It is hoped that the regulations governing the activities will be released by the end of 2014, although various roadblocks will probably delay implementation for an indeterminate time.

CONCLUSIONS

There is no doubt that aquaculture is occurring and will continue to grow. However, the lack of a unified federal regulatory process could be construed as an experiment at the state and regional level. As this experiment plays out, a winning combination of regulatory process and industry development could serve as a model for future development. The questions are, how long this will take and what is the price the nation will pay in foregone jobs and lost fish production?

ACKNOWLEDGMENT

The author wishes to thank David Alves (Greater Atlantic Region Aquaculture Coordinator/NOAA Aquaculture Office, National Marine Fisheries Service, Greater Atlantic Regional Fisheries Office, 55 Great Republic Dr., Gloucester, MA 01930) for his valuable comments and suggestions during the preparation of this informational article.

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Raising Shrimp Raises Concerns, Offers Answers for an Increasingly Invertivorous Public

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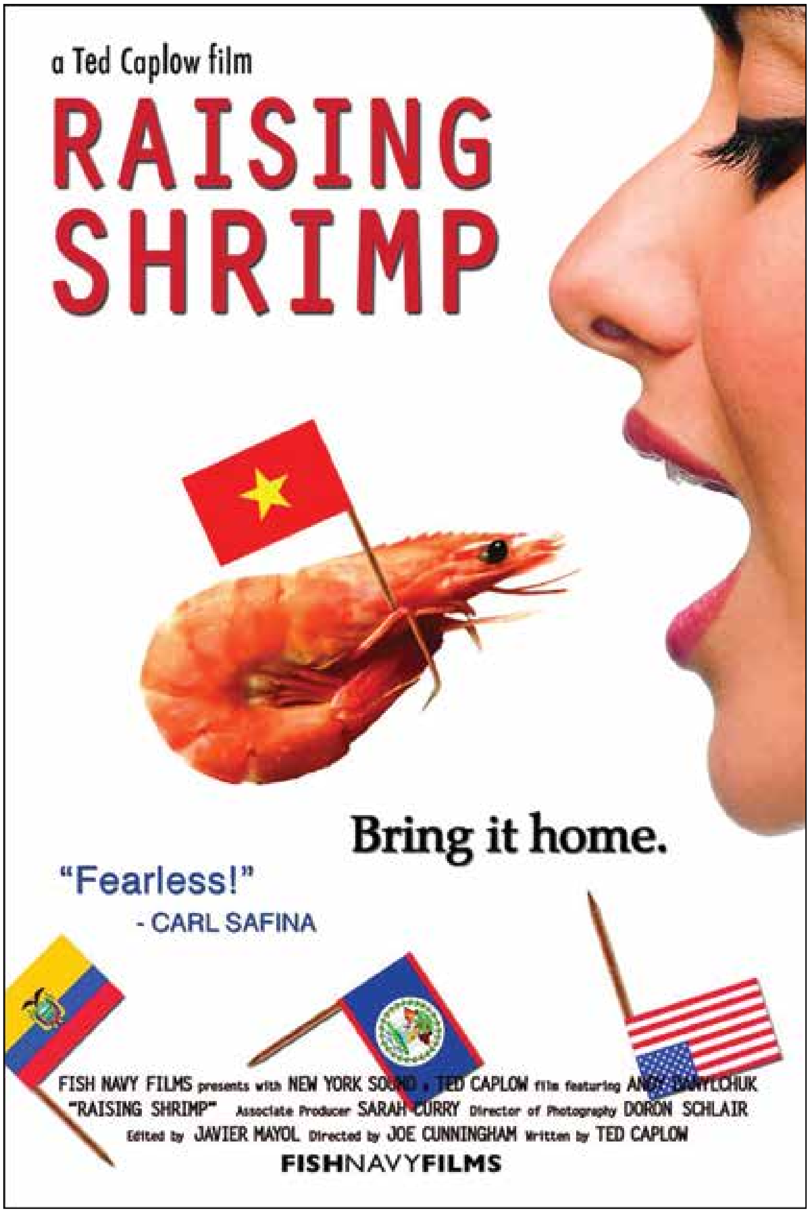

Shrimp is America's favorite seafood: shrimp kebabs, shrimp creole, shrimp gumbo, pan fried, deep fried, stir fried, pineapple shrimp and lemon shrimp, coconut shrimp, pepper shrimp, shrimp soup, shrimp stew, shrimp salad, shrimp and potatoes, shrimp burgers, shrimp sandwiches … I could go on, but it might constitute infringing on a particular film's copyright and I'd rather not find out whether Tom Hanks has a bad side. The point is that most Americans love shrimp. But few of us really know where these beloved "bugs" come from. In their first film, *Fish Meat*, Ted Caplow and AFS member Andy Danylchuk tackled some of the controversies associated with fish farming. In their newest effort, *Raising Shrimp*, the filmmakers dive deeper to get to the bottom of shrimp farming.

Balancing biological and economic viability is a challenge for many sectors of the aquaculture industry: many species are easy to raise, but there is little demand for them; others may command staggering prices in the marketplace but are challenging to culture. Shrimp are unique in that are relatively easy to raise, they aren't especially demanding or picky eaters, and yet consumers can't get enough of them and are willing to pay premium prices for the sweet, salty, unmistakably shrimpy taste they crave. But what does shrimp farming really entail and how do farmed shrimp measure up against wild-caught ones? *Raising Shrimp* gives viewers some insight into the fraught waters of industrialized fishing and aquaculture and how seafood—really all food—is produced, distributed, and consumed throughout the world today.

Wild-caught shrimp are becoming more and more scarce, as evidenced by longer fishing trips, smaller quotas, fewer boats, and dwindling catches. These fisheries also face climbing energy prices—the filmmakers note that it takes about two pounds of fuel to catch one pound of shrimp—and growing unease regarding the ecological consequences of bottom-trawl fisheries. Even at historic levels, the U.S. catch of shrimp couldn't begin to sate domestic demand. Aquaculture is the answer, but after investigating different approaches to shrimp farming, Caplow and Danylchuk conclude that some strategies may be better positioned to deliver on the promise of economic and environmental sustainability.

In addition to telling a compelling story, *Raising Shrimp* is buoyed by an engaging score and beautiful imagery captured in Texas, Belize, and beyond. To view the trailer or to find out more about *Raising Shrimp*, visit Fish Navy Films at www.fishnavy.com.

Little Port Walter Marine Station

What is the name of your facility, how did it get that name, and how long has it been in operation?

The National Marine Fisheries Service's (NMFS) Little Port Walter Marine Station is located on Baranof Island in Southeast Alaska and is named after the small estuarine bay called Little Port Walter where the facility resides. It serves as a remote field station and hatchery for NMFS' Alaska Fisheries Science Center (AFSC) scientists conducting research on a wide variety of fisheries issues. The station is located in the Tongass National Forest and is only accessible by boat or floatplane.

What fish do you raise, approximately how many do you raise, and what are they used for?

All of the fish cultured at Little Port Walter are reared for the sole purpose of research. Currently, we have two stocks of Chinook Salmon *Oncorhynchus tshawytscha* on site: Unuk River stock and Chickamin River stock Chinook. Both stocks are native to Southeast Alaska. The Unuk River stock production serves as an indicator stock model to the Pacific Salmon Commission and both stocks are used in forecasting future returns of Southeast Alaska Chinook Salmon based on harvest.

Gametes from the Unuk and Chickamin stocks were harvested in the late 1970s and brought to the station for culture. Over the last 30 years, five generations of returning adults have provided invaluable data pertaining to hatchery and wild fish interactions in Chinook Salmon. One unique aspect of our Chinook production is that we use coded wire tags for 100% of our fish. This allows us to track every individual fish recovered in local fisheries.

What is the biggest challenge facing your facility today? What challenges do you foresee in the future?

The biggest challenge facing the Little Port Walter station today is accomplishing the necessary work with an ever-shrinking number of staff. Another concern is the age of the facility – there is always the challenge of finding stable funding for large-scale upkeep and major renovations.

Innovation is a part of how any operation deals with emerging challenges. How does innovation happen at your facility and how does it benefit your operation and others?

The station has hosted many cooperative programs with other National Atmospheric and Ocean Administration (NOAA) offices and laboratories, the Alaska Department of Fish and Game, several universities, and regional aquaculture associations. Significant work has been accomplished in cooperation with Little Port Walter, NOAA's Northwest Fisheries Science Center and Purdue University conducting steelhead *Oncorhynchus mykiss* genetic work pertaining to the Endangered Species Act recovery efforts. Research topics focused on the heritability of growth, precocious maturation, genetic characteristics of smolting, effects of inbreeding in captive and wild populations, and recovery work using resident forms of salmonids to develop naturally anadromous forms.

Any recent successes, news, trivia, or facts you can share?

One of our current projects is to assess the applicability of using natural genetic variation to track progeny from individual hatchery mating pairs. This parental-based genotyping project (PBT) is done by collecting genetic samples from broodstock and using the DNA characteristics of the parents to track the

offspring, the efficacy of which will be monitored by comparing identified parentage with coded wire tags. This project is funded by the Pacific Salmon Commission through an award to Andrew Gray, Little Port Walter Station's Manager. In addition, we're developing future projects including evaluating the efficacy of different feed types (Taylor Scott, fish culturist) and laying potential groundwork to develop a new Chinook broodstock to combat inbreeding issues, focusing on one with an "ocean-type" life history trait, meaning some portion of the stock naturally outmigrates as a sub-yearling.

The station was originally a herring saltery in the early 1900s, but has served as a federal research station for the last 78 years. It is the only Chinook Salmon research facility in the state of Alaska, and it is the oldest operational year-round biological research station in the state as well. The station receives over 225 inches of rainfall annually, providing us with excellent water for fish culture, in addition to making Little Port Walter the wettest permanent settlement in North America.

In one sentence, why is fish culture important?

Fish culture is an important tool for management of fisheries and aquatic resources and for developing techniques and technology to maximize hatchery program production goals while minimizing impacts on wild and endangered fish stocks.

How can people reach you?

Email: Taylor Scott, Fish Culturist - taylor.scott@noaa.gov
Website: www.afsc.noaa.gov/ABL/MSI/msi_lpw.htm

To see the complete Better Know a Hatchery feature on the Little Port Walter Marine Station, or to "better know" other fish culture facilities visit fishculturesection.org and click on the Better Know a Hatchery tab.

Aquaculture 101 or… Random Thoughts on Aquaculture

Andrew Fayram

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Aquaculture is a bit of a funny enterprise to me. I'm not sure why. I mean, the advent of agriculture in the Fertile Crescent is often referred to as the genesis of modern civilization. Having a reliable source of food that was, at least somewhat, under one's control was a transformative moment in human society. We have accepted, as a matter of course, dramatic changes in land use to facilitate agriculture. Aquaculture, literally aquatic farming, should simply be an extension of agriculture, no? However, it does seem that there is more tension related to aquaculture than might be expected. Agriculture is a well-accepted component of society. However, aquaculture has historically played a less prominent role, at least in Western cultures.

Aquaculture is prevalent in many societies and has been practiced for millennia, but only about half of the seafood consumed worldwide comes as a result of fish farms. The other half results from the capture of wild fish. Think about that. What if half of our beef was produced from wild cows running willy-nilly on the plains? What if we had to go to the woods to harvest our corn? That situation would seem to be less than sustainable in our modern society, but it is what generally happens with fish. It is an interesting and somewhat novel situation, to be sure. Perhaps our continued reliance on wild-caught fish has made some of us more concerned about the potential environmental and genetic risks associated with aquaculture ventures than we might be about, say, a new breed of cow.

Certainly, fish from aquaculture provide a relatively accessible source of protein. Fish are generally very efficient producers of protein in terms of area required to produce a given amount. This fact is one of the reasons that the FAO and other organizations promote the farming of fish like tilapia in developing countries. In 2012, the worldwide aquaculture production of tilapia was more than 3 million metric tons! That is without a doubt "a lot." For comparison, all the fish harvested in Alaska in 2012 weighed about 2.5 million metric tons. Wow.

What if half of our beef was produced from wild cows running willy-nilly on the plains? What if we had to go to the woods to harvest our corn?

Who doesn't want to be part of an effort that provides relatively cheap protein to the public while using only the resources that are provided in the oceans and inland waters? Well, like most things, it's not quite as simple as we'd like. Aquaculture operations range from backyard catfish raising operations to offshore net-pen raising of juvenile Bluefin Tuna. Yes, aquaculture is a cheap and potentially benevolent way to provide protein. However, there are genetic and environmental concerns as well. There is no doubt that aquaculture can be conducted responsibly. But aquaculture has been implicated, although not always conclusively, in environmental issues such as the transmission of aquatic invasive species (e.g., the Asian carp to the Mississippi River basin). And once you capture juvenile Bluefin Tuna, you have to feed them. This reality is potentially benign…as fish eat other smaller fish no matter where they are, but since they are in a net-pen (similar to many Atlantic Salmon net-pen operations) there are concerns about food that is not consumed drifting to the bottom along with the fish waste, which could result in an artificially nutrient rich environment in the vicinity of the net-pen. This situation can be good or bad (it's usually bad) but needs to be identified and monitored such that environmental conditions are not overly degraded.

Aquaculture practitioners have their own challenges. There are disease issues, production issues, and cost issues just like agriculture practices with cows, pigs, and ducks. Even fish production for fun (i.e., stocking programs that produce fish that people like to catch) can be associated with challenging questions. Do we supplement a wild population even though the genetics of the stocked population may be different? Do we stock a non-native species simply because people will pay to fish for it? Hmmm.

Aquaculture takes many forms and has many goals: endangered species perpetuation, ornamental and hobby endeavors, food production, and the like. The enterprises associated with aquaculture are pretty much here to stay and there is no doubt that there are many potential benefits and good science associated with it, but there are some serious issues to be discussed and debated as well.

I suppose this is why most of us have jobs. If everything was all good, with no issues, there would be a heck of a lot less work to be done. Striking the balance between needs and wants always seems to be the challenge in any endeavor. Aquaculture is the same.

Continued from page 485 (Policy)

approve the "HaMAR Considerations" guidance, proving that AFS can serve a valuable role in compiling the best information on complex issues.

Such efforts are traditionally led by the AFS Resource Policy Committee, the group charged with leading the way in writing new policies and ensuring that our existing 35 policies are relevant. Their effort is often supplanted by experts from throughout our Society. In the aquaculture arena, where AFS and its members have toiled for more than a century, leading aquatic resource scientists and natural resource managers took the lead to describe effective roles of cultured species in aquatic resource management. As paraphrased from the program for our 2013 Annual Meeting, approximately every 10 years a cross section of AFS representatives assembles to reconcile contentious issues regarding hatchery-origin fish. Prior to the HaMAR effort, those AFS members met under the banner of "Propagated Fishes in Resource Management" and produced "Considerations for the Use of Propagated Fishes in Resource Management." Those guidelines were the first publication to connect science-based information with political realities of management and provided the aquatic resources community and decision makers with a set of consensus-guiding principles for the use of hatchery-origin finfish and shellfish.

The intent was to develop science-based fisheries management findings to strengthen decision making. That effort evolved into an assessment of the impacts of hatchery reform, the increasing importance of imperiled species restoration, as well as a number of other emerging issues in hatchery operation and the uses of hatchery-origin aquatic animals. At Little Rock, it was time to set the clock in motion for the next cycle of this process, the HaMAR project, to refine our guiding principles based on contemporary knowledge.

The HaMAR effort is now complete with approval at our 2014 Annual Meeting. That backdrop forms a solid basis for this themed issue of *Fisheries*. As stated above, it also affirms a crucial role for AFS as a society and for each of its members. I hope that each of you will consider using the Society as a neutral platform to debate issues related to aquaculture. We have the benefit of a solid base of existing science and policy, but we must update our efforts based on the latest knowledge. Our expanded influence will help because there are no limits to the scientific inquiry needed to maintain an economically and ecologically solid basis for finfish, shellfish, plant, and other aquatic species culture.

Our work won't end with the HaMAR Considerations or action by the Resource Policy Committee. Just as the science is continually evolving, no policy statement is unassailable. We'll need AFS's experts in policy, management, and science as we engage in aquaculture. Every step must be subjected to academic rigor and peer review, with checks and balances. And we'll need to proceed on a schedule that reflects our largely volunteer capacity rather than some external driver from an agency policy or budget. Those and other connections between science and policy were offered by Chris Tyler (2013) based on his work in England.

Those are difficult challenges. I suspect that most of you have crossed the science, management, policy, and education paths. When I first stepped into the AFS arena in my previous position with the National Oceanic and Atmospheric Administration's National Marine Fisheries Service, I shared my personal dilemma with agency attorneys. Past President Ken Beal had asked me to chair our Resource Policy Committee in 2000, which raised legal and ethical questions. After important caveats about conflicts of interest, the attorney's official response affirmed that it was acceptable for me as a fish habitat program manager to participate in AFS activities as long as I clarified my role and engaged only in issues where my agency had a programmatic interest. Both conditions were easily met and I served as Resource Policy Committee chair for four AFS Presidents.

I am convinced that most AFS members would receive similarly forgiving advice if they were to check with supervisors and attorneys before becoming more involved in our Society. As closely as we scrutinize aquaculture and other topics related to resource management, so will others scrutinize AFS and our personal roles. We must stand ready for both.

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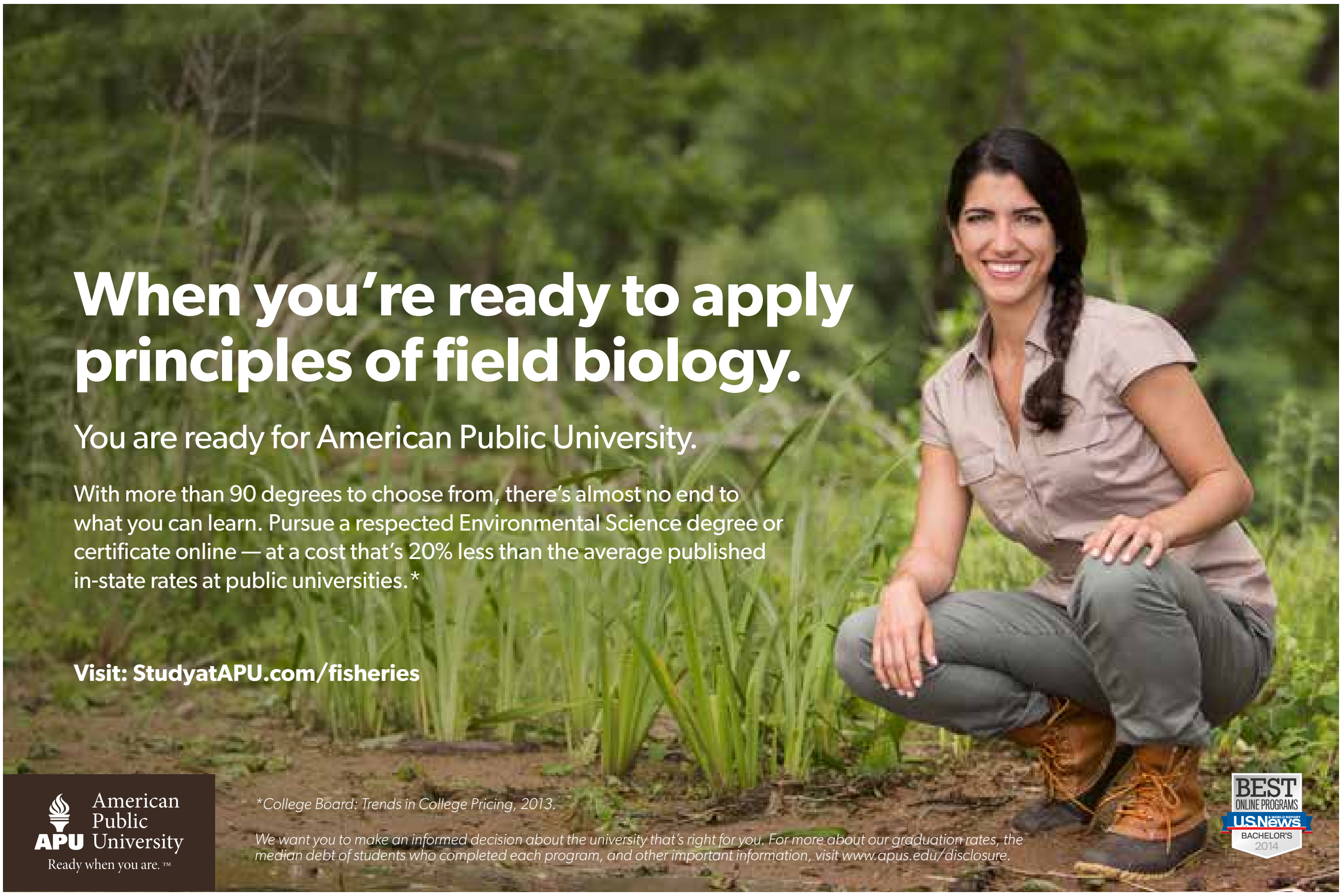

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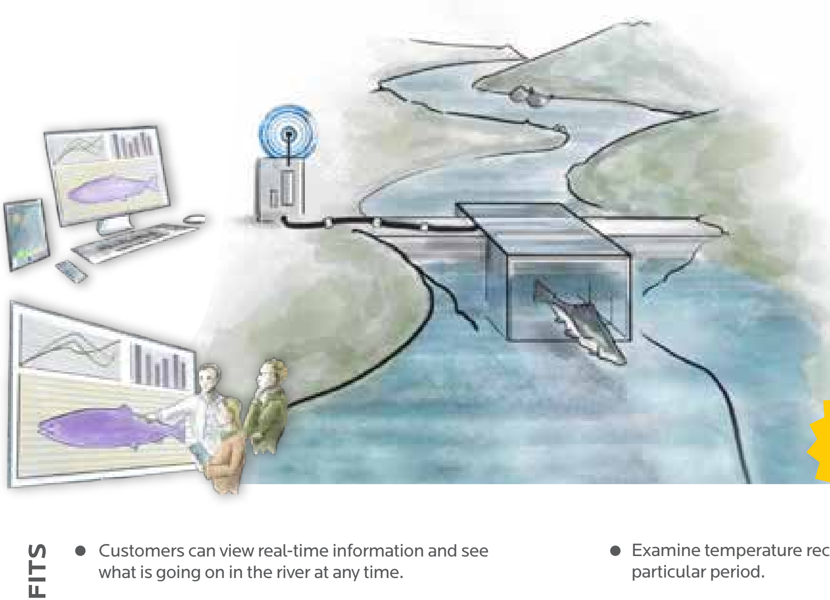

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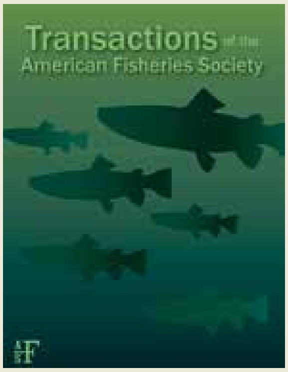

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[Note] Evidence of Atlantic Sturgeon Spawning in the York River System *Christian Hager, Jason Kahn, Carter Watterson, Jay Russo, and Kyle Hartman. 143: 1217–1219.*

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Genetic Composition of the Warm Springs RiverChinook Salmon Population Maintained following Eight Generations of Hatchery Production *Christian T. Smith, Rod French, Jens Lovtang, and David Hand. 143: 1280–1294.*

[Note] Genetic History of Walleyes Spawning in Lake Erie's Cattaraugus Creek: a Comparison of Pre-and Poststocking *Amanda E. Haponski, Hillary Dean, Bevin E. Blake, and Carol A. Stepien. 143: 1295–1307.*

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CALENDAR
Fisheries Events

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

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

More events listed at www.fisheries.org

DATE	EVENT	LOCATION	WEBSITE
November 17–21, 2014	2nd International Ocean Research Conference	Barcelona, Spain	www.tos.org/2nd_ocean_research.pdf
December 9–10, 2014	Congress on Adapting Food Production to a Changing Climate	Washington, DC	www.rnrf.org
January 21–23, 2015	Texas Aquaculture Association–45th Annual Conference & Trade Show	Kemah, TX	www.texasaquaculture.org
January 26–30, 2015	Global Inland Fisheries Conference	Rome, Italy	inlandfisheries.org
January 28–February 1, 2015	2015 AFS Southern Division Annual Meeting	Savannah, Georgia	sdafs.org/meeting2015
February 16–19, 2015	2015 Annual General Meeting, WA-BC Chapter of AFS	Richmond, British Columbia	wabc-afs.org/2014/06/3530/
February 19–22, 2015	Aquaculture America 2015	New Orleans, LA	www.marevent.com
February 22–27, 2015	Aquatic Sciences Meeeting	Granada, Spain	aslo.org/meetings/
February 24–26, 2015	2nd International Conference on Fisheries Aquaculture and Environment in the Indian Ocean	Muscat, Oman	fishconference.com
March 4–6, 2015	2015 Idaho Chapter Annual Meeting	Boise, ID	www.idahoafs.org/2015AnnualMeeting/
April 28–30, 2015	FLOW 2015: Protecting Rivers and Lakes in the Face of Uncertainty	Portland, Oregon	www.instreamflowcouncil.org/flow-2015
May 17–19, 2015	NPAFC International Symposium on Pacific Salmon and Steelhead Production in a Changing Climate: Past, Present, and Future	Kobe, Japan	www.npafc.org
May 26–30, 2015	World Aquaculture 2015	Jeju Island, Korea	www.was.org
June 22–24, 2015	Fish Passage 2015	Groningen, Netherlands	www.fishpassageconference.com
July 12–24, 2015	39th Annual Larval Fish Conference	Vienna, Austria	larvalfishcon.org
July 26–31, 2015	World of Trout	Bozeman, MT	www.troutcongress.org
August 16–20, 2015	AFS Annual Meeting	Portland, OR	2015.fisheries.org
November (TBA), 2015	5th International Symposium on Stock Enhancement and Sea Ranching	Sydney, Australia	www.searanching.org
February 22–26, 2016	Aquaculture 2016	Las Vegas, NV	www.marevent.com
September 19–22, 2016	OCEANS 2016	Monterey, CA	www.oceanicengineering.org

Do You Want Hash Browns with Those?

Milton Love

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In *The Canning of Fishery Products* (1919), J. N. Cobb, pulling out all gastronomic stops, noted that dogfish eggs "Are used for making puddings, pancakes, etc., and otherwise as a substitute for fowls' eggs." My friend Jim Allen tells me that some time in the 1970s he caught a dogfish in Santa Monica Bay, California. He opened it up and, along with a number of fetal sharks, he also saw three unfertilized eggs. Dogfish eggs are big and yellow, and Jim – not averse to trying a new cuisine, albeit from no known culture – took them home, then scrambled, fried, and ate them. "They were pretty good," he reports, "although with kind of an astringent taste." For no particular reason, this reminds me that Samuel Taylor Coleridge's favorite Sunday breakfast was comprised of six fried eggs, seltzer water, and one glass of laudanum.

Jeez, a glass of tincture of opium as a wakeup call may explain why Coleridge apparently coined the term "suspension of disbelief."

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

Pacific Spiny Dogfish, *Squalus acanthias.*