A Simple Method to Predict Regional Fish Abundance:
An Example in the McKenzie River Basin, Oregon

Hatcheries, Conservation, and Sustainable Fisheries—Achieving Multiple Goals:
Results of the Hatchery Scientific Review Group’s Columbia River Basin Review
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Photos: (A) VI Alpha Tags provide individual identification and remain visible through the clear adipose eye tissue of this trout. (B) Combining tag colors and locations produces a coding scheme using VIE, as in this turbot, which is fluoresced with the VI Light. (C) Reptiles and amphibians are commonly identified with VIE and VI Alpha. (D) VIE identifies families for shrimp broodstock development.

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How Large is AFS?

Bill Fisher, President

In recent years we have stated on our website and in other promotional materials that AFS has around 9,000 members. This figure is based on counts of our regular, student, young professional, life, retired and honorary dues-paying members. However, there are many fisheries professionals who pay chapter and/or section dues but do not pay Society dues. In the July 2011 issue of Fish, then President Wayne Hubert and I wrote about these “affiliate” members of AFS. We made affiliate membership the focus of the Governing Board annual retreat at the AFS Annual Meeting in Seattle. The purpose of the retreat was to get a better understanding of just how large the sphere of AFS affiliates may be, identify why affiliate members do not choose to become members of the Society, and develop strategies for recognizing affiliates and enticing them to become members of the Society. This President’s Hook provides a synopsis of the retreat and my plan to move forward in addressing the affiliate membership issue, an issue that has perplexed the Society since chapters were formed.

The AFS does not keep membership records on affiliate members, but chapters do. Prior to the Governing Board retreat, we conducted an online survey of AFS chapter officers (presidents or secretaries-treasurers) to gain a better understanding about the number of their affiliate members, including how many attend annual chapter meetings and whether or not they are students or professionals. The survey was conducted in May 2011, and we received replies from 23 of 48 (48%) of chapter officers. The outcome was surprising, to say the least!

A large, unaccounted segment of fisheries professionals are affiliated with individual chapters but are not members of the Society. Responses were received from chapters in all four divisions including the Northeastern (3), Southern (8), North Central (5), and Western (7). The survey indicated the average number of affiliate members in the 23 chapters to be 58 comprising 31% of the chapters’ membership. Among divisions the proportion ranged from an average of 14% of chapter members in the Western Division to 47% in the Southern Division. The proportion of chapter members identified as affiliates was as high as 72% in one chapter of the North Central Division. The average proportion of affiliates attending recent annual meetings of chapters ranged from 10% in the Western Division to 69% in the North Central Division. The affiliates at annual meetings of chapters included professionals and students with substantially greater numbers of professional affiliates than student affiliates. In short, a very substantial proportion of the membership attending annual meetings of chapters is made up of affiliates, and the majority of those affiliates are professionals.

If we multiply the average number of chapter members who are affiliates (58) by the number of chapters (48), it is estimated that there may be approximately 2,800 affiliate members. However, if the variance of the affiliate chapter members is considered, the number of affiliates may be as high as 6,000. When this upper estimate of affiliates is added to the 9,000 AFS members, AFS may have up to 15,000 fisheries professional who identify themselves as having membership in the Society.

There are also two AFS sections with affiliate members, the Fish Culture and Fish Health sections. Both of these sections have very few affiliates based on information from the section presidents. Section affiliates tend to be fisheries professionals that reside outside of the United States or Canada, wish to maintain professional ties with colleagues of similar interests, and desire access to AFS journals at prices paid by Society members.

So why are affiliate members not regular dues-paying members of the Society? There are several possible reasons based on member responses and surveys. These reasons include: annual Society dues are a financial burden, affiliates no longer work directly in fisheries, inability to attend the annual meetings of the Society, and the fact that most chapters do not require their members to be members of the Society. This last reason was one of the central issues discussed at the AFS Governing Board Retreat, entitled “The Invisible Affiliates of AFS,” at the Annual Meeting in Seattle. A goal of AFS should be to connect with all fisheries professionals, particularly those that affiliate with one of our units. Doing so would enable us to improve communication with and track these affiliates. It would also allow us to identify their needs and the benefits they are seeking, and possibly to increase the geographic, cultural, and ethnic diversity of our membership, particularly by recruiting more international fisheries professionals to join AFS. Some of the solutions to these problems that Governing Board members suggested were: improve our tracking of chapter- or section-only members through online registration at chapter and section meetings, establish affiliate member dues that are lower than regular Society dues and with limited membership benefits, and increase communications to affiliate members in order to market AFS products and services.

I have charged a special committee of Society members to study the issues and opportunities of creating a member category

Continued on page 571
NOAA/NMFS Approves the Mid-Atlantic ACL/AM Omnibus Amendment

After years of discussions, public hearings, and environmental assessments by the National Oceanic and Atmospheric Administration’s National Marine Service (NMFS) and the Mid-Atlantic Fishery Management Council (Council), the two entities have approved the “Omnibus Amendment”—or, as it is sometimes referred to, the “Omnibus ACL/AM Amendment,” which also includes the Amendment’s Environmental Assessment and Essential Fish Habitat Assessment (Amendment), in order to bring all Council FMPs into compliance with the requirements of the Magnuson-Stevens Act (MSA), as amended by the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 (MSRA).

By the end of 2011, all federally managed fisheries must have annual catch limits and accountability measures in place as required by the Magnuson-Stevens Conservation Act; portions retained, plus revisions, in the MSRA include new requirements for annual catch limits (ACLs), accountability measures (AMs), and provisions preventing and ending overfishing (16 U.S.C. §1853(a)(15)). National Standard 1 (NS1) of the MSA requires that conservation and management measures “shall prevent overfishing, while achieving, on a continuing basis, the optimum yield from each fishery.” NS1 guidelines prepared by the NMFS (74 FR 3178; effective February 17, 2009) help FMPs interpret the MSA measure on how to set catch limits for the upcoming fishing year(s), address both scientific and management uncertainty by creating scientific councils, and sustain prolonged consistency to help rebuild and prevent overfishing of fish stocks.

Therefore, in response to the MSA’s requirements and NMFS’s NS1 guidelines, the Council decided to amend the FMPs rulings in a single, comprehensive amendment for Atlantic mackerel, squids, and butterfish; Atlantic bluefish; spiny dogfish; summer flounder, scup, and black sea bass; the surf clam and ocean quahog; and the tilefish. This amendment presents management alternatives that provide a federally managed comprehensive set of uniform and transparent management criteria and accountability for all mid-Atlantic fisheries management plans—in lieu of separate management plans for each fish habitat—that are more likely to be subject to scientific uncertainty and unaccountability. The amendment’s main provisions/actions are as follows:

- Establish a system of accountability (AMs) that address all components of the catch;
- Establish ACLs;
- Describe the process by which the performance of the ACL and comprehensive accountability will be reviewed; and
- Describe the process to modify the measures above in the future.

Lastly, the amendment proposes a unique process for how scientific data will be used by the Council’s Science and Statistical Committee in fishery management plans.

NMFS/Mid-Atlantic Council Fisheries Omnibus Amendment:

NMFS Magnuson-Stevens Act Provisions; Annual Catch Limits; National Standard Guidelines. Final rule Revised National Standard 1:

Magnuson-Stevens Fishery Conservation and Management Act Provisions; Fisheries of the Northeastern United States; Annual Catch Limits and Accountability Measure, NMFS Omnibus Amendment proposed rule:

Mexico and Argentine Fisheries Receive Marine Stewardship Council Certification

Following the independent Marine Stewardship Council (MSC) assessment, the Argentinean Bonaerense anchovy, located in the southwest Atlantic Ocean, has received the MSC’s highly accredited certification standard for sustainable, well-managed fisheries. The Argentine anchovy fishery is the first in the world of its kind to be certified by the MSC. Anchovies are marketed primarily for human consumption; thus, about 80%
of the catch is destined for export to countries such as Spain, Peru, and Morocco. The MSC certification helps fisheries economically grow in markets worldwide while showing them the benefits of continuing sustainable fishing that preserves and conserves the ocean.

The MSC also certified Mexico’s Pacific sardine fishery for being a sustainable, well-managed fishery. Located in the Gulf of California, the Pacific sardine fishery is Mexico’s largest fishery. About 85% of the total catch from the fishery is used for fish meal, and the rest is packed in cans for sale in domestic and international markets.

**Fish Habitats Improved with $3 Million Funding**

The U.S. Fish and Wildlife Service has agreed to provide more than $3.4 million to support 84 Fish Habitat Partnerships (FHPs) in 38 states across the nation under the National Fish Habitat Action Plan. This funding, coupled with $9.8 million in partner contributions (totaling over $13.2 million), will be available for the restoration and enhancement of stream, lake, and coastal habitats. Moreover, the increased funding will be used to improve recreational fishing opportunities and protect endangered species.

So far, 17 FHPs have identified the projects that will receive priority for some of the funding for a variety of needs. In determining where and how these funds will be allocated, the FHPs strategically direct funding (along with other resources to habitat improvement projects) will offer the highest long-term conservation returns for any given aquatic species.

**Legal Reform in New Zealand Supports Aquaculture**


Some examples of the aforementioned legislation specifically include the development of aquaculture development in Tasman and Waikato by amending both regional coastal plans, in areas where aquaculture is already established, in order to enable applicants to farm a wider range of species, including finfish.

Another key aspect of the legal reform is the removal of the requirement for Aquaculture Management areas to be established before consent applications can be made. The coastal plan in Waikato has been amended to establish the Coromandel Marine Farm Zone, giving residents more land to work on aquaculture.

The changes in the laws went into effect on October 1, 2011.
AFS POLICY STATEMENT ON THE NEED FOR AN IMMEDIATE-RELEASE ANESTHETIC/SEDATIVE FOR USE IN THE FISHERIES DISCIPLINES

Issue Definition

Availability of safe and effective fish sedatives or anesthetics is crucial to fisheries research, management, and culture activities. Unlike most terrestrial vertebrates which may be handled without causing mechanical damage, fishes are particularly vulnerable to external and internal injury during physical restraint. Fish that are handled without proper sedation may also be negatively affected by the physiological consequences of the generalized stress response. Fisheries professionals must also consider the issues of animal welfare, and use of sedatives is recommended for procedures that may cause more than momentary or slight pain or distress. Additionally, handling fish without sedation may pose a risk to personnel, particularly in the case of large fish or fish that are otherwise hazardous when handled without proper restraint. In short, if fish are sedated prior to handling, risk to both fish and handler is minimized.

Tricaine methanesulfonate (MS-222) has been approved by the U.S. Food and Drug Administration (FDA) for use in sedating four families of fishes; however, MS-222 is not approved for use in all fish species and treated fish must be held for a 21-day withdrawal period prior to being released into the environment or sold for human consumption. Although carbon dioxide (CO2) may be used as an immediate-release sedative (i.e., no withdrawal period required prior to release or consumption), CO2 is generally not considered a safe or effective sedative as it is slow-acting, difficult to apply uniformly, and often results in adverse reactions including morbidity and mortality in the treated fish. The pursuit of FDA approval of safe and effective immediate release sedative has been long, and to-date, fruitless. This is a consequence of numerous factors, including the 1) complexities of the drug approval process, 2) the substantial human and monetary resources that must be expended in pursuit of an approval, 3) the limited number of personnel and funds dedicated to these activities, and 4) the time required to complete the approval process. To be approved in the U.S., an animal drug must be proven effective for the claim on the label, and safe when used as directed for treated animals, people administering treatment, the environment, and consumers. Efforts are currently underway to evaluate and prioritize the safety and effectiveness of two candidate immediate-release sedatives: Benzoak® (a benzocaine-based product) and AQUI-S® E (a eugenol-based product). A large number of studies have demonstrated the efficacy of benzocaine, eugenol, and closely related compounds in sedating and anesthetizing a variety of fishes. Furthermore, as common constituents of human foods (eugenol) and over-the-counter oral analgesic products (benzocaine), both compounds are considered relatively innocuous and are thought to pose minimal human food safety risk if used as immediate-release sedatives in fish. A conservative (‘worst-case’ scenario, 10-fold margin of safety), semi-quantitative risk assessment revealed that consumers could consume more than one portion of fish treated with benzocaine or eugenol at every meal without undue

On September 3, 2011, the AFS Governing Board voted in favor of the Resource Policy Committee’s motion to distribute the draft policy statement, “AFS Policy Statement on the Need for an Immediate-Release Anesthetic/Sedative for Use in the Fisheries Disciplines” to the AFS membership for a final vote to approve. This action was taken following careful review over the past year: a draft position paper was approved by the AFS Governing Board on September 11, 2010; sent for review to all AFS units on the Governing Board on October 29, 2010; summarized in an article in the March 2011 issue of Fisheries (Fisheries, 36: 3, 132 — 135; http://www.tandfonline.com/doi/pdf/10.1080/03632415.2011.10389085); and revised as necessary to reflect comments received during a public comment period ending June 16, 2011. The time has come to decide whether to adopt the following policy statement and support the expedient approval of immediate-release sedatives for use in the fisheries disciplines.

It was decided that an electronic comment forum and ballot would ensure maximum participation of the AFS membership in this important vote. Please visit http://www.fisheries.org from November 15, 2011 to December 15, 2011 to view and post comments regarding the policy statement. To cast your vote, please visit http://www.surveymonkey.com/s/V5RPFKQ before the close of the poll on December 22, 2011.
risk of health effects from compound residues remaining in the fillets. We conclude that the absence of a suitable immediate-release sedative jeopardizes fishes, fisheries, fish culture, and research, and poses considerable risk to those involved in these activities and fisheries resources. The current candidate sedatives, benzocaine and eugenol (as well as other potential immediate-release sedatives such as Fish-eezzz®, a carvone-based compound), meet a range of criteria that justify an assumption of safety and efficacy as well as minimal risk to fishes, researchers, the environment, and human consumers. The current framework and process for approving either of the candidate sedatives will cost the private and public sectors an exorbitant amount of financial and human resources and will take years to complete. Ultimately, we recommend that the consequences of inaction be balanced against the consequences of approving the use of benzocaine and eugenol as immediate-release sedatives in the fisheries disciplines.

**Policy and Needed Actions**

Accordingly, it is the policy of the American Fisheries Society to engage and assist the U.S. Food and Drug Administration in:

1. Expediting review of the candidate immediate-release sedatives;
2. Implementing a risk management-based approach to establishing the data requirements for the candidate sedatives and other drugs intended for use in minor species including fish;
3. Reducing data requirements for the approval of the candidate sedatives based on the characteristics of the candidate sedatives, the nature of the intended uses, and the experience of the prospective end-users; and
4. Giving the two candidate sedatives deferred regulatory status or, if direct regulatory discretion is not advisable, expanding the current Investigational New Animal Drug (INAD) designations to allow for immediate-release use.
A Simple Method to Predict Regional Fish Abundance: An Example in the McKenzie River Basin, Oregon

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INTRODUCTION

Fisheries managers often seek to conserve or enhance fisheries resources at regional or landscape scales (e.g., Katz et al. 2007), and tools to estimate or predict fish abundances at these large scales are therefore needed. Habitat models can sometimes be used for this purpose. Habitat models use statistical correlations between fish data and suites of physicochemical habitat variables to predict fish abundances and/or distributions at sites where empirical fish data are not available or when habitat conditions change (Fausch et al. 1988; Rosenfeld 2003). For instance, Burnett et al. (2007) created a model of steelhead (Oncorhynchus mykiss) and coho salmon (O. kisutch) rearing habitat in western Oregon streams and then used their model to prioritize land acquisitions and stream restoration activities.

However, habitat models can be difficult to build and calibrate. Large, spatially explicit data sets are needed to quantify the underlying fish–habitat correlations (e.g., Creque et al. 2005; Rashleigh et al. 2005). Geographic Information Systems and freely available geospatial data sets, such as National Hydrography Dataset Plus (NHDDPlus 2010), can expedite the compilation and analysis of physicochemical habitat data, but the corresponding fish data must still be collected through traditional field methods, such as mark–recapture surveys. Highly complex models can also be more difficult for managers to apply (Adkison 2009).

Recently, McGarvey et al. (2010) presented a simple, macroecological model (sensu Brown 1995) that can predict fish abundance at regional scales. Macroecological models use robust statistical patterns to predict large-scale patterns and processes from relatively small-scale observations (Marquet et al. 2005). For example, McGarvey et al. (2010) created a trophic carrying capacity model that used the self-thinning relationship (i.e., the inverse relationship between population size and average body mass; Bohlin et al. 1994) to predict fish population density, given net primary production, in four cold-water and four warm-water systems. Their model (McGarvey et al. 2010) was relatively easy to build: it included only seven parameters and each of these was estimated with existing literature data.

In this study, we use the model of McGarvey et al. (2010) to estimate potential trout carrying capacity, expressed as total standing stock abundance, within the McKenzie River Basin.
(MRB), western Oregon (Figure 1). We refer to this as “potential carrying capacity” because the model assumes that 100% of the available food resources will be consumed and converted to fish tissue. Our specific objectives are to (1) describe the model structure; (2) use the model to predict average trout densities within small, medium, and large streams in the McKenzie Basin; (3) assess model performance by comparing the predicted densities with empirical density estimates from comparable Pacific Northwest streams; and (4) extrapolate the predicted densities across the entire McKenzie Basin stream network to predict potential carrying capacity at the regional scale.

**MODEL STRUCTURE—THE UNDERLYING CONCEPT**

We used the self-thinning relationship

\[ D = aM^{-b} \]

(1)

to predict population density \( D \) from average body mass \( M \).

The scaling exponent \( b \) is generally interpreted as the inverse of metabolism, which scales as \( M^b \), and the coefficient \( a \) is thought to reflect trophic resources, or prey availability (Kerr and Dickie 2001; White et al. 2007). Thus, the self-thinning relationship (equation 1) is a model of ecosystem carrying capacity (Marquet et al. 2005). It predicts the numbers of organisms that can survive on a finite resource base, given that small species will, on average, be more abundant than large species because smaller species consume fewer per capita resources than larger species (Bohlin et al. 1994).

Estimates of \( M \) and \( b \) can be obtained directly with field measurements or inferred from literature values (e.g., Carlander 1969; Elliott 1993; J. W. A. Grant et al. 1998), but a standard method for measuring \( a \) does not yet exist (Bohlin et al. 1994; Fréchette and Lefaivre 1995; Cyr et al. 1997). Following Jennings and Blanchard (2004), we therefore used population biomass (\( B \)) as an estimate of \( a \), as outlined below (see also Kerr and Dickie 2001; McGill 2008).

First, we assumed that trophic resource availability (i.e., food) is the primary determinant of trout carrying capacity in the McKenzie Basin (i.e., other factors such as habitat availability and life history requirements are secondary influences; see Poff and Huryn 1998; Jackson et al. 2001) and that trophic resource availability can be inferred from net primary production (NPP; Jennings and Blanchard 2004; McGill 2008). We then used a conceptual food web diagram (adapted from Macneale et al. 2010) to identify the major autochthonous (i.e., aquatic) and allochthonous (i.e., terrestrial) resources available to trout in the McKenzie Basin (see Figure 2A), as well as major competitors for these resources (primarily salamanders; see Net Primary Production and Salamander Consumption section), and calculated total NPP (\( NPP_{\text{total}} \)) as the sum of autochthonous (\( NPP_{\text{auto}} \)) and allochthonous (\( NPP_{\text{allo}} \)) production minus salamander consumption (\( NPP_{\text{sal}} \)):

\[ NPP_{\text{total}} = NPP_{\text{auto}} + NPP_{\text{allo}} - NPP_{\text{sal}} \]

(2)

Second, we used trophic transfer efficiency (\( \varepsilon \)) estimates from the primary literature (see Figure 2B) to predict trout production (\( P \)), given \( NPP_{\text{total}} \). \( \varepsilon \) is the ratio of production among two adjacent trophic levels and it is often approximately 0.1 (e.g., Lindeman 1942; Slobodkin 1960; Pauly and Christensen 1995; but see Barnes et al. 2010). \( P \) was modeled as

\[ P = NPP_{\text{total}} \varepsilon^{T-1} \]

(3)

where \( T \) is the average trophic level of an adult (age 1+) trout.

Third, we used the production:biomass ratio (\( P_B \)) to predict trout biomass (\( B \)) from \( P \). Empirical \( P_B \) ratios are often used to predict \( P \), which is difficult to measure in situ, from field estimates of \( B \), which are relatively easy to obtain (Waters 1977).
Figure 2. Flow diagram of the fish density model. Each of the basic concepts included in the model is shown in sequence and explained in the text boxes at left. Symbols used in the food web and trophic pyramid diagrams are courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science. The ε distribution was reproduced from Pauly and Christensen (1995; n = 48 aquatic food webs) and is used with permission from the Nature Publishing Group. The PB data are from Randall et al. (1995; n = 51 stream/river samples) and are used with permission from NRC Research Press. The body mass vs. density plot was reproduced from Cyr et al. (1997) and is used with permission from John Wiley & Sons, Inc. The b distribution was compiled from: Egglishaw and Shackley (1977); Elliott (1993); Grant (1993); Bohlin et al. (1994); Cyr et al. (1997); Dunham and Vinyard (1997); Grant et al. (1998); Steingrímsson and Grant (1999); deBruyn et al. (2002); Knouft (2002); Rincón and Lobón-Cerviá (2002); Cohen et al. (2003); and Keeley (2003). Median values and coefficients of variation (CV) are shown for the ε, Pb, and b distributions.
However, the model reversed this role, using empirical $P_b$ estimates (see Figure 2C) to predict trout $B$ given trout $P$. $B$ was then used as an estimate of the constant $a$ in equation (1). Thus, $a$ was calculated as

$$ a \approx B = \frac{P}{P_B}. \quad (4) $$

Whether $B$ is an appropriate estimator of $a$ is debatable. Mechanistic interpretation of $a$ has been achieved for plants but not for aquatic animals (Begon et al. 1986; Hughes and Griffiths 1988). However, the assumption that $a \propto B$ is logical: in general, systems with higher NPP should support higher consumer biomass and higher consumer densities. This assumption is also consistent with studies that have demonstrated a positive relationship between $a$ and NPP or consumer $B$ (e.g., Bohlin et al. 1994; Cyr et al. 1997) and with other models that have applied the self-thinning relationship (e.g., Jennings and Blanchard 2004; McGill 2008).

Finally, we combined equations (2), (3), and (4) with equation (1) to obtain the final model

$$ D = \left[ \frac{NPP_{\text{total}}}{P_B} \right] \cdot M^{-b}. \quad (5) $$

The constant $a$ is bracketed in equation (5) to emphasize that this is not a mechanistic bioenergetics model. It is a macroecological model that uses an estimate of standing stock $B$ and the self-thinning relationship to predict $D$. Thus, when $B$ (in g/m$^2$; equation 4) is multiplied by $M$ (in g; equation 1) the units do not equate to fish/m$^2$. Rather, $B$ is treated as a unitless value when it is used to estimate $a$.

**MODEL APPLICATION — McKENZIE RIVER BASIN EXAMPLE**

**Study Area**

The MRB lies along the west slope of the Cascade Range, on the east side of the Willamette River Basin (Figure 1). It has a surface area of 3,466 km$^2$ and is covered primarily (>90%) by montane forest (Douglas fir, western hemlock, and western red cedar). Hydrology and geology are closely linked in the MRB and three distinct biogeoclimactic provinces are present: (1) a “High Cascades” zone (>1,200 m elevation) with porous, volcanic bedrock and extensive subterranean flow; (2) a “Western Cascades” zone (400–1,200 m elevation) with lower permeability, volcanic bedrock and high surface drainage density; and (3) a “Cascade foothills and valley” zone (<400 m elevation) that is underlain by a combination of alluvium and sedimentary and volcanic bedrock (G. E. Grant 1997). We selected the MRB because an extensive database exists on the physical and biological characteristics of MRB streams (see Representative Streams Section).

**Representative Streams**

We focused exclusively on montane streams, because montane forests are the predominant land cover type in the MRB and trout are common within these systems (Waite and Carpenter 2000). We defined montane streams as those occurring within forested habitats (≥70% forest cover by area) at 500 m elevation or higher—the approximate elevation at which large stands of contiguous forest begin in the MRB (Figure 1). This constrained our analyses to the Western Cascades and High Cascades provinces. Land cover data were obtained from the Pacific Northwest Ecosystem Research Consortium (2009). We used the 1990 version of the Land Use/Land Cover digital data set.

The physical and biological characteristics of montane streams in the MRB were inferred from field studies in the H.J. Andrews Experimental Forest (see Figure 1), which is often used as a model of Pacific Northwest forest ecosystems (Geier 2007). For example, detailed studies of whole-stream metabolism have been conducted in Andrews Forest streams (Naiman and Sedell 1980; Cummins et al. 1983; Bott et al. 1985). These studies provided quantitative estimates of NPP$_{auto}$ and NPP$_{allo}$ (see Figure 3) and were instrumental in tests of the “River Continuum Concept”: they demonstrated the longitudinal transition from small, heavily shaded, heterotrophic streams to large, open-canopy rivers with increasing autotrophic production (Bott et al. 1985).

Because Andrews Forest streams are broadly representative of montane streams in the MRB (Geier 2007), we used the three most intensively studied streams—Mack Creek, Lookout Creek, and the McKenzie River—as surrogates for all similarly sized streams within the MRB. Specifically, we assumed that Mack Creek is representative of small, perennial headwater streams in the MRB (see Figure 3). Mack Creek is typically classified as a third-order stream (e.g., Bott et al. 1985), but it is first order in the 1:100,000 scale NHDPPlus (2010) data set, which we used to estimate the total size of the MRB stream network (see Regional Application of the Modeling Results section). We therefore labeled all first- and second-order montane stream segments in the NHDPPlus data set as “small” (SM) streams and used Mack Creek data to estimate their physical and biological characteristics. This eliminated the smallest streams, which require 1:24,000 scale maps to detect, from our analyses. However, true first-order streams in the MRB (e.g., Devil’s Club Creek; Bott et al. 1985) are often intermittent and rarely support resident trout populations (Murphy and Hall 1981). Next, we assumed that Lookout Creek is representative of “medium” (MD) streams (stream order = 3–4 in NHDPPlus) in the MRB (Figure 3). Finally, we assumed that the McKen-
Figure 3. Physical and biological characteristics of small, medium, and large streams within the McKenzie River Basin. Stream order was interpolated from 1:100,000 scale digital maps (NHDPlus 2010). All physical habitat data are from Bott et al. (1985). NPPauto data are from Webster and Meyer (1997). NPPallo data are from Cummins et al. (1983). Assimilation efficiencies are from Pandian and Marian (1986). NPPsal is represented by a uniform distribution ranging from 0.25–0.75 (U[0.25, 0.75]). Photos are courtesy of Al Levno® (Mack Creek and Lookout Creek) and Nora Waite® (McKenzie River).

Trout Distributions

Common montane fishes in the MRB include cutthroat trout (Oncorhynchus clarkii), rainbow trout (O. mykiss), and bull trout (Salvelinus confluentus); mountain whitefish (Prosopium williamsoni); mottled sculpin (Cottus bairdii); Paiute sculpin (C. beldingi), and torrent sculpin (C. rhythmus); and longnose dace (Rhinichthys cataractae) and speckled dace (R. osculus). We focused entirely on cutthroat and rainbow trout because they are the most abundant and widely distributed salmonids in the MRB (e.g., Murphy and Hall 1981). Cutthroat and rainbow trout were also treated as a single species in our simula-
tions because we did not have sufficient data to distinguish cutthroat and rainbow trout habitats. However, this should not significantly bias our results, because the diets and body masses of cutthroat and rainbow trout are similar in Pacific Northwest streams (see Parameterizing, Running, and Evaluating the Model section).

Parameterizing, Running, and Evaluating the Model

Net Primary Production and Salamander Consumption

Bott et al. (1985) measured gross autochthonous production in Mack Creek, Lookout Creek, and the McKenzie River with recirculating oxygen chambers. These measurements were converted to annual NPP estimates (in g ash-free dry mass per m²) following Webster and Meyer (1997). We then converted the NPP estimates from ash-free dry mass to carbon (C) with a conversion factor of 0.5 (i.e., 1 g ash-free dry mass = 0.5 g C; Waters 1977) and converted the C estimates to g wet weight (ww) with a conversion factor of 10 (i.e., 1 g C = 10 g ww of consumer tissue; Waters 1977). The resulting net production values were used as our NPP estimates in SM, MD, and LG streams (Figure 3).

Allochthonous production was estimated with the annual litterfall data of Cummins et al. (1983; see their Table 9). We converted the litter data from tons C/stream order/year to g ww/m²/year by first using the above C-to-ww conversion factor (1:10). We then divided the per stream order litter estimates by the total stream channel surface areas that corresponded to each stream order using surface area data in Cummins et al. (1983; see their Table 8) and used the resulting per square meter values for first-, third-, and fifth-order streams as our NPP estimates in SM, MD, and LG streams (Figure 3).

On a per unit basis, autochthonous resources are more nutritious than allochthonous resources (Allan 1995). We accounted for this disparity by using mean assimilation efficiencies (47% vs. 15%) from Pandian and Marian (1986) as correction factors. Autochthonous production was multiplied by 0.47 to obtain the final NPP auto estimates and allochthonous production was multiplied by 0.15 to obtain the final NPP allo estimates. We then summed the resulting NPP auto and NPP allo values to estimate trophic resource availability in SM, MD, and LG streams (Figure 3).

Finally, we modified the NPP estimates to account for consumption by the Pacific giant salamander (Dicamptodon tenebrosus). The Pacific giant is the most abundant trout competitor in MRB streams (e.g., Antonelli et al. 1972), where salamander biomass often rivals or exceeds trout biomass (e.g., Hawkins et al. 1983). Unfortunately, direct measurements of salamander consumption rates (NPP sal) were not available. In place of direct measurements, we assumed that salamanders consume between 25% and 75% of the available trophic resources. To do so, we used a uniform distribution ranging from 0.25 to 0.75 (i.e., U[0.25, 0.75]) and a Monte Carlo sampling routine. In each of 5,000 Monte Carlo simulations, we randomly selected an NPPsal estimate from the uniform distribution and then estimated the total primary production (NPPtotal) available to support trout production with equation (2), where NPPtotal = (NPPauto + NPPallo) × U[0.25, 0.75].

Trophic Transfer Efficiency and Trophic Level

We compiled a baseline ε distribution (Figure 2B) from the empirical ε data of Pauly and Christensen (1995). Monte Carlo simulations (×5,000) were then used to sample ε values at random from the baseline ε distribution.

We assumed that T = 3 for cutthroat and rainbow trout because insects generally occur at T ≈ 2, and they are the primary food resource for both species of trout (Behnke 1992). Furthermore, most trout in MRB streams are too small (median fork length = 84 mm; see Average Body Mass and the Self-Thinning Exponent section) to be piscivores (see Mittlebach and Persson 1998). T ≈ 3 has also been verified through gut content analyses (e.g., McHugh et al. 2008) and Fry’s (1991) isotope study of Andrews Forest trout.

Production : Biomass Ratio

The empirical P_b data of Randall et al. (1995) were used to compile a baseline P_b distribution (Figure 2C) and Monte Carlo simulations (×5,000) were used to sample P_b values at random from this distribution.

Average Body Mass and the Self-Thinning Exponent

We used trout data from Andrews Forest streams (53 sampling events; 12,684 individuals sampled; see Gregory 2008) to estimate M. Length measurements (Figure 4A) were converted to body masses with a length–mass regression from Carlander (1969). Separate length–mass relationships were examined for cutthroat and rainbow trout, but they did not differ (Figure 4B). We therefore used a common equation (log₁₀ weight = −4.7 + 2.9 × log₁₀ fork length) to estimate individual body masses for both species. The combined body mass distribution is shown in Figure 4C. The median body mass—7.5 g—was used as our M estimate. This weight is close to the median M reported in a regional survey of Pacific Northwest trout (Platts and McHenry 1988; median standing stock biomass × median density = 7.1 g), and the length–frequency distribution for Andrews Forest trout (Figure 4A) is very similar to length distributions reported in other Pacific Northwest streams (e.g., House 1995; Mellina et al. 2005). Thus, we are confident that the Andrews Forest data were broadly representative of Pacific Northwest trout and that M = 7.5 g was a useful estimate of trout body mass in McKenzie Basin streams.
Note that when $M = 7.5\, g$, the model is effectively predicting the $D$ of age-1 trout: 7.5 g equates to approximately 84-mm fork length (Carlander 1969), which is typical of age-1 trout in the Pacific Northwest (e.g., House 1995). But the model does not explicitly account for age structuring nor does it currently predict the densities of multiple age-classes. This is important because the predicted $D$ should not be interpreted as numbers of larval trout or of large, harvestable trout (see Prospects for Applying and Improving the Model section).

Finally, $b$ data from the primary literature were used to compile a baseline $b$ distribution (Figure 2D), and Monte Carlo simulations ($\times 5,000$) were used to sample from this distribution.

**Model Performance and Sensitivity Analysis**

Model performance was assessed by comparing the predicted $D$ with the observed (OBS) trout density data of Platts and McHenry (1988). Their data, which were compiled from field studies of 50 small to large montane streams throughout the Pacific Northwest, provided a useful benchmark for testing whether the model-predicted $D$ were comparable to estimates obtained with traditional surveying methods (e.g., mark–recapture). We compared the central tendencies of the predicted and OBS data as well as the precision (i.e., spread) of the data.

Sensitivity plots were then created for the model parameters $NPP_{sal}$, $\varepsilon$, $P_{P}$, and $b$. In each sensitivity plot, the predicted $D$ were plotted against the complete range of potential $NPP_{sal}$, $\varepsilon$, $P_{P}$, or $b$ values and the remaining parameters were held constant at their median values. Sensitivity plots were not created for $NPP_{auto}$, $NPP_{allo}$, $T$, or $M$ because they were measured directly in Andrews Forest streams (Cummins et al. 1983; Bott et al. 1985; Fry 1991; Gregory 2008) and were not treated as variable parameters in the model.

**Regional Application of the Modeling Results**

We used the model to predict average trout $D$ in SM, MD, and LG streams, but our final objective was to estimate the potential carrying capacity of all montane streams within the MRB. We therefore estimated the total surface areas of all SM, MD, and LG streams (see Estimating the Total Surface Area of the Stream Network section) and then multiplied these surface areas (m$^2$) by the model-predicted trout $D$ (no./m$^2$) to obtain regional carrying capacity estimates.

**Estimating the Total Surface Area of the Stream Network**

We began by querying all montane stream segments (i.e., those occurring within contiguous forest $\geq 500$ m elevation) in the MRB from the NHDPPlus data set (see Figure 1) using ArcGIS, version 9. We then classified each of the queried segments as SM, MD, or LG using the stream size criteria described above in the Representative Streams section. Stream segment length and stream order were included in the NHDPPlus attribute tables for all segments, but surface area was not. To estimate surface area, we first used a regression model to predict stream channel widths and then multiplied these widths by their corresponding segment lengths.
The stream width regression model was created with data from the U.S. Environmental Protection Agency’s Environmental Monitoring and Assessment Program (Whittier and Peck 2008). We randomly selected 130 montane sample sites distributed throughout the Western Forested Mountains ecoregion (see Figure 1 in Whittier and Peck 2008) and used field-measured habitat data from these sites to test a variety of stream width models. The best overall model was

$$\log_{10} \text{stream width} = (0.30 \times \text{stream order}) - (0.00017 \times \text{elevation}), \quad (6)$$

where stream width and elevation were in meters and stream order was estimated at the 1:100,000 scale. This model fit the observed data well and was highly significant ($P < 0.01$; Figure 5).

**Predicting Regional Trout Carrying Capacity**

When the surface area of each montane stream segment had been estimated, we summed the total surface areas of all SM, MD, and LG streams within the MRB. We then multiplied the total surface areas of SM, MD, and LG streams by their respective model-predicted $D$ values to estimate potential carrying capacity within the MRB. Results were also summarized by major watersheds (10-digit U.S. Geological Survey hydrologic units).

**RESULTS AND DISCUSSION**

**Predicted Trout Densities**

Model-predicted trout $D$ were highest in MD streams and lowest in SM streams: the median predicted $D$ were 0.11, 0.55, and 0.28 trout/m² in SM, MD, and LG streams, respectively (Figure 6). Overall, the model predictions were comparable to OBS trout densities. The predicted $D$ were slightly lower in SM streams than the OBS densities, but the interquartile ranges exhibited considerable overlap (Figure 6). Predicted $D$ in the MD streams exceeded the OBS densities by a relatively large margin. For example, the median predicted $D$ in MD streams was approximately twice the median OBS density (0.24 trout/m²). The median OBS density did, however, occur within the interquartile range of the predicted $D$ in MD streams. And the predicted trout $D$ in LG streams was very similar to the OBS densities: the median predicted $D$ was 0.28 trout/m² (vs. 0.24 OBS) and the interquartile ranges exhibited substantial overlap. Also, 96% of all model predictions (i.e., SM, MD, and LG stream simulations combined) fell within the OBS minimum–maximum range (stars in Figure 6). We therefore conclude that the model-predicted trout $D$ are realistic relative to OBS densities.

Model precision was generally low but comparable to the precision of the OBS trout density estimates. For instance, each}

Figure 5. Relationship between observed (field-measured) and model-predicted stream channel widths. Plotted data points are randomly selected stream segments from the U.S. Environmental Protection Agency’s Environmental Monitoring and Assessment Program, Pacific Northwest region. Points near the 1:1 line indicate close fits between observed and predicted channel widths. The distribution of model residuals (i.e., prediction errors) is shown as an inset. Positive residuals are instances where the model predictions were greater than the observed widths and negative residuals are instances where the model predictions were less than the observed widths. Notably, most predictions are within ±5 m of the observed widths.

Figure 6. Observed (OBS) and model-predicted trout densities in small (SM), medium (MD), and large (LG) streams. All data are presented as box-and-whisker plots: boxes show the 25th, 50th, and 75th percentiles and whiskers show the 5th and 95th percentiles. Stars show the minimum and maximum OBS densities. Each of the model-predicted boxplots reflects 5,000 Monte Carlo simulations. The OBS data reflect empirical trout densities that were measured in a range of small to large streams distributed throughout the Pacific Northwest (Platts and McHenry 1988).
of the model-predicted interquartile ranges spanned approximately 0.75 orders of magnitude, whereas the interquartile range of the OBS densities spanned approximately 0.5 orders of magnitude (Figure 6). Model precision was also comparable with levels of precision reported in other regional-scale field studies. For example, Dauwalter et al. (2009) used a national database of trout densities to quantify natural variability within trout populations and reported an average coefficient of variation (CV) of 0.49. Petty et al. (2005) reported a similar CV (0.48) for eastern brook trout (Salvelinus fontinalis). The CVs for the interquartile ranges of the model-predicted D (calculated by removing the first and fourth quartiles) ranged from 0.49 to 0.50. Thus, the model predictions—particularly the interquartile ranges—may be well suited for estimating trout population densities at regional scales (see McGarvey et al. 2010).

Sensitivity plots showed that the model was least sensitive to changes in \( \text{NPP}_{\text{sal}} \). Predicted \( D \) was a negative, linear function of \( \text{NPP}_{\text{sal}} \) and the slope of this relationship was relatively low, though it varied between SM, MD, and LG streams (Figure 7A). The model was much more sensitive to changes in \( \varepsilon, P_B \), and \( b \) (Figures 7B–7D). Each of these parameters exhibited curvilinear relationships with predicted trout \( D \), with \( D \) increasing more rapidly as \( \varepsilon \) increased or as \( P_B \) or \( b \) decreased. Using site- or region-specific data to narrow the range of potential \( \varepsilon, P_B \), and \( b \) values should therefore be a priority in future research. In particular, one may wish to verify whether \( \varepsilon \geq 0.15 \) (the approximate inflection point in Figure 7B), \( P_B \leq 1 \) (see Figure 7C), or \( b \leq 0.75 \) (see Figure 7D). Doing so could greatly reduce the variability of the \( D \) predictions (i.e., increase model precision) shown in Figure 6.

**Regional Carrying Capacity**

We predict that the potential carrying capacity of all montane streams within the MRB is between 0.8 million (sum of 25th percentiles for all watersheds; see Figure 8) and 4.6 million (sum of 75th percentiles) trout. The median predicted carrying capacity is approximately 2.1 million trout. For individual watersheds, predicted carrying capacity is highest in the Lower McKenzie, due to the combined surface area of LG stream segments (93.3 ha). Predicted carrying capacity is lowest in the Blue River and Quartz Creek watersheds due to the lack of LG stream segments. However, we predict that all watersheds are capable of supporting large numbers of trout. For instance, the median predicted carrying capacities are more than 150,000 trout in all watersheds (Figure 8).

**Prospects for Applying and Improving the Model**

By substituting a simple, robust macroecological equation (i.e., the self-thinning relationship) for the more complex algorithms and data demands of traditional fish habitat models, we were able to predict regional trout carrying capacity in a highly efficient manner. Our model includes only eight parameters (see equations 2 and 5), and most can be estimated using

![Figure 7. Sensitivity analysis results. Sensitivity plots are shown for the model parameters (A) \( \text{NPP}_{\text{sal}} \), (B) \( \varepsilon \), (C) \( P_B \), and (D) \( b \), when the trout density model was run in small, medium, and large streams. In each plot, the predicted trout densities are shown when the full range of potential parameter values (\( \text{NPP}_{\text{sal}}, \varepsilon, P_B \), or \( b \)) is used in the model (equation 5), but the remaining parameters are held constant at their median values (shown on each plot).](image-url)
data published in the primary or gray literature. For example, we have already compiled baseline distributions of $c$, $P_B$, and $b$ values (see Figure 2), and NPP$_{auto}$ and NPP$_{allo}$ have been quantified in many different types of systems (e.g., Bott et al. 1985; Webster and Meyer 1997). Thus, the model can potentially be used to estimate carrying capacity in many different regions.

Several caveats should, however, be considered when applying the macroecological model. First, the model cannot currently predict trout $D$ within specific streams with a high level of precision. Variability in the model outputs reflected the overall sensitivity of the model; large changes in $D$ were sometimes driven by relatively small changes in $c$, $P_B$, and $b$ (Figure 7). More precise parameter estimates may therefore reduce the variability in predicted $D$. That said, trout populations are naturally variable and the interquartile ranges of the predicted $D$ (Figure 6) were comparable to observed rates of variation among years and among sites (e.g., Petty et al. 2005; Dauwalter et al. 2009). This suggests that high model sensitivity or variability is not a problem. Rather, it may be an efficient tool for modeling trout $D$ at regional scales. We therefore recommend that the median predicted $D$ be used to estimate average trout densities at the regional scale and the interquartile ranges be used to characterize natural variation within or among populations (see McGarvey et al. 2010).

Second, by using common M and T values, we assumed that cutthroat and rainbow trout are functionally equivalent in montane streams. This assumption seemed reasonable, given that these species have similar diets and size distributions (see Parameterizing, Running, and Evaluating the Model section). But separate cutthroat and rainbow trout predictions will be necessary if managers have distinct objectives for these species. Thus, the ability to discriminate between cutthroat and rainbow trout could improve the model. For instance, a simple habitat differentiation rule that uses stream size as a predictor may be possible, given that cutthroat trout often occur in smaller, higher gradient streams than rainbow trout (Johnson et al. 1999).

Third, our carrying capacity estimates should not be construed as numbers of harvestable trout because the model used an average trout M of 7.5 g (or ~84 mm fork length), which is well below the minimum size limit for harvest in Oregon ($\geq 203$ mm; Oregon Department of Fish and Wildlife 2011). Harvestable trout abundances could be predicted if an algorithm to partition trophic resources among discrete age- or size-classes and independent M and T estimates for each size-class were available. Size-classes could then be modeled independently, effectively treating them as separate “species” (see McGill 2008). But for the moment, fisheries managers are advised that large, harvestable trout will comprise only a fraction of the predicted carrying capacities shown in Figure 8.

Fourth, the NPP$_{auto}$ estimates did not include terrestrial insect subsidies or marine subsidies (i.e., anadromous salmon carcasses and eggs), which can account for a large fraction of trout production (Wipfli and Baxter 2010). Marine subsidies should not significantly influence our results because dams now prevent migratory salmon from accessing much of their historical habitat in the MRB (Oregon Department of Fish and Wildlife 2005). However, terrestrial insect subsidies may be important, particularly in SM streams where aquatic–terrestrial linkages are strongest and terrestrial insect densities are highest (Wipfli
and Baxter 2010). For instance, Romero et al. (2005) measured terrestrial insect subsidies in small streams along the Oregon coast. If their annual estimate (45.5 g ww/m²/year, using C and ww conversions from Waters 1977) had been added to our NPP_total estimate in SM streams (at T = 2 because terrestrial insects are consumed directly by trout), our median predicted D would have increased to approximately 0.37 trout/m²—a closer fit to the OBS density data than our original prediction for SM streams (Figure 6). Determining whether similar terrestrial insect subsidies are available to MRB trout should therefore be a priority in future research.

Fifth, we assumed that Andrews Forest streams are representative of all montane streams in the MRB. Strictly speaking, we know that this was incorrect and we acknowledge that site-specific data would improve the modeling results. But in the absence of a comprehensive, spatially explicit database, we submit that the Andrews Forest data were a good starting point for our regional simulations, noting that Andrews Forest is widely recognized as a model system for studying montane forest ecology in the Pacific Northwest (Geier 2007). We also emphasize that physical habitat and NPP data from other Pacific Northwest streams have generally corroborated the Andrews Forest data (e.g., Naiman and Sedell 1980).

Finally, our model did not account for nontrophic constraints on trout abundance, such as habitat quality or degradation. These secondary limitations may cause actual trout abundances to be lower than our predicted abundances in many streams (see Poff and Huryn 1998; Jackson et al. 2001). We did not consider this a problem because our objective was to estimate potential carrying capacity at the regional scale. Other models are better suited to predict fish abundance within disturbed habitats or at smaller scales (e.g., Burnett et al. 2007). In future applications, it may be possible to add nontrophic factors to our model. For example, if model parameter estimates were available from logged or agricultural streams, the model could be used to evaluate land use decisions (see Bernot et al. 2010), but doing so will add complexity and may ultimately blur the distinction between our simple model and conventional models. For now, we emphasize that the predicted abundances should be thought of as maximum carrying capacities within minimally impacted systems.

Methods similar to ours have been used in marine systems (e.g., Jennings and Blanchard 2004) but this study is, to the best of our knowledge, the first application in a freshwater environment. The data needed to run the model are, however, available in many freshwater systems (e.g., Webster and Meyer 1997). Our method may therefore be of help to anyone who wants to estimate regional fish abundances or carrying capacities but does not have the resources to build and calibrate more complex models.

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Hatcheries, Conservation, and Sustainable Fisheries—Achieving Multiple Goals: Results of the Hatchery Scientific Review Group’s Columbia River Basin Review

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Criaderos, conservación y pesquerías sustentables-cumplimiento de objetivos múltiples: resultado del Grupo de Revisión Científica de Criaderos de la cuenca del Río Columbia

RESUMEN: las nuevas estrategias de manejo de criaderos en la cuenca del Río Columbia se enfocan en la conservación de las poblaciones naturales desovantes, y dicha conservación se equipara en prioridad al aprovechamiento que se espera de la pesca-esto representa un balance difícil de lograr. El Grupo de Revisión Científica de Criaderos (GRCC) evaluó 178 programas de criaderos y 351 poblaciones de salmónidos para determinar cómo pueden lograrse los objetivos de manejo tanto de la conservación como de las pesquerías sustentables. A través de la modelación se determinó la mejor estrategia utilizando un enfoque basado en la mejor ciencia disponible, identificación de objetivos, capacidad de defensa y manejo adaptativo con el fin de trasladar la atención del paradigma de la acuacultura hacia el paradigma de los recursos naturales renovables. Se concluye que tanto criaderos como poblaciones naturales deben ser administrados bajo los mismos principios biológicos. Las soluciones propuestas por el GRCC han mejorado el estado de conservación de numerosas poblaciones (25 por ciento de la trucha arcoíris, más del 70 por ciento de los salmones Chinook y coho) y a la vez también han incrementado los niveles de captura. Las poblaciones naturales desovantes de trucha y salmón coho se han incrementado de 6,000 a 10,000; y el salmón Chinook en más de 35,000 en comparación a las cifras actuales. La producción en criaderos de juveniles disminuyó ligeramente y en la mayor parte de los casos la producción cambió en las poblaciones de interés. El potencial global de cosecha se incrementó de 717,000 a 818,000 peces gracias que los esfuerzos se redirigieron hacia una pesca más selectiva y a la reubicación de las actividades pesqueras que se desarrollaban dentro de los ríos, hacia zonas más cercanas donde los propios peces se producen. En paralelo a mejoras en el hábitat, se encontró que frecuentemente aquellos peces de origen natural prácticamente duplicaron sus números.
ABSTRACT: New hatchery management strategies in the Columbia River Basin focus on conservation of naturally spawning populations as an equal priority to providing fish for harvest—a difficult balance to achieve. The Hatchery Scientific Review Group (HSRG) assessed 178 hatchery programs and 351 salmonid populations to determine how to achieve managers’ goals for conservation and sustainable fisheries. Modeling determined the best strategy, using an approach based on best available science, goal identification, scientific defensibility, and adaptive management to refocus from an aquaculture paradigm to a renewable natural resource paradigm. We concluded that hatcheries and natural populations must be managed with the same biological principles. HSRG solutions improved the conservation status of many populations (25% for steelhead trout, more than 70% for Chinook and coho salmon) while also providing increased harvest. Natural-origin steelhead trout and coho salmon spawners increased by 6,000 to 10,000; Chinook salmon increased by more than 35,000 compared to current numbers. Hatchery juvenile production decreased slightly, and in most cases production shifted from populations of concern. Overall harvest potential increased from 717,000 to 818,000 fish by focusing on selective fishing and by relocating some in-river harvest closer to where the fish originate. With habitat improvements, often the number of natural-origin fish nearly doubled.

INTRODUCTION

The Pacific Northwest contains the largest number of hatchery programs for anadromous salmonids (Oncorhynchus spp.) in the world. Overall, the states of Washington, Oregon, and Idaho produce over 300 million salmon and from artificial production programs associated with fish hatcheries (Naish et al. 2007). This extensive hatchery system has been developed over the past 100 years, primarily to support fisheries as mitigation for the reduced abundance of natural-origin fish resulting from overfishing, logging, agriculture, hydropower, urbanization, and associated losses of freshwater salmon habitats (Lichatowich 1999). The hatchery system in the Pacific Northwest often contributes over 80% of salmon and steelhead trout harvested in commercial, tribal, and recreational fisheries (Mahnken et al. 1998; Naish et al. 2007). However, despite this huge hatchery system, natural populations of anadromous salmonid fishes in the Pacific Northwest continue to decline, and many are now listed as threatened or endangered under the Endangered Species Act (ESA). Hatchery practices and overharvest have both contributed historically to the overall decline of naturally spawning populations (Waples 1991, 1999; Lichatowich 1999; Levin et al. 2001; Naish et al. 2007).

The philosophy of salmon management in the Pacific Northwest has changed in recent years. Although hatcheries have generally been very successful at supplying fish for fisheries, new management strategies also need to focus on conservation of naturally spawning populations as an equal priority. In 1999, the U.S. Congress established the Hatchery Scientific Review Group (HSRG) to review hatchery programs in the Pacific Northwest with the goal of continuing to provide fish for harvest while at the same time reducing risks to natural populations and contributing to achieving conservation goals for Pacific salmon and steelhead trout. The HSRG was initially charged with reviewing all state, tribal, and federal hatchery programs in Puget Sound and Coastal Washington (Mobrand et al. 2005). The HSRG established a scientific framework and three fundamental principles to guide changes in hatchery programs in the Pacific Northwest. According to these principles, hatchery programs must (1) develop clear, specific quantifiable harvest and conservation goals for hatchery and natural populations; (2) be scientifically defensible, both programmatically and operationally; and (3) include monitoring and evaluation of benefits and risks so that programs can be managed adaptively. Based on the results of those initial reviews in Puget Sound and Coastal Washington, in 2005 Congress directed the National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NOAA Fisheries) to replicate the HSRG project in the Columbia River Basin.

For the Columbia River Basin review process, the HSRG was requested to focus on the potential for compatibility of conservation and harvest. These two issues are of paramount importance to management of fish and fisheries in the Columbia River Basin. For fish listed under the ESA, protecting wild fish is a priority, whereas, for many national acts (e.g., Magnuson Stevens) and international treaties (e.g., USA/Canada, tribal), providing fish for harvest is a high priority. Achieving a scientifically defensible but socially acceptable balance between harvest and conservation has proved to be challenging, both politically and biologically. In this article, we summarize the principles and approach, and we detail the major findings of the HSRG Columbia River Basin review (HSRG 2009).

REVIEW PROCESS

The comanagers’ goals for conservation and harvest were used as the basis for the HSRG review process. The HSRG’s approach was to use the best available science and the three aforementioned principles to change the focus of the Columbia River hatchery system from an agrarian or aquaculture-based model to a renewable natural resource model. Under this new paradigm, the HSRG concluded that the biological principles used to manage hatchery populations and programs had to be the same as the principles that are used for managing natural populations. This paradigm shift requires that hatchery and hatchery managers focus on the biological viability of the populations propagated in, and influenced by, the hatchery environment, as opposed to focusing on the management of physical facilities. Although hatcheries and streams represent two totally different types of environments, HSRG assumed that the biological principles for maximizing population viability in each of those two environments are the same. In the past, most hatchery programs in the Columbia River basin have been
aimed almost exclusively at supplying fish for harvest. The end result is that facilities were managed largely for “maximum production,” with little or no attention focused on population integrity, biological viability, or self-sustainability. For example, if the number of adults returning to a hatchery was insufficient to “fill” a facility with eggs or juvenile fish, adult fish or eyed eggs were imported from elsewhere (commonly called “backfilling”). Hatchery reform centers around the concept that harvest is sustainable only if the targeted populations—both hatchery and wild—are themselves biologically viable and consistent with conservation goals for those populations. The challenge before the HSRG was to determine whether conservation and harvest goals could both be met under this new paradigm and, if so, how.

To facilitate a review over a landscape as large as the U.S. portion of the Columbia River Basin, the HSRG divided the Basin into geographic regions (Figure 1). The regions were then grouped into four areas: (1) lower Columbia, (2) mid-Columbia, (3) upper Columbia, and (4) Snake River. The lower Columbia was defined as the mainstem Columbia River and its tributaries below Bonneville Dam; the mid-Columbia was defined as the mainstem Columbia River and its tributaries between Bonneville and McNary dams; the upper Columbia extends from McNary Dam upstream to Chief Joseph Dam; and the Snake River includes the mainstem Snake River and all tributaries upstream of its confluence with the Columbia River. These four areas encompass all waters of the Columbia River Basin currently accessible to anadromous salmonid fishes. For each Columbia River Basin population within the areas reviewed, the HSRG presented its findings and recommendations in the form of a series of HSRG solutions.

The HSRG’s scientific review was conducted through a series of regional and cumulative workshops. The review began in the Lower Columbia River area in July 2006 and progressed upstream to the mid- and upper Columbia areas, culminating in the Snake River Basin in August 2008. Each regional workshop was preceded by initial fact finding by the HSRG. Data collected from the comanaging agencies and tribes were assembled into draft reports on the salmon and steelhead trout populations and hatchery programs within the region. Each regional workshop began with a field visit to hatchery facilities and watersheds. The HSRG then reviewed and analyzed the compiled data, applied its scientific framework, and developed draft recommendations for each hatchery program within the region under review. The federal, state, and tribal comangers of the region’s hatchery programs participated in the final day of the workshop, answered questions from the HSRG, and provided feedback to the initial draft recommendations. When the regional workshops within an area were completed, a cumulative workshop was held to “roll up” data on all of the populations in the area. This roll-up allowed the HSRG and the area fishery managers to view the “big picture” for that segment of the Columbia River Basin.

**ANALYTICAL METHODS**

The HSRG examined all information using the web-available All H Analyzer (AHA) tool (see Table 1, analytical procedures) developed for the HSRG process (Michael et al. 2009). The input parameters to AHA are based on ecosystem diagnosis and treatment (EDT) parameters commonly in use in the Columbia River Basin (Marcot et al. 2002; Beechie et al. 2003; Blair et al. 2009). These factors include habitat productivity and capacity, mortality associated with downstream (juveniles) and upstream (adults) passage through the hydropower system, harvest (marine and freshwater), and the input of juvenile fish provided by hatcheries. These factors are often referred to colloquially as the “All Hs,” AHA uses a modified Beverton-Holt function to model population dynamic responses to alternative salmon management options. AHA tracks the survival and reproduction of all natural and hatchery populations over many generations until an equilibrium condition is reached. Most important, AHA quantifies the fitness loss of naturally spawning populations caused by hatchery introgression. Based on the fraction of hatchery fish in the natural spawning escapement and on the fraction of natural-origin parents in the
hatchery broodstock (pNOB) over time, AHA calculates a fitness factor (after Ford 2002). This fitness factor is a measure of the productivity of the composite hatchery–natural population relative to a locally adapted natural population. By keeping track of contributions from all hatcheries to each natural population in the Columbia Basin, based on hatchery straying rates, AHA estimates the proportion of hatchery fish (pHOS) and natural origin fish (pNOS) on the spawning grounds. The fitness assumptions used in AHA result in a 50% loss of natural productivity when the contribution of hatchery fish is high (pHOS > 10%) for several generations. On the other hand, when the hatchery contribution is low (e.g., pHOS < 5%) over several generations, the natural productivity approaches that of a locally adapted natural population.

AHA apportions the total number of adult recruits at equilibrium to three terminal outcomes: harvest, interception at a hatchery (or weir), and natural spawning in the habitat. The analysis does not attempt to estimate what might happen in any particular year; rather, it projects the equilibrium outcome of each hatchery and natural population component after multiple generations. The output includes an index termed “portionate natural influence” (PNI) that measures the relative influence of the natural and hatchery environments on the mean phenotypic values of a population at equilibrium based on the relative rates of gene flow between the two environments. This measure is approximated by PNI = pNOB/(pNOB + pHOS) and varies (0 < PNI < 1.0; see Table 1 for complete details of analytical procedures).

AHA was used as a quantitative platform to evaluate the relative benefits and risks of alternative management strategies for balancing the effects of hatcheries, harvest, habitat, and hydroelectric system constraints. Four alternative scenarios were routinely examined: (1) the “baseline” hatchery program (status quo of current conditions), as the program existed during the 2006–2008 time period of the review; (2) the “no hatchery” scenario; (3) the “best segregated” hatchery program; and (4) the “best integrated” hatchery program (Box 1), where “best” was derived after many alternative iterations with changing parameter values (e.g., number of hatchery-origin juveniles released into a watershed). The integrated or segregated hatchery strategy that was judged to best address the managers’ conservation and harvest goals for the population was selected as the “HSRG solution.” In some cases, a segregated hatchery program provided the greatest harvest and conservation benefits, particularly when a hatchery was physically separated geographically from natural populations. In other cases, the integrated approach provided the greatest benefits. Each population and watershed is unique, and only a case-by-case evaluation can determine which management strategy provides the greatest likelihood of achieving harvest and conservation goals.

The HSRG evaluated the effects of a 10% increase in habitat capacity as an addition to the chosen HSRG solution in order to project how planned and ongoing habitat improvements in watersheds could affect population responses to hatchery reform strategies. AHA was not used by the HSRG to make decisions or to judge the “correctness” of management policies but as a way to illustrate the implications of alternative ways of balancing the four Hs so that informed decisions could be made.

HSRG recognizes that there is significant uncertainty in our analyses, but this uncertainty is substantially less than the uncertainties associated with many of the assumptions used to manage hatchery programs in the absence of a quantitative analytical tool such as AHA. Moreover, overall population trends and conclusions resulting from AHA are quite robust to variations of input parameter values, although the predicted absolute number of adult recruits is less so. Hence, for comparative purposes, we believe that AHA provides a scientifically defensible tool for assessing alternative management strategies.
Box 1: integrated vs. segregated hatchery actions.

The HSRG has described two genetic management options: (1) manage a hatchery broodstock as a reproductively distinct population that is genetically segregated from naturally spawning populations, or (2) manage a hatchery broodstock as a genetically integrated component of an existing natural population (Mobrand et al. 2005).

Genetically segregated broodstocks are generally derived strictly from hatchery-origin adults returning back to the hatchery each year. Segregated hatchery programs create a genetically distinct, hatchery-adapted population. Segregated hatchery populations will diverge genetically from naturally spawning populations over time due to founder effects, genetic drift, and domestication selection in the hatchery environment. Such changes may be intentional (e.g., via selective breeding) to maximize benefits or the operational efficiency of a hatchery program. Segregated hatchery programs can provide large benefits for harvest. Fish from segregated hatchery programs would ideally be propagated solely from hatchery returns and not allowed to spawn with the natural population. Natural spawning by hatchery-origin (HOS) fish from a segregated program may pose unacceptable genetic and ecological risks to natural populations.

Genetically integrated broodstocks include a prescribed proportion of natural-origin fish in the broodstock (pNOB) each year to maintain genetic integration with a natural population. For most integrated hatchery programs, the intent is to minimize the genetic and reproductive fitness differences between the hatchery broodstock (fish used for spawning) and the naturally spawning population from which they are derived. To achieve this, at a minimum, the proportion of hatchery broodstock comprised of natural-origin fish has to be greater than the proportion of the naturally spawning population made up of hatchery-origin fish. Integrated hatchery programs require, as a long-term goal, a self-sustaining naturally spawning population capable of providing adult fish for broodstock each year. Integration thus requires suitable natural habitat capable of sustaining a natural population. Using this concept, an integrated hatchery does not replace habitat but adds to existing habitat. An implicit goal of an integrated program is to demographically increase the abundance of a natural population while minimizing the genetic effects of artificial propagation. The size of an integrated hatchery program will necessarily be limited by the habitat available to the natural populations with which it is integrated and by the ability of the hatchery program to restrain natural spawning by hatchery-origin adults.

Normally, conservation programs will be focused on integrated strategies and harvest programs on segregated strategies. However, integrated programs will in many cases also support harvest opportunity. Both integrated and segregated populations can provide risk to natural populations. Both types of programs will require methods (e.g., selective fisheries and control structures such as weirs) to remove hatchery-origin fish prior to spawning grounds to adequately control hatchery/wild fish ratios. For hatcheries relative to co-manager goals for conservation and harvest. However, AHA should not be used—nor is it intended to be used—as a tool for predicting future population abundance in any given year.

To develop solutions that addressed conservation goals for each region, the HSRG needed to understand the relative importance of each population to the grouping as a whole. This was done by establishing the biological significance of a population using the classification system adopted by the Lower Columbia Fish Recovery Board (LCFRB 2004) and population goals supplied by the co-managers. Using this system, all distinct salmonid populations were designated as either primary (populations that must meet the highest viability levels), contributing (populations intended to meet moderate viability levels), or stabilizing (populations that can maintain current viability levels). The HSRG established standards for each population designation regarding the allowable levels of hatchery influence on naturally spawning populations in terms of pHOS and PNI, whereby primary populations would need to experience the lowest level of hatchery influence, contributing populations an intermediate level of influence, and stabilizing populations would not require modification (Box 2). The HSRG then evaluated the overall level of current hatchery

2 In the Columbia River Basin, depending on region and species these groupings are variously referred to as evolutionary significant units (ESU), distinct population segments (DPS), or major population groups (MPG).

Box 2.

HSRG quantitative standards for conservation actions for the proportion of natural-origin spawners made up of hatchery-origin fish (pHOS), the proportion of hatchery broodstock derived from natural-origin fish (pNOB), and the proportionate natural influence (PNI) on an integrated population that results from the combination of pHOS and pNOB.

Primary populations: pHOS should be less than 5% of the naturally spawning population, unless the hatchery population is integrated with the natural population. For integrated populations, pNOB should exceed pHOS by at least a factor of two, corresponding to a PNI value of 0.67 or greater and pHOS should be less than 0.30.

 Contributing populations: pHOS should be less than 10% of the naturally spawning population, unless the hatchery population is integrated with the natural population. For integrated populations, pNOB should exceed pHOS, corresponding to a PNI value of 0.50 or greater and pHOS should be less than 0.30.

Stabilizing populations: The current operating conditions were considered adequate to meet conservation goals. No criteria were developed for pHOS or PNI.
influence on each natural population and compared that to the projected level for the HSRG solution. It is important to point out that in the context of the HSRG work, the primary, contributing, and stabilizing ratings refer to the conservation priority of the population and whether a hatchery solution could be developed to maintain or improve the rating while meeting the comanagers’ goals. Projected improvements in a (primary, contributing, or stabilizing) rating for a population were taken by the HSRG to imply that the chosen hatchery operational solution could benefit the overall conservation of the population (i.e., increase the scope for conservation). The ratings have no relationship to population abundance levels or recovery scenarios. In fact, currently most populations rated as primary in the Columbia River Basin are at low abundance and are listed under the ESA.

The HSRG developed its assumptions (analytical framework/working hypotheses) in order to provide a useful starting point that is based on an explicit, scientifically defensible framework. The review did not include analysis of existing laws, policies, and agreements pertaining to either harvest or hatchery management. However, the flexibility contained in the adaptive management clauses of many of the agreements could accommodate reforms similar to those being proposed. The hypotheses and assumptions that the HSRG used in its analyses were consistent with facts, knowledge, and scientific information available at the time of publication of its report. Nonetheless, uncertainty exists, and alternative hypotheses and assumptions may also be scientifically defensible.

**Population Assessments**

Details are presented for the hatchery and natural salmon and steelhead trout populations reviewed by the HSRG in the Columbia River Basin (Table 2). For each wild and hatchery population within a species category, an individual population report was created describing the history and importance of the population including knowledge and assumptions about baseline (2006–2008 time period) habitat capacity, population productivity, harvest rate, hydrosystem survival conditions; observations about significant hatchery propagation activities; and the AHA analysis results for each of the four solution alternatives. Individual reports per species were then combined (rolled up) on a regional (e.g., local watershed/management unit) basis to determine hatchery effects in local Columbia River Basin subregions for 29 separate population groupings (see Table 1 for complete details of individual and roll-up reports). We have consolidated and summarized the individual and roll-up reports for each salmon grouping and species for the total Columbia River Basin for items of (1) projected population status and hatchery production, (2) projected abundance of natural origin spawners, and (3) projected harvest opportunity (Tables 2–4).

**Chinook Salmon (Oncorhynchus tshawytscha)**

The HSRG evaluated a total of 13 Chinook salmon groups in the Columbia River Basin; this included 106 natural populations and 72 hatchery populations (Table 2). The first priority for each of these evaluations was to develop solutions to address recovery planning scenarios for natural populations. Baseline information indicated that only about half of the primary (51%) and contributing (49%) populations met HSRG standards for the levels of hatchery influence (Figure 2). Under the HSRG solution, more of the primary (86%) and contributing (83%) populations met those standards, increasing the scope for conservation of these Chinook salmon populations (Figure 2). The HSRG solution for populations of Chinook salmon indicated the potential to increase natural origin spawner abundance (NOS) by over 35,000 fish compared to the current (baseline) situation (Figure 3). For the combined Chinook salmon populations, a projected 10% increase in habitat capacity would provide an additional estimated 18% increase in NOS if combined with the HSRG hatchery reform solution (Figure 3). To further evaluate recovery scenarios that comanagers indicated would likely occur in urbanized areas, we also compared the NOS response for a 10% increase in habitat capacity for the baseline condition to the HSRG solutions for the combined lower Columbia and upper Willamette River Chinook salmon populations. Under these scenarios, a hatchery reform plus 10% habitat solution would produce about a 50% larger NOS than simply a 10% increase in habitat capacity alone (Figure 4). For these solutions, total overall projected Chinook salmon hatchery production was reduced only slightly from about 106.2 million to 103.9 million smolts released (Table 2). For Columbia River Chinook salmon, potential harvest was actually increased slightly to moderately in 92% of the populations, with total projected harvest opportunity changing from about 393,000 to 459,000 fish (Figure 5). Potential harvest distribution was altered somewhat from a 61% ocean, 25% mainstem, 14% terminal area distribution to a 54% ocean, 28% mainstem, 18% terminal area distribution (Table 4).

**Lower River Coho Salmon (Oncorhynchus kisutch)**

Lower Columbia River coho salmon is a large and diverse population grouping, consisting of 29 natural populations and 21 hatchery populations evaluated by the HSRG (Table 2). Most of the large natural runs of coho salmon in the lower Columbia River were replaced decades ago by hatchery populations (Flagg et al. 1995). The risk of extinction is “high” or “very high” for all remaining natural populations except the Clackamas in the Cascade MPG (LCFRB 2004). For lower Columbia River coho salmon, the HSRG developed a solution that met the comanagers’ goals for conservation of primary and contributing populations (Figure 2) and provided increased harvest (Figure 5). Baseline information indicated that only
TABLE 2. Summary of number of natural and hatchery populations examined, co-manager population recovery planning goals, and HSRG analysis of current baseline conditions versus proposed preferred solution for both natural population planning and hatchery production for Columbia River salmon stocks.

<table>
<thead>
<tr>
<th>Population Unit</th>
<th>Number of individual populations examined</th>
<th>Natural population status</th>
<th>Hatchery production (1,000s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Natural</td>
<td>Hatchery</td>
</tr>
<tr>
<td>Chinook Salmon:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Columbia River Chinook ESU</td>
<td>31 19</td>
<td>14P, 5C, 12S</td>
<td>5P, 0C, 26S</td>
</tr>
<tr>
<td>Upper Willamette River Chinook Salmon ESU</td>
<td>8 6</td>
<td>3P, 2C, 3S</td>
<td>2P, 0C, 6S</td>
</tr>
<tr>
<td>Middle Columbia River Spring-run Chinook Salmon ESU</td>
<td>10 7</td>
<td>7P, 3C, 05</td>
<td>6P, 1C, 3S</td>
</tr>
<tr>
<td>Deschutes River Summer/Fall-run Chinook ESU</td>
<td>1 0</td>
<td>1P</td>
<td>1P</td>
</tr>
<tr>
<td>Upper Columbia River Spring Chinook ESU</td>
<td>7 6</td>
<td>6P, 0C, 15</td>
<td>0P, 0C, 7S</td>
</tr>
<tr>
<td>Upper Columbia River Summer/Fall Chinook Salmon ESU</td>
<td>10 13</td>
<td>3P, 3C, 45</td>
<td>1P, 1C, 8S</td>
</tr>
<tr>
<td>Snake River Fall-Run Chinook ESU</td>
<td>1 1</td>
<td>1P</td>
<td>1S</td>
</tr>
<tr>
<td>Upper Salmon River Chinook MPG</td>
<td>9 2</td>
<td>3P, 4C, 25</td>
<td>2P, 4C, 35</td>
</tr>
<tr>
<td>Middle Fork Salmon River Chinook MPG</td>
<td>9 0</td>
<td>8P, 1C, 05</td>
<td>9P, 0C, 05</td>
</tr>
<tr>
<td>South Fork Salmon River Chinook MPG</td>
<td>4 3</td>
<td>3P, 0C, 15</td>
<td>2P, 0C, 25</td>
</tr>
<tr>
<td>Grand Ronde and Imnaha Spring Chinook MPG</td>
<td>7 4</td>
<td>5P, 0C, 25</td>
<td>1P, 2C, 45</td>
</tr>
<tr>
<td>Tucannon-Asotin Chinook MPG</td>
<td>2 1</td>
<td>1P, 0C, 15</td>
<td>0P, 1C, 15</td>
</tr>
<tr>
<td>Clearwater River Spring Chinook MPG</td>
<td>7 10</td>
<td>2P, 2C, 35</td>
<td>0P, 0C, 75</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td><strong>106 72</strong></td>
<td><strong>57P, 20C, 29S</strong></td>
<td><strong>29P, 9C, 68S</strong></td>
</tr>
</tbody>
</table>

| Coho Salmon: |         |         |         |                |                  |                        |                  |                        |
| Lower Columbia River Coho Salmon ESU | 29 21 | 10P, 7C, 125 | 6P, 2C, 215 | 11P, 3C, 155 | 16,985.3 | 13,471.3 |
| Upper Columbia River Coho Salmon | 5 6 | 0P, 0C, 55 | 0P, 0C, 55 | 0P, 1C, 4S | 4,787.3 | 4,783.5 |
| **total** | **34 27** | **10P, 7C, 175** | **6P, 2C, 265** | **11P, 4C, 195** | **21,177.6** | **18,254.8** |

| Chum Salmon: |         |         |         |                |                  |                        |                  |                        |
| Lower Columbia River Chum ESU | 17 2 | 8P, 7C, 25 | 10P, 3C, 45 | 8P, 4C, 55 | 299.9 | 1,189.0 |
| **total** | **17 2** | **8P, 7C, 25** | **10P, 3C, 45** | **8P, 4C, 55** | **299.9** | **1,189.0** |

These solutions reduced the total overall lower Columbia River coho salmon hatchery production from about 16.9 million to 13.5 million juveniles (Table 2). Despite this, overall potential harvest opportunity was increased from about 178,000 to 206,500 fish (Table 4). For this example, harvest distribution remained basically stable at about one-third each for ocean, mainstem, and terminal fisheries areas (Table 4).

Chum Salmon (Oncorhynchus keta), Sockeye Salmon (Oncorhynchus nerka) and Upper River Coho Salmon

Columbia River chum salmon, sockeye salmon, and upper river coho salmon populations are relatively small, with hatchery programs associated primarily with conservation. The
HSRG solutions for these populations produced only small changes in the number of primary and contributing populations meeting the HSRG standards (Table 2) and small potential changes in the estimated number of NOS (Table 3). Harvest on each of these populations is relatively minor and was not greatly influenced by suggested HSRG program solutions (Table 4). For these population groups, a projected 10% increase in habitat capacity would provide an additional estimated 15% increase in NOS for upper Columbia River coho salmon, 14% for chum salmon, and 11% for sockeye salmon if combined with the HSRG hatchery reform solutions (Table 3).

**Steelhead Trout (Oncorhynchus mykiss)**

For steelhead trout, the HSRG evaluated a total of 11 regional population groupings (Table 2). This included a total of 81 natural populations and 72 hatchery steelhead trout populations. Most Columbia River steelhead trout hatchery programs are relatively small compared to those for Chinook and coho salmons and currently have either a conservation focus or are managed as segregated programs. Additionally, throughout the Columbia River Basin, the comanagers have designated many smaller tributaries as “hatchery-free zones” for steelhead. Baseline information indicated that about 90% of the primary and 83% of the contributing populations currently met HSRG standards for the levels of hatchery influence (Figure 2). Nonetheless, the HSRG solution was still able to project an increase in the scope of conservation for both primary (110%) and contributing (95%) populations (Figure 2). The HSRG solution would result in a projected increase in NOS of about 6,000 fish compared to the baseline situation (Figure 3). For the combined steelhead trout populations, a projected 10% increase in habitat capacity would provide an additional estimated 20% increase in NOS if combined with the HSRG hatchery reform solution (Figure 3). With these solutions, overall hatchery production was reduced only slightly from 14.9 million to 14.7 million juveniles released (Table 2). With the HSRG solution, total harvest opportunity was increased slightly from 126,000 to 130,000 fish (Figure 5). Under this scenario, projected harvest distribution remained basically stable at under 2% for ocean, about 18% for mainstem, and about 80% for terminal fisheries (Table 4).

**Basin-Wide Effects**

Overall, HSRG population solutions provided a projected increase in the conservation potential for stocks of importance in the Columbia River Basin from about 25% (steelhead trout) to over 70% (Chinook and coho salmon; Table 2). The HSRG analysis indicated that for the combined major popula-
### Table 3. Projected average annual abundance of natural-origin spawners (NOS) for Columbia River salmon for AHA scenarios of current, no hatchery, HSRG proposed solution, and HSRG proposed solution plus 10% habitat improvement.

<table>
<thead>
<tr>
<th>Population Unit</th>
<th>Projected Natural Origin Spawners (NOS)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current (Baseline)</td>
</tr>
<tr>
<td><strong>Chinook Salmon:</strong></td>
<td></td>
</tr>
<tr>
<td>Lower Columbia River Chinook ESU</td>
<td>22029</td>
</tr>
<tr>
<td>Upper Willamette River Chinook Salmon ESU</td>
<td>7515</td>
</tr>
<tr>
<td>Middle Columbia River Spring-run Chinook Salmon ESU</td>
<td>10966</td>
</tr>
<tr>
<td>Deschutes River Summer/Fall-run Chinook ESU</td>
<td>9210</td>
</tr>
<tr>
<td>Upper Columbia River Spring Chinook ESU</td>
<td>1080</td>
</tr>
<tr>
<td>Upper Columbia River Summer/Fall Chinook Salmon ESU</td>
<td>45405</td>
</tr>
<tr>
<td>Snake River Fall-Run Chinook ESU</td>
<td>1737</td>
</tr>
<tr>
<td>Upper Salmon River Chinook MPG</td>
<td>2383</td>
</tr>
<tr>
<td>Middle Fork Salmon River Chinook MPG</td>
<td>1157</td>
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<td>South Fork Salmon River Chinook MPG</td>
<td>1776</td>
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<td>Grand Ronde and Imnaha Spring Chinook MPG</td>
<td>2162</td>
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<td>Tucannon-Asotin Chinook MPG</td>
<td>261</td>
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<tr>
<td>Clearwater River Spring Chinook MPG</td>
<td>941</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td><strong>106622</strong></td>
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<tr>
<td><strong>Coho Salmon:</strong></td>
<td></td>
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<tr>
<td>Lower Columbia River Coho Salmon ESU</td>
<td>35590</td>
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<td>Upper Columbia River Coho Salmon</td>
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<td><strong>total</strong></td>
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<td><strong>Chum Salmon:</strong></td>
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<td>Lower Columbia River Chum ESU</td>
<td>19972</td>
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<tr>
<td><strong>total</strong></td>
<td><strong>19972</strong></td>
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<tr>
<td><strong>Sockeye Salmon:</strong></td>
<td></td>
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<tr>
<td>Lake Wenatchee Sockeye ESU</td>
<td>14803</td>
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<tr>
<td>Snake River Sockeye ESU</td>
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</tr>
<tr>
<td><strong>total</strong></td>
<td><strong>14818</strong></td>
</tr>
<tr>
<td><strong>Steelhead Trout:</strong></td>
<td></td>
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<tr>
<td>Southwest Washington Steelhead DPS</td>
<td>2065</td>
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<tr>
<td>Lower Columbia River Steelhead DPS</td>
<td>8821</td>
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<tr>
<td>Upper Willamette River Winter Steelhead DPS</td>
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<td>Middle Columbia River Steelhead DPS</td>
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<td>Upper Columbia River Steelhead DPS</td>
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<td>Salmon River Steelhead MPG</td>
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<td>Clearwater River Steelhead MPG</td>
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<tr>
<td>Grande Ronde Steelhead MPG</td>
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<td>Imnaha Steelhead MPG</td>
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<tr>
<td>Tucannon–Asotin Steelhead MPG</td>
<td>503</td>
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<tr>
<td>Hells Canyon Steelhead MPG</td>
<td>209</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td><strong>52944</strong></td>
</tr>
</tbody>
</table>

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a. From HSRG AHA analysis. The HSRG cautions that numerical values developed through the AHA analysis are for illustrative purposes only and are only useful to describe potential directional outcomes if managers decide to implement a given strategy.
<table>
<thead>
<tr>
<th>ESU/DPS/MPG Unit</th>
<th>Baseline (1000s)</th>
<th>HSRG solution(^a) (1000s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Harvest</td>
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<tr>
<td></td>
<td>Ocean</td>
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<tr>
<td><strong>Chinook Salmon:</strong></td>
<td></td>
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<tr>
<td>Lower Columbia River Chinook ESU</td>
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<td>Deschutes River Summer/Fall-run Chinook ESU</td>
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<td>Middle Fork Salmon River Chinook MPG</td>
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<tr>
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<tr>
<td>Grand Ronde and Imnaha Spring Chinook MPG</td>
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<td>Tucannon-Asotin Chinook MPG</td>
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<tr>
<td>Clearwater River Spring Chinook MPG</td>
<td>0.036</td>
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<td><strong>total</strong></td>
<td><strong>2.183</strong></td>
<td><strong>23.040</strong></td>
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\(^a\) From AHA analysis. The HSRG cautions that numerical values developed through the AHA analysis are for illustrative purposes only and are only useful to describe potential directional outcomes if managers decide to implement a given strategy.
tion groups of Chinook and coho salmon and steelhead trout, applying HSRG hatchery reform guidelines can improve the average potential scope for conservation for both primary and contributing populations by a factor of about 1.5 (Figure 2). The proposed HSRG hatchery reform solutions provided for an overall slight reduction in total hatchery production for all stocks from about 143 million to 139 million juveniles (Table 2). At the same time, the HSRG solutions provided for a total NOS increase from the current about 233,000 to 280,000 adults and an increase in total harvest opportunity from the current about 715,000 to 819,000 fish (Tables 3 and 4). The no hatchery alternative resulted in a few more NOS fish (294,000 total), but all harvest opportunity was lost with that option. When a modest 10% improvement in habitat conditions was combined with HSRG’s hatchery reform solution, the potential number of NOS fish was increased to a total of 330,000 adults while maintaining harvest (Table 3). The average percentage NOS population increase in response to a 10% habitat improvement was about 16% for all species analyzed, resulting in a projected synergistic beneficial natural population boost of almost 60% (1.6×) compared to habitat efforts alone. However, a 10% habitat improvement was projected to yield a near 50% NOS (5×) increase in the industrialized and urbanized watersheds of the Portland, Oregon, area, suggesting that these could be high-yield areas for improvement.

The HSRG solutions were achieved through combinations of proper broodstock management; shifting hatchery production releases away from primary and contributing populations; shifts in ocean, mainstem, and terminal area harvest efforts; initiating some selective fishing; relocating some in-river harvest benefits closer to the source of fish being harvested; and in some cases suggesting the operation of weirs to keep hatchery fish out of wild fish-spawning areas. These options were utilized to varying degrees, depending on, among other things, the conservation status of the population and size and degree of straying of any nearby hatchery populations; these are fully described in Table 1, individual population reports.

**DISCUSSION AND CONCLUSIONS**

In undertaking this review, the major question was whether hatcheries can contribute to harvest and at the same time be compatible with conservation. Clearly, the answer to this question is “yes” providing that HSRG guidelines are followed, particularly for management of broodstock and harvest. Applying these guidelines improved the conservation status of many populations, usually exceeding the co-managers’ conservation goals while at the same time providing for increased harvest. In some cases increased harvest was possible with reduced production of juveniles. When improvements in habitat were assumed, increases in the potential number of natural-origin fish were significantly enhanced when the habitat improvements were combined with the HSRG’s hatchery reform solutions.
Certain generalized principles and solutions applied to all programs (Box 3). Goals for fish populations were not always explicitly communicated and/or fully understood by the managers and operators of hatchery programs. All too often, the purpose of many hatchery programs was described in terms of numbers of juveniles to be released, without tying those releases to specific benefits or risks to harvest and conservation goals. This is similar to evaluating a farm based on the pounds of seed planted rather than the size and quality of the crop produced. Resource goals should be quantified, where possible, and expressed in terms of values to the community (harvest, conservation, education, research, etc.). Hatchery programs should be evaluated on the basis of their contribution toward these goals. The number of adults produced per spawner along with total adult recruitment should be the key measures of performance for hatchery programs, not the milestone of juvenile output that is often used. It is important to keep in mind that hatcheries are tools available (among others) for meeting these resource goals—they are a means and not an end.

Hatchery strategies should fit within a framework of well-defined natural population and harvest goals. Once a set of goals has been identified, the scientific rationale for a hatchery program (in terms of expected benefits and risks) must be formulated. This rationale should explain how the program expects to contribute to the goals. The purpose, operation, and management of each hatchery program must be scientifically defensible. The strategy chosen must be consistent with current scientific knowledge. Where there is uncertainty, the working hypotheses and assumptions under which the program will proceed should be explicitly articulated. Scientific defensibility should be a central consideration throughout all phases of a hatchery program—when determining whether a hatchery should be built or a program initiated, during the hatchery or program planning and design phase, during the operations phase, and when determining if a program should be changed or terminated. This ensures a scientific foundation for hatchery programs, a means for addressing uncertainty, and a method for demonstrating accountability. Documentation for each hatchery program should include a description of analytical methods used in program development and should be accompanied by citations from the scientific literature. Unless the exact rationale and purpose of a hatchery program is clear, it is not possible to effectively design, operate, or evaluate the program.

Throughout the Columbia River Basin, harvest is a primary goal of most hatchery programs. However, conservation objectives are becoming increasingly important. In order for either strategy to operate consistent with conservation, interactions with natural populations need to be addressed. The HSRG has identified two strategies for limiting the adverse effects that hatchery fish may have on natural populations. One is to sufficiently isolate hatchery fish from wild fish; the second is to assure that the hatchery fish are as similar to wild fish as possible (see Box 1). Hatchery programs should be managed as either genetically integrated with, or segregated from, the natural populations they most directly influence. Normall, hatchery programs with a conservation purpose will follow an integrated strategy to achieve goals of gene conservation, accelerated recolonization of extirpated habitats, and establishment of safety nets for populations at risk of demographic extinction. Harvest programs may be either integrated or segregated, depending on the ability to limit hatchery strays and availability of appropriate wild broodstock. Typically, the intent for either strategy would not include allowing hatchery fish on the spawning grounds with wild fish. Hatchery strays on the spawning grounds pose a risk with either strategy. For conservation programs the demographic benefits of hatchery fish on the spawning grounds must outweigh the risks. HSRG conservation solutions that shift spawning dynamics from conditions of high hatchery influence to conditions of low hatchery influence (e.g., Figure 6) are designed to provide the greatest benefits for wild stocks.
(number of fish) in specific fisheries (e.g., tributary sport or other terminal fisheries) or as mixed-stock, preterminal, sustainable harvest rates. Conservation goals need to be expressed in terms of a population’s biological significance\(^3\) (primary, contributing, stabilizing) and viability (natural-origin spawning abundance, productivity, diversity, and spatial structure; see McElhany et al. 2000). Harvest programs must be managed to achieve full use of hatchery-origin fish. Hatchery fish from harvest programs and from most conservation programs need to be externally marked (e.g., adipose fin-clip) so that the composition of hatchery- vs. natural-origin fish can be effectively managed to meet standards for composition and abundance of natural spawning escapement (pHOS) and hatchery broodstock (pNOB). Because salmon survival in any given year can vary by an order of magnitude, hatchery programs and fisheries must be flexible enough to respond to in-season abundance indicators and considerable uncertainty. If fisheries cannot be managed to fully harvest hatchery salmon, hatchery production may need to be reduced or suspended to avoid adverse effects on natural populations.

Hatchery programs should be sized to achieve goals for harvest and conservation while reducing the effects on natural populations from straying, ecological interactions, and collecting more natural broodstock than the population can support. The appropriate size of an integrated or segregated program is directly related to the productivity and abundance of the natural population, taking into account the effects of harvest, hydropower operations, and habitat conditions. Given concerns about ecological interactions, hatchery production should be as small as possible while still achieving conservation and harvest goals.

Facilities operated in support of hatchery programs (traps, weirs, water intake screens, and hatchery effluent discharges) can have adverse effects on salmonid populations and other aquatic species. The HSRG noted that, for the most part, existing laws and regulations related to facilities and operations are adequate to protect the environment. Not all facilities, however, are in compliance with those laws and regulations. It is important that those facilities that are not in compliance be identified and brought into compliance. Recognizing that weirs and traps have a legitimate role in controlling hatchery strays that could affect naturally spawning populations, the HSRG encourages the use of low impact weirs that have minimal effect on natural populations and their habitats.

In addition to establishing resource goals and a defensible scientific rationale and operational standard for a hatchery program, the HSRG recommends that the managers’ decisions be informed and modified by continuous evaluation of existing programs, changing circumstances, and new scientific information. Decisions about hatcheries must also be made in a broader, integrated context, and hatchery solutions must meet the test of being better, in a benefit/risk sense, than alternative available means to meet similar goals. Ecological systems affected by hatchery programs are dynamic and complex; therefore, uncertainty is unavoidable. Hatchery managers’ decision-making processes must include provisions to monitor the results of their programs and identify when environmental conditions, harvest, or scientific knowledge has changed. Each of these conclusions must be addressed through policy, management, research, and monitoring. The more closely hatchery programs adhere to these principles and recommendations, the greater the likelihood that they will meet stated harvest and conservation goals.

\(^3\) Note that cultural, economic, or social importance may be high for populations with low biological significance.
Box 3. Principles and system-wide recommendations.

Principle #1: Develop clear, specific, quantifiable harvest and conservation goals for natural and hatchery populations within an “all H” context

Recommendation 1: Express conservation goals in terms of a population’s biological significance (primary, contributing, stabilizing) and viability (natural-origin spawning abundance and productivity).

Recommendation 2: Express harvest goals in terms of a population’s contribution to specific fisheries.

Recommendation 3: Ensure that goals for individual populations are coordinated and compatible with those for other populations in the Columbia River Basin.

Principle #2: Design and operate hatchery programs in a scientifically defensible manner

Recommendation 4: Identify the purpose of the hatchery program (i.e., conservation, harvest, or both).

Recommendation 5: Explicitly state the scientific assumptions under which a program contributes to meeting the stated goals.

Recommendation 6: Select an integrated or segregated broodstock management strategy based on population goals and hatchery program purpose.

Recommendation 7: Size hatchery programs based on population goals and as part of an “all H” strategy.

Recommendation 8: Manage harvest, hatchery broodstock, and natural spawning escapement to meet HSRG standards appropriate to the affected natural population’s designation.

Recommendation 9: Manage the harvest to achieve full use of hatchery-origin fish.

Recommendation 10: Ensure that all hatchery programs have self-sustaining broodstocks.

Recommendation 11: Coordinate hatchery programs within the Columbia River Basin ecosystem to account for the effects of all hatchery programs on each natural population and each hatchery program on all natural populations.

Recommendation 12: Assure that facilities are constructed and operated in compliance with environmental laws and regulations.

Recommendation 13: Maximize survival of hatchery fish consistent with conservation goals.

Principle #3: Monitor, evaluate and adaptively manage hatchery programs

Recommendation 14: Regularly review goals and performance of hatchery programs in a transparent, regional, “all H” context.

Recommendation 15: Place a priority on research that develops solutions to potential problems and quantifies factors affecting relative reproductive success and long-term fitness of populations influenced by hatcheries.

Recommendation 16: Design and operate hatcheries and hatchery programs with the flexibility to respond to changing conditions.

Recommendation 17: Discontinue or modify programs if risks outweigh the benefits.

The HSRG review emphasized that hatchery fish cannot replace lost habitat or the natural populations that rely on that habitat. Therefore, hatchery programs must be viewed not as surrogates or replacements for lost habitat but as tools that can be managed as part of a coordinated strategy to meet watershed or regional resource goals, in concert with actions affecting habitat, harvest rates, water allocation, and other important components of the human environment. To be 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 in each watershed. Hatcheries are by their very nature a compromise—a balancing of benefits and risks to the target population, other populations, and the natural and human environment they affect. The benefits and risks of hatchery programs depend on the biological significance of the affected populations and the current and future status of all factors affecting the regional ecosystem within which they operate, including freshwater and marine habitats, hydropower facilities and operations, harvest patterns, and other regional hatchery programs. Hatchery programs should be used only to the extent that they provide a better option, from the benefit/risk standpoint, than available alternative methods to meet the same or similar goals. We now know enough about the science of hatchery fish and hatchery operations to move hatchery reform forward with a high likelihood of success.

The likelihood of meeting the comanagers’ goals for conservation and harvest on a sustainable basis would increase substantially if the proposed (or similar) solutions developed through the HSRG process were adopted. The HSRG solutions should be viewed as demonstrations of what is possible to achieve and a challenge to comanagers to develop equal or better alternatives. The current hatchery scenario cannot meet comanagers’ goals on a sustainable basis. The reforms recommended by the HSRG would affect many entities in the Columbia River Basin—fishery comanagers; funding entities such as electric utilities, the Bonneville Power Administration, and Congress; and regulators such as federal, state, and tribal fisheries managers. All of these entities should have important roles in the implementation of hatchery reform. Hatchery reform must also be a priority of the Northwest Power and Conservation Council, which is charged with developing a comprehensive fish and wildlife program to protect, mitigate, and enhance fish and wildlife resources in the Columbia River and its tributaries. Additionally, proper hatchery management affects the full range of land and water users in the basin, because hatchery practices greatly influence the success of investments in habitat protection and restoration for salmon and steelhead trout conservation. The entire region, therefore, has a stake in hatchery reform. The work of the HSRG can add significant value to the management of salmon and steelhead trout only if the principles and system-wide recommendations are fully integrated into everyday hatchery and harvest planning and operations.
Considering that the current cost of all aspects of salmon recovery actions in the Columbia River Basin is greatly in excess of $1 billion annually, the HSRG believes that details contained in the HSRG solutions for the individual populations would be worthwhile investments and would help guarantee the future of sustainable salmon and steelhead trout populations.

ACKNOWLEDGMENTS

Performing this analysis and developing recommendations for a large number of salmonid populations in the Columbia River Basin would not have been possible without the knowledge, commitment, and hard work of many individuals. The HSRG members extend special thanks to Greg Blair and the staff from ICF for their help with data management and AHA analyses; facilitation staff from the firms of D.J. Warren and Associates; Meridian Environmental, Inc.; Serverside Software; Malone Environmental Consulting; Triangle Associates, Inc.; and Gordon, Thomas, Honeywell, Malanca, Peterson & Daheim. Numerous state, federal, and tribal fishery biologists and managers contributed both their time and expertise in meetings, tours, and report reviews. HSRG member Tom Flagg had primary writing responsibilities for summarizing the Columbia River Basin HSRG report to Congress into the format for this publication and for developing summary analysis from system-wide roll-up reports. Funding and support for these efforts was provided by the Bonneville Power Administration, the National Oceanic and Atmospheric Administration, the Northwest Power and Conservation Council, the Pacific States Marine Fisheries Commission, and the U.S. Congress.

DISCLAIMER

The findings and conclusions in this article are those of the authors and do not necessarily represent the views of their affiliated federal, state and tribal agencies.

REFERENCES


Living on the Edge: Freshwater Mussels on the Brink of Extinction

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It is a hot, humid summer day in North Carolina and I am in a sandy run of the Tar River with a crew of biologists in wetsuits and wading boots. With sediment under our fingernails and the sun in our eyes, we spend the long day combing through the river reaches of the Tar Basin. We are out here for the freshwater mussels—they need our help. Freshwater mussels are not the most charismatic of animals; after all, they don’t even have a face. They can be hard to find when they are burrowed in the stream bed, they are not very active, and even experts can have a hard time telling them apart. However, enthusiasm among those who know them runs high. They are amazing animals.

Most people are familiar with the beautiful shells, pearls, and buttons that freshwater mussels supplied in the past, but mussels also provide valuable services for their underwater neighbors. Freshwater mussels are filter feeders. This means that they clean streams and provide nutrients to the benefit of fish and aquatic insects as they feed themselves (Vaughn et al. 2004, 2008). They are also ecosystem engineers that help to stabilize substrate for the benefit of other aquatic species (Howard and Cuffey 2006). Freshwater mussel larvae (glochidia) are obligatory parasites. For the larvae to metamorphose into the juvenile life stage, the larvae must attach to the gills or fins of a species-specific host fish. Perhaps partly because of their dependence on host fish, these remarkable animals are urgently in need of protection and conservation. Nearly 70% of the 300 species in North America are endangered, threatened, or already extinct (Williams et al. 1993; Graf and Cummings 2007). They are being assaulted on many fronts, and their widespread decline has been broadly attributed to pollution, water quality degradation, and habitat destruction from anthropogenic influences. Ongoing land use changes and changing temperatures and flows associated with climate change pose further danger to freshwater mussels by potentially altering their habitats. It is my job to find out what characteristics make a habitat suitable for freshwater mussels.

One of the last remaining strongholds of freshwater mussel populations in North Carolina is the Tar River Basin (Bogan 2002), and for that reason we are in the river picking up handfuls of sediment, measuring river widths, and recording the embeddedness and compaction of substrates. Instream habitat is only one piece of the suitability puzzle; I am also examining landscape-level attributes that might impact mussels. If I can identify the habitat characteristics that drive mussel distributions, then we can predict the locations of other areas that may have suitable habitat. This is a crucial step in mussel conservation. Because mussels are sessile organisms, they will need our help relocating if the environment changes too quickly, either by watershed development or climate change. Managers need to be able to identify suitable habitats to select relocation or population augmentation locations with a higher likelihood of success.

Back out in the river, there are cries of excitement. A snorkeler just found a Tar River spiny mussel (Elliptio steinstansa). The Tar River spiny mussel is a federally endangered species that is endemic to the Tar River Basin in North Carolina. It exists in only a few small isolated populations and is among the most imperiled species in North America. It is a thrilling experience to hold one of these animals in your hand and yet troubling to know that in the coming decade, another biologist may not be so lucky.

References
New Frontiers in Seattle

New Frontiers in Fisheries Management and Ecology: Leading the Way in a Changing World - was an AFS record-breaking event!

Photos by Richard Grost, along with Will Atlas, Annie Dowling, Emily Haug, Rachel Hovel, Coley Hughes, Amy Kassler, and Lori Ortega

In the middle of rampant economic uncertainty, the 141st Annual Meeting of the American Fisheries Society surged, stronger than ever, into Seattle’s Washington State Convention Center. Hosted by the WA-BC Chapter of the AFS, over 4,300 fisheries professionals, students, and guests from the United States and the world over brought their time, talents and vision to the Seattle meeting, the largest gathering to date. From September 4–8, 2011, attendees considered the theme “New Frontiers in Fisheries Management and Ecology: Leading the Way in a Changing World” while they enjoyed an unusually long bout of sunny days in the beautiful Pacific Northwest.

Initial registrants and continuing education seekers began arriving Saturday, when available classes included “Collaborative Negotiations,” “Effective Speaking When the Heat is On!” and other developmental topics. But the first real treat came with the start of the conference proper and Sunday night’s Welcome Social. Festivities got off to a swinging start at the Sheraton Hotel as guests downed delicious regional seafood inspired by National Geographic Fellow, Chef Barton Seaver, and got to thumb through his book For Cod and Country. After re-establishing connections from the 2010 meeting in Pittsburgh, those who weren’t too stuffed took their dancing feet to the floor for a lesson in swing. After grooving to the tunes of John Holte’s Radio Rhythm Orchestra, conference goers young and old were ready to hit the sack before Monday’s much-anticipated morning Plenary Session and the afternoon opening of the trade show.

Enthusiastic registration numbers forced the Plenary Session to relocate to downtown Seattle’s historic Paramount Theater, where members of the Muckleshoot Tribe offered a special invocation. Dr. Randall Peterman, who launched the Session, is a Professor in the School of Resource and Environmental Management at British Columbia’s Simon Fraser University. His talk, “An Optimistic View of Challenges Facing Fisheries Scientists and Managers,” outlined some current challenges in the fisheries field and laid out some ideas for moving forward, particularly with the training of younger members. Final speaker Dr. Jesse Trushenski, an Assistant Professor at Southern Illinois University Carbondale, also dealt with issues regarding the training of new cohorts to meet new world challenges. Her invigorating presentation was entitled...
“The Ecology of Fisheries Education — Are We Adequately Preparing the Next Cohorts for a Field in Flux?” These speakers sandwiched Billy Frank, Jr. and Dr. Robert Lackey. Frank, a representative of the Nisqually Indian tribe and 22-year Chairman of the Northwest Indian Fisheries Commission, spoke on “Native American Leadership in Management of Pacific Salmon.” Lackey, a retiree from the U.S. Environmental Protection Agency, spoke on “Science: Beacon of Reality” as it pertains to policy in fisheries management.

Students enjoyed their own two-day conference-within-a-conference, starting with the Student-Mentor Social on Monday night. Graduates and undergraduates connected with professionals at the Trade Show to learn more about their interest areas and pick up in-field opportunity tips. Tuesday featured more mentoring served up (with free lunch!) at the Student Colloquium and capped off the student experience with a Social and Career Fair at the Seattle Aquarium that evening. Another special group—the international conference-goers—joined together Tuesday night when International Fisheries Section President Felipe Amezgua hosted an International Reception. Those in attendance enjoyed a Latin American menu and a thought-provoking movie concerning local fisherman who form their own federations, with the goal being management zonation.

Wednesday was a full, with a 6 AM Spawning Run at Alki Beach for the early risers. The Trade Show and Symposium continued, and the Grand Space Needle Progressive Social made for a full night on the town in Seattle. Buskers! The International Fountain! Salmon barbecue! All under the watchful eye of the iconic towering Space Needle.

To conclude the 141st Meeting with a send-off appropriate to its “Changing World” theme, award-winning sustainable sushi chef Bun Lai spoke on – and delivered – the “future of sushi” to conference-goers’ gastronomic delight. The conference concluded with the music and art of Ray Troll and the Ratfish Wranglers, who left attendees swaying to the sound of a happy end to the 2011 Meeting and an enthusiastic look forward to 2012 in the Twin Cities!
The Minnesota Chapter of the American Fisheries Society would like to announce the second call for papers for the 142nd Annual Meeting of the American Fisheries Society in the Twin Cities of Minneapolis and St. Paul, Minnesota! The meeting’s theme, “Fisheries Networks: Building Ecological, Social, and Professional Relationships,” promises to bring forth up-to-date and relevant information and discussions about ecological networks and trophic food webs, social networks that inform human-fisheries interactions, and professional networks that support and enhance interactions among fisheries scientists as well as other issues facing aquatic resource professionals. AFS 2012 will be 19-23 August 2012 at the RiverCentre Convention Center and neighboring Crowne Plaza Riverfront Hotel, in downtown St. Paul. The sister Twin City of Minneapolis will provide additional exciting activities for the meeting. We look forward to seeing you in St. Paul and Minneapolis!

**GENERAL INFORMATION**

Fisheries professionals are invited to submit symposia proposals and abstracts for papers in a range of topics and disciplines, particularly those that focus on the meeting theme. We encourage participation by professionals at all levels and backgrounds, and especially students. The scientific program consists of three types of sessions: Symposia, Contributed Papers, and Posters.

**SYMPOSIA**

The Program Committee invites proposals for symposia. Topics must be of general interest to AFS members, and topics related to the meeting theme will receive priority. The Program Committee also encourages integrative symposia that span freshwater and marine systems (e.g. food web ecology, climate change, stock assessment methods, biotelemetry and other bioengineering methods). Topics that bring inland (especially Great Lakes) scientists and managers together with their marine colleagues will fit well into the “Networks” theme for the meeting.

Symposium organizers are responsible for recruiting presenters, soliciting their abstracts, and directing them to submit their abstracts and presentations through the AFS online submission forms. Organizers are not required to recruit a full symposium at the time of proposal submissions. The Program Committee will work with symposium organizers to incorporate appropriate presentations that were submitted as contributed papers. A symposium should include a minimum of 10 presentations and we encourage organizers to limit their requests to one-day symposia (about 20 oral presentations). Regular oral presentations are limited to 20 minutes, but double time slots (i.e. 40 minutes) may be offered to keynote speakers.

Symposium proposals must be submitted by 6 January 2012, but earlier submissions are strongly encouraged to allow web posting and feedback from AFS members. All symposium proposals must be submitted using the AFS online symposium proposal submission form available on the AFS website (www.fisheries.org). The Program Committee will review all symposium proposals and notify organizers of acceptance or refusal by 27 January 2012. If accepted, organizers must submit a complete list of all confirmed presentations and titles by 2 March 2012. Symposium abstracts (in the same format as contributed abstracts; see below) are due by 9 March 2012.

To increase the accessibility of symposia to all meeting participants and advertise topics, initial symposium ideas and contact information will be posted on a conference web page. This may help you recruit speakers and see if others have similar ideas that could be merged into one proposal.

**FORMAT FOR SYMPOSUM PROPOSALS**

(Submit using AFS online symposium submission form)

When submitting your abstract include the following:

1) **Symposium title:** Brief but descriptive
2) **Organizer(s):** Provide name, address, telephone number, fax number and e-mail address of each organizer. Indicate by an asterisk the name of the main contact person.
3) **Description:** In 300 words or less, describe the topic addressed by the proposed symposium, the objective of the symposium, and the value of the symposium to AFS members and participants.
4) **Format and time requirement:** Indicate the mix of formats (oral, poster, or keynote presentations).
5) **Chairs:** Supply name(s) of individual(s) who will chair the symposium.
6) **Presentation requirements:** Speakers should use PowerPoint for presentations.
7) **Audiovisual requirements:** LCD projectors and laptops will be available in every room. Other audiovisual equipment needed for the symposium will be considered, but computer projection is strongly encouraged.
8) **Special seating requests:** Standard rooms will be arranged theatre-style. Please indicate special seating requests (for example, “after the break, a panel discussion with seating for 10 panel members will be needed”).
9) **List of presentations:** Please supply information on: potential presenters, tentative titles, and oral or poster designations.
10) **Sponsors:** If applicable, indicate sponsorship. Please note that a sponsor is not required.

**CONTRIBUTED PAPERS AND POSTERS**

The Program Committee invites abstracts for contributed paper and poster sessions. Authors must indicate their preferred presentation format:

1. Contributed paper preferred, but poster acceptable.
2. Contributed paper only.
3. Poster only.
Only one contributed paper presentation will be accepted for each senior author. Oral presentations for contributed papers will be limited to 20 minutes (15 minutes for presentation plus 5 minutes for speaker introduction and questions). All oral presenters are expected to deliver PowerPoint presentations.

We encourage poster submissions because of the limited time available for oral presentations. The program will include a dedicated poster session to encourage discussion between poster authors and attendees. In addition, the Program Committee is exploring alternative presentation methods for posters. For example "Speed Presentations", short oral presentations of poster highlights, are being considered, as well as exhibiting symposium posters in the same room as oral symposium. Decisions on these alternatives will be provided in the final call for papers.

**STUDENT PRESENTERS**

Student presenters must indicate if they wish their abstract to be considered for competition for a best presentation (i.e., paper or poster, but not both) award. If they respond "no", the presentation will be considered for inclusion in the Annual Meeting by the Program Committee, but will not receive further consideration by the Student Judging Committee. If students indicate "yes", they will be required to submit an application to the Student Judging Committee. Components of the application will include an extended abstract and a check-off from their mentor indicating that the study is at a stage appropriate for consideration for an award.

**ABSTRACT SUBMISSION**

Abstracts for contributed papers and poster papers must be received by **10 February 2012**. All submissions must be made using the AFS online abstract submission form, available at [www.fisheries.org](http://www.fisheries.org). When submitting your abstract:

- Use a brief but descriptive title, avoiding acronyms or scientific names in the title unless the common name is not widely known;
- List all authors, their affiliations, addresses, telephone numbers, and e-mail addresses;
- Provide a summary of your findings and restrict your abstract to 200 words.

All presenters will receive an email confirmation of their abstract submission and will be notified of acceptance and the designated time and place of their presentation by **13 April 2012**.

The Program Committee will group contributed papers thematically based on the title and two keywords you will choose and prioritize during the abstract submission process.

Late submissions will not be accepted. AFS does not waive registration fees for presenters at symposia, workshops, or contributed paper sessions. All presenters and meeting attendees must pay registration fees. Registration forms will be available on the AFS website ([www.fisheries.org](http://www.fisheries.org)) in **May 2012**; register early for cost savings.

**FORMAT FOR ABSTRACTS**

Title: An example abstract for the AFS 2012 Annual Meeting

**Format:** Oral

**Authors:**
Anderson, Charles. Minnesota Department of Natural Resources, 500 Lafayette Road, St. Paul, MN 55155; 651-259-5188; charles.anderson@state.mn.us
Jacobson, Peter. Minnesota Department of Natural Resources, 27841 Forest Lane, Park Rapids, MN 56470; 218-699-7294; peter.jacobson@state.mn.us

**Presenter:** Charles Anderson

**Abstract:** Abstracts are used by the Program Committee to evaluate and select papers for inclusion in the scientific and technical sessions of the 2012 AFS Annual Meeting. An informative abstract contains a statement of the problem and its significance, study objectives, principal findings and application, and it conforms to the prescribed format. An abstract must be no more than 200 words in length.

**Student presenter? No**

**PROGRAM COMMITTEE CONTACTS**

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**Posters Subcommittee Chair:**
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218-999-7829
Column: 
DIRECTOR’S LINE

Seattle 2011: AFS highlights
Gus Rassam

The 141st AFS annual meeting in Seattle is now over. Breaking all records in attendance (more than 4000), exhibits (more than 110), short courses (17), number of presentations (2000 and 95 symposia), number of non-North American attendees (10% of total from more than 30 countries). And on and on—a huge success by any standard and a milestone to measure against in the future.

So while nearly half of the AFS membership was in Seattle digesting the latest in science and management advances, and enjoying the many, varied, social activities, the AFS leadership (Management Committee, Governing Board, sections) used the venue to meet and consider the business of the society.

Here, I’ll focus on few of the highlights of the Governing Board meeting, one of the two such meetings AFS conducts annually. The AFS Governing Board is composed of elected officials of the chapters (through our four divisions) and the sections. The governing board acts as the strategic arm of the society, examining major policy and structural issues, and acting on behalf of the membership to implement major changes in AFS programs.

• The Society is financially healthy, with a well-endowed reserve, a stable operational budget, and good future prospects.

• A Society retreat examined the issue of “affiliate membership” in chapters and sections. While the core membership has not fluctuated much over the past few years, many members of some chapters are not members of the Parent Society. This is also true, albeit on a much smaller scale, for sections such as Fish Health, Fish Culture, and Physiology. No immediate actions were taken as a result of the retreat, but leadership gained a better understanding of the complexities involved and some possible future directions.

• A presentation was made by our journal publishing partner, Taylor and Francis, and our investment manager, AXA. Starting in January 2011, the actual production and marketing functions of our journals were transferred to Taylor and Francis, and we are already seeing some early indications of increased journal submissions by non-North American authors.

• Our investment portfolio, while suffering a significant decline during the 2008 financial meltdown, has recovered substantially.

• AFS is launching Fisheries Reports, a database of the government reports—state, federal and international—related to fisheries. Abstracts and authors from such “gray literature” can be submitted directly to the database, and linked to the actual reports residing on the publisher servers.

• In 2010-2011, AFS membership approved a policy statement on Climate Change and Fisheries, and a resolution on ecological separation of the Great Lakes and Mississippi River drainage basins. Both are now available in the policy section of the AFS website.

• A major study was undertaken to identify ways to improve the AFS website and electronic communications.

• Relevant committees are working on two policy statements, one on lead in sport fishing tackle and another on the need for an immediate-release anesthetic/sedative for use in fisheries.

• The Coalition of Natural Resource Societies (of which AFS is a founding member) organized a Natural Resource Education and Employment Conference in September 2011.

• The 6th World Fisheries Congress will take place in Edinburgh, Scotland, in May 2012, with strong participation by AFS.

• AFS, together with the US Fish and Wildlife Service and the Wildlife Society, is launching a new diversity scholarship and internship program designed to support the study of fish and wildlife in college by individuals from under-represented communities, and to attract these individuals to an eventual career in the Service. I’ll have more details on this important and innovative program in the future.

AFS Executive Director Rassam can be contacted at grasam@fisheries.org

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Journal Highlights:
Transactions of the American Fisheries Society, Volume 140, Number 4


Foraging Modes of Predators and Behaviors of Prey Determine the Outcome of Multiple Predator Interactions. Michael P. Carey and David H. Wahl. 140: 1015–1022.


Long-Term and Interannual Dynamics of Walleye and Yellow Perch in Saginaw Bay, Lake Huron. Lori N. Ivan, Tomas O. Höök, Michael V. Thomas, and David G. Fielder. 140: 1093–1100.


PHILLIP ALLEN STEWART

Phillip Allen Stewart, Ph.D., Fisheries Manager

Phillip A. Stewart, 67, died of cancer in Fulton, Missouri on May 7, 2011.

Phil was born in Rochester, Minnesota and held degrees from the University of Arizona (B.S., M.S.) and Colorado State University (Ph.D.). His doctoral work (1970) was on physical factors influencing trout densities in streams. His wife Pat, sons Jordan and Matthew, and daughter Sarah, as well as other family members and many friends, survive Phil.

For 27 years, Phil was employed as a biologist and fisheries manager for the Montana Department of Fish Wildlife & Parks (FWP). After working in Columbus (3 years) and Wolf Point (7 years), his next 17 years were spent in Miles City, where as Region 7 fisheries manager he was responsible for the resources of the lower Yellowstone River, including the recreational paddlefish fisheries. Phil presided over the development of the first paddlefish roe (caviar) donation program and implemented regulations and stock assessment activities leading to sustainability of the fishery.

Phil embodied quiet effectiveness. Never one to draw attention to himself or his many skills and accomplishments, he always worked well with other professionals and the public. He was always willing to provide opportunities to beginning fishery biologists, seasonal field assistants, and those of us new to the region. He was a skilled field biologist and, unlike most people, somehow managed to get his reports completed on time. Phil was disciplined. He would rise early to jog and work out in 10-20 below-zero weather before riding his bicycle to work. Those of us who were privileged to know him also saw his wry sense of humor.

In addition to his professional activities, Phil was a deeply religious man whose other interests included fishing with family and friends, choral singing, and vegetable gardening. He developed the lot surrounding his house near the Roche Jaune Fishing Access Site in Miles City into a quarter-acre vegetable garden – like his fishery management activities, all done with quiet, supreme competence. Upon retirement from FWP in 1998, Phil and his family moved to Fulton, Missouri where he developed a larger garden for supplying a nearby farmer’s market.

As fine of a fisheries professional as he was, Phil was an even better person. A role model, he showed great patience in helping all of us who knew him become better fisheries professionals and better people.

Dennis Scarnecchia
Department of Fish and Wildlife Resources
University of Idaho for Montana Fish, Wildlife and Parks

Phil Stewart jaw-tagging an angler-caught paddlefish at Intake, Montana, 1995.
Continued from page 529

for our chapter and section affiliates. I have asked them to report to the Governing Board in 2012 with recommendations about how to move forward. There are constitutional constraints, numerous economic and communication challenges, and other unknown ramifications of creating such a membership category. However, hanging on to the status quo of not tracking or reaching out to our affiliates will not move us forward. We need to account for and include affiliates that align with our Society through chapters and sections. It will ultimately allow AFS to have stronger connections with affiliate members of the Society. I encourage both Society members and affiliates to contact me with suggestions about how to strengthen ties to affiliates who are now aligned with chapters or sections, but are not members of the Society.
Calendar:
FISHERIES EVENTS

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

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

More events listed at www.fisheries.org

<table>
<thead>
<tr>
<th>DATE</th>
<th>EVENT</th>
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<tr>
<td>Jan 26–Jan 30, 2012</td>
<td>AFS Southern Division Meeting</td>
<td>Biloxi, MS</td>
<td><a href="http://www.sdafs.org/meetings/2012/invite.html">http://www.sdafs.org/meetings/2012/invite.html</a></td>
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<tr>
<td>February 2–4, 2012</td>
<td>Arizona-New Mexico AFS Chapter - 45th Joint</td>
<td>Phoenix, AZ</td>
<td><a href="http://www.aznmfishsoup.org/">http://www.aznmfishsoup.org/</a></td>
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**Graduate Ph.D. Assistantship | Invasive Fish Behavior and Tracking Technology | University of Minnesota**

**Salary:** $20,000 /yr with full tuition and health benefits

**Closing:** 12/15 or until filled

**Responsibilities:** Student is expected to design and conduct experiments to determine when and how invasive carps move across large landscapes and how these behaviors can be manipulated using pheromones and other cues. This study will be conducted in close collaboration with computer scientists who are developing automated state of art radio-tracking systems that includes robots for a 3 year NSF project. Some work will be conducted at remote field sites.

**Qualifications:** BA/ BS/MS in a biological field with an emphasis in quantitative areas. Individual will ideally have independent research experience with fish ecology or behavior. Field work experience desirable.

**Contact:** Peter Sorensen, 612-624-4997 or below email

**Link:** http://fweb.cfans.umn.edu/sorensen/

**Email:** soren003@umn.edu

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**Graduate Research Assistantship | Annis Water Resources Institute - GVSU, MI | Student**

**Salary:** Graduate assistantships include a generous 12-month stipend that is eligible for annual renewal, as well as a full tuition waiver.

**Closing:** Until filled

**Responsibilities:** Accepted graduate student applicants will assist with research projects conducted by faculty and staff at AWRI in addition to performing research related to their thesis/project. Some of the current research projects at AWRI involve aquatic toxicology, fish ecology, chemical stressors on aquatic ecosystems, wetland ecology, invasive species, nonpoint source pollution, ecological modeling, primary productivity in streams and lakes, microbial ecology, and GIS-based investigations into watershed management.

**Qualifications:** Students must be accepted to the Master of Science degree program in the Department of Biology at GVSU as a full-time student, and a faculty member at the AWRI must serve as their major advisor.

**Contact:** Mark Luttenton, 616 331-2503 or below email.

**Link:** https://www.gvsu.edu/wri

**Email:** luttentm@gvsu.edu

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**M.S. Graduate Research Assistantship | TX Tech U. | Student**

**Salary:** $16K/y partial health tuition

**Closing:** Until filled

**Responsibilities:** Seeking highly motivated student to conduct research on the relationships between aquatic habitat water quality, harmful algal blooms, and the health of aquatic biota. Duties include field sampling, water analysis, and data analysis and interpretation. Multiple short term travel to field sites is required. For further information, please visit the link below.

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**IGERT PhD Fellowship in Watershed Science and Policy | Southern IL University | Student**

**Salary:** $30,000/year stipends, $10,500/year education allowance, student laptops, annual international river basin tours and support for research and conference travel

**Closing:** 1/15

**Responsibilities:** Southern Illinois University SIU is offering 6-8 Ph.D fellowships as part of NSF’s Integrative Graduate Education Research and Training IGERT program. The 2012 entering IGERT class will have a particularly strong international component, with a targeted research project in the Tisza River Basin of Central Europe involving 4-6 months initial fieldwork in Austria, Slovakia, Hungary, Ukraine, Romania, and/or Serbia.

**Qualifications:** U.S. citizens and permanent residents in any water-, river- or watershed-related field of study, including Geology, Hydrology, Geography, Engineering, Plant Biology, Zoology, Ecology, and other areas. Applicants should have a MS-level degree at the time of enrollment direct Ph.D possible in cases of exceptional merit and should have grades, test scores, and research records commensurate with one of NSF’s most coveted fellowship awards.

**Link:** http://www.igert.siuc.edu

**Email:** igert@siu.edu

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**Assistant Professor | Fish Population Ecology Conservation | University of MA, Amherst | Ph.D.**

**Salary:** Salary is commensurate with qualifications and experience.

**Closing:** 1/17 or until filled

**Responsibilities:** UMass Amherst Department of Environmental Conservation is seeking applications for a 9-month, tenure-track appointment as Assistant Professor in Fish Population Ecology and Conservation with an expected start date of Sep 2012.

**Qualifications:** Candidates should have documented expertise in fish biology and ecology, population dynamics, and fisheries management, and have strong quantitative skills and experience in either marine or freshwater systems. A doctoral degree in Fisheries Science, Fish Ecology, or the equivalent is required.

**Link:** http://eco.umass.edu/
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