Demonstration Flow Assessment and 2-D Modeling

Making the Best Use of Modeled Data: Multiple Approaches to Sensitivity Analysis of a Fish-Habitat Model
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ONE LOOK AT AFS MEMBERS
A look at AFS members...

UPDATE: 318 LEGISLATION AND POLICY
Elden Hawkes, Jr.

FEATURE: 320 FISH HABITAT
Demonstration Flow Assessment and 2-D Modeling: Perspectives Based on Instream Flow Studies and Evaluation of Restoration Projects

The methods presented by Railback and Kadvany (2008) may not give reproducible results, and demonstration flow assessments have significant drawbacks relative to two-dimensional hydraulic and habitat modeling.

Mark Gard

FEATURE: 330 FISH HABITAT
Making the Best Use of Modeled Data: Multiple Approaches to Sensitivity Analysis of a Fish-Habitat Model

Sensitivity analyses are essential tools in appropriately using modeled predictions to make management decisions. We compare three types of sensitivity analysis as applied to an ecosystem model linking salmon and their habitats: E. Ashley Steel, Paul McElhany, Naomi J. Yoder, Michael D. Purser, Kevin Malone, Brad E. Thompson, Karen A. Avery, David Jensen, Greg Blair, Craig Busack, Mark D. Bowen, Joel Hubble, and Tom Kanz

COLUMN: 316 PRESIDENT’S HOOK
William G. Franzin

UPDATE: 345 AFS UNITS

JOURNAL HIGHLIGHTS: 352 TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY

PUBLICATIONS
353 BOOK REVIEW, NEW TITLES, FOR YOUR INFORMATION

AFS ANNUAL MEETING: 356 THE GREENING OF THE AFS’09 ANNUAL MEETING

CALENDAR: 359 FISHERIES EVENTS

ANNOUNCEMENTS: 360 JOB CENTER

COVER: Ambre Chaudoin, Matt Recsetar, and Olin Feuerbacher electrofishing a stream in Southern Arizona.

CREDIT: Scott A. Bonar
A Look at AFS Members...

AFS is a fairly large professional society with a core of dedicated members who pay dues annually or have purchased life memberships to obtain the benefits the Society offers. I suggested what some of these benefits are in my last column. You have seen in Fisheries and on the website that we are about to adopt a new Strategic Plan to guide us over the next several years. The Strategic Plan required the Society to do a bit of research on ourselves; for example, we collected information from our Membership and Membership Concerns committees, President Fabrizio commissioned a consultant to carry out a focus group analysis of a selected group of AFS members to get opinions about AFS member services, and finally we commissioned a membership survey. The 2008 Membership Survey was similar to surveys we conducted in 1997 (Brown 1998) and in 2004 (Brown and Cooke 2005) but also different in that a few new questions were asked. The questionnaire that formed the basis of the 2008 results was developed by a small group of members, officers, and the executive director. The 2008 survey, like the previous two, was conducted for us by the Human Dimensions Research Unit of Cornell University Department of Natural Resources. The common element in all these surveys was Tommy Brown, but this year Nancy Connelly of the same unit led the study. In the 2008 report, Connelly and Brown compared the outputs of the previous surveys with the findings in 2008 so we could investigate some trends in various areas. What I report here will be some of the highlights of the 2008 report and to follow up, Connelly and Brown will provide a detailed article from their report in the August issue of Fisheries. This column is to whet your appetite for a closer look at their article; I think you will find it interesting. In the course of researching this Hook, I also solicited some data from Membership Coordinator Eva Przygodzki at AFS headquarters to examine some trends in recruitment and losses. I was interested in our annual net recruitments and losses in the different categories of membership over the readily available period of record. These are reported below after my précis of the membership survey.

The 2008 survey was conducted entirely electronically via an e-mail sent to 1,500 randomly selected members, of whom 55.7% responded. In the 11 years since 1997, we as a society haven’t changed a great deal. We have a slightly higher percentage of female members, our mean age hasn’t changed much, the core employees remain the same, and we have more student members. Most of our members are fisheries biologists who work more in freshwater than in marine or estuarine ecosystems. More of us are attending Annual Meetings but the meetings still attract a little less than half the membership over a three-year period. In other words, in any one year perhaps only 15–20% of members attend the Annual Meeting. Chapters are more important to most members than Divisions or Sections, probably reflecting our large geographic distribution and the greater ability to participate locally in a Chapter. A noteworthy observation on meetings is that a majority of survey respondents favored web-based broadcasts of symposia from Annual Meetings and the development of online professional development opportunities. There is keen support for mentoring in AFS, both through programs like the Hutton Scholarship Program and mentoring of young professionals by established fisheries professionals. Only about a third of respondents were fully aware of the mechanisms and roles of Chapters, Divisions, and Sections in AFS governance but a majority of surveyed members felt the Society was meeting their needs. Although a majority of survey respondents felt AFS was doing enough to recruit and keep new members, 30–40% thought we could do more and a large majority thought we should do more to involve AFS members in the Society. Finally, of nine future priorities of AFS, large proportions of survey respondents felt that AFS should do more public outreach and political advocacy on behalf of aquatic resources. As I mentioned above, look for the detailed analyses of the questions in the August issue of Fisheries.

I turn now to trends in member recruitment and losses in our various membership categories, annually and over the last few years. The Society’s numbers grew during the middle of the decade but have stabilized at around 8,700 members (Table 1 and Figure 1). I found it interesting that annual recruitment in the period 1999–2003, although proportional to membership numbers, was more than offset by annual losses on average of 129 members per year (<1.5%; Table 2 and Figure 2). If one looks...
at month-to-month gains and losses, we do gain new members at Annual Meetings but often lose many of them in the following year, meaning that each year shows the losses of attendees at the Annual Meeting that don’t maintain membership in AFS. Incrementally our numbers slowly have increased mainly by the addition of student members. In 2002–2003 the losses were declining and we entered a period of alternating gains and losses in 2006–2008 with an overall very small gain. We lost some regular members to the young professional category in the first few years of making that category available but now it appears that a few young professionals are leaving that category but not being picked up as regular members. This indicates that some young professionals are leaving the Society when that benefit runs out. What does all this mean? Our core membership is quite constant and we get a few more new members per year than we lose but not enough to change our dynamic. How do we attract more of the two-thirds of fisheries professionals in North America that are not AFS members? We offer even better member services, even better journals, have even better meetings, and actively recruit new members in the coming years. We can easily add international members with that extra outreach that our members suggest we should do. For example, recently, more than 30 young Mexican members were recruited at the University of Mazatlan by Lourdes Rugge of the International Fisheries Section. Read more about us in the article in the August issue of Fisheries.

REFERENCES

Hearing on National Fish Habitat Conservation Act

On 16 June 2009, the House Committee on Natural Resources’ subcommittee for Insular Affairs, Oceans and Wildlife held a hearing to discuss the National Fish Habitat Conservation Act (NFHCA; H.R. 2565) and the Pacific Salmon Stronghold Conservation Act of 2009 (PSSCA; H.R. 2055). The hearing featured testimony from a diverse group from federal, state, and non-governmental organization representatives. All of the participants agreed that the NFHCA and the PSSCA both seek to achieve healthy habitats, healthy fish populations, and healthy coastal ecosystems, as well as increased ecosystem services, aesthetic value, and fishing opportunities for the U.S. public. It is estimated that they would also provide additional benefits to commercial and recreational fisheries by contributing $10 billion annually to the nation’s economy.

In regard to the PSSCA, many on the panel felt that it would provide a unique cooperative forum for public and private stakeholders to improve current salmon management and conservation policies. The PSSCA will also assist state governments to accelerate implementation of a holistic, comprehensive salmon conservation and management approach that integrates habitat, harvest, hatcheries, and hydropower. It was expressed that the PSSCA would provide the focus and resources necessary to be successful in the healthiest wild salmon rivers and will restore balance to current efforts to recover depleted stocks and maintain healthy ones.

In regards to the NFHCA, many felt that the NFHCA provides a strong overarching framework to build on and further advance fish habitat protection conservation actions nationally. It was stated that the NFHCA will help fish everywhere by supporting public-private efforts to protect and habitat naturally.

All of the panel participants urged the passage of both the NFHCA and the PSSCA by Congress. It was added that the potential additional fisheries losses are too great to not establish the cohesive framework that these bills would create. All members of the panel felt that both the NFHCA and the PSSCA are entirely compatible and complementary. Some expressed a desire to work with the subcommittee and other stakeholders to integrate the purposes and goals of the two bills if the subcommittee decides it would be more efficient to merge them into a comprehensive national approach to fish habitat conservation.

Ocean Conservation, Education, and National Strategy for the 21st Century Act

On 18 June 2009, the House Committee on Natural Resources’ subcommittee for Insular Affairs, Oceans and Wildlife held a hearing to discuss the Ocean Conservation, Education, and National Strategy for the 21st Century Act (H.R. 21). This hearing also heard testimony from a diverse group from federal, state, and non-governmental organization representatives. Kristen Fletcher of the Coastal States Organization testified that H.R. 21 has the components needed to reform ocean governance, improve the health of our oceans and coasts, and create a national ocean policy. Fletcher further stated that the bill would help reorient government to formalize the practice of ecosystem-based management and has the potential to build on the work already done by existing regional ocean partnerships.

Margret Caldwell of the Center for Ocean Solutions stated that leadership similar to that which was demonstrated in legislation like the Clean Water and Clean Air acts is appropriate for the nation’s oceans. This would not only provide a unifying framework for the existing sectoral laws and agencies, but it would also provide a national vision and support system for states whose livelihoods depend on healthy and resilient ocean systems. She concluded her testimony by stating that it is time for the United States to adopt a unified approach to the management of one of its most critical resources and establish a national ocean policy.

Pietro Parravano of the Joint Ocean Commission Initiative testified that passing H.R. 21 should provide a permanent and comprehensive policy and implementation framework for addressing ocean health. The policy should:

- Authorize and fund implementation of comprehensive ocean governance legislation that creates a national ocean policy.
- Codify and strengthen the federal coordinating structure for implementing the national ocean policy.
- Support regional marine and coastal management and governance efforts.

He concluded by stating that with the passage of H.R. 21, the benefits to be gained are enormous and are essential to revitalizing the economic and ecological health of our oceans, coasts, and Great Lakes.
Electronic Ballotting on AFS Constitution and Rules Changes

By Gwen White
AFS Constitutional Consultant Gwen White can be contacted at gwhite@dnr.in.gov.

We are testing a new mechanism for electronic review to facilitate broader and more timely participation of the AFS membership in updating the protocols that guide Society structure and function. We request your patience and welcome any suggestions on creating an effective electronic review process.

The following changes were recommended by the Governing Board at their meeting on 7 March 2009. All three proposals are provided for your review at www.fisheries.org.

Comments can be submitted in the online forum by July 15 or e-mailed to the AFS Constitutional Consultant, Gwen White, gwhite@dnr.in.gov.
Active Members may consider three amendments to the AFS Constitution and Rules for adoption by electronic ballot between August 1 and August 15.

The three proposals address the following protocols:

a. Constitution Article IV and IX. Parliamentarian—Establishes the Constitutional Consultant as a nonvoting member of the Management Committee, creates an Apprentice position to the Constitutional Consultant, and a Past Constitutional Consultant’s Advisory Council.

b. Constitution Articles III, VII, and IX. Appointment of committee and editorial board members—Allows the AFS President to delegate responsibility to appoint committee and editorial board members to the chair and journal editor, respectively.

c. Rule 4.H. Fish Habitat Section—Upon petition from over 100 Active Members, the Governing Board recommends establishing a new Fish Habitat Section.

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ABSTRACT: Railsback and Kadvany (2008) make a compelling case for the use of demonstration flow assessments (DFA) for instream flow assessments as a more robust method than traditional one-dimensional habitat simulation techniques, such as the Physical Habitat Simulation System. But, based on experience with DFAs used for instream flow assessments and evaluation of stream restoration projects, the methods presented by Railsback and Kadvany (2008) may not give reproducible results, and DFAs have significant drawbacks relative to two-dimensional (2-D) hydraulic and habitat modeling. Application of the DFA methodology presented in Railsback and Kadvany (2008) to assess a stream restoration project on the Trinity River, California, did not give reproducible results, with substantial disparity between replicate surveys in the total quantity and spatial distribution of habitat. As an empirical two-dimensional habitat modeling method, DFAs have several drawbacks. Compared to 2-D models, DFAs require interpolation and extrapolation of results from the observed flows, and lack biological realism because they use categorical (binary) habitat suitability criteria. Further, 2-D modeling offers significant benefits over DFA in the context of adaptive management. Advantages of DFAs cited by Railsback and Kadvany (2008), namely the feasibility of assessing habitat with complex hydraulics, the ease in using mechanistic and theoretical conceptual models, and the ability to assess long reaches, also apply to 2-D models. Modification of the DFA methods presented in Railsback and Kadvany (2008) to give reproducible results may increase the cost of DFAs or reduce the length of stream that can be assessed with DFAs to the point where 2-D modeling may be a more cost-effective technique than DFAs.
Método de Evaluación de Regímenes de Caudales y modelación 2-D: perspectivas sobre estudios de caudales ecológicos y evaluación de proyectos de restauración

RESUMEN: Railsback y Kadvany (2008) exponen un sólido caso en cuanto al método de Evaluación de Regímenes Caudales (ERC) aplicado a caudales ecológicos, como una herramienta más robusta que las técnicas tradicionales unidimensionales para simulación de hábitat, como por ejemplo el Sistema de Simulación de Hábitat Físico. Sin embargo, sobre la base de la experiencia con el ERC aplicado para evaluar caudales ecológicos y proyectos de restauración de caudales, los métodos presentados por Railsback y Kadvany (2008) pueden producir resultados no replicables, con diferencias sustanciales entre la réplica de los muestreos en cuanto a la cantidad total y la distribución espacial del hábitat. Como método de modelación empírica de hábitat bidimensional, el ERC tiene algunas desventajas. En comparación con los modelos 2-D, el ERC requiere de la interpolación y extrapolación de los resultados de los caudales observados y carece de realismo biológico ya que se fundamenta en el uso de categorías binarias como criterio para determinar cuán apropiado es un hábitat. Más aún, la modelación 2-D ofrece beneficios significativos en comparación al ERC en un contexto de manejo adaptativo. Las ventajas del ERC mencionadas en Railsback y Kadvany (2008), que consisten en la viabilidad de evaluar el hábitat a partir de aspectos sobre hidráulica, la facilidad de utilizar modelos conceptuales mecanísticos y teóricos, y la habilidad de evaluar canales grandes también aplican a los modelos 2-D. La modificación de los métodos de ERC presentados por Railsback y Kadvany (2008) para generar resultados reproducibles, puede incrementar el costo de los ERC o reducir la longitud del caudal que sea objeto de evaluación, hasta un punto en el que la modelación 2-D puede resultar una técnica más económica.
Figure 4. Habitat availability curves for 1+ coho rearing in the lower Oak Grove Fork using 1-D, 2-D, and DFA methodologies. Adapted from McBain and Trush (2004).

Figure 5. Sacramento River fall-run Chinook salmon spawning habitat suitability criteria for velocity (from Gard 2006), along with corresponding categorical criteria defined as velocities with a suitability greater than 0.5.

Figure 6. Pit River boulder-dominated riffle habitat at 51 m³/s:
A Demonstration flow assessment results (from R² Resources Consultants, Inc. 2003); and
B Two-dimensional hydraulic and habitat modeling results for adult rainbow trout rearing habitat (from Hardin-Davis, Inc. 2003).

The DFA and 2-D results are from different sites, because no boulder-dominated riffle sites were assessed with both DFA and 2-D. The results show areas of adult rainbow trout rearing habitat downstream of boulders which were captured with 2-D but were mostly not captured with DFA due to the minimum polygon size of 2.3 m² for pocket water and 4.6 m² for other mesohabitat types (R² Resources Consultants, Inc. 2003). Specifically, Figure 6(A) only shows two polygons downstream of boulders, despite the presence of many boulders, while Figure 6(B) shows numerous areas of medium to high-quality habitat (yellow, orange and red colors) away from the channel banks, downstream of boulders.
INTRODUCTION

In a recent feature, “Demonstration Flow Assessment: Judgment and Visual Observation in Instream Flow Studies,” Railsback and Kadvany (2008) make a compelling case for the use of a judgment-based habitat evaluation technique, demonstration flow assessments (DFA), to quantify the relationship between fish habitat and flow for instream flow assessments and they identify procedures for improving credibility and reproducibility of the technique. Notably, Railsback and Kadvany (2008) cite many advantages of DFAs versus traditional one-dimensional habitat modeling, such as the Physical Habitat Simulation (PHABSIM) System. The terminology for DFAs is still in flux and relate to a variety of habitat evaluation techniques; DFAs are sometimes referred to as “expert habitat mapping,” “judgment based habitat mapping,” or “habitat criteria mapping.” Recent DFAs in California have been used for instream flow assessments on the Pit (R2 Resources Consultants, Inc. 2003), Lower McCloud (Pacific Gas and Electric Company 2007) and Upper Tuolumne (McBain and Trush, Inc. 2007) rivers, and for evaluation of stream restoration projects on the Trinity River (the subject of this article). These studies illustrate three important aspects of DFAs that should be considered: (1) the ability of the procedure outlined in Railsback and Kadvany (2008) to produce a credible, legally defensible, and reproducible result; (2) the relative performance of two-dimensional (2-D) hydraulic and habitat modeling (Gard 2006) versus DFAs; and (3) the range of flows and actual effort needed for DFAs. Previous applications of judgment-based habitat evaluation techniques have received criticism for their potential lack of reproducibility (Arthington and Zalucki 1998; Young et al. 2004). This lack of reproducibility was demonstrated when replicate surveys of the judgment-based Expert Panel Assessment Method produced disparate results (Swales and Harris 1995). Although I agree with Railsback and Kadvany (2008) that DFAs can represent a substantial improvement over one-dimensional, or transect-based, habitat modeling, I conclude that 2-D habitat modeling produces several advantages over either DFAs or one-dimensional transect-based approaches that should be considered.

The variety of alternative techniques available to evaluate habitat can be broken down into three general categories:

1. Biological response correlations;
2. Demonstration flow assessments; and
3. Habitat modeling (Annear et al. 2004).

Biological response correlations are generally developed by a linear regression of a biological response variable, such as redd superimposition, versus flow. They can be used to evaluate spawning habitat by examining the degree of redd superimposition at different flows (Snider et al. 1996), or to evaluate rearing habitat by examining juvenile production estimates at different flows (Hvidsten 1993). Disadvantages of this approach are:

1. Difficulty in separating out effects of flows from year-to-year variation in escapement, survival, productivity, and other factors;
2. The need for many years of data;
3. The need to assume a linear relationship between the biological response variable and flow between each observed flow;
4. The inability to extrapolate beyond the observed range of flows; and
5. For spawning, the need for intermediate levels of spawning—at low spawning levels, there will not be any redd superimposition even with low habitat abundance, while at high spawning levels, the amount of superimposition cannot be determined because individual redds can no longer be identified.

Demonstration flow assessments (CIFGS 2003) use direct observation of river habitat conditions at several flows; at each flow, polygons of habitat are delineated in the field. Disadvantages of this approach are:

1. Its potential subjectivity;
2. Limitations in the accuracy of delineation of the polygons, using the methods in CIFGS (2003);
3. The need to have categorical (binary) habitat suitability criteria;
4. The need to assume a linear relationship between habitat and flow between each observed flow; and
5. The inability to extrapolate beyond the observed range of flows.

The second disadvantage can be overcome, albeit at increased cost, by surveying in the vertices of the polygons and making extensive depth and velocity measurements to validate the polygon boundaries. The fourth disadvantage can be overcome, again at substantially higher costs, by mapping in habitat at a large number (on the order of 30) of flows.

REPRODUCIBILITY OF DEMONSTRATION FLOW ASSESSMENTS: A CASE STUDY FROM THE TRINITY RIVER

The Trinity River, California, is the subject of a river restoration effort focused on a 64 km reach from Lewiston Dam to the North Fork Trinity River. The goal of the restoration effort is to restore geofluvial processes which will increase the availability of aquatic habitats and result in increased fish populations (U.S. Fish and Wildlife Service and Hoopa Valley Tribe 1999). Agencies and tribes working on recovery need a habitat evaluation method to assess progress toward increasing aquatic habitats. Goodman et al. (2007) evaluated a DFA methodology and study design on the Trinity River similar to that presented by Railsback and Kadvany (2008). In this case study, the DFA was evaluated by conducting replicate surveys at three locations (Figure 1). The results of these surveys are presented herein.

Methods

Six clearly defined habitat types were developed that pertain to species and lifestages of interest to the Trinity River
restoration effort (Table 1). Several species and lifestages with similar habitat requirements were combined into aggregate habitat types, so the types could be distinguished during field observations. The fry habitat type represented high quality rearing habitat for Chinook (Oncorhynchus tshawytscha) and coho (O. kisutch) salmon with a total length (TL) less than 50 mm, as well as egg deposition and larval rearing habitat for the foothill yellow-legged frog (Rana boylii) and western toad (Bufo boreas). The presmolt habitat type corresponded to high-quality rearing habitat for Chinook salmon from 50 to 200 mm TL. The spawning habitat type represented high quality spawning habitat for Chinook and coho. The holding habitat type characterized the holding habitat for adult Chinook salmon. The ammocoete habitat type denoted lamprey rearing habitat. The large woody debris habitat type was applied as a surrogate for western pond turtle (Actinemys marmorata) habitat.

The criteria for the salmonid components of the fry, presmolt, adult holding, and spawning habitat types were defined from Trinity River habitat suitability curves to represent high quality habitat (U.S. Fish and Wildlife Service and Hoopa Valley Tribe 1999; Yurok Tribe and U.S. Fish and Wildlife Service, unpublished data). The foothill yellow-legged frog and western toad require shallow, low-velocity areas for egg deposition and larval development and were included in the fry habitat type (Lind and Wilson 1996; Cavallo 1997; Lind 2004). The ammocoete habitat type was defined as areas of low velocity (< 0.05 m/s), fine substrate, and deposition but excluding areas of anoxic sediments (Potter 1980; Wydoski and Whitney 2003). Large woody debris habitat type is important for the basking behavior of western pond turtles and was applied as a surrogate to describe their habitat (Reese and Welsh 1998).

Maps of the study areas were developed for field observations from 2001, 2005, and 2006 high resolution aerial photography. The maps were developed in ArcGIS (version 9.2) using the map book utility (ESRI 2006). Two sets of 1:207 to 1:276 scale maps were produced for each survey. During field mapping, three habitat types were depicted on each set of maps to avoid errors associated with high levels of overlap among types (e.g., fry and presmolt habitat types). A team of qualified observers was selected from a subset of the agencies involved in the restoration effort, including representatives of the California Department of Fish and Game, Hoopa Valley Tribe, U.S. Fish and Wildlife Service, and Yurok Tribe. Prior to field observations, areas were delineated on the field maps and the observers (a) were trained in the field methods and (b) calibrated their ocular estimates of depths and water velocities to measured values. The survey methodology included a three-step decision-making process for mapping habitats. First, a crew member would identify an area that potentially corresponded to a habitat type. The area would then be discussed among the group regarding habitat-type criteria until a group consensus was reached. Finally, a team member would delineate the habitat area on the map, confirming with the group about its placement and size. The survey maps were scanned and rectified, and the habitat types were digitized into ArcGIS shapefiles (ESRI 2006). A final quality-control step was performed by comparing habitat-type shapefiles against field maps. Habitat-type areas (m²) were calculated from the shapefiles using Xtools for ArcGIS desktop (ESRI 2006) and exported into Microsoft Excel for analyses.

The field effort (training and application) required 11 days to complete. Two days were spent on training and calibration. A total of 20.47 rkm of river habitat were mapped over an additional 9 field days. In general, the survey crew consisted of 3–4 members on 1 raft, with 2 individuals mapping habitats. Map generation prior to the field effort required an additional 20 staff days, while post-processing of the field data using ArcGIS took another 30 staff days, for a total cost of $126,013 to conduct the DFA.

Reproducibility of the DFA methodology was assessed at three sites within the Trinity River, with a total length of 4.06 rkm. The sites were randomly selected to represent the range of habitat conditions in the Trinity River from Lewiston Dam to the North Fork Trinity River, and thus were not selected to be similar. At these sites the observation team conducted two surveys. Although the observation team was not completely the same for the two surveys, some members were shared between repeat surveys. Surveys were completed at summer base flows, when the release from Lewiston Dam was 12.7 m³/s and discharge at the downstream boundary of the mapped reach ranged from 14.1 to 14.8 m³/s at the U. S. Geological Survey (USGS) gauging station above the confluence with the North Fork Trinity River (USGS gage number 11526400). Weather and daylight conditions did not differ between the initial and repeat surveys.

Results

In the Trinity River DFA surveys, discrepancies between initial and repeat habitat areas varied by habitat type and survey segment (Table 2). An example of such discrepancies between initial and repeat surveys is presented in Figure 2. The ammocoete habitat type produced both the largest and smallest discrepancies between initial and repeat surveys. The largest discrepancies were observed in survey segment 3 with a repeat ratio (initial/repeat habitat area) of 11.8, whereas the lowest discrepancies were observed in survey segment 2 with a repeat ratio of 1.1. The repeat ratio in other habitat types varied from adult holding at 0.9 in survey segment 3 to fry at 2.7 in survey segment 2.

Discussion

The rehabilitation actions on the Trinity River are designed to promote geofluvial processes which will in turn increase channel complexity and improve aquatic habitats (Barinaga 1996). Although specific sites on the Trinity River may be restored each year, the evolution of these sites with geofluvial processes into their full habitat potential may occur over decades. Evaluation of the changes in aquatic habitat in the Trinity River requires a method that is reproducible through time. The application of the scientific method requires observations that are unbiased and reproducible. Without a means of creating reproducible observations it is no longer science. The DFA methodology as described above did not create reproducible results despite implementation of the methods listed in Railsback and Kadavy (2008).
the habitat differences between initial and repeated surveys can be related to errors in judgment, field measurement, intergroup variation, or digitizing. Judgment error can be defined as imperfect detection of attributes which define habitats, such as over- or underestimating depths or velocities. Field measurement error is a product of the difference between the actual size of the habitat and the mapped polygon. Another type of field measurement error could occur when a habitat is drawn in the wrong location on the map. Although Goodman et al. (2007) used a group that shared members between repeat surveys, an additional source of error may be intergroup variation if the same observers could not be assembled each time. The final and probably least significant source of error is the difference between what is mapped and what is digitized into ArcGIS due to rigorous GIS post-processing methods.

Railsback and Kadvany (2008) suggested standardization of the DFA decision-making process through the implementation of a conceptual model. This conceptual model lists steps in the decision process to help reduce judgment error associated with the technique. As observed in the Trinity River, the conceptual model described by Railsback and Kadvany (2008) is not sufficient to create reproducible data. I suggest that creating reproducible DFAs will require additional steps to reduce judgment and field measurement errors. For example, judgment errors could be reduced by measuring habitat parameters rather than relying on ocular estimates. Field measurement errors could be reduced by implementing...
more rigorous survey methodologies to accurately identify habitat type boundaries.

Current applications of aquatic habitat assessment on the Trinity River, subsequent to the results reported here, are employing several additional steps to improve the accuracy and reproducibility of habitat assessment within the DFA framework (Damon Goodman, U.S. Fish and Wildlife Service, Arcata, CA pers. comm.). This more rigorous DFA methodology employs parameter measurement for all habitat criteria and incorporates a cover component. Furthermore, the boundaries of habitat types are delineated using tablet computers, high accuracy GPS transceivers, and high resolution aerial photographs. Evaluations of this survey methodology have lead to a more credible and reproducible DFA habitat assessment. This method will be applied to the Trinity River in 2009 to evaluate river restoration sites. The plan includes evaluation of 2.5 km of bank rehabilitation sites at 5 flows and an additional 4.5 km at summer base flow for $216,165. Accordingly, this more rigorous DFA methodology will likely more than double the costs or halve the length of stream that can be assessed, as compared with the methods presented in Railsback and Kadvany (2008). However, there are likely to be tradeoffs of additional field time versus reduced post-processing effort for a more rigorous DFA, compared to the methods presented in Railsback and Kadvany (2008).

**DFAs Versus Two-Dimensional Hydraulic and Habitat Modeling**

Demonstration flow assessments can properly be characterized as empirical two-dimensional habitat modeling, where habitat is empirically determined at a series of flows, rather than being simulated for a range of flows. One of the few cases I am aware of where the results of DFAs and 2-D modeling can be directly compared is from the Pit River, which had one study site where habitat was quantified with both DFA (R² Resources Consultants, Inc. 2003) and 2-D modeling (Hardin-Davis, Inc. 2003). The substantial differences between the results of the two methods (Figure 3) can likely be attributed to a combination of errors in DFA mapping and the use of categorical criteria for the DFA versus continuous criteria for the 2-D modeling. McBain and Trush (2004) present comparisons of the numeric results of the DFA case study in Railsback and Kadvany (2008) versus 2-D modeling. Differences in the results of DFA and 2-D modeling (Figure 4) could possibly affect the decision-making of managers.

Demonstration flow assessments by definition use categorical criteria, while 2-D modeling typically uses continuous criteria (Figure 5). Categorical criteria are generally biologically unrealistic—they either (a) overestimate the habitat value of marginal conditions if the categorical criteria are broadly defined (e.g., setting suitability equal to one for any depths and velocities where the original Habitat Suitability Index value was greater than 0.1) or (b) completely discount the habitat value of marginal conditions. The latter case would be biologically unrealistic because it would not account for substantial fish use in areas that are deemed unsuitable from the categorical criteria. I agree with Railsback and Kadvany (2008) that many of the existing traditional PHABSIM criteria curves are suspect, largely because of biases from habitat availability. As a result, I have been using a more sophisticated approach of logistic regressions (Manly et al. 2002; Ahmadi-Nedush et al. 2006) to develop habitat suitability criteria.

Railsback and Kadvany (2008) cite the following advantages of DFAs, versus traditional one-dimensional hydraulic and habitat modeling:

1. Assessment of habitat with complex hydraulics is more feasible,
2. DFA makes it easier to use mechanistic and theoretical conceptual models, and
3. DFA can assess long reaches.

In contrast, 2-D modeling can handle complex hydraulics, including transverse flows, across-channel variation in water surface elevations, and flow contractions/expansions (Ghanem et al. 1996; Crowder and Diplas 2000; Pasternack et al. 2004). To my knowledge, the only type of hydraulics that would require the use of DFA would be situations where the gradient exceeds 10%; such circumstances violate the assumption of 2-D models that there is not a significant vertical component to velocities. Because DFAs are empirical 2-D models, both DFAs and 2-D modeling can provide the inputs (spatially explicit representations of habitat) needed for mechanistic and theoretical conceptual models. In fact, through geographic information system (GIS) post-processing, complex aspects of habitat, such as:

1. Adjacent velocity criteria (Gard 2006), which addresses the bioenergetic mechanism of transport of invertebrate drift from fast-water areas to adjacent slow-water areas (where fry and juvenile salmonids reside) via turbulent mixing; and
2. Escape cover (Hardy et al. 2006), can be incorporated into 2-D modeling, while it would be challenging to incorporate these into DFAs.

GIS post-processing can also be used to implement spatial resolution considerations mentioned by Railsback and Kadvany (2008), such as eliminating habitat patches that are smaller than a territory size for adult trout (very roughly 1 m²; Railsback et al. 2005) or a redd for spawning, for 2-D modeling. I have used 2-D models to examine two of the mechanistic conceptual models mentioned by Railsback and Kadvany (2008): drying reds (USFWS 2006a) and producing food (USFWS 2006b). In addition, Bowen et al. (2003) used 2-D modeling with alternative habitat suitability criteria, such as measures of habitat diversity, one of the theoretical conceptual models mentioned by Railsback and Kadvany (2008).

Two-dimensional hydraulic and habitat modeling has been used to assess long reaches; Hardy et. al. (2006) and Bowen et al. (2003) modeled a total of 9 and 26.3 km of river, respectively, compared to 0.8 km mapped in the DFA discussed by Railsback and Kadvany (2008). Recent advances in technologies for collecting bed topography data (which requires most of the field effort) for 2-D modeling, including robotic total stations, survey-grade real-time kinematic GPS equipment, acoustic doppler current profilers, and echo sounders, have made it possible to collect the data for 2-D modeling over long reaches fairly quickly. For example, an approximate esti-
mote of the cost (not including capital costs of equipment) of 2-D modeling for 1.9 km of the Lower McCloud River was $450,000 (Craig Addley, Entrix, pers. comm.), compared to an estimated cost of $715,000 for a DFA of 4 km of the Lower McCloud River at 6 flows (Pacific Gas and Electric 2007). In addition, remote sensing techniques, such as photogrammetry and Light Detecting and Ranging (LiDaR), may hold the promise of further increasing the length of river that can be assessed with 2-D models, once they become sufficiently accurate (i.e., 0.03 m elevation) for purposes of simulating microhabitat. In contrast, the cost of a reproducible DFA, including surveying the vertices of habitat polygons and extensive depth and velocity measurements to validate the boundaries of habitat polygons, will likely substantially increase the cost of DFAs or reduce the length of river that can be assessed by DFAs, when compared to the methods presented in Railsback and Kadvany (2008).

Fundamentally, there is a trade-off in costs for DFAs versus 2-D modeling. A much more extensive data collection effort is needed for 2-D modeling to accurately characterize the bed topography of a river reach, but DFAs require that data be collected multiple times for a given river reach, i.e., at each flow to be assessed. In addition, for 2-D modeling, bed topography and substrate and cover mapping data can be collected at a very low flow, with the only data needed at high flow being water surface elevations at the up- and downstream ends of the site and flow, and edge velocities for validation purposes. The cost of DFAs or length of river that can be assessed by DFAs is sensitive to the minimum polygon size used. The use of too large a polygon size can result in errors in mapping (Figure 6), while a small minimum polygon size could substantially increase the cost of a DFA or decrease the length of river assessed by a DFA, particularly for complex habitats. The minimum polygon size selected for use in a DFA should correspond to the relevant scale for the smallest life stage/species assessed by a DFA, for example, on the order of 0.1 m² for trout fry. One aspect of the minimum polygon size that still needs to be defined is whether the relevant scale for adult trout would include an entire feeding station, comprised of both a slow velocity at the fish location and faster adjacent velocities for food delivery, in which case the minimum polygon size for adult trout (only including the slow velocity at the fish location) would be smaller than 1 m².

Railsback and Kadvany (2008) note that assessment of habitat at flows other than the flows mapped during the DFA requires interpolation between, or extrapolation from, results from the observed flows. I view this as a significant disadvantage of DFA, and note that two-dimensional hydraulic and habitat modeling does not require interpolation or extrapolation, because hydraulic parameters are quantified at each flow to compute habitat. The flow dependence of DFA is also a practical limitation because there are many challenges to gathering data, scheduling crews, and getting controlled steady flows. Practitioners of DFA have found that this is a substantial challenge and constraint (Scott McBain, pers. comm. McBain and Trush, Inc., Arcata,CA); 2-D modeling is able to avoid most of these challenges and constraints.

Although errors associated with interpolation can be reduced by mapping additional flows, albeit with an increased associated cost, errors associated with extrapolation likely cannot be alleviated. For example, in the case study presented by Railsback and Kadvany (2008), sampling at flows in excess of 9.2 m³/s was not conducted in part because observers could not wade safely at higher flows. Assessment of habitat at higher flows may be critical in systems where unimpaired high flows during snowmelt provide important benefits, such as juvenile habitat associated with inundated floodplains (Jeffres 2006). Historically, managers have confronted this problem before. Empirical methods were first used for one-dimensional hydraulic and habitat assessments, but were replaced by one-dimensional hydraulic and habitat modeling because of the time efficiency and extrapolative capability of such models (Bovee and Millhous 1978).

I feel that 2-D modeling offers significant benefits over DFA for adaptive management. The following circumstances would require that a DFA be repeated, while 2-D modeling could just be used as is with new sets of habitat suitability criteria:

1. Habitat needs to be evaluated for additional species, such as because of an Endangered Species Act listing;
2. New information becomes available on habitat requirements, requiring a change in the habitat suitability criteria used to quantify habitat; or
3. Biological verification shows errors in the habitat suitability criteria.

In contrast, situations where habitat requirements are poorly understood lend themselves well to the use of 2-D modeling in an adaptive management framework. Preliminary criteria could be developed through a Delphi analysis (Bovee 1986), and as additional information is developed on habitat requirements, resulting revised criteria could be used with the 2-D modeling. Two-dimensional hydraulic and habitat modeling can be used to simulate the amount of habitat for alternative designs prior to construction, a cost-effective method to conduct adaptive management for stream restoration projects (Gard 2006). In contrast, DFA, as an empirical method, cannot be used to quantify the amount of habitat expected with alternative stream restoration project designs prior to construction. DFA also lacks the ability to do sensitivity analyses or construct uncertainty bounds related to habitat suitability criteria.

CONCLUSIONS

Difficulties with the DFA method presented in Railsback and Kadvany (2008), as applied on the Trinity River, include the lack of reproducibility, which was demonstrated by the disparity between replicate survey results. The large disparity between initial and repeated surveys limits the utility of this method unless substantial improvements can be made. Given the additional effort that is needed to obtain reproducible DFA results, 2-D modeling potentially does not require more effort than DFA, but yields more useful information. In addition, 2-D modeling can allow for additional species/life stages to be considered after the fieldwork has been completed, allows for more spatial based assessments of habitat conditions such as
distance to cover, and can provide a fine scale resolution over a wide range of flows not feasible with DFAs.

ACKNOWLEDGEMENTS

Many thanks to D. Goodman for providing copious information on the Trinity River DFA evaluation and reviewing the manuscript. I also thank S. Gallagher, P. Zedonis, D. Threllof, D. Cox, R. Vadas, C. Chamberlain, S. McBain and three anonymous reviewers who contributed insightful comments that greatly improved the manuscript.

REFERENCES


ABSTRACT: Fisheries management has become increasingly dependent on large and complex models; however, tools and technologies for model evaluation have lagged behind model development and application. Sensitivity analyses can test the degree to which particular model inputs or internal parameters affect model outputs and are recommended in model construction, calibration, and assessment. We describe three parallel sensitivity analyses of the Ecosystem Diagnosis and Treatment (EDT) model and draw combined conclusions. The details of how each agency conducted and utilized sensitivity analyses are outlined and the trade-offs between simpler and more intensive sensitivity analyses are described. Combined insights on the EDT model include identification of input parameters to which the model is surprisingly insensitive and quantification of prediction intervals. We conclude that known uncertainties in input data and internal parameters lead to large prediction intervals around estimates of population abundance and productivity but that the identification of high priority reaches for restoration and protection is relatively robust to these uncertainties. We recommend that sensitivity analyses are applied to all models used in fisheries management.

Haciendo mejor uso de los datos: múltiples enfoques al análisis de sensibilidad de un modelo de hábitat en peces

RESUMEN: El manejo de pesquerías se ha vuelto cada vez más dependiente de modelos grandes y complejos; sin embargo, las herramientas y tecnologías para evaluarlos se han mantenido rezagados con respecto a su desarrollo y aplicación. Los análisis de sensibilidad, por un lado, pueden probar a qué grado los parámetros o entradas de un modelo en particular afectan las salidas y, por otro, se recomienda aplicarlos durante la construcción, calibración y evaluación del modelo. Aquí se describen en paralelo tres análisis de sensibilidad sobre el modelo de Tratamiento y Diagnóstico de Ecosistemas (TDE) y se llegan a conclusiones comunes. Se destacan los detalles de cómo las agencias condujeron los análisis de sensibilidad y se describe el balance entre sus formas simples y complejas. Una introspección combinada de estos análisis aplicados al TDE incluye la identificación de aquellos parámetros de entrada a los que el modelo es particularmente insensible y la cuantificación de intervalos de predicción. Se concluye que tanto incertidumbre conocida en los datos de entrada como los parámetros internos dan como resultado amplios intervalos de predicción con respecto a las estimaciones de abundancia poblacional y productividad, pero la priorización de la restauración y protección es relativamente robusta a dicha incertidumbre. Se recomienda que los análisis de sensibilidad se apliquen a todos los modelos de manejo de pesquerías.

INTRODUCTION

Fisheries management has become increasingly dependent on large and complex models. Such models are developed to help natural resource managers address complex issues by providing the estimates of ecosystem parameters or biological response that are necessary for making fisheries and habitat decisions. The challenge for scientists and managers is to develop models that enable informed and transparent decisions based on available scientific information, which is generally imperfect. The EcoPath/EcoSim framework, for example, has been used to study and understand foodwebs in hundreds of marine systems (Pauly et al. 2000). ALFISH is a spatially explicit, age-structured model to explore fish density dynamics that has been applied in the Everglades (Gaff et
al. 2004). The Atlantis modeling framework, developed in Australia, has been employed to support integrated oceans management (Smith et al. 2007). These models are diverse but share a dependence on large numbers of parameters with complex interactions.

Advances in computing and mathematics have enabled such models to grow increasingly complex; however, tools and technologies for model evaluation have lagged behind model development and application. Sensitivity analyses provide objective criteria with which to evaluate model output, allowing users to explore how uncertainties in inputs and in parameter values propagate through the model. The results of sensitivity analyses can be used to provide more detailed model outputs, e.g., confidence intervals or precision estimates, to refine the model structure by removal of unnecessary parameters, and to improve the way modeled results are used to make decisions.

We employed a variety of sensitivity analysis techniques in the evaluation of a complex model used throughout the Pacific Northwest for salmon recovery planning, Ecosystem Diagnosis and Treatment (EDt). Sensitivity analyses were completed by three public agencies and provide an ideal opportunity for exploring the appropriate use of modeled predictions in salmon recovery and freshwater restoration planning, in specific, and in environmental management in general. In this article, we explain sensitivity analyses and describe the EDt model before presenting three different sensitivity analyses of the EDt model (Table 1). In conclusion, we make explicit the trade-offs between these three types of sensitivity analysis, synthesize findings about the EDt model, draw conclusions about multi-agency analyses, and make recommendations about the use of sensitivity analyses for large and complex models.

**SENSITIVITY ANALYSIS**

Sensitivity analyses test the ability of inputs (data input into the model such as empirical observations), parameters (estimated relationships within the model), and model components (smaller sub-models or sets of parameters within the larger model) to affect model outputs and are a standard technique used in model construction, calibration, and assessment (Saltelli et al. 2000a). Sensitivity analyses can aid decision-makers by highlighting those inputs and components with the largest influence on the outputs. They are recommended when model output is used for decision making (Haefner 2005; ISAB 2001) and often provide insights into how the model arrived at a particular prediction and into potential biases in predictions. A further goal of sensitivity analyses is often to reduce the uncertainty in model output. In this case, a sensitivity analysis can identify those input factors or model parameters that, if measured more precisely, would provide the greatest reduction in model output uncertainty.

A useful byproduct of sensitivity analyses can be the estimation of the distribution of modeled outputs, often estimated through Monte Carlo simulations, which would result from incorporation of particular uncertainties. In this article, we refer to the percentile bounds, e.g., 90%, of that output distribution as a prediction interval; these bounds describe the range of predictions that the model produces when a set of known uncertainties is incorporated. As a practical matter, using a distribution of inputs rather than a single-point estimate illustrates that a given model will produce a range of predictions.

<table>
<thead>
<tr>
<th>Agency</th>
<th>U.S. Bureau of Reclamation</th>
<th>Washington Department of Fish and Wildlife</th>
<th>NOAA Fisheries</th>
</tr>
</thead>
<tbody>
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<td>Region (species)</td>
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<tr>
<td></td>
<td>Stream attributes</td>
<td>Stream attributes</td>
<td>Stream attributes, habitat survival rules, benchmarks, adult parameters, all other internal parameters, East Fork Lewis River (fall Chinook), Snoqualmie River (fall Chinook), Germany Creek (coho), and Washougal River (winter steelhead)</td>
</tr>
<tr>
<td></td>
<td>Naches River (summer steelhead); Naches river (spring Chinook); American River (spring Chinook)</td>
<td>All Puget Sound watersheds</td>
<td></td>
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<tr>
<td>Scale of sensitivity analysis</td>
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<td>All parameters simultaneously; groups of related parameters</td>
<td>All parameters simultaneously; groups of related parameters</td>
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<tr>
<td>Type of alternate parameter value selection</td>
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<td>Monte Carlo</td>
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<td>Least sensitive parameters</td>
<td>Hydrologic regime natural, Hydrologic regime regulated, all flow attributes, Habitat-off-channel</td>
<td>Macroinvertebrates</td>
<td>Habitat inputs, internal habitat survival relationship parameters</td>
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**Table 1. Comparison of EDT sensitivity analyses completed by three agencies.**
when all feasible inputs are considered. When modeled output is then used to estimate the effects of an on-the-ground action or group of actions, a decision-maker can make a better decision by considering the full range of plausible model outputs.

Consider an example application. In the Puget Sound Salmon Recovery Plan Executive Summary (Shared Strategy Development Committee 2007), EDT was used to predict that dam removal will improve North Fork Nooksack River Chinook salmon (Oncorhynchus tshawytscha) abundance by 30.8%. Managers tasked with deciding whether to invest in dam removal or other suites of habitat restoration actions would benefit from knowing (a) the range of modeled abundances given uncertainties in user input and internal model parameters, (b) whether and how often the model would predict a population decline post-dam-removal if uncertainty in all model parameters were considered, and (c) the likelihood that the model might have predicted an even more dramatic improvement in fish population performance. For example, should the value of 30.8% be interpreted to mean a range from 30.1 to 40.2% or from –10 to 70%?

There are a variety of methods for sensitivity analysis (Saltelli et al. 2000a). Local analyses, which alter factors “one at a time” (OAT), are the simplest to produce because all parameters, except those specifically being evaluated, are held constant. OAT analyses can determine how uncertainty in any one parameter or in any one input impacts model output but they ignore interactions among parameters. Often the results of an OAT sensitivity analysis can be calculated analytically but computer simulations may be necessary for complex models. Global analyses generally are more difficult to produce; they evaluate output uncertainty when all (or many) input factors are altered simultaneously. Variance partitioning methods take this a step further, producing an estimate of the proportion of the output variance attributable to each input factor. These methods are computationally demanding for complex models (Saltelli et al. 2000a) and have rarely, if ever, been applied to ecological models used in a management context.

Note that sensitivity analyses, in general, cannot estimate model accuracy (the distance between modeled output and the truth) but, rather, model precision (similarity of repeated model runs given a set of uncertainties which might include model structure, parameters, or inputs). In this article, we will report on three different and independent OAT analyses completed by the U.S. Department of the Interior/Bureau of Reclamation (Reclamation), the Washington Department of Fish and Wildlife, and the National Oceanic and Atmospheric Administration Fisheries Service (NOAA Fisheries) as well as global analyses completed by NOAA Fisheries. Because of the complexity of the EDT model, no agency evaluated whether the overall model structure was realistic nor did any agency.

![Figure 1. Results of the variance partitioning for the East Fork Lewis River, Washington, fall Chinook salmon abundance (without harvest). The size of each pie wedge represents the proportion of total model output uncertainty (total effects) attributable to that group of parameters. Parameter groupings identified in white are internal parameters that do not vary from basin to basin. Solid shading indicates parameter groupings which model users can modify when running the model in a particular basin and for a particular population.](image-url)
evaluate the sensitivity of modeled output to variations in model structure.

**ECOSYSTEM DIAGNOSIS AND TREATMENT**

EDT is a system for rating the quality, quantity, and diversity of stream habitat, relative to the species-specific needs of salmon (Lichatowich and Mobrand 1995; Mobrand et al. 1997; Blair et al. in press). EDT has been applied in nearly every salmon-bearing watershed in Washington and many in Oregon. In Puget Sound and in the Columbia Basin, the model has been widely used to assist in setting recovery goals (e.g., Lower Columbia Fish Recovery Board 2004; Northwest Power and Conservation Council 2005) for threatened and endangered salmonids and to predict consequences of proposed management actions (e.g., Shared Strategy Development Committee 2007). The EDT model compares estimated fish performance (e.g., population size or productivity) among current, historical, and potential habitat conditions. To do this, the EDT model requires thousands of data inputs and contains well over 1,000 internal parameters. Data inputs refer to those parameters which model users can modify when running the model in a particular basin and for a particular population. Internal parameters are those that do not vary from basin to basin (Figure 1). As described in the introduction, the EDT model is not unique in its complexity or size; we report the results of sensitivity analyses on the EDT model as a case study of how to conduct and interpret sensitivity analyses of large ecosystem models as well as to provide specific guidance on using EDT output in management decisions.

The EDT model consists of four major components (Blair et al. in press):

1. A reach level stream and environmental description.
   - The reach level environmental description is based on 46 stream attributes (e.g., flow, stream temperature, macroinvertebrate abundance, and habitat types). Users are also asked to enter a "level of proof" rating for each stream attribute which describes the general method used to estimate that parameter (e.g., empirical data or expert opinion).

2. A set of "rules" that relate the environmental condition to life stage survival and capacity (as defined for the Beverton-Holt equation). The species-specific rules are rating curves for each salmonid species that link the stream attributes to life stage survival or density. The habitat rules reduce the predicted species-specific survival and maximum density to reflect local conditions in the stream.

3. Biological data on target species such as adult and juvenile age structure, run timing, sex ratio, fecundity, and ocean survival.

4. Integration of the reach by life stage estimates to the population level based on a disaggregated Beverton-Holt function (Beverton and Holt 1957; Moussalli and Hilborn 1986).

The outputs of an EDT analysis are the productivity and capacity parameters of a Beverton-Holt function, equilibrium abundance, and reach-level restoration and protection priorities. EDT is predominantly a deterministic model. There is no uncertainty in the relationships between fish habitat and fish production nor in population descriptors such as migration timing, fecundity, and ocean survival. An electronic library of EDT documentation is available from ICF Jones & Stokes (http://www.jonesandstokes.com/index.php?option=com_content&task=view&id=488&Itemid=784).

**TESTING THE EXTREMES**

Bureau of Reclamation biologists conducted a sensitivity analysis of the EDT model to determine how the EDT equilibrium abundance output for Chinook salmon and for steelhead (O. mykiss) varies as a function of stream attributes (Yoder et al. 2006). EDT was one model in a chain of hydrological, physical, and biological models employed by Reclamation to evaluate water storage and flow management options in the Yakima River, Washington. By exploring a wide range of input values (that included both plausible and implausible values for flow and habitat alterations), Reclamation analyses provided guidance for managers in how to use EDT output more effectively and in defining priorities for future data collection. Reclamation expected that productivity and abundance estimates would be sensitive to changes in stream attribute inputs; they aimed to discern the set of stream attributes to which the abundance and productivity estimates were most and least sensitive.

Systematically varying model input values over a range and observing the amount of change in model output from a given baseline is one form of model sensitivity analysis (Haefner 2005). Reclamation analyses systematically varied EDT habitat inputs (e.g., maximum temperature, bed scour, etc.) for each river reach. These habitat attributes are typically input into EDT on a 0–4 scale. Reclamation started with the current set of attribute inputs and varied each attribute input, independently, by plus or minus 1, and then reran the model. They then varied each attribute input by plus and minus 2, 3 and 4, working within the limits of possible input values, which are 0–4 for most habitat attributes. Varying the input by ±4 quantified the sensitivity of the model to extreme changes in input attributes. Non-focal habitat attributes and all other parameters were held at their point estimates (Yoder et al. 2006).

Sensitivity ratings for most habitat inputs were calculated using the following equation (after Haefner 2005):

$$S = \frac{(A_0 - A_1)}{A_1} \frac{P_{avg0} - P_{avg1}}{P_{avg}}$$

where:

- $A_0$ is the original EDT output point estimate;
- $A_1$ is the new EDT output point estimate given a change in attribute value;
- $P_{avg0}$ is the mean initial input attribute value over all reaches;
- $P_{avg1}$ is the mean changed input attribute value over all reaches;
A similar equation was used for attribute responses on different numerical scales.

Results: Using sensitivity analysis results to inform decision-making

Reclamation found that model outputs for both steelhead and Chinook salmon populations in the Yakima River were most sensitive to variations in the following stream inputs: alkalinity, embeddedness, fine sediment, habitat backwater pools, habitat primary pools, miscellaneous toxins, temperature-daily maximum, temperature-daily minimum, and turbidity. Reclamation also identified stream inputs to which model results for all steelhead populations in these river segments were relatively insensitive (Table 1), including a large number of flow parameters. Because of the non-linear mathematics within the model, sensitivity analyses were necessary to understand these relationships.

The relative insensitivity of EDT predictions of fish abundance to flow attributes provided valuable information about EDT usage in the evaluation of a proposed water storage and flow management project on the Yakima River. The relative insensitivity of EDT to direct flow attributes reflects the model assumption that flow has a small physiological effect on fish survival and that impacts of flow manifest themselves in other physical attributes. One of the most obvious potential impacts of the proposed water storage project would be the change in flow volumes and flow patterns. However, because flow effects almost all other physical stream attributes, the impact of a real-world change in flow on habitat conditions (e.g., stream wetted area, bed scour, embeddedness, and habitat-type distribution) would need to be determined independently and entered into the model as changes to non-flow attributes. Although Reclamation’s conclusions about the flow attributes are applicable only to the Yakima basin, these conclusions are supported by research in other basins (Northwest Hydraulic Consultants 2005). Subsequently, Reclamation developed support models to calculate the values for those EDT inputs (i.e., habitat and temperature attributes) most influenced by changes in stream flow. Furthermore, based on these findings, Reclamation facilitated the development of a customized version of EDT to address the major ways that flow regimes can be altered by land use practices (Lestelle et al. 2006).

Surveying users to estimate uncertainty in habitat ratings

Washington Department of Fish and Wildlife (WDFW) is responsible for co-managing 14 evolutionarily significant units (ESUs) of salmon including over 100 individual populations. WDFW has used EDT extensively to assist in the development of recovery goals and plans throughout Washington. Because EDT relies on detailed stream habitat input, there is concern that uncertainty in these stream habitat input variables might lead to large amounts of uncertainty in model output. The accuracy and precision of stream habitat data vary widely from stream attribute to stream attribute and from basin to basin depending on data collection methods and on the means of estimating model input values where no empirical data exists. One can then expect that the precision of modeled output will also be basin-specific.

This concern led WDFW to initiate a Monte Carlo simulation study to develop basin-specific estimates of model precision based on the quality of the stream input data (Busack and Thompson 2006). To identify the plausible range of stream attribute values, WDFW developed a survey and queried eight biologists with EDT experience to elicit ranges of plausible stream attribute scores based on both the reported stream attribute score and level of proof rating. For example, the survey asked “If a reach had a score of 2 for turbidity, with a level of proof of 3, what do you think the highest and lowest likely true value for turbidity might be?” WDFW then created triangular probability distributions, using the reported value as the mid-point and the survey’s average range as the endpoints, for each combination of attribute, level of proof, and stream attribute score.

The probability distributions were sampled in two ways. In the first analysis, all stream attribute parameters were varied simultaneously and in the second analysis, each of nine stream attribute parameter groupings were varied sequentially. In each analysis, 500 independent input stream attribute data sets were created for each of 10 Puget Sound watersheds supporting 15 Chinook salmon populations. Each of these 100,000 input data sets (2 analyses X 10 watersheds X 10 parameter groups X 500 iterations) represent plausible stream attribute input data sets, given the stream attribute values and levels of proof recorded in the original EDT runs for reach watershed (Busack and Thompson 2006).

Results: Using sensitivity analysis results to inform decision-making

Using the first WDFW approach, prediction intervals (range of 95% of Monte Carlo outputs) for Puget Sound Chinook salmon populations generally had coefficients of variation of 3.5%, 7%, and 10.5% for productivity, capacity, and equilibrium abundance estimates respectively. WDFW concluded that, given the plausible range of stream-attribute inputs, variability in EDT output was generally low, although model results with larger prediction intervals were observed for some basins or populations (Busack and Thompson 2006). These results suggested that uncertainty in stream-attribute factors alone does not produce large uncertainties in model output. One conclusion from this result is that small errors in stream-attribute inputs will not propagate into large errors in model output, so long as model structure and other inputs such as fecundity, smolt-to-adult survival rates, etc., remain constant. Another possible explanation for these results is that some relationships between habitat inputs and population outputs are not captured in the model.

Using the second approach, in which they varied subsets of habitat parameters sequentially, WDFW identified a set of stream attributes which, across multiple watersheds, provided the largest contribution to the variance of model output for Puget Sound Chinook salmon populations. Generally, Chinook salmon capacity estimates were most sensitive to uncertainty in ratings for the habitat type group (e.g., relative amounts of primary pool, tailout, small cobble riffle) while productivity estimates were most sensitive to uncertainty in...
channel stability and sediment ratings. The precision of model estimates could best be improved by increasing accuracy and precision of attributes in these groups. Of these, only sediment was also identified in the Reclamation analysis (Yoder et al. 2006). Therefore, if the management objective is to increase precision in EDT model outputs and habitat-sampling funds are limited, WDFW recommended not increasing the sampling intensity for macroinvertebrates, an expensive and time-consuming effort. Of course, there may be many important reasons to sample macroinvertebrates other than to improve EDT precision, as we have strong evidence from other sources that macroinvertebrates are a good indicator of salmon habitat quality (Quinn 2005).

WDFW was also able to investigate the sensitivity of rankings of reaches for restoration or protection to habitat inputs. For Puget Sound watersheds, the top restoration and protection rankings were relatively stable within basins. In particular, uncertainty in stream attribute input data caused little shift in the predictions of where the best habitat restoration opportunities exist for Chinook salmon within each watershed. They concluded that managers could be confident that modeled high priority reaches were consistent despite uncertainties in stream attribute input data. Restoration and protection rankings for reaches originally ranked as fourth or lower, however, were not as robust to the uncertainties in stream attribute inputs (Busack and Thompson 2006). Therefore, WDFW concluded that rankings for these mid-priority reaches should be used with caution in decision-making.

**BEYOND HABITAT: SENSITIVITY ANALYSES OF ALL PARAMETERS**

NOAA Fisheries is responsible for overseeing the development of recovery plans for most marine and anadromous species listed as threatened or endangered under the Endangered Species Act (ESA). NOAA Fisheries also contributes information to the management of freshwater and estuarine habitats and to the prioritization of freshwater and estuarine restoration and protection actions. Population parameters modeled using EDT and reach-specific restoration and prioritization actions are often used by state, tribal, and local groups in the processes of developing recovery plans and prioritized lists of restoration and protection actions. Therefore, NOAA needs the best possible understanding of the precision and accuracy of EDT output in order to evaluate whether model output is appropriately used to inform these decisions.

The goals of the NOAA analyses were to quantify a more complete prediction interval, by incorporating uncertainty in non-habitat inputs and in internal parameters, and to identify which input parameters are responsible for the majority of output variability (McElhany et al. in press). NOAA Fisheries designed a global sensitivity analysis (Sobol 1993; Saltelli et al. 2000a, 2000b) that incorporated known or estimated uncertainty on nearly every parameter in the EDT model. In the first step, a potential distribution was defined for each input and internal model parameter. Distributions for stream attributes were defined using WDFW’s survey results (Busack and Thompson 2006). Distributions for other parameters were defined during collaborative meetings (including scientists from Snohomish County, Pierce County, NOAA Fisheries, WDFW, Reclamation, and Mobrand, Jones & Stokes) at which measurement errors, empirical data, simulation studies, and expert opinion were considered. To estimate one prediction interval, the model was run at least 250 times. For each parameter in each run, a value was randomly and independently selected from the distributions defined above. Using this approach, all possible combinations of parameters, both internal and user-defined, had a possibility of being included in the simulation study (McElhany et al.

Figure 2. Histogram of the 894 successful Monte Carlo simulations of abundance (Neq) for the East Fork Lewis fall Chinook salmon population, calculated without harvest. The solid bars represent abundance estimates of 2000 or greater. Note that 1,000 Monte Carlo simulations were attempted but 106 resulted in unusable parameter combinations.
in the distribution of model outputs given known and estimated uncertainties in the stream attributes (from WDFW), the population descriptors, and the internal model parameters.

In conducting the global sensitivity analysis, NOAA Fisheries was also able to estimate the effect of uncertainty in any one parameter, or group of parameters, on the final prediction distribution. The total prediction interval was partitioned using an approach that is analogous to an analysis of variance (ANOVA) to identify the contribution of each parameter or set of parameters to the total output uncertainty (Sobol 1993; Satelli et al. 2000a). Because of the large number of parameters, NOAA applied a hierarchical approach, varying sets of parameters (e.g., all stream attributes) together. Once the most sensitive groups of parameters were identified, the analysis focused on determining which specific parameters in these sensitive groups contributed most to prediction uncertainty (McElhany et al. in press).

Results: Using sensitivity analysis results to inform decision-making

NOAA created prediction intervals for multiple populations. For example, the 80% prediction interval for fall Chinook salmon abundance (equilibrium abundance of a Beverton-Holt model) under current conditions without harvest in the East Fork Lewis River, Washington, using the global sensitivity analysis, ranged from 35 to 2,274 fish with a mean predicted abundance of 941 (median = 635). In other words, given uncertainties in the input data and internal parameters, model output for this scenario was between about 35 and 2,274 fish in 80% of EDT simulations (McElhany et al. in press).

In addition to providing a more informed estimate of the mean model prediction, the analysis also provides managers with a distribution of model predictions (Figure 2). If one needed to know whether the population prediction exceeds, for example, 2,000 fish, inferences based on the mean estimate would suggest not. In contrast, inferences using the prediction intervals indicate that, given the input data, model parameters, and the uncertainty distributions, there is a 17% chance that EDT will produce an estimate greater than 2,000 fish (Figure 2). In this way, prediction distributions for population abundance, productivity, and capacity can provide increased information for model-supported decision-making (Steel et al. in press).

Assessments of the reach priorities for restoration and protection suggest that these may also shift as uncertainty is incorporated into the modeling process but that the suite of high priority restoration reaches is relatively robust to uncertainties in inputs (McElhany et al. in press). These results are consistent with those of WDFW (Busack and Thompson 2006).

Like the other agencies, NOAA was also able to identify groups of parameters to which the model appears less sensitive, at least for the basins examined (Table 1). When a model is not sensitive to variation in particular parameters, it may be because those parameters are not important for estimating the output of interest, the parameter is already estimated with a high degree of precision, the model is not capturing a relationship as expected, or another factor is limiting model output and until this bottleneck is removed the parameter of interest can have no effect. The variance partitioning provided initially unexpected results. Much of the emphasis of EDT critique and evaluation has been on the use of expert opinion to generate stream attributes and on the formulation of the rules or equations linking stream attributes to survival (ISAB 2001). It might have been expected that the uncertainty in stream attribute inputs would have a relatively large effect on the size of the final prediction interval. As shown in an example using East Fork Lewis River fall Chinook salmon (Figure 1), uncertainty in stream attribute inputs had a small relative impact on the size of the prediction interval. Other parameter groups, such as the adult parameters (e.g., fecundity, ocean survival) and the benchmarks, contributed most to the variability in the model prediction.

Variance partitioning results were consistent across all three basins for which NOAA ran the sensitivity analysis (McElhany et al. in press). Although there is variation among populations in which parameter groups have the greatest sensitivities, stream attributes have consistently lower sensitivities than other groups of parameters (McElhany et al. in press). This should not be interpreted to mean that instream habitat is not important to salmon or that stream attribute parameters do not affect EDT results. The importance of the adult parameter group should not be surprising as adult parameters include ocean survival, fecundity, sex ratio, and age structure. This group of parameters defines the reproductive potential of the species and needs to be captured with high precision if estimates of fish production from any model are to reflect observed data.

CONCLUSIONS:
SYNTHESIZING MULTIPLE APPROACHES

Trade-offs between types of sensitivity analyses

Each of the sensitivity analyses described above took a different mathematical approach to questions about the impacts of model inputs on model outputs and about model precision. The Reclamation approach, simply varying an input and observing the response in model output, provided invaluable insights to the first question. As a result of their sensitivity analyses, they were able to avoid misuse of the EDT model, in isolation, for predicting the fisheries response to a range of proposed management actions. Simple sensitivity analyses such as these have limitations. They cannot identify interactions between uncertainties in multiple inputs or between inputs and internal parameters. As well, they provide only crude estimates of model precision, a range rather than a distribution of potential outputs. Reclamation’s systematic sensitivity analysis represent a large amount of work because of the large number of inputs considered. However, often these systematic variations in inputs and internal parameters can be conducted with a minimum of computer programming or specialized software. Failure to conduct such simple sensitivity analyses in model development and before using modeled predictions in management decisions severely reduces the value of modeling for decision making.
Using a Monte Carlo approach to sensitivity analysis adds two levels of complexity to the sensitivity analysis but provides more robust information. The first added complexity is the necessity of quantifying not only the range but also the distribution of possible values for the inputs and internal parameters of interest. WDFW used an opinion survey to estimate the range of plausible values around each estimated stream attribute. In the future, empirical data from pilot studies or other regions could also be used to estimate these input distributions. The second complexity is simply the Monte Carlo sampling routine that requires programming or software support. The added value of the Monte Carlo approach is the quantification of a distribution of plausible outputs that can be used to quantify particular risks of interest (Figure 2).

Variance partitioning is particularly important for complex models because it quantifies not only independent impacts of particular parameters or groups of parameters but interactions between parameters. Variance partitioning allowed NOAA to compare the total impacts of suites of parameters on model outputs and to identify those parameters or groups of parameters whose uncertainty had the greatest impact on model output. Variance partitioning methods require customized programming and more advanced mathematics (Sobol 1993). Their value in complex ecological models is just beginning to be explored.

Value of multi-agencies collaborations

The three analyses described here were conducted in parallel by three public agencies with differing goals and responsibilities. Clear communication between agencies about how the EDT model would be used, about how sensitivity analyses were conducted, and about interpretation of sensitivity analyses has greatly improved each individual analysis. For example, the NOAA analyses were able to build on WDFW’s opinion survey of habitat input distributions. And, sharing of information was required to come to a consensus about the appropriate distribution of plausible parameters for the remaining inputs and internal parameters. Since the final value of sensitivity analyses depends on agreement of these distributions, such consensus building was essential. For example, if one agency felt that the uncertainty around parameter X varied between 5 and 20 while another agency believed that the parameter uncertainty only varied between 16.5 and 17.5, it would be difficult to design one sensitivity analysis that would be considered valid by both agencies. In addition, these complex collaborations enabled all available empirical data to be brought to bear on the discussion.

Each agency has a different mandate for natural resource management and therefore, different objectives for sensitivity analysis. WDFW, for example, calculated customized prediction intervals for every watershed in Puget Sound for which EDT analyses have been completed (Busack and Thompson 2006). They are now able to provide guidance on the best opportunities to reduce model output variance in each Puget
Sound watershed, if additional funding were available for habitat research. By working together, each agency was also able to benefit from the combined results of the three sensitivity analyses and to synthesize the results into one set of conclusions about appropriate uses of the EDT model.

Using sensitivity analyses to draw conclusions about EDT

By combining results from the three sensitivity analyses, we are able to draw several robust conclusions about the EDT model given known and unavoidable uncertainties. First, the model is less sensitive to uncertainties in stream attributes than might have been expected. Investments in increased data collection on habitat may not yield increased precision in EDT output. Using the EDT model in isolation to predict the effects of some environmental changes, such as impacts of flow alterations, can provide misleading results, especially where strong interactions with other stream attributes are expected and not explicitly included in the model. Sensitivity analyses have guided the development of new models in the Yakima Basin and can continue to guide the collection of data to improve model precision. Second, the model is most sensitive to parameters that describe adult populations and reproductive potential. The NOAA sensitivity analyses suggest that most of the uncertainty in model predictions of salmon abundance and productivity does not derive from uncertainty about habitat condition but from uncertainty in the other parameters—even knowing stream attributes perfectly, most of the model uncertainty would remain. Research can provide refined estimates of adult population parameters or rules linking specific stream attributes to survival that would improve model precision. Third, as expected for a complex ecosystem model, prediction intervals for the EDT-based estimates of abundance, productivity, and capacity are large. The size of the prediction intervals suggests that decisions based on point estimates for these fish performance metrics alone are risky. Fourth, the highest priority reaches for restoration and protection are relatively robust to known parameter uncertainties.

Implications for the use of models in fisheries management

The use of models in fisheries management has a long history and models will continue to play an integral role in fisheries and fish habitat management for the foreseeable future. The combination of these three sensitivity analyses and an investigation of the implications of their combined results provide an opportunity for general guidelines on the use of models in fisheries management.

First, managers can improve their use of modeled data by requesting prediction intervals (and if possible confidence intervals). Distributions of model output provide increased information on the risks of achieving or failing to achieve particular thresholds. Confidence or prediction intervals are particularly important where modeled output is passed on as input to another model.

Second, since most models provide predictions that are imperfect, the use of multiple independent models can provide a stronger basis on which to base decisions (ISAB 2001). When multiple independent models provide similar conclusions, it suggests that that conclusion is robust to the architecture and assumptions of any one model. Where competing models are unavailable, sensitivity analyses can suggest whether model output is robust to particular assumptions.

Third, where possible, models must be evaluated with respect to both precision and accuracy. It is frustrating that years of analyses on one model can only produce information about model precision yet this is a common situation. Models are developed to assist decision-makers in exactly the sort of situations for which data to quantify predictive accuracy are unavailable. In these circumstances, it is important to maintain skepticism until empirical data can be collected.

Finally, models should not be used in management decisions without at least some sensitivity analyses. Sensitivity analyses provide essential information when using modeled predictions in a decision-making context. They enable an assessment of the probability of making a wrong conclusion as a result of uncertainties in the data used to run the model and of uncertainties in the parameters used to build the model. Sensitivity analyses can be used to focus research and data collection efforts on parameters that will result in better decision-making and, hopefully, increased cost efficiency and improved fish populations. Sensitivity analyses are particularly important for complex models where the relationships between inputs and outputs are not transparent and for models that rely on inputs or internal parameters that are known to be uncertain. Models are often also used to provide evidence for a specific thesis or as a rationale for specific actions. In these cases, a sensitivity analysis serves to provide transparency to the analysis and can be included as an important element of evidence building (Saltelli et al. 2000b). As increasingly complex management decisions demand increasingly complex models, sensitivity analyses become essential tools in appropriately using modeled predictions in decision-making.

ACKNOWLEDGEMENTS

We would like to acknowledge the support of the Northwest Fisheries Science Center information technology department in conducting these analyses. Bruce Watson and Jesse Schwartz at ICF Jones & Stokes provided reviews of early manuscript drafts. Lars Mobrand at ICF Jones & Stokes provided insight and expertise that contributed greatly to these analyses. George Pess and Mike Ford of NOAA Fisheries provided constructive reviews as did the Science Editor. We also thank Katherine Zehfuss of Science Applications International Corporation for her contributions to the Reclamation analysis.

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sustainable salmon in the future. American Fisheries Society, Bethesda, Maryland.


INTRODUCTION

A city was lost because gear was not standardized. In 1904, Baltimore burned. Known as the Great Fire, the conflagration burned 56 ha of the downtown business district and 1,526 structures, resulting in over $150 million in property damage (Frederick 2004; Welden 2004). The massive destruction probably could have been prevented. There was plenty of water available and hundreds of firefighters from surrounding cities arrived to help, but they could do nothing because the couplings of their fire hoses would not fit onto the city’s hydrants. Although efforts to standardize hose couplings had been emphasized for over 30 years, 600 different coupling sizes were in use at the time. People were rightly angered with the fire-fighting profession because standardization had not yet been accomplished. Because of this fire, standardization of fire couplings across the United States moved forward at a rapid pace, leading to heightened safety in North American cities.

Rarely does failure to standardize have such dramatic consequences. However, standardization of measurements, industrial processes, languages, and data collection has greatly advanced human development (Nesmith 1985). We are often unaware of standardization, yet it is all around us, affecting our everyday lives. It includes business letter formats, time zones, computer components, and shoe sizes. The list of standardized items is seemingly endless. In addition, data collection and summarization for many disciplines are standardized, including medicine (Beers and Berkow 1999), meteorology (Lockhart 2003; Schiel 2003), geology (Assaad et al. 2004), and water chemistry (Eaton et al. 2005). For example, cholesterol, body temperature, and blood pressure are measured by standard medical procedures and compared to data distributions that summarize results from the standard procedures applied to many other individuals and lead to indices of health for an individual. If these diagnostic procedures were not standardized, we would be unable to evaluate even the most basic data about our health. In fact, if standardization was not used in countless other facets of our society, our lives would be much more difficult.

For data collection purposes, standardization means that data are collected in a single defined manner so comparisons can be made. Although routine data collection has been standardized in many other disciplines, for freshwater fish sampling it has not. Before now, most data collections for freshwater fishes in North America were standardized only by state or provincial agencies (Bonar and Hubert 2002).

Many of us have tried to compile fisheries data for region-wide assessments or over long periods of time. Often it is very difficult. Waters are sampled with different gears and reporting of effort is not consistent, making comparisons almost impossible. Data requiring thousands of hours to collect have highly diminished utility because they cannot be compared to data from other waters to provide assessments. Reflect on the lost information that this has cost our profession over many decades because data collection was not standardized.

Standardization of routine fisheries data collection provides several benefits. Data collected over a sequence of years can be compared. Because fish populations often take years to respond to management actions, standardized time-series data can be used to assess the response of fish populations to management actions.

Data can be compared across large geographic regions when standard data collection methods are applied. Increasing numbers of studies at landscape or regional scales are being conducted in fisheries science. Standardized sampling can provide comparable samples to assess the effects of regulations, invasive species, habitat improvements, or other management strategies over large geographic regions. Standardized data can also be useful for measuring large-scale effects, such as global climate change, on population structure, body condition, or abundance of fish.

Standardization can encourage data sharing and improve communications among fisheries professionals and the general public. In addition, standardization can promote cooperation among biologists in different countries who speak various languages.

Other factors can also be enhanced by using standard sampling techniques. Standard techniques to monitor the abundance of rare or endangered species can assist in their conservation. Standardization can allow collected data...
to be compared to regional or range-wide averages to assess fish in individual populations relative to an array of other populations.

An initiative of the Fisheries Management Section of American Fisheries Society (AFS) provided movement toward standardization of freshwater fisheries sampling methods in North America. The North American standardized sampling project involved contributions by at least 284 fisheries biologists from 107 agencies and organizations in Canada, Mexico, and the United States, as well as several countries outside of North America. The development of these procedures was led by the Fisheries Management Section of AFS in partnership with the U.S. Fish and Wildlife Service, U.S. Geological Survey (Cooperative Fish and Wildlife Research Units and National Biological Information Infrastructure program), U.S. Bureau of Reclamation, U.S. Bureau of Land Management, National Park Service, National Fish and Wildlife Foundation, Arizona Game and Fish Department, and the AFS Fisheries Information and Technology and Education Sections.

PROJECT HISTORY

In the 1980s and 1990s, work to move toward standardized fish sampling procedures in the United States was conducted by the Fisheries Techniques Standardization Committee of Fisheries Management Section. This effort resulted in a compilation of methods being used across North America (Gabelhouse et al. 1992); however, selection of a subset of methods for standardized sampling of fish in ponds, lakes, streams, or rivers was not completed.

At the 2004 AFS Annual Meeting, a unanimous vote by attendees at the Fisheries Management Section meeting initiated an effort to extend the work of the Fisheries Techniques Standardization Committee and develop standard sampling procedures. The effort was facilitated by a grant from the Fisheries Management Section, the 10 collaborating agencies listed above, and other entities, as well as a multitude of biologists and agencies that provided various forms of assistance. The project collaborators decided that standard methods could best be reported in a book made available to individuals who would like guidance on sampling methods for particular environments and fish species and who recognize the long-term value of using standardized sampling methods.

The resulting book, *Standard Methods for Sampling North American Freshwater Fishes*, identifies sampling methods for general population assessments and monitoring of fishes in various water body types in North America. The book also provides a means whereby existing and future data can be compiled into databases to enable comparisons of sampling statistics among populations. The standardized sampling methods enable a standard set of indices of population structure and abundance to be computed and compared among populations, across regions, and over time. Previous reviews of fish sampling methods have typically been exhaustive, providing the largest variety of sampling methods possible for a given species or type of water body, and allowing many choices (e.g., Murphy and Willis 1996). The purpose of the standard sampling book was not to review all methods available to sample fish populations in all water bodies, but to recommend a small set of methods that could effectively sample coldwater or warmwater fishes in primary freshwater habitats—small lakes and ponds, reservoirs, large natural lakes, wadable streams, or large rivers.

Forty-seven authors, each a recognized expert in sampling fish in specific aquatic environments, were selected for this project by the editors and members of the AFS Fisheries Management Section. Most of the authors had published extensively on sampling techniques or had been responsible for designing standard sampling procedures for their state, province, or region. Experts were obtained from as wide a geographic range as possible across Canada, Mexico, and the United States, and represented a wide variety of federal, state, and provincial agencies, non-government organizations, and universities.

To develop sampling methods, authors were provided with the information collected by the AFS Fisheries Management Section in the 1980s on sampling techniques used across the United States. In addition, dozens of fish-sampling protocols used by federal, state, and provincial agencies were provided to authors, and these techniques were used as a springboard for selecting standard sampling techniques applicable across North...
America. Guidelines were provided to the authors to insure that their proposed standard methods had the following attributes.

- Standard-sampling methods recommended would be the most common and statistically valid of those used by conservation agencies across North America. Recommendation of common methods will make standardization easier, both politically and logistically. Exceptions may occur if a common method is considerably flawed.
- The book would differ from fisheries techniques books that present a variety of methods, including those that are experimental or “cutting-edge.” Authors were asked to resist the tendency to promote “latest cutting-edge methods” in lieu of commonly used methods.
- The simplest methods possible were chosen because complex methods are much less likely to be standardized.
- Standard-sampling methods will be updated in the future much like Standard Methods for the Examination of Water Quality and Wastewater (Eaton et al. 2005) to reflect advances in fisheries science.
- Standard habitat measuring techniques (e.g., Armantrout 1982; Bain and Stevenson 1999) would not be included, except those used to standardize fish-sampling gear, such as conductivity, Secchi depth, and water color.
- Standard sampling methods focused on large-juvenile and adult life stages that are easily sampled with standard gears.
- Standard sampling methods were designed to minimize fish mortality, so methods such as toxicants and explosives were not included.
- Standard sampling methods should allow for fish species identification and measurement of lengths and weights if possible.

RESULTS

Standard fish-sampling methods were recommended in outline form by authors and the recommendations were reviewed by 54 fisheries professionals from 33 federal, state, and provincial agencies as well as the 3 co-editors of the book. Outlines of recommended methods were turned into text, reviewed by the editors, and constructive criticism was provided to the chapter authors. The second draft of the text of each chapter was then sent for anonymous review by 2–3 specialists. These specialists included project sponsors, other sampling experts, and European experts in fish sampling. The resulting book will be published by the AFS books division in the summer of 2009. Features of the book include:

- Descriptions of specific gears and procedures for sampling either coldwater or warmwater fishes in ponds, natural lakes, reservoirs, small streams, or large rivers.
- North American and regional averages and ranges were reported for indices of length structure, body condition, fish growth, and catch per unit effort for common game and nongame fishes collected using the standard techniques. These averages and ranges were calculated from data representing over 4,000 fish populations in 43 states and provinces across North America. These data were obtained through mail surveys of all federal, state, and provincial agencies in North America.
- Computation of the standard indices are described, as well as how to calculate needed sample sizes to provide precise estimates of the indices. References to other books and book chapters (e.g., Brown and Austen 1996; Guy and Brown 2007) providing more detail regarding statistical analyses are included. Additionally, examples of databases for storage and management of standardized data are included.
- Recommended procedures for converting non-standard data to standard data are included.
- Procedures for preventing transfer of exotic or invasive organisms among water bodies while using standard fish sampling methods are described.
- Methods for standardizing electrofishing power are presented.

Standard sampling methods were reviewed and designed with leadership by the AFS in collaboration with most federal, state, and provincial agencies in North America, but it is important to note that these standard methods are recommendations. In no way are agencies or biologists required to use the methods. The standard methods described in this book are provided to those who would like guidance when initiating standard monitoring programs, those who would like guidance as to how to gather data that can be compared to North American or regional averages, or those who would like to modify existing programs to more standardized programs. Those who are satisfied with local standardized sampling plans already in place are not pressured to change. However, those who decide to use the proposed standard sampling methods in their monitoring or assessment programs will find that they will possess powerful tools to assess fish populations and identify responses to fisheries management actions.

Standard Sampling Methods for North American Fishes identifies sampling methods for general or routine fish population assessments. These methods provide a means to facilitate comparison with data collected across North America and over time. However, it is recognized that standard sampling methods may not be appropriate when conducting specialized research or management studies. Consequently, techniques other than those identified in the standard sampling book, and specifically designed for a particular study, may be appropriate.

FUTURE DIRECTIONS

Even before the publication of the book, natural resource agencies in several states and provinces were moving to adopt these methods. Some directions for future development that will allow these methods to provide even more information are apparent.
Validation of Methods—A continuing challenge for fisheries scientists has been to determine the extent to which sampling data, collected with all of their biases and inconsistencies, represent populations. Use of standard sampling removes considerable variation in the data collected. However, bias still occurs. Validation is the process of defining the extent to which a sampling method represents the true population. Validating the standard methods presented in the book presents a rich area of research that could improve our ability to interpret sampling data. Validation of some of the standard methods is already underway, with Ontario researchers testing the standard gill-netting methods in Canadian lakes (Sandstrom et al. 2008).

Making standardized databases available via Internet—Averages, percentiles and ranges were presented in the book in tabular form for ecoregions and across the ranges of individual species. The organization follows Carlander (1969, 1977, 1997), whose efforts to compile data were of substantial value to fisheries biologists. However, to increase the usefulness of these summaries and to update them more easily, new data need to be incorporated into an interactive database that can be accessed via the Internet. This database could be updated rapidly with the collection of new data, could be a node at various agency websites, and could provide customized averages and ranges for comparison with a push of a button. Development of an interactive database is a challenge for the future.

Updating the standard sampling methods—Typically AFS reference books, such as Fisheries Techniques (Murphy and Willis 1996) and Inland Fisheries Management in North America (Kohler and Hubert 1999), are updated approximately every 10 years. We anticipate that there will be a need to update this reference book and add to the data summaries in a similar fashion.

Undoubtedly, the information in the first edition of the standardized sampling book will need to be improved in the future. Updating methods at regular intervals, while preserving the ability to compare among them between editions, will advance techniques, contribute to their ease of use, and reach a wider audience. Most standard methods manuals are updated on a regular basis. For example, Standard Methods for the Examination of Water Quality and Wastewater is now in its 21st edition (Eaton et al. 2005). A website or other mechanism is needed where comments on the methods could be cataloged and used when writing future editions. In addition, translation of the book into Spanish and French would facilitate communication of the information to additional fisheries professionals in the Americas and allow for greater data sharing and communication.
ACKNOWLEDGEMENTS


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Oregon Chapter: Holds annual meeting in Bend
PHOTOS: www.RichardGrosh.com

The Oregon Chapter annual meeting in February 2009 in Bend drew more than 450 professionals, including a record 60+ students, to participate in “Sharing Our Passion” for fish and fisheries. The theme recognized that as professionals we’re expected to be pragmatic and practical—but we can, and often should, also be passionate. Passionate about the resources we manage, the species and habitats we study, the methods we develop and employ, the information we assemble, and the interpretations we devise. But mostly, passionate about that lowest common denominator we all share. Intentional or not, the AFS serves as a “support group” for professional fish-o-philes—a place we can commiserate in good times and bad, when other workers, friends, even family no longer appreciate the prolific use of our favorite 4-letter “f-word” (fish, of course). This meeting celebrated that root connection and evoked passion like few others.

Fish-art guru Ray Troll set the perfect tone with his entertaining and inspirational presentation “Fish Worship—How I Became a Scientific Surrealist,” explaining how fish and science have infused his entire life and career with passion. His creative, colorful art has spread internationally, celebrating fish and their myriad relation to humans. One oddity revealed: the classic skull and fish design “Spawn til You Die” has become a favorite fashion among demented antagonists in B-rate horror movies. Troll participated throughout the meeting, presenting his work devising and directing community art projects, discussing his explorations of the vicious fishes of the Amazon, and unleashing his musical madness by leading some hard-driving, fish-inspired “sub-aqua-punk-bush-rock” during the Fishhead Jam Session.

Technical sessions accommodated 150 presentations and 36 posters, on subjects as diverse as aquaculture advances, climate and conservation, cyanobacteria and fish dynamics, dam removals, fish passage facilities, estuary and marine research, permitting and statistics, education and outreach, lampreys, bull trout, sea turtles, and, of course, zebra mussels. Notably, one session addressed revision of the Chapter’s white paper regarding marine reserves, and another special session on synthesizing pesticide impacts to aquatic resources was planned and moderated by a panel of undergraduate students led by Chapter Student Liaison Kristle Warren as a project for an Oregon State University (OSU) problem-solving class. An even less conventional (but packed) session highlighted unique and inspiring images of fish, including underwater photography and video with photographer narrations.

Two day-long workshops preceded the meeting and educated some 50 members. “Fisheries Telemetry,” organized by Shaun Clements, John Beeman, and Carl Schreck, had students suturing bananas first, then fish. The workshop was supported by the
Oregon Department of Fish and Wildlife (ODFW), OSU, U.S. Geological Survey (USGS), and vendors including AMIRIX Systems (VEMCO) and Lotek Wireless. Equipment displays helped students visualize how to configure field stations to effectively monitor tagged fish. The second workshop, “Identification and Control of Aquatic Invasive Species—How to Not Be a Vector,” was organized by Jill Hardiman and supported by USGS, U.S. Fish and Wildlife Service, the 100th Meridian Team, Oregon State Marine Board, Sea Grant, U.S. Forest Service, Bureau of Land Management, and Portland State University. It featured a mock boat and trailer inspection, but first, students were familiarized with the scoundrels most recently invading area waters and the methods most useful in monitoring and controlling them. Throughout the meeting, vendors of telemetry equipment, water quality instruments, environmental services, and other products and services displayed along a deck overlooking the snowmelt-laden Deschutes River.

Professional awards were managed expertly by Mindy Simmons and the Awards Committee, resulting in presentation of the following:

**Award of Merit:** Central Oregon Flyfishers, for sustained dedication to conservation work benefiting native fish;

**Award of Merit:** Sunriver Anglers Club, for sustained dedication to conservation work benefiting native fish;

**Award of Merit:** Leesa Cobb, for sustained dedication to marine conservation work;

**Award of Merit:** Port Orford Resources Team, for sustained dedication to community-based marine conservation work;

**Award of Merit:** Bianca Streif and Janine Castro, for exemplary service in planning the 2008 Western Division AFS workshop: “Stream Restoration: Integrating Practical Approaches”;

**Bill Wingfield Memorial Award in Fish Culture:** Tony Amandi (on behalf of the ODFW Fish Health Team), for long-term contributions to fish health and production;

**Fishery Team of the Year:** Tim Hoffnagle, Don Hair, Joseph, Deb Eddy, Sally Gee, and Fred Monzyk; for exemplary research on artificial propagation and recovery of threatened Snake River spring/summer Chinook; and

**Broken Oar:** Tim Shibahara and Chris Karchesky, for surviving a “watch this!” test-drive where the manufacturer swamped his own jet boat at the base of Willamette Falls.

From a record number of scholarship applications, scholarships were awarded to: Kari Rosch, Mount Hood Community College (AA candidate); Autumn Smith, OSU (BS candidate); Mac Barr, OSU (masters candidate); and Ben Clemens, OSU (Ph.D. candidate). The inaugural and uniquely prestigious Carl Bond Scholarship was awarded to Matt Sloat, OSU (Ph.D. candidate), in support of his work on life history evolution and anadromy in Pacific salmonids. Scott Heppell and his committee did an outstanding job managing the scholarship process and evaluating many worthy applicants, most of whom we hope to see again next year.

Best Student Paper honors went to William Brignon (OSU) and Heidi Andersen (OSU, runner-up), while Best Student Poster honors went to Brett Blundon (OSU) and Londi Tomaro (OSU, runner-up). Mike Hudson did his usual excellent job planning for and presenting these important awards.

The Student-Mentor Mixer was packed with some 60 students making rapid-fire, 8-minute “speed-dating” rounds to meet and query all 40 mentors. Despite the hectic pace, students raved about the direct exposure this event provides to a diversity of career options, guidance, and even direct job opportunities. Mentors were mostly hoarse at the end. Christy Fellas was the catalyst with critical assistance from Kristle Warren and Shivonne Nesbitt.

At the business meeting, President Neil Ward announced the renewal of a legislative liaison position to serve as our eyes and ears in the capitol and keep the Chapter abreast of legislative issues and opportun-
ties. Dave Ward updated us on Western Division AFS projects, Doug Young received his past president remembrance (a legacy baby blue T-shirt of his ordering), and External Director Jeremiah Osborne-Gowey updated members on committee activities. Standing committees convened for strategy sessions and there was renewed passion evident, especially within the Marine Habitat, Natural Production, Legislative, and Education and Outreach committees.

The raffle and auction, organized by Terry Smith, featured a huge assortment of desirable stuff including an original Joe Tomelleri burbot painting, custom photo prints by members Richard Grost and Mary Edwards, outdoor gear, boating adventures, and custom art by Ray Troll (including a piece drawn on the tablecloth at dinner). Students deftly worked the floor selling raffle tickets and supporting the auction. Enough passion ensued to raise over $10,000 toward future scholarships and other Chapter activities.

The Jam Session, organized and grounded by bass-man Mike Faler, grew into an amazingly choreographed mass of some 30 member musicians tuning, crooning, and generally synergizing in various combinations until literally booted offstage in the wee hours. The audio feast included classic bluegrass, folk, R&B, rock, and of course the custom fish-fare of Ray Troll. One member used the dance floor to shake her newly-won hip-booties. “Lumpsuckers of love, love, love,” oh yeah.

Finally, some 50 members participated in a post-meeting free-lunch tour of Portland General Electric’s Round-Butte fish passage project. This project, well under construction, is one of the largest and most complex fish passage facilities ever built and a key element to the major anadromous fish restoration project for the upper Deschutes River Basin. Thanks Don Ratliff and Jim Bartlett, for the tour and the chili dogs!

Overall, the 2009 meeting fulfilled expectations as the Oregon Chapter’s largest and most important technical and professional networking event. Thanks are due to all who attended, assisted, presented, moderated, donated, and especially the ExCom for a year of behind-the-scenes planning: President Neil Ward, Past President Doug Young, President Elect Rich Grost, Vice President Christy Fellas, Secretary Treasurer Shaun Clements, Internal Director Martyn Reesman, and External Director Jeremiah Osborne-Gowey. This crew, and incoming President Elect Demian Ebert, are already planning the next Oregon Chapter meeting 24–26 February 2010 at the Hilton in Eugene.

—Rich Grost

Tennessee Chapter
Holds annual meeting at state park

The Tennessee Chapter held its annual meeting 3–4 March 2009 at Montgomery Bell State Park. Approximately 55 people attended, with an additional 30 students joining the group on the second day. Sixteen presentations were given in 4 technical sessions, with 12 presentations by students. Southern Division President Cecil Jennings attended (despite inclement weather conditions in Georgia) and addressed the Chapter during its business meeting. The AFS 2009 planning committee also met on the morning of the first day to continue working on logistics for the Parent Society’s upcoming meeting in Nashville. At the business meeting, Jim Habera (president elect) and Jason Heneger (secretary treasurer) were elected, and join Hayden Mattingly (president) and Frank Fiss (past president) as Chapter officers. The Chapter voted to make a donation to the pending paddlefish book, and set aside $1,500 to help in-state students travel to the AFS 2009 Nashville meeting. At the banquet, Jack Swearingen of Tennessee Wildlife Resources Agency received the Outstanding Fisheries Scientist Award for his work on the state’s muskellunge fishery. Amy Wales of Tennessee Valley Authority was recognized with a Service Award for her long tenure as the Chapter’s secretary treasurer. Johnathan Davis of Tennessee Technological University received the Best Student Paper Award for his presentation on monitoring strategies for the endangered duskytail darter, co-authored by his faculty advisor, Brad Cook. After the banquet, lively musical entertainment was provided by the folk-bluegrass trio “2nd Nature,” along with student-led games on the breaks. The meeting adjourned with a pledge to get everyone involved with preparations for the AFS 2009 Nashville meeting.

—Hayden Mattingly

Dakota Chapter
Holds annual meeting in Bismarck

Despite a meager participation from South Dakota Game Fish and Parks because of out-of-state travel restrictions, the Dakota Chapter meeting was held in Bismarck on 23–25 February. Approximately 70 participants mingled at the socials, attended the sessions, participated in business meeting, and recognized award recipients. Students from South Dakota State University (SDSU) dominated the awards given by the Chapter. North Central Division President Mark Porath and Society President Bill Franzin each participated in the meeting. Three SDSU students tied for the Best Student Paper award. Landon Pierce presented “Evaluating Stocking Success of Paddlefish in Lake Francis Case, SD: a work in progress.” His...
co-authors were Brian Graeb and Jason Sorenson. Justin VanDeHey won for his presentation “Non-Lethal Sampling of Walleye and Yellow Perch for Stable Isotope Analysis: A Comparison of Three Tissues,” co-authored by Mark Fincel and Steve Chipps. Travis W. Schaeffer presented, “Compensatory Growth and Metabolic Responses of Female Yellow Perch Subjected to Symmetric Feed: Fast Cycles,” with co-authors Daniel Spengler, Casey Schoenebeck, Mike Brown, and Steve Chipps.

Two SDSU students tied for the Best Student Poster award. Andy Jansen won for his poster “Effect of a Simulated Cold-Front on Hatching Success of Yellow Perch Eggs.” Brian Graeb and Dave Willis were co-authors. Nick Peterson won for his poster titled, “Determination of Bluegill Size and Age at Maturity in Southeastern South Dakota Impoundments,” co-authored by Justin VanDeHey and Dave Willis.

Bethany Galster from South Dakota State University was the winner of the Schmulbach Memorial Scholarship. Named after James C. Schmulbach, this competitive scholarship is awarded by the Chapter to an eligible junior or senior undergraduate studying fisheries in either North or South Dakota. Sauger scholarships (travel awards) went to South Dakota State University students Bobbi Adams, Ryan Andvik, Nick Peterson, and Andrew Wuestewald. Will French and Andrew Wuestewald from SDSU received Kriel scholarships. Named after long-time Dakota Chapter member Al Kriel, and funded by his family, the award pays for full membership in the American Fisheries Society.

Will Sayler received the Distinguished Professional Service award and the Aquatic Resource Conservation Award was given to the Lake Region Anglers Association (North Dakota).

New Chapter officers were elected at the meeting. Greg Simpson (secretary/treasurer), Brian Fletcher (vice president), and Jeff Hendrickson (president elect), join incoming President Mike Barnes.

—Mike Barnes

North Central Division President Elect Mark Porath attended the meeting, and as this photo shows, raked it in during the raffle!
The Fenske Fellowship: A Graduate Student Opportunity in Fisheries Management
By Amy M. Schueller

Schueller is a doctoral student at the Department of Fisheries and Wildlife at Michigan State University and can be contacted at schuel11@msu.edu.

When I started graduate school at Michigan State University (MSU), it was with the idea that someday, I would like either to become a professor or work for an agency as a researcher. Like many fisheries professionals, my fascination with fisheries management stems from childhood experiences fishing, camping, and hunting. During my time at MSU, I have participated in numerous activities common to the graduate student experience. One opportunity that I didn’t anticipate was applying for and being selected as the first Janice Lee Fenske Excellence in Fisheries Management Fellow for 2007–2008. By taking on this fellowship, I gained insight into how an agency functions, how important human dimensions are to fisheries management, how to effectively communicate in group settings, create timelines, balance duties, and plan meetings. My experience as a Fenske Fellow has helped me to grow both personally and professionally, and has given me the opportunity to influence fisheries management as a student, and I wanted to share my experiences with other students.

The Fenske Fellowship was created by an endowment to the Department of Fisheries and Wildlife at MSU honoring Janice Lee Fenske, the first female biologist in the Michigan Department of Natural Resources (MDNR) Fisheries Division. The fellowship provides individuals from under-represented groups with experience working with a management agency on a fisheries-related project. Besides typical application materials like a CV, project proposals, and reference letters, applying requires a discussion of time constraints.

This is because the fellowship experience is intended to engage the fellow in a project that’s separate from their graduate research and coursework, and the fellowship committee wants to ensure that the fellow can manage the fellowship project in addition to their other responsibilities. For my fellowship, I needed to identify two mentors—one from a management agency and one from MSU—and work with those mentors to develop a project. Thus, the fellowship was also meant to provide experience working within a management agency, along with mentors, on a specific management-related project, as well as expose the student to how agencies are structured and function.

When it came time for me to pick the project that I wanted to work on, I picked a project that would benefit the state as well as provide me an opportunity to play an active role in influencing fisheries management decisions. I also picked a project which provided me the opportunity to write a document that included internal, external, and stakeholder reviews. In 2005, I attended a meeting led by Gary Whelan from the MDNR on current lake sturgeon research projects. At the meeting, the lake sturgeon committee was tasked with updating the state’s Lake Sturgeon Rehabilitation Strategy (LSRS). I later recalled this meeting when I was choosing a project for the Fenske Fellowship application and contacted Gary to inquire about the status of this project. He stated the updates hadn’t progressed much and felt the LSRS needed someone to take a central leadership role to move the project forward. I jumped at this opportunity and elected to work with Gary and Dan Hayes (my advisor) from MSU on the project.

As Fenske fellow, my role in this process was to coordinate Michigan’s sturgeon researchers in order to take their individual expertise and combine it into a coherent update of Michigan’s LSRS. This update will be based on knowledge acquired since the strategy was first compiled in 1997. The new LSRS will benefit lake sturgeon in Michigan by redefining goals and objectives for their populations based on more complete knowledge, leading to better management practices. Because one of the MDNR’s goals is to maintain resources for future generations, my role as Fenske Fellow on this project will aid in establishing management practices for sustaining lake sturgeon in the future.

As a Fenske fellow, I had the opportunity to attend several Management Team meetings for the Fisheries Division. These meetings engage top administrators of the Fisheries Division in group decision-making processes. One of the main meeting tools they use are submitted issue statements, which are documents that include key pieces of information and requests for decisions related to this information. Issue statements can be submitted by anyone in the division to request a Management Team decision on, for example, whether or not a project will receive money, a protocol or regulation will be changed, how fish populations will be managed in the face of a new disease, or if a bill in the state legislature will be supported. This system allows for everyone in the division to have their voice heard on the topics that are important to them and the stakeholders they represent. I was impressed with the MDNR’s ability to work together and come to a consensus even when those involved didn’t agree on all aspects of a topic. As part of the process to update the LSRS, the LSRS will need to be put forth as an issue statement and agenda item for a Management Team meeting. Thus, attending Management Team meetings has given me insight into how issue statements should be posed to be clear and concise and move forward with a decision.

As a graduate student researcher focused on sturgeon biology, it is easy to get somewhat disconnected from the human dimensions of resource management. Lake sturgeon rehabilitation affects many diverse stakeholder groups such as Sturgeon for Tomorrow and Native American tribes. Before becoming the Fenske Fellow, I thought working with stakeholders would be relatively easy, until I found that stakeholders often do not see eye-to-eye when considering how natural resources should be managed. Some stakeholders want lake sturgeon for recreational harvest, others want lake sturgeon...
for cultural and ritualistic reasons, and still others want lake sturgeon for ecosystem rehabilitation. Juggling all of these needs and wants is no small feat; it takes people, money and political management skills which are rarely taught in the classroom. For the most part, these critical people skills are learned on the job. I am fortunate to have gained this insight while still pursuing my graduate studies.

One of the biggest lessons that I took away from this experience is that preparation, planning, and communication are essential to efficient and effective decision making. We worked with a lake sturgeon committee to update the LSRS. Keeping these members informed of the progress of the project was crucial to keeping the project moving forward. Also, effective preparation for the committee meeting, where goals, objectives, and management actions were discussed, allowed for efficient decision making. Having a prepared framework for decision making, like an issue statement, for committee members to comment on and change was much more efficient than starting completely from scratch. This is just one of the beneficial lessons that I took away from Management Team meetings.

Through my involvement in the Fenske Fellowship, I feel fortunate to have had the opportunity to influence fisheries management as a graduate student. I was able to be involved and take a central leadership role during the decision making process thus far, for lake sturgeon management in the state of Michigan. The Fenske Fellowship is a unique opportunity which fosters student participation with a variety of professionals, who work together toward progress on pressing fisheries management issues.

Although I have officially finished my tenure as a Fenske Fellow, the update to the Lake Sturgeon Rehabilitation Strategy is ongoing and I plan to continue my involvement. The completed update of the Lake Sturgeon Rehabilitation Strategy will help guide lake sturgeon management efforts in Michigan, and maintain a sustainable population in the future for all stakeholders. It is rewarding to know that I was a part of these efforts, and these incredible experiences are something I would not have had if it were not for the Fenske Fellowship. Finally, I encourage students to search out these types of opportunities in order to influence management decisions because this was definitely a professional learning experience.


Seasonal Patterns of Abundance, Growth, and Site Fidelity of Juvenile Steelhead in a Small Coastal California Stream. Susan M. Sogard, Thomas H. Williams, and Heidi Fish, pages 549-563.


The Genetic Legacy of Stocking Muskellunge in a Northern Minnesota Lake. Loren M. Miller, Steven W. Mero, and Jerry A. Younk, pages 602-615.


Skeena River Fish and Their Habitat
Allen S. Gottesfeld and Ken A. Rabnett, Ecotrust, Portland, Oregon
2008, ISBN: 978-0-9779332-5-9, 352 p. $29.95, paperback

The Skeena River is the second largest river system in British Columbia, Canada, draining 54,432 km² of the north-central region of the province. It has a limited fish fauna (about 32 species) but supports commercially and culturally important populations of Pacific salmon (*Oncorhynchus* spp.) as well as trout, char, whiteshines, sturgeon, burbot, and eulachon. Although parts of the basin have suffered some habitat degradation from logging, mining, ranching, and urban development, most fisheries habitat has been little altered. The Skeena could, therefore, provide a habitat reference for more developed basins in the Pacific Northwest. As yet, there has been no comprehensive synthesis of information on Skeena River habitat and fishery resources that would allow managers and researchers to take advantage of this opportunity. In *Skeena River Fish and Their Habitat*, Gottesfeld and Rabnett take the first steps toward such a synthesis.

The book appears to be an enlarged and updated version of a report the authors prepared for the Skeena Fisheries Commission (Gottesfeld et al. 2002), an Aboriginal organization that focuses on fisheries management, science, and conservation in the Skeena River basin. Ecotrust, an environmental non-governmental organization, assisted with publication of the book as part of its collaboration with the Wild Salmon Center in Portland, Oregon, to document the distribution and status of Pacific salmon population throughout their range.

The book is organized into two main sections—an overview of physical, ecological and fisheries characteristics of the whole Skeena basin, followed by more detailed descriptions of 18 sub-basins. The basin and each sub-basin are described in terms of environment (physical characteristics, water quality, vegetation), fish resources, fisheries, and human development. The Skeena drains a diverse geography from dry interior plateau to wet coastal forest and includes 7 of British Columbia’s 14 biogeoclimatic zones. The 18 sub-basins reflect this biogeoclimatic diversity in only a very general way. *Skeena River Fish and Their Habitat* also deals primarily with Pacific salmon species, including steelhead (*O. mykiss*). Other freshwater species are covered briefly in the first section and barely mentioned again. This is a reflection of the limited data on species other than salmon and steelhead.

The authors have done an excellent job of locating and summarizing the information on Skeena fisheries hidden in government reports and memoranda. Of the more than 783 citations in the book, 689 are gray literature. Although this makes the Skeena seem scientifically neglected, in fact the river has a distinguished history as a site of Pacific salmon research. Studies by scientists of the Fisheries Research Board of Canada between the 1940s and the 1970s, particularly at Lekelse Lake and Babine Lake, helped establish the foundation of salmon management in the Pacific Northwest. In the past few decades, however, most new information has come from intermittent monitoring and management surveys.

Although the book presents a lot of information that most individuals would otherwise have difficulty accessing, it also has a number of important limitations. There is no obvious logic to the selection of the 18 sub-basins, except that they divide up the catchment. Each sub-basin is discussed as though it was an independent unit rather than part of a whole. This criticism applies equally to the sub-sections of each main section. For example, descriptions of geology, vegetation, water quality, etc., are not presented in the context of Pacific salmon needs, which is the focus of the book. Nor do the authors make any attempt to locate the Skeena in relation to other larger river systems. The book is a description of data on the Skeena River and nothing more. Finally, perhaps because the book is an expanded report, I found the prose dry and uninteresting.

—Michael Healey
Professor Emeritus,
Institute for Resources Environment and Sustainability
University of British Columbia
Current Address: Peachland, British Columbia
healey@interchange.ubc.ca

REFERENCE

**New Titles**


This annual compilation of reviews this year includes various papers of potential interest to AFS members: Lessios on divergence of marine organisms across the Panama isthmus, Pyke on the biology of mosquitofish, Crowder et al. on the impacts of marine fisheries in an ecosystem-based context, and Schwartz on the performance of the Endangered Species Act. This year’s volume includes more color and better quality graphics than ever before.

**Biology, Assessment, and Management of North Pacific Rockfishes.** Edited by J. Heifetz, J. Dicosimo, A. J. Gharrett, M. S. Love, V. M. O’Connell, and R. D. Stanley. Alaska Sea Grant College Program, Fairbanks. 2007. 550 pp. $50.00 (cloth); seagrant.uaf.edu/bookstore/pubs/AK-5G-07-01.html.

This book represents the proceedings of the 23rd Lowell Wakefield Fisheries Conference on North Pacific Rockfishes.
Symposium held in 2005 as part of the AFS Annual Meeting in Anchorage. The volume includes 28 papers that cover life history, population structure and speciation, age and growth, fishery management, habitat requirements, and stock assessments.


Twenty years after the publication of the first edition of this book comes a thoroughly revised and updated second edition. The book is intended primarily for anglers and naturalists but contains an extensive bibliography for those who might want to use it as a reference book. The text is well illustrated with photographs, line drawings, and maps. It contains 15 chapters, 3 of which are introductory, while the others focus on extant (and extinct) subspecies.

For Your Information


**Enclosing the Fisheries**  
**People, Places, and Power**

*Marie E. Lowe and Courtney Carothers, editors*

Economic logic that guides the limitation and privatization of access rights seeks to address overcapitalization and inefficiencies that result from open access fisheries. This type of fisheries management, often called rationalization, has gained international common sense appeal. Yet the contested social impacts of restricted access, market-based resource management programs are increasingly documented in academic literature and continue to be a focus of social resistance and mobilization among those who have been displaced, or rationalized out of fishing in this process. The outcomes of ownership consolidation, loss of jobs and income, decreased labor mobility, prohibitive entry costs, loss of fishing rights from small communities and other distributional inequities can be understood broadly as the sociocultural effects of fisheries access restrictions this volume addresses.

Drawing on rich ethnographic research in coastal communities in Alaska, British Columbia, Iceland, and New Zealand, this diverse collection of papers demonstrates the wide reach of privatization discourses and policies as experienced by people and communities dependent on fishing for livelihood and identity.

223 pages  
List price: $35.00  
AFS Member price: $25.00  
Item Number: 540.68P  
Published December 2008

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We’re proud to bring the AFS meetings to the South, where the diversity of our freshwater fishes is unrivaled in the country. World-class fishing opportunities abound nearby, or you can join the field trip to the Duck River, which harbors one of the most diverse aquatic faunas in the country, if you’re more inclined to non-game fishes. As an organization responsible for helping to conserve this diversity, each year we look for ways to further reduce our impact on aquatic life. This year, we’ve focused our attention in reducing the amount of waste that is caused by the meeting.

IN NASHVILLE, YOU WON’T RECEIVE:

- An author index in your printed meeting book and program guide.
- A CD or memory stick with all of the abstracts.
- An expensive tote bag that will be stashed in the back of your closet.
- Drink tickets for soft drinks, beer, and wine

IN NASHVILLE, YOU WILL RECEIVE:

- A lighter meeting book and program guide sans author index (which saved 20,000 pages of paper when we printed the book). While author indices are handy for finding talks given by your
favorite fishery biologists (or your own talk!), we have decided to eliminate it to save paper and ink. Instead, you will receive...

- **Instructions on how to download and search the program and abstract files.** These files will be posted on the AFS website before the meetings, where it will be a snap to electronically search for your favorite speakers (or poster authors) and read their abstracts. You can create a schedule of talks you want to hear prior to arriving at the meeting, or you can easily download the program and abstract files to your laptop computer to search for speakers and strategize during the meeting. The program and abstract files will also be uploaded onto the computers in the Internet Café to facilitate speaker searches.

- **Reusable and recyclable bags.** Conferences have been green for years by handing out canvas bags that can be used at the grocery store. Our bags are made of recycled materials that can also be used to carry lunch, plant lettuce and herbs for portable gardens, or carry field gear. If you’re already overwhelmed with conference bags, you can drop these off along with your milk jugs at a recycling center.

- **Good food and drinks.** Southern hospitality is legendary, and we’re going to ensure that you experience the best of it by providing food and beverages. There will be no drink tickets in Nashville for soft drinks, beer, or wine at the four main socials. The kegs, which are reusable, will also save on packaging waste from bottles or cans. In case you have trouble remembering the great time you had in Nashville, we’re also giving you coasters for your drinks, made from 100% post-consumer recycled tires. The main social will be held at Smiley Hollow, a working farm that has been in the Smiley Family since the 1800s. Much of the produce that you will eat that night is grown locally—on the farm itself.

Finally, don’t forget to think about sustainability when making your personal decisions on travel to the meeting. In this time of tight travel restrictions, try to carpool to the meeting or share hotel space. We have set up a discussion board on the AFS Facebook site so that you can list or look for rides to the meeting. We look forward to seeing y’all there!
Fisheries experts increasingly acknowledge the importance of globalization on local, national, and international fisheries. This book brings together fisheries and governance experts from across the globe who present case studies on a broad spectrum of the internationally shared fisheries that inhabit diverse freshwater and marine ecosystem types.

Case studies provide the biological background of the fisheries resource, including status and threats to the resource and its ecosystem. The case studies review the evolution and current governance institutions of the fisheries resource, with particular focus on international or global institutions. Each study concludes with an evaluation of the effectiveness of the current fisheries governance institutions, and recommendations for changes.
**CALeNDAR:**

**FISHERIES EVENTS**

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

More events listed at [www.fisheries.org](http://www.fisheries.org), click "Who We Are," click “Calendar”.

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<tr>
<td>Jul 20-24</td>
<td>Sixth International Fisheries Observer and Monitoring Conference</td>
<td>Portland, Maine</td>
<td><a href="http://www.st.nmfs.noaa.gov/iformc209">www.st.nmfs.noaa.gov/iformc209</a></td>
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<td>Jul 22-27</td>
<td>Early Life History Section’s 33rd Annual Larval Fish Conference and American Society of Ichthyologists and Herpetologists Conference</td>
<td>Portland, Oregon</td>
<td><a href="http://www.dce.k-state.edu/conf/jointmeeting">www.dce.k-state.edu/conf/jointmeeting</a></td>
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<td>Aug 24-28</td>
<td>4th International Otolith Symposium</td>
<td>Monterey, California</td>
<td><a href="mailto:Otolith2009@noaa.gov">Otolith2009@noaa.gov</a></td>
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<td>Aug 30-Sep 3</td>
<td>American Fisheries Society 139th Annual Meeting</td>
<td>Nashville</td>
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<td>World Fishing Exhibition 2009</td>
<td>Vigo, Spain</td>
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<td>Sep 21-25</td>
<td>International Council for the Exploration of the Sea Annual Science Conference</td>
<td>Berlin, Germany</td>
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<td>Oct 22-24</td>
<td>Western Division of the AFS 2nd Annual Student Colloquium</td>
<td>Fort Collins, Colorado</td>
<td>Nate Cathcart: cn <a href="mailto:cathca@rams.colostate.edu">cathca@rams.colostate.edu</a> or <a href="http://welcome.warnercnr.colostate.edu/afs-home/index.php">http://welcome.warnercnr.colostate.edu/afs-home/index.php</a></td>
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<td>Oct 25-30</td>
<td>Sixth International Symposium on Sturgeon</td>
<td>Wuhan, Hubei Province, China</td>
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<td>Dec 9-12</td>
<td>Fourth Shanghai International Fisheries and Seafood Expo</td>
<td>Shanghai, China</td>
<td><a href="http://www.gehuaexpo.com">www.gehuaexpo.com</a></td>
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**2010**

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<td>Mar 1-5</td>
<td>Aquaculture 2010</td>
<td>San Diego, California</td>
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Closing: Until filled.
Responsibilities: Assist member tribes natural resource directors in managing harvest of salmon, steelhead, and marine fish resources. Responsibilities include stock assessment, fisheries management planning, providing advice on the regulation of fisheries, and working cooperatively with other tribes and state/federal agencies. Coordinate with other Treaty Council staff as part of an integrated fisheries management program that includes hatchery management planning, salmon recovery, and habitat protection/ restoration.
Qualifications: Desire M.S. with study emphasis in at least two of the following areas: fish biology, population assessment, statistical procedures, applied research, natural resource economics, and natural resources management. Two or more years of professional experience required. Actual fisheries management experience is desirable as is knowledge of U.S. vs. Washington and treaty fishing rights. Self-starter with demonstrable communication skills, ability to prioritize and willingness to take tasks to completion.

Contact: PNPTC, attn HR, 7999 NE Salish Lane, Kingston, Washington 98346; jmclaughlin@pnptc.org; 360/297-6544.

Communications Specialist (2 positions), NOAA, Fisheries, Office of Habitat Conservation.
Salary: $60,900–133,500.

Closing: 10 July 2009.
Responsibilities: Develop and implement strategies for raising the visibility and improving the understanding of the mission of OHC with a variety of audiences, including NMFS and NOAA leadership, Capitol Hill, media working with NOAA Public Affairs, state and federal partners, and other stakeholders. Support the process to define objectives and key messages for communication efforts and assist in developing an annual strategic communications plan. Responsible for development of written promotional and information materials including press releases, brochures, annual accomplishment reports, and web site content to increase constituents understanding of specific program issues and initiatives. Duties also include development of new media such as video and audio segments. Assist in developing constituent relationships and preparing executives for outreach events. Coordinate communications messaging and activities across the office.
Qualifications: Experience working on or leading projects and programs, writing and editing communications materials, and conveying natural resource information to diverse audiences. College degree.


Ph.D. Research Assistantship, Department of Ecology, Montana State University.
Salary: Stipend of $18,000 per year with substantial tuition waiver.

Closing: 1 August 2009.
Responsibilities: Investigate the role of biodiversity in infectious disease risk using salmonid whirling disease of western streams as the model system. Collaborate with engineering and molecular population genetics faculty. Direct involvement in both field surveys and laboratory experiments relating the tubificid community to disease risk in salmonids.
Qualifications: B.S. or M.S. degree in ecology, zoology, biology, or a related field. Strong quantitative and writing skills. Prior experience with field methods used in stream ecology and benthic macroinvertebrate collection and identification and/or disease ecology preferred.

Contact: Submit cover letter, resume, copies of transcripts and GRE scores, and names and telephone numbers of 3 references to by either e-mail or regular mail to Billie L. Kerans, bkerans@montana.edu, 406/994-3725, www.montana.edu/wwwbi/staff/kerans/kerans.html.

Postdoctoral Scientist, Department of Fish Wildlife, Colorado State University, Fort Collins.
Salary: Commensurate with qualifications and experience.
Responsibilities: Study climate change effects on native cutthroat trout. Model persistence of native cutthroat trout given impending changes to interacting aquatic and terrestrial factors caused by climate change. Work involves climate modeling, data analysis, and developing a Bayesian Belief Network decision-support tool.
Qualifications: Earned Ph.D. in aquatic or fisheries ecology, experience in research on ecology of stream fishes, substantial experience with modeling, ability to create and manage large databases, skill in using statistics and computers, strong record of publishing papers in high-quality refereed journals. Desired experience with climate models and fish conservation.
Contact: E-mail cover letter, resume with four references, transcript copies, and publications to Kurt Fausch, kurtf@warnercnr.colostate.edu. Department of Fish, Wildlife, and Conservation Biology, CSU, Fort Collins, CO 80523.

Ph.D. Research Assistantship, Fisheries and Illinois Aquaculture Center, Department of Zoology, Southern Illinois University, Carbondale.
Salary: $1,426 per month plus full tuition waiver.
Closing: 1 July 2009.
Responsibilities: Conduct research evaluating the dynamics of fatty acid profile change and accumulation of persistent organic pollutants in hybrid striped bass, with the goal of identifying nutritional strategies to minimize risk and maximize value of cultured seafood. Address the controversial use of marine-derived feedstuffs i.e., fish oil and fish meal, as vectors for environmental contaminants that can accumulate in fish tissues along with nutritionally beneficial long-chain polyunsaturated fatty acids. See http://fisheries.siu.edu.
Start date: Fall 2009.
Qualifications: M.S. in aquaculture, aquatic toxicology, or related field. Must meet admission requirements for the graduate school and Department of Zoology at SIUC at www.science.siu.edu/zoology/programsgraduate.html.
Contact: Submit a letter of interest, resume and CV, contact information for three references, copies of transcripts and GRE scores to: Jesse Trushenski, Southern Illinois University Fisheries Illinois Aquaculture Center, 1125 Lincoln Drive, Room 173 Carbondale, Illinois 62901-6511; saluskis@siu.edu; 618/536-7761

Ph.D. Assistantship in Mapping Ecosystem Services, Virginia Polytechnic Institute.
Salary: $22,000–24,000 per year plus tuition.
Responsibilities: Participate in a multidisciplinary effort to examine where/when biological conservation enhances delivery of aquatic ecosystem services. Participate in conceptual-model development for and spatial analyses of relations among conservation practices, biodiversity, delivery of ecosystem services, and human well being in a U.S. river basin. Perform project data analysis and report writing, while completing Ph.D. coursework.
Qualifications: M.S. in landscape ecology, ecological economics, conservation biology, geography, or related discipline. Commitment to multidisciplinary research, demonstrated scientific productivity, including peer-reviewed publications, strong statistical skills experience with large geo-spatial datasets, excellent writing skills.
Contact: Send letter of interest, resume, GRE scores,
M.S. Graduate Research Assistantship, Aquaculture and Fisheries Center, University of Arkansas.

Salary: First year—$17,800. Second year—$18,800.

Closing: 1 August 2009 or until filled.

Responsibilities: Use store scanner data to analyze market trends and retail pricing issues for catfish, crawfish, clam, and shrimp, and use household-based scanned data to analyze consumer behavior.

Qualifications: Admission requires a B.S. degree in aquaculture, fisheries, agricultural economics, or a related field, a minimum GPA last 2 years of 3.0 and GRE score of 1,000 verbal quantitative. Minimum TOEFL score of 550 paper based or equivalent for international students. Strong quantitative statistics, mathematics skills, and computer proficiency required. Maintenance of large data set is desired.

Contact: Complete forms at below link and mail hardcopy to Dey Aqua and Fish Center, UAPB 1200 North University Drive, Mail Slot 4912, Pine Bluff, Arkansas 71601. For questions see www.uaex.edu/aqfi, mdey@uaex.edu.
How to Tag a Shrimp (Once) that Molts 30 Times

Faster growing strains of disease-resistant shrimp are providing a significant boost to the aquaculture industry. Developing these strains is easier if the performance of various families, reared together under identical conditions, can be easily identified for evaluation.

Tagging shrimp and other crustaceans is complicated by an exoskeleton which can be shed as many as 30 times as the animal grows to a marketable size. Hawaii’s Oceanic Institute’s Shrimp Program, with assistance of experts from Washington Dept. of Fish and Wildlife, set out to find the right tag for the job. Trials were conducted using NMT’s Visible Implant Elastomer (VIE). VIE is injected as a liquid under clear or translucent tissue, and it then cures to a pliable solid that remains externally visible. The tags are available in 10 colors, of which six are fluorescent for enhanced visibility and detection. VIE was injected into the muscle of the sixth abdominal segment in juvenile shrimp ranging from 0.2 g to 3.9 g, and adults weighing from 23 g to 47 g. After 10 to 14 weeks, tag retention in shrimp tagged as juveniles was 99.9% while 100% of the tags were retained in those tagged as adults1. The utility of VIE has since been proven with many species of shrimp2 and other crustaceans (see www.nmt.us for references). The tags are typically retained well through molting and have little effect on growth or survival.

Researchers around the world use VIE to evaluate the performance of various strains of shrimp3. By varying tag locations and colors, VIE provides the many unique codes required to identify test groups. Please contact us if we can help with your research.


Top: VIE Tags in a posterior abdominal section of a pandalid shrimp. Center: VIE is injected into the sixth abdominal segment of a juvenile white shrimp. (Photo courtesy of S. Arce.) Bottom: An NMT Air Driven Elastomer Injection System can be used to tag 500 shrimp per hour.
Using Acoustic Tags to Illustrate Salmon's Real-Time Response to New Non-Physical Barrier

Nested in an area of agriculture near the city of Lathrop, California, researchers from the California Department of Water Resources (DWR) have been busy testing a new fish barrier at the divergence of Old River from the San Joaquin River. This is a non-physical barrier designed to keep juvenile Chinook salmon and steelhead on course as they migrate to the Pacific Ocean.

Preliminary results show that the barrier is working. The researchers know the juvenile salmon are being successfully diverted because they have observed fish behavior using fish tagged and tracked with HTI's Model 795 Acoustic Tags. Each tagged fish's response to the barrier was revealed in real-time, fine-scale 3D tracks. Results from releases of the acoustically tagged salmon indicate that the barrier has increased the number of fish staying in the San Joaquin River to continue their out-migration to San Francisco Bay and the ocean.

HTI is proud to provide the advanced fisheries tools needed for California DWR and the researchers on this project, making a positive difference by helping salmon stay the course. If you'd like to learn more about acoustic tag technology or this study, visit us at HTIsonar.com.

See the Clearer Picture with proven real-time acoustic tracking