THE CENTER FOR TRANSPORTATION AND THE ENVIRONMENT
NORTH CAROLINA STATE UNIVERSITY

IMPACTS OF CULVERTS ON ANADROMOUS AND NON-ANADROMOUS FISH PASSAGE II

PREPARED BY CTE INFORMATION SERVICES
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The Center for Transportation and the Environment (CTE) is a university research institute funded by the US Department of Transportation and the North Carolina Department of Transportation, and located at The Institute for Transportation Research and Education, North Carolina State University. CTE's mission is to conduct programs of research, education, and technology transfer that mitigate the impacts of surface transportation on the environment.

This literature search is on the topic of the effects of culverts on aquatic organisms. The majority of the results focus on the effects of culverts on fish passage. Few studies mention bridges, and none of them addressed bridges versus culverts.

LIST OF DATABASES SEARCHED

Aquatic Sciences and Fisheries Abstracts
BIOSIS Previews
CAB Abstracts
NTIS
Ei Compendex
Enviroline
Environmental Bibliography
FISHLIT
Inside Conferences
Life Sciences Collection
Pollution Abstracts
TRANSPORT
TRB RIP
TRIS
Water Resources Abstracts
Zoological Record Online

Literature indexed from 2000 through December 2002.

Effects of Culverts on Aquatic Organisms

1. "Fishways: biological basis, design criteria and monitoring." *Bulletin Francais De La Peche Et De La Protection Des Milieux Aquatics.* 2002; (364 Supplement):1-207.
   Abstract: The authors outline in this paper the basic principles that can be used as a guide for planning fish passage facilities at dams or obstructions. The first part addresses the negative effect of barriers across rivers on natural fish population, contributing to the reduction of abundance and even the extinction of species. French statutory legislation on fish passage at obstructions is given. Functional features and design parameters are described for different types of fish facilities, focusing on the advantages, the limits and the cost of each type: pool type fish passes, baffle fish passes, fish locks, fish elevators, natural bypass channels, pre-barrages. Stress is laid on the importance of the location of the fishway, hydraulic conditions, and the flow discharge at the entrance. Special mention is made of fish facilities for shad, young eels and elvers. Various monitoring techniques to evaluate fish passage efficiency are presented (trapping, automatic counters, video recording, telemetry). Fish passage through culverts, rock weirs, and at estuarine obstructions is addressed. Downstream migration problems at hydroelectric power plants are discussed in the last part: evaluation of fish mortality in spillways and hydraulic turbines, design of fish screening and alternative behavioral diversionary techniques used to prevent entry of downstream migrants into intakes. Special mention is made of the most popular technology in France, i.e., surface downstream bypasses associated with conventional trash racks, focusing on their design criteria, advantages and limits.

2. Land Management Agencies. *Restoring Fish Passage through Culverts on Forest Service and BLM Lands in Oregon and Washington Could Take Decades. Report to the Congress.* 2001 Nov; PC A04/MF A01.38 Product reproduced from digital image. Order this product from NTIS by: phone at 1-800-553-NTIS (U.S. customers); (703)605-6000 (other countries); fax at (703)605-6900; and email at orders@ntis.gov. NTIS is located at 5285 Port Royal Road, Springfield, VA, 22161, USA.
   Abstract: The Bureau of Land Management, within the Department of the Interior, and the Forest Service, within the U.S. Department of Agriculture, manage over 41 million acres of federal lands in Oregon and Washington, including 122,000 miles of roads that use culverts -pipes or arches made of concrete or metal to allow water to flow from one side of the road to the other. Many of the streams that pass through these culverts are essential habitat for fish and other aquatic species. When culvert openings are too high above the streams for fish to jump into or culverts are positioned at a grade too steep for fish to ascend, they pose barriers to fish attempting to access their natural rearing and spawning habitat. Passage through culverts is particularly important to anadromous fish, such as Coho and Chinook salmon (some of which are threatened or endangered), which are spawned in freshwater streams, but must travel to the ocean to mature, then travel back to the streams to spawn. In this context, you asked us to determine (1) the number of culverts that may impede fish passage on Bureau of Land Management and Forest Service lands in Oregon and Washington, (2) the factors affecting the agencies' ability to restore passage through culverts acting as barriers to fish (hereafter referred to as barrier culverts), and (3) the results of the agencies' efforts to restore fish passage.

3. Adams, S. Reid; Hoover, Jan Jeffrey, and Killgore, K. Jack. "Swimming performance of the Topeka shiner (Notropis topeka) an endangered midwestern minnow". *The American Midland Naturalist*. 2000 Jul.
   Abstract: The Topeka shiner (Notropis topeka) is imperiled by extensive changes in stream hydrology. Responses of shiners to changes or variation in stream hydraulics, however, have not been quantified, hampering conservation efforts. We quantified swimming endurance and behavior for Topeka shiners in a laboratory swim tunnel. Sustained swimming (>200min) was observed at water velocities of 30-40cm/s. Prolonged and burst swimming (approximately 10min to less than 0.1min) was observed at water velocities of 40-75cm/s and endurance was negatively correlated with water velocity. Larger individuals (4.4-5.5cm standard length) exhibited greater sustained swimming ability than smaller individuals (3.0-4.2cm standard length). Oral grasping of wire mesh within the swim tunnel was frequently employed at moderate water velocities (35-50cm/s); this behavior may limit downstream displacement of shiners during freshets. Topeka shiners are capable of swimming speeds faster than water velocities that they typically inhabit. Fishways and culverts, therefore, may

be employed to facilitate dispersal and recolonization. Swimming endurance data are used to determine optimal size and water velocities for such structures.

4. Alaska Department of Transportation and Public Facilities. *Design Discharge for Juvenile Salmon*. 2000 Oct 1; TRB Accession Number: 802400. For more information go to: http://rip.trb.org/browse/dproject.asp?n=5325
Notes: Research in Progress
Abstract: The Alaska Department of Fish and Game uses criteria specifically for Arctic grayling to determine stream discharges that are then used to design culverts for fish passage. While this application is certainly appropriate where Arctic grayling exist, blind application of designs developed for grayling results in potentially inappropriate designs for other species. This can be both costly and inefficient. It is know that juvenile salmon use the boundary layer along the culvert walls to pass through the culvert. Unfortunately, a lack of understanding exists about the velocities of the flow near the culvert walls. Culvert inlets represent a major barrier to fish passage. Researchers will investigate methods to remove this barrier. The objectives of this research are to: (1) better understanding how inlet and culvert velocities affect swimming of specific fish species; (2) develop reasonable criteria to determine design discharges to more closely match geography and fish species; and (3) culvert installations that are neither over- nor under-designed.

5. Bolton, S.; Moss, J.; Southard, J.; Williams, G.; DeBlois, C., and Evans, N. (Washington State Transportation Center , University of Washington, 1107 NE 45th Street, Suite 535, Seattle, WA 98105- USA). *Juvenile Coho Movement Study*. 2002 Mar; WA-RD 539.1. 61.
Abstract: This pilot study was initiated to investigate movement patterns, habitat utilization, and velocity preferences for young of the year coho salmon (Oncorhynchus kisutch) during the spring in Western Washington and to examine potential factors controlling redistribution timing in the fall. Water velocity appeared to be an important factor in predicting juvenile coho (<55 mm) distribution. Mark-recapture studies indicated that upstream movement by juvenile coho through culverts is low. Timing for fall redistribution of juvenile coho from main channels into off-channel habitat was investigated in relation to water temperature, stream flow, date, and moon phase. The majority of movement by juvenile coho in the Skagit, Suiattle, and Stillaguamish River basins occurred during new and half moon phases. Movement into off-channel habitat by juvenile coho in the Hoh River basin corresponded with floods where flow increased by 2000 cubic feet per second and coincided with a new moon. Studies at Remote Site Incubators indicate that recently emerged coho fry move upstream and downstream. Upstream movement ranged between 100 and 200 meters from April through June. After June, coho fry were found over 500 meters upstream.

6. Chestnut, T.J. (Dept. of Fisheries & Oceans. North Coast Division. Habitat & Enhancement Branch, Kamloops, (British Columbia).) *Review of closed bottom stream crossing structures (culverts) on fish-bearing streams in the Kamloops Forest District, June 2001*. Canadian manuscript report of fisheries and aquatic sciences. (no. 2602). 2002; MIC10205617. Order this product from NTIS by: phone at 1-800-553-NTIS (U.S. customers); (703)605-6000 (other countries); fax at (703)605-6900; and email at orders@ntis.gov. NTIS is located at 5285 Port Royal Road, Springfield, VA, 22161, USA. NTIS Prices: PC E07/MF E01.
Abstract: This report describes & presents results of a field survey of closed-bottom culverts installed in roads in the Kamloops Forest District of British Columbia. The survey examined 31 culverts installed on fish-bearing streams to assess whether the fish & fish habitat provisions of the Fisheries Act were being achieved. At each culvert site, the likelihood of juvenile fish passage and the maintenance of fish habitat were assessed. Based on the results, the report makes recommendations for achieving fish passage, fish habitat, and sedimentation objectives as they pertain to relevant sections of the Fisheries Act.

7. Department of Fisheries and Oceans, Kamloops, BC, Canada Habitat & Enhancement Branch. "A review of closed bottom stream crossing structures (culverts) on fish-bearing streams in the Kamloops forest district, June 2000." *Can. Manuscr. Rep. Fish. Aquat. Sci./Rapp. Manuscr. Can. Sci. Halieut. Aquat.* 2002; Vol 2602:45pp.
Abstract: A review of closed bottom culverts was conducted to assess whether the fish and fish

habitat provisions of the Fisheries Act were being achieved. A total of thirty-one culverts, installed on fish-bearing streams, in the Kamloops Forest District were assessed. At each culvert site the likelihood of juvenile fish passage and the maintenance of fish habitat was assessed. Only one of the thirty-one culverts assessed met Fisheries and Oceans objectives for juvenile fish passage and maintenance of fish habitat. Two other culverts were likely to provide juvenile fish passage but failed to maintain fish habitat. Fisheries and Oceans fish passage and fish habitat protection objectives associated with closed bottom stream crossing structures are rarely being achieved in the Kamloops Forest District. It is recommended that clear span, open bottom structures, i.e., bridges, be used on all fish bearing streams.

8. Ead S.A.; Rajaratnam N., and Katopodis C. "Generalized study of hydraulics of culvert fishways." *Journal of Hydraulic Engineering-ASCE*. 2003; 128(11):1018-1022.
   Abstract: This study presents a comprehensive analysis of the experimental observations, collected previously in an extended project on culvert fishways with offset baffle, slotted weir baffle, weir baffle, spoiler baffle, Alberta fishweir, and fishbaffle systems. It has been found that a general correlation exists between the dimensionless discharge Q(*) = Q/root(gS(0)D(5)) and the relative depth of flow (y(0)/D) for each value of the relative baffle height (h/D). Furthermore, for relative baffle heights in the practical range of 0.1-0.15, longitudinal baffle spacing should be limited to a maximum of D. The velocity field in the centerplane of each of these culvert fishways was analyzed and was found to be similar with the similarity profiles having different shapes for different baffle systems. A general correlation was also found for the normalized velocity scale. Even though most of the baffle systems worked reasonably well in the range of parameters recommended, the weir and slotted weir baffle systems are simpler yet equally effective. The results presented in this paper will hopefully facilitate the design and building of successful culvert fishways.

9. Engelson, Andrew. "Tribes Fight to Clear the Roads for Salmon." *High Country News*. 2001 Jul 2; 33(13):5-6.
   Abstract: Many native populations of salmon and other migrating fish in the Pacific Northwest are under significant risk of extinction. Human mismanagement of water resources and poor engineering practices have prevented many populations of these fish from returning to their historical spawning grounds. Improperly designed culverts that guide streams under roadways in the region prevent fish access to many acres of wetlands. Culvert improvement projects are fairly popular as they are not controversial. Although the state of Washington has allocated funds for repairs of the 2400 state-owned culverts, these repairs are expected to take up to 100 years. Several Native American tribes have voiced objections to these delays. Resulting controversies and successful culvert repair projects are discussed.

10. Florida Department of Transportation. *Regional channel characteristics for maintaining natural fluvial geomorphology in Florida streams.* 2002 Oct 18. For more information go to: http://rip.trb.org/browse/dproject.asp?n=7218.
    Notes: Research in Progress
    Abstract: The traditional approach to designing highway structures over water crossings has been based on rigid, one-dimensional channel hydraulics. This approach has limitations and may affect stream stability, causing reduced meanders, costly upstream and downstream erosion problems, water quality impacts, barriers to fish passage, and altering associated wetland and floodplain function. Increasingly, engineers and environmental professionals are turning toward design procedures that minimize disruption of stable stream channels. They are beginning to design in accordance with the natural fluvial geomorphology of rivers. These principles can also be used to restore the physical, biological, and aesthetic characteristics of degraded rivers or help to maintain the natural stream properties for newly constructed projects. Nationwide, there is strong support for this natural stability approach from federal and state regulatory agencies involved in the review of highway projects. Thus, the U.S. Fish and Wildlife Service will lead a cooperative study with the FDOT to survey and classify stream channel characteristics from gaged stream locations in two of Florida's hydro-physiographic regions: the Northern Region and the Central Highlands. This empirical data will be used to develop regional curves, which characterize stream channel hydraulic geometry (i.e., width, depth, and cross-sectional area) in relationship to bankfull discharge and watershed area. These regional curves will assist in predicting bankfull discharge and channel

attribute in un-gaged stream reaches and aid in natural channel design for FDOT projects. This study will provide a model for future efforts to analyze streams statewide. By furthering our understanding of regional stream stability, improved guidelines can be developed for designing culverts and bridges to preserve natural bankfull channel dimensions and their associated floodplains and wetlands. A final element to this study is to transfer this information and technology to FDOT engineers.

11. Forest Service, USDA San Dimas Tech and Development Center 444 E Bonita Avenue San Dimas CA 91773 USA. *Fish X-ing. Water/Road Interaction Toolkit.* 2001.
Abstract: This CD-ROM is an interactive toolkit presenting audio and video segments discussing and describing culvert design and fish passage design flow. Designing for fish passage requires extensive knowledge about the needs of the fish population, all stages of life and during different seasons. Examples of good and bad culvert design are included along with diagrams and photos of several study sites.

12. Gillespie, G. (Dept. of Fisheries & Oceans, Ottawa.). "Design standards for improving fish habitat management." *Canadian manuscript report of fisheries and aquatic sciences*. 2592 ed.; 2002; SSC-FS97-4/2592. 89. Order this product from NTIS by: phone at 1-800-553-NTIS (U.S. customers); (703)605-6000 (other countries); fax at (703)605-6900; and email at orders@ntis.gov. NTIS is located at 5285 Port Royal Road, Springfield, VA, 22161, USA.
Abstract: This report describes the proceedings of a workshop that brought together scientists & managers from a variety of disciplines & agencies to develop scientific design standards for assessing the effectiveness of fish habitat mitigation & compensation measures. The report also outlines the entire process that was taken to organize the workshop. A series of keynote presentations introduced concepts about stream ecosystem research, integrated experimental design, and the use of hypothesis-of-effects models in the development of generic study designs. Breakout sessions then produced study designs for three specific development activities that are frequently submitted for review and that often require mitigation or compensation measures: Culverts, stream realignment, and shoreline stabilization. Knowledge gaps & research needs for improved management of fish habitat related to the three activities are also identified. Appendices include information about the models developed.

13. Gumpinger, C. "Interruption of the river continuum by barriers: the example of the River Pram system (upper Austria)." *Osterreichs Fischerei. Salzburg [Oesterr. Fisch.]*. 2001; 54(4):84-93.
Abstract: In the 382 km super(2) catchment area of the river Pram a mapping of all the anthropogenous migration barriers was earned out in 1999. Alltogether 374 obstacles have been counted and characterized in 19 surveyed rivers and brooks. The investigated stretch has a total length of about 160 km, with averagely 2.3 barriers every kilometer. 47 of the 374 obstacles are totally impassable for the whole aquatic fauna, for upstream and downstream migration respectively. On the other hand 29 of the cross-buildings are passable for all animals living in the river. Fish bypass systems are existing only at two locations, both of which do not function very well, as design criteria are indicating. 80.5 % of the weirs are not economically exploiter presently; nevertheless, they impede fish migrating throughout the river system. 10.2 % are diversion dams of power plants, 8.0% are road and railway culverts. The remaining 1.3 % distribute among different utilisations, for example consolidated fords. The alarming situation of the fish-stocks in the Pram River requires restoration measures immediately. The drawdown of unused dams and the installation of fish bypass systems at sites, actually used, has to be forced in the very near future.

14. Johnson Peter N.; Goetz Frederick A., and Ploskey Gene R. "Evaluation of strobe lights for vertically displacing juvenile salmon near a filling culvert intake at the Hiram M. Chittenden Locks, Seattle, Washington." *American Fisheries Society Symposium*. 2001; (26):13-25. Technical report for the U.S. Army Corps of Engineers, Seattle District, Seattle, Washington, USA

15. Kosicki, A. J. and Davis, S. R. "Consideration of stream morphology in culvert and bridge design." *Transportation Research Record.* 2001; 1743:57-59.
Abstract: In 1992, the Maryland State Highway Administration (SHA) initiated new design procedures to limit the impact of constructing culverts and bridges in streams. Elements of the new

procedures included studies to define the characteristics of Maryland streams regarding bankfull widths, depths, and discharges; training of engineers in basic and advanced courses in stream morphology presented by David Rosgen; and updating the SHA culvert design manual to address consideration of stream morphology, fish passage, and other environmental features. The revised design procedure emphasizes the need to identify all appropriate objectives at the start of the design process so the best overall solution can be determined. The design concept is to construct a stream system that is stable and that neither scours nor aggrades. Elements of this approach include maintaining the consistency of dimension, pattern, and profile of the stream with particular attention given to maintaining bankfull width and width/depth ratio. Flood plain culverts are provided where appropriate to relieve the hydraulic load on the main channel culvert to limit downstream scour and erosion. Several culverts recently were constructed by using the stream morphology concepts discussed. These initial efforts have been quite successful and indicate that it is practical to consider stream morphology concepts in culvert design.

16. Larinier, M. "Fish passage through culverts, rock weirs and estuarine obstructions." *Bulletin Francais De La Peche Et De La Protection Des Milieux Aquatics.* 2002; (364 (Supplement)):119-134.

17. Oregon Department of Transportation. *Fish Passage through Culverts.* 1999 Jul 1; TRB Accession Number: 821372. For more information go to: http://rip.trb.org/browse/dproject.asp?n=6200
Notes: Research in Progress
Abstract: As part of the Oregon Plan for Salmon and Watersheds, highway culverts that are barriers to fish passage must be retrofitted or replaced in order to pass fish. It is unknown whether the culverts that have been retrofitted or constructed are effective. This project will evaluate the extent of fish movement and test various types and placements baffles to develop recommendations for the design of culverts for maximum fish passage.

18. Papanicolaou, Athanasios N. and Talebbeydokhti, Nasser. "Discussion of "Turbulent Open-Channel Flow in Circular Corrugated Culverts " by S. A. Ead, N. Rajaratnam, C. Katopodis, and F. Ade." *Journal of Hydraulic Engineering.* 2002 May; 128(5):547-9.
Abstract: Two discussions of the October 2000 paper by Ead et al. on turbulent open-channel flow in circular corrugated culverts are presented. In the first, Papanicolaou and Talebbeydokhti contend that fish suitability should be related to more detailed flow structures and 3-D analysis should be considered. In the second, Prasad and Manson contend that the authors' model for delineating the low velocity regions is based on 2 equations that actually represent the regions corresponding to the log law and outerlaw, respectively. In reply, Ead et al., point out that when the velocity profiles are available, their approach is better than the resistance equation method.

19. Paul, Michael J. and Judy L. Meyer. "Streams in the urban landscape." *Annual Review of Ecology and Systematics*. 2001.
Abstract: The world's population is concentrated in urban areas. This change in demography has brought landscape transformations that have a number of documented effects on stream ecosystems. The most consistent and pervasive effect is an increase in impervious surface cover within urban catchments, which alters the hydrology and geomorphology of streams. This results in predictable changes in stream habitat. In addition to imperviousness, runoff from urbanized surfaces, as well as municipal and industrial discharges, result in increased loading of nutrients, metals, pesticides, and other contaminants to streams. These changes result in consistent declines in the richness of algal, invertebrate, and fish communities in urban streams. Although understudied in urban streams, ecosystem processes are also affected by urbanization. Urban streams represent opportunities for ecologists interested in studying disturbance and contributing to more effective landscape management.

20. Pearson, W. *International Conference on Ecology & Transportation.*; Keystone, CO (USA). 2001.
Abstract: The Washington State Department of Transportation (WSDOT) has identified the need to evaluate all aspects of Department programs that may affect Pacific salmon and their habitats under the Endangered Species Act, and to correct situations where adverse effects exist. The great deal of research and engineering conducted to date has resulted in enhanced passage of returning adult

salmon. However, the movement of juvenile salmonid both up and downstream throughout the year is now recognized as substantial, and the need for them to pass this life stage has made the problem even larger in scope. Tens of thousands of culverts exist in the state of Washington alone, and many are judged as blocking juvenile salmonids from thousands of miles of habitat. Determining appropriate hydraulic and fish passage designs for new and retrofitted culverts before installation has both substantial cost and environmental implications. The optimal conditions for culvert passage by juvenile salmonids are not well understood, and thus are a key area upon which WSDOT has decided to focus its research efforts. In partnership with WSDOT, the Pacific Northwest National Laboratory has undertaken a phased program to address the hydraulic and behavioral issues associated with juvenile salmonid fish passage through culvert systems. This program addresses the testing and assessment of culvert designs, along with associated measurements of hydraulic conditions and fish behavior occurring in full-scale physical models of culvert systems deployed in an experimental test bed. Experiments in the testing apparatus will measure the hydraulic conditions (velocity, turbulence, and water depth) associated with various culvert designs under various slopes and flow regimes and then relate these measures to repeatable, quantitative measures of fish passage success. The long-term intent is to develop the test bed into a regional and national-level capability that can be used by other agencies that need to develop appropriate culvert designs to enhance the passage juvenile fish.

21. Poulakis Gregg R.; Shenker Jonathan M., and Taylor D. Scott. "Habitat use by fishes after tidal reconnection of an impounded estuarine wetland in the Indian River Lagoon, Florida (USA)." *Wetlands Ecology and Management.* 2002 Feb; 10(1):51-69.
Abstract: Most of the wetlands located along the Indian River Lagoon (IRL) in east-central Florida (USA) have been impounded since the 1950's and 1960's to reduce mosquito reproduction. Impounded marsh (i.e., impoundment) dikes physically separate the wetlands from the estuary to allow artificial flooding of the impoundments during the mosquito-breeding period (May to October). Presently, Rotational Impoundment Management (RIM) is the preferred impoundment management technique in the IRL. Impoundments maintained under RIM have culverts installed through the dikes, which are kept closed during the mosquito-breeding season (to control mosquitoes) and are allowed to remain open for the remainder of the year (to allow tidal flow). A 24.3 ha impoundment 8 km north of Sebastian Inlet that had been isolated from the IRL for over 39 years was studied for 12 months to determine habitat use by fishes after tidal reconnection and the implementation of RIM. Fish sampling was conducted with a seine in the perimeter ditch and with clover and minnow traps in the upper marsh and tidal creek areas of the impoundment. Water level, impoundment bottom topography, and the seasonal nursery function of the impoundment were factors that contributed to observed patterns of fish habitat use during the study. Within the first 15 weeks of perimeter ditch sampling, an increase from 9 to 40 species was observed. Transient species used the perimeter ditch almost exclusively and entered the impoundment primarily during the spring open period. Juvenile Pogonias cromis (Linnaeus), Elops saurus Linnaeus, Centropomus undecimalis (Bloch), and Megalops atlanticus Valenciennes were the most abundant recreationally important species, respectively. Habitat use by the most abundant resident species (Gambusia holbrooki Girard, Poecilia latipinna (Lesueur), Cyprinodon variegatus Lacepede, and Fundulus confluentus Goode & Bean) was influenced primarily by water level fluctuations. Resident species used the upper marsh and tidal creek habitats during summer flooded periods and the cyprinodontids left the interior surface of the impoundment last as water levels decreased. This study is the first to document the recovery of fish populations in a reconnected impoundment north of Sebastian Inlet using both active and passive sampling techniques.

22. Raposa, Kenneth B. *Nekton utilization of tidally restricted, restoring, and reference New England salt marshes.*: Ph.D. Dissertation, Graduate School of Oceangr., Univ. of Rhode Island, Kingston, RI.; 2000.
Abstract: Salt marshes provide important habitat for estuarine nekton (fishes and decapod crustaceans), yet tidal flow to New England marshes is often restricted due to roads, causeways, and culverts . The objectives of this study were to determine the most effective method for sampling salt marsh nekton and use this method to quantify nekton use of tidally restricted, restoring, and reference New England salt marshes. Throw traps are often used for sampling nekton in specific salt

marsh microhabitats. When compared to seines, another common sampling gear, throw traps were more efficient, quantitative, and easier to use. Throw traps were used to sample multiple habitats within a tidally restricted and unrestricted salt marsh at Hatches Harbor, Provincetown, MA, over a one-year period. Nekton use of tidal creeks and the salt marsh surface was similar in both marshes, but utilization of pools differed substantially on either side of the tide-restricting dike. In the same Cape Cod marsh, restricted salt marsh pools provided overwintering habitat for the mummichog, Fundulus heteroclitus. Unrestricted pools were not utilized by this species during the winter. Nekton responded rapidly to restoration of the tidally restricted Galilee salt marsh in Narragansett, RI. After two years of tidal restoration, densities of F. heteroclitus, Fundulus majalis, and Callinectes sapidus were higher than under restricted conditions. Species richness and densities of Lucania parva and Cyprinodon variegatus decreased after restoration. Changes were continuing after two years and studies of longer duration are needed to assess the long-term responses by nekton to restoration. In a meta-analysis, nekton use was related to the degree of tidal restriction at three sites. Nekton density and richness were similar between the restricted and unrestricted sides of the two moderately restricted marshes, but both were lower on the restricted side of the severely restricted marsh. Density and richness each increased by approximately 150% with restoration of the severely restricted marsh; smaller changes were observed with restoration of the other two marshes. These patterns suggest that severe tidal restrictions result in degraded nekton communities and the most dramatic shifts towards more natural assemblages will occur with restoration of severely restricted salt marshes.

23. Ribbens, J. “Overview of the forestry-aquatic biodiversity issue and future trends (UK).” *Kungl. Skogs- Och Lantbruksakademiens Tidskrift.* 2002; 141(7):69-75.
Notes: Also published in: Sustainable forestry to protect water quality and aquatic biodiversity. Conference in Orby, Sweden, 13-15 March 2001
Abstract: This paper discusses the three main areas in which forestry may influence the aquatic environment, and thus its biodiversity, these are: water quality, physical and hydrological affects. The West Galloway Fisheries Trust in Scotland believes that acidification is the main cause of the decline of salmon stocks while in Dumfries-shire a serious bloom of cyanobacteria was linked to forest fertilizer application, and on the River Cree elevated P levels were blamed on considerable increases in macrophyte growth over a number of years. In addition, the effect of geological sedimentation to aquatic species is also discussed. Excessive shading of afforested watercourses, habitat alteration and culvert design (physical) and ploughing and drainage operations caused by afforestation (hydrological) are discussed. Future perspectives regarding the impacts of forest plantations (Picea sitchensis) on aquatic biodiversity are briefly discussed.

24. Roman Charles T.; Raposa Kenneth B.; Adamowicz Susan C.; James-Pirri Mary-Jane, and Catena John G. “Quantifying vegetation and nekton response to tidal restoration of a New England salt marsh.” *Restoration Ecology*. 2002 Sep; 10(3):450-460.
Abstract: Tidal flow to salt marshes throughout the northeastern United States is often restricted by roads, dikes, impoundments, and inadequately sized culverts or bridge openings, resulting in altered ecological structure and function. In this study we evaluated the response of vegetation and nekton (fishes and decapod crustaceans) to restoration of full tidal flow to a portion of the Sachuest Point salt marsh, Middletown, Rhode Island. A before, after, control, impact study design was used, including evaluations of the tide-restricted marsh, the same marsh after reintroduction of tidal flow (i.e., tide-restored marsh), and an unrestricted control marsh. Before tidal restoration vegetation of the 3.7-ha tide-restricted marsh was dominated by Phragmites australis and was significantly different from the adjacent 6.3-ha Spartina-dominated unrestricted control marsh (analysis of similarities randomization test, $p<0.001$). After one growing season vegetation of the tide-restored marsh had changed from its pre-restoration condition (analysis of similarities randomization test, $p<0.005$). Although not similar to the unrestricted control marsh, Spartina patens and S. alterniflora abundance increased and abundance and height of Phragmites significantly declined, suggesting a convergence toward typical New England salt marsh vegetation. Before restoration shallow water habitat (creeks and pools) of the unrestricted control marsh supported a greater density of nekton compared with the tide-restricted marsh (analysis of variance, $p<0.001$), but after one season of restored tidal flow nekton density was equivalent. A similar trend was documented for nekton

species richness. Nekton density and species richness from marsh surface samples were similar between the tide-restored marsh and unrestricted control marsh. Fundulus heteroclitus and Palaemonetes pugio were the numerically dominant fish and decapod species in all sampled habitats. This study provides an example of a quantitative approach for assessing the response of vegetation and nekton to tidal restoration.

25. Roni, P.; Beechie, T.J.; Bilby, R.E.; Leonetti, F.E.; Pollock, M.M., and Pess, G.R. "A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific northwest watersheds." *North American Journal of Fisheries Management*. 2002; 22(1):1-20.
Abstract: Millions of dollars are spent annually on watershed restoration and stream habitat improvement in the U.S. Pacific Northwest in an effort to increase fish populations. It is generally accepted that watershed restoration should focus on restoring natural processes that create and maintain habitat rather than manipulating in-stream habitats. However, most process-based restoration is site-specific, that is, conducted on a short stream reach. To synthesize site-specific techniques into a process-based watershed restoration strategy, we reviewed the effectiveness of various restoration techniques at improving fish habitat and developed a hierarchical strategy for prioritizing them. The hierarchical strategy we present is based on three elements: (1) principles of watershed processes, (2) protecting existing high-quality habitats, and (3) current knowledge of the effectiveness of specific techniques. Initially, efforts should focus on protecting areas with intact processes and high-quality habitat. Following a watershed assessment, we recommend that restoration focus on reconnecting isolated high-quality fish habitats, such as in-stream or off-channel habitats made inaccessible by culverts or other artificial obstructions. Once the connectivity of habitats within a basin has been restored, efforts should focus on restoring hydrologic, geologic (sediment delivery and routing), and riparian processes through road decommissioning and maintenance, exclusion of livestock, and restoration of riparian areas. In-stream habitat enhancement (e.g., additions of wood, boulders, or nutrients) should be employed after restoring natural processes or where short-term improvements in habitat are needed (e.g., habitat for endangered species). Finally, existing research and monitoring is inadequate for all the techniques we reviewed, and additional, comprehensive physical and biological evaluations of most watershed restoration methods are needed.

26. Winston Matthew, R. "Distribution and abundance of the goldstripe darter (Etheostoma parvipinne) in Missouri." *Southwestern Naturalist*. 2002 Jun; 47(2):187-194.
Abstract: From 1997 to 1999, I surveyed for the goldstripe darter (Etheostoma parvipinne), an endangered species in Missouri, to describe its distribution and abundance at 3 scales. At the largest scale, I sampled all small, flowing streams on Crowley's Ridge and the Ozark fall-line in southeastern Missouri. I identified 5 spatially distinct communities by their unique species: the goldstripe darter community, the gizzard shad (Dorosoma cepedianum) community, the orangethroat darter (Etheostoma spectabile)-central stoneroller (Campostoma anomalum) community, the banded pygmy sunfish (Elassoma zonatum) community, and the blacktail shiner (Cyprinella venusta)-blunt-nose minnow (Pimephales notatus) community. Despite exhaustive sampling, I did not find goldstripe darters at Romine Spring, the 1 historic locality on the Ozark fall-line, nor anywhere else on the Ozark fall-line. I did find them in the 3 historically sampled streams in the Holly Ridge area on Crowley's Ridge, plus 3 previously unsampled streams in the immediate vicinity. At an intermediate scale, I failed to capture goldstripe darters in 12 of 18 streams in the Holly Ridge area. The streams without goldstripe darters were associated with human modifications such as gravel mining, small impoundments, household effluent, and pipe culverts. At the smallest scale, I collected 106 goldstripe darters at 15 sites on 6 streams. I estimated total length of habitat for goldstripe darters in Missouri to be 5.7 km of stream. I found that there were more goldstripe darters in a larger area than previously thought; however, goldstripe darters were still one of the rarest fish species in Missouri.