

Donald W. Zaroban, Idaho Division of Environmental Quality, 1410 N. Hilton Street, Boise, Idaho 83706

Michael P. Mulvey, Oregon Department of Environmental Quality, 1712 SW 11th, Portland, Oregon 97201

Terry R. Maret, U.S. Geological Survey, 230 Collins Road, Boise, Idaho 83702

Robert M. Hughes, Dynamac Corporation, 200 SW 35th Street, Corvallis, Oregon 97333

and

Glenn D. Merritt, Washington Department of Ecology, 300 Desmond Drive, P.O. Box 300, Olympia, Washington 98504

Classification of Species Attributes for Pacific Northwest Freshwater Fishes

Abstract

Fish assemblages integrate physical and chemical habitat conditions and are used to evaluate the condition of water resources in the Pacific Northwest. To facilitate such evaluations, we classified each of the 132 freshwater fish species known to occur in the Pacific Northwest (Idaho, Oregon, Washington) by its origin, overall pollution tolerance, adult habitat, adult feeding, and water temperature preference. Recommendations from regional fishery experts, published literature, and the aggregate experience of the authors were used to classify species. The attribute classifications were responsive to human disturbance of aquatic habitats when applied to fish assemblages sampled from throughout the region. Our attribute classification of fish species promotes use of fish assemblages to evaluate water resource conditions regionally and fosters greater acceptance of biological measures of water resource quality.

Introduction

The use of fish assemblages for assessing water quality is in response to mandates of the Clean Water Act (Water Environment Federation 1997) requiring States to restore and maintain biological integrity. The U.S. Environmental Protection Agency (USEPA) recommends that States do this by developing narrative and numeric biological criteria (USEPA 1990, Gibson 1996). To date, northwestern states have developed only narrative biological criteria. For example, in the vast majority of streams in the Pacific Northwest, state statutes call for protection of "beneficial uses" of water, such as salmonid spawning, cold water biota, or no detrimental changes in biological communities (Idaho Department of Health and Welfare 1993, Oregon Secretary of State 1998, Washington Administrative Code 1997). Previously, however, not all freshwater fish species of the Pacific Northwest were classified by metrics commonly found useful for quantitatively evaluating attainment of beneficial uses and biological integrity (e.g., as described by Yoder and Rankin 1998). In addition, there were inconsistent metric classifications for the same species in drain-

ages shared by multiple states, hindering interstate assessments and regional collaboration. Because of high public and economic interest in these resources, USEPA support for quantitative biocriteria, and the interstate ranges of many of the fish species, there is clearly a need to develop more effective assessment tools to evaluate Pacific Northwest water bodies using their fish assemblages.

Fish assemblages have proven useful to describe and assess biological condition of specific waters in the Pacific Northwest (Hughes and Gammon 1987, Fisher 1989, Friesen and Ward 1996, Maret et al. 1997, Hughes et al. 1998). This is because fish are integrators of water resource conditions, and information about their structure and function may be used to assess these conditions (Li et al. 1987). Specifically, fish assemblages are useful in evaluating biotic integrity, defined as "the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition comparable to that of the natural habitats within a region" (Frey 1977, Karr and Dudley 1981).

According to Karr et al. (1986), the capability of fish assemblages to accurately reflect environmental quality lies in their integration of five major factors that determine the condition of a water resource. These factors include hydrology, water quality, biological interactions, physical habitat structure, and energy resources. Because fish assemblages integrate these characteristics of their environments, they are useful for evaluating the effects of human activities on particular sites or across entire regions (Karr 1981).

Assessments of biotic integrity have typically included classes of attributes or metrics describing species richness, species composition, trophic structure, fish abundance, and fish condition (Miller et al. 1988, Hughes and Noss 1992, Simon and Lyons 1995, Simon 1998). Each metric reflects the quality of a different aspect of the fish assemblage that responds in a different manner to aquatic ecosystem stressors. The index of biotic integrity (IBI), first formulated by Karr (1981), combines these metrics into an index of water resource condition. Recent applications summarized in Simon (1998) have shown that the IBI concept is widely adaptable, but metrics must be modified, deleted, or added to reflect regional differences in fish distribution and assemblage structure.

Fish assemblage attributes such as origin (native or alien), overall tolerance to pollution, habitat and temperature preferences, and trophic structure have been found responsive to human disturbance (Hughes and Gammon 1987, Simon and Lyons 1995, Karr and Chu 1999) and useful in evaluating biotic integrity (Miller et al. 1988, Chandler et al. 1993, Yoder and Rankin 1998). Human disturbance can increase taxa richness in cold water streams (Lyons et al. 1996, Maret 1997) as cool and warm water species invade where water temperature regimes have been altered by such activities as agriculture, logging and urban development. Highly altered aquatic habitats are particularly vulnerable to invasion by alien (introduced, non-native, exotic) species (Moyle and Nichols 1973, Holden and Stalnaker 1975, Leidy and Fiedler 1985, Moyle 1986, Hughes and Gammon 1987). The percentage of individuals that are alien reflects biological pollution, which has usually been less reversible than chemical and physical disturbance (Hughes et al. 1998); it was the second most commonly cited cause of fish species extinction after physical habitat change (Miller et al. 1988). Likewise, the proportion of

tolerant, warmwater adapted individuals tends to increase as a result of habitat degradation and/or water quality degradation of coldwater streams (Lyons et al. 1996, Maret 1997).

Changes in the biotic integrity of streams can be expressed by the trophic composition of the fish assemblage. For example, organic pollution entering streams alters food sources, resulting in changes to the trophic structure of fish assemblages (Karr et al. 1986). These enriched conditions favor tolerant omnivorous individuals that adapt easily to disrupted food sources. The proportion of omnivores (primarily common carp and some catostomid species) increases with human disturbance in western rivers (Hughes and Gammon 1987, Maret 1997).

The proportion of individuals occupying a particular habitat type is useful for evaluating the effects of altered physical habitat (Karr et al. 1986). For example, the number of native "hider" species, which are commonly found in substrate interstices or among macrophytes or organic debris, tends to decline with habitat disturbance (Hughes et al. 1998). The number of small benthic dwelling species (sculpins and dace), large benthic species (suckers), or both have been recommended as indicators of biotic integrity (Karr et al. 1986, Hughes and Gammon 1987). Other benthic species metrics such as number of cottid age classes may provide useful information as well.

Although it is not our intent to develop a multimetric index in this paper, an essential step in the development process is publication of metric classifications for the fish species in this region for widespread review and comment. This type of fish species information previously has been inconsistent and separately located. Our goal is to provide a single information source so scientists can more effectively use fish assemblage information in their assessments of the condition of surface waters. We offer consistent species classifications that are applicable to surveys across the Pacific Northwest, large portions of its states, or at site and watershed scales.

Methods

We compiled a list of freshwater fish species known to occur in Idaho, Oregon, and Washington from species descriptions by Bond (1963, 1973, 1994), Scott and Crossman (1973), Moyle (1976), Wydoski and Whitney (1979), Lee et al. (1980),

Simpson and Wallace (1982), McPhail and Lindsey (1986), Minckley et al. (1986), Sigler and Sigler (1987, 1996), Robins et al. (1991), Behnke (1992), Moseley and Groves (1992), Mongillo (1993), Mongillo and Hallock (1995), and the Washington Department of Natural Resources (1997). A number of estuarine and brackish water species were also listed if commonly found in freshwater fish collections. We used the scientific and common names of species as listed by Robins et al. (1991).

A set of attributes believed responsive to or indicative of human disturbance was selected. Additionally, these attributes were assumed to reflect either biological processes or criteria contained in state water quality standards. We based our species classifications on the accounts from the authors cited in the preceding paragraph, plus Carlander (1969, 1977), National Academy of Sciences and National Academy of Engineering (1972), Minckley (1973), Pflieger (1975), Coutant (1977), Hokanson (1977), Trautman (1981), Becker (1983), Smith (1985), Woodling (1985), Courtenay et al. (1986), Ohio Environmental Protection Agency (1987), Bond et al. (1988), Robison and Buchanan (1988), Page and Burr (1991), Rinne and Minckley (1991), LaRivers (1994), Baxter and Stone (1995), and our aggregate experience. The personal observations of the authors and reviewers were used in instances where sources disagreed on a particular species classification or if no information was available.

Each Pacific Northwest freshwater fish species was classified as either native or alien on a state by state basis. We defined native species as those believed to have been present in the state prior to European settlement. Alien species were those that are introduced through human intervention in a given state or in the region.

We classified the overall pollution tolerance of species as sensitive (S), tolerant (T), or intermediate (I). Sensitive species were those that tend to either disappear or are greatly reduced in association with human disturbances (Karr et al. 1986). These species are typically intolerant of siltation, turbidity, increased water temperature, and lowered dissolved oxygen and tend to be replaced by intermediate and tolerant species. We defined tolerant species as fishes that tend to increase in abundance with human disturbances, particularly in relation to increased siltation, turbidity, and water temperature, and lowered con-

centrations of dissolved oxygen. Species that tend to be neither tolerant nor sensitive to increased siltation, turbidity, temperature, or lowered dissolved oxygen, but are typically replaced by tolerant species in those situations, were considered intermediate. Species classified as having intermediate tolerance are unlikely to be useful indicators in highly disturbed waters with very poor water quality. However, where the disturbance is limited to moderate degradation of high quality waters or where it is mostly an alteration of physical habitat structure, these species are expected to be useful indicators.

Adult habitat attributes were classified as benthic, water column, or hider to help detect human induced changes to habitat structure (Oberdorff and Hughes 1992, Simon and Lyons 1995, Hughes et al. 1998). Benthic species were those that typically occur on or near the bottom of lakes or streams. Water column species were fish that tend to occur throughout the various depths or near the water surface. Fish species classified as hidiers were commonly found buried in sediments or hidden in dense cover such as aquatic macrophytes, undercut banks, crevices, or overhanging vegetation.

Changes in food resources can cause shifts in the trophic structure of fish assemblages (Karr et al. 1986). To detect effects of human disturbances on the aquatic food web, we classified Pacific Northwest fishes into six feeding groups based on literature descriptions of primary diet and distinguishing anatomy. Our classifications of adult feeding attributes also include the freshwater juveniles of anadromous or non-feeding adult species. We defined feeding groups as filterer, herbivore, omnivore, invertivore, piscivore/invertivore, and piscivore. Filterers ingest fine particles from the water column and typically have modified mouth parts or gill rakers for filtering. Herbivores feed primarily on aquatic vegetation, typically have mouth parts modified for scraping, and have an elongated gut to aid in digestion of cell walls. Species classified as omnivores primarily eat plant and animal material (at least 25% of each). Invertivores consume invertebrate prey, primarily insects. Piscivore/invertivores eat considerable proportions of fish and invertebrates and typically have an enlarged mouth relative to non-piscivorous species. Piscivores primarily consume fish and usually have numerous teeth, large eyes, and large mouths.

To assess the effects of human induced changes on the thermal regime of water resources, we classified fish species as cold water, cool water, or warm water (Hokanson 1977, Eaton et al. 1995). We determined the temperature classifications from species ranges, spawning seasons, spawning temperatures, and physiological optima (Hokanson 1977).

Results and Discussion

We provide classifications of origin, overall pollution tolerance, adult habitat, adult feeding, and water temperature for 132 species of freshwater fish known to occur in the Pacific Northwest (Table 1). Of these species, 78 occur in Idaho, 104 in Oregon, 85 in Washington, and 53 species are common to all three states. There are 2, 9, and 1 fish species endemic to the three respective states.

To demonstrate ichthyogeographic patterns in classifications of fish species attributes, we provide state and regional examples (Figure 1). Fifty of the 132 freshwater fish species in the Pacific Northwest are aliens. The numbers of species that are alien to Idaho, Oregon, and Washington are 38, 38, and 36, respectively. Regionally, 37 species are warm-water fish, but 33 of these are aliens. In Idaho, 24 species are classified as warm water (all of these are aliens), while 29 warm water species (26 alien) occur in Oregon, and 20 (19 alien) in Washington. Tolerant species show similar numbers. Regionally, 46 freshwater species are tolerant, 32 of which are aliens. In Idaho, Oregon, and Washington, 30, 37, and 24 of the species are tolerant, respectively. Most of these tolerant species (24, 26, and 18, respectively) are aliens. These comparisons show that, on regional and state scales, the majority of warm water and tolerant fish species are alien and have the potential to significantly disturb fish assemblages in stressed habitats.

To illustrate the use of fish attribute classifications in site evaluations, we examined three markedly different metrics (% alien individuals, % omnivorous individuals, and % sensitive species) from two wadeable and two large river sites in each state (Table 2). Although raw species composition data are useful for fish biologists, it is easier for managers and the public to compare such a set of metric scores. The first site in each pair represents a physically and/or chemically disturbed habitat; these support relatively more

aliens, more omnivores, fewer sensitive species, or perhaps all three. The second site in each pair represents less disturbed habitat. These disturbance rankings were made independently of the fish metric percentages. Only reticulate sculpin was collected at the Bone River, Washington site. Since the reticulate sculpin is not classified as alien, omnivorous, or sensitive, it renders these metrics meaningless at this site. Useful metrics may be combined into indices of fish assemblage integrity once reference (minimally impacted or historical) conditions are determined against which metric scores are judged.

To be effective and credible in using fish assemblages to assess the integrity of water resources regionally, biologists must agree on the attribute classifications of the fish species present. These attribute classifications promote interagency and interstate comparisons of fish assemblage integrity at least across our five agencies and three states. For example, since all six large river sites in Table 2 are in similar-sized Columbia River tributaries, their fish assemblages can be compared or ranked by degree of impact from low (Snake River at Flag), to intermediate (Willamette River at McKenzie, Yakima River at Umtanum), to high (all three disturbed river sites).

Users of these classifications are cautioned that this is a work in progress and at least seven limitations need to be considered.

(1) Much of the information contained in Table 1 was obtained from "fishes of" books as opposed to the primary literature. Such information therefore reflects subjective opinions of the authors as well as our own.

(2) There are substantial biogeographic limitations in applying our classifications. For example, a species that is generally tolerant in the Willamette Valley ecoregion is unlikely to occur in the high elevation Willamette River tributaries of the Coast Range and Cascades. Sites in such places will lack tolerant species as classified here, so intermediate species may be used for assessing disturbance. Similar modifications will apply elsewhere in mountainous regions. Adaptations of local fish stocks or subspecies (e.g. redband trout, Lahonton cutthroat trout) to elevated temperature may require modification of these classifications to increase metric sensitivity. Also, rainbow trout planted in streams inhabited by west-slope cutthroat trout must be considered aliens

TABLE 1. Classifications of freshwater fish species known to occur in Idaho, Oregon, or Washington (families listed alphabetically).

Family/Species	Common Name	Origin by State	Overall Tolerance ³	Adult Freshwater Habitat	Adult Freshwater Temperature	Adult Freshwater Feeding
<u>Acipenseridae</u>						
<i>Acipenser medirostris</i>	green sturgeon	OR, WA	S	benthic	cold	piscivore
<i>Acipenser transmontanus</i>	white sturgeon	ID, OR, WA	I	benthic	cold	invert/piscivore
<u>Catostomidae</u>						
<i>Catostomus ardens</i>	Utah sucker	ID	T	benthic	cool	omnivore
<i>Catostomus catostomus</i>	longnose sucker	ID, WA	I	benthic	cold	invertivore
<i>Catostomus columbianus</i>	bridgelip sucker	ID, OR, WA	T	benthic	cool	herbivore
<i>Catostomus discobolus</i>	bluehead sucker	ID	I	benthic	cool	herbivore
<i>Catostomus macrocheilus</i>	largescale sucker	ID, OR, WA	T	benthic	cool	omnivore
<i>Catostomus occidentalis</i>	Sacramento sucker	OR	T	benthic	cool	omnivore
<i>Catostomus platyrhynchus</i>	mountain sucker	ID, OR, WA	I	benthic	cool	herbivore
<i>Catostomus rrimiculus</i>	Klamath smallscale sucker	OR	I	benthic	cool	omnivore
<i>Catostomus snyderi</i>	Klamath largescale sucker	OR	I	benthic	cool	omnivore
<i>Catostomus tahoensis</i>	Tahoe sucker	OR	I	benthic	cool	omnivore
<i>Catostomus warnerensis</i>	Warner sucker	OR	I	benthic	cool	omnivore
<i>Chasmistes brevirostris</i>	shortnose sucker	OR	S	benthic	cool	invert/planktivore
<i>Deltistes luxatus</i>	Lost River sucker	OR	I	benthic	cool	invertivore
<u>Centrarchidae</u>						
<i>Ambloplites rupestris</i>	rock bass	A	I	water column	warm	invert/piscivore
<i>Archoplites interruptus</i>	Sacramento perch	A	T	water column	warm	invert/piscivore
<i>Lepomis cyanellus</i>	green sunfish	A	T	water column	warm	invert/piscivore
<i>Lepomis gibbosus</i>	pumpkinseed	A	T	water column	cool	invert/piscivore
<i>Lepomis gulosus</i>	warmouth	A	T	water column	warm	invert/piscivore
<i>Lepomis macrochirus</i>	bluegill	A	T	water column	warm	invert/piscivore
<i>Lepomis microlophus</i>	redeer sunfish	A	T	water column	warm	invert/piscivore
<i>Micropterus dolomieu</i>	smallmouth bass	A	I	water column	cool	piscivore
<i>Micropterus salmoides</i>	largemouth bass	A	T	water column	warm	piscivore
<i>Pomoxis annularis</i>	white crappie	A	T	water column	warm	invert/piscivore
<i>Pomoxis nigromaculatus</i>	black crappie	A	T	water column	warm	invert/piscivore
<u>Cichlidae</u>						
<i>Cichlasoma nigrofasciatum</i>	convict cichlid	A	T	water column	warm	invert/piscivore
<i>Tilapia aurea</i>	blue tilapia	A	T	water column	warm	invert/piscivore
<i>Tilapia mossambica</i>	Mozambique tilapia	A	T	water column	warm	invert/piscivore
<u>Clupeidae</u>						
<i>Alosa sapidissima</i>	American shad	A	I	water column	cool	invertivore
<u>Cobitidae</u>						
<i>Misgurnus anquillicaudatus</i>	oriental weatherfish	A	T	benthic	warm	omnivore
<u>Cottidae</u>						
<i>Cottus aleuticus</i>	coastrange sculpin	OR, WA	I	benthic	cool	invertivore
<i>Cottus asper</i>	prickly sculpin	OR, WA	I	benthic	cool	invert/piscivore
<i>Cottus bairdi</i>	mottled sculpin	ID, OR, WA	I	benthic	cool	invertivore
<i>Cottus beldingi</i>	Paiute sculpin	ID, OR, WA	I	benthic	cold	invertivore
<i>Cottus cognatus</i>	slimy sculpin	ID, WA	I	benthic	cold	invertivore
<i>Cottus confusus</i>	shorthead sculpin	ID, OR, WA	S	benthic	cold	invertivore

TABLE 1. Classifications of freshwater fish species known to occur in Idaho, Oregon, or Washington (families listed alphabetically).

Family/Species	Common Name	Origin by State ¹	Overall Tolerance ²	Adult Freshwater Habitat	Adult Freshwater Temperature	Adult Freshwater Feeding
<i>Cottus extensus</i>	Bear Lake sculpin	ID	I	benthic	cold	invertivore
<i>Cottus greenei</i>	Shoshone sculpin	ID	S	benthic	cold	invertivore
<i>Cottus gulosus</i>	rifle sculpin	OR, WA	I	benthic	cool	invertivore
<i>Cottus klamathensis</i>	marbled sculpin	OR	I	benthic	cool	invertivore
<i>Cottus leiopomus</i>	Wood River sculpin	ID	S	benthic	cold	invertivore
<i>Cottus marginatus</i>	marginated sculpin	OR, WA	I	benthic	cool	invertivore
<i>Cottus perplexus</i>	reticulate sculpin	OR, WA	I	benthic	cool	invertivore
<i>Cottus pitensis</i>	pit sculpin	OR	T	benthic	cool	invertivore
<i>Cottus princeps</i>	Klamath Lake sculpin	OR	I	benthic	cold	invertivore
<i>Cottus rhotheus</i>	torrent sculpin	ID, OR, WA	I	benthic	cold	invert/piscivore
<i>Cottus tenuis</i>	slender sculpin	OR	I	benthic	cool	invertivore
<i>Leptocottus armatus</i>	Pacific staghorn sculpin	OR, WA	I	benthic	cold	invertivore
<u>Cyprinidae</u>						
<i>Acrossocheilus alutaceus</i>	chiselmouth	ID, OR, WA	I	benthic	cool	herbivore
<i>Carassius auratus</i>	goldfish	A	T	benthic	warm	omnivore
<i>Catostomus commersoni</i>	lake chub	ID, WA	I	water column	cold	invertivore
<i>Ctenopharyngodon idella</i>	grass carp	A	T	water column	warm	herbivore
<i>Cyprinus carpio</i>	common carp	A	T	benthic	warm	omnivore
<i>Gila alvordensis</i>	Alvord chub	OR	T	water column	warm	omnivore
<i>Gila atraria</i>	Utah chub	ID	T	water column	cool	omnivore
<i>Gila bicolor</i>	tui chub	ID, OR, WA	T	water column	cool	omnivore
<i>Gila boraxobius</i>	Borax Lake chub	OR	I	water column	warm	invertivore
<i>Gila coerulea</i>	blue chub	OR	T	water column	cool	omnivore
<i>Gila copei</i>	leatherside chub	ID	I	water column	cool	invertivore
<i>Hesperoleucis symmetricus</i>	California roach	OR	T	benthic	warm	omnivore
<i>Mylocheilus caurinus</i>	peamouth	ID, OR, WA	I	water column	cool	invertivore
<i>Notemigonus crysoleucas</i>	golden shiner	A	T	water column	warm	omnivore
<i>Oregonichthys crameri</i>	Oregon chub	OR	I	hider	cool	invertivore
<i>Oregonichthys kalawatseti</i>	Umpqua chub	OR	I	hider	cool	invertivore
<i>Pimephales promelas</i>	fathead minnow	A	T	water column	warm	omnivore
<i>Ptychocheilus oregonensis</i>	northern squawfish ³	ID, OR, WA	T	water column	cool	invert/piscivore
<i>Ptychocheilus umpquae</i>	Umpqua squawfish ⁴	OR	T	water column	cool	invert/piscivore
<i>Rhinichthys cataractae</i>	longnose dace	ID, OR, WA	I	benthic	cool	invertivore
<i>Rhinichthys evermanni</i>	Umpqua dace	OR	I	benthic	cool	invertivore
<i>Rhinichthys falcatus</i>	leopard dace	ID, OR, WA	I	benthic	cool	invertivore
<i>Rhinichthys osculus</i>	speckled dace	ID, OR, WA	I	benthic	cool	invertivore
<i>Richardsonius balteatus</i>	redside shiner	ID, OR, WA	I	water column	cool	invertivore
<i>Richardsonius egregius</i>	Lahontan redside	OR	I	water column	cool	invertivore
<i>Tinca tinca</i>	tench	A	I	water column	warm	invertivore
<u>Cyprinodontidae</u>						
<i>Fundulus diaphanus</i>	banded killifish	A	T	water column	warm	invertivore
<i>Lucania parva</i>	rainwater killifish	A	T	water column	warm	invertivore
<u>Embiotocidae</u>						
<i>Cymatogaster aggregata</i>	shiner perch	OR, WA	S	benthic	cold	invertivore
<u>Esocidae</u>						
<i>Esox americanus</i>	grass pickerel	A	I	water column	cool	piscivore
<i>Esox lucius</i>	northern pike	A	I	water column	cool	piscivore

TABLE 1. Classifications of freshwater fish species known to occur in Idaho, Oregon, or Washington (families listed alphabetically).

Family/Species	Common Name	Origin by State ¹	Overall Tolerance ²	Adult Freshwater Habitat	Temperature	Adult Freshwater Feeding
<u>Gadidae</u>						
<i>Lota lota</i>	burbot	ID, OR, WA	I	benthic	cold	piscivore
<u>Gasterosteidae</u>						
<i>Gasterosteus aculeatus</i>	threespine stickleback	OR, WA	T	hider	cool	invertivore
<u>Ictaluridae</u>						
<i>Ameiurus catus</i>	white catfish	A	T	benthic	warm	invert/piscivore
<i>Ameiurus melas</i>	black bullhead	A	T	hider	warm	invert/piscivore
<i>Ameiurus natalis</i>	yellow bullhead	A	T	hider	warm	invert/piscivore
<i>Ameiurus nebulosus</i>	brown bullhead	A	T	hider	warm	invert/piscivore
<i>Ictalurus furcatus</i>	blue catfish	A	T	benthic	warm	invert/piscivore
<i>Ictalurus punctatus</i>	channel catfish	A	T	benthic	warm	invert/piscivore
<i>Noturus gyrinus</i>	tadpole madtom	A	T	hider	warm	invert/piscivore
<i>Pylodictis olivaris</i>	flathead catfish	A	T	benthic	warm	piscivore
<u>Osmeridae</u>						
<i>Hypomesus pretiosus</i>	surf smelt	OR, WA	S	water column	cold	invertivore
<i>Spirinchus thaleichthys</i>	longfin smelt	OR, WA	I	water column	cool	invertivore
<i>Thaleichthys pacificus</i>	eulachon	OR, WA	I	water column	cool	invertivore
<u>Percichthyidae</u>						
<i>Morone chrysops</i>	white bass	A	I	water column	cool	piscivore
<i>Morone saxatilis</i>	striped bass	A	I	water column	cool	piscivore
<u>Percidae</u>						
<i>Perca flavescens</i>	yellow perch	A	I	water column	cool	invert/piscivore
<i>Stizostedion vitreum</i>	walleye	A	I	water column	cool	piscivore
<u>Percopsidae</u>						
<i>Percopsis transmontana</i>	sand roller	ID, OR, WA	I	hider	cool	invertivore
<u>Petromyzontidae</u>						
<i>Lampetra ayresii</i>	river lamprey	OR, WA	I	hider	cool	filter feeder ⁵
<i>Lampetra lethophaga</i>	Pit-Klamath brook lamprey	OR	I	hider	cool	filter feeder ⁵
<i>Lampetra minima</i>	Miller Lake lamprey	OR	I	hider	cool	piscivore ⁵
<i>Lampetra richardsoni</i>	western brook lamprey	OR, WA	I	hider	cool	filter feeder ⁵
<i>Lampetra similis</i>	Klamath River lamprey	OR	I	hider	cool	filter feeder ⁵
<i>Lampetra tridentata</i>	Pacific lamprey	ID, OR, WA	I	hider	cool	filter feeder ⁵
<u>Pleuronectidae</u>						
<i>Platichthys stellatus</i>	starry flounder	OR, WA	S	benthic	cold	invertivore
<u>Poeciliidae</u>						
<i>Gambusia affinis</i>	western mosquitofish	A	T	water column	warm	invertivore
<i>Poecilia mexicana</i>	shortfin molly	A	T	water column	warm	omnivore
<i>Poecilia reticulata</i>	guppy	A	T	water column	warm	omnivore
<i>Xiphophorus helleri</i>	green swordtail	A	T	water column	warm	omnivore

TABLE 1. Classifications of freshwater fish species known to occur in Idaho, Oregon, or Washington (families listed alphabetically).

Family/Species	Common Name	Origin by State ¹	Overall Tolerance ²	Adult Freshwater		Adult Freshwater Feeding
				Habitat	Temperature	
<u>Salmoidae</u>						
<i>Coregonus chupeaformis</i>	lake whitefish	A	I	water column	cold	invertivore
<i>Oncorhynchus aguabonita</i>	golden trout	A	S	hider	cold	invert/piscivore ⁵
<i>Oncorhynchus clarki</i>	cutthroat trout	ID, OR, WA	S	water column	cold	invert/piscivore
<i>Oncorhynchus gorbuscha</i>	pink salmon	OR, WA	S	water column	cold	invertivore ⁵
<i>Oncorhynchus keta</i>	chum salmon	OR, WA	S	water column	cold	invertivore ⁵
<i>Oncorhynchus kisutch</i>	coho salmon	ID, OR, WA	S	water column	cold	invertivore ⁵
<i>Oncorhynchus mykiss</i>	rainbow trout	ID, OR, WA	S	hider	cold	invert/piscivore
<i>Oncorhynchus nerka</i>	sockeye salmon	ID, OR, WA	S	water column	cold	invertivore ⁵
<i>Oncorhynchus tshawytscha</i>	chinook salmon	ID, OR, WA	S	water column	cold	invertivore ⁵
<i>Prosopium abyssicola</i>	Bear Lake whitefish	ID	I	water column	cold	invertivore
<i>Prosopium coulteri</i>	pygmy whitefish	ID, WA	I	water column	cold	invertivore
<i>Prosopium gemmiferum</i>	Bonneville cisco	ID	S	water column	cold	invertivore
<i>Prosopium spilonotus</i>	Bonneville whitefish	ID	I	water column	cold	invertivore
<i>Prosopium williamsoni</i>	mountain whitefish	ID, OR, WA	I	benthic	cold	invertivore
<i>Salmo salar</i>	Atlantic salmon	A	S	water column	cold	invert/piscivore ⁵
<i>Salmo trutta</i>	brown trout	A	I	hider	cold	invert/piscivore
<i>Salvelinus alpinus</i>	Arctic char	A	S	hider	cold	invert/piscivore
<i>Salvelinus confluentus</i>	bull trout	ID, OR, WA	S	hider	cold	invert/piscivore
<i>Salvelinus fontinalis</i>	brook trout	A	I	hider	cold	invert/piscivore
<i>Salvelinus malma</i>	Dolly Varden	WA	S	hider	cold	invert/piscivore
<i>Salvelinus namaycush</i>	lake trout	A	S	benthic	cold	piscivore
<i>Thymallus arcticus</i>	Arctic grayling	A	S	water column	cold	invert/piscivore
<u>Umbridae</u>						
<i>Novumbra hubbsi</i>	Olympic mudminnow	WA	T	hider	warm	invertivore

¹ A = alien (non-native, exotic, or introduced) to all three states. ID = native to Idaho, OR = native to Oregon, WA = native to Washington (Does not imply occurrence in all three states.)

² I = intermediate species, S = sensitive species, T = tolerant species

³ recommended for name change to northern pikeminnow (Nelson et al. 1998)

⁴ recommended for name change to Umpqua pikeminnow (Nelson et al. 1998)

⁵ characterizes most of freshwater life

even though they are native to the state. In other words, regional classifications may require modification when applied at local scales.

(3) A key consideration in developing metrics or biotic indices is that they should detect a range of conditions for the various water bodies assessed. If metrics or indices fail to detect a range of conditions, it may be a result of nondiscriminating species classifications given the fish fauna present. Before developing an index, the fish species present and their classifications must be examined to ensure that a sufficient range of characteristics occurs in the classifications of interest. If there are

only sensitive native species present in headwater mountain streams, the overall tolerance and origin classifications cannot be responsive to disturbance, so substitute metrics will be needed.

(4) Although all life stages should be considered in making assessments about fish assemblage integrity (Angermeier and Karr 1986, Northcote 1997), the number of young-of-year individuals is largely stochastic (Yant et al. 1984) and such variability adds an undesirable amount of error into metric interpretation. In addition, survival of young-of-year fishes into later age classes is a better indicator than mere presence or even abundance

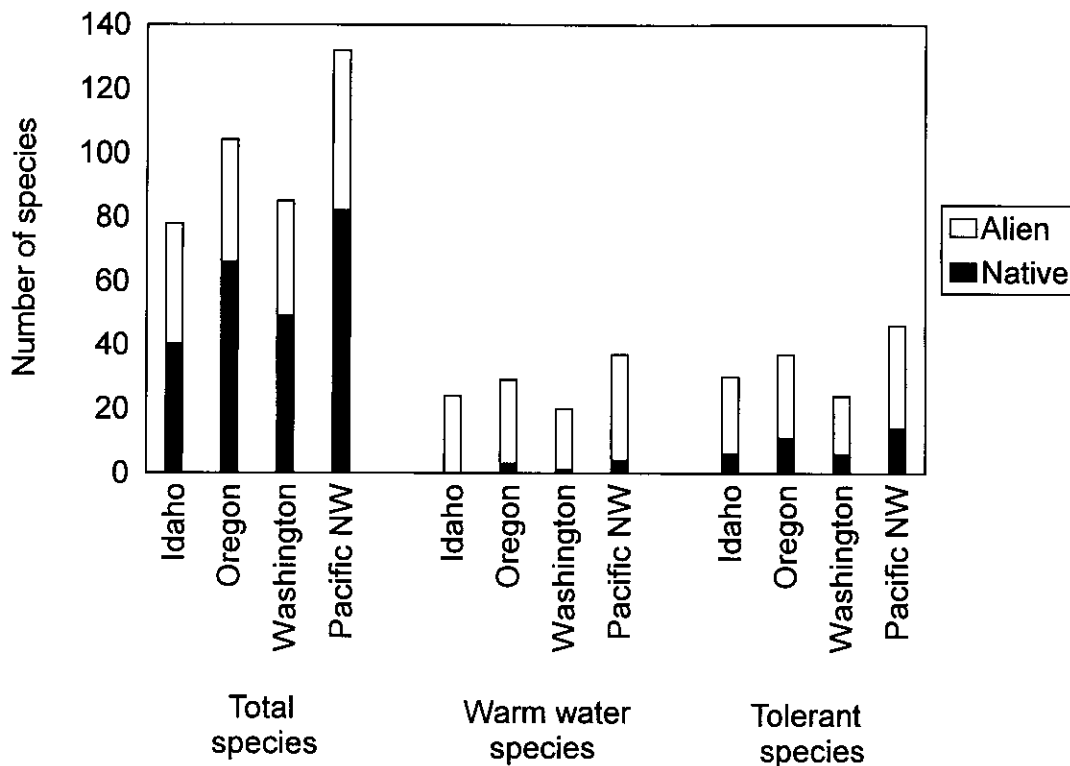


Figure 1. State and regional patterns in origin, temperature, and tolerance attributes.

of young-of-year (Karr et al. 1986), especially in species rich waters. However, where only one to three species of fish exist, as is common in many Pacific Northwest mountain streams, it is essential to collect and assess all life stages, simply to determine if the site can support them all. The emphasis in such cases should be on the presence of the life stages rather than attempting accurate counts of all individuals.

(5) Sampling effort must be sufficient to obtain nearly all species present in a reach at their relative abundances, and fish collected must be identified to the species level. This is especially critical for sculpins, a family that is often identified only to genus. Examination of Table 1 indicates marked differences in overall tolerance and temperature preference among cottid species, which is lost without accurate identification. Fish ecologists should learn to identify all the fish species in their study areas or collect specimens for identification by experts.

(6) Specimen vouchering is critical as a quality assurance and control measure. Museum specimens are crucial for advancing our knowledge of taxonomy and distribution. They also offer the most irrefutable evidence of a collection. To be most useful, specimens must be properly preserved (kill in 10% formalin, slit specimens greater than 15 cm long, and provide ample space in jars to allow for thorough tissue fixing). If specimens are allowed to die and are preserved later, they produce poor quality specimens. This is especially true if the holding water and air temperatures are warm. Collection sites must also be accurately located, preferably by latitude and longitude, using a geographic positioning device so the data can be easily manipulated in a geographic information system.

(7) Additional research on water temperature and feeding preferences of fish species and more thorough distributional studies of fishes would improve our attribute classifications. We found

TABLE 2. Example of metric scores for the proportion of alien species, omnivorous species, and sensitive species from paired wadeable (w) streams and large river (l) sites that represent disturbed and less disturbed physical or chemical habitats in Idaho, Oregon, and Washington.

Site and (type)	Condition	% Alien Individuals	% Omnivorous Individuals	% Sensitive Species
<u>Idaho</u>				
Malad River (w) ¹	disturbed	60	47	0
Little Wood River (w) ²	less disturbed	3	0	40
Snake River @ Buhl (l) ³	disturbed	16	45	0
Snake River @ Flagg (l) ⁴	less disturbed	5	1	25
<u>Oregon</u>				
Spoon Creek (w) ⁵	disturbed	100	0	0
Smallman Creek(w) ⁶	less disturbed	0	0	14
Willamette River @ Portland (l) ⁷	disturbed	19	27	0
Willamette River @ McKenzie (l) ⁸	less disturbed	0	45	23
<u>Washington</u>				
Bone River (w) ⁹	disturbed	0	0	0
Mill Creek (w) ¹⁰	less disturbed	0	0	66
Yakima River @ Kiona (l) ¹¹	disturbed	17	46	0
Yakima River @ Umtanum (l) ¹²	less disturbed	0	32	14

¹ black bullhead, common carp, largescale sucker, redbside shiner, smallmouth bass (Maret 1997).

² brook trout, mountain whitefish, rainbow trout, speckled dace, Wood River sculpin (Maret 1997).

³ chiselmouth, common carp, largescale sucker, mottled sculpin, northern squawfish, peamouth, rainbow trout, redbside shiner, speckled dace, Utah chub (Maret 1997).

⁴ brook trout, brown trout, cutthroat trout, longnose dace, mottled sculpin, mountain sucker, mountain whitefish, Paiute sculpin, rainbow trout, redbside shiner, speckled dace, Utah sucker (Maret 1997).

⁵ largemouth bass, warmouth, western mosquitofish, white crappie, yellow bullhead (Hughes et al. 1998).

⁶ brown bullhead, cutthroat trout, redbside shiner, reticulate sculpin, speckled dace, threespine stickleback, western brook lamprey (Hughes et al. 1998).

⁷ common carp, largemouth bass, largescale sucker, northern squawfish, prickly sculpin, reticulate sculpin, yellow perch (Hughes and Gammon 1987).

⁸ chinook salmon, chiselmouth, largescale sucker, mountain sucker, mountain whitefish, northern squawfish, Paiute sculpin, peamouth, rainbow trout, redbside shiner, reticulate sculpin, speckled dace, torrent sculpin (Hughes and Gammon 1987).

⁹ reticulate sculpin (Merritt et al. 1999).

¹⁰ coho salmon, cutthroat trout, riffle sculpin, speckled dace, torrent sculpin, western brook lamprey (Merritt et al. 1999).

¹¹ bridgelip sucker, largescale sucker, mountain whitefish, northern squawfish (Cuffney et al. 1997).

¹² bridgelip sucker, chiselmouth, largescale sucker, mountain sucker, mountain whitefish, northern squawfish, rainbow trout (Cuffney et al. 1997).

few comprehensive regional studies documenting the diets of fishes of the Pacific Northwest and the temperatures at which they are most successful. When and where sufficiently large databases allow them, data analyses are needed along gradients of habitat and human disturbance. Finally, better information concerning reproduction and longevity might lead to additional attribute classifications.

In summary, we produced attribute classifications for the freshwater fishes of the Pacific Northwest and demonstrated their applicability in evaluating 12 sites. Additionally, attribute classifications were used to compare species richness, origin, overall pollution tolerance, and water temperature preference in Idaho, Oregon, and Washington. We recognize that our classifications will change with further research and local applications. We

encourage additional study of life histories, autecology, and distributional patterns of non-salmonid Pacific Northwest freshwater fishes. We hope this attribute classification will stimulate more fish ecologists to assess entire fish assemblages, either by direct application of these metrics or by incorporating them in fish assemblage indices. We also want this paper to stimulate criticism and improvement of these classifications and encourage communications by readers to further that end.

Acknowledgements

Motivational support was provided by the Pacific Northwest Bioassessment Work Group and Gretchen Hayslip, USEPA Region 10. M. Hallock

provided comments regarding species distributions in Washington. Helpful comments on manuscript drafts were provided by C. Bond, S. Brenkman, W. Clark, G. Larson, H. Li, D. Markle, P. Mongillo, B. Rieman, E. Schreiner, T. Short, and R. Wallace. We also thank the many American Fisheries Society professionals that supplied comments and information on species attributes. The support of the Orma J. Smith Museum of Natural History and Albertson College of Idaho is greatly appreciated. This paper was supported by the Environmental Monitoring and Assessment Program (EMAP), partially funded through contract 68-C6-0005 to Dynamac, and subjected to Environmental Protection Agency peer and administrative review and approved for publication.

Literature Cited

- Angermeier, P. L. and J. R. Karr. 1986. Applying an index of biotic integrity based on the stream-fish communities: considerations in sampling and interpretation. *North American Journal of Fisheries Management* 6(3): 418-429.
- Baxter, G. T. and M. D. Stone. 1995. *Fishes of Wyoming*. Wyoming Game and Fish Department, Cheyenne.
- Becker, G. C. 1983. *Fishes of Wisconsin*. University of Wisconsin Press, Madison.
- Behnke, R. J. 1992. *Native Trout of Western North America*. American Fisheries Society Monograph 6. Bethesda.
- Bond, C. E. 1963. Distribution and ecology of freshwater sculpins, genus *Cottus*, in Oregon. University of Michigan, Ann Arbor. Ph. D. Dissertation.
- _____. 1973. Keys to Oregon Freshwater Fishes. Technical Bulletin 58. Oregon State University, Corvallis.
- _____. 1994. Keys to Oregon Freshwater Fishes. Oregon State University Book Stores, Incorporated, Corvallis.
- Bond, C. E., E. Rexstad, and R. M. Hughes. 1988. Habitat use of twenty-five common species of Oregon freshwater fishes. *Northwest Science* 62(5):223-232.
- Carlander, K. D. 1969. *Handbook of Freshwater Fishery Biology*, Vol. 1. Iowa State University Press, Ames.
- _____. 1977. *Handbook of Freshwater Fishery Biology*, Vol. 2. Iowa State University Press, Ames.
- Chandler, G. L., T. R. Maret, and D. W. Zaroban. 1993. Protocols for assessment of biotic integrity (fish) in Idaho streams. Water Quality Monitoring Protocol Number 6. Idaho Division of Environmental Quality, Boise, Idaho. 40 p.
- Courtenay, W. R., D. A. Hensley, J. N. Taylor, and J. A. McCann. 1986. Distribution of exotic fishes in North America. In C. H. Hocutt and E. O. Wiley (eds.) *The Zoogeography of North American Freshwater Fishes*. John Wiley and Sons, New York.
- Coutant, C. C. 1977. Compilation of temperature preference data. *Journal of the Fisheries Research Board of Canada*. 34:739-745.
- Cuffney, T. F., M. R. Meador, S. D. Porter, and M. E. Gurtz. 1997. Distribution of fish, benthic invertebrate, and algal communities in relation to physical and chemical conditions. Yakima River basin, Washington, 1990. United States Geological Survey Water Resource Investigation Report 96-4280. Raleigh, North Carolina. 94 p.
- Eaton, J. G., J. H. McCormick, B. E. Goodno, D. G. O'Brien, H. G. Stefan, M. Hondzo, and R. M. Scheller. 1995. A field information-based system for estimating fish temperature tolerances [techniques]. *Fisheries* 20 (4): 10-18.
- Fisher, T. R. 1989. Application and testing of indices of biotic integrity in northern and central Idaho headwater streams. University of Idaho, Moscow. M.S. Thesis.
- Frey, D. G. 1977. Biological integrity of water—an historical approach. In R. K. Ballentine and L. J. Guarraia (eds.) *The integrity of water*. United States Environmental Protection Agency. Washington, D. C. Pp. 127-140.
- Friesen, T. A. and D. L. Ward. 1996. Status and condition of fish assemblages in streams of the Tualatin River basin, Oregon. *Northwest Science* 70: 120-131.
- Gibson, G.R., editor. 1996. *Biological criteria: technical guidance for streams and small rivers*. United States Environmental Protection Agency. EPA 822-B-96-001. Washington, D. C.
- Hokanson, K. E. F. 1977. Temperature requirements of some percids and adaptations to the seasonal temperature cycle. *Journal of the Fisheries Research Board of Canada* 34: 1524-1550.
- Holden, P. B. and C. B. Stalnaker. 1975. Distribution and abundance of mainstream fishes of the middle and upper Colorado River basins, 1967-1973. *Transactions of the American Fisheries Society* 104: 217-231.
- Hughes, R. M. and J. R. Gammon. 1987. Longitudinal changes in fish assemblages and water quality in the Willamette River, Oregon. *Transactions of the American Fisheries Society* 116(2): 196-209.
- Hughes, R. M. and R. F. Noss. 1992. Biological diversity and biological integrity: current concerns for lakes and streams. *Fisheries* 17(3): 11-19.

- Hughes, R. M., P. R. Kaufman, A. T. Herlihy, T. M. Kincaid, L. Reynolds, and D. P. Larsen. 1998. A process for developing and evaluating indices of fish assemblage integrity. *Canadian Journal of Fisheries and Aquatic Sciences* 55: 1618-1631.
- Idaho Department of Health and Welfare. 1993. Idaho water quality standards and wastewater treatment requirements, Title 1, Chapter 2. Division of Environmental Quality, Boise, Idaho.
- Karr, J. R. 1981. Assessment of biotic integrity using fish communities. *Fisheries* 6(6): 21-27.
- Karr, J. R. and D. R. Dudley. 1981. Ecological perspective on water quality goals. *Environmental Management* 5:55-68.
- Karr, J. R. and E. W. Chu. 1999. Restoring life in running waters. Island Press, Covelo.
- Karr, J. R., K. D. Fausch, P. L. Angermeier, P. R. Yant, and I. J. Schlosser. 1986. Assessing biological integrity in running waters: a method and its rationale. Illinois Natural History Survey Special Publication 5. Champaign.
- La Rivers, I. 1994. Fishes and Fisheries of Nevada. University of Nevada Press, Reno.
- Lee, D. S., C. R. Gilbert, C. H. Hocutt, R. E. Jenkins, D. E. McAllister, and J. R. Stauffer, Jr. 1980. Atlas of North American Freshwater Fishes. North Carolina State Museum of Natural History, Raleigh.
- Leidy, R. A. and P. L. Fiedler. 1985. Human disturbance and patterns of fish species diversity in the San Francisco Bay drainage, California. *Biological Conservation* 33: 247-267.
- Li, H. W., C. B. Schreck, C. E. Bond, and E. Rexstad. 1987. Factors influencing changes in fish assemblages of Pacific Northwest streams. In W. J. Matthews and D. C. Heins (eds.) *Community and Evolutionary Ecology of North American Stream Fishes*. University of Oklahoma Press, Norman. Pp. 193-202.
- Lyons, J., L. Wang, and T. D. Simonson. 1996. Development and validation of an index of biotic integrity for coldwater streams in Wisconsin. *North American Journal of Fisheries Management* 16(2): 241-256.
- Maret, T. R. 1997. Characteristics of fish assemblages and related environmental variables for streams of the upper Snake River basin, Idaho and western Wyoming. United States Geological Survey Water Resource Investigation Report 97-4087. Boise, Idaho. 50 p.
- Maret, T. R., C. T. Robinson, and G. W. Minshall. 1997. Fish assemblages and associated environmental correlates in least-disturbed streams of the upper Snake River basin, western USA. *Transactions of the American Fisheries Society* 126(2): 200-216.
- McPhail, J. D. and C. C. Lindsey. 1986. Zoogeography of the freshwater fishes of Cascadia (the Columbia system and rivers north to the Stikine). In C. H. Hocutt and E. O. Wiley (eds.) *The Zoogeography of North American Freshwater Fishes*. John Wiley and Sons, New York.
- Merritt, G. D., B. Dickes, and J. S. White. 1999. Biological assessment of small streams in the coast range ecoregion and the Yakima River basin. Washington State Department of Ecology. Publication Number 99-302. Olympia, Washington. 59 p.
- Miller, D. L., P. M. Leonard, R. M. Hughes, J. R. Karr, P. B. Moyle, L. H. Schrader, B. A. Thompson, R. A. Daniels, K. D. Fausch, G. A. Fitzhugh, J. R. Gammon, D. B. Halliwell, P. L. Angermeier, and D. J. Orth. 1988. Regional applications of an index of biotic integrity for use in water resource management. *Fisheries* 13(5): 12-20.
- Minckley, W. L. 1973. *Fishes of Arizona*. Sims Printing, Phoenix.
- Minckley, W. L., D. A. Hendrickson, and C. E. Bond. 1986. Geography of western North American freshwater fishes: description and relationships to intracontinental tectonism. In C. H. Hocutt and E. O. Wiley (eds.) *The Zoogeography of North American Freshwater Fishes*. John Wiley and Sons, New York.
- Mongillo, P. E. 1993. The distribution and status of bull trout/Dolly Varden in Washington State. Rep. No. 93-22. Washington Department of Fish and Wildlife, Olympia, Washington. 45 p.
- Mongillo, P. E. and M. Hallock. 1995. Resident nongame fish investigations, 1993-1994 report. Report Number IF95-04. Washington Department of Fish and Wildlife, Olympia, Washington. 78 p.
- Moseley, R. and C. Groves. 1992. Rare, threatened and endangered plants and animals of Idaho. Idaho Department of Fish and Game, Boise, Idaho. 38 p.
- Moyle, P. B. 1976. *Inland Fishes of California*. University of California Press, Berkeley.
- . 1986. Fish introductions into North America—patterns and ecological impacts. In Mooney, H. A. and J. A. Drake (eds.) *Ecology of Biological Invasions of North America and Hawaii*. Springer-Verlag Publishers, New York.
- Moyle, P. B. and R. D. Nichols. 1973. Ecology of some native and introduced fishes of the Sierra Nevada foothills in central California. *Copeia* 1973: 478-490.
- National Academy of Sciences and National Academy of Engineering. 1972. *Water quality criteria 1972*. United States Environmental Protection Agency, Washington, D.C.
- Nelson, J. S., E. J. Crossman, H. Espinosa-Pérez, C. R. Gilbert, R. N. Lea, and J. D. Williams. 1998. Recommended changes in common fish names: pikeminnow to replace squawfish (*Ptychocheilus* spp.). *Fisheries* 23 (9): 37.
- Northcote, T. G. 1997. Potamodromy in Salmonidae: living and moving in the fast lane. *North American Journal of Fisheries Management* 17(4): 1029-1045.
- Oberdorff, T. and R. M. Hughes. 1992. Modification of an index of biotic integrity based on fish assemblages to characterize rivers of the Seine basin, France. *Hydrobiologia* 228: 117-130.
- Ohio Environmental Protection Agency. 1987. Biological criteria for the protection of aquatic life: Vol III. Standardized biological field sampling and laboratory methods for assessing fish and macroinvertebrate communities. Document 0046e/0013e. Division of Water Quality Monitoring and Assessment, Columbus, Ohio. 80 p.
- Oregon Secretary of State. 1998. Oregon Administrative Rules. Sections 340-41-0006 and 340-41-0024. Salem, Oregon.

- Page, L. M. and B. M. Burr. 1991. *A Field Guide to Freshwater Fishes, North America North of Mexico*. Houghton Mifflin Co. New York.
- Pflieger, W. L. 1975. *The Fishes of Missouri*. Missouri Department of Conservation, Jefferson City.
- Rinne, J. N. and W. L. Minckley. 1991. Native fishes of arid lands: a dwindling resource of the desert southwest. United States Department of Agriculture. Forest Service General Technical Report RM-206. Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colorado. 45 p.
- Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1991. *Common and Scientific Names of Fishes from the United States and Canada*. 5th ed. Special Publication 20. American Fisheries Society, Bethesda.
- Robison, H. W. and T. M. Buchanan. 1988. *Fishes of Arkansas*. University of Arkansas Press, Fayetteville.
- Scott, W. B. and E. J. Crossman. 1973. *Freshwater Fishes of Canada*. Fisheries Research Board of Canada, Bulletin 184. Ottawa.
- Sigler, W. F. and J. W. Sigler. 1987. *Fishes of the Great Basin, a Natural History*. University of Nevada Press, Reno.
- _____. 1996. *Fishes of Utah*. University of Utah Press, Salt Lake City.
- Simon, T. P. 1998. *Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities*. CRC Press, Boca Raton.
- Simon, T. P. and J. Lyons. 1995. Application of the index of biotic integrity to evaluate water resource integrity in freshwater ecosystems. *In* W. S. Davis and T. P. Simon (eds.) *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making*. Lewis Press, Boca Raton. Pp. 245-262.
- Simpson, J. C. and R. L. Wallace. 1982. *Fishes of Idaho*. University of Idaho Press, Moscow.
- Smith, C. L. 1985. *The Inland Fishes of New York State*. New York State Department of Environmental Conservation, Albany.
- Trautman, M. B. 1981. *The Fishes of Ohio*. Ohio State University Press, Columbus.
- United States Environmental Protection Agency (USEPA). 1990. *Biological criteria: national program guidance for surface waters*. EPA-440/5-90-004. Washington, D. C.
- Washington Administrative Code. 1997. *Water quality standards for surface waters of the State of Washington, Section 173-201A*. Olympia, Washington.
- Washington Department of Natural Resources. 1997. *Washington Animal Species List*. Nat. Hert. Prog. http://www.wa.gov/dnr/htdocs/fr/nhp/animal_ranks.html. Olympia, Washington.
- Water Environment Federation. 1997. *The Clean Water Act 25th Anniversary Edition*. Alexandria.
- Woodling, J. 1985. *Colorado's little fish, a guide to the minnows and other lesser known fishes in the state of Colorado*. Colorado Department of Natural Resources, Denver.
- Wydoski, R. S. and R. R. Whitney. 1979. *Inland Fishes of Washington*. University of Washington Press, Seattle.
- Yant, P. R., J. R. Karr, and P. L. Angermeier. 1984. Stochasticity in stream fish communities: an alternative interpretation. *American Naturalist* 124: 573-582.
- Yoder, C. O. and E. T. Rankin. 1998. The role of biological indicators in a state water quality management process. *Environmental Monitoring and Assessment* 51: 61-88.

Received 6 October 1998

Accepted 5 April 1999