Physical Habitat and the Assessment of Stream Health

Doug Pirhalla
1403 Pennington Ct., Edgewater, MD 21037
Doug.Pirhalla@noaa.gov

A critical survey component in nearly all local, state, and regional programs that aim to assess the biological condition or health of aquatic resources is the assessment of physical habitat. According to the U.S. Environmental Protection Agency (Barbour et al., 1999), physical habitat assessments evaluate how the structure of the surrounding habitat influences the quality of the stream and the condition of its resident aquatic community. In this article, I provide background information on the fish-habitat relationship and, by using data from a statewide study, show how physical habitat variables influence the abundance and composition of monitored fish populations.

So how did I get interested in this subject? Well, like many native fish enthusiasts, it all started when I was a child, standing on a rock, peering into a stream, captivated by the creatures living below the surface . . .

A Memory of Lampreys

It was the early 1970s. The setting was a small tributary to the Christina River in northern New Castle County, Delaware, where friends and I had spent countless hours catching fish as common as the creek chub (*Semotilus atromaculatus*), as isolated as the flier (*Centrarchus macropterus*), or as unexpected as the transplanted rainbow trout (*Oncorhynchus mykiss*). Being on the fringe of both the Eastern Piedmont and Coastal Plain physiographic provinces seemed to set the faunal diversity of this particular first-order stream in motion. In early spring, during especially wet years, we would sometimes happen upon groups of large, eel-like silhouettes in the shallow riffles of this stream, partially exposed in water no more than three inches deep. Seemingly unconcerned by our presence and unwavering in their pursuit, they appeared to be heading upstream in search of something unbeknownst to us. Awestruck and inspired, some of us jumped on rocks for an improved vantage point, while others dashed away, interested only in reaching safe haven from these ominous-looking prehistoric fish from the Atlantic. These were parasitic sea lamprey (*Petromyzon marinus*) on their upstream spring migration to spawn. As a five-year-old, seeing these fish for the first time, I gained an instant appreciation for the diversity of life that can be found in even the smallest of tributaries.

So where does the story go from here? Is this another "Where-are-they now?" story for a lost fish species? Maybe. As it turns out, the sea lamprey is one of many species that has since vanished from this tributary of the Delaware River basin. Through informal sampling, I also suspect the disappearance of the once-abundant longnose dace (*Rhinichthys cataractae*), spotfin shiner (*Cyprinella spiloptera*), and common shiner (*Luxilus cornutus*). The reason for losing these species could be the result of numerous factors (including man-made controls, as in the case of the sea lamprey). But if you could see, as I have, how much this tributary has degraded over the past 20-plus years, it's clear that habitat loss is a major culprit.

With the support and guidance from numerous fisheries biologists, ecologists and statisticians, I've been fortunate to study some of the native fishes that I remember seeing as a child. Here are some of the things I've learned about the habitats they depend on for their reproduction and survival.

The Fish-Habitat Relationship

First, let me say that studying the direct cause-and-effects relationships between habitat impairment and fish community

Fig. 1.
Example of a stream reach exhibiting a general lack of stable habitat structure and substrate, limited streamflow diversity, and minimal stream cover. Photo by Maryland DNR.

Fig. 2.
Example showing a highly modified stream with excessive bank scour and erosion, widened stream banks, extreme channelization, and siltation. Photo by Maryland DNR.

or population declines is extremely difficult without stringent environmental controls and/or long-term studies. There is an inherent problem in developing management policies surrounding these relationships when fish responses to degraded habitat are generally coincident with other factors of stream decline.

With that said, it is probably not surprising to most NANFA members that in the case of many stream systems, numerous instream habitat characteristics such as streamflow velocity, water depth, substrate quality, and instream cover are generally considered critical components to a healthy aquatic community (Barbour et al., 1999). For example, velocity and substrate qualities are important features of habitat diversity and are critical for sustained reproduction of macroinvertebrate and fish populations. Depth and cover are important attributes for determining the amount and variety of habitat space available for fish communities. Streams supporting numerous pools and an abundance of submerged woody debris provide fish with a large number of niches, thus increasing habitat potential for species throughout all life stages. And, riffles and runs are primary habitat for benthos and provide critical spawning and feeding areas for numerous fish species (Roth et al., 1999).

Nor is it surprising that within a fish community certain life stages, feeding patterns, critical spawning areas, and behavioral strategies are all invariably impacted by altered habitat structure (Barbour et al., 1999; Karr et al., 1986). In fact, habitat alteration has been cited as a leading cause of fish species extinctions, contributing to 73% of the extinctions in North America during this century (Miller et al., 1989; Allan and Flecker, 1993). Excessive siltation from agricultural activity and habitat modification has been cited as one of the most widespread pollutants impacting rivers and streams in the United States (EPA, 1998). Siltation affects the feeding strategies and reproductive activities of fishes—especially in riffle/pool-dominated communities—by reducing normal spawning habitat for fish and benthos and thereby adversely impacting the preferred food supply (Berkman and Rabeni, 1987). Stream channelization alters runoff patterns, reduces bank stability, and increases bank scour and erosion. Impervious surfaces from residential development can increase runoff, alter water temperatures within streams, and eventually widen stream banks, causing a homogeneous, shallow habitat structure (Roth et al., 1999).

Five Habitat Parameters

The setting for this part of the story is Maryland, which covers seven physiographic provinces, 17 major drainage basins, and encompasses numerous stream and river miles throughout its 250 mile east-to-west extent. I used statewide biological monitoring information to quantify the relative importance of various components of instream habitat condition to determine which species are most intolerant to habitat disturbance, and to determine a fish-habitat tolerance measure that could be used to improve our understanding of the threats facing native fish populations. Using Maryland Biological Stream Survey (MBSS 1995-1997) data from

Fig. 3.
Habitat loss can have numerous and far-reaching impacts on aquatic residents far downstream of any residential areas and impervious zones. Photo by Maryland DNR.

Fig. 4.
Patterns of habitat degradation are sometimes reflected in the landscape surrounding the stream. Low gradient streams are naturally more susceptible to increased channelization and sediment loadings (Roth et al., 1999). Photo by Maryland DNR.

nearly 1,000 stream sampling locations throughout the state (Roth et al., 1999), a reliable geographic framework, and proven statistical techniques to evaluate individual fish-habitat responses, I was able to discern numerous species' sensitivities to poor physical habitat quality.

The MBSS dataset contains a wealth of information regarding habitat and biota, including an assessment of physical habitat condition for all stream sites sampled. A total of 13 characteristics of stream habitat were qualitatively assessed in the survey, but only five were used throughout my study:

Instream habitat structure. The amount of stable habitat structure such as rocks, logs, rootwads, undercut banks, and aquatic plants available in a stream.

Epifaunal substrate. The amount and variety of hard, stable substrates available to benthic macroinvertebrates. Suitable environments are typically stream bottoms free from fine sediments or flocculent materials.

Velocity/depth diversity. The variability in velocity vs. depth streamflow regimes (slow-shallow, slow-deep, fast-shallow, fast deep).

Pool/glide/eddy quality. The variety, extent, and spatial complexity of slow or stillwater habitats.

Riffle quality. The depth, variety, complexity, and functional importance of riffle and run habitat within the sampled segment.

These five habitat parameters are somewhat interrelated, but all have been documented by EPA as essential bioassessment protocols in state stream monitoring efforts (Barbour et al., 1999). They also proved to be unique in terms of individual species-habitat responses. A complete description of habitat assessments and methods applied can be found in my paper "Evaluating Fish-Habitat Relationships for Refining Regional Indexes of Biotic Integrity: Development of a Tolerance Index of Habitat Degradation for Maryland Stream Fishes," which appeared in the January 2004 issue (vol. 133, no. 1) of the *Transactions of the American Fisheries Society*. You can download a PDF of this paper from here:

`www.ccma.nos.noaa.gov/publications/rsd_fishhabitat.pdf`

Habitat Sensitivities of Maryland Fishes

Okay, enough background. Here are some things I determined—some obvious and some not so obvious—about the habitat sensitivities of some of our native fishes. The dendrogram (Fig. 8) illustrates the habitat parameters most and least important to individual species as it relates to presence and abundance.

In general, species in the family Salmonidae rely on optimal habitat structure, epifaunal substrate and riffle quality. Brown trout (*Salmo trutta*, a European native) showed very pronounced responses to changing habitat conditions. In Maryland, brook trout (*Salvelinus fontinalis*) are generally found in smaller streams than the brown trout and are classified as more intolerant to anthropogenic (human-caused) stress and temperature increases than its

Fig. 5.
A portion of the Upper Paint Branch Special Protection Area (SPA) in Montgomery County, MD. Photo by the author. For more information on this SPA, see the text box below.

Fig. 6.
Streams marked by diversity in stream-flow, increased spatial complexity of slow or stillwater habitats, and the existence of stable habitat structure are important attributes for many reproducing fish and insect populations. Photo by Maryland DNR.

Salmo counterpart. This is potentially why the occurrence and abundance of brook trout were low in third-order streams in optimal habitat; larger streams tend to have higher ambient temperatures in summer.

All of the species analyzed in the family Percidae, except for yellow perch (*Perca flavescens*), are generally classified as benthic species. Greenside darter (*Etheostoma blennioides*), fantail darter (*E. flabellare*) and shield darter (*Percina peltata*) had a strong affinity for optimal riffle quality. Fantail darter appeared to be more sensitive to poor velocity/depth diversity when compared to shield darter. Swamp darter (*Etheostoma fusiforme*) and tessellated darter (*E. olmstedi*) showed a very slight to moderate sensitivity to complex pool habitat, respectively.

The two sculpin species sampled during the 1995-1997 MBSS were similar in their associations to habitat quality. Mottled sculpin (*Cottus bairdii*) showed more sensitivity to streams with poor instream habitat structure and appeared to be more silt-intolerant than the Potomac sculpin (*C. girardi*). Margined madtom (*Noturus insignis*) showed the most sensitivity to poor habitat quality in the family Ictaluridae.

In the family Centrarchidae, there was a moderate-to-strong relationship between species presence and abundance and the habitat parameters of pool/glide/eddy quality and instream habitat structure, especially for smallmouth bass (*Micropterus dolomieu*), rock bass (*Ambloplites rupestris*), green sunfish (*Lepomis cyanellus*), and redbreast sunfish (*L. auritus*). Smallmouth bass, rock bass and green sunfish, all non-native to Maryland, were found to be sensitive to streams with a low diversity of pool settings and habitat structure. Species that are less sensitive to poor pool quality and habitat structure—bluespotted sunfish (*Enneacanthus gloriosus*) and banded sunfish (*E. obesus*)—are classified as invertivores, suggesting that feeding strategies may have an influence on fish-habitat responses in this group.

Of all the families analyzed, cyprinids showed greatest sensitivities to poor physical habitat quality. Some cyprinids, such as the spotfin shiner (*Cyprinella spiloptera*), spottail shiner (*Notropis hudsonius*), and silverjaw minnow (*N. buccatus*), showed sensitivities indicative of having a preference for relatively larger streams with complex, slow or still-water habitats. Rosyside dace (*Clinostomus funduloides*) and bluntnose minnow (*Pimephales notatus*) were found in small to moderately sized streams, and neither species was sampled often in the tributaries of far western Maryland. This may be

The Upper Paint Branch SPA

In 1995, the Montgomery County (MD) Department of Environmental Protection designated a portion of the Upper Paint Branch watershed as a Use III Special Protection Area (SPA). This area is a unique urban cold-water resource containing naturally reproducing trout, which are unusually sensitive to area disturbance. In cases like this one, water quality protection measures probably fall well short of protecting instream habitat. Therefore, land-use controls are strictly enforced, with specific limits on land development throughout the SPA. Stream buffer areas have been successful at protecting both in- and out-of-stream habitat and water quality in the area.

Fig. 7.
Habitat quality is reflected in a suite of measurable in- and out-of- stream attributes, all of which have important implications to the biological health and sustainability of the water resource.
Photo by Maryland DNR.

due to lower temperatures within streams west of the Great Valley physiographic province where conditions may be too cold for these species.

Two species of the family Catostomidae, creek chubsucker (*Erimyzon oblongus*) and white sucker (*Catostomus commersonii*), were found in small to moderately sized streams. These species showed negative and moderate associations to almost all of the parameters analyzed, respectively. In general, northern hog sucker (*Hypentelium nigricans*) is highly sensitive to streams with a low diversity of habitat. It is found in relatively large streams and rivers throughout the Eastern/Western Piedmont and in the Appalachian Plateau Provinces of Maryland.

The parasitic sea lamprey (*Petromyzon marinus*) and the non-parasitic least brook lamprey (*Lampetra aepyptera*) showed a very slight to moderate association to deeper, more complex pool settings. The deeper pools possibly provide fine sediment for burrowing and filter feeding for these species.

American eel (*Anguilla rostrata*) was present in numerous streams with poor habitat quality, although definite increases in abundance of this species were evident in optimal habitat. Eels are mostly nocturnal feeders, with the greatest abundance in streams with complex pool quality, cover and adequate instream habitat structure.

Both the banded killifish (*Fundulus diaphanus*) and mummichog (*F. heteroclitus*) showed a slight sensitivity to poor pool quality. Both species are found in lowland environments, including marshes. These species are well adapted to sluggish creeks and backwaters; habitat requirements appear to be minimal, based on the habitats measured by the MBSS.

And finally, eastern mudminnow (*Umbra pygmaea*) showed an increase in occurrence and abundance in suboptimal to poor quality habitats for velocity/depth diversity and epifaunal substrate, suggesting that its habitat requirements are minimal.

Lessons, Applications, Implications

Simply stated, results of my study revealed that physical habitat characteristics are probably the single most important determinant of fish abundance and composition in Maryland stream systems. So, how can we use this information to improve our understanding of the factors affecting populations of native fishes, and of biological stream health in general? In other words, how can we use this information to potentially improve local, state, and federal watershed-based programs designed to monitor and assess the status of our stream ecosystems? Although the general concept of fish dependence on habitat seems to be fairly intuitive for those who spend time in and around streams, this work provided some technical information necessary to test ways to utilize fish-habitat tolerance relationships for improved assessments of biological stream health in Maryland, which could be applied to other areas of the Mid-Atlantic as well. A further discussion of this application can be found in my paper.

Generally speaking, there still appears to be an over-reliance on water quality in the assessment of stream health and a general lack of scientific assessments properly utilizing habitat evaluations in some watershed-based monitoring programs. In addition, I believe that overall habitat condition in many stream systems continues to worsen, in part because of a general lack of emphasis on regionalized watershed protection efforts. Most water resource managers, fisheries biologists, and freshwater ecologists know full well that changes to a landscape can change instream characteristics such as temperature, bedload capacity, and channel morphology.

Remedial solutions relating to habitat loss (e.g., stream bank stabilization, base flow and stream corridor rejuvenation projects, riparian buffers, and improved farming practices) are well-founded and very successful. Nevertheless, the problem of overlooking instream habitat persists in many states. The fish Index of Biotic Integrity, or IBI, developed and improved upon by James Karr (1981), is the vehicle I used for developing an understanding of the problem and for testing this approach; it proved to be an important reference throughout the assessment process.

Research over the past 20 years continues to reflect the importance of habitat in aquatic communities, but stream

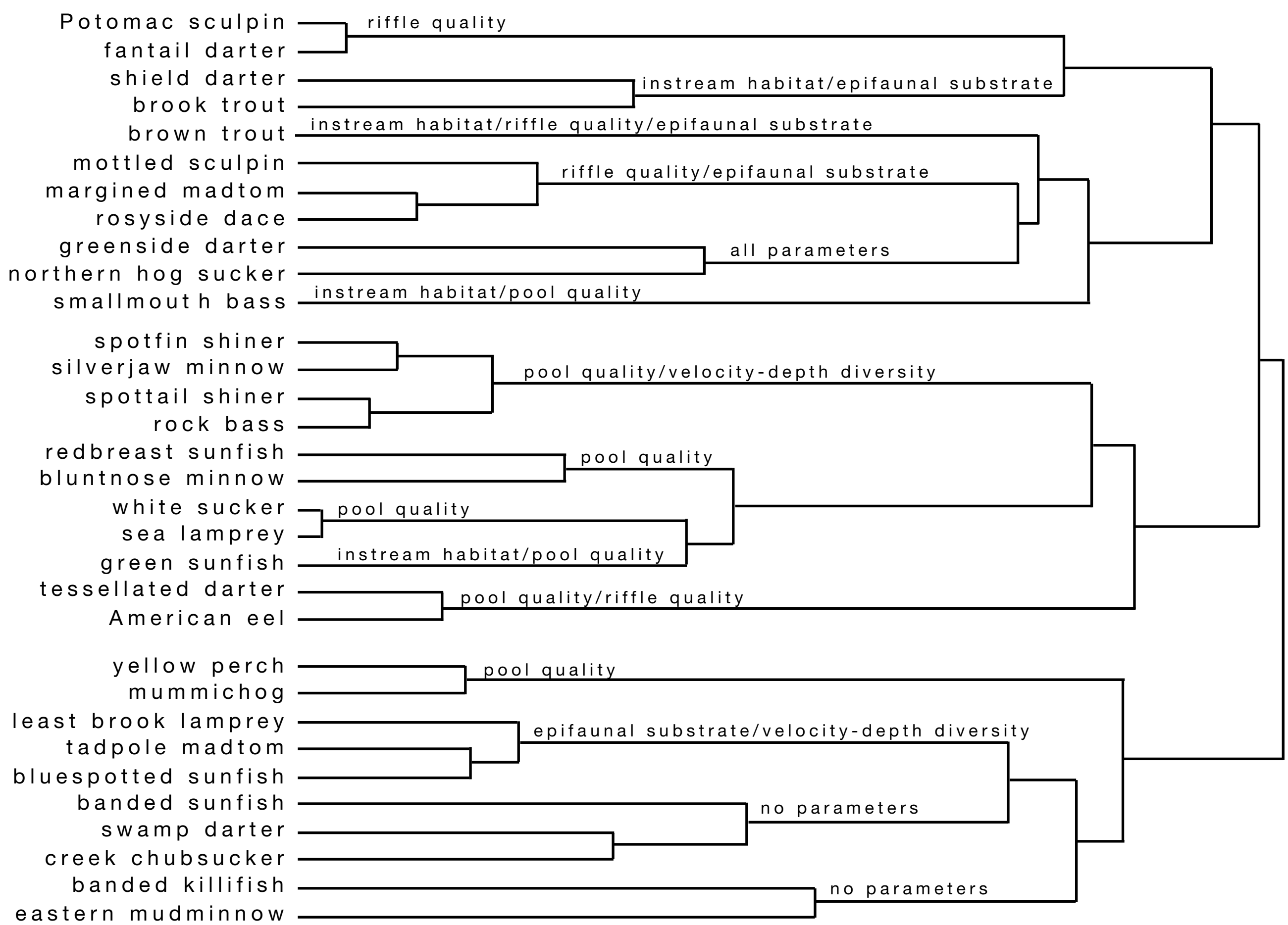

Fig. 8.
Cluster dendrogram for 32 Maryland freshwater fish species showing general similarities of species responses (based on presence and abundance) to ranges of habitat quality in streams. Note differences in fish-habitat response characteristics across family groups. See author's paper (link on p. 19) for more complete description of methods.

systems are still degrading in many areas throughout the United States. Watershed protection efforts are the key to the health and survival of our freshwater ecosystems.

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