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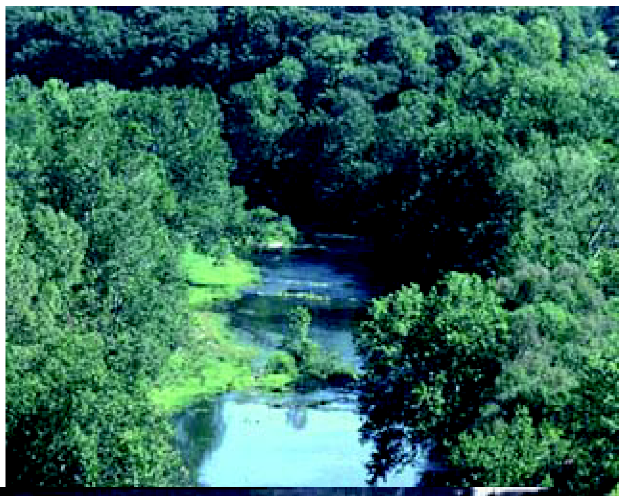
Wetland Science Institute

Using a Regional Index of Biotic Integrity (IBI) to Characterize the Condition of Northern Virginia Streams, With Emphasis on the Occoquan Watershed:

A Case Study



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Using A Regional Index of Biotic Integrity (IBI) to Characterize the Condition of Northern Virginia Streams, With Emphasis on the Occoquan Watershed: A Case Study

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Introduction

In his 1998 State of the Union Address, President Clinton announced a major new Clean Water Initiative to speed the restoration of the Nation's waterways (EPA 1998). This new initiative aims to achieve clean water by strengthening public health protections, targeting community-based watershed protection efforts at high priority areas, and providing communities with new resources to control polluted runoff. The plan focuses on a watershed approach through which units of government, the public, and the private sector will work together to sustain the health of watersheds of the nation. In the plan, watersheds are recognized as the key to future water resource improvement because clean water is the product of a healthy watershed. Focusing on the whole watershed helps strike the best balance among efforts to control point source pollution, polluted runoff, and protect drinking water sources and sensitive natural resources, such as wetlands. Working at the watershed level also encourages the public to get involved in efforts to restore and protect their water resources and is the foundation for building strong, clean water partnerships.

Watersheds are ecosystems composed of a mosaic of different land cover patches that are connected by a network of streams. Watersheds function hydrologically by collecting, storing, and discharging water, and ecologically by providing diverse sites and pathways along which environmental reactions take place and by providing habitat for flora and fauna. As our human population grows we affect our watersheds in many ways. The adverse effects of human influence have caused major reductions in the ability of many watersheds to sustain their functions and have resulted in the marked decline or decimation of many aquatic species (Miller et al. 1989; Minckley and Deacon 1991; Warren et al. 1997).

The ability to measure and monitor watershed health is key to identifying and solving natural resource problems. Although health of a watershed is an abstract concept that cannot be measured directly, it can be characterized by the stability of its aquatic ecosystems, their ability to function within their potential, and their ability for self-repair and maintenance. In most cases, the most direct and effective way to assess the health of a waterbody is to (1) measure the condition of its biological communities, and (2) support those data by measuring its physical and chemical characteristics (Danielson 1998).

During the past century, biological monitoring has evolved from the use of simple diversity indexes into a variety of approaches. One of the more recent and successful approaches has been the development of the Index of Biotic Integrity (IBI), a multimetric approach that uses species assemblages to assess the biological condition of streams (Karr et al. 1986). Now well documented and widely used, the IBI combines multiple metrics with appropriate sampling design and statistical analysis to evaluate a stream's ability to support undisturbed living systems. Metrics, in context of the IBI, are defined measurable components of a biological system that are empirically shown to change in value along a gradient of human disturbance (Karr and Chu 1997). Metrics are chosen for the IBI on the basis of how well they reflect specific and predictable responses of fish assemblages to human activities in the watershed.

In addition to assessing the condition of streams, the IBI has also been used to assess conditions contributing watersheds (Fausch et al. 1990; Roth et al. 1996; Wang et al. 1997). Several authors have used it to assess the impacts of various human disturbances on watershed health (Berkman et al. 1986; Leonard and Orth 1986; Steedman 1988; and Hughes and Gammon 1987). The technique, because of its firm ecological foundation, is well suited for assessing the recovery of aquatic ecosystems (Hughes et al. 1990). In addition, the IBI can help watershed managers make better decisions through an accurate evaluation of the health for each watershed sub-basin. Most of the United States (48 States) and Canadian provinces currently use various versions of the IBI (Davis et al. 1996).

The Occoquan River Watershed in northern Virginia is the focus of this study. It currently has the distinction of having the water supply reservoir (Occoquan Reservoir) with the greatest amount of wastewater inflows and urban runoff of any in North America (Schueler 1996). By 1996, the population of the watershed had risen three times above the suggested threshold for safe drinking water, and projected growth is nearly five times the threshold by 2020. Urban land use has climbed from less than 7 percent of the watershed area in the 1970s to a present level of 31 percent, and is projected to grow significantly more over the next several years (Schueler 1996).

Because of the grave environmental concerns within the watershed, several studies have been commissioned to examine the problems and make recommendations for improvement. In a report to the Audubon Naturalist Society of the Mid-Atlantic States, Schueler (1996) recommended a comprehensive inventory of the physical and biological quality of the basin's streams and a plan for the protection of the ecological integrity of those streams. This study, in part, addresses that need by calculating an IBI for stream reaches that represent the majority of the watershed's sub-basins and relating that information to human disturbances. The study also provides an example of how the IBI can be used to determine a baseline condition for watershed planning purposes and identify problem areas in need of remediation. The study also provides a foundation for assessing the effectiveness of specific conservation practices and programs designed to improve the condition of streams in the Chesapeake Bay Watershed (e.g., Conservation Reserve Enhancement Program). With information from the IBI, watershed managers can more effectively and efficiently target activities to address natural resource concerns (Danielson 1998).

The Occoquan Watershed

Land use trends

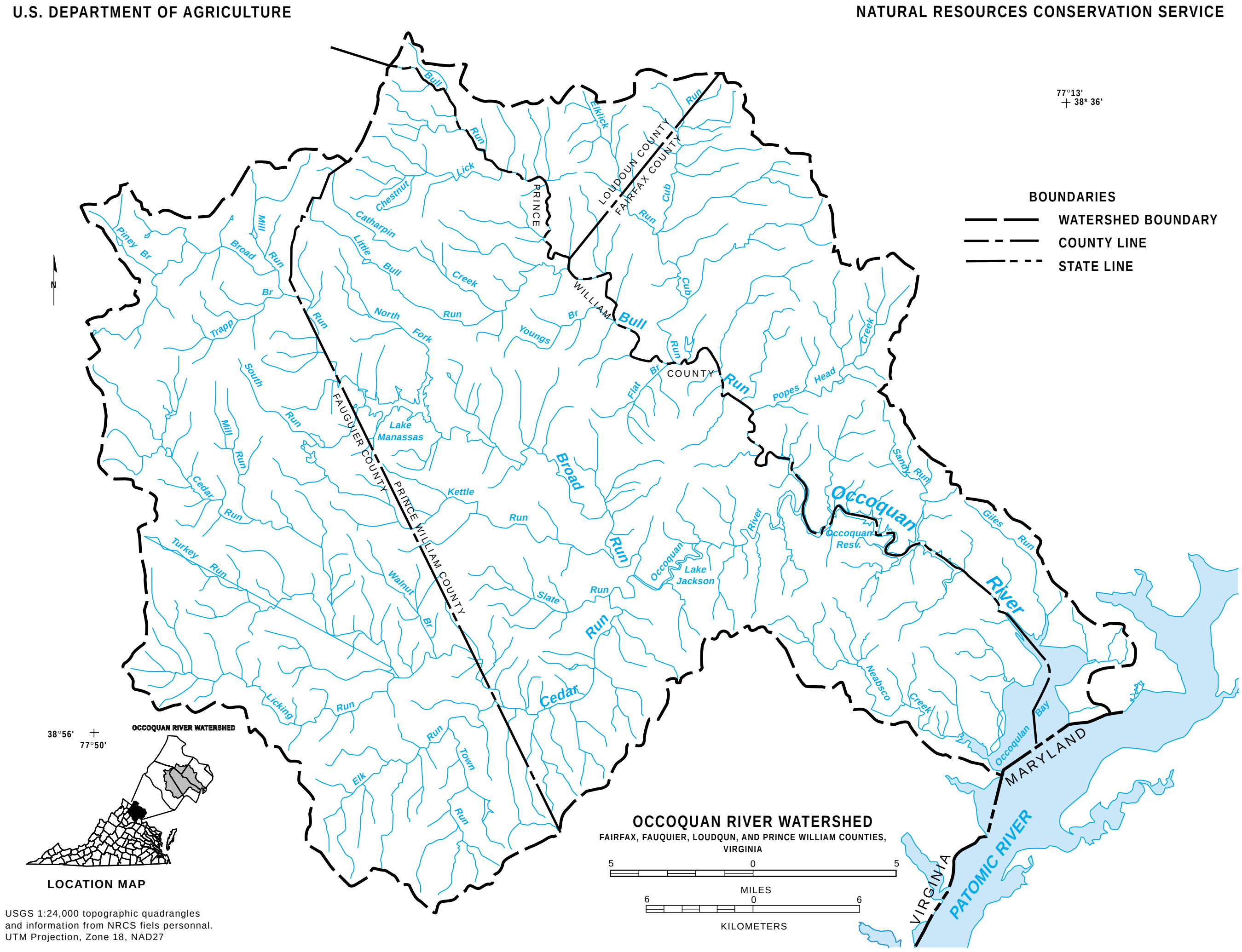
The Occoquan Watershed is about 30 to 50 miles to the south and west of the Nation's Capital (fig. 1). The boundaries of the watershed lie in the counties of Loudoun, Fairfax, Fauquier, and Prince William. The drainage area of the watershed is approximately 416,000 acres, with basin elevations rising from nearly sea level at the mouth of the Occoquan River to about 1,300 feet above sea level at Bull Run Mountain to the west. Most of the watershed occurs within the Piedmont physiographic province.

Since the 1950s, the watershed has been evolving from a rural landscape into a series of edge cities and suburban developments surrounding the Washington, D.C., metropolitan area. Because of concerns with the water supply, land use tracking within the basin has been a routine element of the Occoquan Basin Nonpoint Pollution Management Program since the late 1970s. Since that time, populations within the watershed have risen dramatically. According to census records, approximately 255,000 people lived in the watershed in 1990, twice the population recorded in 1977. Today, the watershed's population stands at about 300,000. Recent Census Bureau figures show Washington, D.C.'s, western fringe to be one of the fastest growing areas in the nation. For example, among counties with more than 10,000 people, Loudoun County's 7.7 percent growth for 1996-97 ranked eighth in the nation, and for 1998-99, its 8.1 percent growth ranked fifth. Since 1990, the human population in Loudoun County has increased by more than 55 percent.

Urban land uses in the watershed in 1989 consisted of over 78,000 acres of residential development, over 4,000 acres of commercial development, and over 8,000 acres of industrial development. In the 12 years between 1977 and 1989, more than 50,000 acres of forest and idle lands and 58,000 acres of agriculture and pasturelands were converted to urban use. In 1989, about 25 percent of the watershed consisted of urban development, which was concentrated primarily in the watershed's eastern third.

Based on conservative estimates of future growth from the Center for Watershed Protection (Schueler 1996), the trend toward suburban sprawl in the Occoquan Watershed will continue to increase. For example, urban land use comprised less than 10 percent of the total watershed area in 1977. Presently,

Figure 1 Occoquan Watershed



about a third of the watershed is devoted to urban land use. Based on the Center's projections, the share of urban land in the watershed will increase to 42 percent in a decade and surpass 50 percent by 2020 (fig. 2).

While the amount of land converted to urban use is sharply increasing, most recent development has been of a low-density residential character (fig. 3). About two-thirds of all urban land in the basin as of 1989 was either in low density or estate residential zoning categories (i.e., half-acre lots or larger). The remaining third of urban development is in higher density residential, townhouse, commercial, industrial, and institutional uses. The low-density land use distribution is typical of recent suburban sprawl. Decisions to downzone parts of the basin to protect reservoir water quality has been partly responsible for low-density suburban land use in the watershed.

It should be noted, however, that low-density residential development is not always environmentally benign on either a regional or watershed basis (Schueler 1995). For example, nearly two-thirds of the impervious surface created by new development is for the roads, streets, sidewalks, and driveways that serve each individual lot (City of Olympia 1994). GIS output provided by Northern Virginia Planning District Commission (1994) suggests that as of 1989 more than 2,200 miles of streets, roads, and highways extended across the basin to connect low-density development, resulting in the creation of 13 to 20 square miles of impervious surface. An indicator of the basin's continuing urbanization is that there are now 1,000 more miles of roads than streams in the basin.

Percent impervious surface is an excellent measure of the cumulative impact of urban land development on aquatic systems (Arnold and Gibbons 1996, Schueler 1995). Since 1977, impervious cover has steadily increased from 3 percent to an estimated 11 percent in 1995. By 2006, impervious cover is projected to grow to 16 percent of the basin, and then reach 20 percent by the year 2020 (fig. 4). Simply put, within 30 years, 2 out of every 10 acres in the watershed will be paved. Such a marked shift is likely to induce major changes in hydrology and water quality across the watershed.

Figure 2 Urban and non-urban land use in the Occoquan Basin: 1977–2020 (Schueler 1996)

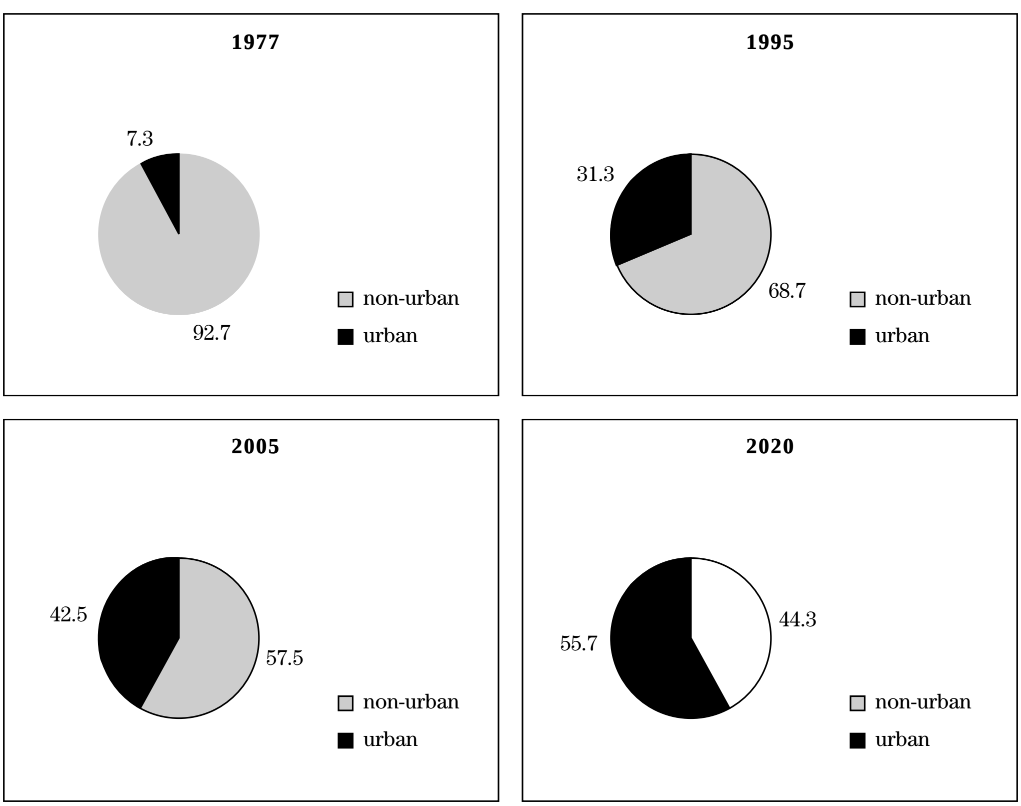


Figure 3 Distribution of urban land use in the Occoquan Basin: 1989 (Schueler 1996)

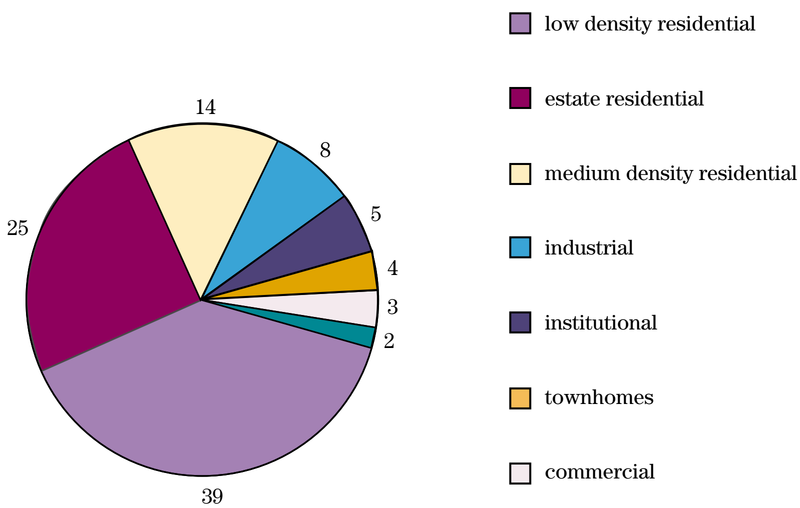
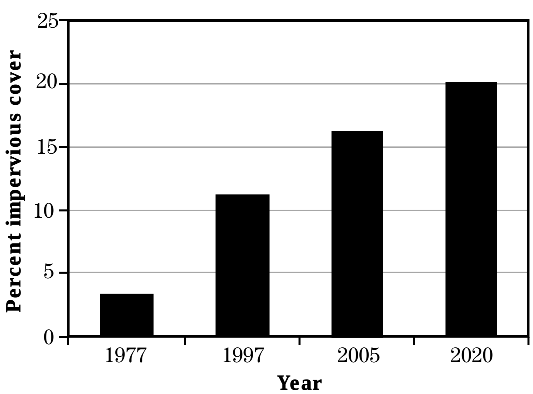


Figure 4 Growth in impervious surface in the Occoquan Basin: 1977–2020 (Schueler 1996)



Despite the rapid suburban development, the watershed is still predominantly rural, especially the western portion. Currently, approximately 70 percent of the entire watershed is either classified as agriculture, pasture, or forested/idle lands. Future development is expected to sharply reduce the acreage of forest, crops, and pasture in the basin (fig. 5). Collectively, these three rural land uses are projected to dwindle by 40 percent by the year 2020. Cropland, in particular, is expected to be reduced to less than 40,000 acres in the next decade. On the positive side, farmers are increasingly using conservation practices on their land to reduce erosion and nutrient export. For example, as of 1989, farmers were employing conservation tillage practices on nearly half the cropland in the watershed. At the same time that cropland is declining across the watershed, intensively managed turf (lawns, golf courses) is rapidly increasing (fig. 6).

As the watershed takes on a more urban character, industrial land uses are expected to increase substantially. In 1989, more than 12 square miles of the watershed were already classified as industrial. Industrial sites have the potential to become hotspots for many stormwater pollutants, such as hydrocarbons, trace metals, and toxic pollutants. As this land use category becomes greater in size, the risk is higher for spills, leaks, and pollutant washoff and infiltration that could affect water quality.

Figure 5 Growth of urban land and high-input turf in the Occoquan Basin: 1977–2020 (Schueler 1996)

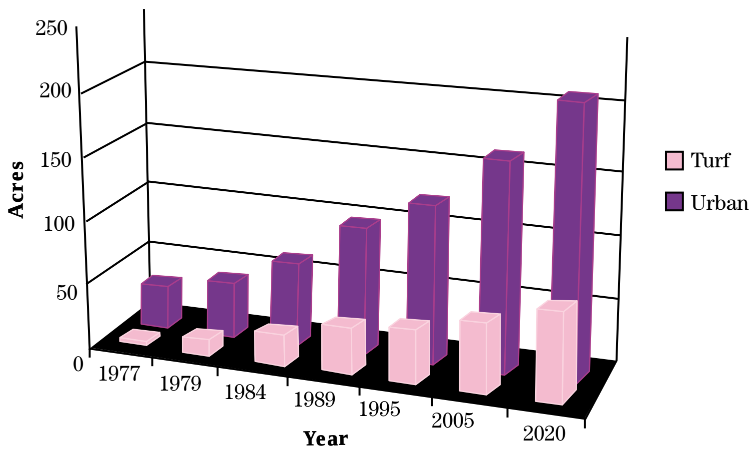
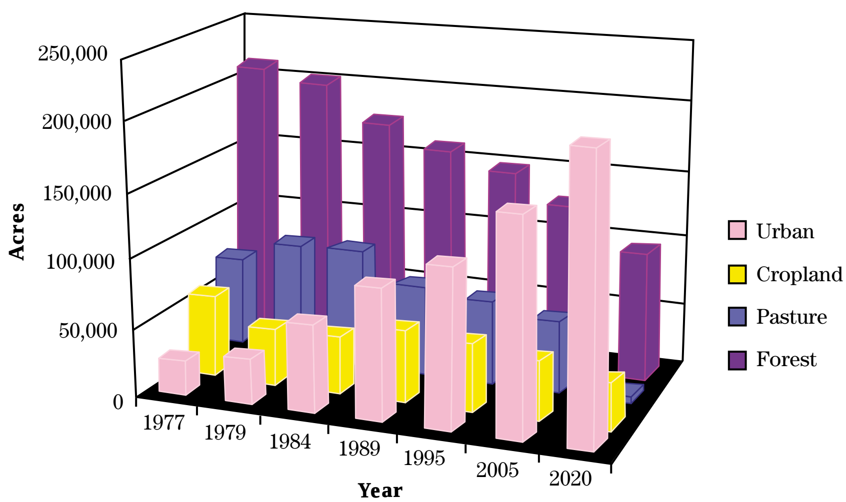


Figure 6 Loss of forest, pasture, and cropland in the Occoquan Basin: 1977–2020 (Schueler 1996)



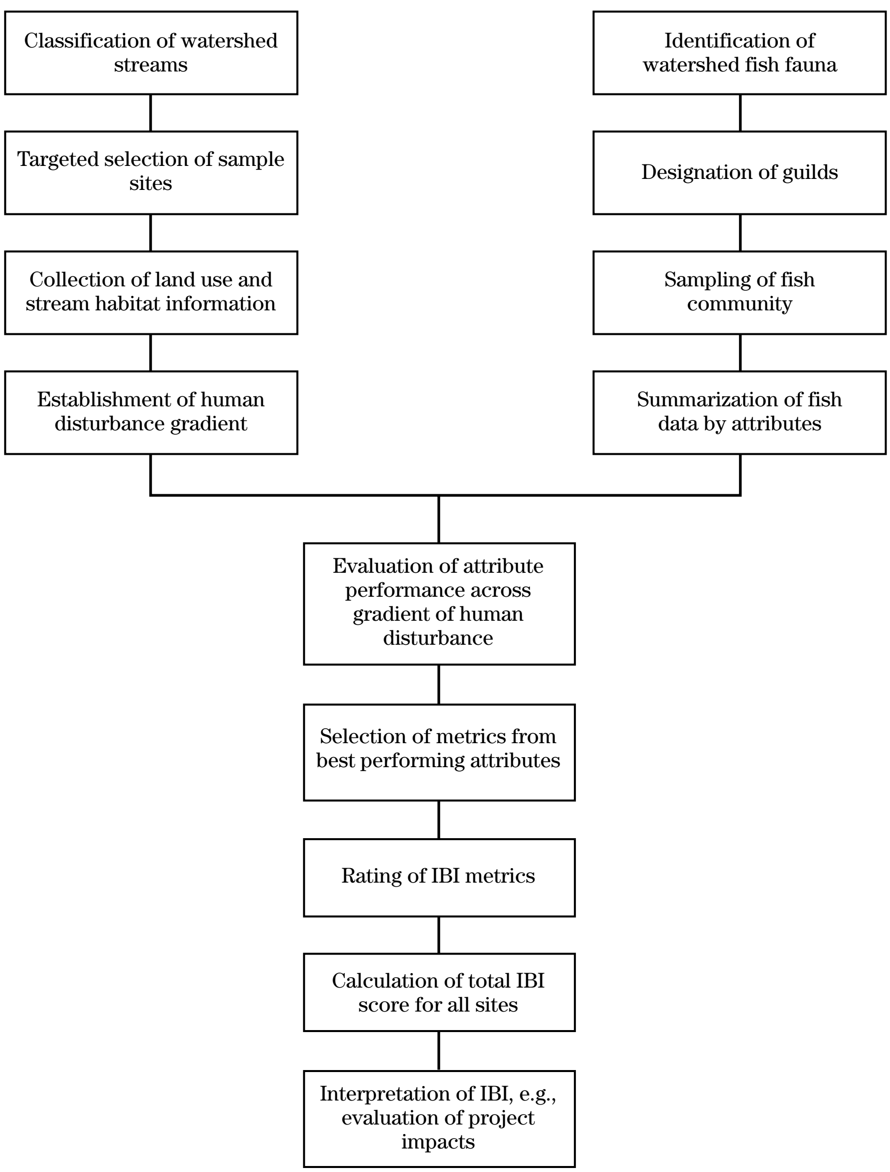
Watershed streams

Three major stream systems of approximately equal proportions combine to compose the Occoquan River: Bull Run, Broad Run, and Cedar Run. All begin in the watershed's western rural portion and flow eastward where they unite near the upper end of Occoquan Reservoir. Land use patterns within the western portions of the three major systems are similar. The streams flow through three separate zones of the Piedmont before reaching the Potomac estuary (Hack 1982). The headwaters arise in the prominent ridges (e.g., Bull Run Mountain) of the Outer Piedmont in predominantly forested landscapes. As the streams flow eastward, they traverse a rural, rolling landscape of interspersed pasture and woodlands with occasional cropland. Streams in this part of the watershed generally have moderate gradient with frequent riffles composed of substrates of gravel or rubble, and sometimes boulder or bedrock. As the streams leave the Foothill Zone, they enter the more level landscape of the Culpeper Basin, where land use intensifies from both agriculture and suburban development. Streams within the Basin have gentler slopes. Riffles and runs decrease in frequency and generally consist of loose gravel composed of reddish shale or sandstone derived from the parent materials that underlie the basin. Silt and embeddedness that are a result of modest land relief and two centuries of farming are common features of basin streams. As the three main streams flow eastward, they join in the Inner Piedmont. First, Cedar and Broad Run unite near the upper end of Lake Jackson to form Occoquan Creek, which later joins Bull Run in the upper end of Occoquan Reservoir to become the Occoquan River. This part of the watershed is primarily residential with low to medium density housing toward the city of Manassas and higher density developments toward the watershed's eastern edge near Woodbridge (see fig. 1).

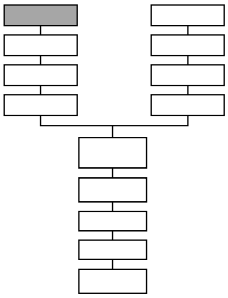
Methods

The IBI is a widely used approach for evaluating the health of streams. However, an IBI developed in one region generally cannot be applied in another region without modification because of regional differences in fish fauna and environmental conditions. Essentially, an IBI must be built for each regional assemblage based on knowledge of the range of observable responses in the area and reference conditions derived from the region's least disturbed streams. The following hierarchical process was used to develop the IBI for this study (fig. 7).

Figure 7 Sequence of activities in developing IBI (adapted from Karr et al. 1986)



Classification of watershed streams



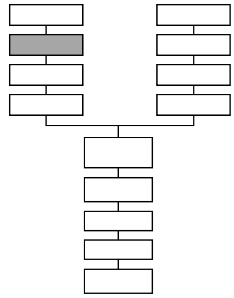
The process of developing an IBI begins by selecting an appropriate sampling design, which is influenced by the scale at which the IBI is expected to function. A study area must be large enough to represent the full range of human influence, but small enough to minimize the effects from natural variables, such as stream size. One major challenge is that there are few, if any, places left that have not been influenced by human actions, particularly in the area surrounding the Washington suburbs. Some common pitfalls in sizing a study area and establishing an appropriate reference include

- using local sites that are degraded rather than looking over a wide area of minimally disturbed sites,
- arbitrarily defining reference sites without adequate screening site evaluation, and
- classifying sites inaccurately so that degraded sites are put into reference sets (Karr and Chu 1997).

The goal of this study was to inventory streams in the Occoquan River Watershed to determine their biological condition; however, as previously described the watershed is rapidly developing, raising issue with whether any streams in the watershed retain enough integrity to be used as *least-impaired reference*. To address this issue, the study area was expanded into the neighboring upper Rappahannock River and Goose Creek Watersheds. Those watersheds lie immediately west of the Occoquan and have much in common with it except for comparably less urban and suburban development. Thus, the IBI in this study was based on a 1997 to 1999 fish survey that included 157 sites on tributaries of the Occoquan River, upper Rappahannock River, and Goose Creek (fig. 8 and 9).

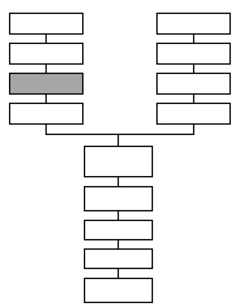
Stream drainage area size classes of less 17 square kilometers, 17 to 34 square kilometers, and more than 34 square kilometers were established within the study area to ensure the inclusion and even distribution of different size streams. The size of the three classes was determined by 4 years of previous sampling in the Occoquan Watershed, which demonstrated similarity in species richness within those classes. ArcView geographic information system was used to delineate and calculate the drainage area above each sample site on digital raster graph (DRG) topographic maps.

Targeted selection of sample sites



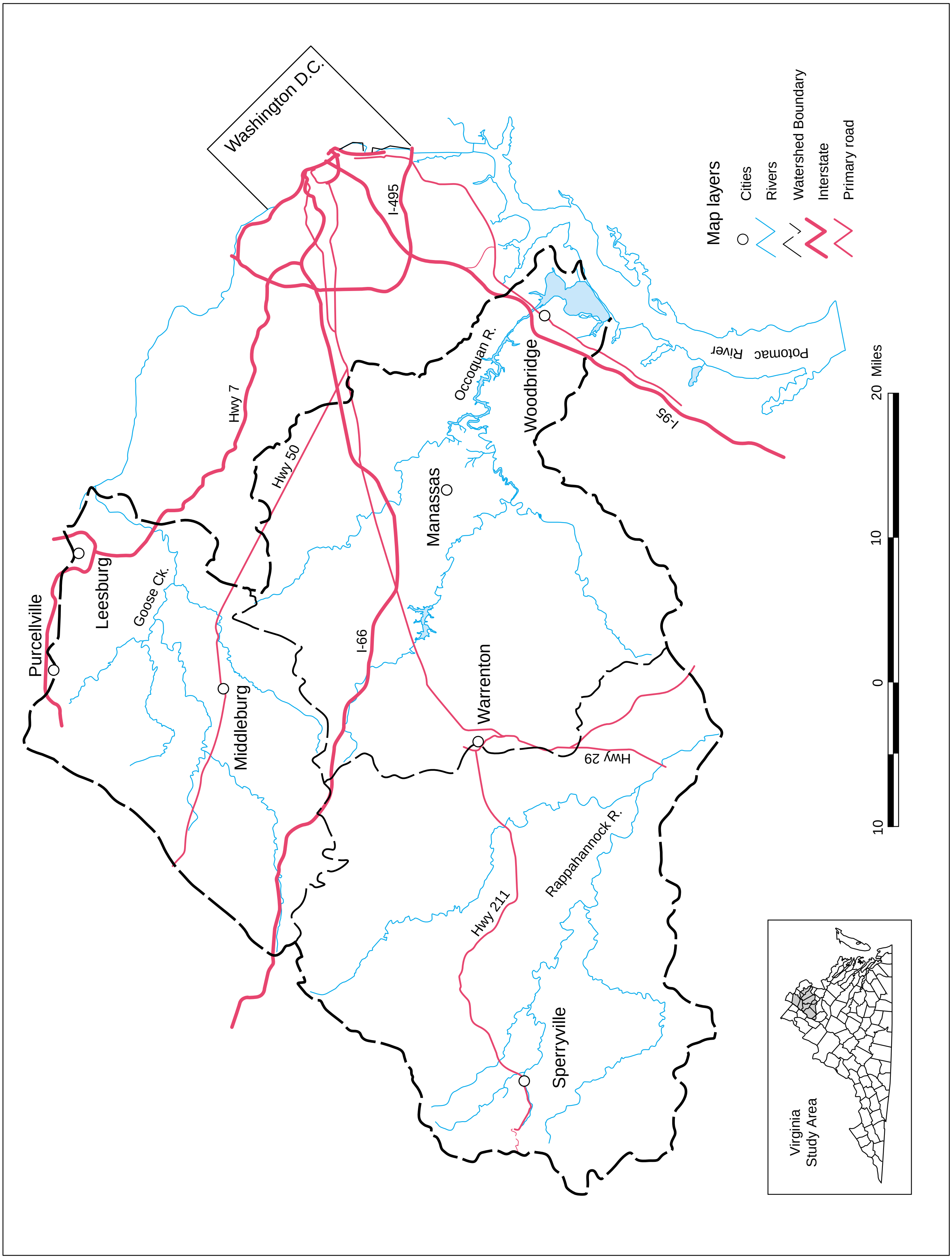
Since human influences arise from varied and complex sources, it may be virtually impossible to represent the gradient of human disturbance or select reference sites through an entirely random approach. Rather, a targeted approach is recommended to ensure that the ends of the disturbance gradient are adequately reflected and that relatively secure and accessible reference sites are available for sampling (Karr and Chu 1997). To help capture the ends of the gradient in the study area, five least- and most-impaired sites from each stream size class were identified prior to fish sampling based on an assessment of impairment using local land use maps, aerial photography, and a field reconnaissance. Other sites were later added to ensure that the full range of disturbance was included, as well as a relatively even distribution of sample sites across the study area. Specific locations for each of the 157 sites are listed and illustrated in the appendix (appendix table 7 and fig. 35–37).

Collection of stream habitat and land use information



The need to test and validate biological responses of individual metrics across degrees of human influence is a core assumption of IBI (Karr and Chu 1997). A metric is a measurable component of a fish assemblage that is empirically shown to change in value along a gradient of human influence (e.g., total number of species or the percentage of individuals that are omnivores) (Karr and Chu 1997). Metrics are chosen on the basis of how well they reflect specific and predictable biological responses to human activities. Before starting the field sampling, enough information should be gathered about the watershed so that potential locations for fish sampling can be targeted and ranked from least to most impaired along a gradient of disturbance. Such information is generally gathered from both published information and field reconnaissance. In addition, the information gathered during this stage can help verify that streams are classified correctly and provide insights into why biological communities are damaged during the IBI interpretation phase.

Figure 8 Study area watershed boundaries

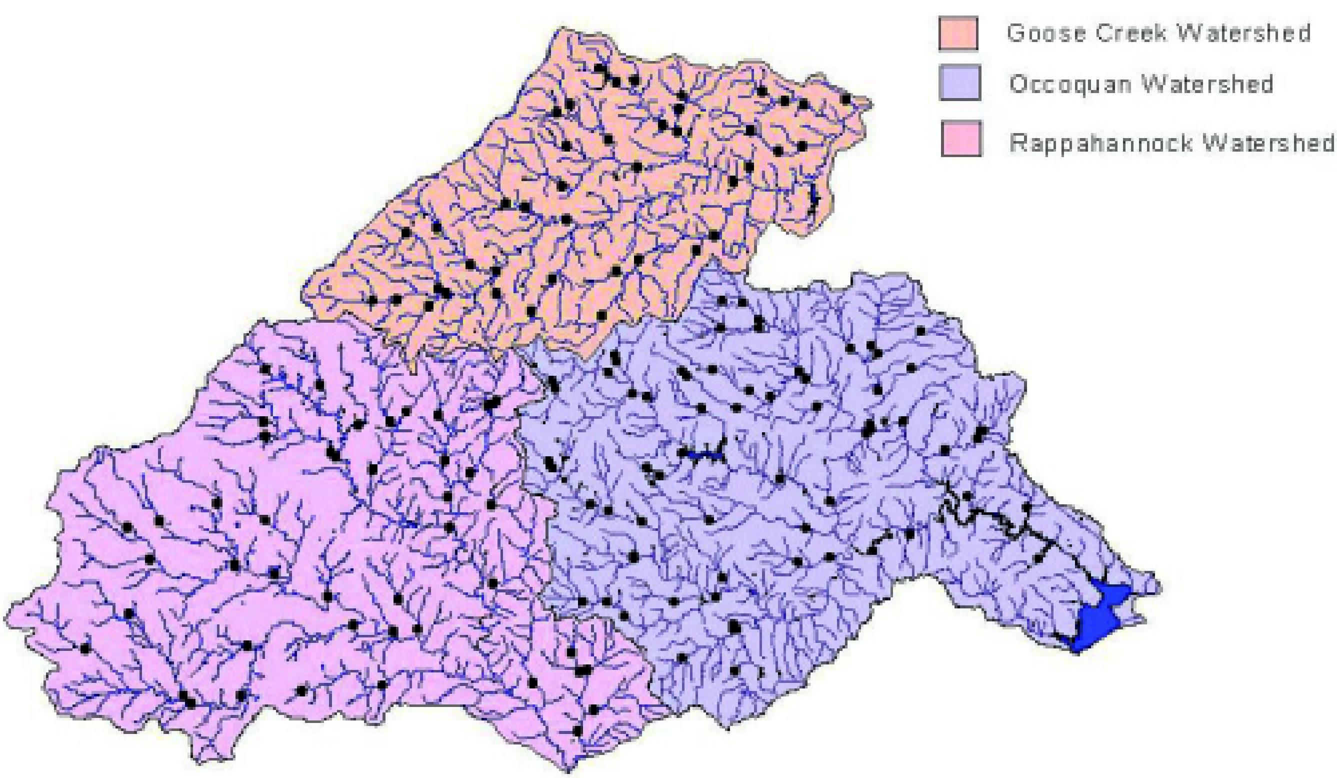


The collection of habitat and land use information may be greatly aided by a Geographic Information System (GIS). For example, several recent GIS studies have found significant negative correlations between watershed-wide agricultural or urban land uses and stream health, as represented by the IBI (Lenat and Crawford 1994, Richards et al. 1996, Roth et al. 1996, Wang et al. 1997). Although GIS can be a powerful tool for helping define a disturbance gradient, it is not a replacement, or even a good surrogate, for the IBI itself or for biological monitoring (Karr and Chu 1997). In addition to the broad spatial relationships examined by GIS, onsite visits are generally required to define more local impacts.

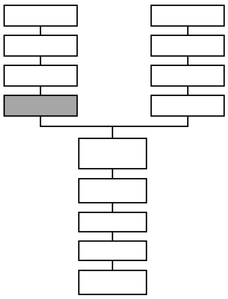
A number of onsite techniques have been developed to assess the habitat of streams; for example: USEPA, Rapid Bioassessment Procedures (RBP) and EMAP; Ohio EPA, Qualitative Habitat Evaluation Index (QHEI); and NRCS, Stream Visual Assessment Protocol (SVAP) (USDA 1998). SVAP was chosen as the onsite assessment technique. This technique is designed to assess on-farm reach impairments with private landowners based primarily on physical conditions of the stream, which aligns closely with the goals of our study. The SVAP technique was independently applied by three members of the crew after conducting the fish survey at each site.

ArcView was used to delineate drainage areas above each sample site and overlaid data layers to calculate the percentage of cropland, pastureland, rural nonagricultural land, and urban land within those drainages. Land use information was obtained from the Virginia Geographic Information System (VirGIS) and the Virginia Gap Analysis.

Figure 9 Study area and fish sampling locations



Establishment of human disturbance gradient



Once sites have been targeted for selection into the reference and land use and habitat information have been gathered, the sites should be ranked according to degrees of human disturbance. This is important to ensure that metrics are sensitive. Human disturbance serves as the gradient along the X-axis to which biological attribute data along the Y-axis are compared. Determining the disturbance gradient must be done before sampling begins, rather than as an afterthought. The reason for this is that post-hoc categorization may reveal that the full range of human disturbance was not captured, thus requiring additional sampling or limiting the usefulness of the IBI.

In most circumstances, diverse human activities interact to affect conditions in watersheds, waterbodies, or stream reaches (Karr and Chu 1997). In fact, it is virtually impossible to find regions influenced by only a single human activity, thus making the disturbance gradient difficult to construct. Where there is adequate information, the development and use of a Human Disturbance Index (HDI) may greatly help to define the disturbance gradient (Karr and Chu 1997). Such an index should incorporate values representing various degrees and combinations of prevailing human disturbances for all sites, not just the least- and most-disturbed. Although a standard protocol for constructing such an index does not exist, it should be derived from a variety of disturbances rather than from a single source. Furthermore, the disturbances should be represented from both watershed and local scales. For example, scores from the landscape (e.g., percent cropland, pastureland and urban land) should be combined with scores from onsite assessments.

In this study, an HDI was developed for the region based on

- percent of drainage above each sample reach in cropland, pasture, or urban land uses;
- proximity of the sample reach to fish barriers; and
- an assessment of onsite impairments within each reach using results from the NRCS Stream Visual Assessment Protocol (1998) (fig. 10).

Land use scores were assigned by determining the percentage of urban land, cropland, and pastureland in the drainage area above each fish sampling location. Criteria for land use scoring were then established by dividing the minimum and maximum percentages over all the drainages into equal fifths for each land use. Scoring was then accomplished by assigning scores to the resulting categories, with categories having the greatest land use intensity receiving the lowest score, following the process illustrated in figure 10. Because a combination of percentages of land use could occur within each drainage, the process used the combination and percentage that was most limiting to determine the score. For example, if greater than 20 percent of a drainage was urban, then it would score only 2 points for both the cropland/urban land and pastureland/urban land components, without regard to how much cropland or pastureland was actually present. Likewise, if less than 5 percent of a drainage was urban, and between 21 and 30 percent was cropland, then it would score 4 for the urban/cropland component. Scores for proximity to fish barriers were assigned based on the Stream Visual Assessment Protocol (USDA 1998). Proximity of sample locations to fish barriers was determined through interpretation of USGS topography maps and USDA aerial photography and by observations made during the reach assessments. Stream Visual Assessment Protocol scores were determined by dividing the range of SVAP results over all sites into equal tenths and assigning scores based on the process illustrated in figure 10.

Figure 10 Criteria and scoring for Human Disturbance Index (HDI)

Urban/Cropland (condition applies that would result in lowest score)

<5% of drainage urban; or <11% cropland	5–10% of drainage urban; or 11–20% cropland	11–15% of drainage urban; or 21–30% cropland	16–20% of drainage urban; or 31–38% cropland	>20% of drainage urban; or >38% cropland
10	8	6	4	2

Urban/Pastureland (condition applies that would result in lowest score)

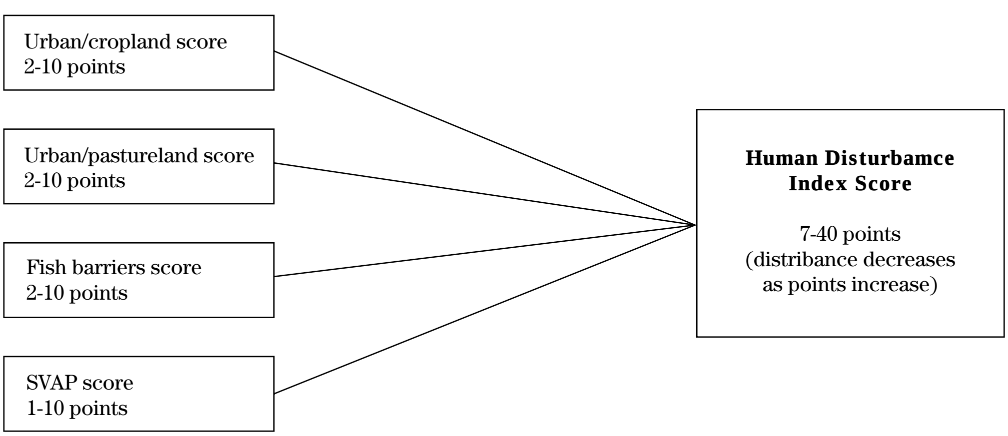
<5% of drainage urban; or <13% pasture	5–10% of drainage urban; or 13—22% pasture	11–15% of drainage urban; or 23–32% pasture	16–20% of drainage urban; or 33–42% pasture	>20% of drainage urban; or >42% pasture
10	8	6	4	2

Fish Barriers

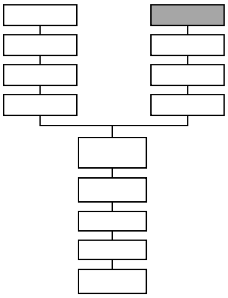
No barriers	Seasonal water withdrawals inhibit fish movement	Drop structures, culverts, dams, or diversions (<0.3 m drop) within the reach	Drop structures, culverts, dams, or diversions (>0.3 m drop) within 5 km of the reach	Drop structures, culverts, or diversions (>0.3 m drop) within or bordering the reach
10	8	6	4	2

Reach Impairment (SVAP) Score

> 9.6	9.0–9.6	8.3–8.9	7.6–8.2	6.9–7.5	6.2–6.8	5.5–6.1	4.8–5.4	4.1–4.7	< 4.0
10	9	8	7	6	5	4	3	2	1



Identification of watershed fish fauna



Before fish are sampled and their numbers recorded, all species in the regional fish fauna must be recorded (Karr et al. 1986). Based on the work of previous researchers and species range maps provided by Jenkins and Burkhead (1993), we expected to collect over 50 species in the study area. The cumulative total for the study area was 57 species with 42 collected in Occoquan, 43 collected in Goose Creek, and 43 collected in the upper Rappahannock. However, some species are found in only one or two of the watersheds. For example, Potomac sculpin (*Cottus girardi*) is found in Goose Creek, but not the other two watersheds (table 1 and appendix, fig. 33).

Table 1 List of species collected by watershed

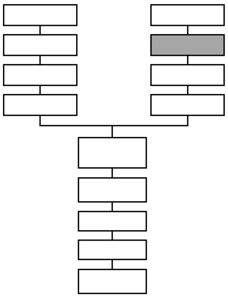
Scientific name and taxonomic reference	Common name	Occoquan	Rappahannock	Goose Creek
Petromyzontidae (1)				
Lampetra appendix (Dekay)	American brook lamprey		x	
Clupeidae (1)				
Dorosoma cepedianum (Lesueur)	Gizzard shad	x		
Anguillidae (1)				
Anguilla rostrata (Lesueur)	American eel		x	
Esocidae (1)				
Esox americanus Gmelin	Redfin pickerel	x		
Umbridae (1)				
Umbra pygmaea (Dekay)	Eastern mudminnow	x		
Cyprinidae (23)				
Cyprinus carpio (Linnaeus)	Common carp*	x		
Notemigonus chrysoleucas (Mitchil)	Golden shiner	x	x	x
Phoxinus oreas (Cope)	Mountain redbelly dace*		x	
Clinostomus funduloides Girard	Rosyside dace	x	x	x
Semotilus corporalis (Mitchil)	Fallfish	x	x	x
Semotilus atromaculatus (Mitchil)	Creek chub	x	x	x
Nocomis micropogon (Cope)	River chub	x	x	x
Nocomis leptocephalus (Girard)	Bluehead chub		x	
Exoglossum maxillingua (Lesueur)	Cutlips minnow	x	x	x
Rhinichthys atratulus (Hermann)	Blacknose dace	x	x	x
Rhinichthys cataractae (Valenciennes)	Longnose dace	x	x	x
Campostoma anomalum (Rafinesque)	Central stoneroller			x
Hybognathus regius (Girard)	Eastern silvery minnow	x	x	x
Luxilis cornutus (Mitchil)	Common shiner	x	x	x
Cyprinella analostana (Girard)	Satinfin shiner	x	x	x
Cyprinella spiloptera (Cope)	Spotfin shiner	x		x
Pimephales notatus (Rafinesque)	Bluntnose minnow*	x	x	x
Pimephales promelas Rafinesque	Fathead minnow*	x		x
Notropis amoenus (Abbot)	Comely shiner	x	x	x
Notropis hudsonius (Clinton)	Spottail shiner	x	x	x

Table 1 List of species collected by watershed—Continued

Scientific name and taxonomic reference	Common name	Occoquan	Rappahannock	Goose Creek
Cyprinidae (continued)				
Notropis procne (Cope)	Swallowtail shiner	x	x	x
Notropis rubellus (Agassiz)	Rosyface shiner	x	x	x
Notropis buccatus (Cope)	Silverjaw minnow		x	x
Catostomidae (6)				
Catostomus commersoni (Lacepede)	White sucker	x	x	x
Erimyzon oblongus (Mitchil)	Creek chubsucker	x	x	x
Hypentelium nigricans (Lesueur)	Northern hogsucker	x	x	x
Thoburnia rhothoeca (Thoburn)	Torrent sucker*		x	
Moxostoma erythrurum (Rafinesque)	Golden redhorse*	x		x
Moxostoma macrolepidotum (Lesueur)	Shorthead redhorse		x	
Ictaluridae (4)				
Ictalurus punctatus (Rafinesque)	Channel catfish*			x
Ameiurus natalis (Lesueur)	Yellow bullhead	x	x	x
Ameiurus nebulosus (Lesueur)	Brown bullhead	x	x	x
Noturus insignis (Richardson)	Margined madtom	x	x	x
Fundulidae (1)				
Fundulus diaphanus (Lesueur)	Banded killifish	x		x
Poeciliidae (1)				
Gambusia holbrooki (Girard)	Eastern mosquitofish	x	x	x
Cottidae (2)				
Cotus bairdi (Girard)	Mottled sculpin		x	
Cottus girardi Robins	Potomac sculpin			x
Centrarchidae (9)				
Lepomis auritus (Linnaeus)	Redbreast sunfish	x	x	x
Lepomis cyanellus (Rafinesque)	Green sunfish*	x	x	x
Lepomis gibbosus (Linnaeus)	Pumpkinseed	x	x	x
Lepomis macrochirus (Rafinesque)	Bluegill*	x	x	x
Lepomis microlophus (Gunther)	Redear sunfish*	x		
Ambloplites rupestris (Rafinesque)	Rock bass*		x	x
Pomoxis annularis (Rafinesque)	White crappie*	x	x	x
Micropterus dolomieu (Lacepede)	Smallmouth bass*	x	x	x
Micropterus salmoides (Lacepede)	Largemouth bass*	x	x	x
Percidae (6)				
Percina peltata (Stauffer)	Shield darter	x	x	x
Percina notogramma (Raney)	Stripeback darter		x	
Etheostoma olmstedi Storer	Tesselated darter	x	x	x
Etheostoma vitreum (Cope)	Glassy darter		x	
Etheostoma flabellare (Rafinesque)	Fantail darter	x		x
Etheostoma blennioides (Rafinesque)	Greenside darter*			x

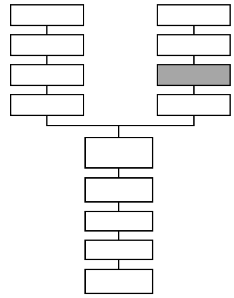
* Indicates non-native species.

Designation of guilds



The IBI requires the classification of species from the regional fish fauna into a number of biological groupings, or guilds, from which potential metrics (attributes) are proposed, tested, and selected as metrics for the IBI. Before fish are sampled and their numbers recorded, all species in the regional fish fauna must be characterized according to food requirements, tolerance status, and other such characteristics (table 2). With few exceptions, the biological groupings for this study follow Smogor (1996), who classified freshwater fish species in over 140 Virginia collections for purposes of IBI development. One notable exception is the classification for tolerant and intolerant species. In this case, only the species collected in the study area were used as the basis for designations, whereas Smogor used species collected over the entire state. Karr and Chu (1997) recommended including no more than 5 to 15 percent of the species in the regional fauna to be designated as tolerant or intolerant. Since 57 species were collected in the study area (Occoquan, upper Rappahannock, and Goose Creek combined), 8 species were designated as tolerant and intolerant for the study area (approximately 14%) (table 2).

Sampling of fish community



A basic premise of IBI is that the entire fish fauna has been sampled in its true relative abundance without bias toward taxa or size of fish (Karr et al. 1986). As this assumption is relaxed, the reliability of inferences based on the IBI is reduced. However, with any method there are certain inherent biases that affect the quality of the sample. Therefore, it is important to understand method limitations and adhere as strictly as possible to sampling protocols to maintain consistency of data and reduce sampling variability.

Seines were chosen as the method to collect fish in this study. Seines are reportedly the best tool for sampling fish in small, relatively simple streams (Karr et al. 1986). They are inexpensive, simple, easy to use, and seldom break down. In addition, seining can be employed with less fish mortality than certain other techniques, such as electrofishing. Seines are also relatively nonselective for different sizes of fish, whereas a higher rate of capture of large fish than small fish may occur in electrofishing (Cooper 1952, Johnson 1965). However, as several studies have suggested, seining also has a number of disadvantages

Table 2 Biological groupings for fish species collected across the three watersheds (designations adapted from Smogor 1996)

Non-native: Species considered by Jenkins and Burkhead (1993) to be non-native to the above drainages.
Tol: Species designated as tolerant or intolerant (each limited to 15% of the total fauna).
No. food groups: Number of food groups upon which a species normally relies.
Trophic groups: PIS = piscivore, INV = invertivore, AHI = algivore/herbivore/invertivore,
IP = invertivore/piscivore, DAH = detritivore/algivore/herbivore
Ben: Species considered benthic (bottom dwelling).
Lith: Species considered simple lithophils (scatter their eggs in gravel and provide no care for their young).
Late maturing: Species that normally do not breed until at least their third year.
Var. spawner: Species that can manipulate various substrates to spawn.

Common name	Non-native	Tol.	No. food groups	Trophic	Ben.	Lith.	Pio.	Late maturing	Var. spawner
American brook lamprey		I	2	DAH	x			x	
Gizzard shad			2	AHI					x
American eel			2	IP				x	
Redfin pickerel		I	1	PIS					
Eastern mudminnow			1	INV					x
Common carp	x		4	AHI			x	x	x
Golden shiner			2	AHI			x		
Mountain redbelly dace	x		3	DAH		x			

Table 2 Biological groupings for fish species collected across the three watersheds (designations adapted from Smogor 1996)—Continued

Common name	Non-native	Tol.	No. food groups	Trophic	Ben.	Lith.	Pio.	Late maturing	Var. spawner
Rosyside dace			1	INV		x			
Fallfish			4	IP					
Creek chub		T	4	IP			x		
River chub			3	INV				x	
Bluehead chub			3	AHI				x	
Cutlips minnow			1	INV					
Blacknose dace		T	3	INV		x			
Longnose dace			2	INV	x	x			
Central stoneroller			2	DAH		x			
Eastern silvery minnow			2	AHI					
Common shiner			4	INV		x			
Satinfin shiner			2	INV					
Spotfin shiner			3	INV					
Bluntnose minnow	x	T	3	AHI			x		x
Fathead minnow	x		3	AHI			x		x
Comely shiner			1	INV		x			
Spottail shiner			2	INV					
Swallowtail shiner			2	INV		x			
Rosyface shiner		I	1	INV		x			
Silverjaw minnow		T	3	AHI		x			
White sucker		T	3	AHI	x	x			
Creek chubsucker			3	INV	x		x		
Northern hogsucker			2	INV	x	x		x	
Torrent sucker	x		2	INV	x	x		x	
Golden redhorse	x		3	INV	x	x		x	
Shorthead redhorse			3	INV	x	x		x	
Channel catfish	x		3	IP				x	x
Yellow bullhead			3	IP			x		x
Brown bullhead			3	IP				x	x
Margined madtom		I	2	INV	x			x	
Banded killifish			1	INV					
Eastern mosquitofish		T	1	INV			x		
Mottled sculpin		I	1	INV	x				x
Potomac sculpin		I	1	INV	x				x
Redbreast sunfish			2	IP					
Green sunfish	x	T	2	IP			x		x
Pumpkinseed			2	INV			x		x
Bluegill	x	T	1	INV			x		x
Redear sunfish	x		1	INV					x
Rock bass	X		2	IP					
White crappie	x		2	IP			x		x
Smallmouth bass	x		2	PIS					x
Largemouth bass	x		1	PIS					x
Shield darter		I	1	INV	x				
Stripeback darter			1	INV	x	x			
Tesselated darter			1	INV	x				x
Glassy darter		I	1	INV	x				
Fantail darter			1	INV	x				
Greenside darter	x		1	INV	x				

that may, if not properly addressed, inappropriately influence the IBI. For example, in several studies seining was found to underestimate species richness in streams with slab boulders and cobbles, which interfered with efficient use of the seine (Hoover 1938; Yoder and Smith 1999).

In addition, in Ohio seining was found to produce variable results caused by differing levels of skill between field crews (Ohio EPA 1998). Finally, the number of large fish may be underestimated because they are more likely to evade the seine.

Because of the various inherent limitations regarding the use of seines, extreme caution was used in this study to conduct sampling in a manner that would reduce method bias and maintain as much consistency as posible across sample locations. For example, all sampling was conducted using a 2.4 meter (length) by 1.8 meter (depth) minnow seine. To maintain consistency in the application of the technique and accuracy in the identification of species, the primary investigator performed all sampling. The 2- to 3-person crew that assisted in sampling was trained and supervised by the primary investigator. Together, they performed all sampling within a standard timeframe, which included the time required to move from one point to the next and to sort the samples (fig. 11). All habitat types, such as pools, runs, and riffles that could be covered within the standard timeframe were sampled in proportion to their occurrence. Because uneven bottoms and obstructions reportedly limit the utility of seines, special care was taken to sample in and around such obstructions, although seining may have been difficult. Large pools were sampled by trapping fish against the bank or at the ends of pools with repeated short seine hauls. Microhabitats, such as spaces beneath logs and boulders, undercut banks, drifts,

Figure 11 Sampling method: clockwise from upper left: (1) probing undercut bank microhabitat, (2) sorting and recording fish, (3) observing SVAP evaluation components within sample reach, and (4) completing SVAP forms

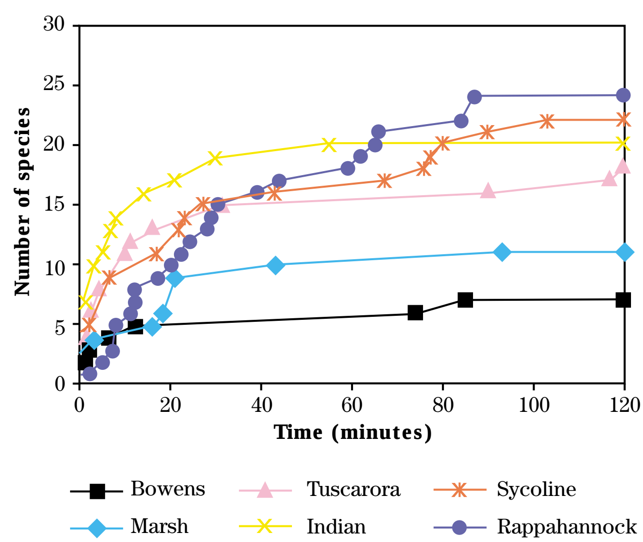
logjams, gravel riffles, and aquatic vegetation, were sampled by disturbing the area and then quickly seining through. Each microhabitat was sampled as comprehensively as possible to avoid missing species or misrepresenting relative abundance.

To reduce identification error and temporal bias to young-of-the-year fish, only specimens more than 25 mm long were enumerated and included in the data (Angermeier and Karr 1986). These were identified to species, counted, recorded, and then released back into the stream. Specimens that could not be identified were preserved in 10 percent formalin and taken to the laboratory for identification. All sampling was conducted between late May and mid-September, in daylight hours, and during periods of low flow. In this part of the country, we are well into the growing season by late May. The trees all have leaves, and it is the peak migration period for songbirds. Observations of hybrids and, anomalies were also enumerated and recorded on data sheets.

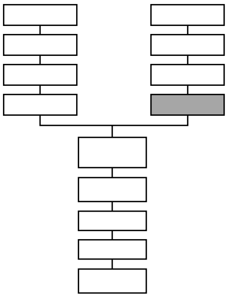
Our level of sample effort was determined interactively by sampling some of the watersheds' lesser impaired streams prior to the 1997-99 fish survey to assess the length of stream or amount of time necessary to secure an adequate sample. Through that process, we found that we were unable to achieve consistent results and frequently underestimated species richness when the sample reach was based on fixed lengths of various dimensions (up to 300 meters). Other studies have demonstrated that standard sample lengths may not always be long enough to account for discontinuity in fish distributions (Angermeier and Smogor 1994, Lyons 1992). Therefore, species composition or relative abundance should not be misrepresented because sampling effort has been too little. Angermeier and Smoger (1994) recommend interactive approaches to ensure that the length of the sample reach is adequate. For example, they suggest maintaining a cumulative list of species found and to stop sampling when a predetermined number of additional sampling efforts fail to yield additional species. Lyons (1992) concludes that meaningful estimates of species richness for assessments can be achieved only if the length of each stream segment sampled approaches or exceeds the length at which the cumulative species number becomes asymptotic. Accordingly, for electrofishing, he recommended sampling 35 times the mean stream width to yield an acceptable estimate of species richness. However, he acknowledged that that distance might not be appropriate for all sampling gears.

Because seining is generally considered to be a more passive sampling technique and because all of our efforts to produce consistent results using fixed lengths met with failure, we tested a 2-hour time limit as a standard for sampling instead. The 2-hour limit was set by sampling some of the region's least impaired and most physically complex streams and determining the amount of time it would take for the cumulative species number to become asymptotic (*species/area curve* begins to level off indicating diminishing returns per sample effort). In our analysis, the amount of time required to reach diminishing returns differed somewhat among streams; however, it was always encountered well before the 2-hour frame had elapsed. In addition, during the 1997-99 fish survey, *species-area curves* were plotted for streams from a variety of size classes and degrees of impairment to help confirm our previous analysis (fig. 12). In all instances, sampling within the specified timeframe produced an asymptotic curve. Although no standard distances were covered with this method, the length of stream sampled for all sites was generally well in excess of 300 meters (range = 237.3 – 955.4, mean = 662.3, sd. = 117.1).

Figure 12 Species-area curve patterns for selected sites ranging from small, most-impaired (Bowens) to large, least-impaired streams (Rappahannock)

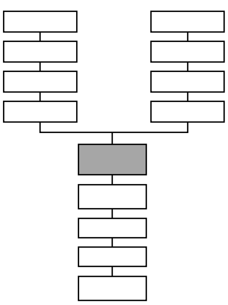


Summarization of fish data by attributes



After defining the regional fish fauna and classifying species into the appropriate biological groupings, attributes were then developed. Attributes, in the context of biological assessments, are defined as measurable components of a biological system that are expected to increase or decrease along a gradient of human disturbance (Karr and Chu 1997). Our attributes were chosen based on the original Karr et al. 1986 metrics and metrics proven to be successful in neighboring regions (Ohio EPA 1988, Hall et al. 1996, and Smogor 1996). We identified 28 attributes of the fish assemblage to use as candidate metrics (table 3). Using a Microsoft Excel spreadsheet, values for the 28 attributes were calculated for each of the 157 sampling locations.

Evaluation of attribute performance across gradient of human disturbance



The need to test and validate biological responses of metrics across degrees of human influence is a core assumption of IBI (Karr and Chu 1997). Metrics are attributes empirically shown to change in value along that gradient. The biological metrics incorporated into a multimetric index are selected because they

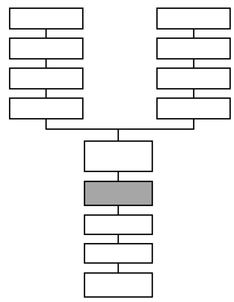
- reflect specific and predictable responses of organisms to changes in landscape condition,
- are minimally affected by natural variability,
- are sensitive to a range of factors that stress biological systems, and
- are relatively easy to measure and interpret (Karr and Chu 1997).

Metric selection involved a screening process in which each of the 28 attributes were tested against the following criteria in the listed sequence:

1. Did the attribute distinctly separate ($p < 0.05$) the least from the most impaired sites (appendix, fig. 30)?
2. Was the attribute closely correlated ($r > .25$, $p < 0.1$) with the Human Disturbance Index (appendix, fig. 31)?
3. Did the metric perform, within a given metric category, substantially better than one of the original Karr et al. (1986) metrics?

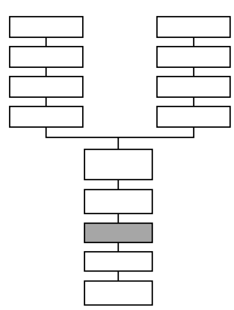
After certain metrics had been eliminated through this process, the remaining were assessed for redundancy by comparing the similarity in species composition of metrics within each metric category (table 3). Even if certain metrics survived the initial screening steps, as indicated by the **Yes** mark in the first three columns of table 3, only the least redundant were chosen for the IBI, as indicated by the checkmark in the last column.

Selection of metrics from best performing attributes



Ideally, metrics selected for an IBI should be sensitive to a range of biological stresses and not narrowly focused on one particular aspect of the community or another (e.g., species richness). Each chosen metric should reflect the quality of a different aspect of biota that responds in a different manner to stream disturbances (Hughes and Noss 1992). In selecting metrics, all the criteria listed in the previous step were considered in view of achieving some overall balance by having each of the categories (e.g., species composition and richness, trophic balance) represented in the IBI. Thus, metrics were selected based on how well they performed within the categories, rather than in the IBI overall. A description of metric function and the rationale for inclusion of each metric into the IBI are in the Results section.

Scoring of metrics



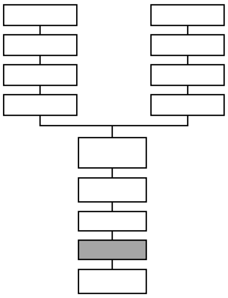
The selected metrics were scored by assigning values of 5, 3, or 1 depending on whether the data they represent are comparable to, deviate somewhat from, or deviate greatly from values exhibited by the watersheds' least-impaired streams, respectively (Karr et al. 1986). Since certain metrics tend to increase or decrease in value with increasing stream size (Smogor and Angermeier 1999), scoring for all metrics were based on the trisection technique described by Lyons (1992) that considers size of drainage in the scoring process (appendix, fig. 32). For metrics positively correlated to the HDI, values falling in the higher range scored a 5, those in the middle scored a 3, and those in the lower third scored a 1. For negatively correlated metrics, the scoring was reversed.

Table 3 Metric evaluation process used to screen attributes to select the 12 metrics that would best compose the IBI

Species richness and composition	Separates least from most impaired sites ($p < 0.05$)	Correlates with Human Disturbance Index ($r > 0.25$)	Performs notably better than one of Karr's (1986) original metrics	Selected metrics
1. Total # of species	yes	yes	*	
2. # of native species	yes	yes	yes	x
3. # of non-native species	no	no	no	
4. # of darter species	yes	yes	*	x
5. # of darter and sculpin sp.	yes	no	no	
6. # of sunfish species	no	no	*	
7. # of sucker species	no	no	*	
8. # of minnow species	yes	yes	yes	x
Tolerance/intolerance				
9. % dominant species	yes	yes	yes	x
10. % pioneers	yes	yes	yes	
11. # of intolerant species	yes	yes	*	x
12. % tolerant individuals	yes	yes	*	x
Trophic				
13. % omnivores (AHI)	yes	yes	*	x
14. % AHI + DAH	yes	yes	no	
15. % generalist feeders	no	no	no	
16. % insectivorous minnows	yes	yes	*	
17. % benthic invertivores	yes	yes	yes	x
18. % specialist carnivores	yes	no	no	
19. % specialist carn. - tol	yes	yes	yes	x
20. % piscivores	no	no	*	
Abundance, condition, and reproduction				
21. % simple lithophils	yes	no	no	
22. % simple lith. - tol	yes	yes	yes	x
23. # late maturing species	yes	yes	yes	x
24. % manipulative spawners	yes	yes	yes	
25. Total individuals	yes	no	*	
26. % anomalies	yes	yes	*	x
27. % hybrids	yes	no	*	
28. % anomalies + hybrids	yes	yes	no	

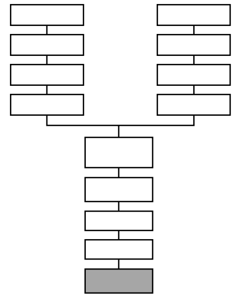
AHI algivore/herbivore/invertivore trophic group
DAH detritivore/algivore/herbivore trophic group
* one of the Karr et al. 1986 original metrics

Calculation of total IBI scores for all sites



An IBI is composed of the summed response signatures of the individual metrics that collectively provide a relative measure of biological condition and individually point to likely causes of degradation at different sites (Karr et al. 1986, Yoder and Rankin 1995). IBI scores were calculated for each site by adding the scores of the 12 selected metrics (table 4).

Interpretation of IBI; e.g., evaluation of project impacts



Once IBI scores were calculated for each sample location, various interpretations were made. For example, sites and their contributing watersheds were categorized by degrees of impairment by establishing IBI integrity classes (table 5), and causes of impairment were examined using GIS to define spatial relationships (Results section).

Table 4 Study area sites and IBI scores by watershed and size class

Goose Creek Watershed

Drainage area < 17 km²

Site #	Site name	Size km²	IBI
38	Sim 719	11.61	24
39	Jacks 690	3.77	34
40	Crom 702	11.32	20
41	Buch 626	16.05	38
42	Dog 630	11.44	24
43	N. fk(b) 725	11.64	32
44	Crook 848	11.41	24
45	Dry Mill 699	12.73	26
46	Cattail 773	6.49	26
47	Big 650	6.28	42
48	Hungry 632	16.93	34
49	Burnt 626	10.80	26
50	Syco 15	10.25	18
51	Chat 624	16.63	28

Drainage area 17–34 km²

Site #	Site name	Size km²	IBI
88	Goose 688	24.79	44
89	Big 55	17.18	24
90	Crom 715	20.65	24
91	Jeff 719	24.18	30
92	Beav 790	25.85	32
93	N.Fkg 791	28.47	34
94	Crook 727	28.36	42
95	Tusc 621	20.13	32
96	Syco 621	23.03	38
97	Little 705	20.92	36
98	Crook 688	19.55	28
99	Gap 710	20.38	36
100	Tusc 643	30.53	28

Drainage area > 34 km²

Site #	Site name	Size km²	IBI
143	Crook 623	38.63	46
144	Goose 17	115.98	50
145	Gap 623	34.77	44
146	Panth 623	57.00	46
147	N Fk. 722	60.19	26
148	N.Fkb 611	48.66	38
149	N Fk. 729	96.85	32
150	Beav 734	123.55	30
151	Goose733	701.82	44
152	Goose 710	208.26	48
153	Goose 611	318.09	42
154	Little 776	65.72	28
155	Little 50	106.37	40
156	Goose 55	43.14	32
157	Syc 643	36.20	36

Occoquan River Watershed

Drainage area < 17 km²

Site #	Site name	Size km²	IBI
1	Airlie up	9.06	26
2	Airlie mit	9.06	20
3	Airlie dn	9.06	20
4	Gup 602	6.33	32
5	Owl 616	13.29	22
6	Wal 767	15.10	24
7	Broad GM	14.51	42
8	Pine 246	8.92	38
9	Mill up	14.79	30

Drainage area 17–34 km²

Site #	Site name	Size km²	IBI
52	Mill 605	18.06	44
53	Turk 602	27.23	44
54	Lick 674	23.11	36
55	Town 639	21.89	28
56	Slate 649	30.38	24
57	Trapp 55	24.38	30
58	S. Fk 684	17.35	32
59	Kett 604	22.39	40
60	L Bull 676	19.42	26

Drainage area > 34 km²

Site #	Site name	Size km²	IBI
101	Cedar 674	49.91	42
102	Lick up	40.69	32
103	Lick dn	40.69	30
104	Elk 806	53.56	34
105	Town 611	36.18	42
106	Broad Avnl	47.90	42
107	Kett 611	59.50	38
108	Cat 704	51.49	54
109	Cat 234	68.32	46

Table 4 Study area sites and IBI scores by watershed and size class—Continued

Occoquan River Watershed—Continued

Drainage area < 17 km^2				Drainage area 17–34 km^2				Drainage area > 34 km^2			
Site #	Site name	Size km^2	IBI	Site #	Site name	Size km^2	IBI	Site #	Site name	Size km^2	IBI
10	Mill dn	14.79	36	61	Cat 676	19.75	48	110	Cedar 602	85.23	46
11	N. Fk 15	11.82	32	62	Chest 686	20.73	46	111	Town 806	90.36	38
12	S. Fk up	12.22	32	63	Bull 624	21.88	50	112	Broad 55	98.95	38
13	S. Fk dn	12.22	28	64	Flat Lmnd	18.21	16	113	Bull 659	96.20	44
14	L Bull up	5.97	32	65	Slate 611	17.11	32	114	Cedar 806	242.94	42
15	L Bull dn	5.97	32	66	Chest 701	30.09	48	115	Broad 619	232.90	40
16	Cat 15	10.31	44	67	Bull 705	28.31	52	116	Bull RP	242.43	50
17	Black 15	7.06	48	68	E. Fk 660	17.76	30	117	Cub 620	41.48	32
18	Young 234	14.48	40	69	Elklick 609	27.40	28	118	Cub 29	105.77	26
19	Flatlick 50	7.57	22	70	Flatlic 620	18.01	34	119	Cub RP	134.61	46
20	Rocky 645	13.20	34	71	L. Roc 658	17.59	46	120	Popes Clif.	44.16	38
21	Piney 660	11.32	30	72	Popes 612	29.75	34				
22	Hooes 641	9.09	30								
23	Long 695	8.29	36								
24	Cannon 28	8.05	34								
25	Purcel 643	10.06	30								
26	Elk 607	16.38	30								
27	Wolf 643	14.22	26								
28	Sandy 647	15.62	40								

Rappahannock River Watershed

Drainage area < 17 km^2				Drainage area 17–34 km^2				Drainage area > 34 km^2			
Site #	Site name	Size km^2	IBI	Site #	Site name	Size km^2	IBI	Site #	Site name	Size km^2	IBI
29	Horner 691	13.90	30	73	South 737	29.82	42	121	Carter 681	130.40	50
30	South 738	8.92	32	74	Buck 735	18.03	36	122	Carter 738	39.75	52
31	E. Th. 647	13.06	42	75	Fiery 635	23.99	34	123	Carter up	35.74	44
32	Bowens 28	7.17	20	76	Battle 633	26.07	34	124	Great 687	63.68	52
33	Great 678	14.95	34	77	Tinpot 657	22.64	24	125	W. Th. 647	43.96	40
34	Muddy 729	8.18	34	78	Brown 653	28.99	20	126	Th. R. 736	77.96	44
35	Waterf 229	11.33	36	79	Indian 626	18.30	36	127	Jordan 637	88.76	48
36	Piney 600	16.62	46	80	Jacob 626	26.62	40	128	Rapah 647	192.89	50
37	Rap 635	16.22	42	81	Jordan 522	21.88	40	129	Rush 211	37.13	46
				82	Marsh 17	25.06	20	130	Cov 626	107.80	48
				83	Craig 805	21.35	20	131	Hugh 707	35.47	38
				84	Hazel 231	24.07	46	132	Thor 622	134.49	46
				85	Thorn 522	26.04	46	133	Hazel 707	60.35	48
				86	Cov 522	27.09	30	134	Hugh 644	120.23	46
				87	Hittles 522	20.44	42	135	Hazel 522	200.01	48
								136	Black 615	36.53	44
								137	Rap W'loo	475.26	48
								138	Indian 624	35.16	36
								139	Thor 618	261.41	48
								140	Muddy 630	57.61	36
								141	Marsh 668	94.76	24
								142	Hazel 628	726.55	48

Metric evaluation and selection

Because the effects of human actions on the environment are varied and complex, multiple levels of information are generally needed to accurately assess biological condition. As previously described, the process for selecting metrics into a multimetric index involves the testing of a larger set of biological attributes and reducing them to the metrics that work best. The purpose of this process is to cull attributes, even those that may show some relationship to the human disturbance gradient, to select those few that are highly sensitive yet not redundant, to form the IBI. The following section describes the metrics selected in this study, their biological function, and the rationale for their inclusion into the IBI. Results of tests for selected metrics and a representative fish species are illustrated by the figures that follow the metric descriptions. Test results for all attributes are illustrated in the appendix, figures 30 and 31.

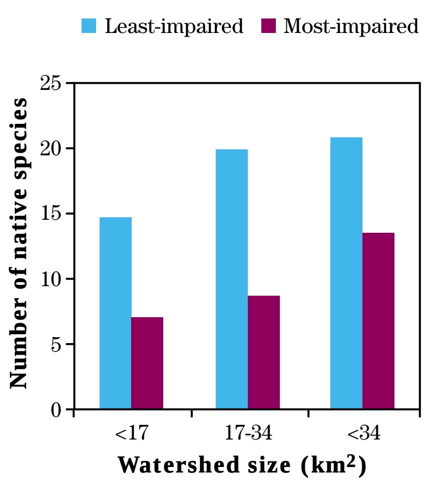
Species composition and richness

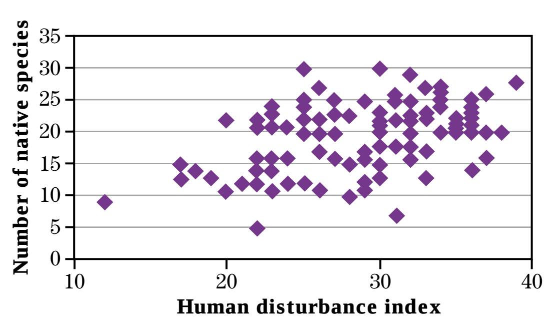
In general, attributes in this category display a declining response to added human disturbance (Karr 1981). Usually, a population must be viable at a site for some period before one can consistently detect a species' presence (Karr and Chu 1997). The absence of a species at a site may suggest that viable populations are not being maintained. Over time, species assemblages have evolved that are capable of withstanding or rapidly recovering from most natural perturbations. However, changes in the environment caused by humans often cannot be tolerated, and thus one or more species declines in abundance or becomes extirpated (Karr et al. 1986).

Metric 1. Number of native species

The total number of native species per sample make up metric 1 (fig. 13) . If other features are similar, the number of species supported by streams of a given size in a given region decreases with environmental degradation, with the effect more pronounced for species that are native to the region (Karr et al. 1986).

Figure 13 River chub (*Nocomis micropogon*), representative for the *number of native species* metric, and charts of metric evaluation results



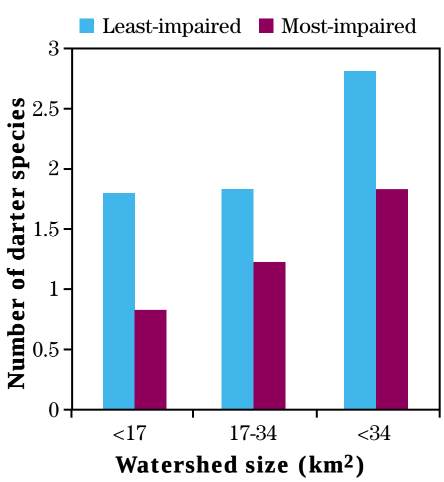


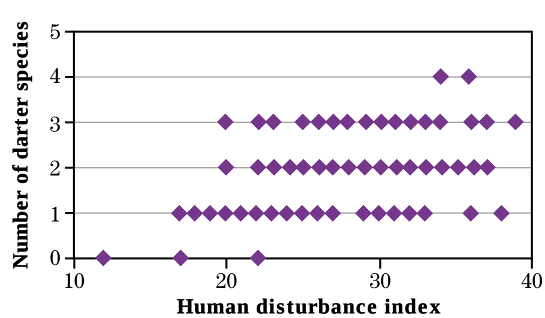
Fortunately for the state of Virginia, river-basin specific information is available for the native and non-native status for all freshwater fish species (Jenkins and Burkhead 1993), enabling the added sensitivity for this metric. In this study, 57 fish species were collected between the three watersheds: 42 in the Occoquan, 43 in the Rappahannock, and 43 in Goose Creek. Of the 57 species collected, 42 are considered native (or probably native) by Jenkins and Burkhead (1993), 32 in the Occoquan, 34 in the Rappahannock, and 32 in Goose Creek (see table 1).

Metric 2. Number of darter species

The number of species per sample of the subfamily Etheostomatinae (darters) make up metric 2 (fig. 14). Darters are sensitive to degradation, particularly as a result of their specificity for reproduction and feeding in benthic habitats (Page 1983, Kuehne and Barbour 1983). Such habitats are degraded by channelization, siltation, and reduction in oxygen content. Overall, six darter species were collected among the three watersheds: three in the Occoquan and Goose Creek and four in the Rappahannock. In addition to the overall performance of this metric, it was also chosen because no sculpin species were collected in the Occoquan Watershed, and none are presumed to occur because of natural rather than human influences. Thus, selection of an alternative metric of combined benthic taxa (e.g., *number of darter and sculpin species*) would automatically penalize all Occoquan streams in context of the regional IBI.

Figure 14 Tesselated darter (*Etheostoma olmstedi*), representative for the *number of darter species* metric, and charts of metric evaluation results



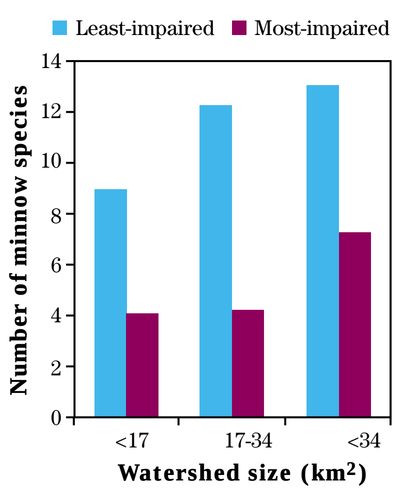


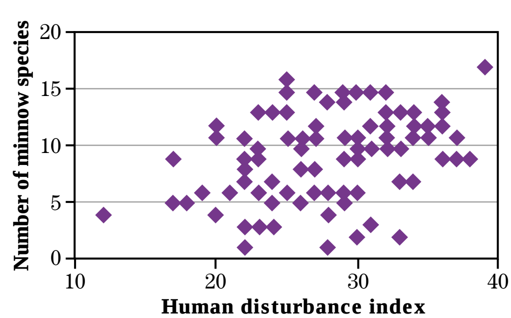
Metric 3. Number of minnow species

The number of species per sample from the family Cyprinidae (minnows) was evaluated against the *number of sunfish species* and the *number of sucker species*, both original Karr et al. 1986 metrics. Unexpectedly, a negative relationship between *number of sunfish species* and the Human Disturbance Index was observed. In Wisconsin, Lyons (1992) concluded that the proximity of lakes or ponds enable sunfish to frequent streams in which they would not ordinarily occur, thus influencing the IBI. In the three watersheds of our study, only two of the six sunfish species are considered by Jenkins and Burkhead (1993) to be native (*Lepomis auritis* and *L. gibbosus*). The others are considered introductions or probable introductions and may have displaced native fauna. Also, two of the six species that occur in the watersheds are considered by Smogor (1996) and our study team to be tolerant (*L. macrochirus* and *L. cyanellus*). Although the "sucker metric" did respond to the disturbance gradient as predicted, it did not perform as well as the “minnow metric.” Because of the asymmetric distribution of sucker species in Virginia, Smogor (1996) also suggested excluding the sucker metric.

Conversely, minnows are the dominant taxonomic group in all three watersheds, both in terms of relative abundance and species richness. Twenty-three species were collected overall: 19 in the Occoquan, 19 in the Rappahannock, and 20 in Goose Creek. The minnow metric has been successfully used in IBIs in a number of other locations (Hughes and Gammon 1987, Ohio EPA 1988), owing its utility to the variety of habitats in which minnows occur and their sensitivity to physical and chemical disturbances (Hall et al. 1996) (fig. 15).

Figure 15 Common shiner (*Luxilis cornutus*), representative for *number of minnow species* metric, and charts of metric evaluation results





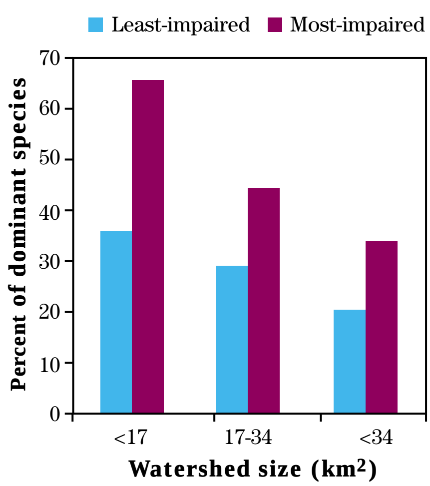
Tolerance/intolerance

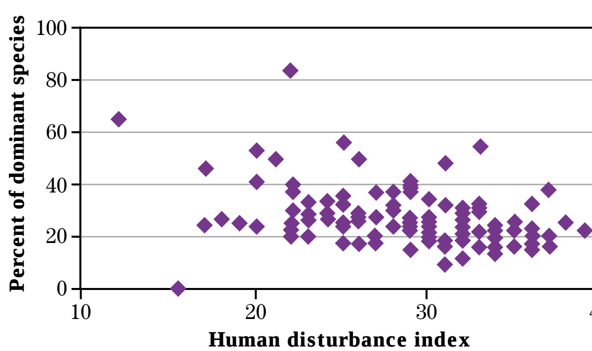
Tolerance and intolerance, as it relates to IBI development, implies the general tolerance of a species, or group of species, to a variety of human influences, rather than tolerance or intolerance to a specific variable. Therefore, in attribute development, the concept is applied to any fish species, or group, that are particularly sensitive or insensitive to the combined effects of human disturbance. Because of their close functional relationship, tolerance, intolerance, dominance, and pioneering species have been treated collectively in this group.

Metric 4. Percent of the dominant species

The proportion (percent) of the most abundant species per sample make up metric 4 (Hall et al. 1996, Ohio EPA 1988). This metric is based on many studies that have demonstrated a retrogression in dominance by opportunistic species in response to environmental stress (Karr et al. 1986, Ohio EPA 1988, and Hall et al. 1996). In his recommendations for IBI development in Virginia streams, Smogor (1996) suggested including balance among metrics, not overly relying on taxonomic metrics and placing adequate emphasis on metrics that incorporate independent signal. All attributes within this category performed reasonably well; however, according to a factor analysis of our data (Hatcher 1994) the *percent dominant species* was the least redundant and therefore selected (fig. 16).

Figure 16 Fallfish (*Semotilus corporalis*) to creek chub (*Semotilus atromaculatus*), examples of species typically involved in retrogression of dominance, and charts of metric evaluation results

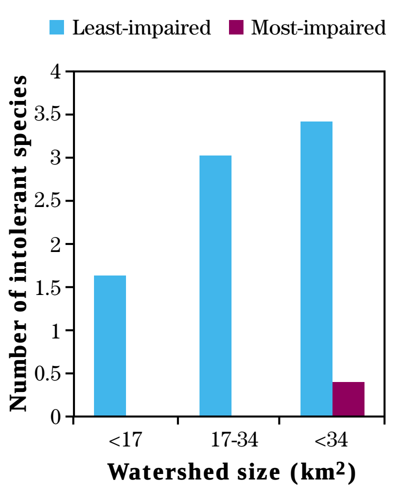


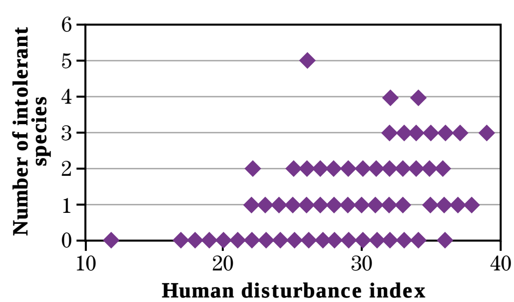


Metric 5. Number of intolerant species

Metric 5 (fig. 17) is the number of species per sample that are intolerant to effects of human disturbance, such as siltation, turbidity, lowered flows, inundation, riparian alteration, low dissolved oxygen, pollution. Intolerant species are among the first to be decimated after perturbation (Karr et al. 1986). The mere presence of very sensitive taxa is a strong indicator of good biological condition; however, the relative abundance of these taxa, because they are relatively rare, is often difficult to estimate. Therefore, the number of species, rather than proportion of individuals, is used as this metric's measure. To improve the discriminatory ability of this metric, Karr and Chu (1997) recommend designating no more than 5 to 15 percent of the regional fauna as tolerant or intolerant. We considered 8 (about 14%) of the 57 species collected among the three watersheds to be intolerant. The higher end of recommended range was chosen to provide opportunity for the metric to function equally across the three watersheds and provide the ability to include at least some intolerant species that occur in only one watershed or another.

Figure 17 Redfin pickerel (*Esox americanus*), representative for *number of intolerant species* metric, and charts of metric evaluation results





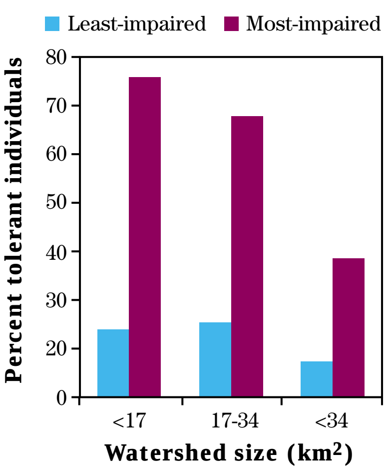
Metric 6. Percent tolerant individuals

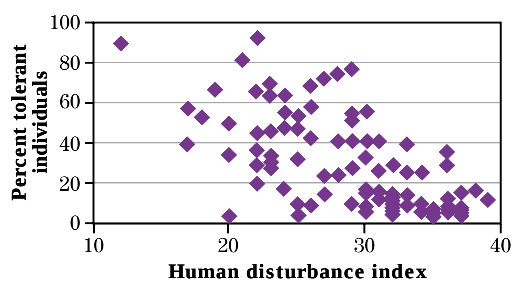
The proportion (percent) per sample of individuals of species that are tolerant (least susceptible to impairment) make up metric 6. Under the same rationale described for *number of intolerant species*, we chose only 8 (about 14%) of the most tolerant species to represent this category from Smogor's (1996) larger list of tolerants. *Percent tolerant individuals* was selected over *percent pioneering species* because of its better overall performance and because similarity in species composition between the two metrics precluded selecting them both into the IBI (fig. 18).

Trophic structure

The energy base and the trophic dynamics of a stream community are assessed by the metrics in this category. Species groupings for these metrics follow Smogor (1996), who based his designations on the feeding patterns of freshwater adults. Because the food base is central to the maintenance of a community, information about trophic composition is important to an IBI (Karr et al. 1986). All organisms require a reliable source of energy. Fish assemblages are affected dramatically by changes or reductions in those energy sources. The dominance of trophic generalists occurs as specific components of the food base become less reliable and the opportunistic foraging habits of the generalists make them more successful than specialized foragers (Karr et al. 1986). Thus, the trophic structure of a community can provide information on the production and consumption patterns that are affected by impairment. Alterations in water quality or other habitat conditions, including land use in the watershed, commonly result in changes in the fish community because of fluctuating food resources (Karr et al. 1986).

Figure 18 Green sunfish (*Lepomis cyanellus*), representative for *percent tolerant individuals* metric, and charts of metric evaluation results



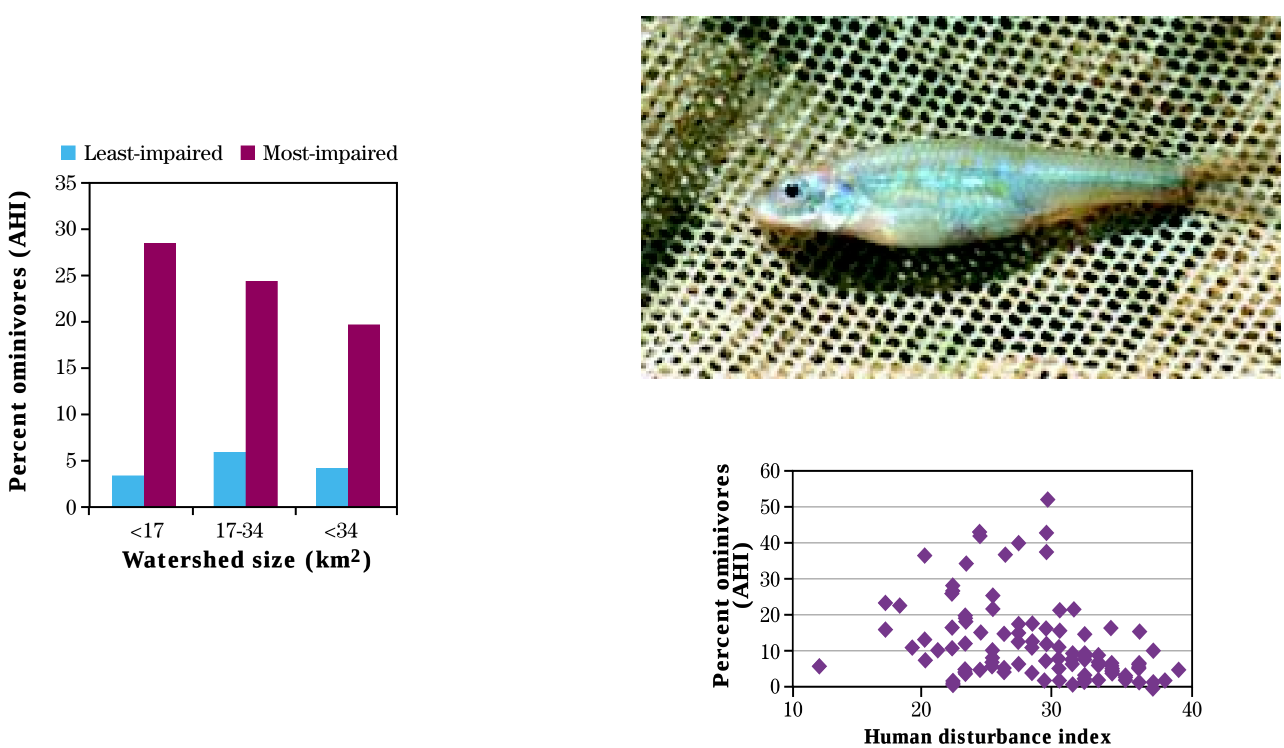


Metric 7. Percent omnnivores (AHI - algivore/herbivore/invertivore) feeding group

Excessive instream production of many herbivorous fishes are characteristic of heavily grazed landscapes, where riparian corridors may be damaged and excessive nutrients from livestock waste are entering the stream (Karr and Chu 1997). Similar relationships have been observed in intensively cultivated areas with altered riparian zones and heavy nutrient input from excessive fertilization. Karr et al. (1986) included a similar metric in their original study that was expressed as *proportion of individuals as omnivores*. Omnivores were considered to be species that take significant quantities of both plant and animal materials (including detritus) and have the ability, usually indicated by the presence of a long gut and dark peritoneum, to utilize both. In their study, Karr et al. defined omnivores as species whose diets contain at least 25 percent plant and 25 percent animal foods.

Because of the difficulty in determining which species actually consume the requisite percentages of plant and animal matter to be considered omnivorous, in this study we have chosen to use three of Smogor's classifications (proportion of individuals as: algivore/herbivore/invertivore (AHI), AHI plus detritivore/algivore/herbivore (DAH), and generalist feeders) as different means of expressing Karr's ominivore metric. In this study, proportion of individuals as AHI was evaluated against proportion of individuals as AHI and DAH and proportion of individuals as generalist feeders. Both AHI and DAH + AHI metrics performed well against all performance tests; however, the AHI metric performed somewhat better overall (fig. 19).

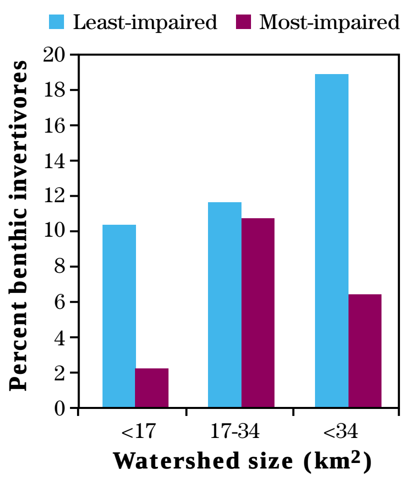
Figure 19 Silverjaw minnow (*Notropis buccatus*), representative for *percent omnivorous individuals* metric, and charts of metric evaluation results

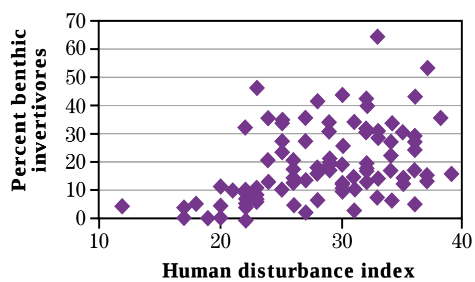


Metric 8. Percent benthic invertivore

The proportion (percent) per sample of individuals from species designated as invertivores that are also benthic make up this metric. This group has both very select feeding behavior (feed only on the bottom) and food requirements (feed only on invertebrates); therefore, they are particularly sensitive to alterations in the aquatic environment. Siltation and turbidity, environmental stressors that are severely detrimental to benthic organisms, are the most pervasive deleterious factors to Virginia icthyofauna (Jenkins and Burkhead 1993). Benthic organisms are disproportionately impacted by these and other influences; e.g., heavy metals and toxic substances, which tend to accumulate in bottom sediments and affect their food base (Rosenberg and Resh 1993). This metric was evaluated against percent insectivorous minnows, one of Karr's et al. (1986) original metrics. Both metrics performed well against all tests and have been widely used elsewhere. Therefore, either or both could have been chosen for this category. However, because we selected one metric related to minnows under the species composition and richness category, the benthic invertivore metric was chosen to reduce redundancy (fig. 20).

Figure 20 Potomac sculpin (*Cottus girardi*), representative for *percent benthic invertivore* metric, and charts of metric evaluation results

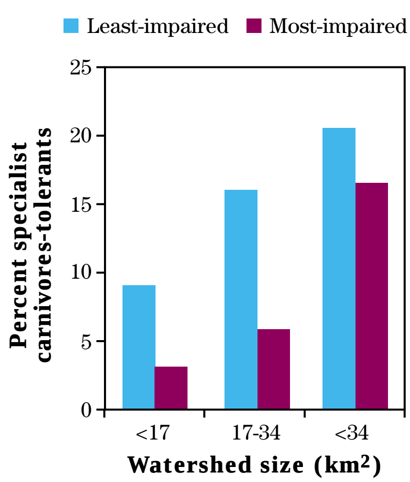


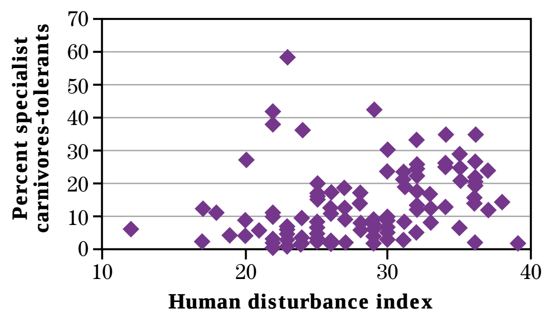


Metric 9. Percent specialist carnivores minus tolerant species

This metric is the proportion (percent) per sample of individuals from species designated as piscivores or invertivore/piscivores, minus the tolerant species. Viable and healthy populations of carnivorous species indicate a healthy, trophically diverse community (Karr et al. 1986). This metric includes individuals of all species in which the adults are predominantly piscivores or as adults feed on the combination of fish and invertebrates. Tolerant species that fit this profile have been subtracted to improve the metric's discriminatory power. This metric was evaluated against *proportion of individuals as piscivores*, one of the original Karr et al. metrics, and *proportion of individuals as specialist carnivores* without subtracting the tolerants. S*pecialist carnivores minus tolerants* performed better than either of those comparisons (fig. 21).

Figure 21 Rockbass (*Ambloplites rupestris*), representative for *percent specialist carnivores - tolerants* metric, and charts of metric evaluation results





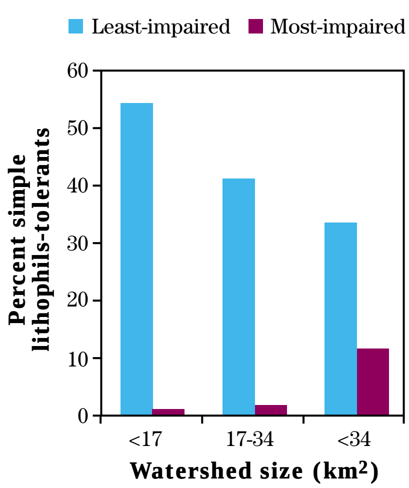
Fish reproduction, growth, and condition

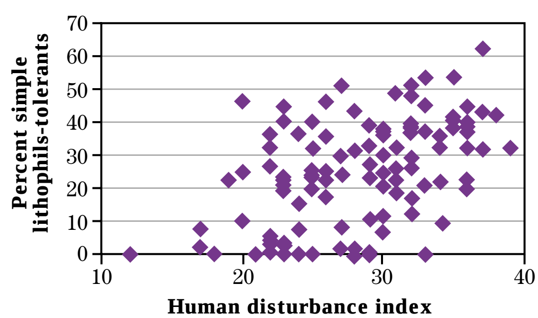
The three metrics in this category evaluate such attributes of populations as reproduction, growth, and condition of individual fishes. Ecosystems can maintain health only if its living members are able to compensate for population loss through reproduction. Under normal circumstances (disregarding stocking) new members are added only through natural reproduction, meaning that conditions must be favorable for reproduction to occur and for the young to survive. In addition, conditions must be favorable for individuals to grow and reach sexual maturity and thus enable the continuance of the reproductive cycle.

Metric 10. Percent simple lithophilic spawners minus tolerants

Metric 10 is the proportion (percent) per sample of individuals from species designated as simple lithophils (species that scatter their eggs over rock, rubble, or gravel substrates without nest preparation or parental care to the eggs) minus the tolerant species of that group. This metric is sensitive to the adverse effects of siltation and is designed to assess the effects of human impairments on fish reproduction (Hall et al. 1996). Metric 10 was compared with *total number of individuals* and *percent simple lithophils* (without subtracting the tolerants) against which it performed better in all tests (fig. 22).

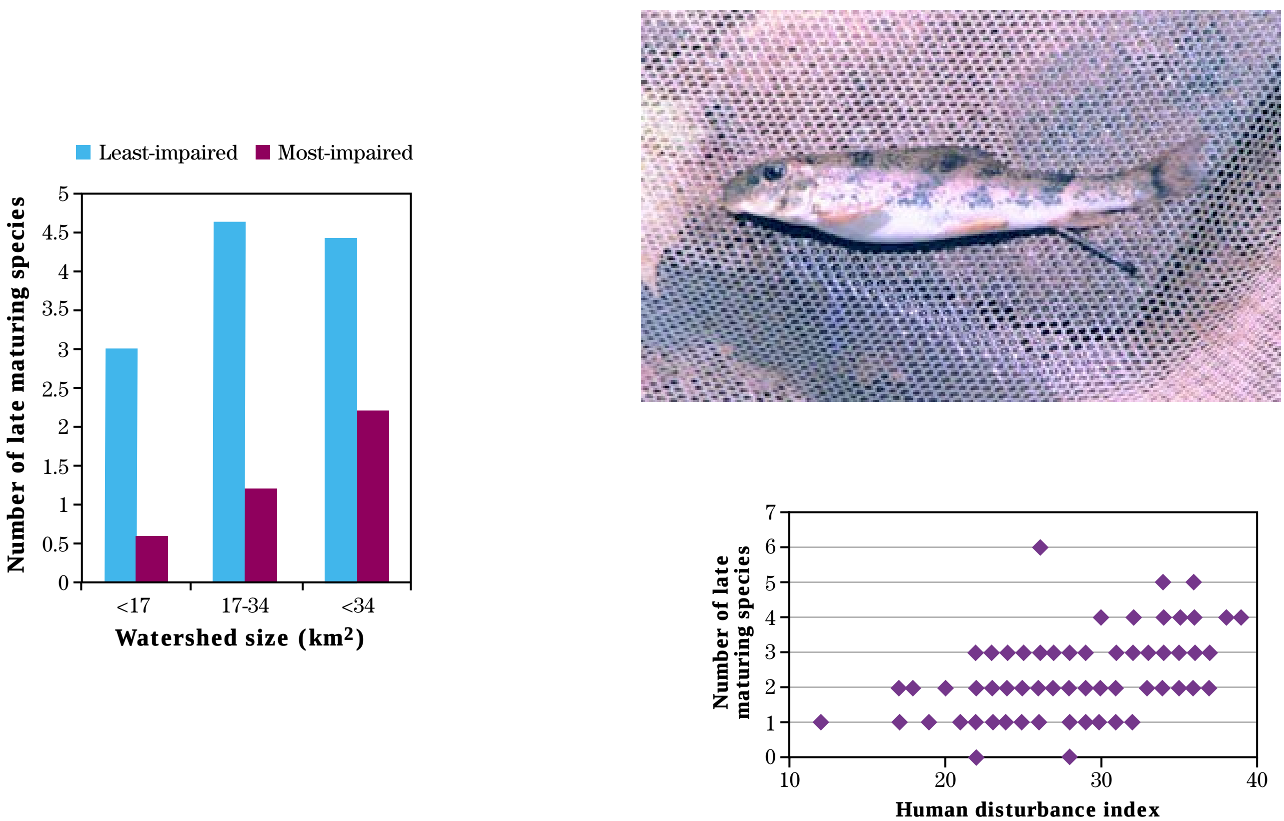
Figure 22 Stripeback darter (*Percina notograma*), representative for *percent simple lithophils - tolerants* metric, and charts of metric evaluation results





Metric 11. Number of late-maturing species
The number of species per sample that normally do not breed until their third year or after make up this metric. Species that require longer periods to complete their reproductive cycle are disproportionately affected by environmental degradation. Often stream impairments are short-term, and recovery is more likely for those species that are able to quickly reproduce and recolonize. However, that task is much more difficult for species that require a number years to reach sexual maturity. If long-lived taxa are present, one can infer that the spatial and temporal components they require are also present (Karr and Chu 1997). This metric was evaluated against *variable substrate manipulative spawners*, a reproductive metric designed to assess the quality of spawning habitat. Both metrics met all performance criteria; however, *number of late maturing species* performed somewhat better overall (fig. 23).

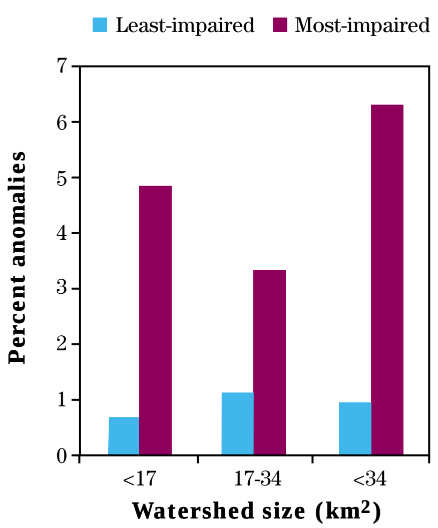
Figure 23 Northern hogsucker (*Hypentelium nigricans*), representative for *number of late maturing species* metric, and charts of metric evaluation results

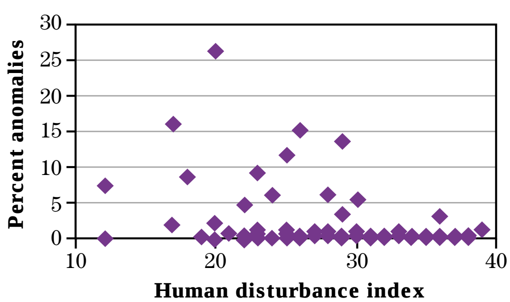


Metric 12. Percent of individuals with disease, tumors, fin damage, and skeletal anomalies

The proportion (percent) per sample of individuals with externally visible abnormalities represent metric 12 (fig. 24). Sites with especially severe degradation often yield a high number of individuals in poor health (Mills et al. 1966, Brown et al. 1973, and Baumann et al. 1982). Parasitism has been shown to reflect both poor environmental condition and reduction in reproductive capacity (sterility) in fish (Mahon 1976). Indications of poor health include tumors, fin damage or other deformities, heavy infestations of parasites, discoloration, excessive mucus, and hemorrhaging. In this study the number of individuals with anomalies was extremely small except for streams in the Goose Creek system, which contained a relatively high incidence of black spot disease (caused by the larval stage of a trematode parasite; e.g., *Uvulifer ambloplitis* and *Crassiphiala bulboglossa).* Leonard and Orth (1986) also found increases in the incidence of disease and anomalies only after substantial degradation was evident, indicating that this metric may be sensitive only at the most severely impacted sites. However, in this study the metric did function in detecting several of the watershed's most degraded streams, and overall anomalies were present in sufficient quantities to correlate with the disturbance gradient.

Figure 24 Open lesion and blackspot disease, representing the *anomalies* metric, and charts of metric evaluation results





Open lesion

Blackspot disease

Results

In this study a total of 57 fish species were collected across the three watersheds: 42 in the Occoquan, 43 in the Rappahannock, and 43 in Goose Creek. Of the 57 species collected, 42 are considered native (or probably native) by Jenkins and Burkhead (1993): 32 in the Occoquan, 34 in the Rappahannock, and 32 in Goose Creek (see table 1). The number of species per site ranged from 5 to 24 for sites where drainage is less 17 square kilometers, 9 to 27 for those with drainage of 17 to 34 square kilometers, and 11 to 30 for those more than 34 square kilometers. Total number of individuals per site ranged from 124 to 1,325 (mean = 483.8, s.d. = 221.6) (appendix, table 7 and 8). Most of the species collected were represented in each of the three watersheds; however, a few species were collected in only one watershed or another (see table 1 and appendix fig. 33). IBI scores ranged from 16 to 54 with similar ranges in values observed for each of the three watersheds: Occoquan 16 to 54, Rappahannock 20 to 52, and Goose Creek 18 to 50 (see table 4 and fig. 25).

It follows that if individual metrics have been selected because they were highly correlated to degrees of human impairment, then the composite score of those metrics (the IBI) would be also. If the scores from the HDI are plotted against the IBI, a close relationship is observed (r = 0.71) indicating high sensitivity of the IBI in detecting combined effects of human disturbances (fig. 26).

Integrity classes were determined for the study area according to a system devised by Karr et al. (1986) by dividing the range of IBI scores for all sites into equal fifths (table 5). A clear pattern is detected when the drainages of the sites with poor and very poor classifications are observed spatially through GIS (fig. 27). As projected, a higher incidence of drainages classified as poor and very poor occur in the eastern portion of the study area, where human populations and pressures from urban development are greatest. Conversely, a greater percentage of drainages with good to excellent integrity ratings occur in the study area's western portion. A significant number of the sites in the Occoquan watershed received low integrity ratings. Of the 69 Occoquan drainages sampled, 30 (43.5%) were classified as poor or very poor, compared to 52.4 percent of the Goose Creek sites and 19.6 percent of the Rappahanncock sites.

Most of the drainages with low integrity ratings were clumped in four distinct areas (fig. 27):

- highly developed Washington suburbs in the northeastern portion of the Occoquan watershed,
- drainage's intensively used for agriculture along the Highway 28 corridor southwest of Manassas,
- developing rural landscape along the Interstate 66 corridor west of Manassas, and
- agricultural and developing land in the vicinity of Leesburg and Purcellville.

With the exception of Marsh Run and its tributaries, the upper Rappahannock watershed had only a few drainages classified as poor or very poor.

Figure 25 Distribution of IBI scores by stream size, watershed, and integrity class

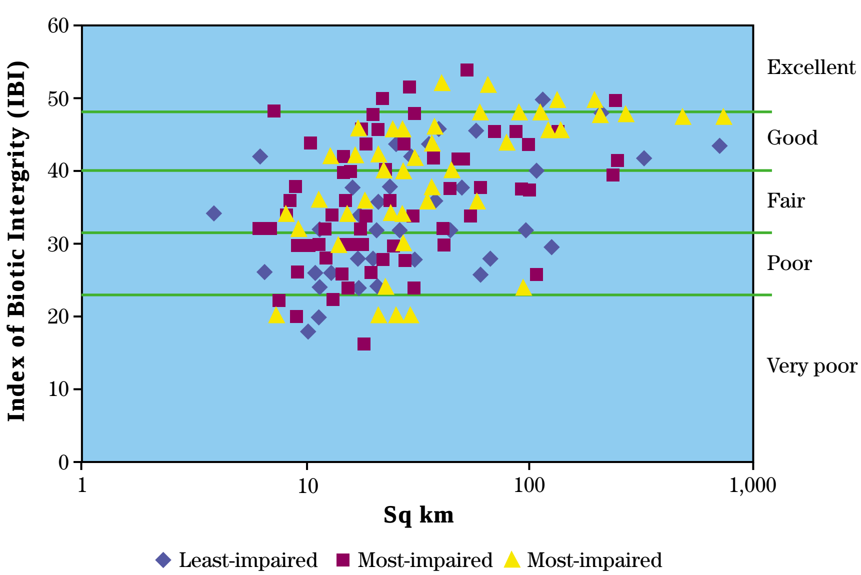


Figure 26 Relationship of the IBI and Human Disturbance Index (disturbance increases as Human Disturbance Index values diminish)

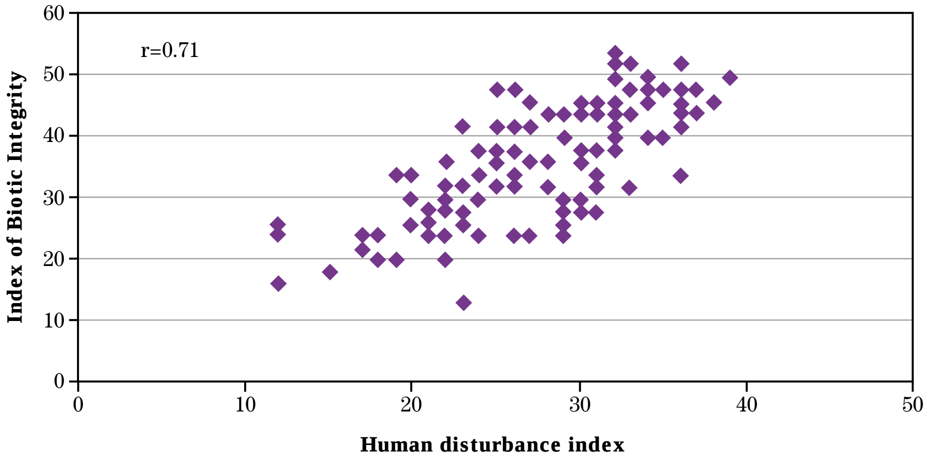
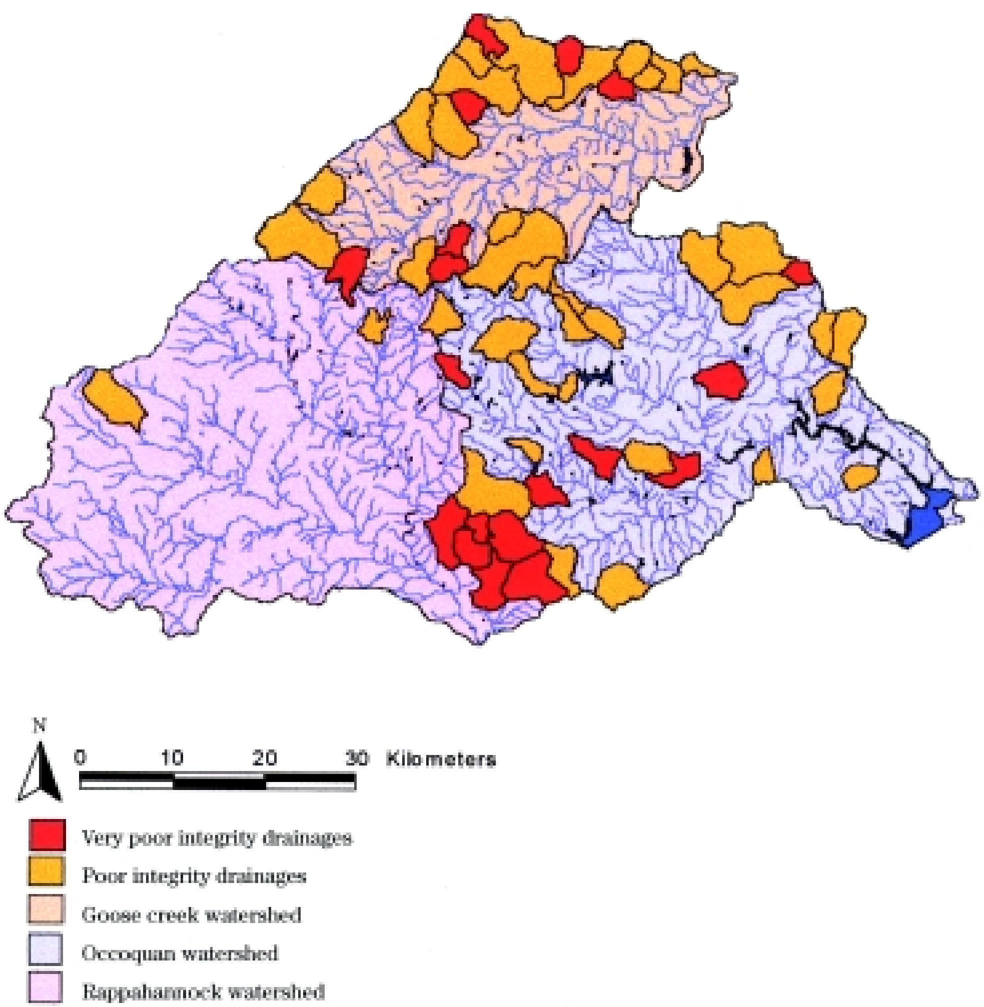


Figure 27 Location of drainages classified as poor and very poor



In general, the western portion of the study area exhibited better quality streams, with most drainages originating in the Blue Ridge receiving good to excellent impairment ratings (fig. 28). However, the Occoquan Watershed also contains some high quality streams; for example, the Bull Run system above the city of Manassas and the upper portions of the Cedar and Broad Run systems. The Rappahannock Watershed had the highest percentage of drainages rated good to excellent (52.2%), followed by the Occoquan (30.4%), and then Goose Creek (23.8%).

The biological integrity of the fish assemblage, as measured by the IBI, was closely correlated with the reach assessment scores of the SVAP, consistent with a number of others studies relating fish assemblages to habitat quality (Roth et al. 1996, Matthews 1987) (fig. 29). SVAP is designed to assess impairments of a specific stream reach, particularly those impacts that are associated with agriculture and land management (livestock grazing, channel alterations, riparian width). Of the four components used to construct the Human Disturbance Index (percent cropland/urban; percent pasture/urban; fish barriers; and SVAP), the SVAP had the highest correlation with the IBI (r = 0.64). Because IBI is an integrated assessment technique that incorporates many influences in combination, it is not expected that each individual SVAP component would be highly correlated with the IBI. However, the single component *macroinvertebrates observed* was more correlated to the IBI individually (r = 0.66) than was the SVAP overall (r = 0.64). Other SVAP components with relatively high degrees of correlation (r ≥ 0.35) were riffle embeddedness, invertebrate habitat, water appearance, and instream fish cover (table 6).

Table 6 Pearson's correlation coefficients for individual SVAP components and the IBI

SVAP assessment component	Pearson's coefficient
Channel condition	0.3
Hydrologic alteration	0.2
Riparian quality	0.18
Bank stability	0.19
Water appearance	0.43
Nutrient enrichment	0.32
Instream fish cover	0.36
Pool quality	0.31
Invertebrate habitat	0.49
Canopy cover	0.15
Manure presence	0.09
Riffle embeddedness	0.52
Macroinvertebrates observed	0.66

Table 5 Biological Integrity classification system for study area sites (adapted from Karr et al. 1986)

Total IBI score (sum of the 12 metric ratings)	Integrity class	Attributes
49–54	Excellent	Comparable to the best situations across the three watersheds with minimal disturbance; contains all species expected for the watershed for the habitat and stream size, including the most intolerant forms; exhibits balanced trophic structure and reproductive success.
41–48	Good	Species richness somewhat below expectation, especially due to the loss of the most intolerant forms; some species are present with less than optimal abundances; trophic structure and reproduction shows some sign of stress.
33–40	Fair	Signs of additional deterioration include loss of intolerant forms, fewer species, highly skewed trophic structure (e.g., increasing frequency of omnivores or tolerant species); older age classes of top predators may be rare.
25–32	Poor	Dominated by omnivores, tolerant forms, and habitat generalists; few top carnivores; reproductive and condition factors commonly depressed; diseased fish often present.
16–24	Very Poor	Dominated by highly tolerant forms (e.g., green sunfish, creek chubs etc.); disease, lesions, parasites, fin damage, and other anomalies may be regular.

Figure 28 Location of drainages classified as good and excellent

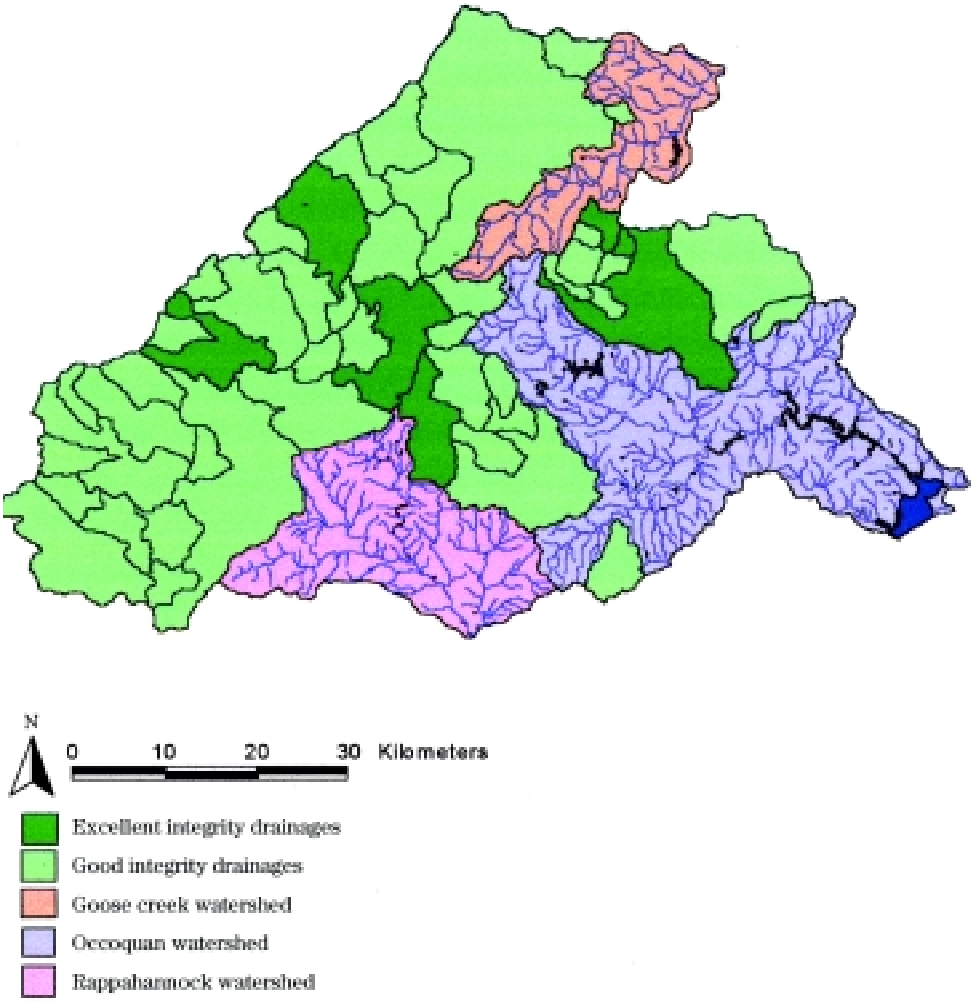
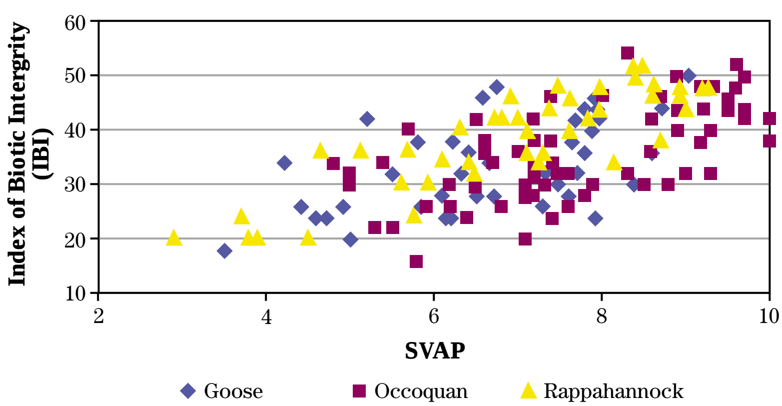


Figure 29 Correlation of IBI and SVAP scores



Discussion

Efficacy of the IBI

The data from this study suggest that prevailing human influences, ecological structure of fish assemblages, and species composition of the fish fauna are similar across the three watersheds; therefore, a single regional IBI can be developed and applied to the three watersheds collectively. The development of a regional IBI also permits the selection of sample locations over a broad enough area to capture the full range of human influence and reduces the possibility of placing degraded sites into reference sets.

Testing and validating the biological response of each metric enabled the development of an IBI that was highly sensitive to regional human disturbances as measured by the HDI (see fig. 26). This was accomplished by maintaining the structure and function of the Karr et al. (1986) IBI and modifying or replacing only those original metrics that did not perform as well as others tested in the metric evaluation process. Several similar examples of this approach exist across the United States, many of which were summarized by Simon 1999.

The IBI in this study included 12 metrics—each explicitly selected because it provided strong biological signal that changed predictably as human influence increased. The IBI enabled the calculation of a single numeric value for each site that represented its biological condition relative to the best and worst streams in the study area. Those IBI scores included the summed response of each metric; thus, the measured values of the component metrics were not lost when the IBI was calculated.

Condition of the streams

Results from a number of studies indicate that stream ecosystems are adversely affected by human alteration of surrounding lands (Steedman 1988, Schlosser 1991, Roth et al. 1996, and Wang et al. 1997). Generally, high levels of forest, wetland, and intact riparian habitat are associated with healthy streams. Major nonpoint source pollution and habitat destruction from watershed land use practices occur when land is converted from natural vegetation to agricultural or urban uses. Degradation increases through the use of intensive farming practices, such as overapplications of fertilizers, pesticides, and herbicides to improve crop yields and concentrating high densities of livestock into barnyards and feedlots to increase production. Urban development degrades streams by added pollution and runoff, which in turn leads to impaired water quality, more frequent and severe flooding, accelerated channel erosion, and altered stream channel form and bed composition. The data from this study suggest that smaller streams are more likely to be impacted than larger rivers. The drainage areas of smaller streams can have high levels of urban and agricultural land uses while such uses tend to comprise a smaller proportion of larger drainages in the study area. These results highlight the need to maintain vegetated buffers and use other best management practices to protect small streams.

Until recently, watershedwide studies of factors contributing to stream degradation have been difficult to conduct because of method limitations in quantifying watershed land use. However, Geographic Information System technology has enabled the examination of relationships between watershed and streams (Lenat and Crawford 1994, Roth et al., 1996; Wang et al. 1997). In most instances, those studies have found significant negative correlations between watershedwide agricultural or urban land uses and stream biological integrity (Wang et al. 1997).

Occoquan Watershed

In this study, clear patterns of impairment are observed when drainages with poor and very poor integrity ratings are viewed geospatially (see fig. 27). The broad causes of impairment become apparent by examining the HDI and each of its individual components in context of the IBI. For example, in the Occoquan most of drainages sampled in the urbanized or rapidly developing eastern suburbs received low integrity ratings (e.g., Flatlick 50, Piney 660, Hooes 641, Purcel 643, Wolf 643, Flat Lmnd, East Fk 660, Elklick 609, Cub 620, and Cub 29) (see table 4 and fig. 25). Of the 69 sites sampled in that watershed, 30 (43.5%) fell within the poor or very poor integrity classes. Our study supports Schueler's (1996) assertion that there is a continuing trend of stream degradation in the Occoquan. According to his projections, in 1989, 60 percent of all stream miles in the Occoquan could be classified as high-quality streams, 33 percent as showing signs of urban impact, and 7 percent as not supporting aquatic life. By the year 2005, he projected that only 22 percent of the streams would be classified as high-quality, with 64 percent showing clear signs of deterioration, and 14 percent shifting to the nonsupporting category.

Although suburban sprawl is responsible for the diminished quality of many Occoquan drainages, it is not the only cause. For example, along Highway 28 corridor southwest of Manassas, intensive agriculture has severely impacted most of that area's streams (Gup 602, Owl 616, Elk 607, Wal 767, Town 639, Slate 649, Slate 611, Lick up, and Lick dn) (see table 4 and fig. 27). To help put the problem in perspective, that part of the watershed is relatively level, fertile, and conducive to intensive farming, and most of it has been actively cultivated for more than 200 years. Therefore, the problem is not new, nor is it likely to intensify with added urban pressures. In 1996, cropland was the largest single source of nutrients in the Occoquan (Schueler 1996). Although cropland is expected to decline significantly in the area over the next 3 decades, it is still projected to be a major source of nutrients and sediments to watershed streams. In addition to cropping, that part of the watershed contains the region's highest concentration of dairy and livestock operations, which contributes not only to the nutrient problem, but also to eroded streambanks, sedimentation, and diminished riparian quality.

The other clump of drainages with low integrity ratings in the Occoquan occur along the Interstate 66 corridor west of Manassas (Trapp 55, Mill up, L. Bull up, L. Bull dn, N. Fk 15) and extends westward into the Rappahannock and Goose Creek Watersheds. Causes of impairment in that portion of the watershed are complex and varied; for example, the combined effects of suburban development, reservoirs and impoundments, and agriculture. Although, the incidence and degree of impairment is not as high in this portion of the watershed as that in the two areas previously described, the rate of suburban development is rapid in certain locations (e.g., the Gainesville vicinity) and stream condition is expected to deteriorate rapidly as well.

The adverse impact of impoundments on fish populations has been well documented in other studies (Avery 1978, Etnier and Starnes 1993, Minckley and Deacon 1991, Winston et al. 1991) and is clearly illustrated by our results in the Occoquan. For example, a number of sample sites in this study were strategically located above and below impoundments to examine the effect of dams on the IBI (i.e., S. Fk 684 and N. Fk 15 above Lake Manassas, S. Fk up and S. Fk dn above and below Lake Brittle, L. Bull up and L. Bull dn above and below Silver Lake, Lick up and Lick dn above and below Germantown Lake, and Airlie up and Airlie dn above and below Airlie Lake). The locations of those sites were determined solely by their proximity to impoundments, without regard to other factors that may have influenced the IBI. With the exception of Mill dn, each of those sample locations had scores in the poor or very poor integrity classes. Although other factors may have contributed to the low scores at those sites, the preponderance of scores in the low integrity classes strongly suggests that impoundments negatively influence the IBI. This observation provides additional rationale for why the negative effects of impoundments should be considered while constructing regional disturbance gradients.

Although the focus of this report is the Occoquan Watershed, patterns of impairment were also observed in the other watersheds. As stated, the Interstate 66 corridor west of Manassass displays a clump of scattered drainages of poor or very poor integrity along its route all the way to the Blue Ridge (Horner 691, Crom 702, Crom 715, Chat 624, Big 55, and Goose 55). Although the highway itself, scattered housing developments, and the small towns (Plains, Marshall, Markham) may contribute pollutants, livestock access to streams is probably the principal cause of impairment to that group of streams. SVAP scores for each of those sites are low and indicate that unimpeded livestock access to the streams is the main cause.

Goose Creek Watershed

Another band of impaired drainages occurs at the northern border of the Goose Creek Watershed (Cattail 773, Tusc 643, Tusc 621, Dry Mill 699, Syco 15, N. Fk 729, N. Fk 722, Crook 848, Sim 719, Beav 734, and Dog 630). Suburban sprawl around the city of Leesburg is probably responsible for low scores in the Tuscarora system (Tusc 643, Tusc 621, and Dry Mill 699) and in Cattail Branch. A combination of sprawl around the towns of Hamilton, Purcellville, and Round Hill, in addition to livestock impairments, are more than likely responsible for the low scores at N. Fk 729, N. Fk 722, and Crook 848. Isolation from Sleeter Lake and sprawl from the towns of Round Hill and Purcellville are most likely responsible for the low score at Sim 719. Livestock are probably responsible for the remaining low scores at Syco 15, Beav 734, and Dog 630.

Rappahannock Watershed

In the Rappahannock watershed, few drainages displayed significant signs of impairment. However, the Marsh Run mainstem, each of its contributing drainages, and neighboring Tinpot Run were all classified as very poor, suggesting that that area is perhaps the most impaired of the entire region. Like the intensively farmed portion of the Occoquan, those Rappahannock drainages occur in the relatively flat terrain of the Culpeper Basin and have been cultivated for many years. Agricultural nonpoint pollution from both cropping and concentrated livestock are most likely responsible for their low scores.

Use of IBI results in management decisions

With this study, a baseline condition that is benched in a regional IBI has been constructed for the Occoquan and its neighboring watersheds. This and other studies demonstrate that fine-tuning and regionalization of the metrics that compose the IBI can provide an accurate assessment of the condition of streams and their contributing drainages, particularly at local levels. This study also helps achieve Schueler's (1996) recommendation to undertake a comprehensive inventory of the physical and biological quality of the 1,300 miles of streams that drain the basin to determine their current status and restoration potential.

The study also provides a direct linkage between the watershed's biology and its broadly based human influences. The IBI has been used similarly in other studies to identify land use problems and causes of impairment. For example, Roth et al. (1996) found that stream biotic integrity was more strongly influenced by broad land use patterns. Sites whose upstream drainages were dominated by agriculture ranked lowest by both the IBI and their measure of human influence, whereas sites with land areas that contained higher percentage of naturally vegetated land, particularly wetlands, tended to rank higher. Although Roth et al. found watershedwide land use patterns tended to be a better predictor of biological integrity, other studies point to local impairments as a greater influence. For example, in Wisconsin, Wang et al. (1997) found in a number of sites that grazing had removed grasses and woody vegetation from riparian areas, resulting in higher stream temperature and loss of overhanging cover for fish. Along with high watershed slope, livestock grazing and trampling had destabilized the banks, leading to extensive erosion and sedimentation.

Although this and several other studies have used multimetric indexes to identify watershed problems, application of specific management approaches based on the IBI has yet to mature much beyond past uses of physical and chemical water quality modeling (Yoder and Smith 1999). However, using this report as a basis, further analysis of land use data and site information could help pinpoint sources of impairment and provide targeted solutions to the identified problems. For example, some of the streams damaged by livestock, as identified by the IBI, would improve dramatically if fences were built to restrict or eliminate livestock access. Local planning officials could also analyze relationships between degrees of urban development and the IBI scores of associated streams. This type of analysis could help with several other management activities, including

- identifying land use patterns with the least impact on the environment,
- establishing thresholds on the amount of impervious surfaces allowed in subwatersheds,
- identifying problem areas in need of need restoration (e.g., riparian areas),
- locating sites for the purchase of conservation easements, and
- evaluating the performance of conservation practices, such as riparian buffers.

Although the IBI and HDI are expected to agree in most instances, there will be some instances where they will not. For example, the HDI cannot possibly account for all causes of impairment (e.g., toxic chemical spills, historical pesticide use) and does not effectively deal with temporary disturbances. However, such impacts are integrated and should be detectable by the IBI. If low IBI scores should occur without HDI agreement, then some disturbing factor is still more than likely responsible. In such instances, the metrics that are most affected should be identified and reasons for their impairment should be explored. In some cases a full explanation may not be revealed without examining historical land use practices (e.g., the application of persistent pesticides) or designing more comprehensive monitoring of current physical and chemical stream parameters.

A key objective in conducting this study was to evaluate IBI as a technique for assessing the effects of conservation. Because the IBI is able to integrate both positive and negative effects of human influence, it may afford a unique measure of the combined effects of conservation practices (e.g., buffer strips, conservation tillage, terraces, windbreaks) typical of those recommended by NRCS in cooperation with private landowners. In this context, it may also serve as a useful tool to assess the effectiveness of conservation programs that are targeted to solve specific watershed problems (e.g., the Conservation Reserve Enhancement Program). For example, in the Occoquan Watershed, Schueler (1996) states that one of the major difficulties in achieving greater nutrient reduction from the agricultural sector is poor participation in available conservation cost-sharing programs. However, recent implementation of the Conservation Reserve Enhancement Program has significantly improved those incentives statewide. The program's goal is to establish 35,000 acres of buffers consisting of trees and native grasses next to streams to reduce sediment, nutrients, and other polluted runoff. Farmers will be eligible for 75 to 100 percent cost-share for taking land out of production and placing it in temporary and permanent easements. Having a regional IBI established prior to implementation will provide the ability to conduct before and after assessments of that program's practices and lead to the improved design of specific conservation measures. In this way, the IBI can be used not only as a tool to assess watershed condition, but as an endpoint to measure the achievement of watershed goals.

Literature cited

Angermeier, P.L., and J.R. Karr. 1986. An index of biotic integrity based on stream fish communities: considerations in sampling and interpretation. N. Am. J. Fish. Mgt, 6:418-429.

Angermeier, P.L., and R. Smogor. 1994. Estimating number of species and relative abundance in stream-fish communities: effects of sampling effort and discontinuous spatial distributions. Can. J. Fish. Aquat. Sci. 52:936-949.

Arnold, C., and C. Gibbons. 1996. Impervious surface coverage: the emergence of a key environmental indicator. J. Am. Plan. Assoc. 62(2):243-258.

Avery, E.L. 1978. The influence of chemical reclamation on a small trout stream in southwestern Wisconsin. Techn. Bull. No. 110. Wisconsin Dep. Natural Resourc., Madison, Wisconsin, 35 pp.

Baumann, P.C., W.D. Smith, and M. Ribick. 1982. Hepatic tumor rates and poly-nuclear aromatic hydrocarbon levels in two populations of brown bullhead (*Ictalurus nebulosus*). *In* M.W. Cooke, A.J. Dennis, and G.L. Fisher, eds., Polynuclear Aromatic Hydrocarbons: Sixtieth International Symposium on Physical and Biological Chemistry, Batelle Press, Columbus, Ohio, pp. 93-102.

Berkman, H.E., C.F. Rabeni, and T.P. Boyle. 1986. Biomonitors of stream quality in agricultural areas: fish versus invertebrates. Environ. Mgt. 10:413-419.

Brown, R.E., J.J. Hazdra, L. Keith, I. Greenspan, and J.B.G. Kwapiniski. 1973. Frequency of fish tumors in a polluted watershed as compared to non-polluted Canadian waters. Cancer Research 33:189-198.

City of Olympia. 1994. Impervious surface reduction study. Final report. Water Resources Program. Public Works Dep., City of Olympia.

Cooper, E.L. 1952. Rate of exploitation of wild eastern brook trout and brown trout populations in the Pigeon River, Otsego County, Michagan. Trans. Am. Fish. Soc. 81:224-234.

Danielson, T.J. 1998. Wetland bioassessment fact sheets. EPA843-f-98-001. U.S. Environ. Protection Agency, Office of Wetlands, Oceans, and Watersheds, Wetlands Division, Washington, D.C.

Davis, W.S., B.D. Snyder, J.B. Stribling, and C. Stoughton. 1996. Summary of state biological assessment programs for streams and rivers. EPA 230-R-96-007. U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation, Washington, D.C.

Etnier, D.A., and W.C. Starnes. 1993. The fishes of Tennessee. Univ. Tenn. Press. Knoxville, Tennessee, 681 pp.

Fausch, K.D., J. Lyons, J.R. Karr, and P.L. Angermeier. 1990. Fish communities as indicators of environmental degradation. Am. Fish. Soc. Symp. 8:123-144.

Hack, J.T. 1982. Physiographic division and differential uplift in the Piedmont and Blue Ridge. U.S. Geological Survey Prof. Pap. 1265.

Hall, L.W. Jr., M.C. Scott, W.D. Killen, Jr., and R.D. Anderson. 1996. The effects of land-use characteristics and acid sensitivity on the ecological status of Maryland coastal plain streams. Environ. Toxicol. and Chem., 15:384-394.

Hatcher, L. 1994. A step-by-step approach to using the SAS® system for factor analysis and structural equation modeling. SAS Inst., Inc., Cary, North Carolina.

Hoover, E.E. 1938. Fish populations of primitive brook trout streams of northern New Hampshire. Trans. N. Am. Wildl. Conf. 3:486-496.

Hughes, R.M., and J.R. Gammon. 1987. Longitudinal changes in fish assemblages and water quality in the Willamette River, Oregon. Trans. Am. Fish. Soc. 116:196-209.

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., T.R. Whittier, and C.M. Rohm. 1990. A regional framework for establishing recovery criteria. Environ. Mgt. 14:673-683.

Jenkins, R.E., and N.M. Burkhead. 1993. The freshwater fishes of Virginia. Am. Fish. Soc., Bethesda, Maryland.

Johnson, M.G. 1965. Estimates of fish populations in warmwater streams by the removal method. Trans. Am. Fish. Soc. 94:351-357.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. Fisheries (Bethesda) 6(6):21-27.

Karr, J.R., and E.W. Chu. 1997. Biological monitoring and assessment: using multimetric indexes effectively. EPA 235-297-001. University of Washington, Seattle.

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. Ill. Nat. Hist. Survey Spec. Publ. 5, Urbana, Illinois.

Kuehne, Robert A., and R.W. Barbour. 1983. The American Darters. The Univ. Press of KY, Lexington, Kentucky.

Lenat, D.R., and J.K. Crawford. 1994. Effects of land use on water quality and aquatic biota of three North Carolina Piedmont streams. Hydrobiologia 294:185-199.

Leonard, P.M., and D.J. Orth. 1986. Application and testing of an index of biotic integrity in small, coolwater streams. Trans. Am. Fish. Soc. 115:401-415.

Lyons, J. 1992. Using the indexes of biotic integrity (IBI) to measure environmental quality in warmwater streams of Wisconsin. Gen. Tech. Rep. NC-149. St. Paul, MN, U.S. Dep. Agric., Forest Serv., N.Cen. Forest Exp. Sta.

Mahon, R. 1976. Effect of the cestode *Ligula intestinalis* on spottail shiners, *Notropis hudsonius*. Can. J. Zoology 54:2227-2229.

Matthews, W.J. 1987. Community and evolutionary ecology of North American stream fishes. Univ. Okla. Press, Norman, Oklahoma.

Miller, R.R., J.D. Williams, and J.E. Williams. 1989. Extinctions of North American fishes during the past century. Fisheries 14(6):22-38.

Mills, H.B., W.C. Starrett, and F.C. Bellrose. 1966. Man's effect on the fish and wildlife of the Illinois River. Ill. Nat. Hist. Surv. Biol. Notes 57:1-24.

Minckley, W.L., and J.E. Deacon. 1991. Battle against extinction. Univ. Ariz. Press, Tuscon, Arizona.

Northern Virginia Planning District Commission. 1994. U.S. EPA clean lakes report for the Occoquan Watershed. N. Va. Plan. Dist. Comm., Annandale, Virginia.

Ohio Environmental Protection Agency. 1988. Biological criteria for the protection of aquatic life. Div. Water Qual. Monitor. and Assess., Surface Water Sec., Columbus, Ohio.

Page, L.M. 1983. Handbook of darters. TFH Publ., Inc., Neptune City, New Jersey.

Richards, C.L., L.B. Johnson, and G.E. Host. 1996. Landscape-scale influences on stream habitats and biota. Can. J. Fish. Aquat. Sci. 53 (suppl. 1): 295-311.

Rosenberg, David M., and Vincent H. Resh, eds. 1993. Freshwater biomonitoring and benthic macroinvertebrates. Chapman & Hall, New York, New York.

Roth, N.E., J.D. Allan, and D.E. Erickson. 1996. Landscape influences on stream biotic integrity assessed at multiple spatial scales. Landscape Ecol. 11:141-156.

Schlosser, I.J. 1982. Fish community structure and function along two habitat gradients in a headwater stream. Ecol. Monogr. 52:395-414.

Schlosser, I.J. 1991. Stream fish ecology: a landscape perspective. BioScience 41:704-711.

Schueler, T. 1995. Site planning for urban stream protection. Ctr. for Watershed Protec., Metro. Washington Council Gov., Silver Spring, Maryland.

Schueler, T. 1996. The limits to growth: sustainable development in the Occoquan Basin. Ctr. for Watershed Protec., Metro. Washington Council Gov., Silver Spring, Maryland.

Simon, T.P., ed. 1999. Assessing the sustainability and biological integrity of water resources using fish assemblages. CRC Press, Boca Raton, Florida.

Smogor, R. 1996. Developing an index of biotic integrity (IBI) for warmwater wadeable streams in Virginia. MS thesis, Va. Poly. Insti. and State Univ., Blacksburg, Virginia.

Smogor, R.A., and P.L. Angermeier. 1999. Relations between fish metrics and measures of anthropogenic disturbance in three IBI regions of Virginia. *In* T.P. Simon, ed., Assessing the sustainability and biological integrity of water resources using fish assemblages, CRC Press, Boca Raton, Florida, pp. 585-610.

Steedman, R.J. 1988. Modification and assessment of an index of biotic integrity to quantify stream quality in southern Ontario. Can. J. Fish. and Aquatic Sci. 45:492-501.

United States Department of Agriculture, Natural Resources Conservation Service. 1998. Stream visual assessment protocol. Nat. Water and Climate Ctr. NWCC-TN-99-1, Portland, Oregon.

United States Environmental Protection Agency. 1998. Clean water action plan: Restoring and protecting America's waters. EPA-840-R-98-001, Ntl. Cen. Environ. Publ. and Info., Cincinnati, Ohio.

Wang, L., J. Lyons, P. Kanehl, and R. Gatti. 1997. Influences of watershed land use on habitat quality and biotic integrity in Wisconsin streams. Fisheries 22(6):6-12.

Warren, M.J., P.L. Angermeier, B.M. Burr, and W.R. Haag. 1997. Decline of a diverse fish fauna: patterns of imperilment and protection in the southeastern United States. *In* Aquatic Fauna in Peril. S.E. Aquatic Inst. Spec. Publ. 1. Decatur, Georgia, pp. 105-164.

Winston, M.W., C. Taylor, and J. Pigg. 1991. Upstream extirpation of four minnow species due to damming of a prairie stream. Trans. Am. Fish. Soc. 120:98-105.

Yoder, C.O., and E.T. Rankin. 1995. Biological criteria development and implementation in Ohio. *In* W.S. Davis and T.P. Simon, eds., Biological assessment and criteria: tools for water resource planning and decision making, Lewis, Boca Raton, Florida, pp. 109-144 .

Yoder, C.O., and M.A. Smith. 1999. Using fish assemblages in a state biological assessment and criteria program: essential concepts and considerations. *In* T.P. Simon, ed., Assessing the sustainability and biological integrity of water resources using fish communities, CRC Press, Boca Raton, Florida, pp. 17-56.

Appendix

Tables and Figures Developed in the Study

Tables

Figures

Table 7 Location descriptions of fish sampling sites

Site names are based on the intersection of the specified stream and route number of the state or county road, unless otherwise indicated. Reach locations begin immediately downstream or upstream of the crossing, accounting for a safe distance beyond the bridge or similar structure that may affect the results.

Drainage area <17 km^2

Occoquan River Watershed

Site #	Site name	Location
1	Airlie up	Cedar Run between route 628 and private road immediately above Airlie mitigation area
2	Airlie mit	the mitigation cells on Cedar Run at Airlie
3	Airlie dn	Cedar Run below the multi-purpose dam at Airlie
4	Gup 602	Gupton Run above crossing
5	Owl 616	Owl Run above crossing
6	Wal 767	Walnut Run above crossing
7	Broad GM	Broad Run at Great Meadows, upstream of fence at the lower end of property
8	Pine 246	Piney Branch of Broad Run above crossing
9	Mill up	Mill Run above lake at Kinloch Farm
10	Mill dn	Mill Run below dam at Kinloch Farm
11	N. Fk 15	North Fork of Broad Run above crossing
12	S. Fk up	South Fork of Broad Run above Lake Brittle
13	S. Fk dn	South Fork of Broad Run below dam of Lake Brittle
14	L Bull up	Little Bull Run above Silver Lake
15	L Bull dn	Little Bull Run below dam of Silver Lake
16	Cat 15	Catharpin Creek below crossing
17	Black 15	Black Branch below crossing
18	Young 234	Youngs Branch above crossing
19	Flatlick 50	Flatlick Branch below crossing
20	Rocky 645	Rocky Run above crossing
21	Piney 660	Piney Branch of Popes Head Creek above crossing
22	Hooes 641	Hooes Run above crossing
23	Long 695	Long Branch above confluence of Occoquan Creek (Lake Jackson)
24	Cannon 28	Cannon Run below crossing
25	Purcel 643	Purcell Run below crossing
26	Elk 607	Elk Run below crossing
27	Wolf 643	Wolf Run below crossing
28	Sandy 647	Sandy Run below crossing

Rappahannock River Watershed

29	Horner 691	Horner Run below crossing
30	South 738	South Run below crossing
31	E. Th. 647	East Branch of Thumb Run below crossing
32	Bowens 28	Bowens Run below crossing
33	Great 678	Great Run above crossing
34	Muddy 729	Muddy Run below crossing
35	Waterf 229	Waterford Run below crossing
36	Piney 600	Piney Falls Fork of the Thornton River below crossing
37	Rap 635	Rappahannock River below crossing

Table 7 Location descriptions of fish sampling sites—Continued

Drainage area <17 km^2—Continued

Goose Creek Watershed

Site #	Site name	Location
38	Sim 719	Simpsons branch above crossing
39	Jacks 690	Jacks Branch below crossing
40	Crom 702	Cromwells Run below crossing
41	Buch 626	Butchers Branch below crossing
42	Dog 630	Dog Branch above crossing
43	N. fk(b) 725	North Fork of Beaverdam Creek below crossing
44	Crook 848	Crooked Run of lower Goose Creek below crossing
45	Dry Mill 699	Dry Mill Branch above crossing
46	Cattail 773	Cattail Branch below crossing
47	Big 650	Big Branch of lower Goose Creek below crossing
48	Hungry 632	Hungry Run above bridge at barn about 1 mile north of confluence with Little River
49	Burnt 626	Burnt Mill Run below crossing
50	Syco 15	South Branch of Sycoline Creek below crossing
51	Chat 624	Chattin's Run above crossing

Drainage area 17 to 34 km2

Occoquan River Watershed

Site #	Site name	Location
52	Mill 605	Mill Run below crossing
53	Turk 602	Turkey Run above crossing
54	Lick 674	Licking Run above crossing
55	Town 639	Town Run above crossing
56	Slate 649	Slate Run above crossing
57	Trapp 55	Trap Branch above crossing
58	S. Fk 684	South Fork of Broad Run above crossing
59	Kett 604	Kettle Run below crossing
60	L Bull 676	Little Bull Run above crossing
61	Cat 676	Catharpin Creek above crossing
62	Chest 686	Chestnut Lick below crossing
63	Bull 624	Bull Run below crossing
64	Flat Lmnd	Flat Branch below bridge of Lomond Drive in the city of Manassas
65	Slate 611	Slate Run above crossing
66	Chest 701	Chestnut Lick below crossing
67	Bull 705	Bull Run above the confluence with Chestnut Lick
68	E. Fk 660	East Fork of Popes Head Creek above crossing
69	Elklick 609	Elklick Run above crossing
70	Flatlick 620	Flatlick Branch above crossing
71	L. Roc 658	Little Rocky Run above crossing
72	Popes 612	Popes Head Creek above crossing

Table 7 Location descriptions of fish sampling sites—Continued

Drainage area 17 to 34 km^2—Continued

Rappahannock River Watershed

Site #	Site name	Location
73	South 737	South Run below crossing
74	Buck 735	Buck Run below crossing
75	Fiery 635	Fiery Run below crossing
76	Battle 633	Battle Run below crossing
77	Tinpot 657	Tinpot Run above crossing
78	Brown 653	Browns Run above crossing
79	Indian 626	Indian Run below crossing
80	Jacob 626	Jacob's run above crossing
81	Jordan 522	Jordan River above crossing
82	Marsh 17	Marsh Run above crossing
83	Craig 805	Craig Run below crossing
84	Hazel 231	Hazel River below crossing
85	Thorn 522	Thornton River below crossing
86	Cov 522	Covington River above crossing
87	Hittles 522	Hittles Mill Run below crossing

Goose Creek Watershed

88	Goose 688	Goose Creek below crossing
89	Big 55	Big Branch of upper Goose Creek above crossing
90	Crom 715	Cromwells Run above crossing
91	Jeff 719	Jeffries Branch above crossing
92	Beav 790	Beaverdam Creek above crossing
93	N.Fkg 791	North Fork of Goose Creek below crossing
94	Crook 727	Crooked Run of lower Goose Creek above crossing
95	Tusc 621	Tuscarora Creek below bridge on old route 621 in city of Leesburg
96	Syco 621	Sycoline Creek above crossing
97	Little 705	Little River below crossing
98	Crook 688	Crooked Run of upper Goose Creek below crossing
99	Gap 710	Gap Run above crossing
100	Tusc 643	Tuscarora Creek below crossing

Table 7 Location descriptions of fish sampling sites—Continued

Drainage Area > 34 km^2

Occoquan River Watershed

Site #	Site name	Location
101	Cedar 674	Cedar Run below crossing
102	Lick up	Licking Run above Germantown Lake
103	Lick dn	Licking Run below dam of Germantown Lake
104	Elk 806	Elk Run above crossing
105	Town 611	Town Run above crossing
106	Broad Avnl	Broad Run above the bridge at Avenel
107	Kett 611	Kettle Run above crossing
108	Cat 704	Catharpin Creek above crossing
109	Cat 234	Catharpin Creek above crossing
110	Cedar 602	Cedar Run above centerline of planned Auburn Dam
111	Town 806	Town Run below the confluence of Elk Run
112	Broad 55	Broad Run below crossing
113	Bull 659	Bull Run below crossing
114	Cedar 806	Cedar Run above crossing
115	Broad 619	Broad Run below crossing
116	Bull RP	Bull Run at Bull Run Regional Park, above the confluence of Cub Run
117	Cub 620	Cub Run above crossing
118	Cub 29	Cub Run below crossing
119	Cub RP	Cub Run at Bull Run Regional Park, above the confluence with Bull Run
120	Popes Clif	Popes Head Creek above Webb Sanctuary property

Rappahannock River Watershed

121	Carter 681	Carters Run below crossing
122	Carter 738	Carters Run above crossing
123	Carter up	Carters Run above the confluence of Horner Run
124	Great 687	Great Run below crossing
125	W. Th. 647	West Thumb Run above crossing
126	Th. R. 736	Thumb Run below crossing
127	Jordan 637	Jordan River above crossing
128	Rapah 647	Rappahannock River below crossing
129	Rush 211	Rush River below crossing
130	Cov 626	Covington River above crossing
131	Hugh 707	Hughes Run below crossing
132	Thor 622	Thornton River above crossing
133	Hazel 707	Hazel River above crossing
134	Hugh 644	Hughes River above crossing
135	Hazel 522	Hazel River above crossing
136	Black 615	Blackwater Creek below crossing
137	Rap W'loo	Rappahannock River above route 613 crossing at Waterloo
138	Indian 624	Indian Run above crossing
139	Thor 618	Thornton River below crossing
140	Muddy 630	Muddy Run above crossing
141	Marsh 668	Marsh Run below crossing
142	Hazel 628	Hazel River below crossing

Table 7 Location descriptions of fish sampling sites—Continued

Drainage Area > 34 km^2—Continued

Goose Creek Watershed

Site #	Site name	Location
143	Crook 623	Crooked Run of upper Goose Creek above crossing
144	Goose 17	Goose Creek below crossing
145	Gap 623	Gap Run above crossing
146	Panth 623	Pantherskin Creek below crossing
147	N Fk. 722	North Fork of Goose Creek above crossing
148	N.Fkb 611	North Fork of Beaverdam Creek below crossing
149	N Fk. 729	North Fork of Goose Creek below crossing
150	Beav 734	Beaverdam Creek below crossing
151	Goose733	Goose Creek above bridge at Limestone Kiln farm
152	Goose 710	Goose Creek above crossing
153	Goose 611	Goose Creek below crossing
154	Little 776	Little River above crossing
155	Little 50	Little River below crossing
156	Goose 55	Goose Creek below crossing
157	Syc 643	Sycoline Creek below crossing

Table 8 Raw fish data for 157 sites in study

Common name	1 Airlie up	2 Airlie mit	3 Airlie dn	4 Gup 602	5 Owl 616	6 Wal 767	7 Broad GM	8 Pine 246	9 Mill up	10 Mill dn	11 N. Fk 15
American brook lamprey	0	0	0	0	0	0	0	0	0	0	0
Gizzard shad	0	0	0	0	0	0	0	0	0	0	0
American eel	0	0	0	0	0	0	0	0	0	0	0
Redfin pickerel	0	0	0	0	0	0	0	0	0	0	0
Eastern mudminnow	0	0	0	0	0	0	0	0	0	0	11
Common carp	0	0	0	0	0	0	0	0	0	0	0
Golden shiner	0	1	0	0	10	8	23	2	0	0	5
Mountain redbelly dace	0	0	0	0	0	0	0	0	0	0	0
Rosyside dace	11	0	0	2	0	0	35	0	73	5	0
Fallfish	3	0	0	11	0	3	0	0	3	69	0
Creek chub	0	0	0	0	0	0	0	0	0	0	0
River chub	0	0	0	0	0	0	0	0	9	3	0
Bluehead chub	0	0	0	0	0	0	0	0	0	0	0
Cutlips minnow	50	0	0	0	0	0	1	0	5	1	0
Blacknose dace	115	0	0	0	0	0	5	0	99	4	0
Longnose dace	0	0	0	0	0	0	0	0	0	0	0
Central stoneroller	0	0	0	0	0	0	0	0	0	0	0
Eastern silvery minnow	0	0	0	16	27	8	0	0	0	0	0
Common shiner	2	0	0	3	0	3	16	0	57	48	0
Satinfin shiner	0	0	0	87	0	0	90	14	0	0	0
Spotfin shiner	0	0	0	0	0	0	0	0	0	0	0
Bluntnose minnow	68	12	2	19	10	10	98	7	45	1	0
Fathead minnow	0	0	0	0	7	1	0	0	0	0	0
Comely shiner	0	0	0	0	0	0	0	0	0	0	0
Spottail shiner	0	0	0	0	0	0	0	0	0	0	0
Swallowtail shiner	0	0	0	3	4	0	4	0	0	0	0
Rosyface shiner	0	0	0	0	0	0	0	0	0	0	0
Silverjaw minnow	0	0	0	0	0	0	0	0	0	0	0
White sucker	3	0	0	47	4	39	1	0	10	19	0
Creek chubsucker	0	0	0	7	5	3	2	3	0	0	3
Northern hogsucker	0	0	0	0	0	0	0	0	0	4	0
Torrent sucker	0	0	0	0	0	0	0	0	0	0	0
Golden redhorse	0	0	0	0	0	0	0	0	0	0	0
Shorthead redhorse	0	0	0	0	0	0	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0	0	0	0	0	0
Yellow bullhead	0	1	1	2	0	0	30	3	0	0	6
Brown bullhead	0	0	0	0	0	1	0	0	0	0	0
Margined madtom	0	0	0	0	0	0	21	3	0	0	0
Banded killifish	0	0	0	0	0	0	0	0	0	0	0
Eastern mosquitofish	0	0	0	0	0	0	0	0	0	0	0
Mottled sculpin	0	0	0	0	0	0	0	0	0	0	0
Potomac sculpin	0	0	0	0	0	0	0	0	0	0	0
Redbreast sunfish	0	6	0	3	1	3	52	47	1	5	14
Green sunfish	65	127	11	1	8	1	24	8	0	3	0
Pumpkinseed	2	29	6	0	20	2	3	0	1	0	5
Bluegill	0	6	138	19	88	54	27	15	14	9	30
Redear sunfish	0	0	0	0	0	0	0	0	0	0	0
Rock bass	0	0	0	0	0	0	0	0	0	0	0
White crappie	0	0	0	0	0	1	0	0	0	0	0
Smallmouth bass	0	0	0	0	0	0	0	0	0	0	0
Largemouth bass	0	1	0	11	4	5	1	15	0	0	1
Shield darter	0	0	0	0	0	0	1	0	0	0	0
Stripeback darter	0	0	0	0	0	0	0	0	0	0	0
Tesselated darter	4	0	0	5	2	1	192	46	0	4	37
Glassy darter	0	0	0	0	0	0	0	0	0	0	0
Fantail darter	38	0	0	1	0	0	47	15	39	1	12
Greenside darter	0	0	0	0	0	0	0	0	0	0	0
Hybrids	0	0	6	0	2	1	0	0	0	0	0
Total	**361**	**183**	**164**	**237**	**192**	**144**	**673**	**178**	**356**	**176**	**124**
Anomalies	0	1	0	2	4	0	0	0	0	0	0

Table 8 Raw fish data for 157 sites in study—Continued

Common name	12 S. Fk up	13 S. Fk dn	14 L Bull up	15 L Bull dn	16 Cat 15	17 Black 15	18 Young 234	19 Flatlick 50	20 Rocky 645	21 Piney 660	22 Hooes 641
American brook lamprey	0	0	0	0	0	0	0	0	0	0	0
Gizzard shad	0	0	0	0	0	0	0	0	0	0	1
American eel	0	0	0	0	0	0	0	0	0	0	0
Redfin pickerel	0	0	0	0	1	0	0	0	0	0	0
Eastern mudminnow	0	0	0	0	0	0	0	0	0	0	0
Common carp	0	0	0	0	0	0	0	0	0	0	0
Golden shiner	8	3	0	0	0	1	0	0	2	0	0
Mountain redbelly dace	0	0	0	0	0	0	0	0	0	0	0
Rosyside dace	1	0	421	4	171	4	72	0	9	11	0
Fallfish	0	0	187	0	41	0	39	0	0	2	0
Creek chub	80	0	0	5	0	3	17	72	33	6	11
River chub	0	0	0	0	0	0	0	0	0	0	0
Bluehead chub	0	0	0	0	0	0	0	0	0	0	0
Cutlips minnow	0	0	0	4	15	27	0	0	1	1	0
Blacknose dace	5	1	223	0	24	0	5	8	19	291	73
Longnose dace	0	0	0	0	8	0	0	1	22	6	0
Central stoneroller	0	0	0	0	0	0	0	0	0	0	0
Eastern silvery minnow	0	0	0	0	0	2	1	0	1	0	0
Common shiner	0	0	0	0	71	71	2	0	5	19	0
Satinfin shiner	2	0	0	0	16	7	17	0	113	0	224
Spotfin shiner	0	0	0	0	0	0	0	0	0	0	0
Bluntnose minnow	3	4	0	16	2	5	0	226	30	28	0
Fathead minnow	0	0	0	0	0	0	0	0	0	0	0
Comely shiner	0	0	0	0	0	46	16	0	0	0	0
Spottail shiner	0	0	0	0	0	7	1	7	0	0	3
Swallowtail shiner	0	0	0	0	21	22	138	0	89	61	333
Rosyface shiner	0	0	0	0	0	0	0	0	0	0	0
Silverjaw minnow	0	0	0	0	0	0	0	0	0	0	0
White sucker	7	3	4	5	4	2	11	5	0	8	5
Creek chubsucker	0	0	0	6	0	0	0	2	0	0	1
Northern hogsucker	0	0	0	0	5	0	0	0	1	1	0
Torrent sucker	0	0	0	0	0	0	0	0	0	0	0
Golden redhorse	0	0	0	0	0	0	0	0	0	0	0
Shorthead redhorse	0	0	0	0	0	0	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0	0	0	0	0	0
Yellow bullhead	7	50	0	7	0	5	0	0	0	0	0
Brown bullhead	0	0	0	0	0	0	0	0	0	0	0
Margined madtom	0	0	0	0	0	2	0	0	0	0	0
Banded killifish	0	0	0	0	0	0	0	0	0	0	0
Eastern mosquitofish	0	0	0	37	0	0	0	0	0	0	0
Mottled sculpin	0	0	0	0	0	0	0	0	0	0	0
Potomac sculpin	0	0	0	0	0	0	0	0	0	0	0
Redbreast sunfish	0	47	0	2	14	7	16	2	29	3	0
Green sunfish	0	0	0	15	2	3	26	1	10	11	13
Pumpkinseed	1	4	0	1	0	1	0	0	2	0	0
Bluegill	24	52	1	60	0	4	4	16	20	7	34
Redear sunfish	0	0	0	0	0	0	0	0	0	0	0
Rock bass	0	0	0	0	0	0	0	0	0	0	0
White crappie	32	12	0	0	0	0	0	0	0	0	0
Smallmouth bass	0	0	0	0	0	0	0	0	0	0	0
Largemouth bass	0	6	0	18	0	6	0	4	0	0	0
Shield darter	0	0	0	0	0	0	0	0	0	0	0
Stripeback darter	0	0	0	0	0	0	0	0	0	0	0
Tesselated darter	0	13	4	1	18	23	66	7	6	25	29
Glassy darter	0	0	0	0	0	0	0	0	0	0	0
Fantail darter	53	0	24	6	30	17	13	9	28	41	0
Greenside darter	0	0	0	0	0	0	0	0	0	0	0
Hybrids	0	0	0	0	0	1	0	0	4	1	0
Total	**223**	**195**	**864**	**187**	**443**	**266**	**444**	**360**	**424**	**522**	**727**
Anomalies	0	0	0	0	0	1	0	6	5	0	1

Table 8 Raw fish data for 157 sites in study—Continued

Common name	23 Long 695	24 Cannon 28	25 Purcel 643	26 Elk 607	27 Wolf 643	28 Sandy 647	29 Horner 691	30 South 738	31 E. Th. 647	32 Bowens 28	33 Great 678
American brook lamprey	0	0	0	0	0	0	0	0	0	0	0
Gizzard shad	0	0	0	0	0	0	0	0	0	0	0
American eel	0	0	0	0	0	0	0	0	0	0	0
Redfin pickerel	0	0	0	0	0	0	0	0	0	0	0
Eastern mudminnow	0	0	0	0	0	0	0	0	0	0	0
Common carp	0	0	0	0	0	3	0	0	0	0	0
Golden shiner	1	0	0	0	0	0	6	0	0	2	8
Mountain redbelly dace	0	0	0	0	0	0	0	0	0	0	0
Rosyside dace	10	0	197	3	2	0	33	220	48	0	2
Fallfish	28	3	15	0	5	8	2	35	94	0	1
Creek chub	7	0	44	169	33	9	8	3	3	0	6
River chub	0	1	0	0	0	0	3	9	2	0	0
Bluehead chub	0	0	0	0	0	0	0	0	0	0	25
Cutlips minnow	0	3	0	0	0	0	3	1	2	0	0
Blacknose dace	36	0	69	0	201	11	109	176	134	0	15
Longnose dace	0	0	0	0	0	1	7	6	38	0	0
Central stoneroller	0	0	0	0	0	0	0	0	0	0	0
Eastern silvery minnow	0	2	0	30	0	2	0	0	0	0	0
Common shiner	1	1	0	0	1	0	16	45	23	0	19
Satinfin shiner	7	0	0	113	1	0	17	0	23	0	0
Spotfin shiner	0	0	0	0	0	0	0	0	0	0	0
Bluntnose minnow	14	62	0	20	0	0	137	0	0	0	113
Fathead minnow	0	0	0	0	0	0	0	0	0	0	0
Comely shiner	0	0	0	4	0	0	0	0	0	0	0
Spottail shiner	0	8	0	101	9	129	0	0	0	0	0
Swallowtail shiner	96	86	0	35	68	88	24	0	13	0	0
Rosyface shiner	0	0	0	4	0	0	0	0	0	0	0
Silverjaw minnow	0	0	0	0	0	0	8	121	13	0	0
White sucker	4	22	28	55	27	4	80	3	52	0	9
Creek chubsucker	0	9	0	3	0	3	6	0	0	1	2
Northern hogsucker	1	0	0	0	13	0	1	0	23	0	0
Torrent sucker	0	0	0	0	0	0	0	0	0	0	0
Golden redhorse	0	0	0	0	0	0	0	0	0	0	0
Shorthead redhorse	0	0	0	0	0	0	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0	0	0	0	0	0
Yellow bullhead	1	3	1	14	0	5	0	0	0	0	0
Brown bullhead	0	0	0	0	0	0	0	0	0	0	0
Margined madtom	0	0	0	0	0	2	0	0	0	0	3
Banded killifish	0	2	0	0	0	0	0	0	0	0	0
Eastern mosquitofish	0	2	0	0	4	0	0	0	0	574	0
Mottled sculpin	0	0	0	0	0	0	0	6	0	0	0
Potomac sculpin	0	0	0	0	0	0	0	0	0	0	0
Redbreast sunfish	7	23	0	2	0	0	17	0	2	0	25
Green sunfish	8	15	30	23	3	24	2	2	1	17	2
Pumpkinseed	0	0	1	5	0	1	1	0	1	5	61
Bluegill	37	55	4	4	14	35	0	5	6	42	35
Redear sunfish	0	0	0	0	0	0	0	0	0	0	0
Rock bass	0	0	0	0	0	0	0	0	0	0	1
White crappie	0	0	0	0	0	0	0	0	0	19	0
Smallmouth bass	0	0	0	0	0	0	0	0	0	0	0
Largemouth bass	1	12	0	3	2	12	0	0	1	0	11
Shield darter	0	0	0	0	0	0	0	0	0	0	0
Stripeback darter	0	0	0	0	0	0	1	0	1	0	1
Tesselated darter	6	6	33	61	38	13	53	33	161	0	16
Glassy darter	0	0	0	0	0	0	0	0	0	0	0
Fantail darter	8	5	4	0	4	3	0	0	0	0	0
Greenside darter	0	0	0	0	0	0	0	0	0	0	0
Hybrids	0	0	0	0	1	3	0	0	0	3	0
Total	**273**	**320**	**426**	**649**	**426**	**356**	**534**	**665**	**641**	**663**	**355**
Anomalies	0	0	2	0	43	1	33	0	1	0	2

Table 8 Raw fish data for 157 sites in study—Continued

Common name	34 Muddy 729	35 Waterf 229	36 Piney 600	37 Rap 635	38 Sim 719	39 Jacks 690	40 Crom 702	41 Buch 626	42 Dog 630	43 N. fk(b) 725	44 Crook 848
American brook lamprey	0	0	0	0	0	0	0	0	0	0	0
Gizzard shad	0	0	0	0	0	0	0	0	0	0	0
American eel	0	0	1	0	0	0	0	0	0	0	0
Redfin pickerel	0	0	0	0	0	0	0	0	0	0	0
Eastern mudminnow	0	0	0	0	0	0	0	0	0	0	0
Common carp	0	0	0	0	0	0	0	0	0	0	0
Golden shiner	0	0	0	0	0	0	0	1	0	5	0
Mountain redbelly dace	11	73	48	0	0	0	0	0	0	0	0
Rosyside dace	112	6	197	69	1	126	0	300	18	78	74
Fallfish	40	56	51	18	0	0	0	0	0	0	0
Creek chub	87	53	0	2	14	138	99	28	18	28	45
River chub	0	0	12	21	0	0	0	0	0	0	0
Bluehead chub	77	105	0	0	0	0	0	0	0	0	0
Cutlips minnow	0	0	2	12	0	0	0	0	0	0	0
Blacknose dace	42	5	88	19	30	135	248	293	21	65	212
Longnose dace	4	3	7	0	0	0	0	0	0	0	37
Central stoneroller	0	0	0	0	0	0	0	0	0	0	3
Eastern silvery minnow	5	1	0	0	0	0	0	0	0	0	0
Common shiner	104	34	69	138	0	0	0	16	4	13	3
Satinfin shiner	33	282	0	5	0	0	0	0	0	0	0
Spotfin shiner	0	0	0	0	1	0	0	0	0	0	0
Bluntnose minnow	1	76	0	0	1	11	138	0	53	85	115
Fathead minnow	0	0	0	0	0	0	7	0	0	0	0
Comely shiner	0	1	0	1	0	0	0	0	0	0	0
Spottail shiner	0	0	0	0	1	28	0	2	0	0	4
Swallowtail shiner	79	18	0	1	0	0	0	0	0	0	0
Rosyface shiner	0	1	1	0	0	0	0	0	0	0	0
Silverjaw minnow	239	326	0	0	0	8	80	0	18	9	154
White sucker	20	20	8	27	20	42	11	9	6	5	69
Creek chubsucker	0	0	0	0	0	0	0	1	5	5	2
Northern hogsucker	1	0	1	10	0	0	0	0	0	0	0
Torrent sucker	0	0	0	1	0	0	0	0	0	0	0
Golden redhorse	0	0	0	0	0	0	0	0	0	0	0
Shorthead redhorse	0	0	0	0	0	0	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0	0	0	1	0	0
Yellow bullhead	0	2	0	0	0	3	0	0	0	0	4
Brown bullhead	0	0	0	0	0	0	0	0	0	0	0
Margined madtom	0	6	2	1	0	0	0	0	0	0	0
Banded killifish	0	0	0	0	0	0	0	0	0	0	0
Eastern mosquitofish	0	0	0	0	0	0	0	0	1	0	0
Mottled sculpin	0	0	18	1	0	0	0	0	0	0	0
Potomac sculpin	0	0	0	0	0	0	0	36	0	5	1
Redbreast sunfish	9	10	0	1	0	0	5	8	0	8	39
Green sunfish	0	6	0	0	2	0	4	0	4	10	0
Pumpkinseed	0	0	0	0	2	1	1	0	2	7	0
Bluegill	12	2	0	3	104	41	6	0	70	26	0
Redear sunfish	0	0	0	0	0	0	0	0	0	0	0
Rock bass	0	1	9	12	0	0	0	0	0	0	0
White crappie	0	0	0	0	0	4	0	0	0	0	0
Smallmouth bass	0	3	6	9	0	0	0	0	0	0	0
Largemouth bass	4	0	2	3	13	15	0	0	2	3	0
Shield darter	0	0	0	0	0	0	0	0	0	0	0
Stripeback darter	3	0	0	0	0	0	0	0	0	0	0
Tesselated darter	38	26	13	4	0	0	15	5	0	5	0
Glassy darter	0	0	0	0	0	0	0	0	0	0	0
Fantail darter	0	0	0	0	22	5	25	25	2	5	15
Greenside darter	0	0	0	0	0	0	0	4	0	0	1
Hybrids	0	0	0	0	0	0	0	0	0	2	0
Total	**921**	**1116**	**535**	**358**	**211**	**557**	**639**	**728**	**225**	**364**	**778**
Anomalies	4	2	0	2	2	3	25	17	0	2	51

Table 8 Raw fish data for 157 sites in study—Continued

Common name	45 Dry Mill 699	46 Cattail 773	47 Big 650	48 Hungry 632	49 Burnt 626	50 Syco 15	51 Chat 624	52 Mill 605	53 Turk 602	54 Lick 674	55 Town 639
American brook lamprey	0	0	0	0	0	0	0	0	0	0	0
Gizzard shad	0	0	0	0	0	0	0	0	0	0	0
American eel	0	0	0	0	0	0	0	0	0	0	0
Redfin pickerel	0	0	0	0	0	0	0	0	0	12	0
Eastern mudminnow	0	0	0	0	0	0	0	0	0	0	0
Common carp	0	0	0	0	0	0	0	0	0	0	0
Golden shiner	0	0	0	0	0	8	0	1	0	0	14
Mountain redbelly dace	0	0	0	0	0	0	0	0	0	0	0
Rosyside dace	3	0	60	24	35	0	9	33	12	31	2
Fallfish	0	0	4	0	0	0	1	15	10	0	0
Creek chub	45	33	31	14	31	41	26	0	0	0	41
River chub	0	0	0	0	0	0	0	0	0	0	0
Bluehead chub	0	0	0	0	0	0	0	0	0	0	0
Cutlips minnow	0	0	0	0	0	0	0	3	13	0	0
Blacknose dace	47	9	123	105	160	22	131	24	1	3	0
Longnose dace	2	0	15	20	1	1	0	0	0	0	0
Central stoneroller	190	74	52	0	0	13	6	0	0	0	0
Eastern silvery minnow	0	1	0	0	0	0	0	0	7	0	0
Common shiner	0	0	9	0	0	2	5	4	21	0	0
Satinfin shiner	0	0	1	0	0	0	4	10	229	0	59
Spotfin shiner	0	13	0	0	0	0	8	0	0	0	0
Bluntnose minnow	71	82	44	100	9	318	122	25	2	0	65
Fathead minnow	0	0	0	0	0	0	2	0	0	0	0
Comely shiner	0	0	0	0	0	0	0	15	40	0	0
Spottail shiner	0	0	2	0	0	2	8	8	8	0	0
Swallowtail shiner	0	0	0	0	0	0	0	20	154	0	81
Rosyface shiner	0	0	0	0	0	0	0	1	0	0	0
Silverjaw minnow	0	6	44	0	25	0	14	0	0	0	0
White sucker	30	5	6	7	1	48	14	31	32	5	9
Creek chubsucker	3	0	0	1	1	4	16	0	0	53	3
Northern hogsucker	0	0	0	1	0	0	3	9	15	0	0
Torrent sucker	0	0	0	0	0	0	0	0	0	0	0
Golden redhorse	0	0	0	0	0	0	0	0	0	0	0
Shorthead redhorse	0	0	0	0	0	0	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0	0	0	0	0	0
Yellow bullhead	0	1	2	1	2	11	2	0	0	27	3
Brown bullhead	0	0	0	0	0	0	0	0	0	0	0
Margined madtom	0	0	0	0	0	0	0	0	0	1	0
Banded killifish	0	0	0	0	0	0	0	0	0	0	0
Eastern mosquitofish	0	0	0	0	0	0	0	0	0	0	0
Mottled sculpin	0	0	0	0	0	0	0	0	0	0	0
Potomac sculpin	0	0	37	5	6	0	0	0	0	0	0
Redbreast sunfish	25	4	2	128	66	28	26	20	54	25	22
Green sunfish	0	44	10	0	11	100	2	3	2	5	1
Pumpkinseed	1	10	1	0	0	0	0	0	0	4	3
Bluegill	9	84	5	0	4	1	4	20	2	35	21
Redear sunfish	0	0	0	0	0	0	0	0	0	0	0
Rock bass	10	0	0	0	0	0	0	0	0	0	0
White crappie	0	0	0	0	0	0	0	0	0	0	0
Smallmouth bass	0	0	1	0	0	0	0	0	0	0	0
Largemouth bass	0	0	0	0	4	4	2	26	1	1	2
Shield darter	0	0	0	0	0	0	0	0	2	0	0
Stripeback darter	0	0	0	0	0	0	0	0	0	0	0
Tesselated darter	0	0	1	2	0	0	51	27	6	66	76
Glassy darter	0	0	0	0	0	0	0	0	0	0	0
Fantail darter	23	11	12	2	3	7	6	67	49	0	0
Greenside darter	1	3	1	14	3	0	3	0	0	0	0
Hybrids	2	3	0	1	3	2	1	0	0	0	0
Total	**462**	**383**	**463**	**425**	**365**	**612**	**466**	**362**	**660**	**268**	**402**
Anomalies	49	29	3	103	29	125	40	1	0	1	0

Table 8 Raw fish data for 157 sites in study—Continued

Common name	56 Slate 649	57 Trapp 55	58 S. Fk 684	59 Kett 604	60 L Bull 676	61 Cat 676	62 Chest 686	63 Bull 624	64 Flat Lmnd	65 Slate 611	66 Chest 701
American brook lamprey	0	0	0	0	0	0	0	0	0	0	0
Gizzard shad	0	0	0	0	0	0	0	0	0	0	0
American eel	0	0	0	0	0	0	0	0	0	0	0
Redfin pickerel	0	0	0	0	0	1	6	4	0	0	0
Eastern mudminnow	0	0	0	0	0	0	0	0	0	0	0
Common carp	0	0	0	0	0	0	0	0	0	0	0
Golden shiner	17	0	0	2	9	0	8	0	0	4	4
Mountain redbelly dace	0	0	0	0	0	0	0	0	0	0	0
Rosyside dace	0	2	0	0	4	6	12	0	0	0	6
Fallfish	1	2	0	0	0	15	1	4	9	0	10
Creek chub	4	0	0	0	0	0	0	0	188	5	0
River chub	0	49	0	0	0	0	0	0	0	0	0
Bluehead chub	0	0	0	0	0	0	0	0	0	0	0
Cutlips minnow	0	10	0	0	0	10	17	8	0	0	37
Blacknose dace	0	44	6	0	0	9	0	1	57	0	0
Longnose dace	0	0	0	0	0	11	0	1	0	0	0
Central stoneroller	0	0	0	0	0	0	0	0	0	0	0
Eastern silvery minnow	0	0	0	9	8	1	2	43	0	0	93
Common shiner	0	43	0	0	0	9	58	38	0	0	21
Satinfin shiner	0	2	0	44	0	61	11	13	0	0	4
Spotfin shiner	0	0	0	0	0	0	0	0	0	0	0
Bluntnose minnow	75	6	1	34	61	5	1	3	7	7	0
Fathead minnow	0	0	0	0	0	0	0	0	0	0	0
Comely shiner	0	0	0	20	0	20	3	70	0	0	87
Spottail shiner	0	0	0	10	0	0	1	14	0	60	8
Swallowtail shiner	18	1	0	18	1	75	18	14	0	41	18
Rosyface shiner	0	0	0	0	0	0	0	0	0	13	0
Silverjaw minnow	0	0	0	0	0	0	0	0	0	0	0
White sucker	6	151	3	34	184	38	11	16	10	1	25
Creek chubsucker	2	0	0	5	17	2	3	0	12	0	1
Northern hogsucker	0	0	1	3	0	5	3	3	0	0	14
Torrent sucker	0	0	0	0	0	0	0	0	0	0	0
Golden redhorse	0	0	0	0	0	0	0	0	0	0	0
Shorthead redhorse	0	0	0	0	0	0	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0	0	0	0	0	0
Yellow bullhead	7	6	3	13	24	4	20	5	0	0	1
Brown bullhead	0	0	0	0	0	0	0	0	0	0	0
Margined madtom	0	4	0	0	0	1	0	8	0	0	12
Banded killifish	0	0	0	2	0	0	0	0	0	11	0
Eastern mosquitofish	27	1	2	0	0	0	0	0	0	95	0
Mottled sculpin	0	0	0	0	0	0	0	0	0	0	0
Potomac sculpin	0	0	0	0	0	0	0	0	0	0	0
Redbreast sunfish	4	7	8	36	22	75	36	18	8	3	33
Green sunfish	7	0	0	15	20	5	1	8	1	1	4
Pumpkinseed	1	0	0	1	0	1	1	2	0	1	0
Bluegill	8	8	44	24	0	6	2	9	1	18	1
Redear sunfish	0	0	1	0	0	0	0	0	0	0	0
Rock bass	0	0	0	0	0	0	0	0	0	0	0
White crappie	0	0	3	0	0	0	0	0	0	0	0
Smallmouth bass	0	0	0	1	0	2	0	0	0	0	2
Largemouth bass	10	0	7	62	0	5	12	15	0	1	3
Shield darter	0	0	0	0	0	3	0	2	0	0	5
Stripeback darter	0	0	0	0	0	0	0	0	0	0	0
Tesselated darter	26	42	123	67	24	29	14	3	0	16	10
Glassy darter	0	0	0	0	0	0	0	0	0	0	0
Fantail darter	19	38	20	18	105	19	8	52	0	1	3
Greenside darter	0	0	0	0	0	0	0	0	0	0	0
Hybrids	0	0	0	0	0	0	0	0	0	0	0
Total	**232**	**416**	**222**	**418**	**479**	**418**	**249**	**354**	**293**	**278**	**402**
Anomalies	0	0	0	0	0	0	0	2	22	4	0

Table 8 Raw fish data for 157 sites in study—Continued

Common name	67 Bull 705	68 E. Fk. 660	69 Elklick 609	70 Flatlick 620	71 L. Rock 658	72 Popes 612	73 South 737	74 Buck 735	75 Fiery 635	76 Battle 633	77 Tinpot 657
American brook lamprey	0	0	0	0	0	0	0	0	0	0	0
Gizzard shad	0	0	0	0	0	0	0	0	0	0	0
American eel	0	0	0	0	0	0	0	0	0	0	0
Redfin pickerel	4	0	2	0	0	0	0	0	0	0	0
Eastern mudminnow	0	0	0	0	0	0	0	0	0	0	0
Common carp	0	0	0	0	0	0	0	0	0	0	0
Golden shiner	4	0	6	0	5	0	0	6	0	0	34
Mountain redbelly dace	0	0	0	0	0	0	0	0	0	0	0
Rosyside dace	18	70	0	0	0	107	158	11	75	0	0
Fallfish	9	0	0	4	40	3	113	49	59	9	6
Creek chub	1	24	2	4	4	23	5	0	0	51	7
River chub	0	0	0	0	1	0	28	0	3	110	0
Bluehead chub	0	0	0	0	0	0	0	0	0	0	2
Cutlips minnow	24	2	0	0	3	7	1	0	2	7	0
Blacknose dace	4	258	0	2	6	27	70	120	142	54	0
Longnose dace	0	3	4	16	11	1	15	11	7	71	0
Central stoneroller	0	0	0	0	0	0	0	0	0	0	0
Eastern silvery minnow	20	0	3	0	0	0	0	0	0	0	22
Common shiner	137	9	0	0	5	60	248	51	103	52	12
Satinfin shiner	18	0	0	0	1	0	2	11	4	40	0
Spotfin shiner	0	0	0	0	1	0	0	0	0	0	0
Bluntnose minnow	3	83	6	14	46	87	1	0	0	0	8
Fathead minnow	0	0	0	0	0	0	0	0	0	0	0
Comely shiner	38	0	0	0	0	0	0	0	0	0	0
Spottail shiner	20	0	0	6	1	0	0	0	0	0	0
Swallowtail shiner	5	58	0	0	6	117	19	50	2	39	7
Rosyface shiner	0	0	0	0	0	0	0	0	0	0	0
Silverjaw minnow	0	0	0	0	0	0	84	0	0	122	4
White sucker	17	13	3	2	8	21	32	4	7	25	5
Creek chubsucker	2	0	1	0	0	1	0	0	0	0	0
Northern hogsucker	13	4	0	0	2	9	7	3	0	14	0
Torrent sucker	0	0	0	0	0	0	0	0	4	0	0
Golden redhorse	0	0	0	0	0	0	0	0	0	0	0
Shorthead redhorse	0	0	0	0	0	0	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0	0	0	0	0	0
Yellow bullhead	3	0	6	1	0	0	0	0	0	0	13
Brown bullhead	0	0	0	0	0	0	0	0	0	0	0
Margined madtom	3	0	0	0	0	0	0	0	0	0	0
Banded killifish	0	0	0	0	0	0	0	0	0	0	0
Eastern mosquitofish	0	0	0	0	13	0	0	0	0	0	0
Mottled sculpin	0	0	0	0	0	0	10	0	0	0	0
Potomac sculpin	0	0	0	0	0	0	0	0	0	0	0
Redbreast sunfish	14	31	40	4	42	31	2	0	0	3	0
Green sunfish	6	5	47	3	5	1	0	0	0	9	54
Pumpkinseed	0	0	0	0	0	0	1	0	0	0	32
Bluegill	4	4	3	33	2	2	16	17	1	16	12
Redear sunfish	0	0	0	0	0	0	0	0	0	0	0
Rock bass	0	0	0	0	0	0	0	0	0	7	0
White crappie	0	0	0	0	0	0	0	0	0	0	0
Smallmouth bass	1	0	0	0	3	0	0	0	0	0	0
Largemouth bass	5	1	12	25	3	0	0	0	2	1	9
Shield darter	17	0	0	0	0	0	2	0	0	0	0
Stripeback darter	0	0	0	0	0	0	0	0	0	0	0
Tesselated darter	11	44	0	14	42	57	62	140	15	35	0
Glassy darter	0	0	0	0	0	0	0	0	0	0	0
Fantail darter	18	40	0	4	13	31	0	0	0	0	0
Greenside darter	0	0	0	0	0	0	0	0	0	0	0
Hybrids	0	0	0	1	1	0	0	0	0	0	1
Total	**419**	**649**	**135**	**133**	**264**	**585**	**876**	**473**	**426**	**665**	**228**
Anomalies	0	0	0	1	0	109	0	0	0	0	37

Table 8 Raw fish data for 157 sites in study—Continued

Common name	78 Brown 653	79 Indian 626	80 Jacob 626	81 Jordan 522	82 Marsh 17	83 Craig 805	84 Hazel 231	85 Thorn 522	86 Cov 522	87 Hittles 522	88 Goose 688
American brook lamprey	0	0	1	1	0	0	0	0	0	0	0
Gizzard shad	0	0	0	0	0	0	0	0	0	0	0
American eel	0	0	0	0	0	0	0	0	0	0	0
Redfin pickerel	0	0	0	0	0	0	0	0	0	0	0
Eastern mudminnow	0	0	0	0	0	0	0	0	0	0	0
Common carp	0	0	0	0	0	0	0	0	0	0	0
Golden shiner	23	1	1	1	47	77	0	0	0	0	0
Mountain redbelly dace	0	4	0	0	0	0	0	0	0	0	0
Rosyside dace	0	50	4	24	0	0	13	9	42	0	21
Fallfish	2	13	67	32	0	0	67	73	12	3	0
Creek chub	0	53	110	8	0	1	9	0	5	3	8
River chub	0	0	0	20	0	0	40	33	7	34	0
Bluehead chub	0	54	65	21	0	0	9	0	20	2	0
Cutlips minnow	0	11	1	8	0	0	1	2	49	4	0
Blacknose dace	0	0	7	75	0	0	42	25	346	15	22
Longnose dace	0	0	0	1	0	0	10	19	17	0	12
Central stoneroller	0	0	0	0	0	0	0	0	0	0	0
Eastern silvery minnow	33	0	0	0	0	0	0	0	0	0	0
Common shiner	0	203	137	151	0	0	142	38	507	50	0
Satinfin shiner	0	0	150	73	0	0	12	0	0	10	9
Spotfin shiner	0	0	0	0	0	0	0	0	0	0	17
Bluntnose minnow	59	83	1	0	33	23	0	0	0	0	16
Fathead minnow	0	0	0	0	0	0	0	0	0	0	0
Comely shiner	0	0	0	0	0	0	1	1	0	1	0
Spottail shiner	36	0	16	0	0	1	0	0	0	0	0
Swallowtail shiner	0	26	5	10	0	0	0	0	0	2	0
Rosyface shiner	0	0	0	0	0	0	27	1	0	0	0
Silverjaw minnow	0	121	89	3	0	0	0	0	0	0	0
White sucker	6	31	18	22	9	3	2	1	20	9	6
Creek chubsucker	0	0	0	0	16	2	0	0	0	0	1
Northern hogsucker	2	5	0	1	0	0	17	4	5	0	17
Torrent sucker	0	0	0	12	0	0	0	0	0	13	0
Golden redhorse	0	0	0	0	0	0	0	0	0	0	0
Shorthead redhorse	0	0	0	0	0	0	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0	0	0	0	0	0
Yellow bullhead	31	0	1	0	3	0	0	0	0	0	0
Brown bullhead	0	1	0	0	0	0	0	0	0	0	0
Margined madtom	0	1	1	2	0	0	1	3	0	6	0
Banded killifish	0	0	0	0	0	0	0	0	0	0	0
Eastern mosquitofish	34	0	0	0	815	553	0	0	0	0	0
Mottled sculpin	0	0	0	2	0	0	2	3	0	0	0
Potomac sculpin	0	0	0	0	0	0	0	0	0	0	20
Redbreast sunfish	0	36	4	18	6	0	10	1	13	33	17
Green sunfish	100	25	1	31	169	110	0	0	0	18	1
Pumpkinseed	18	0	0	0	0	1	0	0	0	0	0
Bluegill	6	3	4	234	1	5	1	0	0	41	38
Redear sunfish	0	0	0	0	0	0	0	0	0	0	0
Rock bass	0	0	1	4	0	0	6	12	1	43	0
White crappie	0	0	0	0	0	0	0	0	0	0	0
Smallmouth bass	0	0	2	0	0	0	2	9	8	8	5
Largemouth bass	10	0	0	8	1	0	0	0	0	0	0
Shield darter	0	0	0	0	0	0	0	0	0	0	0
Stripeback darter	0	16	0	0	0	2	0	0	0	0	0
Tesselated darter	20	73	6	16	1	18	20	13	23	8	0
Glassy darter	0	0	0	0	0	0	0	0	0	0	0
Fantail darter	0	0	0	0	0	0	0	0	0	0	23
Greenside darter	0	0	0	0	0	0	0	0	0	0	2
Hybrids	1	0	1	1	0	0	0	0	0	0	0
Total	**381**	**810**	**693**	**779**	**1101**	**796**	**434**	**247**	**1075**	**303**	**235**
Anomalies	34	13	7	44	1	1	0	2	73	1	4

Table 8 Raw fish data for 157 sites in study—Continued

Common name	89 Big 55	90 Crom 715	91 Jeff 719	92 Beav 790	93 N.Fkg 791	94 Crook 727	95 Tusc 621	96 Syco 621	97 Little 705	98 Crook 688	99 Gap 710
American brook lamprey	0	0	0	0	0	0	0	0	0	0	0
Gizzard shad	0	0	0	0	0	0	0	0	0	0	0
American eel	0	0	0	0	0	0	0	0	0	0	0
Redfin pickerel	0	0	0	0	0	0	0	0	0	0	0
Eastern mudminnow	0	0	0	0	0	0	0	0	0	0	0
Common carp	0	0	0	0	0	0	0	0	0	0	0
Golden shiner	0	0	0	5	2	0	0	8	0	0	0
Mountain redbelly dace	0	0	0	0	0	0	0	0	0	0	0
Rosyside dace	153	0	15	65	6	67	0	0	179	271	41
Fallfish	0	0	0	0	0	0	0	0	0	0	0
Creek chub	71	24	22	16	4	34	33	17	0	83	60
River chub	0	0	0	0	0	0	0	0	0	0	0
Bluehead chub	0	0	0	0	0	0	0	0	0	0	0
Cutlips minnow	0	0	0	0	0	0	0	0	0	0	0
Blacknose dace	310	124	153	79	42	84	69	64	107	664	204
Longnose dace	0	0	2	7	14	97	33	202	14	52	24
Central stoneroller	0	0	4	0	0	6	24	71	0	0	49
Eastern silvery minnow	0	0	0	0	0	0	0	0	0	0	0
Common shiner	2	0	12	23	3	3	0	2	0	35	3
Satinfin shiner	0	0	46	0	14	1	0	0	0	2	421
Spotfin shiner	0	0	8	0	12	5	1	5	0	1	3
Bluntnose minnow	0	56	76	60	55	42	56	56	18	50	121
Fathead minnow	0	0	0	0	0	0	0	0	0	0	0
Comely shiner	0	0	0	0	0	1	0	0	0	0	0
Spottail shiner	0	0	56	1	19	55	0	45	0	0	0
Swallowtail shiner	0	1	0	0	207	1	50	1	0	11	15
Rosyface shiner	0	0	0	0	0	0	0	0	4	0	0
Silverjaw minnow	1	97	0	67	0	84	6	0	21	2	23
White sucker	27	42	10	10	10	20	11	12	48	17	0
Creek chubsucker	0	0	3	3	2	0	4	1	4	2	1
Northern hogsucker	0	0	7	0	7	8	3	1	15	3	6
Torrent sucker	0	0	0	0	0	0	0	0	0	0	0
Golden redhorse	0	0	0	0	0	0	0	1	0	0	0
Shorthead redhorse	0	0	0	0	0	0	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0	0	0	0	0	0
Yellow bullhead	0	0	1	1	3	1	0	2	0	2	3
Brown bullhead	0	0	0	0	0	0	0	0	0	0	1
Margined madtom	0	0	0	0	0	0	0	0	0	0	0
Banded killifish	0	0	0	0	0	0	0	0	0	12	28
Eastern mosquitofish	0	0	0	0	0	0	0	0	0	0	0
Mottled sculpin	0	0	0	0	0	0	0	0	0	0	0
Potomac sculpin	6	0	1	1	0	15	0	12	9	22	1
Redbreast sunfish	0	4	26	8	24	17	12	20	29	21	219
Green sunfish	6	0	3	1	0	0	28	17	0	0	21
Pumpkinseed	0	0	9	0	2	0	12	0	0	0	3
Bluegill	9	6	44	26	61	7	73	2	3	0	25
Redear sunfish	0	0	0	0	0	0	0	0	0	0	0
Rock bass	0	0	0	0	0	0	0	0	0	0	0
White crappie	0	0	0	1	4	2	0	0	0	0	0
Smallmouth bass	0	0	0	0	0	0	0	0	0	0	0
Largemouth bass	6	3	0	19	13	3	0	6	0	0	0
Shield darter	0	0	0	0	0	0	0	0	0	0	0
Stripeback darter	0	0	0	0	0	0	0	0	0	0	0
Tesselated darter	0	58	12	10	0	4	0	9	11	0	23
Glassy darter	0	0	0	0	0	0	0	0	0	0	0
Fantail darter	25	41	35	7	3	10	53	51	9	43	30
Greenside darter	0	0	4	2	1	5	8	14	15	0	0
Hybrids	0	0	0	0	1	0	2	0	0	0	0
Total	**616**	**456**	**549**	**412**	**509**	**572**	**478**	**619**	**486**	**1293**	**1325**
Anomalies	0	0	30	4	11	68	73	57	31	118	10

Table 8 Raw fish data for 157 sites in study—Continued

Common name	100 Tusc 643	101 Cedar 674	102 Lick up	103 Lick dn	104 Elk 806	105 Town 611	106 Broad Avnl	107 Kett 611	108 Cat 704	109 Cat 234	110 Cedar 602
American brook lamprey	0	0	0	0	0	0	0	0	0	0	0
Gizzard shad	0	0	0	0	0	0	0	0	0	0	0
American eel	0	0	0	0	0	0	0	0	0	0	0
Redfin pickerel	0	0	2	0	0	0	1	0	12	5	0
Eastern mudminnow	0	0	0	0	0	0	0	0	0	0	0
Common carp	0	0	0	0	0	0	0	0	0	0	0
Golden shiner	0	0	2	26	7	4	1	1	0	0	0
Mountain redbelly dace	0	0	0	0	0	0	0	0	0	0	0
Rosyside dace	0	0	0	0	2	14	0	0	1	0	9
Fallfish	0	5	0	0	0	9	7	4	49	93	9
Creek chub	18	0	0	0	10	28	0	0	0	0	0
River chub	0	9	0	0	0	0	45	0	1	1	86
Bluehead chub	0	0	0	0	0	0	0	0	0	0	0
Cutlips minnow	0	2	2	0	0	0	93	0	9	3	23
Blacknose dace	9	14	0	0	0	0	0	0	21	5	1
Longnose dace	5	0	0	0	0	0	0	0	8	1	0
Central stoneroller	38	0	0	0	0	0	0	0	0	0	0
Eastern silvery minnow	0	0	0	0	9	19	2	51	76	40	5
Common shiner	0	15	0	0	0	2	184	4	43	51	110
Satinfin shiner	0	98	0	268	23	125	65	21	7	54	60
Spotfin shiner	5	0	0	0	0	0	0	0	0	0	0
Bluntnose minnow	64	49	0	10	20	14	13	16	0	11	42
Fathead minnow	1	0	0	0	0	0	0	0	0	0	0
Comely shiner	0	7	0	0	11	4	19	22	20	21	15
Spottail shiner	109	0	0	0	7	82	0	69	1	11	2
Swallowtail shiner	0	29	2	53	16	71	20	45	33	2	20
Rosyface shiner	0	1	0	0	8	1	0	1	5	0	1
Silverjaw minnow	8	0	0	0	0	0	0	0	0	0	0
White sucker	11	10	19	4	65	21	27	14	12	15	6
Creek chubsucker	0	4	3	1	1	0	0	10	2	4	1
Northern hogsucker	4	13	0	1	5	9	8	5	1	7	22
Torrent sucker	0	0	0	0	0	0	0	0	0	0	0
Golden redhorse	0	0	0	0	0	0	0	0	0	0	0
Shorthead redhorse	0	0	0	0	0	0	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0	0	0	0	0	0
Yellow bullhead	0	3	8	29	9	1	3	35	0	2	4
Brown bullhead	0	0	1	0	0	0	0	0	0	0	0
Margined madtom	0	1	1	0	0	0	0	0	2	0	1
Banded killifish	0	0	0	0	0	0	0	9	0	0	0
Eastern mosquitofish	0	0	0	0	0	0	0	0	0	0	0
Mottled sculpin	0	0	0	0	0	0	0	0	0	0	0
Potomac sculpin	0	0	0	0	0	0	0	0	0	0	0
Redbreast sunfish	23	40	23	109	5	2	68	8	34	23	13
Green sunfish	3	2	5	0	10	1	2	12	0	1	2
Pumpkinseed	7	0	3	0	0	0	0	0	0	0	0
Bluegill	3	43	32	9	1	1	19	5	2	0	10
Redear sunfish	0	1	1	0	1	0	0	0	0	1	0
Rock bass	31	0	0	0	0	0	0	0	0	0	0
White crappie	0	0	0	0	0	0	0	0	0	0	0
Smallmouth bass	0	0	0	0	0	0	6	1	4	8	1
Largemouth bass	0	2	12	0	13	1	0	29	1	2	0
Shield darter	0	4	0	0	1	3	0	0	1	1	13
Stripeback darter	0	0	0	0	0	0	0	0	0	0	0
Tesselated darter	0	26	8	1	15	95	16	26	23	7	9
Glassy darter	0	0	0	0	0	0	0	0	0	0	0
Fantail darter	12	29	0	0	10	22	48	21	17	5	31
Greenside darter	11	0	0	0	0	0	0	0	0	0	0
Hybrids	1	0	0	0	0	0	0	0	0	0	0
Total	**363**	**407**	**124**	**511**	**249**	**529**	**647**	**409**	**385**	**374**	**496**
Anomalies	33	0	0	0	2	3	0	0	0	0	0

Table 8 Raw fish data for 157 sites in study—Continued

Common name	111 Town 806	112 Broad 55	113 Bull 659	114 Cedar 806	115 Broad 619	116 Bull RP	117 Cub 620	118 Cub 29	119 Cub RP	120 Popes Clif.	121 Carter 681
American brook lamprey	0	0	0	0	0	0	0	0	0	0	1
Gizzard shad	0	0	0	0	0	0	0	0	0	0	0
American eel	0	0	0	0	0	0	0	0	0	0	0
Redfin pickerel	0	0	0	0	0	0	0	0	0	0	0
Eastern mudminnow	0	0	0	0	0	0	0	0	0	0	0
Common carp	0	0	0	0	0	0	0	0	0	0	0
Golden shiner	0	0	0	3	1	3	0	1	0	0	0
Mountain redbelly dace	0	0	0	0	0	0	0	0	0	0	0
Rosyside dace	0	0	0	0	0	0	0	0	0	19	8
Fallfish	31	44	33	45	4	42	39	0	100	81	190
Creek chub	16	0	0	0	0	2	0	0	7	11	6
River chub	0	144	0	10	5	28	0	2	21	25	14
Bluehead chub	0	0	0	0	0	0	0	0	0	0	0
Cutlips minnow	0	4	15	5	0	24	0	1	3	8	0
Blacknose dace	0	19	5	0	4	1	0	0	3	63	10
Longnose dace	0	0	17	0	0	49	13	1	6	13	53
Central stoneroller	0	0	0	0	0	0	0	0	0	0	0
Eastern silvery minnow	69	33	34	5	1	25	4	0	4	0	0
Common shiner	3	24	32	38	30	48	0	18	56	66	52
Satinfin shiner	92	70	28	91	58	19	10	0	28	0	52
Spotfin shiner	0	0	0	0	0	0	0	0	2	0	0
Bluntnose minnow	26	8	24	25	8	28	50	23	2	0	0
Fathead minnow	0	0	0	0	0	0	0	0	0	0	0
Comely shiner	4	3	26	9	14	4	0	0	1	0	18
Spottail shiner	67	6	15	14	19	14	61	104	4	0	0
Swallowtail shiner	104	21	41	37	92	38	42	20	40	37	1
Rosyface shiner	1	0	1	0	3	2	0	0	0	0	2
Silverjaw minnow	0	0	0	0	0	0	0	0	0	0	10
White sucker	36	35	15	7	2	1	6	0	4	16	3
Creek chubsucker	1	0	2	1	0	1	1	2	1	0	0
Northern hogsucker	11	14	8	17	5	6	0	0	1	11	18
Torrent sucker	0	0	0	0	0	0	0	0	0	0	0
Golden redhorse	0	0	0	0	0	3	0	0	0	0	0
Shorthead redhorse	0	0	0	0	0	0	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0	0	0	0	0	0
Yellow bullhead	4	6	3	1	16	1	0	3	2	1	0
Brown bullhead	0	0	0	0	0	0	0	0	0	0	0
Margined madtom	0	0	0	0	0	0	0	0	0	1	0
Banded killifish	0	0	0	0	2	0	0	0	0	0	0
Eastern mosquitofish	0	0	0	0	0	1	9	6	5	0	0
Mottled sculpin	0	0	0	0	0	0	0	0	0	0	3
Potomac sculpin	0	0	0	0	0	0	0	0	0	0	0
Redbreast sunfish	13	11	35	23	52	7	32	18	7	15	8
Green sunfish	2	0	1	1	0	15	36	6	6	2	0
Pumpkinseed	0	0	0	0	0	0	0	0	0	0	0
Bluegill	4	4	1	13	0	1	1	5	1	3	0
Redear sunfish	0	0	1	0	0	0	0	0	0	0	0
Rock bass	0	0	0	0	0	0	0	0	0	0	2
White crappie	0	0	0	0	0	0	0	0	0	0	0
Smallmouth bass	0	4	22	0	4	4	0	1	0	4	2
Largemouth bass	5	3	1	4	0	1	2	4	2	0	2
Shield darter	14	0	2	2	0	12	0	0	1	0	22
Stripeback darter	0	0	0	0	0	0	0	0	0	0	0
Tesselated darter	39	20	12	25	15	14	16	7	21	23	104
Glassy darter	0	0	0	0	0	0	0	0	0	0	24
Fantail darter	10	38	22	28	17	16	3	2	1	24	0
Greenside darter	0	0	0	0	0	0	0	0	0	0	0
Hybrids	0	0	0	0	0	0	0	0	0	1	0
Total	**552**	**511**	**396**	**404**	**352**	**410**	**325**	**224**	**329**	**424**	**605**
Anomalies		0	0	0	0	0	0	1	0	51	0

Table 8 Raw fish data for 157 sites in study—Continued

Common name	122 Carter 738	123 Carter up	124 Great 687	125 W. Th. 647	126 Th. R. 736	127 Jordan 637	128 Rapah 647	129 Rush 211	130 Cov 626	131 Hugh 707	132 Thor 622
American brook lamprey	0	0	0	0	1	0	1	0	0	0	0
Gizzard shad	0	0	0	0	0	0	0	0	0	0	0
American eel	0	0	0	0	0	1	0	0	0	0	0
Redfin pickerel	0	0	0	0	0	0	0	0	0	0	0
Eastern mudminnow	0	0	0	0	0	0	0	0	0	0	0
Common carp	0	0	0	0	0	0	0	0	0	0	0
Golden shiner	0	6	0	0	0	0	0	0	0	0	0
Mountain redbelly dace	0	0	0	0	0	0	0	0	0	12	0
Rosyside dace	46	70	2	22	3	0	0	5	0	387	0
Fallfish	110	53	87	167	83	102	178	33	56	1	99
Creek chub	5	30	0	1	0	0	1	12	0	3	6
River chub	19	13	11	2	4	66	83	25	89	17	60
Bluehead chub	0	0	0	0	0	0	0	0	0	3	0
Cutlips minnow	2	2	1	0	0	3	1	5	8	2	5
Blacknose dace	29	184	3	28	1	4	5	30	7	109	2
Longnose dace	14	20	25	26	30	25	102	28	113	19	6
Central stoneroller	0	0	0	0	0	0	0	0	0	0	0
Eastern silvery minnow	0	0	12	0	0	0	0	0	0	0	0
Common shiner	81	117	29	32	100	81	35	80	108	106	44
Satinfin shiner	41	23	79	31	79	84	109	0	26	0	24
Spotfin shiner	0	0	0	0	0	0	0	0	0	0	0
Bluntnose minnow	4	29	7	0	0	4	0	0	0	0	2
Fathead minnow	0	0	0	0	0	0	0	0	0	0	0
Comely shiner	22	1	76	0	1	13	5	0	2	0	0
Spottail shiner	0	0	3	0	0	0	1	0	19	0	7
Swallowtail shiner	16	12	5	20	3	24	20	8	4	0	42
Rosyface shiner	0	0	1	7	54	65	76	0	40	1	126
Silverjaw minnow	4	36	3	8	0	23	5	0	0	0	6
White sucker	24	26	4	1	4	3	8	5	0	4	5
Creek chubsucker	0	0	0	0	0	0	0	0	0	0	0
Northern hogsucker	16	6	13	3	2	3	7	9	7	0	4
Torrent sucker	0	0	0	0	0	19	21	0	0	48	0
Golden redhorse	0	0	0	0	0	0	0	0	0	0	0
Shorthead redhorse	2	0	0	0	0	0	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0	0	0	0	0	0
Yellow bullhead	0	0	0	0	0	0	3	0	1	0	5
Brown bullhead	0	0	0	0	0	0	0	0	0	0	0
Margined madtom	0	0	1	0	0	0	0	1	1	0	7
Banded killifish	0	0	0	0	0	0	0	0	0	0	0
Eastern mosquitofish	0	0	0	0	0	0	0	0	0	0	0
Mottled sculpin	0	1	0	0	0	14	3	2	0	19	0
Potomac sculpin	0	0	0	0	0	0	0	0	0	0	0
Redbreast sunfish	8	5	8	0	3	1	4	1	6	0	16
Green sunfish	0	0	3	0	0	9	7	0	0	0	3
Pumpkinseed	0	2	0	0	0	0	3	1	0	0	0
Bluegill	0	2	10	3	5	3	9	3	3	0	8
Redear sunfish	0	0	0	0	0	0	0	0	0	0	0
Rock bass	2	0	4	0	0	16	0	3	8	1	84
White crappie	0	0	0	0	0	0	0	0	0	0	0
Smallmouth bass	1	0	1	0	2	13	8	7	5	3	15
Largemouth bass	0	0	0	4	2	0	5	1	0	0	2
Shield darter	10	3	3	0	0	12	10	0	3	0	3
Stripeback darter	13	6	0	0	0	0	0	0	0	0	0
Tesselated darter	26	95	31	47	22	78	60	46	133	14	35
Glassy darter	51	0	0	0	0	0	0	0	0	0	0
Fantail darter	0	0	0	0	0	0	0	0	0	0	0
Greenside darter	0	0	0	0	0	0	0	0	0	0	0
Hybrids	0	0	0	0	0	0	0	0	0	1	0
Total	**546**	**742**	**422**	**402**	**399**	**666**	**770**	**305**	**639**	**750**	**616**
Anomalies	3	4	11	0	1	1	0	1	1	1	3

Table 8 Raw fish data for 157 sites in study—Continued

Common name	133 Hazel 707	134 Hugh 644	135 Hazel 522	136 Black 615	137 Rap W'loo	138 Indian 624	139 Thor 618	140 Muddy 630	141 Marsh 668	142 Hazel 628	143 Crook 623
American brook lamprey	0	0	0	0	0	0	0	0	0	1	0
Gizzard shad	0	0	0	0	0	0	0	0	0	0	0
American eel	0	0	0	0	0	0	0	0	0	1	0
Redfin pickerel	0	0	0	0	0	0	0	0	0	0	0
Eastern mudminnow	0	0	0	0	0	0	0	0	0	0	0
Common carp	0	0	0	0	0	0	0	0	0	0	0
Golden shiner	3	0	0	0	0	1	0	9	17	0	0
Mountain redbelly dace	0	0	0	0	0	0	0	0	0	0	0
Rosyside dace	0	0	0	4	0	8	0	0	0	0	13
Fallfish	43	80	137	40	64	90	29	32	4	16	5
Creek chub	6	19	1	5	0	12	1	1	0	0	6
River chub	93	69	89	45	62	35	33	0	1	15	0
Bluehead chub	0	0	0	0	0	0	0	20	0	0	0
Cutlips minnow	1	5	3	2	5	0	15	0	0	2	5
Blacknose dace	0	0	1	11	0	2	1	0	0	0	13
Longnose dace	20	32	60	16	5	15	105	19	0	3	15
Central stoneroller	0	0	0	0	0	0	0	0	0	0	5
Eastern silvery minnow	0	0	0	0	0	1	0	18	79	0	0
Common shiner	92	37	35	99	15	119	31	41	2	35	43
Satinfin shiner	23	52	32	7	72	57	39	354	0	43	25
Spotfin shiner	0	0	0	0	0	0	0	0	0	0	146
Bluntnose minnow	0	0	0	0	0	53	5	4	117	0	16
Fathead minnow	0	0	0	0	0	0	0	0	0	0	0
Comely shiner	0	0	2	1	3	4	7	35	26	1	3
Spottail shiner	0	0	0	0	2	37	1	0	17	9	35
Swallowtail shiner	13	1	6	17	65	15	6	17	2	26	18
Rosyface shiner	65	70	143	2	49	0	32	0	0	114	0
Silverjaw minnow	11	0	8	18	16	23	19	0	0	21	5
White sucker	2	2	2	3	0	14	1	5	10	1	8
Creek chubsucker	0	0	0	0	0	0	0	0	2	0	0
Northern hogsucker	7	2	6	9	4	9	1	7	1	4	7
Torrent sucker	0	6	1	0	3	0	0	0	0	0	0
Golden redhorse	0	0	0	0	0	0	0	0	0	0	0
Shorthead redhorse	0	0	0	0	0	0	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0	0	0	0	0	0
Yellow bullhead	0	0	0	0	3	0	1	0	3	3	1
Brown bullhead	0	0	0	0	0	0	0	0	0	0	0
Margined madtom	7	1	0	0	4	0	1	0	0	9	1
Banded killifish	0	0	0	0	0	0	0	0	0	0	3
Eastern mosquitofish	0	0	0	0	0	0	0	0	75	0	0
Mottled sculpin	5	13	1	5	2	0	0	0	0	0	0
Potomac sculpin	0	0	0	0	0	0	0	0	0	0	8
Redbreast sunfish	13	3	8	3	32	14	28	20	0	29	32
Green sunfish	7	1	0	1	2	8	3	1	125	9	12
Pumpkinseed	0	0	0	0	0	0	0	1	8	1	0
Bluegill	0	1	0	5	6	30	5	8	33	6	13
Redear sunfish	0	0	0	0	0	0	0	0	0	0	0
Rock bass	34	22	22	8	10	0	48	0	0	23	0
White crappie	0	0	0	0	0	0	0	0	3	0	0
Smallmouth bass	27	18	9	4	23	2	8	0	0	1	0
Largemouth bass	11	0	0	0	2	2	0	1	7	1	0
Shield darter	1	1	2	0	22	0	8	0	0	11	0
Stripeback darter	0	0	0	0	1	0	0	6	1	0	0
Tesselated darter	31	25	36	19	43	24	73	36	16	23	0
Glassy darter	0	0	0	0	4	0	0	0	0	6	0
Fantail darter	0	0	0	0	0	0	0	0	0	0	13
Greenside darter	0	0	0	0	0	0	0	0	0	0	8
Hybrids	0	0	0	0	0	0	0	0	0	1	0
Total	**515**	**460**	**604**	**324**	**519**	**575**	**501**	**635**	**549**	**415**	**459**
Anomalies	2	15	1	1	1	0	3	1	26	2	2

Table 8 Raw fish data for 157 sites in study—Continued

Common name	144 Goose 17	145 Gap 623	146 Panth 623	147 N. Fk 722	148 N.Fkb 611	149 N Fk. 729	150 Beav 734	151 Goose 733	152 Goose 710	153 Goose 611	154 Little 776
American brook lamprey	0	0	0	0	0	0	0	0	0	0	0
Gizzard shad	0	0	0	0	0	0	0	0	0	0	0
American eel	0	0	0	0	0	0	0	0	0	0	0
Redfin pickerel	0	0	0	0	0	0	0	0	0	0	0
Eastern mudminnow	0	0	0	0	0	0	0	0	0	0	0
Common carp	0	0	0	0	0	0	0	0	0	0	0
Golden shiner	0	2	0	0	5	0	5	1	0	0	0
Mountain redbelly dace	0	0	0	0	0	0	0	0	0	0	0
Rosyside dace	8	3	13	5	267	9	145	0	0	0	48
Fallfish	2	6	0	1	0	2	0	3	34	19	0
Creek chub	1	7	2	3	21	3	5	0	3	2	0
River chub	1	0	0	0	0	0	0	25	29	40	0
Bluehead chub	0	0	0	0	0	0	0	0	0	0	0
Cutlips minnow	2	2	0	0	0	0	0	2	0	12	0
Blacknose dace	23	67	22	70	185	72	104	12	19	18	92
Longnose dace	35	9	22	63	8	34	1	15	23	62	4
Central stoneroller	2	12	8	0	1	0	0	2	2	3	0
Eastern silvery minnow	0	0	0	0	0	0	0	0	0	0	0
Common shiner	28	17	23	2	50	7	50	36	17	41	24
Satinfin shiner	38	65	72	8	0	17	0	31	28	41	0
Spotfin shiner	74	30	37	10	0	52	2	134	79	100	0
Bluntnose minnow	7	35	32	172	46	41	113	39	8	45	15
Fathead minnow	0	0	0	0	0	0	0	0	14	0	0
Comely shiner	44	0	0	0	0	4	0	16	11	0	0
Spottail shiner	108	24	80	119	5	199	38	64	11	221	0
Swallowtail shiner	13	60	53	101	6	68	58	122	15	3	0
Rosyface shiner	7	0	0	0	0	0	0	0	18	60	0
Silverjaw minnow	13	0	0	54	111	81	70	1	6	11	15
White sucker	3	17	3	38	18	4	10	11	8	0	32
Creek chubsucker	0	9	2	0	0	0	2	3	6	0	2
Northern hogsucker	12	3	8	10	3	26	7	20	32	70	51
Torrent sucker	0	0	0	0	0	0	0	0	0	0	0
Golden redhorse	0	0	0	0	0	0	0	0	0	0	0
Shorthead redhorse	0	0	0	0	0	0	0	0	0	0	0
Channel Catfish	0	0	0	0	0	0	0	0	0	0	0
Yellow bullhead	0	2	2	4	1	0	0	5	15	8	1
Brown bullhead	0	0	0	0	0	0	0	0	0	0	0
Margined madtom	1	0	0	0	0	0	0	1	0	0	0
Banded killifish	0	0	1	0	0	0	0	0	5	0	0
Eastern mosquitofish	0	0	0	0	0	0	0	0	0	0	0
Mottled sculpin	0	0	0	0	0	0	0	0	0	0	0
Potomac sculpin	13	8	6	0	49	2	3	3	2	0	38
Redbreast sunfish	5	18	9	17	12	18	9	20	36	14	20
Green sunfish	0	0	4	0	0	2	4	1	0	0	0
Pumpkinseed	0	0	1	0	3	2	0	0	0	0	0
Bluegill	7	1	14	24	4	27	16	1	3	3	1
Redear sunfish	0	0	0	0	0	0	0	0	0	0	0
Rock bass	0	0	0	0	0	0	0	5	2	12	0
White crappie	0	0	0	4	0	1	0	0	0	0	0
Smallmouth bass	2	5	0	0	0	0	0	1	8	5	0
Largemouth bass	2	0	2	5	5	2	5	2	4	2	0
Shield darter	0	0	0	0	0	0	0	0	0	0	0
Stripeback darter	0	0	0	0	0	0	0	0	0	0	0
Tesselated darter	1	2	18	11	8	4	40	9	8	9	11
Glassy darter	0	0	0	0	0	0	0	0	0	0	0
Fantail darter	5	41	85	3	19	0	3	20	18	62	19
Greenside darter	10	5	5	1	5	6	24	86	19	69	6
Hybrids	0	0	0	0	0	1	0	1	2	0	0
Total	**467**	**450**	**524**	**725**	**832**	**684**	**714**	**692**	**485**	**932**	**379**
Anomalies	3	3	6	190	13	10	6	10	5	5	53

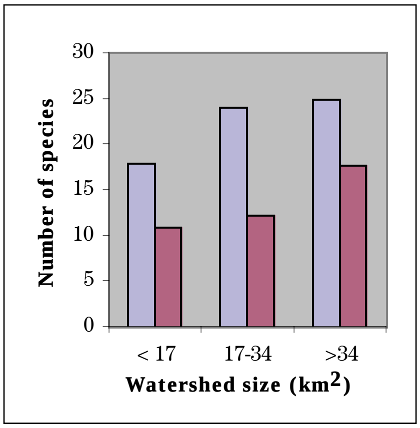
Table 8 Raw fish data for 157 sites in study—Continued

Common name	155 Little 50	156 Goose 55	157 Syco 643
American brook lamprey	0	0	0
Gizzard shad	0	0	0
American eel	0	0	0
Redfin pickerel	0	0	0
Eastern mudminnow	0	0	0
Common carp	0	0	0
Golden shiner	0	0	0
Mountain redbelly dace	0	0	0
Rosyside dace	90	3	0
Fallfish	8	0	0
Creek chub	58	5	13
River chub	0	0	0
Bluehead chub	0	0	0
Cutlips minnow	7	0	0
Blacknose dace	144	0	18
Longnose dace	22	0	16
Central stoneroller	8	3	67
Eastern silvery minnow	0	0	0
Common shiner	43	0	13
Satinfin shiner	0	0	0
Spotfin shiner	2	82	12
Bluntnose minnow	16	28	53
Fathead minnow	0	0	0
Comely shiner	23	1	0
Spottail shiner	21	0	57
Swallowtail shiner	31	0	0
Rosyface shiner	5	0	0
Silverjaw minnow	4	14	0
White sucker	30	2	3
Creek chubsucker	2	36	0
Northern hogsucker	28	2	3
Torrent sucker	0	0	0
Golden redhorse	0	0	0
Shorthead redhorse	0	0	0
Channel Catfish	0	0	0
Yellow bullhead	0	12	1
Brown bullhead	0	0	0
Margined madtom	0	0	0
Banded killifish	0	1	0
Eastern mosquitofish	0	0	0
Mottled sculpin	0	0	0
Potomac sculpin	35	1	3
Redbreast sunfish	7	161	27
Green sunfish	0	28	7
Pumpkinseed	0	0	1
Bluegill	1	26	7
Redear sunfish	0	0	0
Rock bass	0	18	8
White crappie	0	0	1
Smallmouth bass	4	0	0
Largemouth bass	0	0	2
Shield darter	0	0	0
Stripeback darter	0	0	0
Tesselated darter	20	0	2
Glassy darter	0	0	0
Fantail darter	4	0	7
Greenside darter	26	0	19
Hybrids	0	1	0
Total	**639**	**424**	**340**
Anomalies	23	7	42

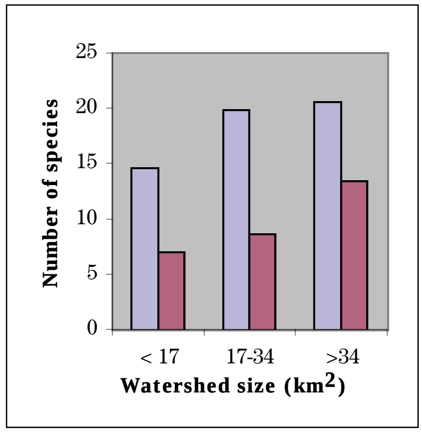
Figure 30 Metric evaluation: Separation of least from most impaired sites

Least impaired
Most impaired

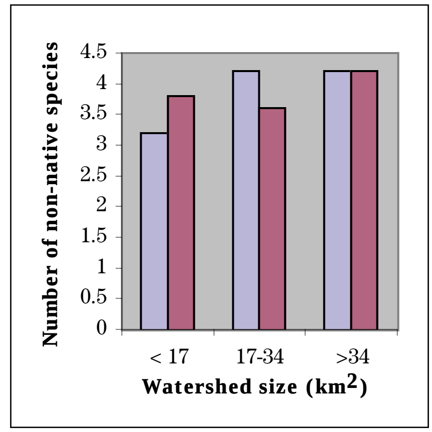
1. Number of species



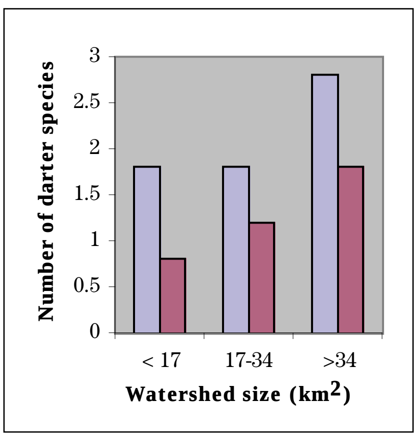
2. Number of native species



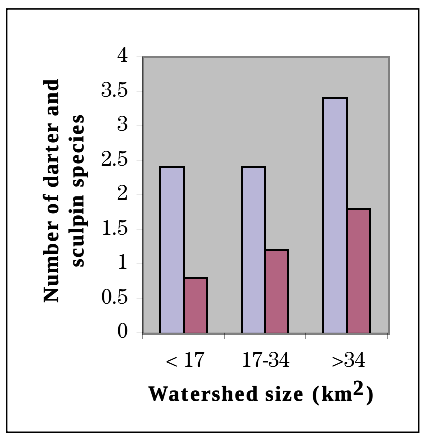
3. Number of non-native species



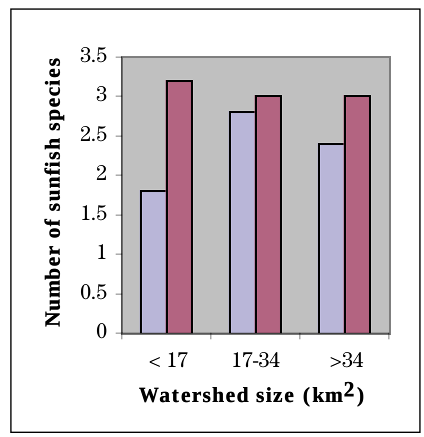
4. Number of darter species



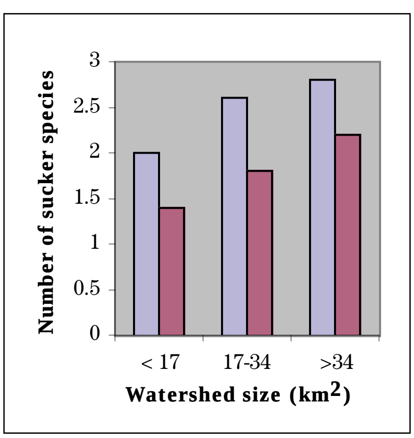
5. Number of darter + sculpin species



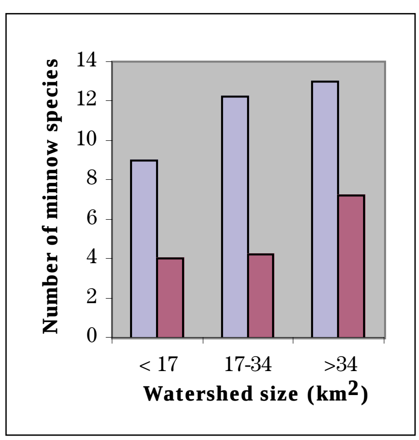
6. Number of sunfish species



7. Number of sucker species



8. Number. of minnow species



9. Percent dominant species

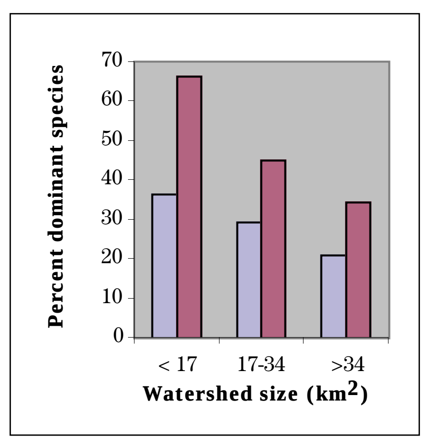
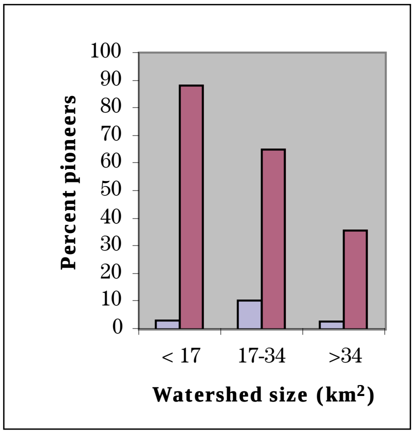
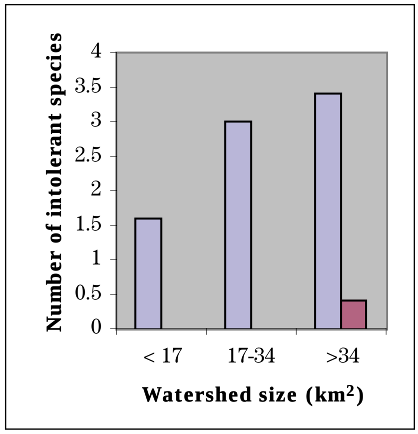


Figure 30 Metric evaluation: Separation of least from most impaired sites—Continued

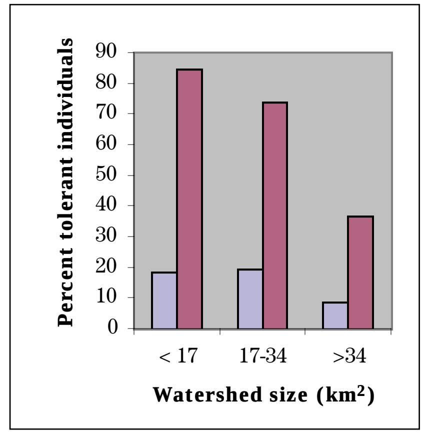
10. Percent pioneers



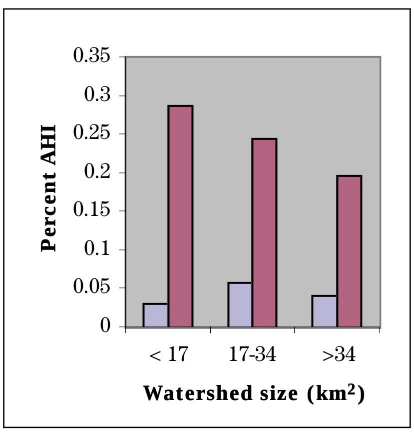
11. Number of intolerant species



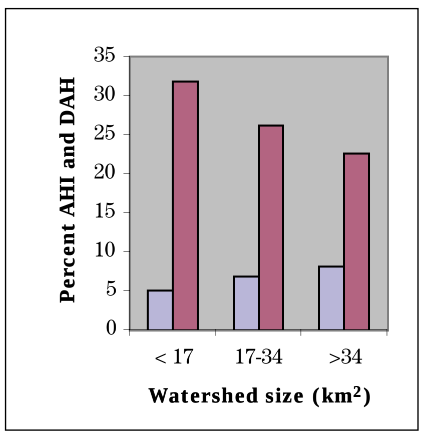
12. Percent tolerant individuals



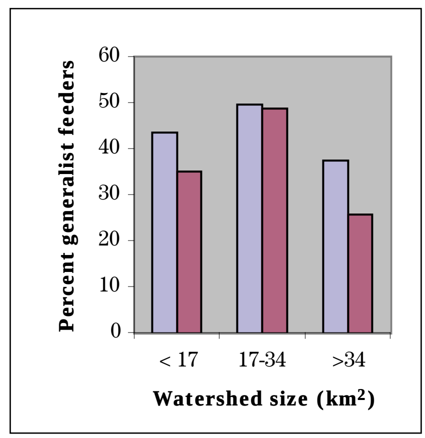
13. Percent AHI



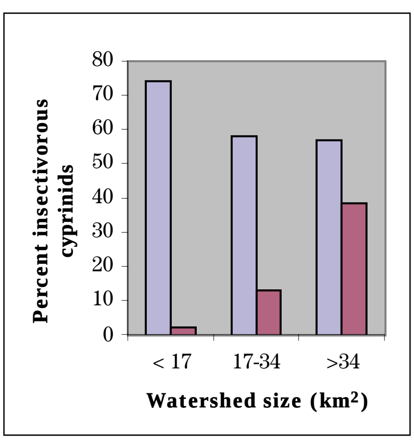
14. Percent AHI and DAH



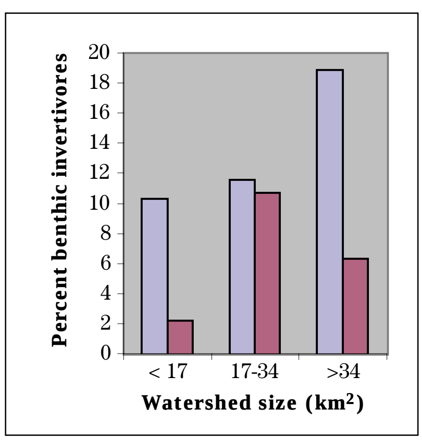
15. Percent generalist feeders



16. Percent insectivorous cyprinids



17. Percent benthic invertivores



18. Percent specialist carnivores

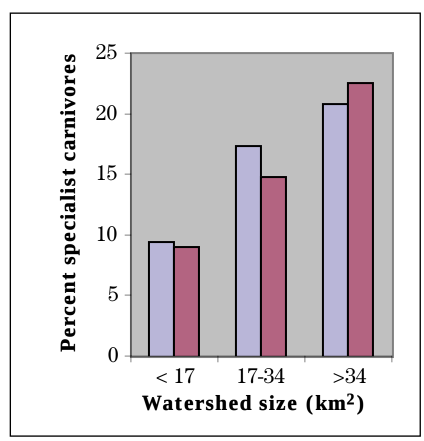
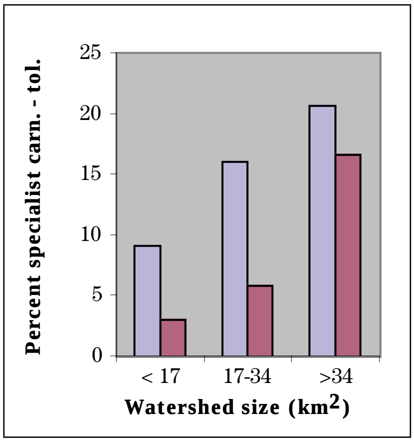


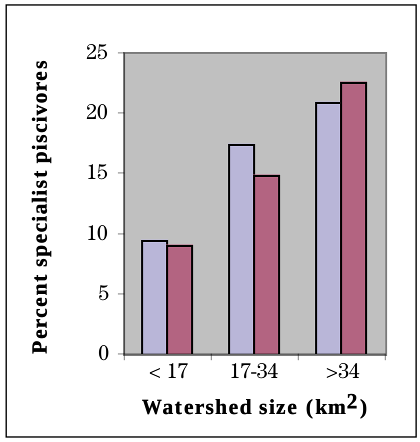
Figure 30 Metric evaluation: Separation of least from most impaired sites—Continued

Least impaired
Most impaired

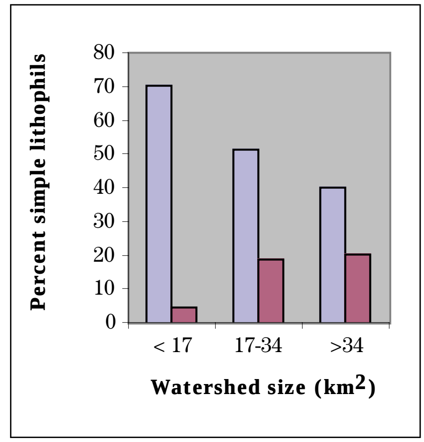
19. Percent specialist carnivores - tol.



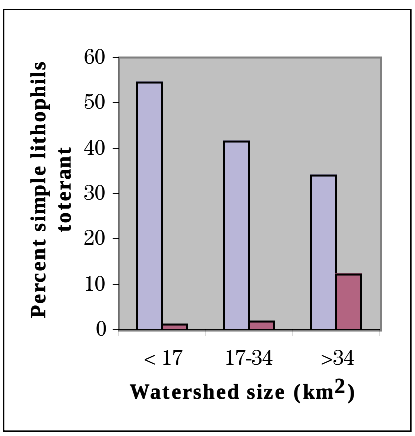
20. Percent piscivores



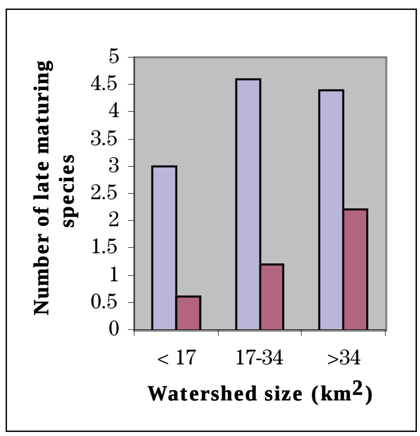
21. Percent simple lithophils



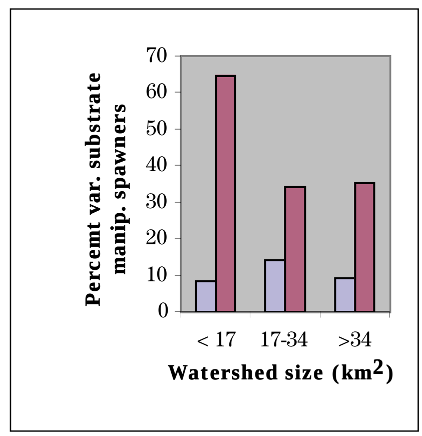
22. Percent simple lithophils - tol.



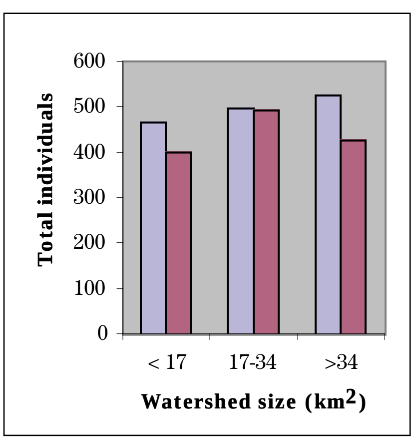
23. Number of late maturing species



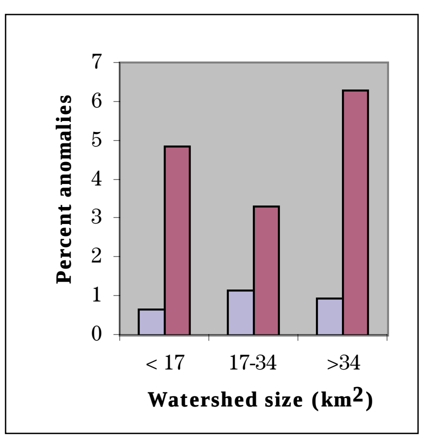
24. Perc. var. substrate manip. spawners



25. Total individuals



26. Percent anomalies



27. Percent hybrids

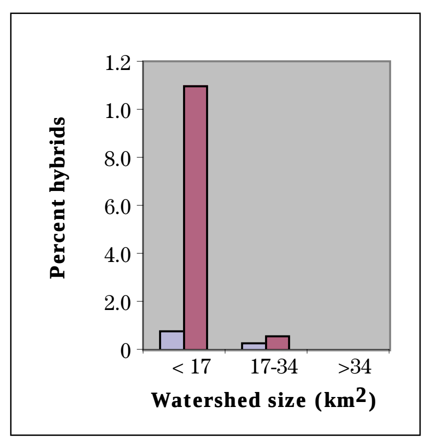


Figure 30 Metric evaluation: Separation of least from most impaired sites—Continued

28. Percent anomalies and hybrids

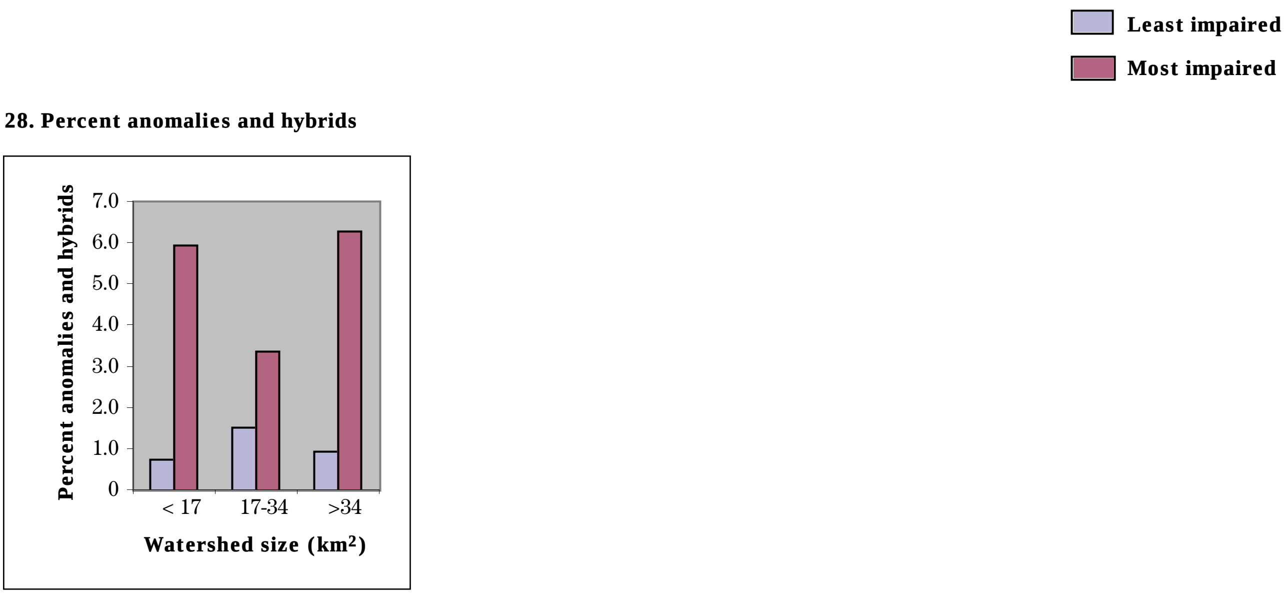
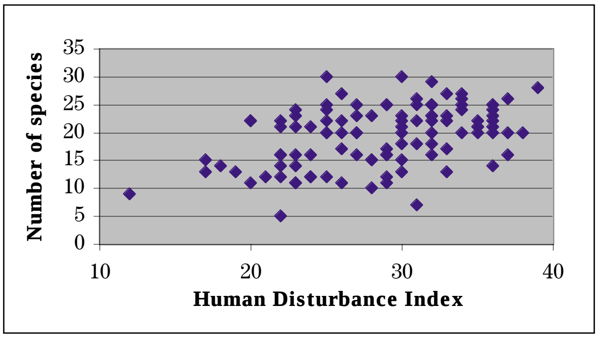
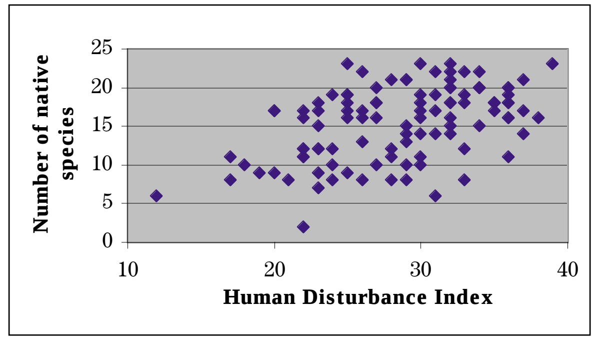


Figure 31 Correlation of individual attributes/metrics with the Human Disturbance Index (r = Pearson's correltation coefficient)

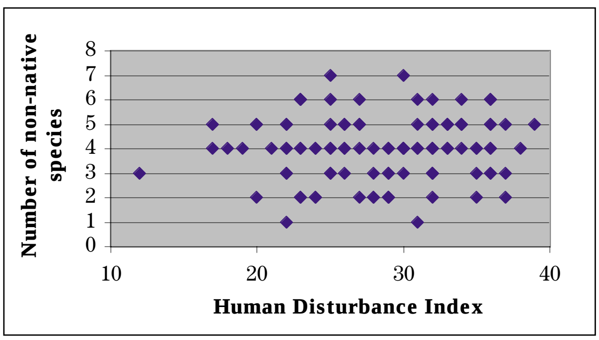
1. Number of species (r = 0.44)



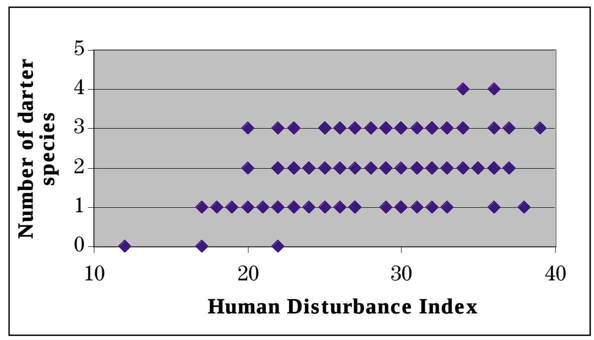
2. Number of native species (r = 0.49)



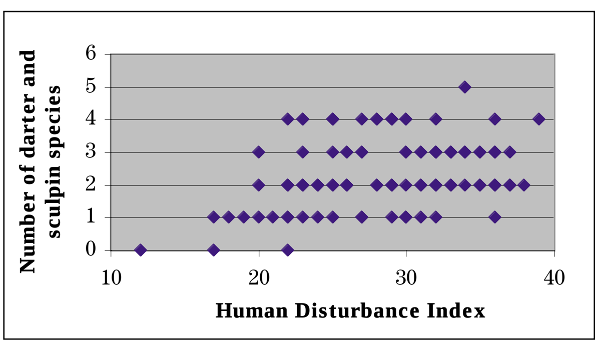
3. Number of non-native species (r = 0.07)



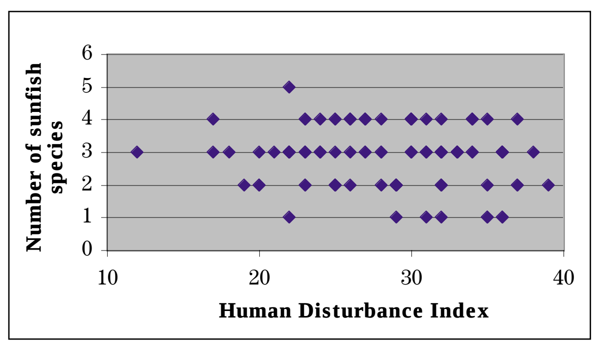
4. Number of darter species (r = 0.35)



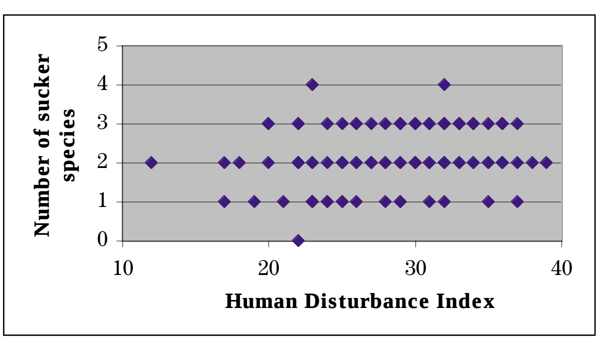
5. Number of darter and sculpin species (r = 0.33)



6. Number of sunfish species (r = - 0.12)



7. Number of sucker species (r = 0.23)



8. Number of minnow species (r = 0.40)

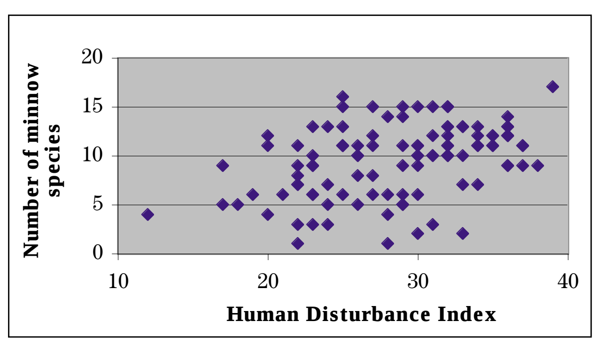
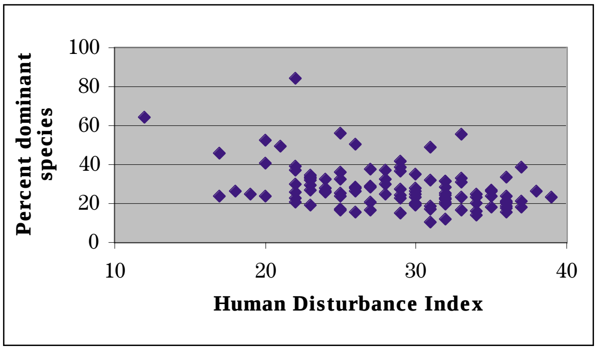
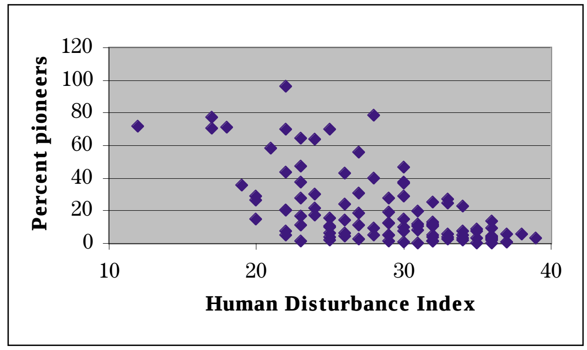


Figure 31 Correlation of individual attributes/metrics with the Human Disturbance Index (r = Pearson's correltation coefficient)

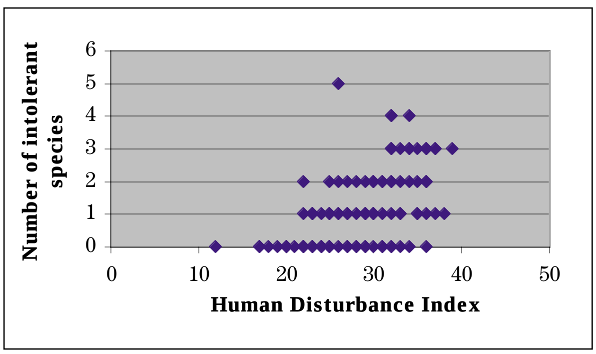
9. Percent dominant species (r = - 0.41)



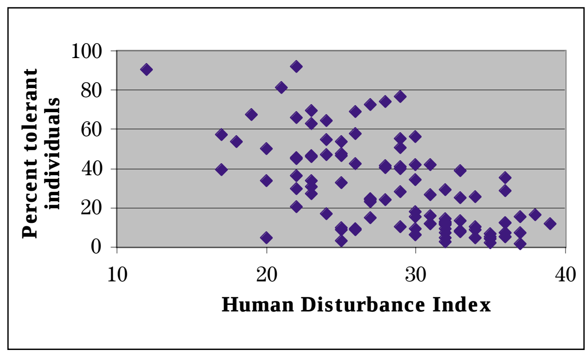
10. Percent pioneers (r = - 0.60)



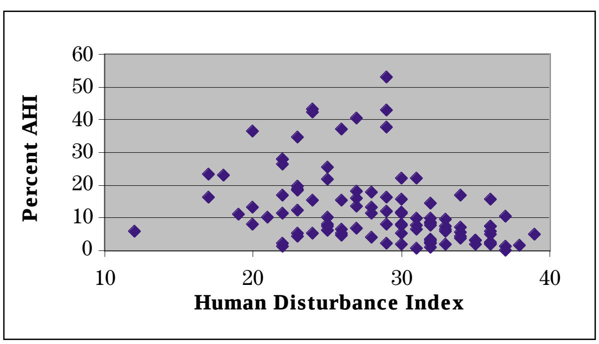
11. Number of intolerant species (r = 0.54)



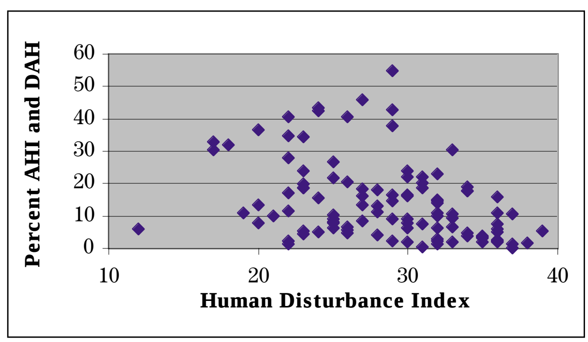
12. Percent tolerant individuals (r = - 0.62)



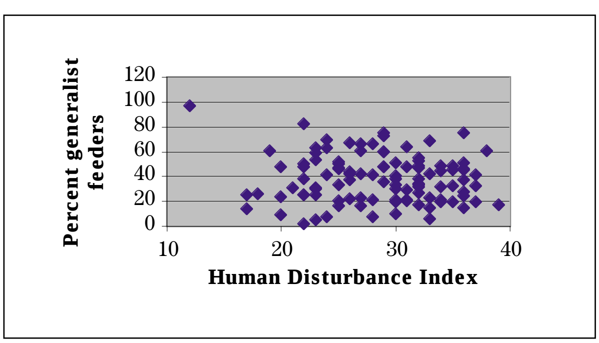
13. Percent AHI (r = - 0.39)



14. Percent AHI and DAH (r = - 0.37)



15. Percent generalist feeders (r = - 0.09)



16. Percent insectiv. Cyprinids (r = 0.37)

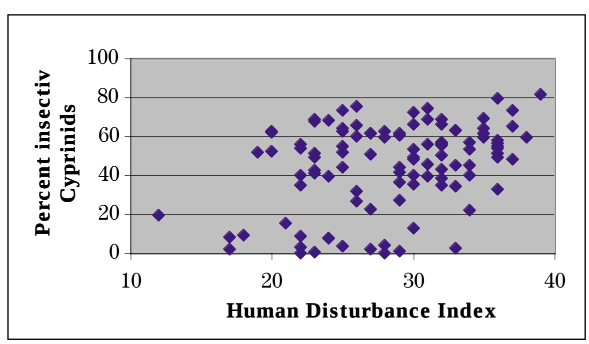
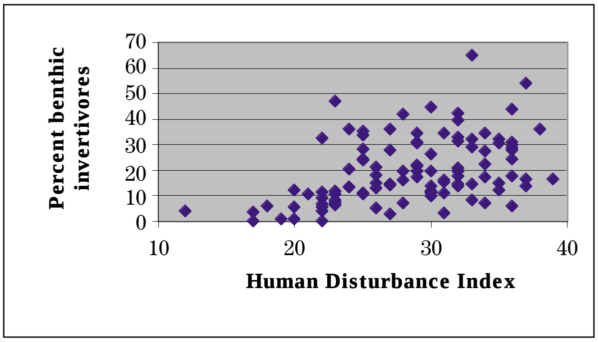
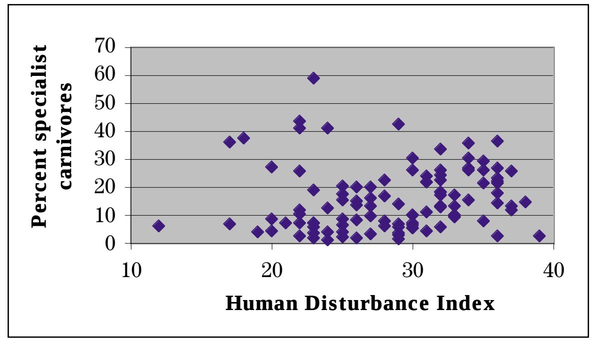


Figure 31 Correlation of individual attributes/metrics with the Human Disturbance Index (r = Pearson's correltation coefficient)

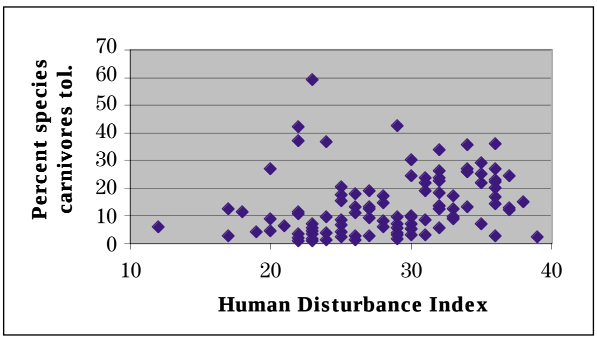
17. Percent benthic invertivores (r = 0.44)



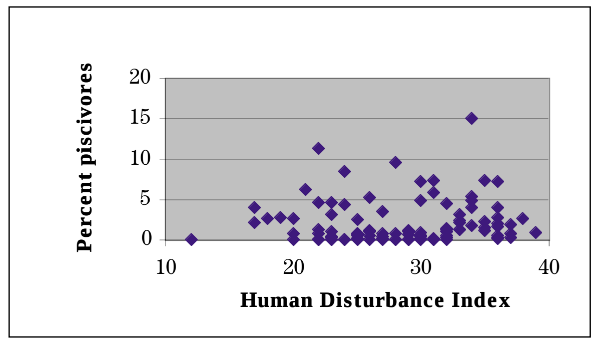
18. Percent specialist carnivores (r = 0.11)



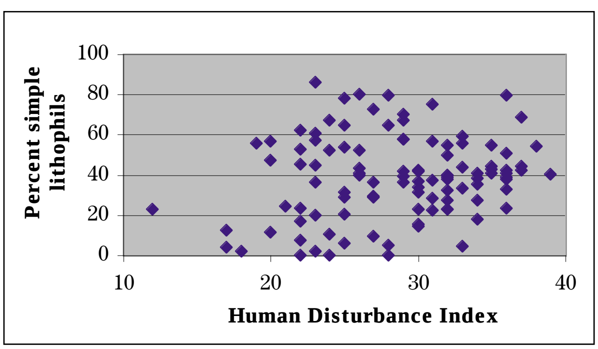
19. Percent spec. carnivores - tol. (r = 0.25)



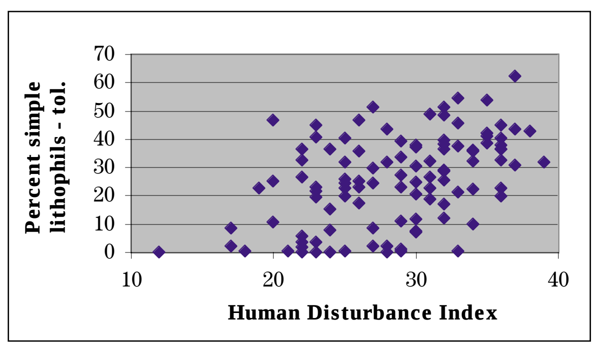
20. Percent piscivores (r = 0.07)



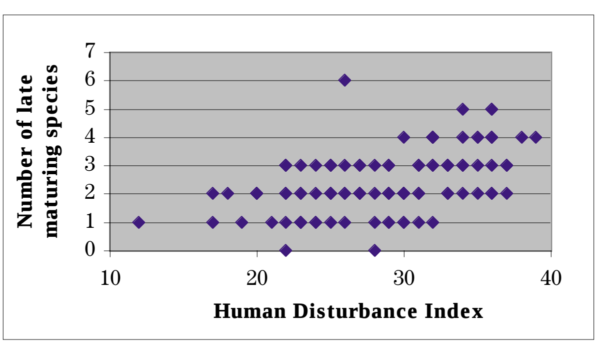
21. Percent simple lithophils (r = 0.18)



22. Percent simple lithophils - tol. (r = 0.47)



23. Number of late maturing species (r = 0.50)



24. Percent various substrate manip. spawners (r = - 0.35)

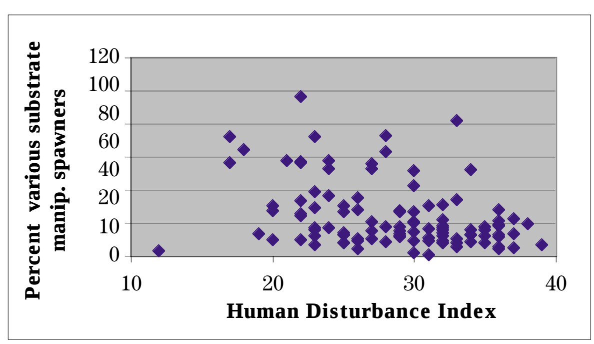
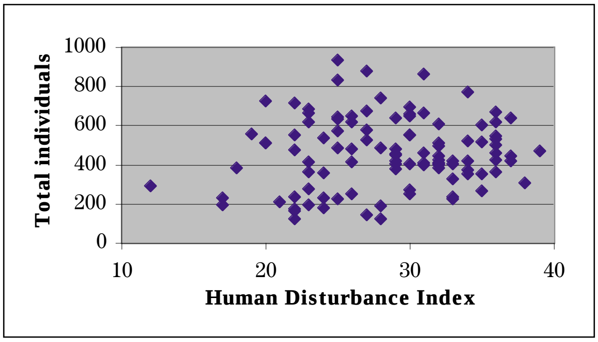
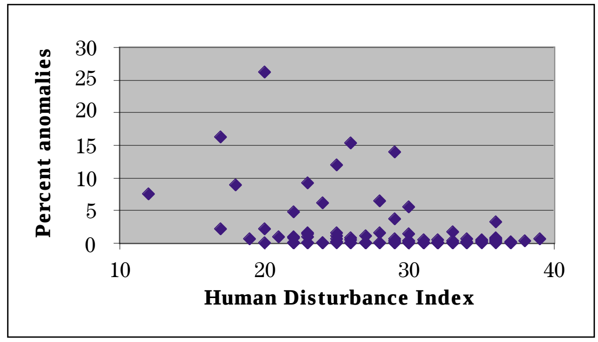


Figure 31 Correlation of individual attributes/metrics with the Human Disturbance Index (r = Pearson's correltation coefficient)

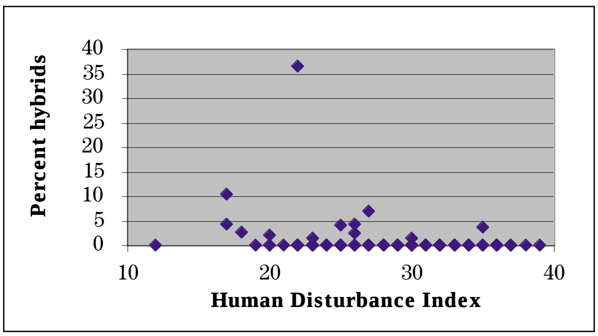
25. Total individuals (r = - 0.11)



25. Percent anomalies (r = - 0.36)



27. Percent hybrids (r = - 0.22)



28. Percent anomalies and hybrids (r = - 0.38)

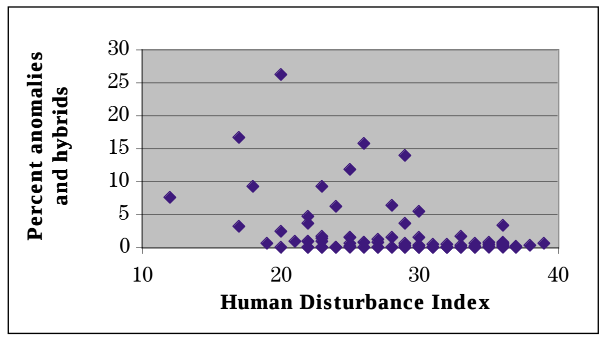
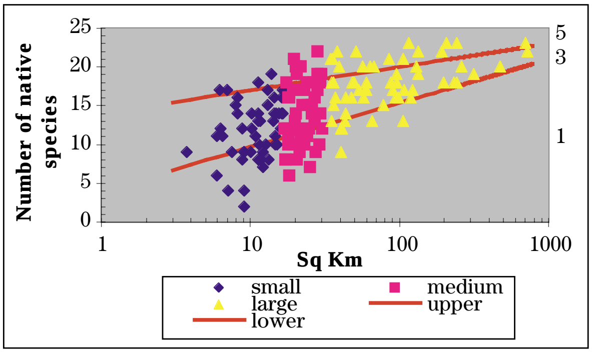
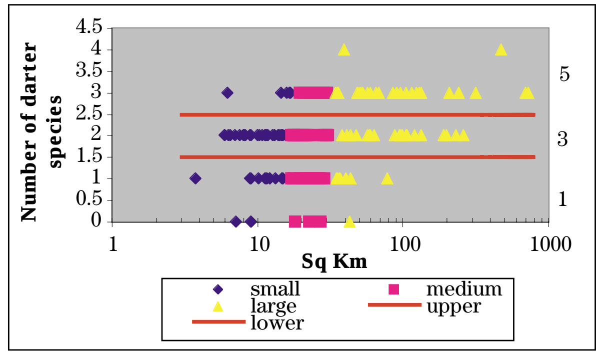


Figure 32 Metric scoring

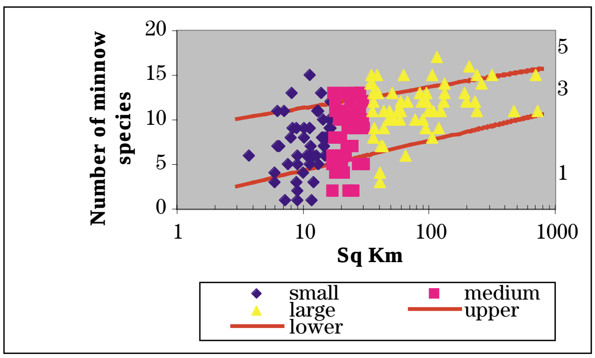
1. Number of native species



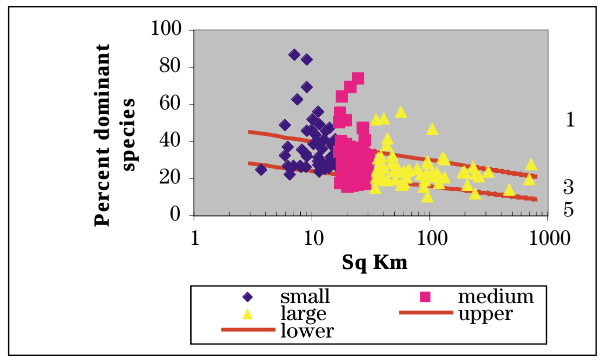
2. Number of darter species



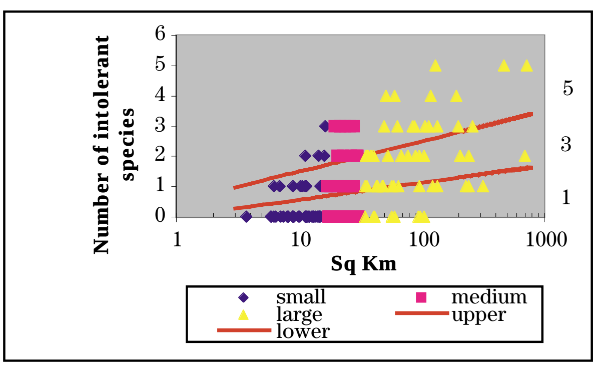
3. Number of minnow species



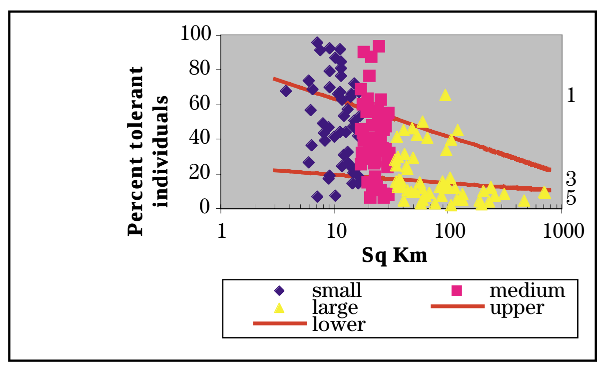
4. Percent dominant species



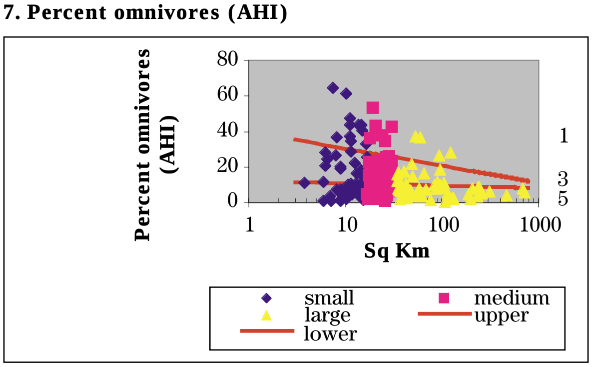
5. Number of intolerant species



6. Percent tolerant individuals



7. Percent omnivores (AHI)



8. Percent benthic invertivores

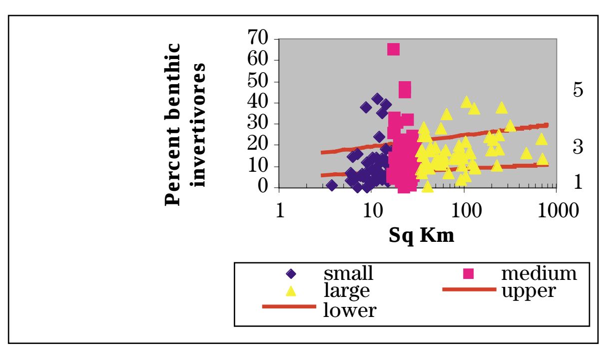
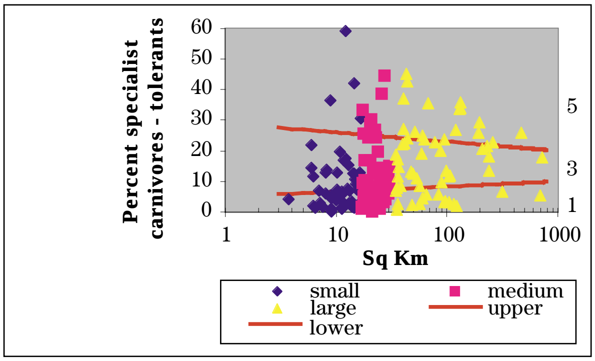
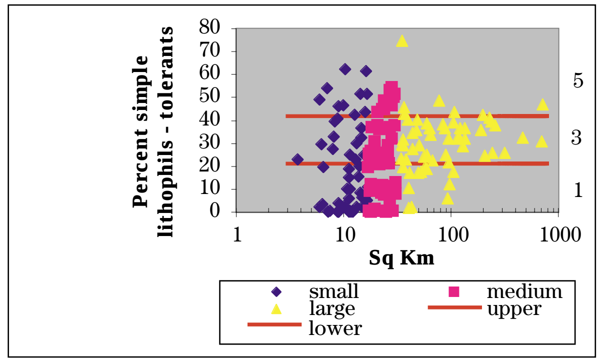


Figure 32 Metric scoring

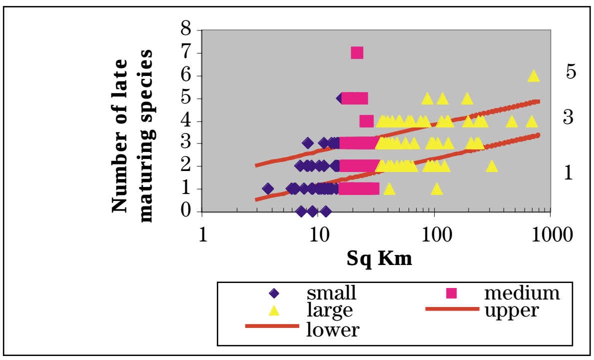
9. Percent specialist carnivores - tolerants



10. Percent simple lithophils - tolerants



11. Number of late maturing species



12. Percent anomalies

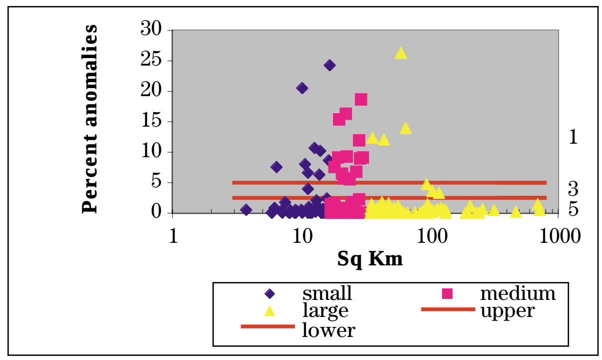


Figure 33 Distribution charts for species collected in the study area

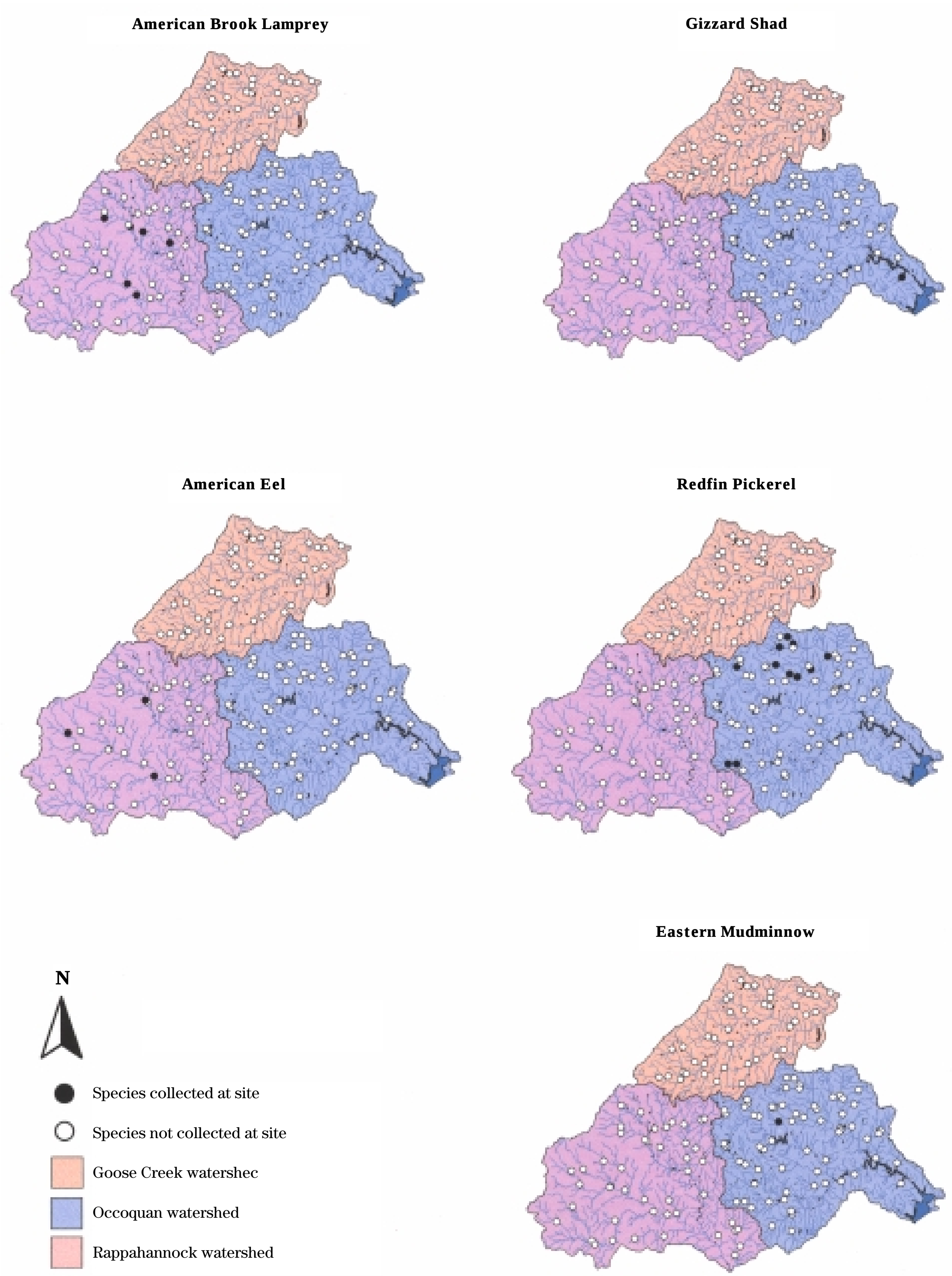


Figure 33 Distribution charts for species collected in the study area—Continued

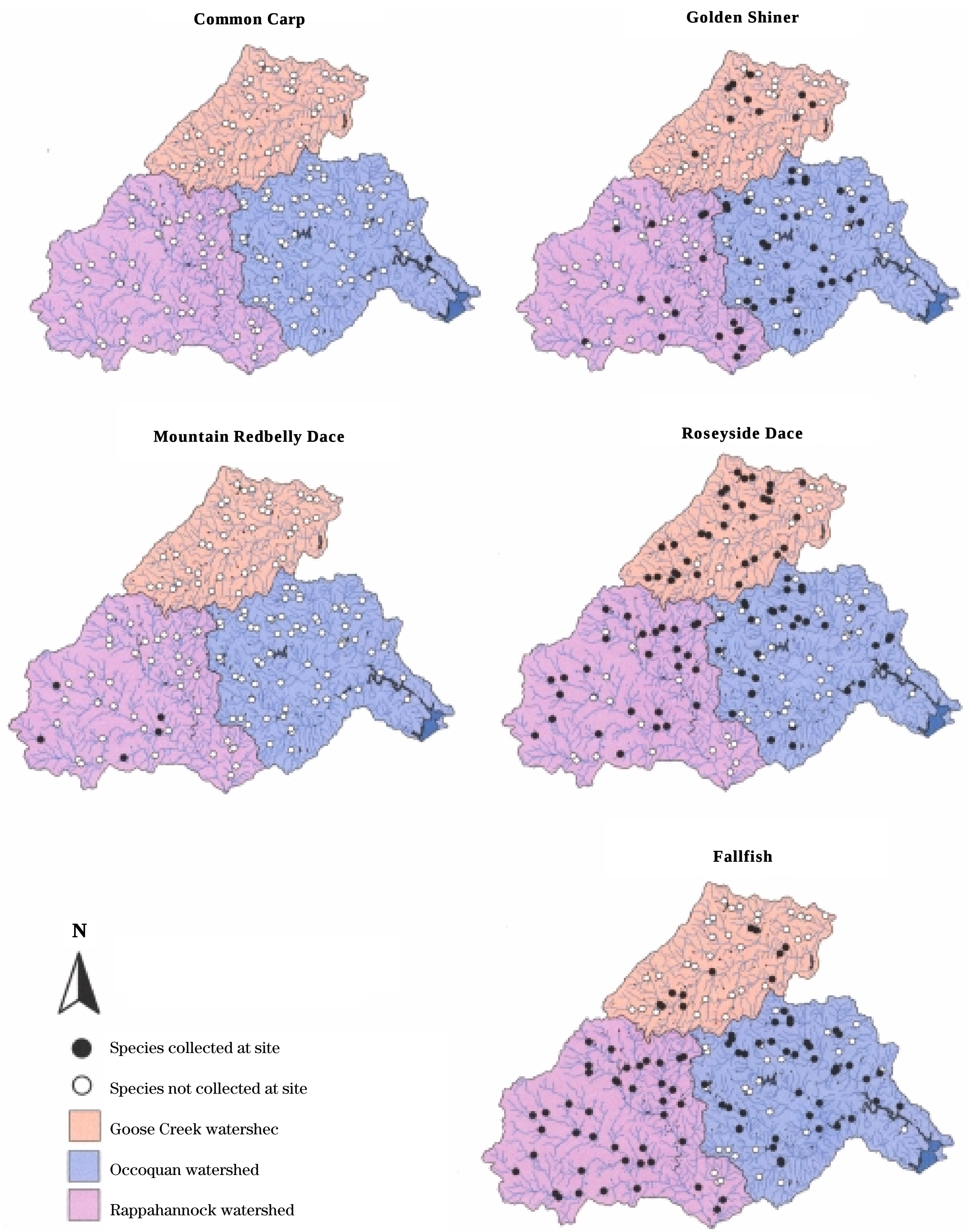


Figure 33 Distribution charts for species collected in the study area—Continued

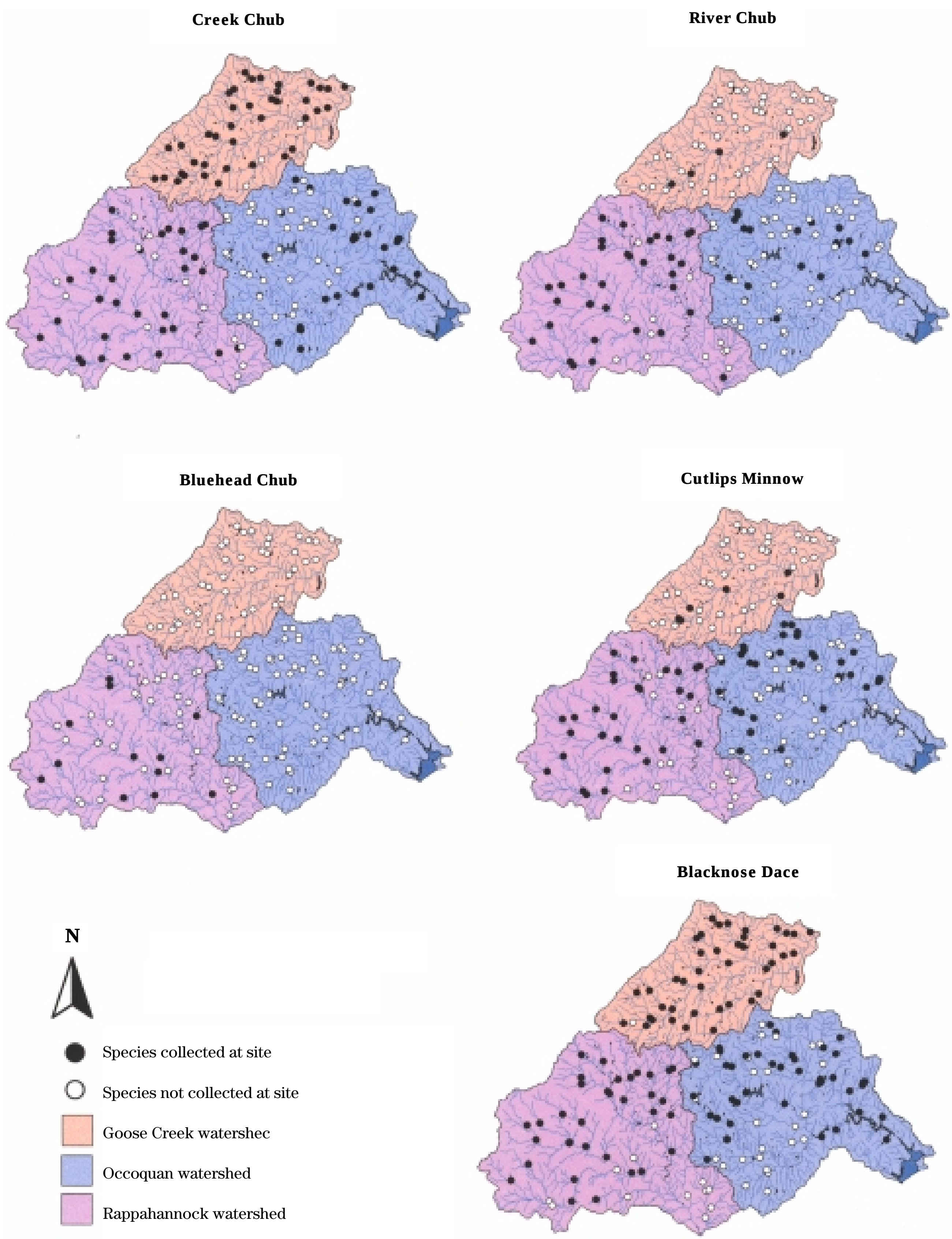


Figure 33 Distribution charts for species collected in the study area—Continued

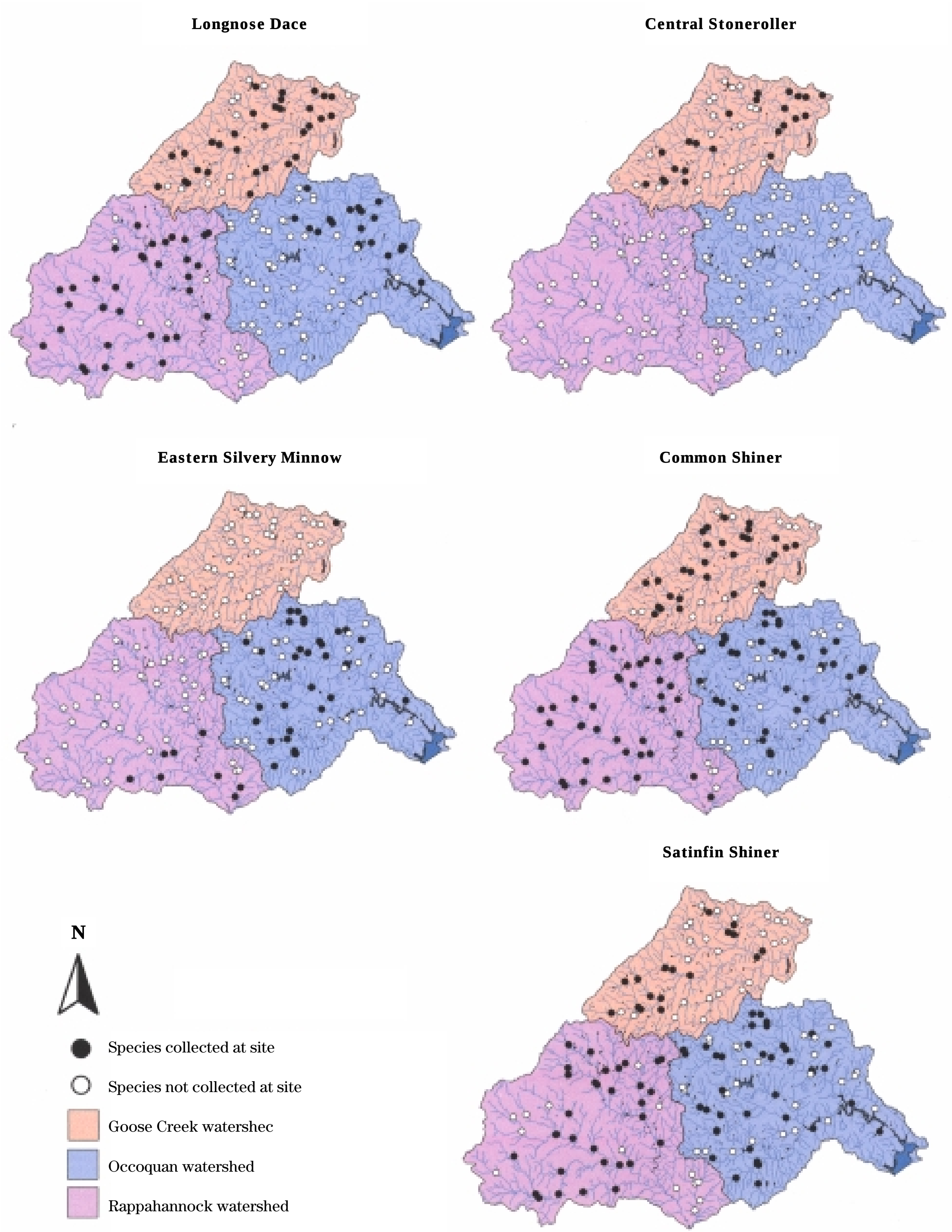


Figure 33 Distribution charts for species collected in the study area—Continued

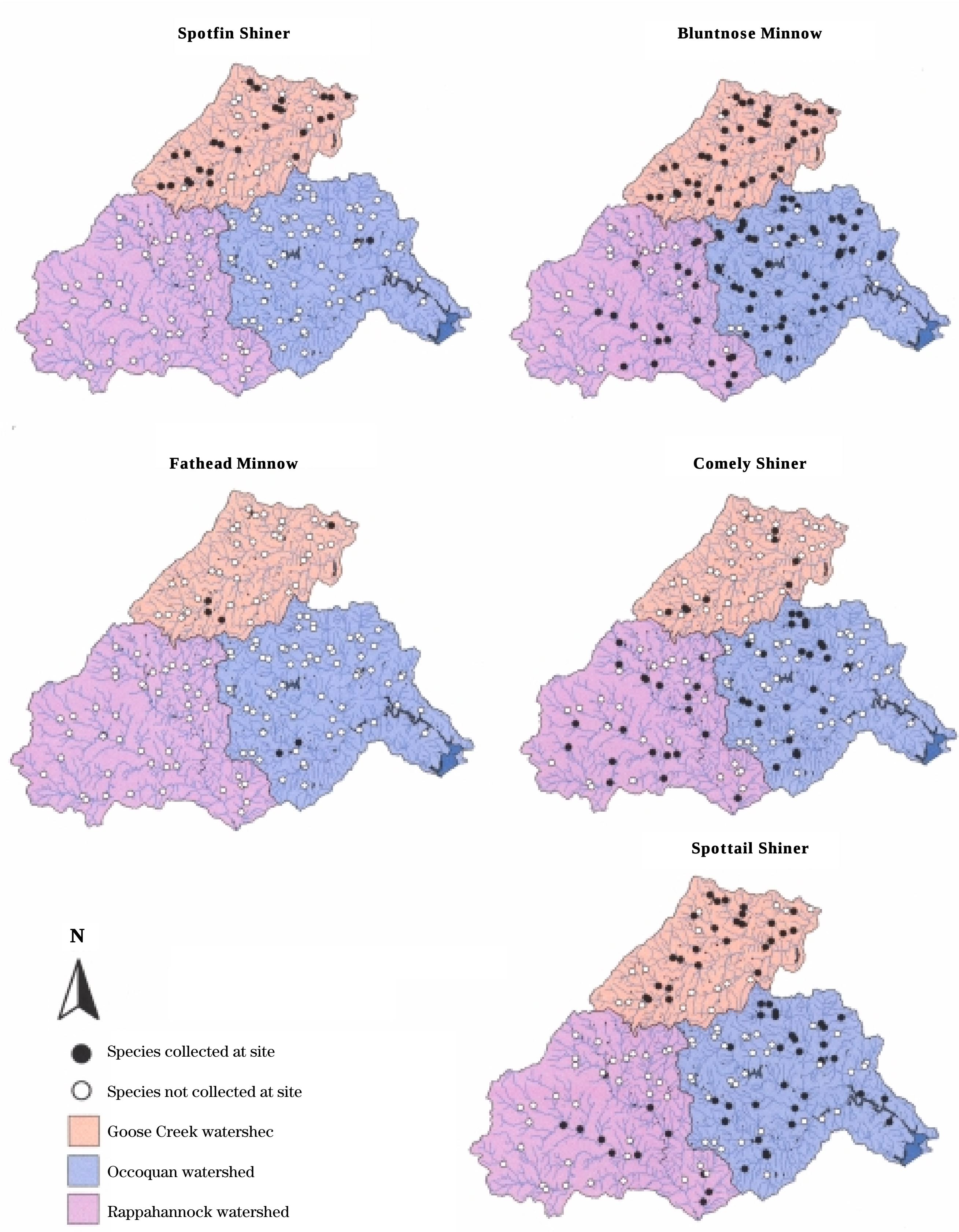


Figure 33 Distribution charts for species collected in the study area—Continued

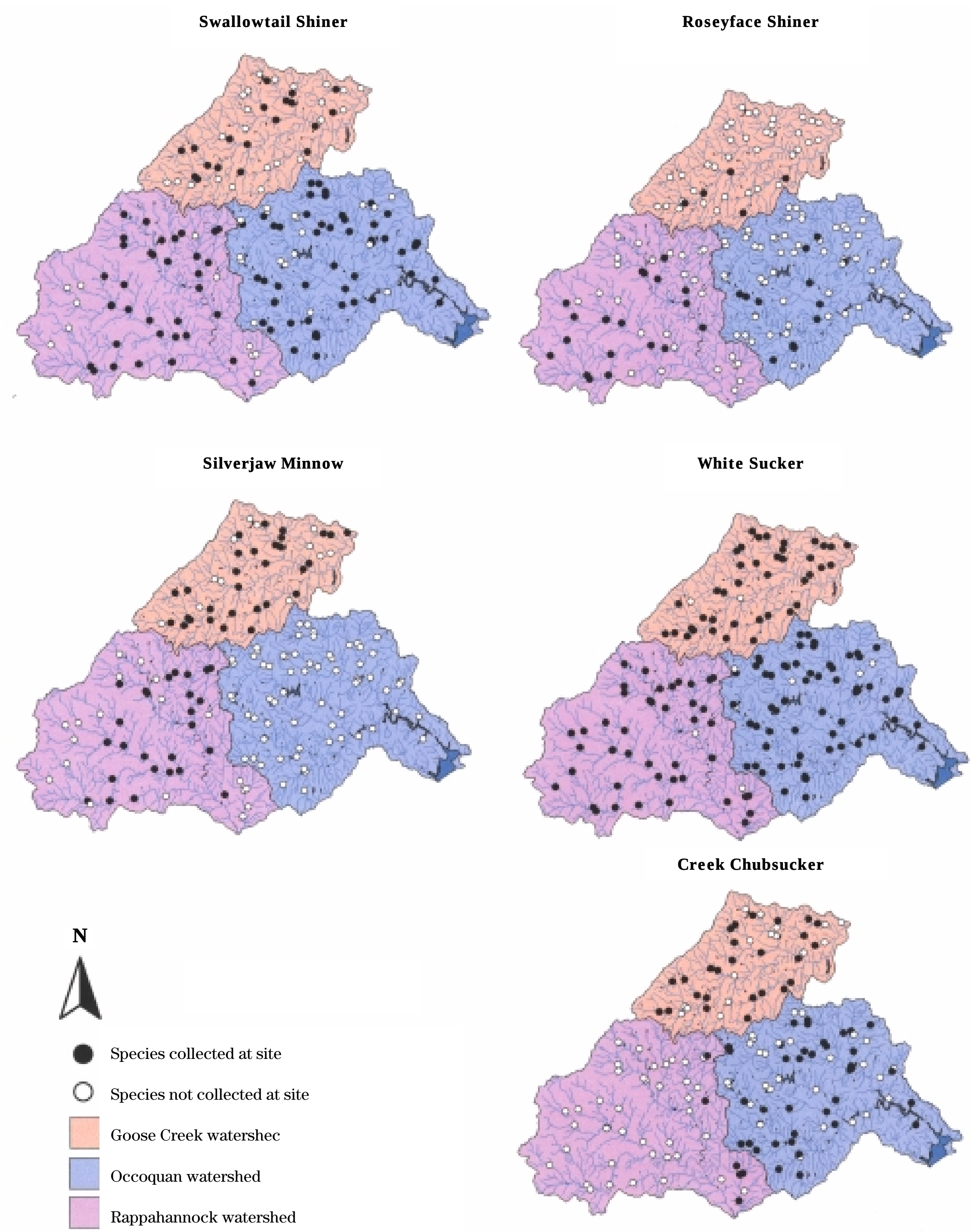


Figure 33 Distribution charts for species collected in the study area—Continued

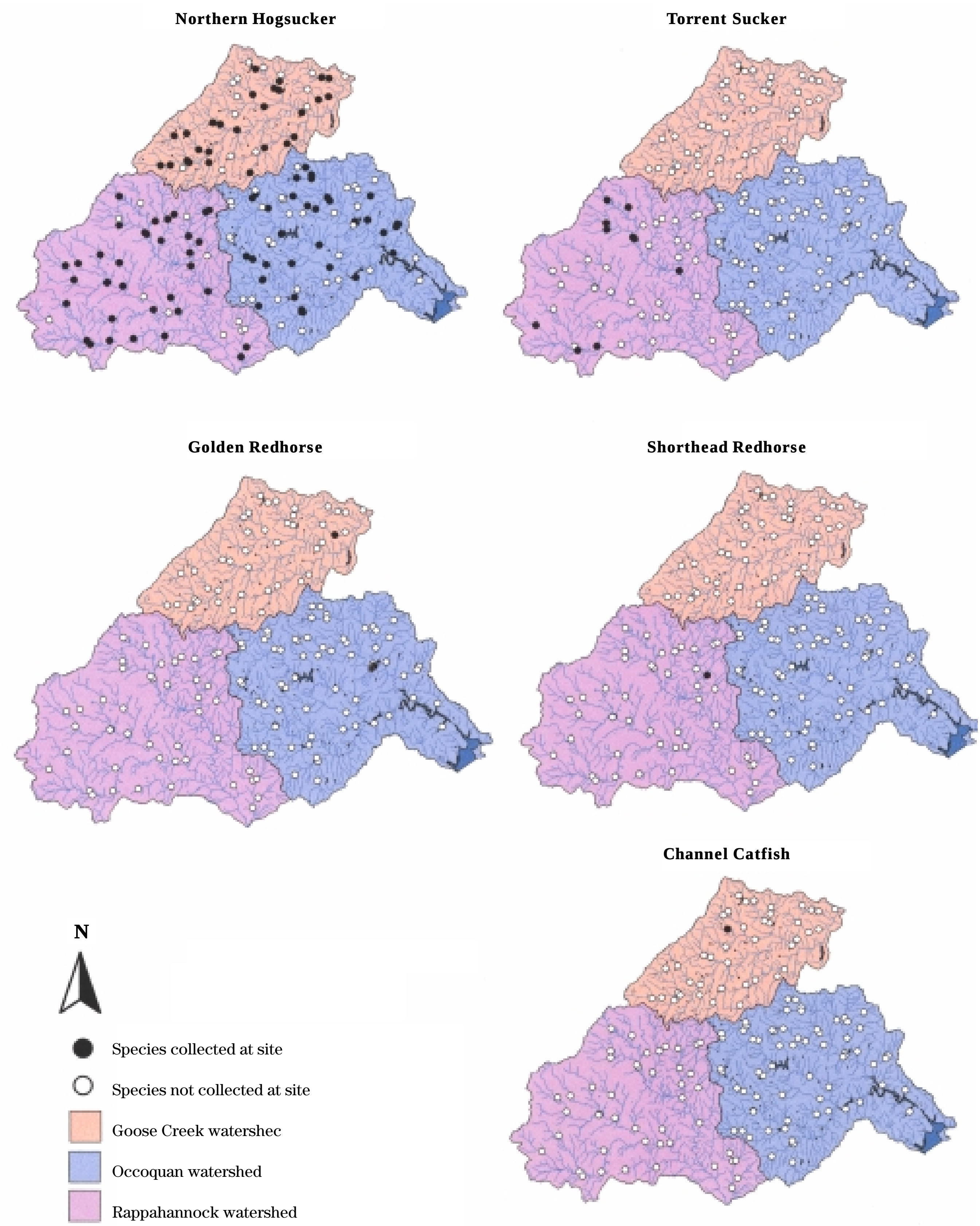


Figure 33 Distribution charts for species collected in the study area—Continued

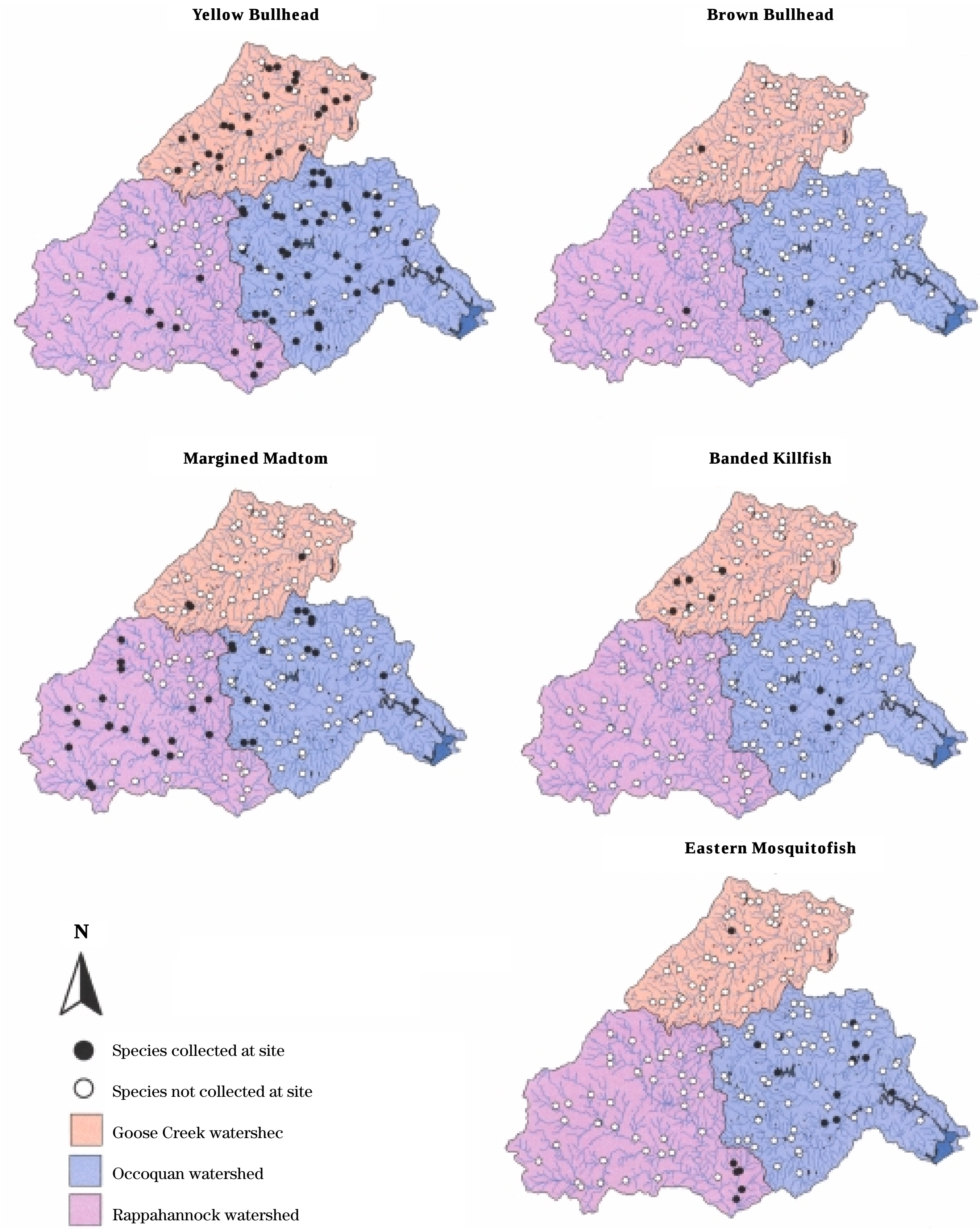


Figure 33 Distribution charts for species collected in the study area—Continued

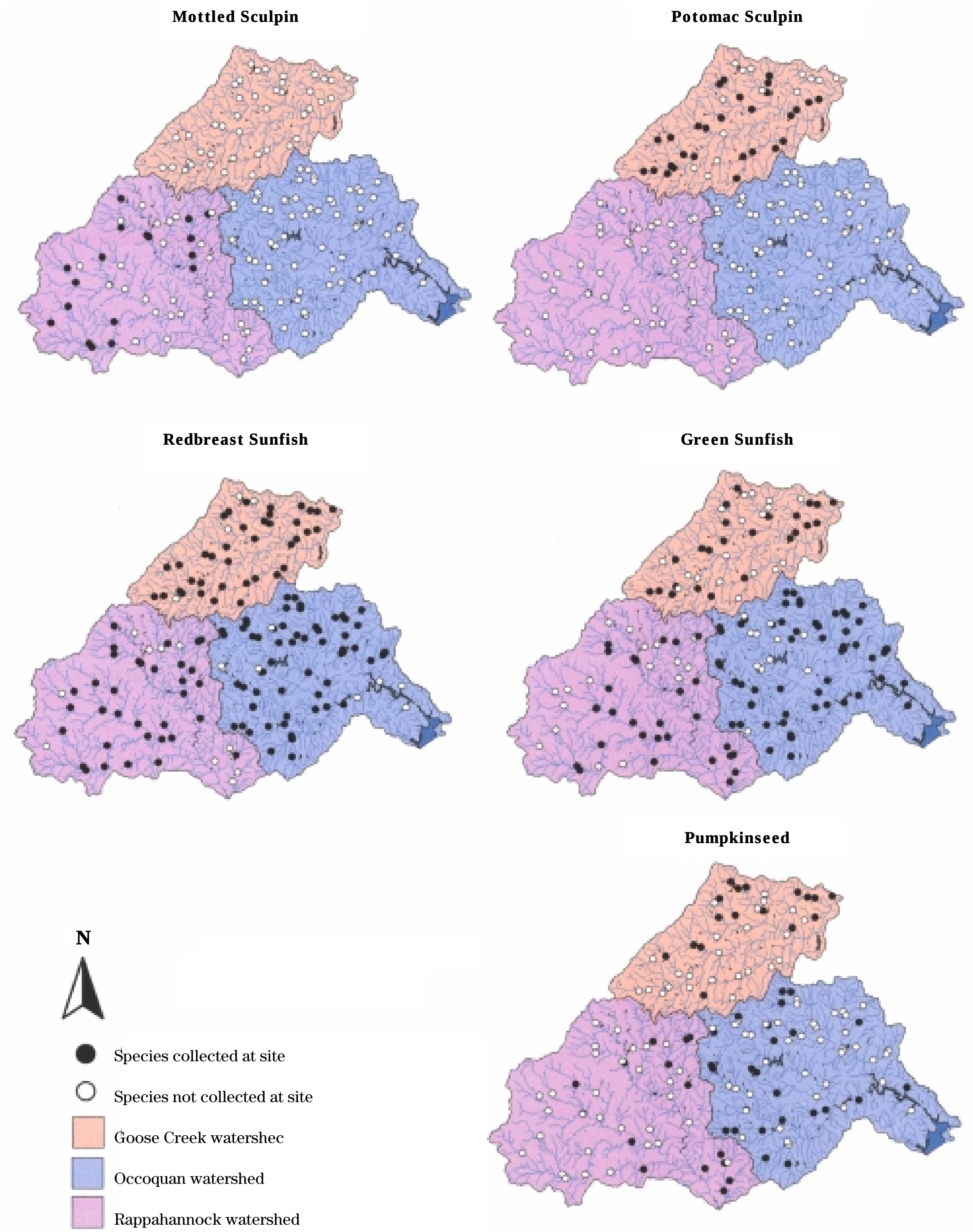


Figure 33 Distribution charts for species collected in the study area—Continued

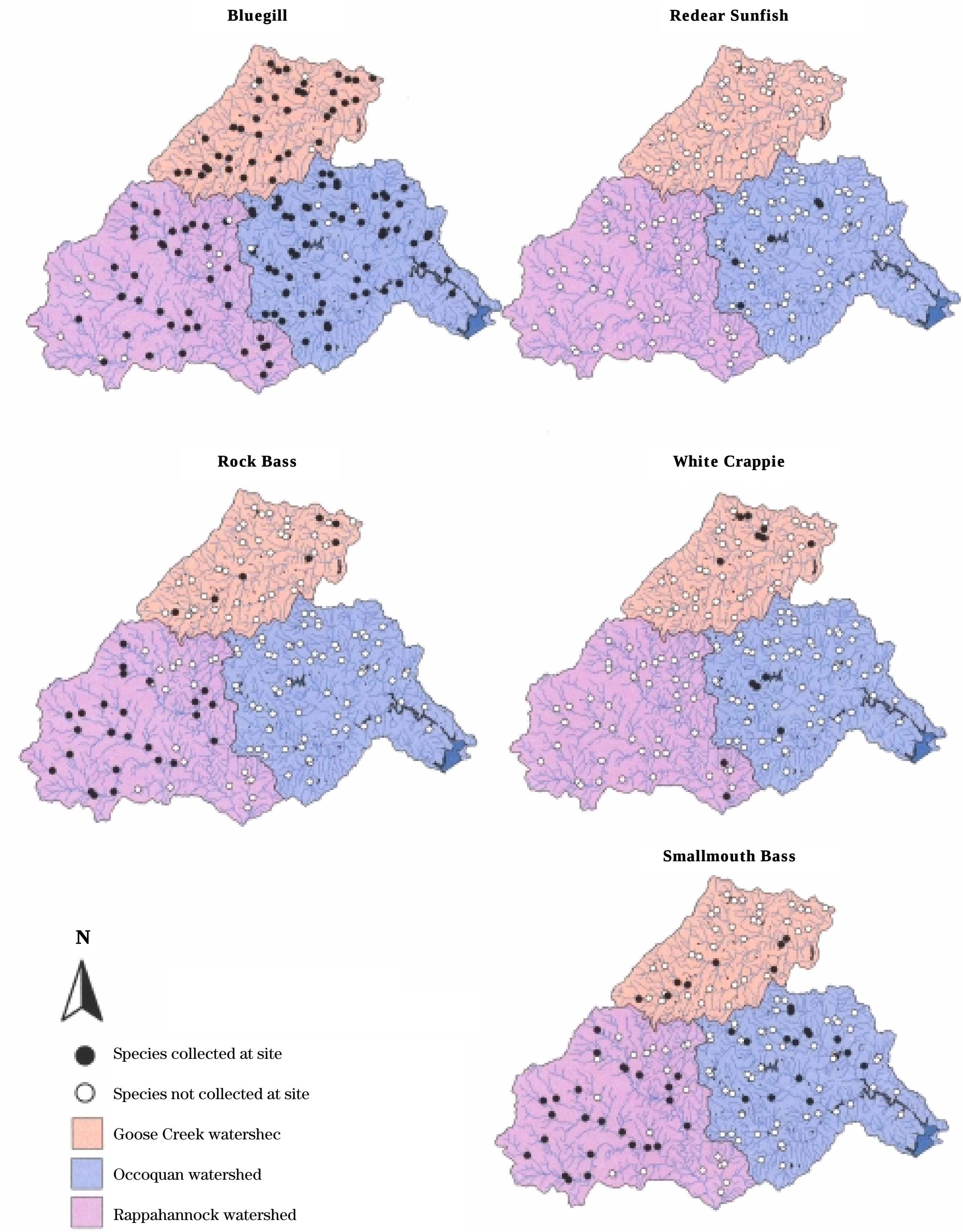


Figure 33 Distribution charts for species collected in the study area—Continued

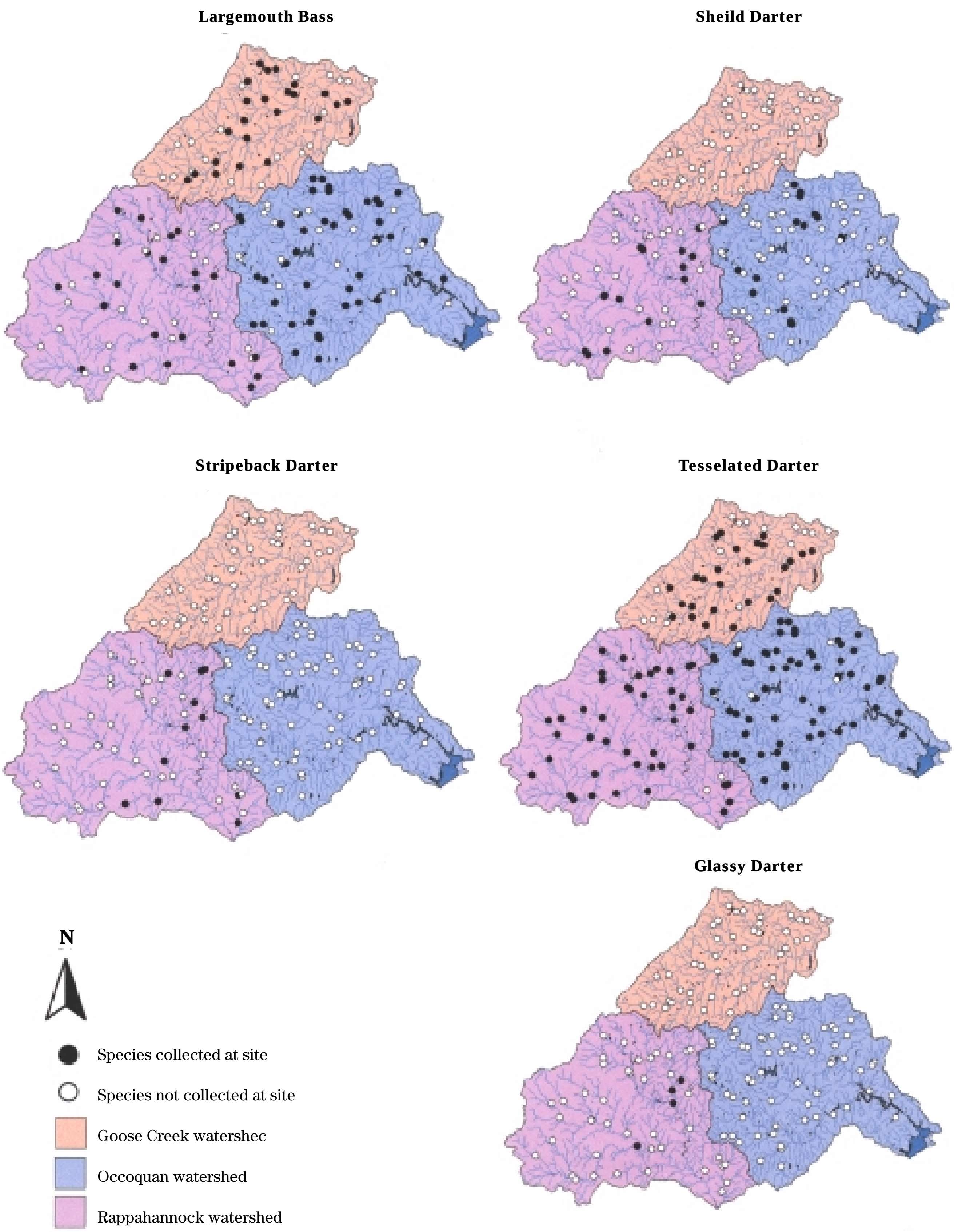


Figure 33 Distribution charts for species collected in the study area—Continued

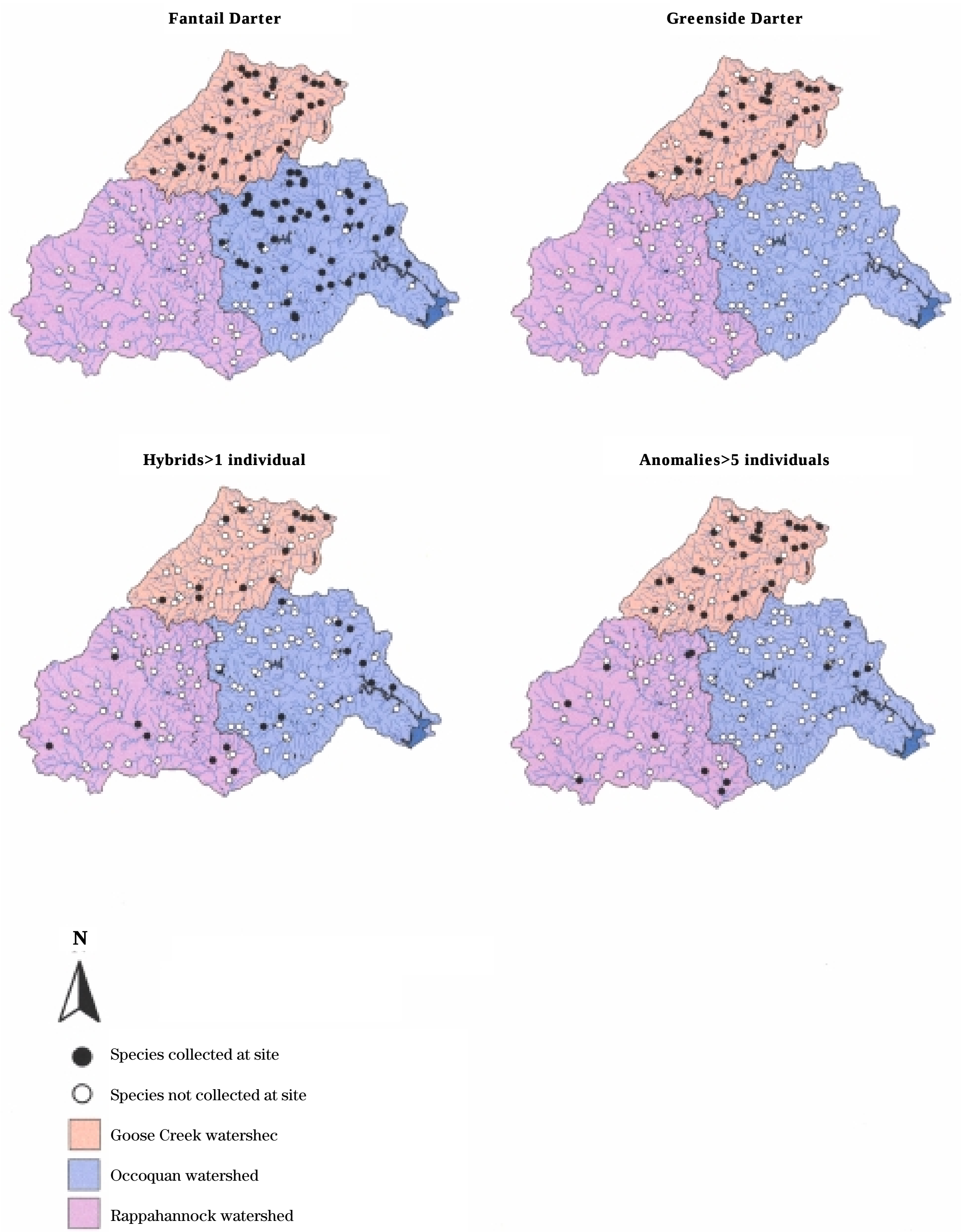


Figure 34 Integrity classification for fish sampling locations

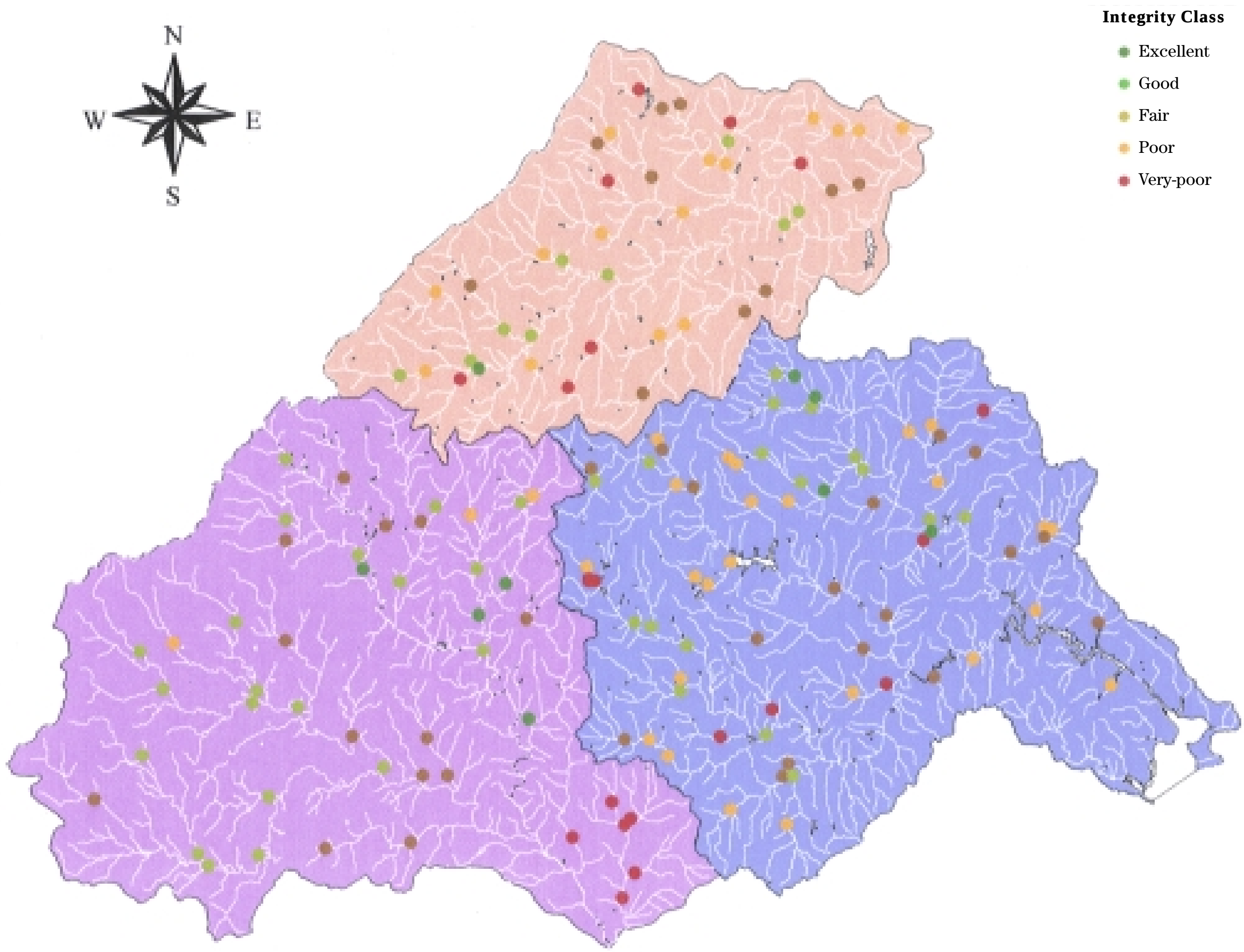


Figure 35 Goose Creek Watershed sample locations

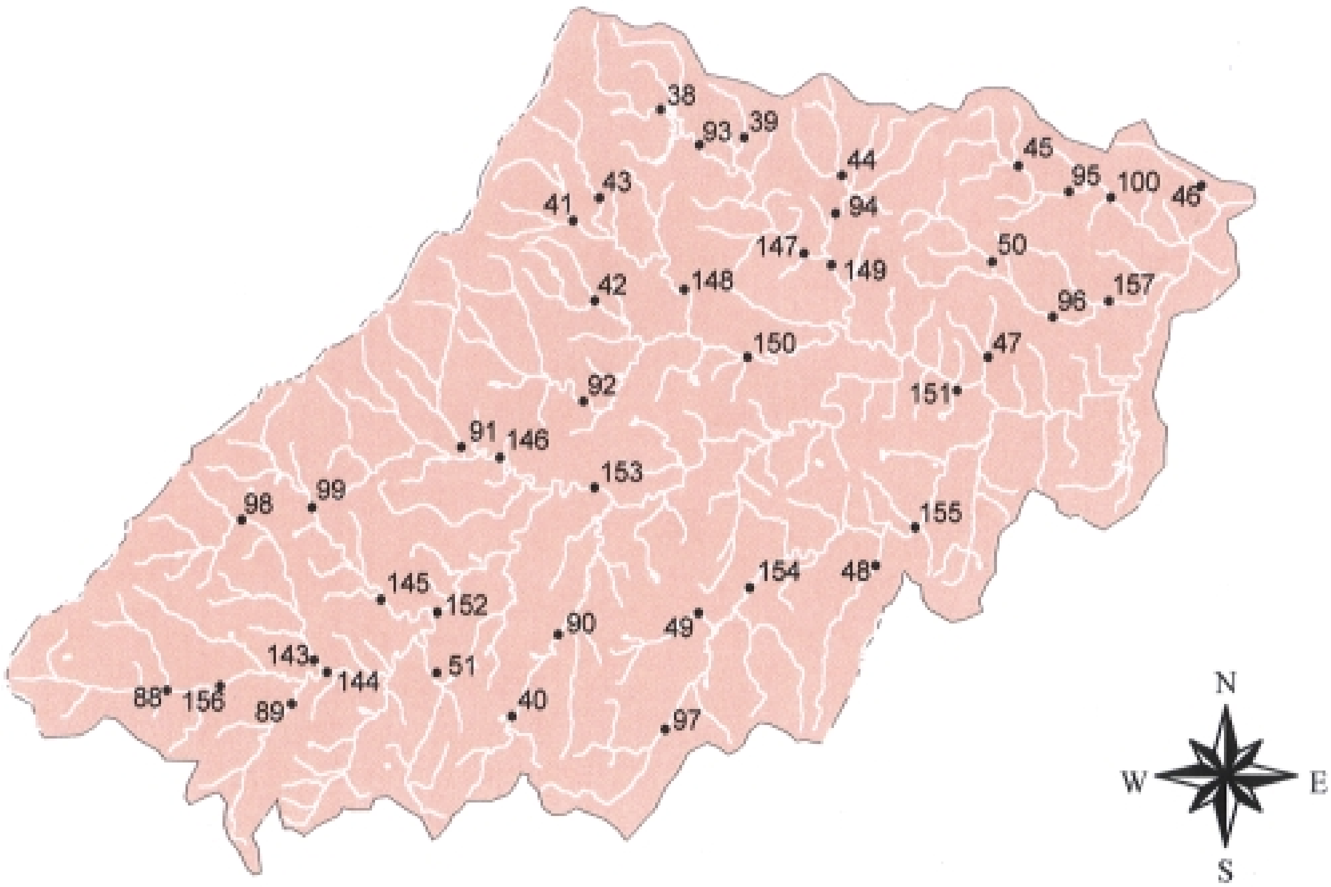


Figure 36 Occoquan River Watershed sample locations

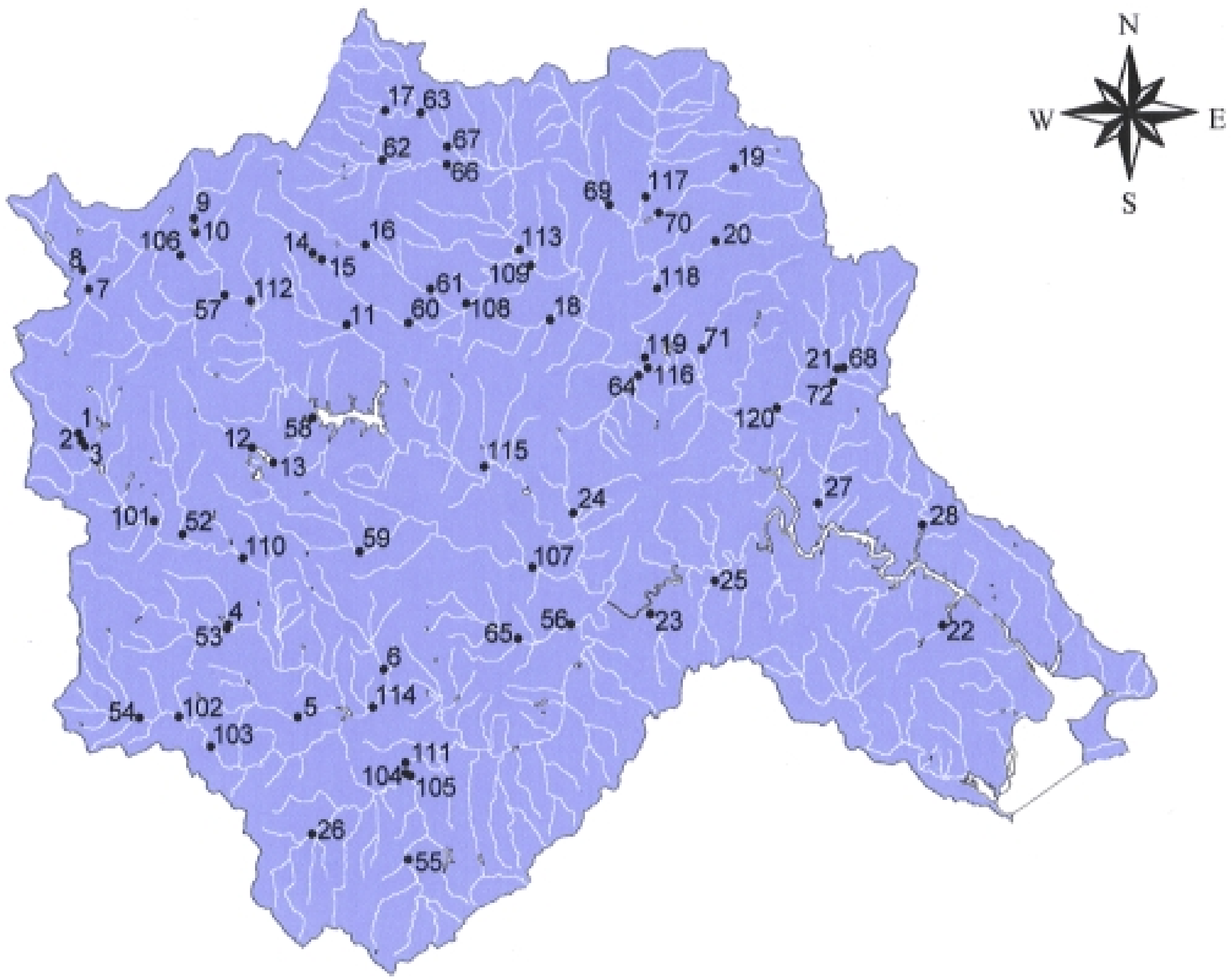


Figure 37 Rappahannock River Watershed sample locations