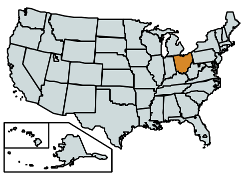
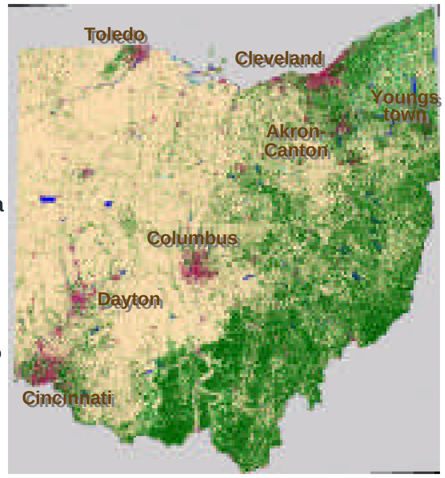
Fundamentals of Aquatic Ecology

Sustainable Watershed Planning: Fundamentals of Aquatic Ecology

OHIO FACTS

Population (1990): 10,887,325
Land Area: 106,800 km^2
Major Watersheds: 23
Streams & Rivers: 46,956 km
Number of Lakes: 447
Lakes Surface Area: 48,078 ha
Scenic Rivers: 1015 km
Wetland Acrage: Unknown
Original Wetlands Lost: 90%
Current Forest Cover: 30%
Original Forest Cover: 90-95%





Watersheds and Their Streams Are Living Systems

Quality is Evident in Symptoms of Ecosystem Health

- A system for converting organic matter and nutrients into biomass.
- Multiple steps and transfers in the process.
- ***Healthy Systems*** support numerous and complex processes - produce ***desirable*** biomass and other attributes (*e.g.*, high divesrsity, intolerant organisms).
- ***Unhealthy Systems*** exhibit fewer steps and simple processes - produce *undesirable* biomass and attributes (e.g., tolerant organisms, nuisance populations).

Aquatic Ecosystems: Structure and Function

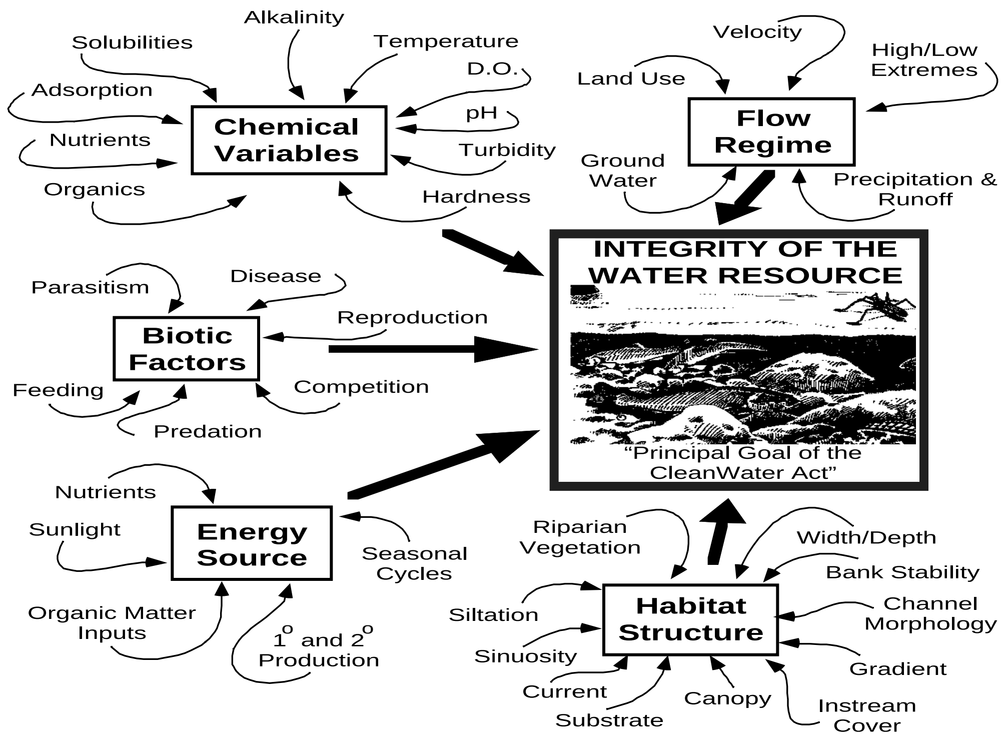
Structure:

- Biological components (species, numbers, biomass)
- Physical components (water, habitat attributes)
- Energy & Materials (organic and inorganic chemicals)

Function:

- The product of the interaction of the structural components and the processes therein

Major Factors Which Determine the Integrity of Surface Water Resources



Water Resource Integrity Attributes

Environmental Goods and Services Provided By Watersheds

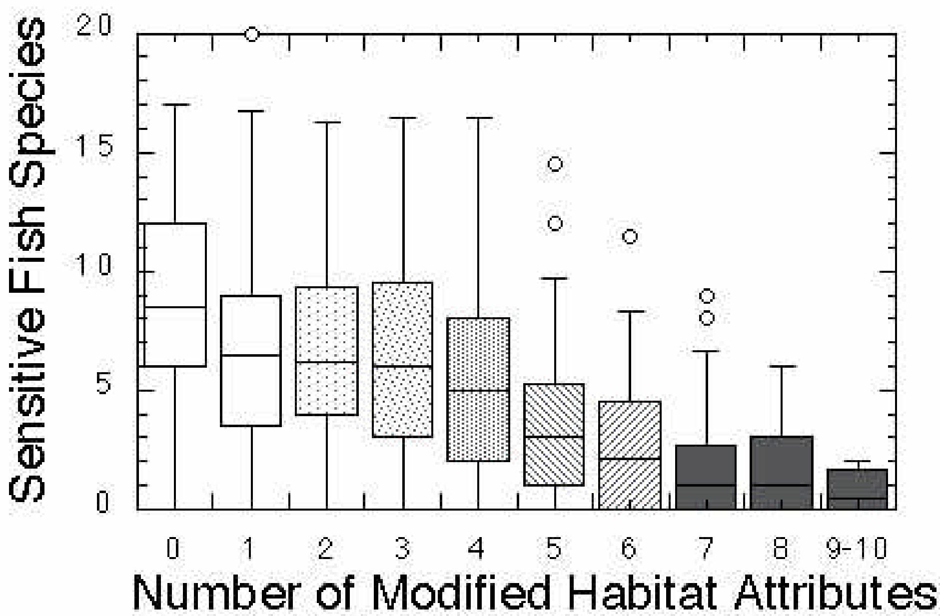
- Ecological resources
- Recreational activities
- Waste assimilation
- Water supplies
- Aesthetics

Attributes of Ecosystems With High Ecological Integrity

- Inherent potential is realized.
- Condition is stable.
- Capacity for self-repair is intact.
- Minimal external support or management is required.

(after Karr et al. 1986)

Aquatic Life is Limited by Habitat Quality



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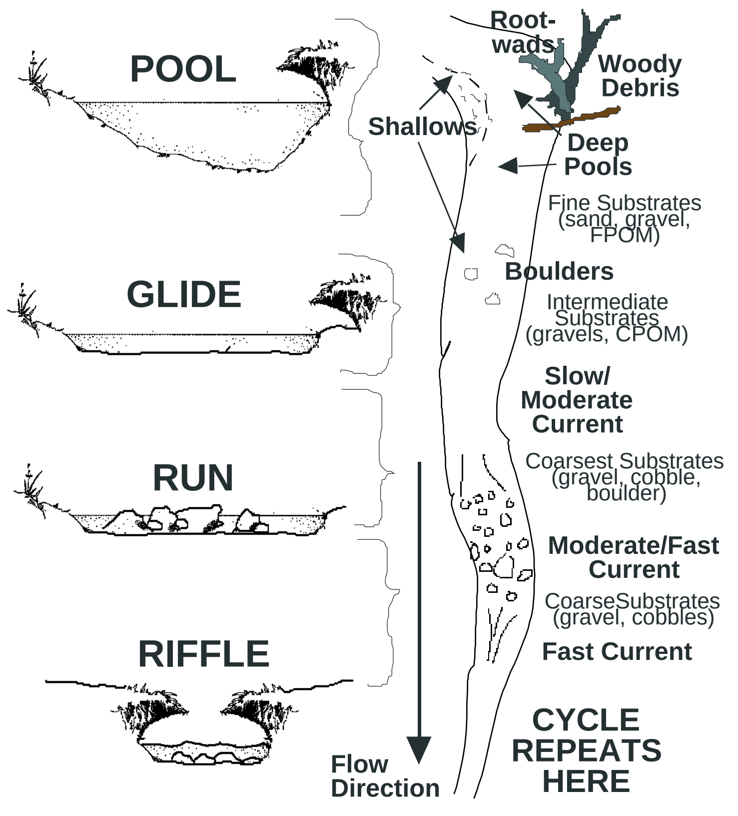


ONE CYCLE OF STREAM HABITAT

LONGITUDINAL SEQUENCE OF STREAM HABITAT TYPES & FUNCTIONS:

Pool Functions:

- Critical niche habitat & cover
- Low flow refugia
- Resting area
- Feeding area for top carnivores
- Nursery area
- Depositional area (FPOM[1])

Run Functions:

- Critical niche habitat
- Spawning area
- Feeding area for insectivores & herbivores
- Macroinvertebrate production
- Primary production habitat (filamentous algae, diatoms)

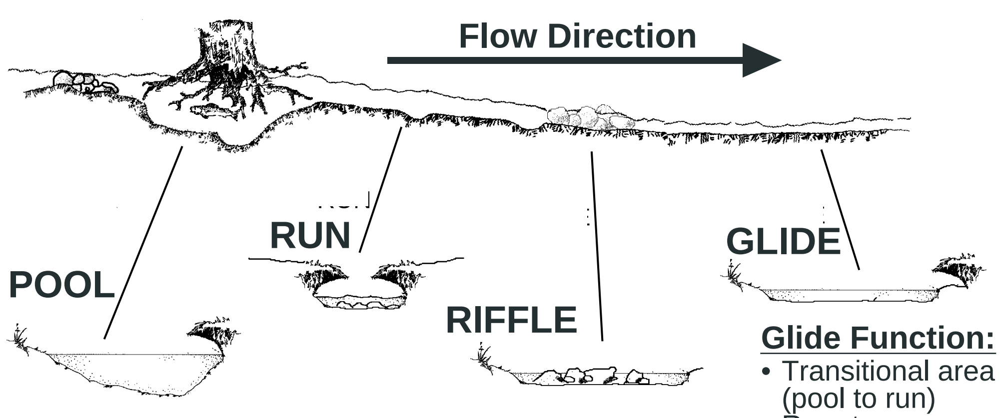
Riffle Functions:

- Critical niche habitat
- Spawning area
- Reaeration
- Invertebrate production
- Primary production habitat (filamentous algae, diatoms)

Glide Functions:

- Transition habitat (pool to run)
- Does not predominate in high quality streams

PRIMARY CHANNEL HABITAT TYPES AND ASSOCIATED FUNCTIONS OF EACH



Glide Function:

- Transitional area (pool to run)
- Rare to un-common in high quality streams

Pool Functions:

- Critical niche habitat & cover
- Low flow refugia
- Resting area
- Feeding area for top carnivores
- Nursery area
- Depositional area (FPOM[1])

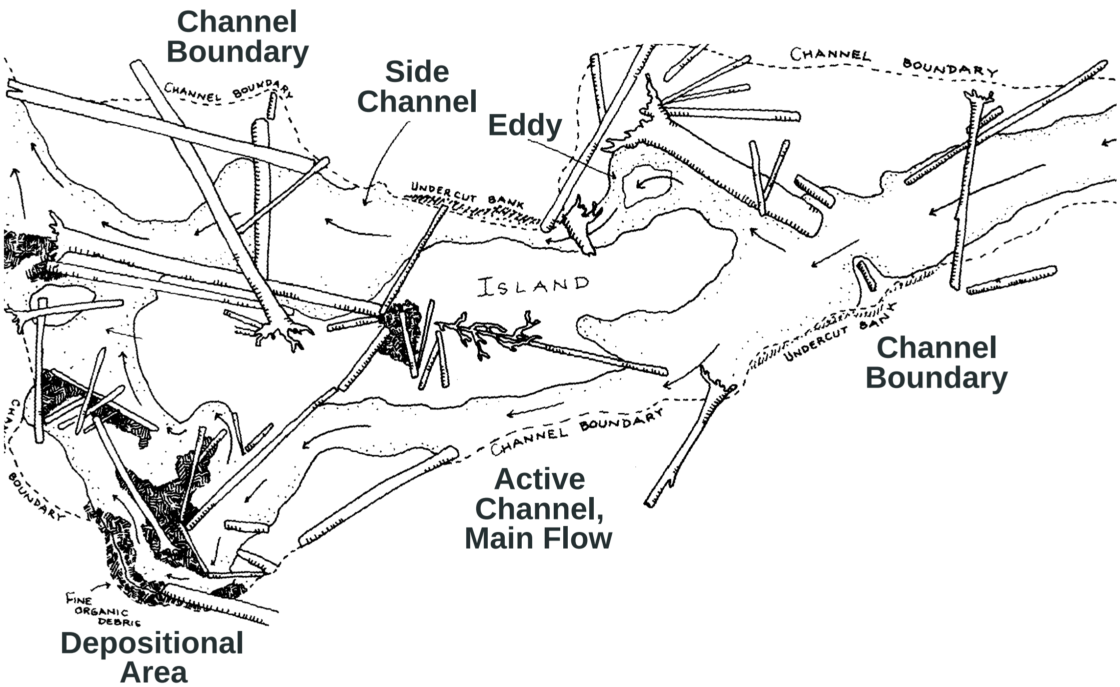
Run Functions:

- Critical niche habitat
- Spawning area
- Feeding area for insectivores & herbivores
- Macroinvertebrate production
- Primary production habitat (filamentous algae, diatoms)

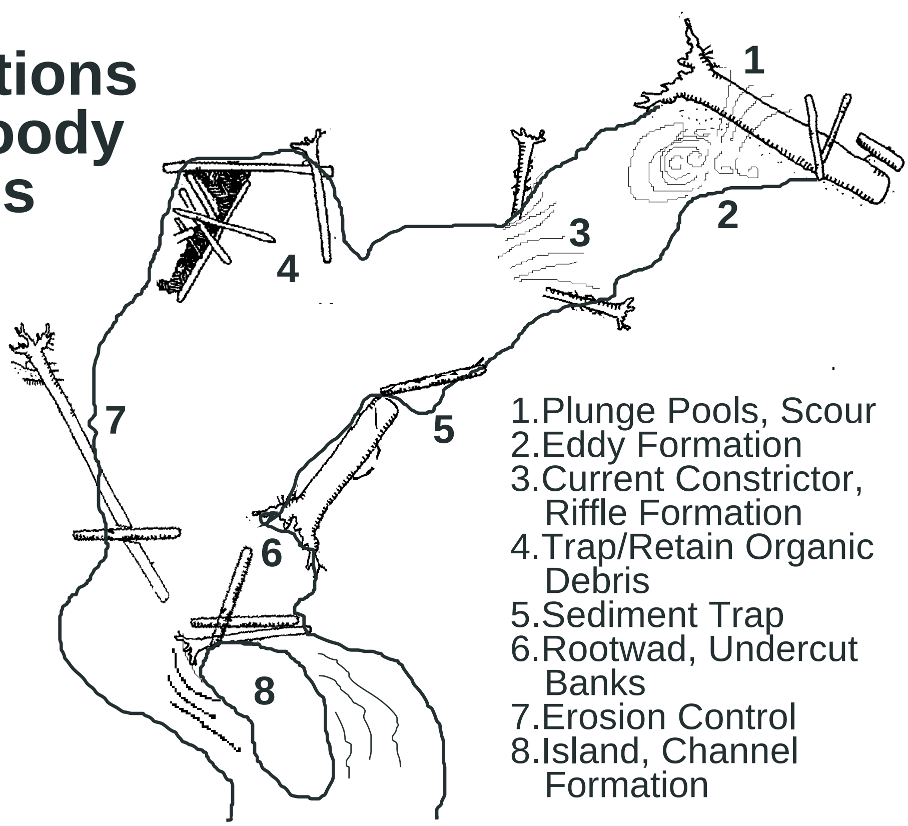
Riffle Functions:

- Critical niche habitat
- Spawning area
- Reaeration
- Macroinvertebrate production
- Primary production habitat (filamentous algae, diatoms)

IMPORTANCE OF WOODY DEBRIS TO STREAM HABITAT FORMATION AND MAINTENANCE



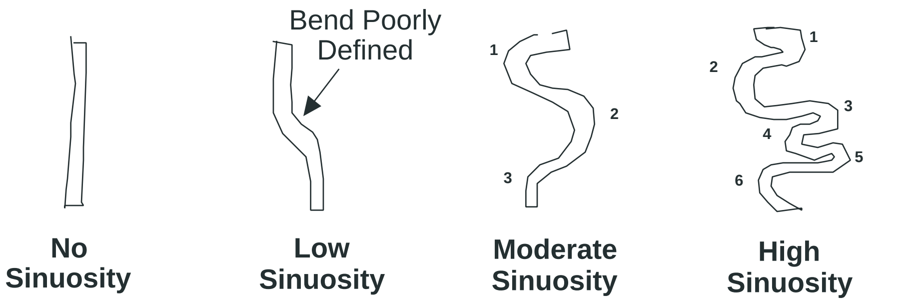
Functions of Woody Debris



1. Plunge Pools, Scour
2. Eddy Formation
3. Current Constrictor, Riffle Formation
4. Trap/Retain Organic Debris
5. Sediment Trap
6. Rootwad, Undercut Banks
7. Erosion Control
8. Island, Channel Formation

Sinuosity

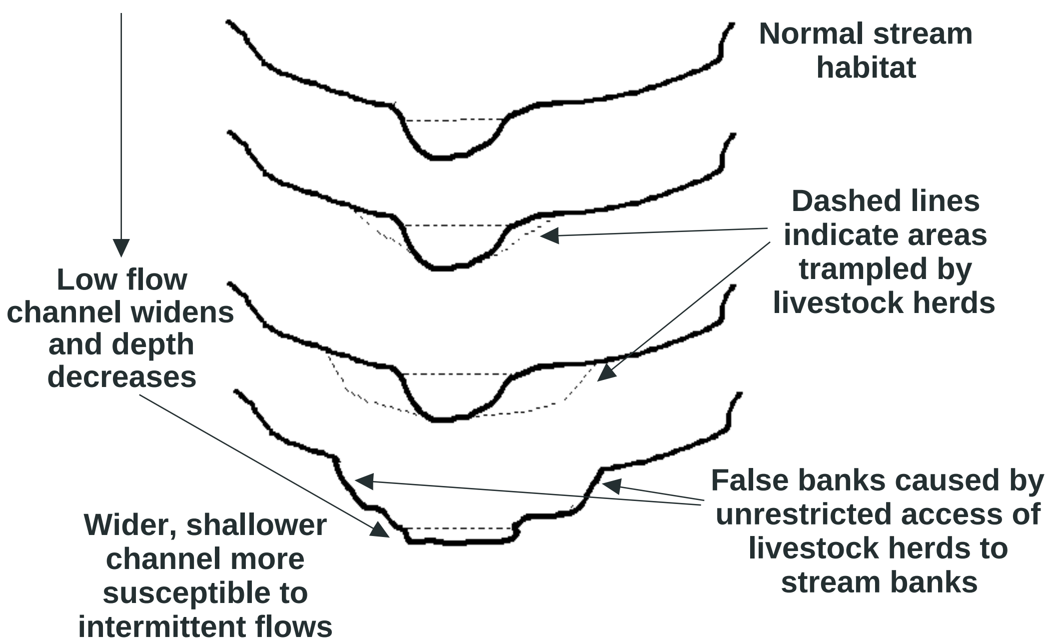
- Ratio of Channel Length to Downvalley Distance



Function: Creates depth and habitat heterogeneity, more habitat per unit distance

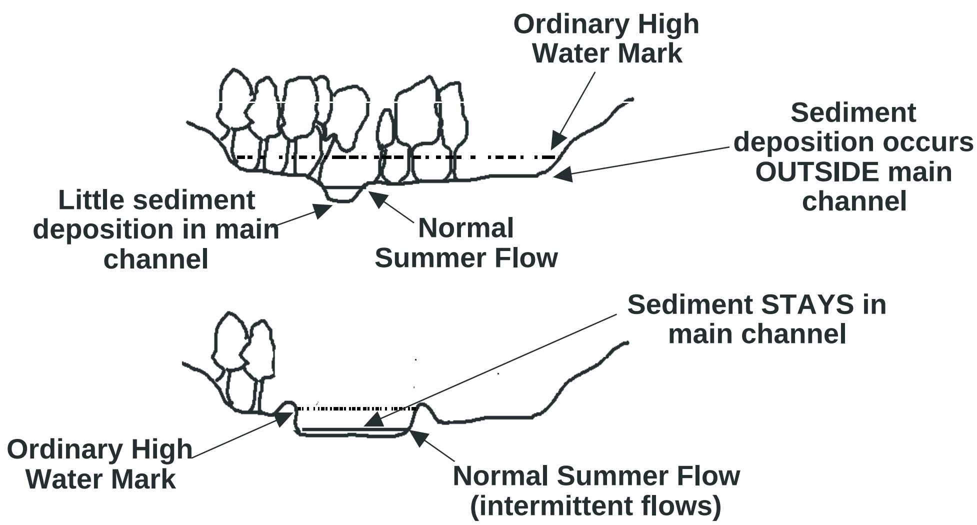
False Banks

- Sequence of development of false banks

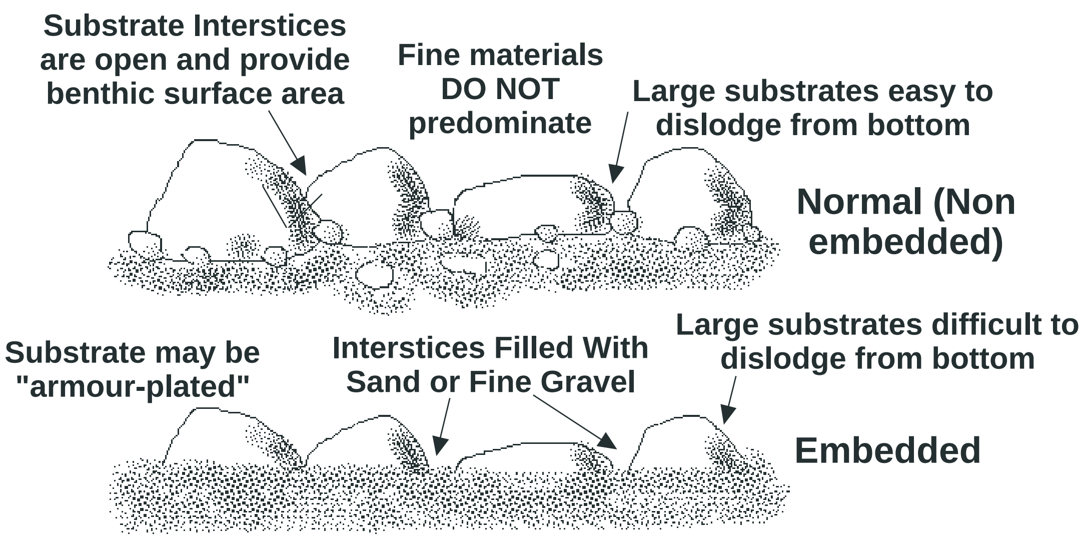


Channel Modifications

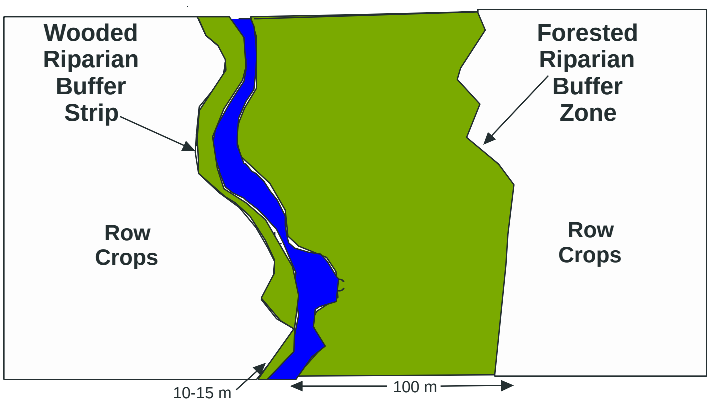
- Channel modification affects how and where fine sediment is deposited



Substrate Embeddedness



RIPARIAN WIDTH AND ADJACENT LAND USES



Riparian Buffer Zones: Beneficial Functions

"More Than Filters for Excess Nutrients and Sediment"

- Habitat forming function - rootwads & large woody debris form different habitats & provide cover.
- Bank stabilization - large tree root systems.
- Retention and uptake of excess water - large trees.
- Assimilation of excess nutrients and sediment.
- Groundwater recharge and maintenance of flows.
- Temperature moderation in summer - shading.
- Primary source of organic matter - leaves & detritus.

Riparian Buffer Zones: Management Guidelines

Many negative effects of encroachment are cumulative and occur off-site.

- Encroachment, modification, and outright elimination debilitates and eventually eliminates the delivery of beneficial and essential functions.
- 50' to 120' on both sides of the bank full channel is a "rule of thumb" *minimum* necessary to maintain a high quality aquatic ecosystem (likely wider for larger rivers).
- *not* a "hands-off" zone, but must be managed to meet the needs of the aquatic ecosystem (i.e., to maintain a designated use).

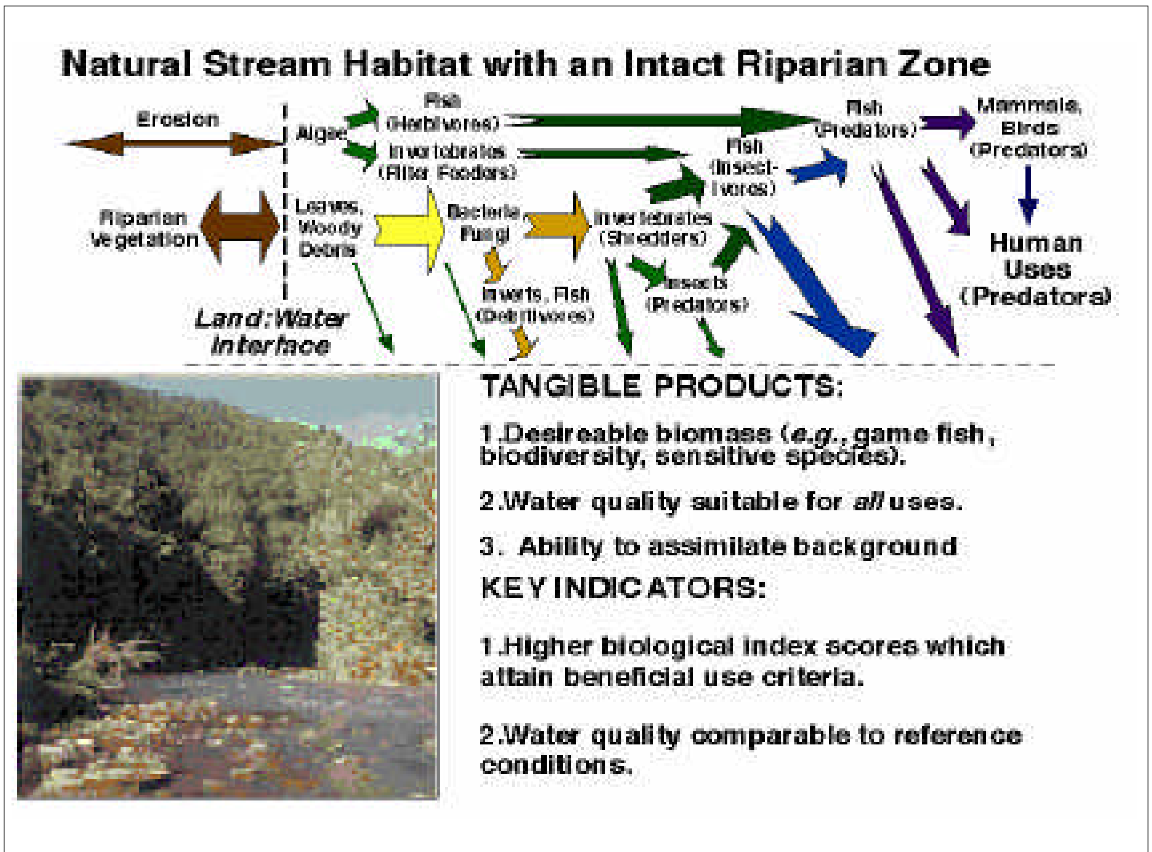
Primary Energy Sources for Aquatic Ecosystems

Outside ("Allochthonous"):

- **Organic matter** (primarily leaves, plant matter, and woody debris)
- Ground and surface waters carry **solutes** and particles (e.g., attached and dissolved N and P)

Inside ("Autochthonous"):

- **Primary production** by algae and plants (photosynthesis)



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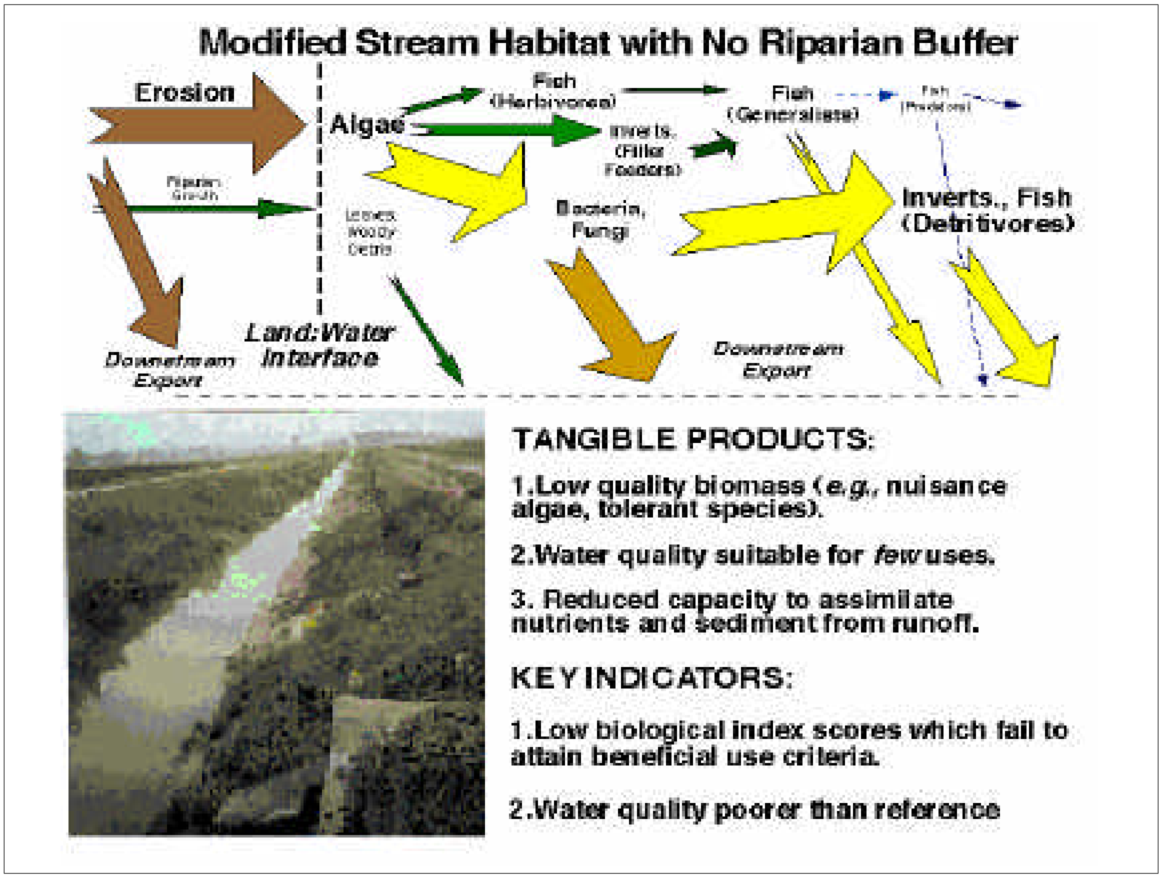
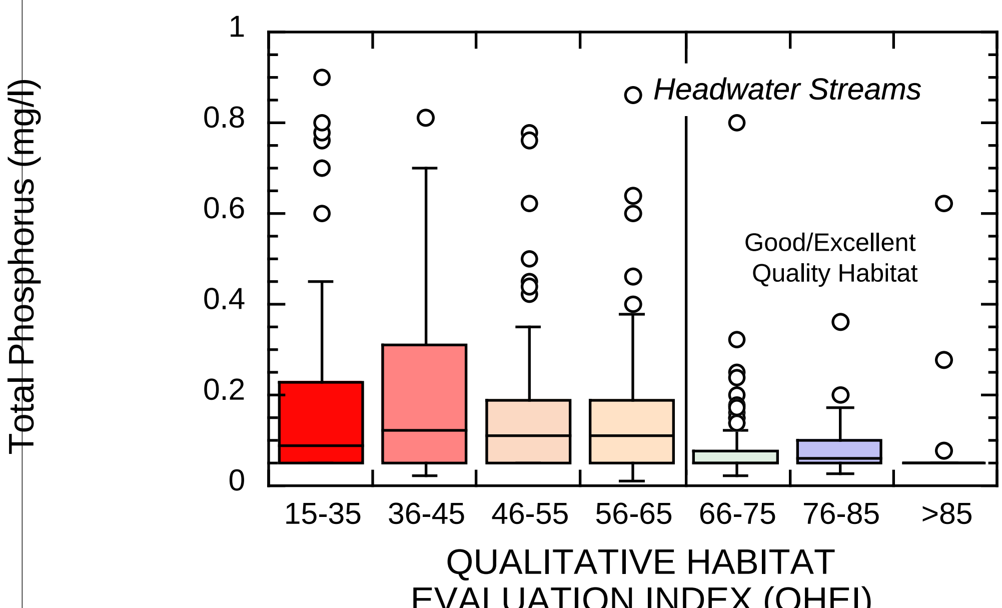
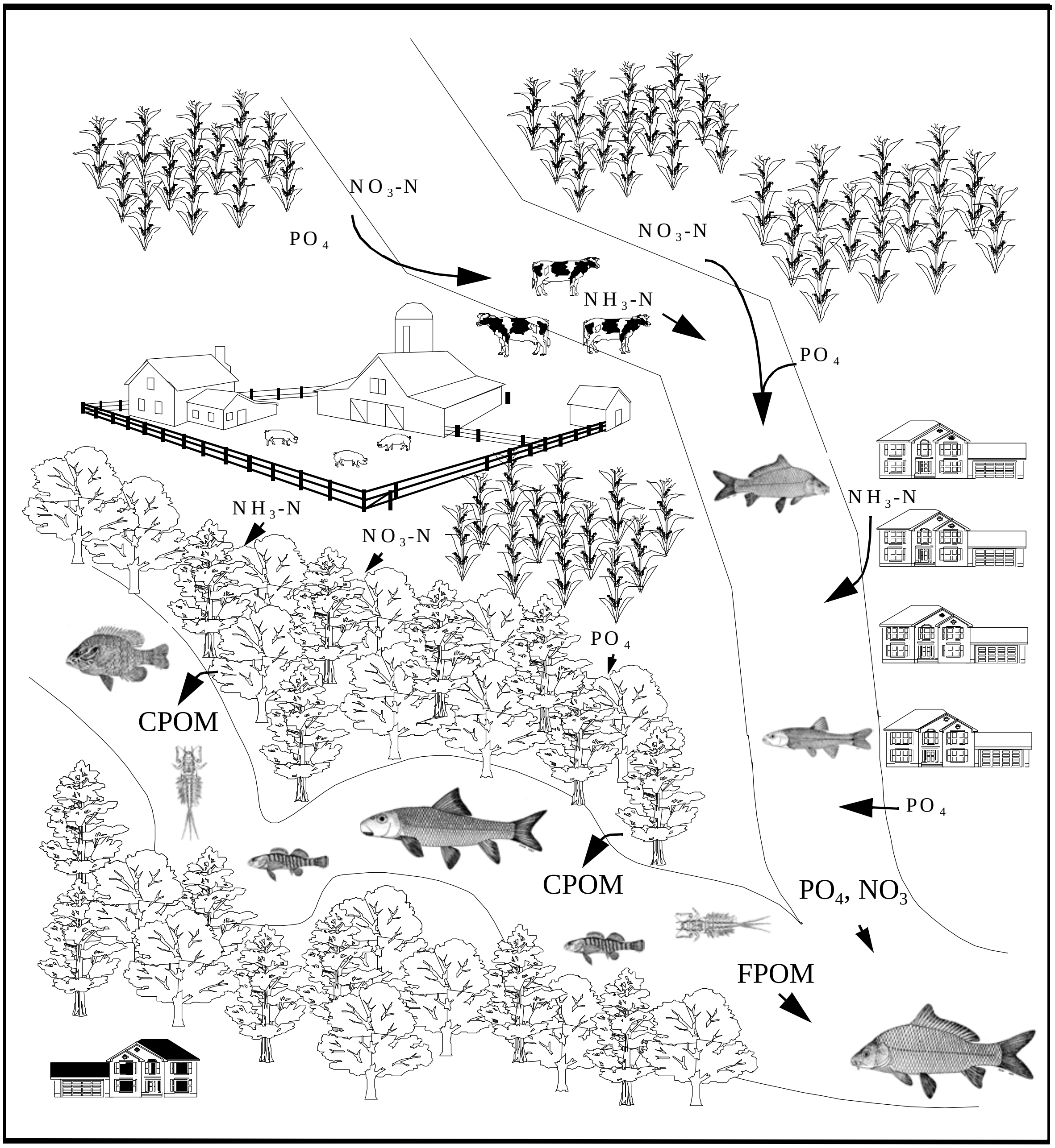


Relationship of Stream Habitat to Total Phosphorus: Headwater Streams



Association Between Nutrients, Habitat, and the Aquatic Biota in Ohio Rivers and Streams

Ohio EPA Technical Bulletin MAS/1999-1-1



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Benefits of Stream & Riparian Habitat Protection in Ohio

The purpose of this fact sheet is to explain Ohio EPA's rationale for developing a plan to protection stream and riparian habitat in Ohio. This document summarizes some of the evidence supporting the protection and restoration of instream and riparian habitat on the basis of observed trends of degradation in Ohio, basic research on the function of stream ecosystems, and an increased effort to protect and restore stream and riparian habitats across the United States.

Status of Instream and Riparian Habitat in the United States

Instream and riparian habitat has been subjected to varying degrees of degradation and modification over the past 150 years. Recent moves to protect stream ecosystems is nationwide in scope with the goal of preserving and restoring aquatic habitats in streams and rivers that are becoming biologically imperiled. Nationally, aquatic biota are "disproportionately imperiled compared to terrestrial fauna". One of every three fish species and two of every three crayfish species are rare or imperiled. In addition one in ten freshwater mussel species have become extinct this century and 73% of the remaining species are rare or imperiled.[1]

Even where most of the orgininal stream species are still present, the ecological integrity of many streams is often seriously impaired because of the disturbance of instream habitat, sedimentation, flow regime, water quality, and riparian destruction. The five major factors that control and influence the ecological integrity of streams are illustrated in Figure 1. Traditionally, water

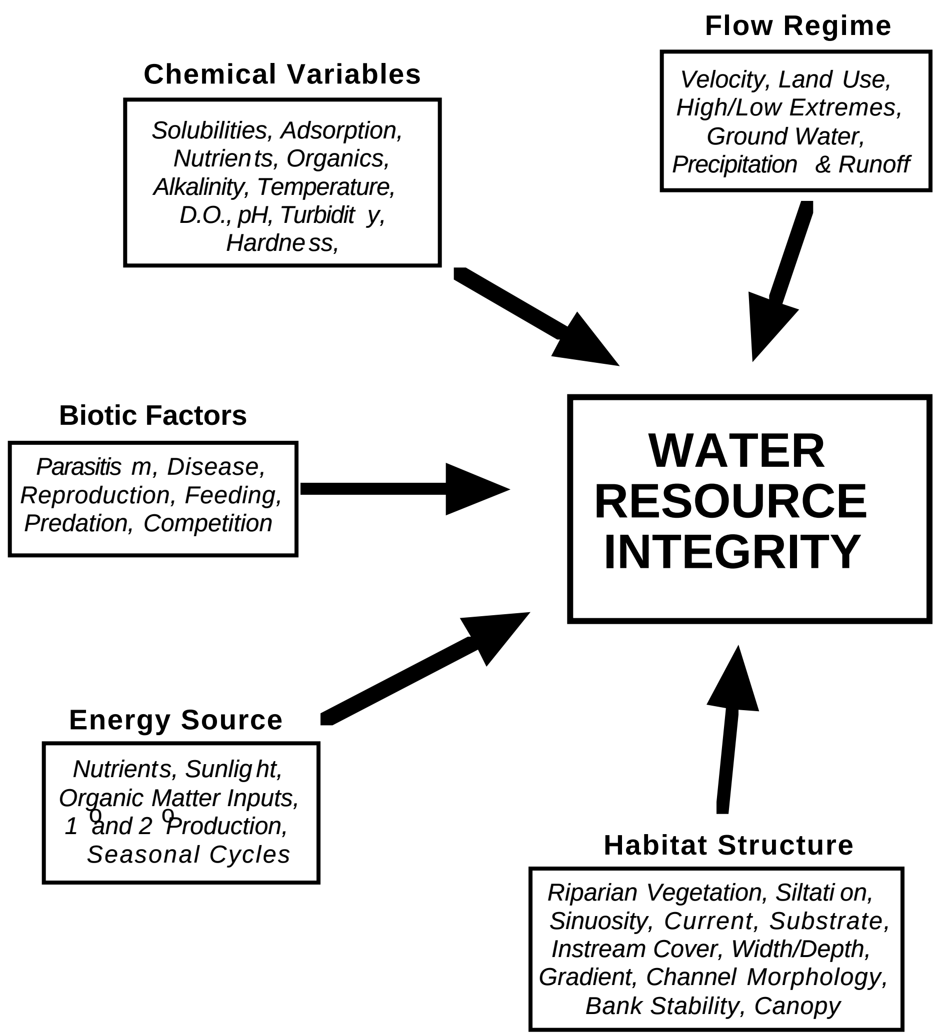

Figure 1. Five Major Factors that Influence Water Resource Integrity in Streams

resource management efforts have focused largely on chemical water quality parameters. It is now conceded, however, that habitat loss and other non-chemical impacts are likely responsible for more extensive losses of biodiversity, and hence, ecological integrity.[2] Based on a U. S. Fish and Wildlife Service "Nationwide Rivers Inventory" completed in 1992 only 2% of the streams and rivers in the lower 48 states had sufficient existing high-quality features to warrant special federal protection.[3]

Because of the marginal, poor, or declining condition of streams and their riparian areas, the National Academy of Sciences' National Research Council committee on aquatic habitat restoration recommends that: (1) erosion control programs should be accelerated for both soil conservation and environmental restoration purposes, (2) grazing practices should be altered to minimize damage to river-riparian ecosystems, (3) erosion control, where feasible, should favor "soft" (e.g., restoring wooded riparian vegetation) engineering over "hard" engineering (e.g., channelization) approaches, (4) unnecessary dikes and levees should be openned to re-establish hydrological connections between riparian habitats and streams, and (5) riparian areas should be classified as wetland systems, on the basis of their structural and functional connections to rivers.

This committee also set a goal of restoring 400,000 miles of riparian-river ecosystems (12% of total U.S. rivers and streams) within the next 20 years. Obviously, habitat protection and restoration is a growing national concern.

Status of Instream and Riparian Stream Habitat and Biota in Ohio

Given the national concerns with instream and riparian habitat protection and restoration as outlined above, are the same concerns pertinent to Ohio? The answer to this question is an unqualified yes. Statewide monitoring of streams and rivers since 1980 indicates that habitat degradation and sedimentation are the second and third leading cause of biological impairment to streams (Figure 2).[4] This data was largely collected to assess point sources of pollution (e.g., municipal or industrial dischargers) and likely underestimates the relative extent of

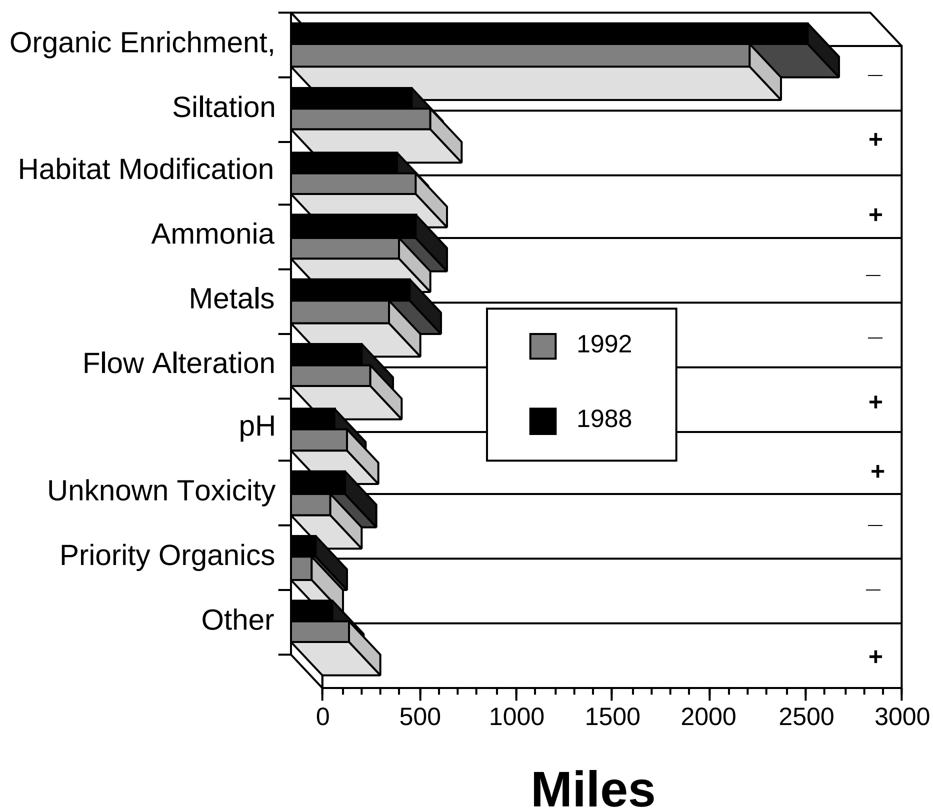

Figure 2. Causes of impairment to aquatic life in Ohio streams and rivers on data from 1979-1987 and data from 197-1991. Sign on graph indicates trend in extent of each cause.

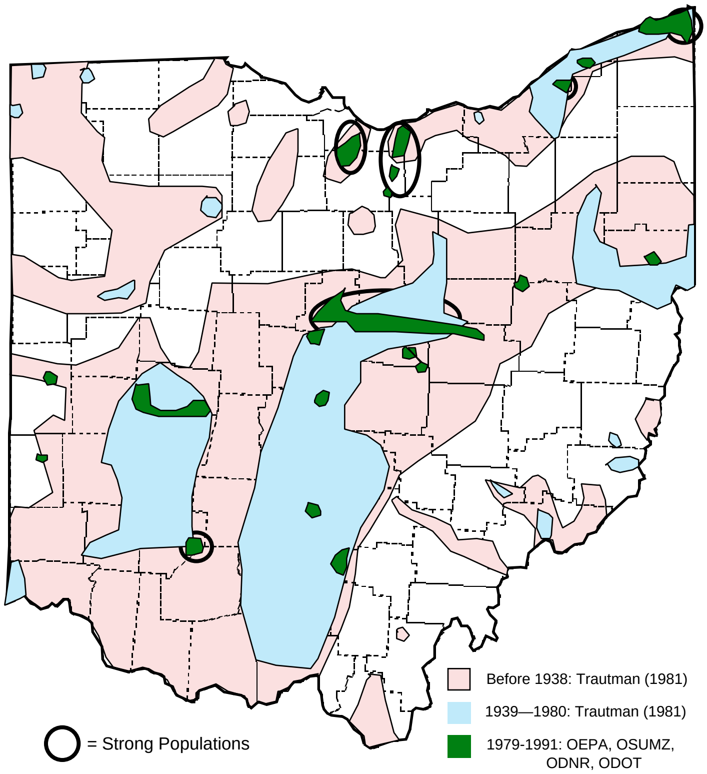

Figure 3. Decline in thedistribution of the bigeye chub in Ohio during the past 90 years.

nonpoint pollution. This does not mean that point sources are not a serious area of concern in Ohio. The basic physical structure and functioning of stream ecosystems needs to be maintained, however, if we are to expect a reasonable full recovery and restoration of impaired waters as a result of the past investments of $4 billion in point source pollution control.

In addition to data on impairment of streams and rivers caused by habitat degradation and siltation in Ohio, declines in individual species populations and distribution in Ohio mirrors national trends. Species such as the blue pike (extinct) and crystal darter (extirpated) are no longer found in Ohio, likely as a result of the siltation of critical habitats and changes in stream flows. More alarmingly, species once common across Ohio have now been greatly reduced in range, particularly in the last half of this century. One example of such a decline is in the range of the bigeye chub (Figure 3). Prior to 1930 this species, which requires pools free of clayey-silts and a continuous supply of cool, clean water, was widely distributed across Ohio; over the last ten years extensive sampling has documented a serious decline to a series of small, widely separated portions of its former range. The 1992 Ohio Water Resource Inventory identifies similar declines for an additional 16 species which are not presently listed as endangered, threatened, or special concern status by Ohio DNR. While it might be argued that these species individually may be of little direct economic or social significance, thier role as "mine canaries" must be taken seriously. The fact that more than 40% of the native Ohiofauna is declining also has serious implications for the continued provision of aquatic ecosystem services in the future. While our monitoring data has documented a substantial recovery of aquatic life from wastewater treatment impacts in rivers across Ohio, habitat destruction has not been slowed and in some cases is increasing. This will result in not only a net loss of ecological resource value but will blunt the benefits of the more than 5 billion that has been spent in controlling chemical water quality.

Functions of Stream Habitats and Riparian Areas

A short summary of the important functions of riparian areas and stream habitat to ecosystems is important to an understanding of the importance of these resources, the present threats to these areas, and the rationale of Ohio EPA's Stream Protection Policy. While most people recognize the benefits of shading of streams by riparian forests, the function of these habitats goes substantially beyond the moderation of stream temperatures:

✓ Woody riparian vegetation naturally filters sediments, nutrients, fertilizers, and other nonpoint source pollutants, from overland runoff, and mimimizes stream temperature fluctuations,

✓ Woody riparian vegetation stabilizes stream banks; vegetated streams banks are up to 20,000 times more resistant to erosion than bare stream banks,

✓ The input of large woody debris (i.e., trees) into streams has been shown to be critically important to stream habitat diversity; 99% of woody debris in streams originates within 100 feet of the stream bank,

✓ Greater than 50% of the breeding bird species in Ohio use riparian wooded areas to nest. Riparian areas are also critical migration habitats; during the spring and fall, migratory birds are 10 to 14 times more abundant in riparian habitats than in surrounding upland habitats,

✓ Leaves and woody debris are important food sources for stream invertebrates, which in turn, are essential for fish growth and survival. Healthy riparian zones also reduce sedimentation which would otherwise inhibit invertebrate populations.

✓ Riparian systems are widely recognized as being essential to the hydrological cycle by maintaining and mediating flow in streams. Riparian wetlands store surplus water and dampen stream discharge fluctuations; they can also be important groundwater recharge and discharge areas. Groundwater discharge can be critical to streams during low flow periods and degradation of riparian forests often reduces this benefit,

In order to understand the threats to streams and riparian areas and, therefore, the basis of Ohio EPA's Stream Protection Policy, it is important to understand the many functions of riparian and stream habitats. Some of these functions are summarized below:

✓ Streams are characterized by a one-way flow of water which transports nutrients, sediments, pollutants and organisms downstream. Natural streams have many ways to slow such movements (fallen trees, wide floodplains) and species are adapted to assimilating the material trapped by trees and living in the habitats they create.

✓ Streams are open systems and have important exchanges of energy and materials with adjacent terrestrial systems. The bordering terrestrial environment (the riparian area) has the greatest effect on a stream ecosystem and the effect diminishes with distance from the streams. This means that protection of riparian areas will usually be the most cost-effective method of assimilating upland inputs compared to management targeted on uplands. Because of the openness and directional movement of materials in streams the cumulative effects of conditions in headwater streams have major influences on downstream, mainstem ecosystems integrity (i.e., "River Continuum Concept").[5]

✓ Stream flow varies greatly through time, and floods of moderate frequency are responsible for most rehabilitation of stream channels; these are flows that continually flush fine sediments downstream. Protection of streams includes maintenance of flows that rehabilitate stream beds, stream channels, and floodplains. As described by the National Research Council: "If the observer could view several hundred years of changes in a few minutes, using time-lapse aerial photography, the river channel would appear to writhe like a snake, with meander loops moving downstream, throwing off oxbows as they go. The dynamic equilibrium in the physical system creates a corresponding dynamic equilibrium in the biological system."[1]

✓ Streams are characterized by habitat patchiness" with alternating riffles and pools, eddies, vegetated and unvegetated channel borders, permanent backwaters, and seasonal floodplain habitats. Modifications to streams, such as flow regulation and channelization, usually results in the loss of this "patchiness" and more uniform, monotonous habitat that has greatlyu reduced assimilative capacity.

✓ Because stream communities are a product of a dynamic physical environment, in most cases they may respond well to stream protection and restoration that return this dynamism to stream ecosystems.

✓ As natural areas become fewer and fragmented by development, streams and wide riparian areas can become refugia and vital corridors for migration of animals and plants and the flow of genetic material between populations.[6]

✓ Extensive modifications to streams generally require extensive amounts of maintenance which, if properly accounted for, would discourage most projects in streams or riparian areas on the basis of economic costs alone. Downstream affects of activities in streams and floodplains often includes increase flooding, bank erosion, and degraded ecosystem health. Channel projects often follow a downstream progression, or domino effect, with upstream activities sending flow downstream more quickly resulting in the need for channel work and maintenance there, which in turn exacerbates problems downstream of these activities, ad infinitum. The overall accumulative effect of such activities is costly "stream maintenance" activities and degraded ecosystem integrity.

Fortunately, most solutions to the degradation of instream and riparian habitats are simple and straightfoward. By increasing the width of riparian buffers through land use setback, most instream and riparian habitats will recover naturally over time. Some aspects of aquatic habitat restoration will be much more difficult to deal with (e.g., deforestation, watershed scale flow alterations) and will need more integrated watershed planning approaches to mesh environmental protection with the need for economic development, which contrary to some notions, are not mutually exclusive. High quality streams, riparian habitats, and other natural area are a benefit of living in Ohio that people rightly expect and that is essential to Ohio's long-term economic health.

Glossary

Riparian Area: Areas adjacent to streams that are hydrologically and ecological linked to streams and rivers. The size of the area that has strong interactions with a stream or river will vary with stream morphology, stream size, geologic features, etc., however, for purposes of Ohio's Stream Protection Policy it is defined as 2-1/2 times the stream width (bank full) on each side of the stream up to 120 feet.

Ecological Integrity: This refers to the expected condition of an ecosystem in anatural, relatively undisturbed state. This is not a definition of pristine, but is derived by examining existing, intact ecosystems .

Impairment: Deviation of the biological health of a stream from the criteria set in Ohio's Water Quality Standards based on minimally unimpacted reference sites

Siltation: Covering of natural substrates by higher than normal layers of erdoed soils and other fine substrates

References

[1]**U. S. National Research Council.** 1992. Restoration of aquatic ecosystems: science, technology, and public policy. National Academy of Science. National Academy Press, Washington, DC.

[2]**Allan, J. D. and A. S. Flecker.** 1993. Biodiversity conservation in running waters. BioScience 43(1): 32-43.

[3]**Benke, A. C.** 1990. A perspective on America's vanishing streams. Journal of the North American Benthological Society 9: 77-88.

[4]**Ohio Environmental Protection Agency. 1992.** Ohio water resource inventory: status and trends, Editors. E. T. Rankin, C. O. Yoder, and D. A. Mishne. Ohio EPA, Division of Water Quality Planning as Assessment, Columbus, Ohio.

[5]**Knopf, F. L., R. Johnson, T. Rich, F. B. Samson, and R. C.Szaro.** 1988. Conservation of riparian ecosystems in the United States. Wilson Bulletin 100(2): 272-284.

[6]**Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing.** 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Science 37: 130-137.

[7]**Noss, R. F. 1987.** Protecting natural areas in fragmented landscapes. Natural Areas Journal 7(1): 2-13.

Table 1. Selected riparian buffer zone widths recommended for protection of stream and riparian habitat and water quality.				
Management Recommendations				
Reference	Recom-mends Width (ft)	Location	Obtained Reference	Annotation
USDA (1987)	100’	Missouri	√	Sediment from agriculture; from SCS pamphlet on stream corridor management
Kansas Dept of Health & Environment	66’ minimum	Kansas	√	Multiple benefits: reduce erosion, reduce temperature, improve wildlife habitat
Murphy (1991)	50’ for intermit-tent streams; 100’ for permanent streams	Connecti-cut	√	from edge of stream
Newberry (1992)	75’ minimum + 20’ Grass	Nationwide	√	Urban Streams
Welsch (1991)USFWS	75’ minimum Forest Zone + 20’ grass upslope	Nationwide	√	15’ Fixed Forest Zone + 60’ minimum Managed Forested (this width expands based on soil conditions or existence of major pollutant sources upland) + 20’ minimum dense grasses and forbes upslope
Zampala & Roman (1983)	300’ setback			Septic Nutrients
Shertzer (1992)	100’ constr. setback	Pennsylva-nia	√	Construction Activities near High Quality Waters
Shertzer (1992)	50’ buffer + 4’ per 1˚ Slope	Pennsylva-nia	√	High Quality Waters, guidelines for erosion control, road siting. 70 degree slope would require 330’ buffer; 25-330’ buffer for timber harvest near HQ waters.
USEPA (1993)	35-50’		√	Forest SMA, additional buffer depending on slope
Florida	0-140’			Forest SMA, additional buffer depending on erodability, etc.

Reference	Recom-mends Width (ft)	Location	Obtained Reference	Annotation
N. Carolina	50' minimum .	North Carolina		Forest SMA; additional buffer (0-150') depending on slope and presence of trout in streams.
USEPA (1993)	50' in headwater; up to 200' for larger streams		√	urban runoff control
Alexandria, VA	100'	Virginia City of Alexandria		unless smaller justified
ODNR - Scenic R.	120'	Ohio	√	along Scenic River
National Marine Fisheries Service	100' minimum	West Coast		Salmonid Protection - related to woody debris in streams
Nieswand (1990)	50' or $W=2.5*T*S^{0.5}$; $W=500*S^{0.5}$			Model where W = Riparian width, T = Transit time of overland flow, and S = slope; for optimal conditions and 50' minimum flow, T=200
IEP, Inc (1990)	Model			Model to reduce TSS on basis of infiltration rates, riparian width
U. S. Forest Service	66' minimum			A buffer less than 66' is not considered windfirm
Schueler (1987)	50-75' preferable			20' grass strip absolute minimum; 50-75 feet preferable + 4' for each percent increase in slope
Karr, Toth, and Garman (1977)	82-230'	Midwest	√	25 m (82') for small, low to medium gradient streams; 70 m (230') for large rivers and mountain streams with steep banks (> 60%)
Erman et al. (1977)	100'	California		Buffer zone to protect aquatic invertebrates from sedimentation and channel instability.

Table 1. Continued

Table 2. Selected studies documenting the efficiency of the nitrate removal from subsurface and surface flows.

Reference	Width (m)/% reduction	Width feet	Location	Obtained Reference	Annotation
Nitrate Reduction (Subsurface)					
James, Bagley, & Gallagher (in press)	10 (60-98%)	33’			Forested Buffer
Jacobs & Gilliam (1985)	16 (93%)	53’			Forested Buffer
Peterjohn & Correll (1984)	19 (93%)	62’			Forested Buffer
Schnabel (1986)	19 (40-90%)	62’			Forested Buffer
Lowrance, Todd, & Asmussen (1984)	25 (68%)	82’			Forested Buffer
Pinay & Decamps (1988)	30 (100%)	98’			Forested Buffer
Peterjohn & Correll (1984)	50 (99%)	164’			Forested Buffer
Schnabel (1986)	27 (10-60%)	89’			Grassed Buffer
Schnabel (1986)	19 (40-90%)	62’			Forested Buffer
Pinay ET AL. (1993)	30 (100%)	98’	France	X	Forested Buffer
Nitrate Reduction (Surface)					
Doyle, Standton, & Wolf (1977)	30 (98%)	98’			Forested Buffer
Peterjohn & Correll (1984)	50 (79%)	164’			Forested Buffer
Dillaha et al (1989)	9 (73%)	30’			Grassed Buffer
Dillaha et al (1989)	5 (54%)	16’			Grassed Buffer
Young, Huntrods, & Asmussen (1980)	27 (84%)	89’			Grassed Buffer

Table 2. Selected studies documenting the efficiency of riparian buffer zones in removing nitrate and phophorus from subsurface and surface flows, removing sediment from overland flow, maintaining ambient temperature in streams, and providing woody debris for aquatic organisms in streams.

	Nitrate Surface Runoff	Nitrate Subsurface Runoff	Phophorus Surface Runoff	Phospho-rus Subsurface Runoff	Sediment Removal	Tempera-ture	Woody Debris &CPOM Provision			
Reference	Width (m)/% reduction [Width ft]	Width (m)/% reduction [Width ft]	Width (m)/% reduction [Width ft]	Width (m)/% reduction [Width ft]	Width (m) to Remove "Substan-tial" Fraction [Width ft]	Width to Maintain Ambient Tempera-ture	Width Needed to Supply Structure or CPOM	Location of Study	Obtained Refer-ence	Annotation
James, Bagley, & Gallagher (in press)	10 (60-98%) [33']									Forested Buffer
Jacobs & Gilliam (1985)	16 (93%) [53']									Forested Buffer
Peterjohn & Correll (1984)	19 (93%) [62']		19 (33%) [62']	19 (74%) [62']	19 [62']			Maryland	✓	Forested Buffer
Schnabel (1986)	19 (40-90%) [62']									Forested Buffer
Lowrance, Todd, & Asmussen (1984)	25 (68%) [82']									Forested Buffer
Pinay et al. (1993)		30 (100%) 98'						France	✓	Forested Buffer (noted importance of forested buffers as carbon source for denitrification)

Table 2. Continued

Reference	Nitrate Surface Runoff	Nitrate Subsurface Runoff	Phophorus Surface Runoff	Phosphorus Subsurface Runoff	Sediment Removal	Temperature	Woody Debris &CPOM Provision			
	Width (m)/% reduction [Width ft]	Width (m)/% reduction [Width ft]	Width (m)/% reduction [Width ft]	Width (m)/% reduction [Width ft]	Width (m) to Remove "Substantial" Fraction [Width ft]	Width to Maintain Ambient Temperature	Width Needed to Supply Structure or CPOM	Location of Study	Obtained Reference	Annotation
Pinay & Decamps (1988)	30 (100%) [98']									Forested Buffer
Peterjohn & Correll (1984)	50 (99%) [164']	50 (79%) [164']	50 (-114%) [164']	50 (85%) [164']					√	Forested Buffer; Sediment from agriculture
Schnabel (1986)	27 (10-60%) [89']									Grassed Buffer
Schnabel (1986)	19 (40-90%) [62']									Forested Buffer
Doyle, Standton, & Wolf (1977)	30 (98%) [98']									Forested Buffer
Dillaha et al (1989)	9 (73%) [30']			9 (79%) [30']						Grassed Buffer
Dillaha et al (1989)	5 (54%) [16']			5 (61%) [16']						Grassed Buffer
Cooper & Gilliam (1987)				16 (50%) [52']						Forested Buffer

Table 2. Continued

	Nitrate Surface Runoff	Nitrate Subsurface Runoff	Phophorus Surface Runoff	Phospho-rus Subsurface Runoff	Sediment Removal	Tempera-ture	Woody Debris &CPOM Provision			
Reference	Width (m)/% reduction [Width ft]	Width (m)/% reduction [Width ft]	Width (m)/% reduction [Width ft]	Width (m)/% reduction [Width ft]	Width (m) to Remove "Substan-tial" Fraction [Width ft]	Width to Maintain Ambient Tempera-ture	Width Needed to Supply Structure or CPOM	Location of Study	Obtained Refer-ence	Annotation
Aubertin & Patrick (1974)*					10-20 [33-66']	10-20 [33-66']		West Virginia		Sediment from clearcut
Haupt & Kidd (1965)*					9 [30']			Idaho		Sediment from logging road
Trimble & Sartz (1957)*					15-45 [49- 148']			New Hampshire		Sediment from logging road
Kovacic & Osborne (unpublished)*					19 [62']			Illinois		Sediment from agriculture
Lynch & Corbett (1990)*						31 [102']		Pennsylvania		
Brazier & Brown (1973)*						10 [33']		Oregon		Mountain stream
Corbett, Lynch, & Sopper (1978)*						12 [39']		North Carolina	√	Mountain stream

Table 2. Continued

Reference	Nitrate Surface Runoff Width (m)/% reduction [Width ft]	Nitrate Subsurface Runoff Width (m)/% reduction [Width ft]	Phophorus Surface Runoff Width (m)/% reduction [Width ft]	Phospho-rus Subsurface Runoff Width (m)/% reduction [Width ft]	Sediment Removal Width (m) to Remove "Substan-tial" Fraction [Width ft]	Tempera-ture Width to Maintain Ambient Tempera-ture	Woody Debris &CPOM Provision Width Needed to Supply Structure or CPOM	Location of Study	Obtained Refer-ence	
Murphy (1991) Literature Review							30 [100']	Western States		Majority of woody debris from within 100' of streams; some large debris can remain in stream for > 100 years
Benke (1985)							-	Southeast US	√	Documented importance of woody debris for macroinvertebrate production in low gradient rivers
Erman (1977)							30 [100']			Forested Buffers > 100' Protect Aquatic Inverts
Karr and Schlosser (1977)					25-70 [82-230']		25-70 [82-230']		√	
Andrus et al. (1984)							50 years	Northwest US		Found that riparian trees must grow to at least 50 yrs to ensure stable supply of LOD
Young, Huntrods, & Asmussen (1980)	27 (84%) [89']			27 (83%) [89']						Grassed Buffer

Table 3. Selected studies documenting the efficiency of the phosphorus removal from subsurface and surface flows.					
Phosphorus Reduction (Subsurface)					
Reference	Documents Effects: Width (m)/% reduction	Width Feet	Location	Obtained Reference	Annotation
Peterjohn & Correll (1984)	19 (33%)	62’			Forested Buffer
Peterjohn & Correll (1984)	50 (-114%)	164’			Forested Buffer
Phosphorus Reduction (Surface)					
Cooper & Gilliam (1987)	16 (50%)	52’			Forested Buffer
Peterjohn & Correll (1984)	19 (74%)	62’			Forested Buffer
Peterjohn & Correll (1984)	50 (85%)	164’			Forested Buffer
Dillaha et al (1989)	9 (79%)	30’			Grassed Buffer
Dillaha et al (1989)	5 (61%)	16’			Grassed Buffer
Young, Huntrods, & Asmussen (1980)	27 (83%)	89’			Grassed Buffer

Table 4. Selected studies documenting the efficiency of the sediment removal from surface flows.					
Sediment Control					
Reference	Documents Effects Width m	Width	Location	Obtained Reference	Annotation
Haupt & Kidd (1965)*	9 m	30’			Sediment from logging road
Trimble & Sartz (1957)*	15-45 m				Sediment from logging road
Aubertin & Patrick (1974)*	10-20 m	33-66’			Sediment from clearcut
Peterjohn & Correll (1984)	19 m	62’			Sediment from agriculture
Kovacic & Osborne (unpublished)*	19 m	62’			Sediment from agriculture

Table 5. Selected studies documenting the moderating effects of forested riparian zones on stream temperature.

Stream Temperature					
Reference	Documents Effects Width (m)	Width Feet	Location	Obtained Reference	Annotation
Karr and Schlosser (1977)	25m-70m		Midwest	√	25m
Aubertin & Patrick (1974)*	10-20 m				West Virginia
Lynch & Corbett (1990)*	31m				Pennsylvania stream
Brazier & Brown (1973)*	10				Oregon Mountain stream
Corbett, Lynch, & Sopper (1978)*	12m				North Carolina mountain stream

Table 6. Selected studies documenting the importance of forested riparian zones for woody debris delivery and other habitat fucntions in streams.

Woody Debris				
Reference	Reccomends Width	Documents Effects	Obtained Reference	Annotation
Karr and Schlosser (1977)	25m-70m		√	25m