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FISH HABITAT AND STREAMSIDE MANAGEMENT: PAST AND PRESENT

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ABSTRACT

A stream ecosystem context for considering the definition of biological integrity is presented and provides suggestions for maintaining integrity which are consistent with natural ecosystem structure and function. To do this, we provide examples of how "nature managed" streamsides and fish habitats. This historical understanding of ecosystems serves as a basis for suggesting some guidelines for future practices that will best preserve and restore both physical and biological integrity in stream ecosystems and allow us to evaluate past and future impacts on streamsides and fish habitats. Case studies of the S. Fork Hoh River in Washington and the Satilla River in Georgia are discussed in terms of the dependence of the fisheries on snags and large organic debris (boles and branches >20 cm diameter) in the channel.

Our central premise is that resource managers wishing to maintain or restore biological integrity within forested stream ecosystems can relate management schemes to four key structural components of streamside forests: (1) large live trees in riparian zones, (2) large snags, (3) large logs on the floodplain, and (4) large snags and large organic debris in the stream. The benefits of these structural components for biological and fisheries resources can be incorporated into managed stands for small costs.

INTRODUCTION

In 1972, Congress amended the Federal Water Pollution Control Act (FWPCA). The Act's stated objective is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." An interim goal was to achieve, wherever attainable, swimmable and fishable waters. The interim goal, however, is not equivalent to the primary objective to maintain the integrity of the Nation's waters. The Act makes no clear definition of biological integrity, but others have done so, for example, Ballentine and Guarraie (1975) and Karr and Dudley (1981) present excellent discussions of biological integrity. We agree with Karr and Dudley's statement (1981, p. 56) that "the integrity objective encompasses all factors affecting the ecosystem and can be defined as the 'capability of supporting and maintaining a balanced, integrated adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region.'"

It is clear that water quality of many streams has been improved through prevention and control of water pollution, but improvements in biological integrity have been minor at best. In addition to water quality, attention to physical habitat, flow regime, and food resources must also be given. The biological integrity mandate of the Clean Water Act depends on addressing the entire water resources system at the basin level rather than isolated consideration of local stream reaches.

The purpose of our paper is to present a context for considering the definition of biological integrity of stream ecosystems and provide suggestions for maintaining integrity which is consistent with natural ecosystem structure and function. To do this, we provide examples of how "nature managed" streamsides and fish habitats. This historical understanding of ecosystems serves as a basis for suggesting some guidelines for future practices that will best preserve and restore both physical and biological integrity in stream ecosystems and allow

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NATURAL STREAM ECOSYSTEM STRUCTURE AND FUNCTION

Recently, Vannote et al. (1980) proposed that the coalescing network of streams in a river drainage system is a continuum or spectrum of physical environments and associated biotic communities. The river continuum concept views streams as longitudinally linked systems in which system-level processes (cycling of organic matter and nutrients, ecosystem metabolism, net metabolism) in downstream areas are linked to in-stream processes in upstream areas. The concept provides a general framework for dealing with streams as spatially heterogeneous systems (O'Neill et al. 1979). This view of stream environments leads to useful generalizations concerning the magnitude and variation through time and space of the organic matter supply, the structure of invertebrate and fish communities, and resource partitioning along the length of the river.

The point of this discussion is that small first- and second-order[1/] streams feed small rivers with a partially processed food resource. The river system is a continuum in which transported food materials become progressively smaller. In small streams under old growth forests, a significant proportion of the basic invertebrate food resource is derived from wood or leaf litter. The influence of the forest diminishes in progressively larger streams. The energy base of the stream is derived more from algae and less from forest litter where the canopy is open over the stream (fig. 1). The greatest influence of the forest is found in very small streams, whereas the most diversity in organic input mechanisms and habitats is found in intermediate (third- to fifth-order) streams. Invertebrates reflect these downstream shifts with fewer shredders (leaf eaters) and more grazers (algal feeders) in small rivers (fig. 1). As the size of streams change in any forest, corresponding changes occur in dominant organisms and the role each functional group of organisms plays in using organic materials (fig. 1). In larger rivers, shredders will be found in backwaters and sloughs along the flood plain.

The utility of visualizing an entire river system as a continuum of communities with associated abiotic factors may be illustrated by considering a small woodland stream (first-order) and an intermediate-size river (sixth-order) shown in figure 1. Both systems have the same organic processing components. The difference between the two is in the relative magnitude of the components, the rates and amounts of organic transfer between components, and the actual species engaged in the transfers. But, the two systems are essentially modifications of the same trophic scheme and the entire stream-to-river complex can be viewed as one ecosystem composed of a series of communities along a continuum.

The continuum concept presented here deals primarily with food resources of invertebrates to fish. What is less well understood but more important to the resource manager is the ecology rationale for a streamside vegetation zone along all sizes of streams and rivers. Streamside vegetation zones are justified on the grounds of temperature control, bank stabilization, and providing food resources to the stream ecosystem. Streamside vegetation is also the primary supplier of large organic debris. We define large organic debris or snags to be tree boles >20 cm diameter with the rootwads attached. Tree branches over 20 cm diameter also qualify as large organic debris.

The sources, fates, and roles of large debris and snags in small streams on forested lands form an excellent example of interactions among forest vegetation, erosion processes, and stream ecosystems which have important implications for land managers. Forests adjacent to streams are the source of large debris (boles, root wads, large limbs). Erosion processes may contribute debris to streams and account for downstream transport of debris pieces. Organic debris in streams increases diversity of aquatic habitat by forming pools and protected backwater areas, serves as a source of nutrients and substrate for biological activity, and affects sediment movement and storage by dissipating energy of flowing water and trapping sediment.

The importance of these functions of organic debris in streams has been generally ignored by aquatic ecologists, hydrologists, and geomorphologists until the last few years. It is now realized that large organic debris has historically been an abundant and important part of natural forested streams. Recognition of its importance in streams in western states developed from a forest management perspective (Heede 1972, Froehlich 1973, Marzolf 1978) and from an ecosystem perspective (Swanson et al. 1976; Sedell and Triska 1977; Meehan et al. 1977; Bilby and Likens 1980; Bilby 1981).

There is a growing awareness of the historic role of large wood in small streams in virtually all of North America except portions of the desert. The details of how streamside forests and small stream systems interact can be found in Meehan et al. 1977, Karr and Scholsser 1978, Swanson et al in press. Swanson and Lienkaemper (1978) and Keller and Swanson (1979) present case studies for small streams and rivers in Oregon and Indiana. More importantly, large wood and snags have profound effects on channel form and fluvial processes in streams of all sizes. Two examples will illustrate this: (1) South Fork Hoh River in the Olympic National Park in Washington and (2) Satilla River in Georgia. The extreme contrasts between these two examples illustrates the importance of snags in medium to large rivers regardless of gradient or type of forest bordering the river. The South Fork Hoh River is a high-gradient, coarse-bed, glacier-fed river bordered by old-growth conifers. The Satilla is low-gradient, fine-bed river bordered by pine and hardwoods.

SOUTH FORK HOH RIVER, WASHINGTON

The South Fork of the Hoh River is a sixth-order river that drains 11,400 ha, and precipitation in the watershed averages over 3200 mm annually. The main channel meanders within a wide channel of exposed gravel bars that average 100 m. Wetted widths average 10 m at low flow and 40 m in winter. Sedell et al. (1980) examined the contribution of woody debris to the fish-habitat quality of this large river system (table 1). Swanson and Lienkaemper (1980) mapped a 900-m stretch of river (fig. 2). They found that woody debris (snags) accumulated at the head of gravel bars below the cutting bends of the river. These accumulations commonly regulated water movement into off-channel areas. Off-channel areas are both subsidiary channels within the active exposed lower flood plain and forested flood channels in the forested flood plain (fig. 2). These subsidiary channels are the most productive salmonid rearing areas in the basin.

In general, the main channel and off-channel areas utilized trees and large pieces of wood that originated upstream from the accumulations of debris. Forests along flood-plain tributaries and side tributaries contributed the wood usually found in these streams. Debris was a major contributor to both spawning and rearing habitat requirements of the species present. The salmonid productivity of this system is largely dependent upon stable stream networks created and maintained by woody debris, especially in off-channel habitat within the forested flood plain.

The rivers of Olympic National Park represent the last pristine coastal systems of intermediate size in the western United States. As such, they provide important insights into the condition of coastal rivers in their wild state. Other evidence can be gathered from sketchy historical descriptions. For example, the original survey of the lower Nasel River (Secretary of War 1893) (sixth-order) on the central coast of Washington (fig. 3) shows snags in the same positions as were found in the South Fork Hoh River. The evidence indicates that the questions managers pose regarding where, how much, and what kind of woody debris to provide in managed streams can be answered with some certainty by examining pristine systems.

SATILLA RIVER, GEORGIA

The Satilla River is a sixth-order black-water river in southern Georgia. The portion of the watershed sampled drained 7300 km^2 with a gradient of about 10 m/km and an average discharge of 62 m^3/s. Cypress-black gum swamps are adjacent to the river along much of its length, and pine forests and some agriculture occupy most of the drainage basin.

Benke et al. (1979) studied the utilization of invertebrates as food by the major fish species, the distribution of invertebrate production, and the role of invertebrate drift. They found invertebrate diversity and production were both high, with the most intense production on snag habitat, in contrast to the sand benthic community in the main channel and the mud benthic community in backwater areas. Although standing stock biomass of benthic animals was low compared to snags, a high turnover rate of chironomid midge larvae resulted in fairly high production because of the large surface area of sand. The relative surface area of snag, mud, and sand habitats were 1:3:20. The snag habitat, about 4 percent of the area, contained about 54 percent of the invertebrate biomass for a section of river, but supported only 13 percent of the invertebrate production compared to 72 percent for the sand habitat. Even though total snag habitat surface area was less than that of the benthic habitats for a length of river, roughly 80 percent of the numbers and biomass of invertebrates found in the drift actually originated from snags.

Snags are clearly a physical feature of great importance to the trophic dynamics in southern rivers. Several species of Centrarchidae are the major game fish in the Satilla, and most of them (particularly bluegill and redbreast sunfishes) depend upon snags as their major source of invertebrate food. On the other hand, Benke et al. (1979) found insects from sand benthic communities (mostly very small midges) were the major source of food for small forage fishes and large suckers. Forage fishes were the major food item for the piscivorous fishes.

INTERACTIONS OF FLUVIAL PROCESSES AND VEGETATION

Floated large organic debris has both positive and negative effects on live vegetation. Debris carried by flood flows can severely batter living plants on the flood plain, though this is generally restricted to a narrow belt closest to the channel. Stabilized, down, large debris provides protected sites where alder and other pioneering species may become established. Once established, living vegetation itself begins to stabilize geomorphic surfaces with developing root systems, and flow resistance of stems reduces water velocity and combs fine sediments and organics from flood waters. Swanson and Lienkaemper (1980) have observed downed trees protecting alder thickets on the exposed channel bars. Alder stems in bordering areas not protected by the down trees have been repeatedly and heavily pruned by floating organic debris and moving bedload sediment. The major downed trees protecting the thicket and trees in the thicket itself create a localized quiet-water environment where fine sediment and organics are deposited during high flows. This process coupled with litter production by the stand, accelerates soil development and growth of the stand. The large, down debris helps the stand reach a stage of structural development where it can better withstand most floods.

Snags lying in gravel bars also provide sites where transported hardwood species and shrubs can reroot and grow. Additionally many hardwoods will resprout after their arrival on a gravel bar.

The restabilization of streams following a major flood, debris torrent, or catastrophic erosional event is accelerated by large woody debris along and within the channel. Swanson and Lienkaemper (1978) document the inputs of snags to a stream following a wildfire. The aquatic habitat was maintained after fire by wood in the stream and the supply of large organic debris was provided by the snags of the pre-fire forest while the post-fire stand was developing. In many instances, present streamside salvage in areas where campgrounds or cabins are not a concern serves to destabilize the stream from an aquatic habitat and channel structure point of view. Fish habitat recovers more quickly with a continued supply of large merchantable trees.

HISTORICAL LOGGING PRACTICES AND STREAM INTEGRITY

In the eighteenth and nineteenth centuries, the only economical mode of transporting logs was via waterways. The Federal government claimed jurisdiction over navigation and set about to clear rivers and streams to allow steamboats, log rafts, barges, and other vessels to have unimpeded passage at most river stages.

Lumbermen regardless of their location in North America had a major problem in transporting logs to mills. Fortunately logs floated and in the gulf states problems with getting cypress to float were soon overcome. Lumbermen were largely responsible for having smaller streams declared navigable so that they could be kept free of dams, bridges, and other obstructions to log drives. Streams in north coastal California were not as intensively used for log transportation because of the size of the redwood trees and may be one of the rare lumber producing areas whose streams were not cleared for log navigation reasons.

Stream improvement for navigation began on big tributaries of the Mississippi River and the mainstem. Over 800,000 snags were pulled in a 50-year period along the lower 1,000 miles of river. These cottonwood and sycamore snags averaged 5 feet in diameter at the base and 2 feet at the top and had an average length of 120 feet. Huge drift dams of snags up to 5 miles long were common on most of the large rivers in south coastal, south central, southwest, north central, gulf coast, and west coast regions of the United States. Between 1878 and 1910 extensive projects by the U.S. Army Corps of Engineers worked to improve navigation on rivers. This time period was the same for all parts of the country.

Table 2 provides a conservative estimate of snags pulled from several rivers in virtually every corner of the United States. It provides a graphic description of the extent to which fish habitat in large rivers was dependent on large snags and how lumbering converted riparian forests to brush, and diverse and productive streams to navigable aquatic highways.

On the smaller tributaries which would not always float a log, streams were dammed. To get logs to the mill, a system of log dams was constructed to maintain ponds for holding logs and to provide a supply of water to move cut timber to mills downstream. The dams not only were barriers to fish migration but when opened ("splashed"), substrates were dug up, streambanks gouged, and streambeds scoured of gravel.

By the late 1880's, there were about 70 dams on the St. Croix River and its tributaries, 41 dams in the Menominee Valley, and some 25 dams on the 95-mile-long Red Cedar River in the Upper Mississippi (Rector 1949). Over 150 major dams existed in coastal Washington rivers (Wendler and Deschamps 1955), and over 160 splash dams were used on coastal and Columbia River tributaries in Oregon. These dams were just the major ones which were used for several seasons. Thousands of simple, light temporary dams were constructed and used for one or two seasons as logging progressed up the small tributaries.

The point of this history is that a great deal of the biological integrity of a majority of our woodland streams and rivers was lost by 1910. The biological communities of fish and invertebrates evolved with the structural habitat and geomorphic components provided by snags and large wood as well as food resources provided by trees. Once land reclamation, channelization, and stream cleanup was established, the biological integrity of aquatic systems declined rapidly. Accelerated sedimentation and habitat destruction from snag pulling increased temperatures, and altered food resources. Even the oldest of the oldtimers saw highly altered river systems.

Fish habitat was not a concern at the time when streams and rivers were being prepared for log transportation commerce. Table 3 provides a summary of relative size of stream and time frame for the major stream and river perturbations related to transportation and timber harvest. History records over 100 years of "diligent" stream and river cleanup. The rationale of the cleanups and snagging has shifted from creation of unimpeded navigation routes, to land drainage and flood protection, to protecting biological integrity and allowing fish passage. In the 1950's and 1960's, many streams in the Pacific Northwest were clogged with logging slash. Stream cleanup of this slash became a necessity for the fisheries resource in many streams. The problem has largely been corrected and recurrences are few because of current forest practices. Any current stream cleanup operations must consider the role large woody debris plays in maintaining fish habitat. The biological integrity of river systems cannot be maintained by using the navigation rationale of 140 years ago.

CURRENT STREAM RENOVATION AND RESTORATION OF BIOLOGICAL INTEGRITY

The bulk of channel work in urban areas and agriculture areas is done to improve storm-water drainage, and the most efficient channels have large cross sectional areas and low resistance to flow. To be effective, channel work must involve clearance of logjams, clearing of debris, and removal of natural channel constrictions that restrict flow. Channel and flood-plain resistance can be lowered by removing shrubs, saplings, and other permanent woody vegetation within the streambanks, and by eliminating the tangled undergrowth of vine and shrubs found along the flood plain immediately adjacent to streams. Nunnally (1978) and Keller and Hoffman (1976) recommend three guidelines for alluvial channel improvements: (1) do not straighten the channel and increase the slope; (2) promote bank stability by leaving as many trees as possible, minimizing channel reshaping, seeding grass in disturbed areas, and judicious placement of riprap; (3) emulate nature in designing channel form. Nunnally's guidelines have been incorporated by the Wildlife Management Institute (1980) in a brochure contracted by the Environmental Protection Agency and are used extensively by USDA Soil Conservation Service. The emphasis is on maintaining meanders and removal of obstructions, snags, and leaning trees. The drainage focus is on correcting stream-blockage problems, maintaining biological productivity, reducing flooding, providing natural drainage, and otherwise allowing the waterways to function normally. From a hydraulics point of view, water and sediments will pass downstream.

There is no question that allowing an alluvial stream to meander is important. But the biological integrity of these streams is not being maintained by removing obstructions and leaning trees. The "biological integrity" of streams developed with much less efficient channels, greater flood-plain flooding, and more channel obstructions and overhanging trees. Leaving stumps in place is not enough; whole trees plus root wads should be left in place.

Habitat structure is a strong determinant of biotic conditions in a stream. In the Pacific Northwest, lack of habitat diversity is a major problem. Pools lack structural complexity and are generally too few to provide low flow as well as high flow rearing habitat for salmonids. In an experiment where logs were removed from one side of a channel (in a stream in Illinois), Karr and Dudley (1981) observed fish biomass was 5 to 9 times higher in the areas with structurally complex habitats. Further, the larger fish, and especially the top predators, selected the structured habitat. The complex habitat seemed to provide two things: habitat for small fish including a diversity of substrates for food organisms, and hiding places (cover) from which large fish can prey on smaller species.

Snagging operations in lowland streams and small rivers removes the major food base for many fish species and results in a significant decline in fish production. It is unlikely that this food deficit will be replaced by invertebrates from other habitats, although some fishes might continue to do well in swamps and backwaters if these habitats are unaffected by the stream management. Benke et al. (1979) concluded that on the basis of food supply alone, complete snagging would reduce production of most major fish species in the Satilla River by at least 50 percent, but the effect probably would be much more for some species.

Such habitat structure if lost cannot be reestablished quickly unless the streamside trees are allowed to fall into streams and remain in place with root wads acting like grappling hooks.

Fishery biologists' perceptions of salmonid and other fishes migrational and rearing needs have changed little in over 100 years. We still take an anthropomorphic view of a fish's migrational needs, perceiving the need to maintain rivers totally free of barriers. The contradiction of requiring streamside vegetation zones yet removing blowdown or leaning trees which obstruct channel flow must be resolved. The historical situation and evolutionary development of natural stream systems occurred in the presence of an abundance of large woody debris. We have incorporated the meander into the planning process for alluvial streams. But, for mountain streams, the gradient has been evened from years of log drives, by sluiceouts from roads, and by zealous stream cleanup. The "biological integrity" of natural stream systems evolved in an inefficient channel with numerous obstructions. As a result, natural streams were rich in habitats and species and interacted intensively and dependently with their flood plain. It is time to "get back to nature" with management of fluvial ecosystems.

While we tend to ignore the influence of debris in the physical channel of large rivers, its role in forming and maintaining anadromous fish habitats is very important regardless of stream size. Large trees transported in the main channel of the Hoh maintain the very productive off-channel areas for invertebrates and fish. Without a continued supply of large debris, the productivity of off-channel areas would drop markedly.

Large trees or wood in streams do not have to dam a channel completely to have a major influence on fish habitat. The majority of debris constricting channels influences only one-third or less of the channel width. But even partial constrictions create diverse stream velocities, pocket pools, and cover, which result in stable and diverse fish habitat.

RECOMMENDATIONS AND CONCLUSIONS

Manage streamside vegetation zones to develop large trees which are allowed to fall into streams.

If blowdown occurs, it is often a benefit for fisheries and biological integrity of streams, not a disaster. Local bankcutting may occur but habitat diversity will increase.

State and Federal agencies presently emphasize removal of stream obstructions as the basis for stream and fisheries habitat improvement programs. The current emphasis cannot be justified in light of the evidence from natural and experimental streams.

All streams regardless of size have important fisheries components which are maintained and created by trees with attached root wads (snags).

The cost of adding complexity later exceeds the cost of leaving it now. For example, the cost to remove, buck, yard, and transport a merchantable log from a stream channel, and then replace the log with an artificial structure such as a gabion that will mitigate lost habitat complexity, exceeds the value of the log removed.

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[1]As defined by Strahler (1957), first-order streams are smallest streams with no tributaries; junctions of first-order stream segments mark the upstream end of a second-order stream segment; the junction of two second-order segments marks the head of a third-order segment, and so on.

Table 1--Physical characteristics of the major aquatic habitats in the South Fork of the Hoh River, Autumn 1978, adapted from Sedell et al. (1981)

Habitat type	Physical characteristics: Stability	Physical characteristics: Debris	Pool	Riffle
			Percent	Percent
Main river sites	Poor stability, winter and spring floods cause cutting and deposition.	Debris collected in small jams at cutting areas on bends in river, stabilizes banks and deflects flow.	20	80
Off-channel sites	Good stability except during extremely high main river flows.	Debris accumulations on main channel create and maintain most off-channel areas. Individual pieces offer fish cover.	70	30
Terrace Tribs sites	Very good stability low gradient, debris protected banks.	Individual pieces reduce cutting of banks and offer fish cover.	80	20
Lower Valley Wall Tribs.	Very good stability high gradient, boulder, and debris stabilized banks.	Individual pieces help stabilize banks and form some plunge pools.	40	60
Upper Valley Wall Tribs. sites	Excellent stability high gradient steep banks, boulder formed plunge pool and falls.	Large individual pieces offer some bank stability and with boulders form plunge pools and fish cover.	90	10

Table 2--Summary of snags pulled from rivers in the United States for navigation improvement from 1867 to 1912 (Secretary of War 1915). Most rivers in the United States lost significant amounts of fish habitat by the year 1910

Rivers by region	Period of snagging	Miles snagged	Snags removed	Streamside trees cut	Logs pulled	Drift piles removed
		SOUTHEAST REGION				
Pamunkey R., Va.	1880-1912	30	3,677	369	67	
North Landing R., N.C. and Va.	1879-1897	17	9,012	9	1,685	
Pamlico and Tar R., N.C.	1879-1912	49	29,260	7,625	728	
Contentnia Cr., N.C.	1881-1912	70	10,372	5,223	1,320	2
Black R., N.C.	1887-1912	70	11,685	785	6,789	30
Edisto R., S.C.	1882-1906	75	26,512	8,447	1,896	164
Savannah R. to Augusta, Ga.	1881-1912	248	37,812	1,167	9,766	
Oconee R., Ga.	1877-1912	99	44,840	16,480	1,742	
Noxubee R., Ala. and Miss.	1890-1901	69	143,700			13
Pearl R., Miss.	1879-1912	451	294,300			39
Tombigbee R., Miss.	1892-1912	481	286,220	243		1,076
Guyandot R., W. Va.	1890-1899	81	8,060			
Cumberland R., above Nashville, Tenn.	1879-1908	358	38,828	38,273		
Choctawhatchee R., Fla., and Ala.	1874-1912	212	177,599			
Oklawaha R., Fla.	1891-1911	62	9,089	1,080	984	
Caloosahatchee R., Fla.	1886-1911	22	7,874	6,860	1,192	
		CENTRAL REGION				
Grand R., Mich.	1905-1911	38	2,019			
Minnesota R., Minn.	1867-1912	240	13,740	13,613		
Red River, N.D. and Minn.	1877-1912	320	3,600	4,160	335	
Red Lake R., N.D. and Minn.	1877-1912	150	1,500			
Wabash R., Ill. and Ind.	1872-1906	48	7,700	154		109
Missouri R.	1879-1901	1,750	25,030	330		82
Arkansas R.	1879-1912	1,200	139,214	53,246		130
White R., Ark.	1880-1912	300	22,500	37,118		177
Cache R., Ark.	1888-1912	98	26,030	7,918		319
St. Francis and L'Anguille R., Ark.	1902-1912	220	6,700	21,800		115
		SOUTHWEST REGION				
Guadalupe R., Texas	1907-1912	52	70,583			
		WEST COAST REGION				
Sacramento R., Calif.	1886-1920	230	33,545			
Chehalis R., Wash.	1884-1910	15	4,838			2
Willamette R., Oreg., above Albany	1870-1880	55	5,362			10

Table 3. Major management activities affecting large organic debris in streams of the United States, 1868 to the present.

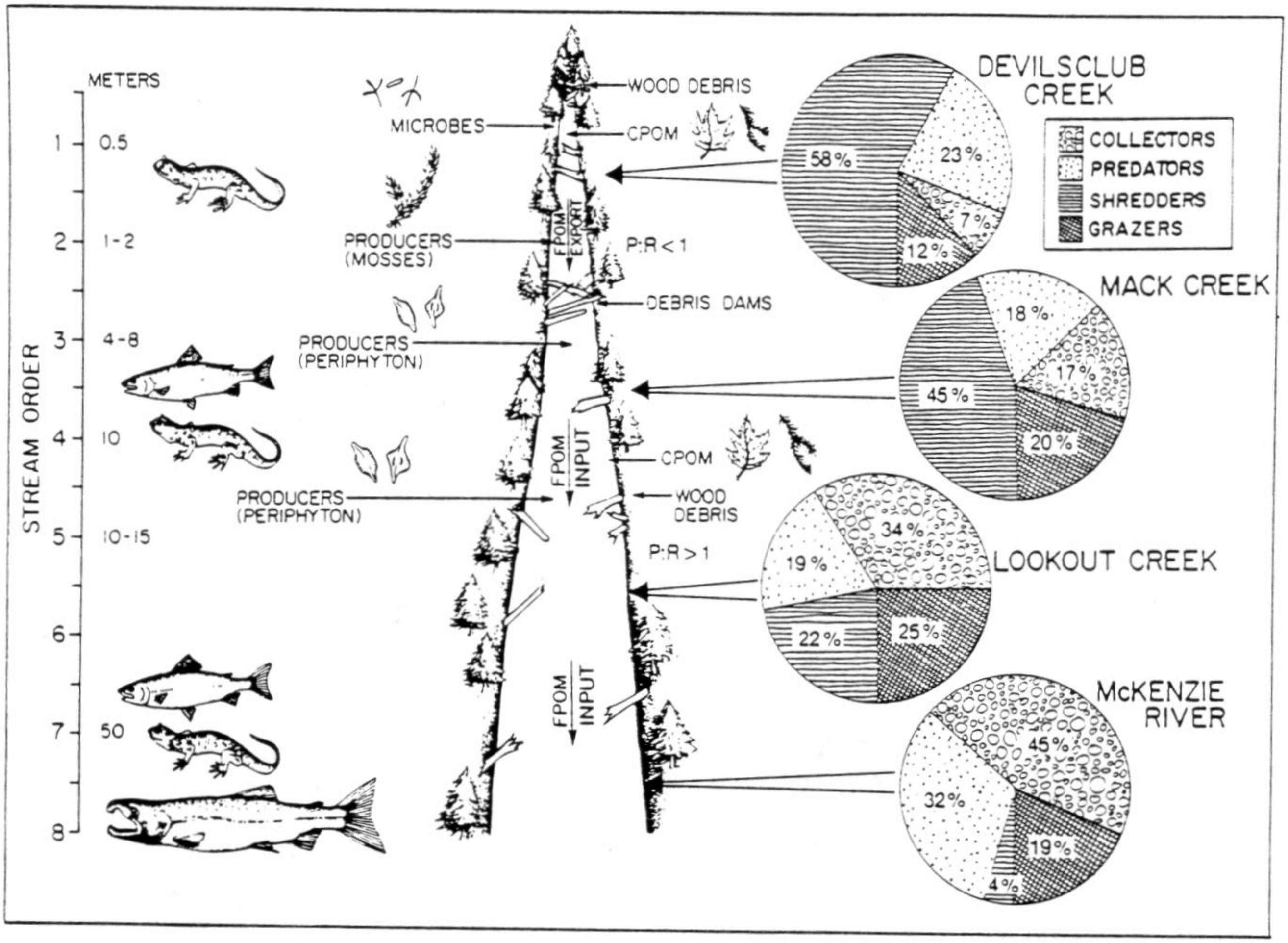
<table>
<tr><th rowspan="2">Time Period</th><th colspan="8">Stream Order Affected</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th></tr>
<tr><td>1868-1910</td><td></td><td colspan="3">Splash Dams</td><td colspan="4">Snagging for Navigation</td></tr>
<tr><td>1910 to Present</td><td></td><td></td><td></td><td></td><td colspan="4">Minor Snagging for Recreation, Commerce</td></tr>
<tr><td></td><td colspan="4">Sluicing from Clearcuts, Roads in Steeplands</td><td></td><td></td><td></td><td></td></tr>
<tr><td>1950 to Present</td><td colspan="4">Snagging, Brush Removal in Lowlands</td><td></td><td></td><td></td><td></td></tr>
</table>

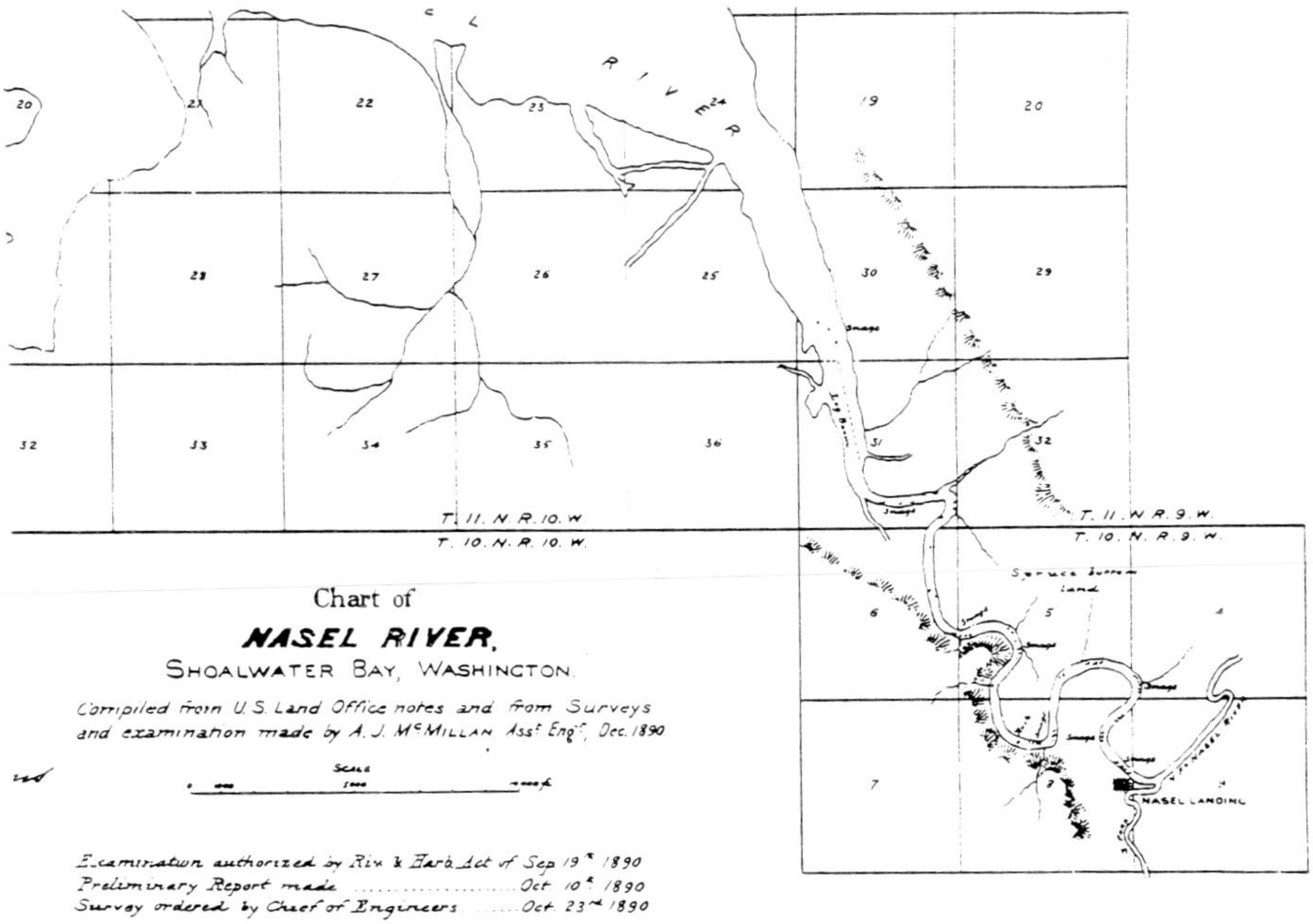
FIGURE CAPTIONS

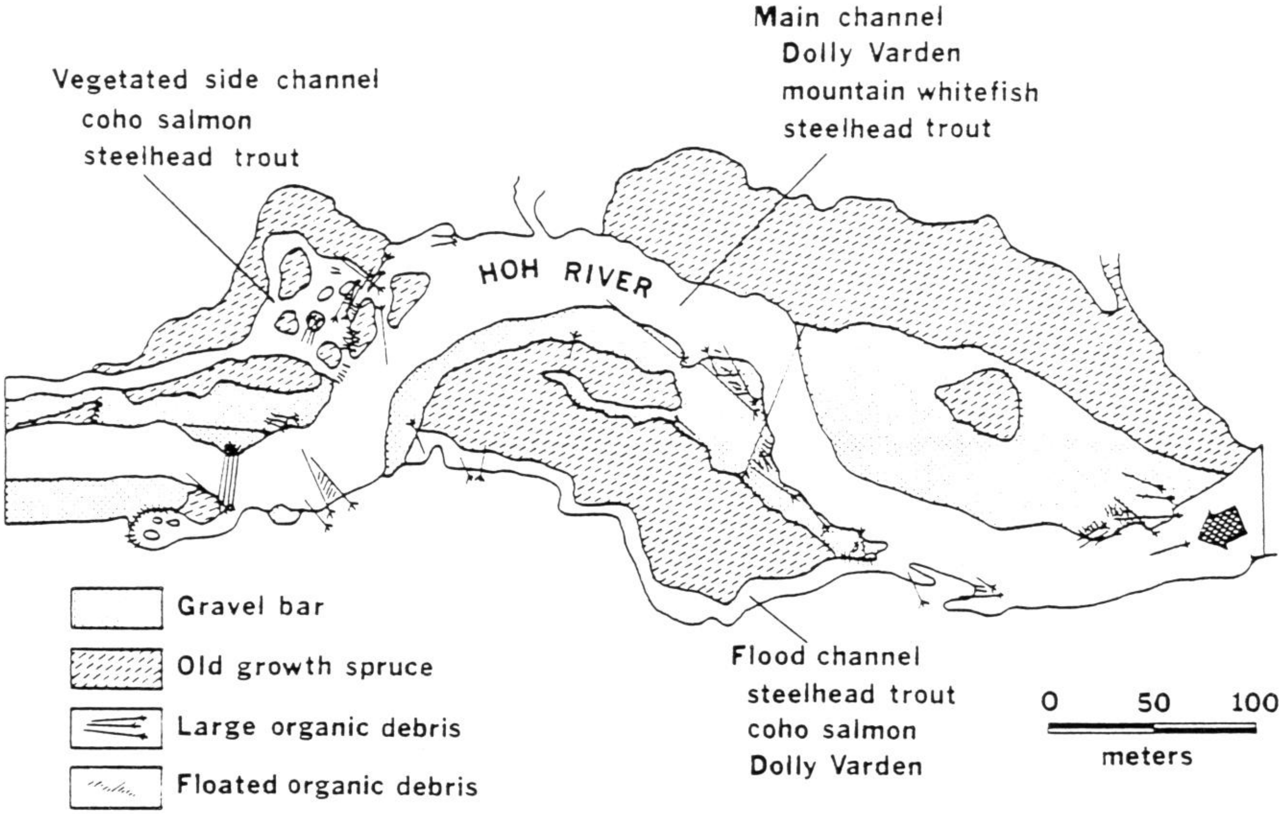
Figure 1.--Diagram of first- to eighth-order streams showing width (meters), dominant predators, producer groups, P:R (production:respiration) ratios, importance of wood, and proportion of invertebrate functional groups (adapted from Vannote et al. 1980). CPOM = coarse particulate organic matter; FPOM = fine particulate organic matter.

Figure 2.--Map of geomorphic surfaces, channel position, and large organic debris in a section of the South Fork Hoh River.

Figure 3.--Lower Nasel River, Washington, as mapped by the U.S. Army Corps of Engineers, 1891-92. Note location of snags is similar to that observed on undisturbed reaches of the Hoh River.


METERS
STREAM ORDER
1
2
3
4
5
6
7
8
0.5
1-2
4-8
10
10-15
50
WOOD DEBRIS
MICROBES
CPOM
PRODUCERS (MOSSES)
FPOM EXPORT
P:R < 1
DEBRIS DAMS
PRODUCERS (PERIPHYTON)
FPOM INPUT
CPOM
PRODUCERS (PERIPHYTON)
WOOD DEBRIS
P:R > 1
FPOM INPUT
DEVILSCLUB CREEK
58%
23%
7%
12%
COLLECTORS
PREDATORS
SHREDDERS
GRAZERS
MACK CREEK
18%
17%
45%
20%
LOOKOUT CREEK
34%
19%
22%
25%
McKENZIE RIVER
45%
32%
19%
4%


River
T. 11. N. R. 10. W.
T. 10. N. R. 10. W.
T. 11. N. R. 9. W.
T. 10. N. R. 9. W.
Spruce bottom land
Nasel Landing
Chart of
NASEL RIVER,
SHOALWATER BAY, WASHINGTON.
Compiled from U.S. Land Office notes and from Surveys
and examination made by A. J. McMillan Asst. Engr., Dec. 1890
Scale
Examination authorized by Riv & Harb Act of Sep 19th 1890
Preliminary Report made .... Oct 10th 1890
Survey ordered by Chief of Engineers ...... Oct 23rd 1890


Vegetated side channel
coho salmon
steelhead trout
Main channel
Dolly Varden
mountain whitefish
steelhead trout
HOH RIVER
Gravel bar
Old growth spruce
Large organic debris
Floated organic debris
Flood channel
steelhead trout
coho salmon
Dolly Varden
0 50 100
meters