

Table 1. Regional effects of hydrologic alteration on riverine fauna in the temperate world.

Taxa-Region	Effect of hydrologic alteration	Reference(s)
<b>Diadromous taxa</b>		
Salmonids (Pacific Coast, North America) <i>Oncorhynchus</i> , 7 spp. <sup>a</sup>	More than 214 native stocks at risk of extinction; more than 100 native stocks extirpated; 24 stocks presently protected under the Endangered Species Act (ESA); primary causes: inadequate dam passage, water diversions, and altered flows	Nehlsen et al. 1991
Atlantic salmon (Atlantic Coast, North America) <i>Salmo salar</i>	Extirpated from native range south of Maine (United States); migrations blocked by dams; remaining US anadromous populations proposed for ESA listing	Lee et al. 1980, Smith 1985
White sturgeon (Columbia River Basin, Pacific Northwest, North America) <i>Acipenser transmontanus</i>	Population fragmented by dams, reduced by flow and habitat alteration; landlocked Kootenai River population protected under the ESA	Miller et al. 1995
Sturgeons (Atlantic Coast and Gulf of Mexico, North America) <i>Acipenser oxyrinchus</i> , <i>Acipenser brevirostrum</i>	Extirpated from portions of native ranges, in part because dams block passage to spawning and summer habitat; <i>Acipenser oxyrinchus desotoi</i> and <i>Acipenser brevirostrum</i> protected under the ESA	Woolley and Croteau 1985, Jenkins and Burkhead 1994
Shads and herrings (Atlantic Coast and Gulf of Mexico, North America) <i>Alosa</i> , 5 spp. <sup>c</sup>	Extirpated from extensive portions of native freshwater ranges where dams impede upstream migrations	Regional references <sup>b</sup> , Lee et al. 1980
American eel (Atlantic Coast and Gulf of Mexico) <i>Anguilla rostrata</i>	Extirpated or reduced in upstream portions of river systems where dams impede upstream migrations	Regional references <sup>b</sup>
Freshwater shrimps (taxa abundant in streams of the Caribbean Islands and many mainland tropical streams) <i>Macrobrachium</i> , <i>Atya</i> , and <i>Xiphocaris</i> spp.	Native amphidromous shrimps eliminated from upstream reaches above large dams lacking spillways, and reduced in richness and abundance above large dams with spillways in Puerto Rico; high mortality of migratory larval shrimp traveling to estuaries as a result of water intakes associated with dams	Holmquist et al. 1998, Benstead et al. 1999
<b>Potamodromous taxa</b>		
Sturgeons (Eastern North America) <i>Acipenser fulvescens</i> , <i>Scaphirhynchus suttkusi</i> , <i>Scaphirhynchus platyrhynchus</i> , <i>Scaphirhynchus albus</i>	Extirpated or severely reduced in drainages with extensive mainstem impoundment; for example, Coosa River system ( <i>A. fulvescens</i> ), Tennessee River system ( <i>A. fulvescens</i> , <i>S. platyrhynchus</i> ), Mobile River system ( <i>Scaphirhynchus suttkusi</i> ), Mississippi and Missouri River systems ( <i>Scaphirhynchus albus</i> ; protected under the ESA)	Cross and Moss 1987, Pfeleger and Grace 1987, Etnier and Starnes 1993, Burke and Ramsey 1995, Mettee et al. 1996, Burkhead et al. 1997
Colorado River mainstem fishes (Western North America), for example, <i>Ptychocheilus lucius</i> , <i>Xyrauchen texanus</i> , <i>Gila cypha</i> , <i>Gila elegans</i>	Native ranges reduced, fragmented by mainstem impoundments; populations diminished by barriers to migrations, hydrologic alteration, loss of warm-water habitat, and predation by reservoir-tolerant non-native fishes; four species listed under the ESA	Minckley et al., 1991, Tyus 1991, Mueller 1995, Starnes 1995
Suckers (Eastern North America), for example, <i>Moostoma robustum</i> , <i>Cycleptus elongatus</i> , <i>Cycleptus meridionalis</i>	Extirpated or diminished in portions of native ranges; for example, <i>M. robustum</i> extirpated from approximately 80% of native range in south Atlantic slope rivers; <i>C. elongatus</i> populations diminished in Mississippi River Basin; <i>C. meridionalis</i> extirpated from portions of Mobile River basin	Robison and Buchanan 1988, Etnier and Starnes 1993, Burkhead et al. 1997
Lakesuckers (Western North America) <i>Chasmistes mueri</i> , <i>Chasmistes liorus</i> , <i>Chasmistes liorus mictus</i> , <i>Chasmistes brevis</i> , <i>Chasmistes culus</i> , <i>Delostes luxatus</i>	Dams and agricultural water diversions block spawning migrations from native lakes, and have facilitated hybridization with cooccurring sucker species. Two taxa extinct ( <i>Chasmistes mueri</i> , <i>Chasmistes liorus liorus</i> ); remaining four taxa listed under the ESA	Miller et al. 1989, Scopettone and Vinyard 1991
Coporo (abundant in major river basins of South America) <i>Prochilodus</i> and <i>Semaprochilodus</i> spp.	Diminished migratory runs in western Venezuela and Columbia; causes attributed to dams and deforestation	Caia 1995, Duque et al. 1998
Amazon River Dolphin (occurs in Amazon and Orinoco river systems from headwaters to oceans in South America) <i>Inia geoffrensis</i> ; Gray Dolphin (occurs in both coastal areas, large rivers, and their tributaries in South America) <i>Sotalia fluviatilis</i>	Dams disrupt migrations and fragment populations into genetically isolated sub-populations; affect food source by severing migrations of fish prey; stranding in drying pools	Perrin et al. 1989, Carpinio 1994, Reeves and Leatherwood 1994
<b>Small-bodied obligate riverine taxa</b>		
Minnows, darters, and madtom catfishes (Southeast United States) Cyprinidae, Percidae, Ictaluridae, more than 320 spp. total	Approximately 20% of species imperiled; ranges fragmented, mainstem populations extirpated from impounded reaches, for example, at least 17 species in eight genera extirpated or isolated in tributaries in the Tennessee River (containing 57 dams), including seven species protected under the ESA	Williams et al. 1989, Etnier and Starnes 1993, Walsh et al. 1995

Taxa-Region	Effect of hydrologic alteration	Reference(s)
<b>Small-bodied obligate riverine taxa (continued)</b>		
Prairie fishes (Central North America), for example, <i>Macrhybopsis aestivalis</i> , <i>Macrhybopsis meeki</i> , <i>Macrhybopsis geyeri</i> , <i>Platygobio gracilis</i> , <i>Notropis potteri</i> , <i>Notropis girardi</i> , <i>Notropis bairdi</i> , <i>Hypognathus placitus</i> , <i>Funaulus zebrius</i>	Drastically reduced abundances of many formerly widespread species adapted to turbid, fluctuating flow regimes characteristic of plains streams; large reservoirs and flow diversions have reduced turbidity and dampened seasonal flow variation; more than 75% reduction in range of two cyprinid taxa dependent on high flows for successful reproduction. Channelization, levees, and flood control have eliminated productive backwater habitats; at least 16 lower Missouri River fishes considered imperiled	Cross and Moss 1987, Pfeleger and Grace 1987, Hesse et al. 1993, Echelle et al. 1995, Galat et al. 1998
Freshwater snails (Mobile River basin, southeast United States) Gastropoda, 118 spp.	Mainstem, shoal-dwelling populations decimated by 33 impoundments; at least 38 endemic species and four genera presumed extinct; one species protected under the ESA; extant species surviving in isolated tributary and tailwater populations	Bogan et al. 1995, Lydeard and Mayden 1995, Neves et al. 1997
Freshwater mussels (North America) Unionidae and Margaritiferidae	Over 71% of 297 native taxa imperiled. Local assemblages decimated by impoundment of river shoals and adverse conditions in tailwaters; for example, 36 extinct or imperiled species in the Cumberland River system (11 dams); 63 extinct, extirpated, or imperiled species in the Tennessee River (nine mainstem dams)	Williams et al. 1993, Layzer et al. 1993, Neves et al. 1997
<b>Flood-dependent taxa</b>		
Fishes dependent on floods or flooded habitats for reproduction (North America)	Reduced abundances where flood control or levees restrict availability of inundated floodplain habitats (e.g., for <i>Ictiobus</i> spp., <i>Carpoides</i> spp.), or eliminate high flows necessary to initiate spawning and suspend eggs (e.g., for <i>N. girardi</i> , <i>M. aestivalis</i> in prairie streams).	Cross and Moss 1987, Baker et al. 1991, Etnier and Starnes 1993, Echelle et al. 1995, Galat et al. 1998
Main channel riverine fishes that periodically exploit flooded habitats (North America)	Potentially substantial reductions in population abundances and secondary productivity as a result of decreased floodplain and side-channel inundation; for example, more than 80% of main channel fishes in the lower Mississippi River and Apalachicola River, southeast United States, exploit floodplain habitats	Gullory 1979, Baker et al. 1991, Light et al. 1995
Euryhaline fishes (Sacramento-San Joaquin Delta, California), for example, <i>Hypomesus transpacificus</i> , <i>Pogonichthys macrolepidotus</i>	Declining abundances as a result of water diversions that reduce freshwater inflows and degrade tidal freshwater and brackish estuarine habitats; two fishes protected under the ESA	California Department of Fish and Game 1992, Moyle et al. 1992
<b>Exotic and lentic-adapted species</b>		
Reservoir-tolerant fishes (North America), for example, Ictaluridae Centrarchidae, <i>Cyprinus carpio</i>	Displacement of native faunas by exotic species introduced into reservoirs and tailwaters, and favored by altered flow and thermal regimes; dominance of tailwater fish assemblages by species with generalized habitat requirements, or tolerant of low dissolved oxygen or altered water quality	Li et al. 1987, Minckley and Meffe 1987, Minckley et al. 1991, Courtenay and Moyle 1992, Kinsolving and Bain 1993, Mueller 1995
Reservoir-tolerant fishes (South America) <i>Plagioscion squamosissimus</i>	Proliferation in reservoirs throughout Brazil; second or third most important fish species caught commercially in Itaipu Reservoir on the Brazil-Paraguay border	Petrere and Agostinho 1993, Agostinho et al. 1994, Paiva et al. 1994, Petrere 1996
Reservoir-tolerant fishes (South America) Piranhas, <i>Serrasalminus</i> spp.	Proliferation within reservoirs throughout Brazil that do not have fish bypass facilities	Branco and Rocha 1977, Bonetto and Castello 1985
Reservoir-tolerant fishes (South America) Nile tilapia, <i>Oreochromis niloticus</i>	Main fish caught in 10 years of records from 17 large reservoirs in northeastern Brazil; purposely introduced into reservoirs for commercial fishery; dominant fish taxon in Betania Reservoir, Columbia	Paiva et al. 1994, Caia 1995
Reservoir-tolerant mussel taxa (North America), for example, <i>Anodonta</i> spp., <i>Potamimus</i> spp., <i>Dreissina</i> spp.	Proliferation in impoundments, replacing native riverine fauna; spread of invasive exotics facilitated by navigational traffic through impounded waterways	Neves et al. 1997

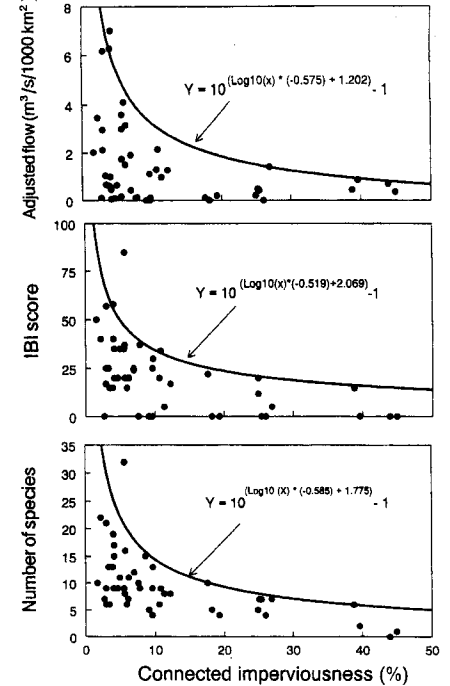


Figure 1. Plots between watershed percent connected imperviousness and number of fish species, IBI score, and base flow (m<sup>3</sup>/sec./1000 km<sup>2</sup> of watershed area). The models were developed by first log<sub>10</sub>-transforming the dependent variables, then performing 90% quantile regression on these semitransformed data to develop linear models, and finally back-transforming the linear models into nonlinear models using anti-logarithms. The coefficients of determination of the models, equivalent to r<sup>2</sup> in least square regression, are 0.40 for number of fish species, 0.42 for IBI score, and 0.26 for adjusted base flow.

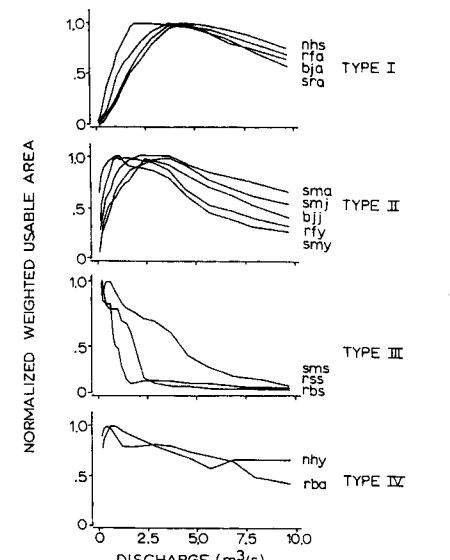


Figure 3. — Life stages of eight fish species in Dunlap Creek, Virginia, grouped by type of relation between normalized weighted usable area and discharge. The first two letters of each three-letter code indicate species: sm = smallmouth bass, rb = rock bass, rs = redbreast sunfish, ch = chubs, nh = northern hog sucker, rf = rosenfin shiner, sr = central stoneroller, bj = black jumprock. The last letter of each code indicates life stage: s = spawning, y = young of year, j = juvenile, a = adult.

<sup>a</sup> *Oncorhynchus tshawytscha*, *Oncorhynchus kisutch*, *Oncorhynchus nerka*, *Oncorhynchus keta*, *Oncorhynchus gorbuscha*, *Oncorhynchus mykiss*, *Oncorhynchus clarki*  
<sup>b</sup> Robison and Buchanan 1988, Etnier and Starnes 1993, Jenkins and Burkhead 1994, Mettee et al. 1996, Burkhead et al. 1997  
<sup>c</sup> *Alosa sappidissima*, *Alosa alabamae*, *Alosa chrysochloris*, *Alosa aestivalis*, *Alosa pseudoharengus*

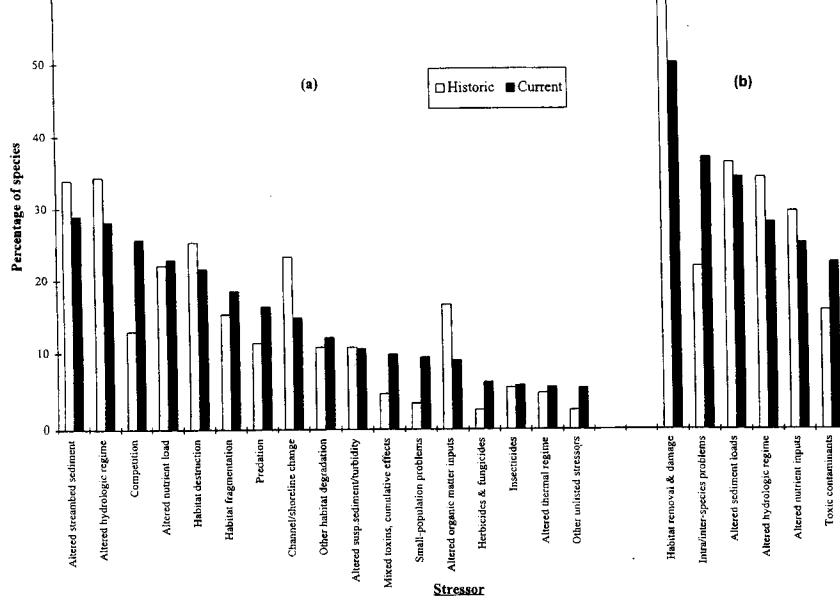


Figure 2. Stressors implicated for historic versus current conditions for all species evaluated: individual stressors (a) and grouped stressors (b). Only those stressors implicated for more than 5% of species under either historic or current conditions are shown.

Table 3. Proportions of ecological specialists and generalists extirpated from Virginia waters.

Attribute	Proportion of Specialists Extirpated*	Proportion of Generalists Extirpated
Physiography	1 province 0.217 (69)	>1 province 0.086 (128)
Flow	lotic only 0.152 (132)	lotic/lentic 0.092 (65)
Water Size	1 size 0.220 (59)	>1 size 0.094 (138)
Vertical Position	benthic 0.155 (103)	nonbenthic 0.106 (94)
Trophic Group	1 food type 0.148 (128)	>1 food type 0.101 (69)

\* Numbers in parentheses indicate the total species from which proportions were computed. Specialization is based on four habitat and one trophic attribute from Table 2.

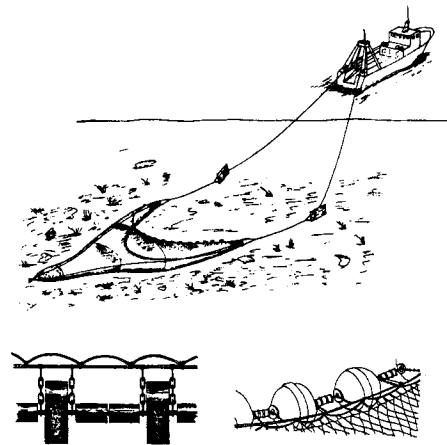


Figure 1. A modern bottom trawl shown in operation on the seabed (top); two types of roller gear applied to the ground rope of the net to aid in trawling over very rough bottom conditions (bottom) (reprinted with permission from Sainsbury 1996).

Table 23. General Environmental Flow Component hypotheses (The Nature Conservancy 2005) and their relevance to the Rivanna.

Environmental Flow Component	Ecosystem Influences	Likely to be Relevant in Rivanna?	Data available relevant to Rivanna?	Addressed in this Report?
Monthly low flows	Provide adequate habitat for aquatic organisms	Yes	Some	Yes
	Maintain suitable water temperatures, dissolved oxygen, and water chemistry	Yes	Some	Partially
	Maintain water table levels in floodplain, soil moisture for plants	Maybe	None	No
	Provide drinking water for terrestrial animals	Yes	None	No
	Keep fish and amphibian eggs suspended	Yes	Some	Partially
	Enable fish to move to feeding and spawning areas	Yes	Some	Yes
Extreme low flows	Support hyporheic organisms (living in saturated sediments)	Yes	None	No
	Enable recruitment of certain floodplain plant species	Yes	Some	No
	Purge invasive, introduced species from aquatic and riparian communities	Maybe	None	No
	Concentrate prey into limited areas to benefit predators	Yes	None	No
High flow pulses	Shape physical character of river channel, including pools, riffles	Yes	Some	Partially
	Determine size of streambed substrates (sand, gravel, cobble)	Yes	Some	Partially
	Prevent riparian vegetation from encroaching into channel	Yes	None	No
	Restore normal water quality conditions after prolonged low flows, flushing away waste products and pollutants	Yes	None	No
	Aerate eggs in spawning gravels, prevent siltation	Yes	Some	Partially
Small floods (applies to small and large floods)	Maintain suitable salinity conditions in estuaries	No	N/A	N/A
	Provide migration and spawning cues for fish	Yes	Some	Yes
	Trigger new phase in life cycle (i.e insects)	Maybe	None	No
	Enable fish to spawn in floodplain, provide nursery area for juvenile fish	No	N/A	N/A
	Provide new feeding opportunities for fish, waterfowl	No	N/A	N/A
	Recharge floodplain water table	Yes	None	No
	Maintain diversity in floodplain forest types through prolonged inundation (i.e. different plant species have different tolerances)	Maybe	None	No
Large floods (applies to small and large floods)	Control distribution and abundance of plants on floodplain	Yes	Some	Partially
	Deposit nutrients on floodplain	Yes	None	No
	Maintain balance of species in aquatic and riparian communities	Yes	Some	Partially
	Create sites for recruitment of colonizing plants	Yes	Some	Partially
	Shape physical habitats of floodplain	Yes	Some	No
	Deposit gravel and cobbles in spawning areas	Yes	None	No
	Flush organisms, materials (food), and woody debris (habitat structures) into channel	Yes	None	No
	Purge invasive, introduced species from aquatic and riparian communities	Maybe	None	Partially
	Disperse seeds and fruits of riparian plants	Yes	Some	Yes
	Drive lateral movement of river channel, forming new habitats (secondary channels, oxbow lakes)	Yes	Some	Partially
Provide plant seedlings with prolonged access to soil moisture	Yes	None	Partially	