Published in final edited form as:
Limnologica. 2021 March 1; 87: 125859. doi:10.1016/j.limno.2021.125859.

Sampling Efforts for Estimating Fish Species Richness in Western USA River Sites

Robert M. Hughes[a,b], **Alan T. Herlihy**[b], **David V. Peck**[c]

[a]Amnis Opes Institute, 2895 SE Glenn Street, Corvallis, Oregon, 97333, USA

[b]Department of Fisheries & Wildlife, 104 Nash Hall, Oregon State University, Corvallis, Oregon, 97331, USA

[c]United States Environmental Protection Agency, Office of Research and Development, Center for Public Health and Environmental Assessment, Pacific Ecological Systems Division, Western Ecology Division, 200 SW 35th Street, Corvallis, Oregon 97333, USA

Abstract

Fish species richness is an indicator of river ecological condition but it is particularly difficult to estimate in large unwadeable rapidly flowing rivers. Intensive multi-gear sampling is time consuming, logistically complex and expensive. However, insufficient sampling effort underestimates species richness and yields inaccurate data about the ecological condition of river sites. We raft-electrofished 10 river sites in 10 different ecoregions and six western USA states for distances equal to 300 times their mean wetted channel widths (MCWs) to estimate the effort needed to approach asymptotes in fish species richness. To collect 90% of the observed fish species at the sites, we found that an average of 150 MCWs (ranging 80–210 MCWs) were needed, with the number of MCWs increasing in rivers with a higher proportion of spatially rare species. Frequently, the second or third additional 100 MCWs produced only one or two additional singletons or doubletons (species occurring only once or twice at a site). Before initiating sampling programs for adequately estimating species richness, we recommend assessing sampling effort, particularly if rare or uncommon species are expected or desired.

Keywords

EMAP; rare species; biomonitoring; bioassessment

Introduction

Fish species richness has been a common indicator of river biological condition for many years (Karr, 1981; Simon, 1998; Whittier et al., 2007; Pont et al., 2009). Because observed species richness is at least partially determined by sampling effort, it is important to determine what constitutes sufficient sampling effort in research projects and for biomonitoring and bioassessment programs (Smith and Jones, 2005; Archdeacon et al. 2020). This is certainly true when the costs of additional sampling at a site must be balanced

Corresponding author: hughes.bob@amnisopes.com.

against needs for sampling more sites. Typically, when sampling rivers and streams, fish species richness rises quickly with the site distance sampled, but further distances produce declining numbers of new species (Lyons, 1992; Angermeier and Smogor, 1995; Paller, 1995; Patton et al., 2000; Reynolds et al., 2003; Dauwalter and Pert, 2003; Glowacki and Penczak, 2005; Terra et al., 2013). This pattern produces asymptotic species accumulation curves. Consequently, short site lengths greatly underestimate true species richness of sites, but long site lengths limit the number of sites that can be sampled in a study (Fritz et al., 2006; Flotemersch et al., 2011).

Site sampling distance has been considered sufficient by some researchers when 90–95% of the species observed or expected in a stream or river segment are collected (Angermeier and Smogor, 1995; Patton et al., 2000; Reynolds et al., 2003; Dauwalter and Pert, 2003). But accumulation curve shapes and differences in sufficient sampling distances are associated with several natural conditions. These include size of the river species pools (Cao et al., 2001), number of uncommon species (Paller, 1995; Kanno et al., 2009; Terra et al., 2013), patchy species distributions (Angermeier and Smogor, 1995; Paller, 1995; Kanno et al., 2009), fish abundances (Angermeier and Schlosser, 1989; Angermeier and Smogor, 1995; Glowacki and Penczak, 2005), habitat complexity (Angermeier and Smogor, 1995; Angermeier and Winston, 1998), and meta-community processes (Leibold et al., 2004; Brown et al., 2017). In addition, sufficient sampling distances are associated with site sampling decisions, such as sampling methodologies (Kimmel and Argent, 2006), gear types (Meador and McIntyre, 2003; Glowacki and Penczak, 2005), and survey objectives and crew training (Hughes and Peck, 2008). Nonetheless, standardized fishing methods are sorely needed to facilitate consistent data and study comparisons (Hughes and Peck, 2008; Bonar et al., 2009; Curry et al., 2009; USEPA, 2016a).

If survey objectives involve estimating species richness or non-native species across large regions (Lomnicky et al., 2007) or along entire riverscapes (Fausch et al., 2002), their designs must balance the effort spent at a site against the number of sites that can be sampled (Smith and Jones, 2005; Hughes and Peck, 2008; Smith and Jones, 2008; Fischer and Paukert, 2009; Archdeacon et al. 2020). Sampling too few sites underestimates regional or river species richness (Erõs, 2007; Leal et al., 2018; Casarim et al., 2020) whereas sampling too many sites needlessly increases survey costs (Hughes and Peck, 2008; Kanno et al., 2009). Smith and Jones (2005) determined that sampling 17–49 sites, each 30 mean channel widths (MCWs) long, produced 90% of the fish species in nine Michigan basins. Fischer and Paukert (2009) determined that longer site lengths lowered the number of sites needed to estimate segment richness of Great Plains streams. Nonetheless, sampling more shorter sites produced the same species richness with reduced total sampling effort.

Most sampling effort studies have focused on wadeable streams rather than boatable rivers. However, Gammon (1976) found that species richness in site lengths of 350–1500 m in the Wabash River, Indiana, did not reach an asymptote. With the goal of sampling one large river site per day, Hughes et al. (2002) determined that 85 MCWs were needed to produce 95% of the species collected from 100 MCW in 45 Oregon river sites via raft electrofishing. Wolter et al. (2004) recommended compositing data from multiple 400-m long sites into segment assessments because 400-m sites produced 95% of littoral-zone fish species in

German rivers. Dußling et al. (2004) composited data from 400-m macrohabitats into sites 40 MCWs long for German rivers, but they increased sampling if the number of individuals captured did not reach 30 times the expected number of species and at least 101 fish. LaVigne et al. (2008a) determined that 500 to 1000 m-long sites in the Willamette River, Oregon, produced half as many species as sites 50 MCWs (4–11 km) long. Erõs et al. (2008) determined that 50–75 sites (each 5–7.5 km; 8–25 MCWs) were necessary to produce 90% of the species richness produced in 125 sites in the Danube River, Hungary. Blocksom et al. (2009) found that 15 out of 19–32 sites, each 500-m long and sampled by night electrofishing, produced 90% of the species in seven Ohio River pools that were 58–153 km long. Hughes et al. (2012) reported that sampling 11–16 randomly selected sites, each 50 MCWs long and sampled by raft electrofishing along seven Washington and Oregon rivers, produced 90–95% of the fish species collected from 20 sites per river. Robinson et al. (2019) determined that boat electrofishing was markedly more effective than four fyke nets and ten concertina traps in 1-km long sites in the Murray-Darling River, Australia. Although shoreline electrofishing produces significantly more species, others have recommended the use of benthic trawls to collect deep water benthic species that are typically missing from electrofishing (Galat et al., 2005; Guy et al., 2009; Szalóky et al., 2014; Zajicek and Wolter, 2018). Dunn and Paukert (2020) determined that four complementary gears (electrofishing, seining, trawling, mini-fyke nets) produced 90% of the fish species with only 52% of the initial sampling effort employed at nine sites in six Missouri rivers. However, it is also important to consider meta-assemblage and riverscape effects on the distribution dynamics of fish presence and absence at a site, particularly the influences of tributaries, migration barriers, season and differing habitat complexity (Fausch et al., 2002; Hitt and Angermeier, 2008; Erős, 2017, Kaufmann et al. IN REVIEW).

In this study, we raft-electrofished 10 river sites in 10 different ecoregions and six western USA states for 300 MCWs to determine distances needed to reliably collect 90% of their observed fish species. We assessed two hypotheses. 1) Greater MCWs would be needed in the larger and more species-rich rivers than in the smaller relatively species-poor rivers. 2) More MCWs would be needed in sites with greater numbers of spatially rare species (singletons and doubletons).

Methods

Fish Sampling

We sampled 10 widely distributed river sites one time from 2001 to 2003 (Figure 1). The sites were selected as a sub-component of the USEPA’s Environmental Monitoring and Assessment Program, which was based on a probability site-selection process. We used the U.S. Geological Survey National Hydrography Dataset (NHD-Plus) as the sample frame from which sites were randomly selected. Site selection was balanced to ensure sites were chosen from each Strahler order and to ensure that they were allocated across each USA ecoregion (USEPA 2016b). This randomization and spatial balancing ensured that sites were representative of the rivers in each ecoregion, instead of biasing site selection by access convenience or degree of anthropogenic disturbance. On 10 occasions when 2 sites were relatively near each other on the same river, sampling was conducted continuously to achieve a 300 MCWs distance. Our 10 sites varied in mean channel width (25–160 m), thalweg depth (0.6–4.4 m), slope (0.03–1.2 %), turbidity (0.56–25.80 NTU), and conductivity (46–1190 µS) as one would expect from the wide variety of river types in the western USA (Table 1). Because of the range in site MCWs, the total length of the site electrofishing distances for 300 MCWs ranged from 7.5 to 48 km.

Before initiating fish sampling, we measured wetted channel widths with a range finder at five points and determined the MCWs of the sites. We then sampled 300 MCWs, which typically took 2–3 days, through use of raft electrofishing (Hughes and Peck, 2008). This method allowed us to fish very near the shores in shallow water as well as in turbulent white water rivers. In all but the fastest riffles or rapids, the oarsman was able to slow, reverse or maneuver the raft to retrieve stunned fish, if necessary. Also, in all but the Colorado and Sheyenne sites, water clarity allowed the crew to detect fish along the riverbed at depths of 1–2 m (Table 1). Our inflatable electrofishing raft was 3.7 m by 4.3 m and fitted with an aluminum rowing frame, frame-mounted generator and control box (Smith-Root model 2.5 GPP), live well, cathode arrays of aluminum pipe and steel cable along the sides of the raft, and two anodes of steel cable extending in front of the raft. The electrofishing raft was equipped with three safety switches (generator, control box, netter foot pedal). Unlike large electrofishing boats that employ 2 netters, fish were netted from the bow by a single netter (because of space limitations in the bow of the raft) as the oarsman rowed the raft downriver slightly faster than the river current. The netter was instructed to choose fish that were smaller and behaved differently when multiple species approached the anode to ensure that larger and more commonly occurring species were not the only fish netted. We used pulsed DC (30 or 60 pulses per second, 400–1,000 V) depending on river conductivity to attract fish but minimize injury. We laid out transects parallel with the river flow along the site every 10 MCW so there were 30 longitudinal transects in each site. After fishing one transect (or more often if fish in the live well showed signs of stress), the raft was tied to the shore and all netted fish were identified to species, counted and (except for voucher specimens) returned to the river alive. Unless river conditions or safety precluded it, we alternated river side after fishing one side for two longitudinal transects to minimize effects of differential shading (Hughes and Peck, 2008). Actual electrofishing (button) times were usually 1–2 h/d, which because of sample processing time and rowing to and from the site, required 18–24 h of total sampling time for each site. Voucher specimens of all smaller species were preserved in 10% buffered formalin and deposited at the Oregon State University Museum of Ichthyology; individuals exceeding our collection jar sizes were photographed. Collection permits were obtained from the U.S. Fish and Wildlife Service, National Marine Fisheries Service, Arizona Department of Fish and Game, Colorado Parks and Wildlife, Montana Department of Fish, Wildlife and Parks, North Dakota Game and Fish Department, Oregon Department of Fisheries and Wildlife, and Wyoming Game and Fish Department.

Environment Sampling

A two-person crew in a second inflatable raft measured conductivity with a Model HQ30D Hach multimeter at the beginning of each transect. This crew also collected environmental data including thalweg depths through use of a 7.5-m round fiberglass telescoping survey rod (Crain LR, Forestry Suppliers) every MCW while floating downriver. Channel slopes were determined from 1:24,000-scale topographic maps.

Data Analyses

Using the presence/absence data for species occurrence at each transect, we determined cumulative species richness curves versus the number of transects fished for each site by using Monte Carlo analysis. For each transect composite size, we performed 1000 simulations by randomly picking from the 30 transects sampled and calculated the mean composite fish species richness. For example, for a composite size of 8 transects, we randomly picked 8 of the 30 transects and then calculated species richness. We repeated this process 1000 times for each composite size and then calculated mean species richness for each transect composite size from 1–30. Thus, for a composite size of 30, the Monte Carlo mean is just the total richness for the entire site; for a composite size of 1, it is only the mean transect richness. We used a similar approach for calculating the Bootstrap and Jackknife species richness estimators with a copy of EstimateS software (Colwell, 1997).

Randomizing transect selection removed the potential bias of choosing an initial transect (Reynolds et al., 2003; Hughes and Herlihy, 2007). These results were plotted for each of the 10 river sites to facilitate determining the number of additional fish species typically obtained in each additional MCW of sampling. We also plotted the percent of total species richness observed against the number of transects sampled to determine the number of transects (MCWs) typically needed to reach 75% and 90% of the species collected in 300 MCWs of sampling.

Results

We collected a total of 82 fish species in our study, 62 of which occurred at only one or two sites (Appendix A). We believe that our raft electrofishing methodology was effective at collecting a wide variety of fish species because it produced large benthic taxa (*Acrocheilus, Ameiurus, Aplodinotus, Catostomus, Ictalurus, Lota, Prosopium, Pylodictis*) and small and cryptic benthic genera (*Cottus, Entosphenus, Etheostoma, Lampetra, Noturus, Percina, Percopsis, Platygobio, Rhinichthys*) as well as water column fishes. The number of species collected ranged from eight in the Clark Fork, North Platte and John Day sites to 25 in the Snake and 26 in the Sheyenne sites. The number of individuals collected per site ranged from to 268 (Clark Fork) to 12,535 (Yellowstone).

The most commonly occurring species (≥5 sites) were Common Carp *Cyprinus carpio*, Longnose Dace *Rhinichthys cataractae*, Rainbow Trout *Oncorhynchus mykiss*, Mountain Whitefish *Prosopium williamsoni*, and Smallmouth Bass *Micropterus dolomieu* (Table 2; Appendix A). The most abundantly collected species (>1000 individuals) across all study sites were Common Carp, Flathead Chub *Platygobio gracilis*, Mountain Sucker *Catostomus platyrhynchus*, Shorthead Redhorse *Moxostoma macrolepidotum*, and Smallmouth Bass (Appendix B). Only Flathead Chub, Longnose Dace, Mountain Sucker, Mountain Whitefish, and Shorthead Redhorse are native to all the sites in which they were collected. Lomnicky et al. (2007) also reported that non-native fish species were abundant and commonly occurred in large western USA rivers.

Results of the Monte Carlo analysis for the four least-speciose sites (Fig. 2) and the four most-speciose sites (Fig. 3) show the variability across the 1000 random simulations for each composite transect size. The interquartile range in the simulations for a particular composite size was typically 1–2 species throughout most of the MCWs, although the total range exceeded 10 species in the Sheyenne, the most speciose site. Variability, of course, does decrease towards zero as the composite sample size nears 30 (300 MCWs), which is the composite of the total sample.

Cumulative species accumulation curves using the mean of the 1000 simulations show the expected pattern of initial rapid increases in species richness followed by a leveling off at all sites as the number of transects increases (Fig. 4). Accumulation curves were also plotted with percent of total site richness on the y-axis (Fig. 5) to quantify when 75% and 90% of the species were captured. Capturing 75% of the species required an average of 69 MCWs (SD=31) across the 10 sites. On average, it required 150 MCWs (SD=42) to capture 90% of the species. Values ranged from 80–90 MCWs in the Colorado and North Platte sites to 200–210 MCWs in the John Day and Green sites (Table 3). The longer MCWs occurred because singletons or doubletons (species only collected in one or two of the 30 transects sampled in a site) were proportionally much more common in the John Day and Green versus the Colorado and North Platte sites. On the other hand, sites from which we collected <10 species (John Day, Green, Clark Fork, North Platte) required 90–210 MCWs versus 110–170 MCWs for sites in which we collected >20 species (Sheyenne, Snake, Yellowstone; Table 3). Similarly, sites from which we collected <500 individuals (Clark Fork, Verde) required 160–180 MCWs as opposed to 80–170 MCWs for sites where we collected >1000 individuals (Colorado, North Platte, Rogue, Snake, Yellowstone). Except for the John Day, Sheyenne and Snake, the Bootstrap and Jaccard2 estimated species richness was only one or 2 species greater than that which we observed. In other words, the proportion of spatially rare species had a greater effect on the number of MCWs needed to collect 90% of the species observed at a site than did the total number of species or individuals collected.

Discussion

Our results from western USA river sites ranging in widths of 25–160 m and containing at least 8–26 fish species indicate that 80–210 MCWs (2.8–12 km) or an average of 150 MCWs were needed for collecting 90% of the fish species collected at the sites via raft electrofishing (Table 3). We emphasize that these results may be restricted to the types of western USA rivers that we sampled (Figure 1; Table 1) as well as the electrofishing gear that we used. We also stress that our results are based only on the fish that we collected; additional gears and different habitat types could have produced additional species. Our conclusions may not be appropriate for much larger, deeper, more turbid, slower flowing, and more speciose systems. However, we have subsequently used the same gear and sampling approach in 341 western USA river sites, representing 38,000 river kilometers over the past 20 y as part of the USEPA’s Environmental Monitoring and Assessment Program (EMAP) and National Rivers and Streams Survey (NRSA) (Stoddard et al. 2005; USEPA 2016a; Herlihy et al. 2020).

EPA Author Manuscript

EPA Author Manuscript

The main driver of the number of MCWs needed to obtain 90% of observed fish species was the proportion of the species pool that was rare, in agreement with our second hypothesis. Rare in this case refers to spatially rare species, those found at only one or two of the 30 possible transects. A high proportion of rare species in a river or site makes it difficult to get over 90% of the species pool without sampling many MCWs or using additional gears (Zajicek and Wolter, 2018; Dunn and Paukert, 2020). The two sites that required 200 or more MCWs to obtain 90% of observed species had the highest proportion of rare species (John Day, 3/8; Green, 4/9). The two sites that required <100 MCWs to reach 90% of species (North Platte and Colorado) both had only one rare species out of a total pool of 8 or 10 (Table 3, Appendix A). Note that in species-poor sites (≤10 species), to get over 90% of the observed species required capturing all of them. Kanno et al. (2009) reported that removing singletons and doubletons markedly decreased the sampling effort needed to collect 90% of the fish species at a site. However, Leitao et al. (2016; 2018) reported that rare species contributed disproportionately to fish assemblage functional structure and tended to be more sensitive to multiple anthropogenic disturbances. Also, if collected at sufficient numbers of sites, native rare and sensitive fish species are excellent indicators of land cover change (Stranko et al., 2008), excess fine sediments (Bryce et al. 2010), climate warming (Isaac et al., 2018), and riparian vegetation loss (Dala-Corte et al., 2020).

Contrary to our first hypothesis, larger and more species-rich rivers did not require sampling a greater number of MCWs than did sampling smaller relatively species-poor rivers (Table 3). For example, the two largest rivers that we sampled (Snake, Yellowstone), with 25 and 21 species collected required 170 and 110 MCWs, respectively, and the smaller but speciose Sheyenne River (26 species) required 150 MCWs to collect 90% of the fish species. Although the Jackknife2 indicated that our observed species were three and five species fewer, respectively, than estimated for the Sheyenne and Snake. However, small rivers with <10 species collected required 90–210 MCWs (North Platte, Green). Clearly, another factor than site width and species richness drove the sampling effort needed to collect 90% of the observed fish species.

Many river sampling programs use fixed site lengths of 500 m. These lengths may suffice if multiple sites are used to assess entire river segments (Dußling et al., 2004; Wolter et al., 2004; Blocksom et al., 2009; Yoder et al., 2019) or entire riverscapes (Gammon et al., 1976; Hughes and Gammon, 1987; Pearson et al., 2011). But our results suggest that 500 m is insufficient for assessing single western USA sites with widths ranging from 25–160 m if one wants to collect 90% of expected fish species at a site. Those sites required 80–210 MCWs (3,200–27,200 m). In addition, if one wants to assess an entire river, LaVigne et al. (2008a) and Hughes et al. (2012) determined that 500 to 1000 m-long sites produced half as many species as 11–16 randomly selected sites 50 MCWs (4–11 km) long. Dußling et al. (2004) also recommended sampling until the number of individuals captured reached 30 times the expected number of species and at least 101 fish to ensure robust estimates of species richness and proportional metrics. In all cases but the Verde River, we collected many more than both those recommended numbers of individuals (Appendix B).

Although the actual time that the electrofisher was running was 1–2 h/d for each site, the total time spent at each site required 18–24 h. In other words, a crew spent 2–3 days to sample 300 MCWs depending on the river size and flow velocity, its channel complexity, site access and especially the number of fish netted and processed. Therefore, effectively electrofishing the average 150 MCWs needed for obtaining 90% of the species likely to be observed at one site would likely require 1–1.5 days. Based on the results of this sampling effort research, if the sampling objective is the assessment of an entire river 4–160 m wide, we recommend electrofishing 40–50 MCWs at 10–15 randomly selected sites (LaVigne et al., 2008a; 2008b; Hughes et al., 2012; Hughes et al. 2020). That level of sampling effort has allowed us to sample 2–3 sites per day—depending on the difficulty of accessing the sites, river size and flow velocity, channel complexity, and the number of fish collected.

Metrics that comprise a multimetric index (MMI) of condition or index of biotic integrity (IBI) are mostly either richness-based or based on a percentage of individuals (Hughes and Gammon, 1987; Lyons et al., 2001; Mebane et al., 2003; Pearson et al., 2011; Ruaro et al., 2020). The robustness of a percent of individual metric is related to the total number of individuals in the sample. A minimum total number of individuals can be stated as a sampling requirement and that number defined by the desired precision of the percent of individual metric. Likewise, the robustness of a species richness metric is a function of sampling effort and species richness and composition (especially the number of singletons and doubletons). It is not possible to define a minimum number of species to capture for a field protocol; therefore, having a method that robustly samples for richness is very important for assessing biotic condition. Sampling with enough effort so as to approach the asymptote of richness-effort curves helps ensure that sampling effort alone is not a major driver of measures of fish species richness across sites.

The sites that we sampled contained fewer fish species than other large rivers such as those in the central USA (Gammon, 1976; Lyons et al., 2001; Pearson et al., 2011; Dunn and Paukert, 2020), Europe (Eros et al., 2008; Trautwein et al., 2012; Zajicek and Wolter, 2018), or South America (Araujo et al., 2003; Leal et al., 2017; Leitão et al., 2018; Pompeu et al., 2019). Based on the species richness-sampling effort pattern shown in our results, and as recommended by Dußling et al. (2004), greater electrofishing distances are likely needed to produce 90% of the expected fish species expected at sites in such rivers. Our results are in agreement with Cao et al. (2007), who determined that species richness estimates based on rarefaction and statistical estimators produce biased results because of inadequate initial sampling effort and varying species occurrence patterns. Therefore, before initiating sampling programs for adequately estimating species richness, we strongly recommend assessing sampling effort—rather than picking some arbitrary site length--particularly if rare or uncommon species are expected or sought.

Acknowledgments

We thank the field crew members who collected the data (Jason Adams, Thomas Archdeacon, Trey Burns, Rob Curl, Jason Libby, Ariel Muldoon, Austin Stonebreaker, Ryan Touhy) and Randy Comeleo, who produced the map. This research was performed while ATH held a National Research Council Senior Research Associateship award at the USEPA Center for Public Health and Environmental Assessment, Pacific Ecological Systems Division, Corvallis, Oregon. This manuscript has been subjected to Agency review and has been approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. The views expressed in this paper are those of the authors and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency. We appreciate the constructive reviews of an earlier manuscript by Thomas Archdeacon, Joseph Flotemersch, Christian Wolter and two anonymous reviewers.

Appendix

Appendix A.

Alphabetical list of fish species observed in the 10 western USA study sites. The numbers indicate the number of transects (30 possible) in which the species was observed.

Name	CLAR	COLO	GREE	JDAY	NOPL	ROGU	SHEY	SNAK	VERD	YELL
Banded Killifish *Fundulus diaphanus*								6		
Black bullhead *Ameiurus melas*				1						
Blacknose dace *Rhinichthys atratulus*							1			
Blackside darter *Percina maculata*							10			
Bluegill *Lepomis macrochirus*									1	
Bluehead Sucker *Catostomus discobolus*		6								
Bluntnose Minnow *Pimephales notatus*							2			
Bridgelip Sucker *Catostomus columbianus*				2				18		
Brook Trout *Salvelinus fontinalis*			2							
Brown Trout *Salmo trutta*		30	3		15					20
Burbot *Lota lota*										5
Channel Catfish *Ictalurus punctatus*				4			28	25	2	
Chinook Salmon *Oncorhynchus tshawytscha*						10				

Name	**CLAR**	**COLO**	**GREE**	**JDAY**	**NOPL**	**ROGU**	**SHEY**	**SNAK**	**VERD**	**YELL**
Chiselmouth *Acrocheilus alutaceus*								20		
Coastrange Sculpin *Cottus aleuticus*						3				
Coho Salmon *Oncorhynchus kisutch*						1				
Common Carp *Cyprinus carpio*				5	12		24	30	22	29
Common Shiner *Luxilus cornutus*							1			
Creek Chub *Semotilus atromaculatus*							2			
Cutthroat Trout *Oncorhynchus clarkii*	5		5		8					
Desert Sucker *Catostomus clarkii*									16	
Emerald Shiner *Notropis atherinoides*										12
Fathead Minnow *PImephales promelas*								18		5
Flannelmouth Sucker *Catostomus latipinnis*		8								
Flathead Catfish *Pylodictis olivaris*								3	12	
Flathead Chub *Platygobio gracilis*										25

Name	CLAR	COLO	GREE	JDAY	NOPL	ROGU	SHEY	SNAK	VERD	YELL
Freshwater Drum *Aplodinotus grunniens*							11			
Golden Redhorse *Moxostoma erythrurum*							30			
Golden Trout *Oncorhynchus aguabonita*					1					1
Goldeye *Hiodon alosoides*							19			20
Green Sunfish *Lepomis cyanellus*									3	4
Johnny Darter *Etheostoma nigrum*							3			
Klamath Smallscale Sucker *Catostomus rimiculus*						3				
Lake Chub *Couesius plumbeus*										2
Lake Trout *Salvelinus namaycush*			2							
Largemouth Bass *Micropterus salmoides*								12	16	3
Largescale Sucker *Catostomus macrocheilus*	20			22				29		
Leopard Dace *Rhinichthys falcatus*								1		
Longnose Dace *Rhinichthys cataractae*	4			12	17		4	6		25
Longnose Sucker *Catostomus catostomus*		30			17					12

Name	CLAR	COLO	GREE	JDAY	NOPL	ROGU	SHEY	SNAK	VERD	YELL
Mooneye *Hiodon tergisus*							2			
Mottled Sculpin *Cottus bairdii*		21	25			2				
Mountain Sucker *Catostomus platyrhynchus*			1					19		30
Mountain Whitefish *Prosopium williamsoni*	25	24	24					10		23
Northern Pike *Esox lucius*	1									
Northern Pikeminnow *Ptychocheilus oregonensis*	21			1				5		
Pacific Lamprey *Entosphenus tridentatus*						8				
Paiute Sculpin *Cottus beldingii*								1		
Peamouth *Mylocheilus caurinus*								9		
Prickly Sculpin *Cottus asper*						23				
Pumpkinseed *Lepomis gibbosus*								9		3
Quillback *Carpiodes cyprinus*							9			
Rainbow Trout *Oncorhynchus mykiss*	22	8	14		23	9				18
Razorback Sucker *Xyrauchen texanus*									2	
Red Shiner *Cyprinella lutrensis*									3	

Name	CLAR	COLO	GREE	JDAY	NOPL	ROGU	SHEY	SNAK	VERD	YELL
Redside Shiner *Richardsonius balteatus*	2					28		4		
Reticulate Sculpin *Cottus perplexus*						19				
Riffle Sculpin *Cottus gulosus*						17		1		
River Carpsucker *Carpiodes carpio*										4
River Redhorse *Moxostoma carinatum*							11			
Rock Bass *Ambloplites rupestris*							4			
Roundtail Chub *Gila robusta*		1							1	
Sand Shiner *Notropis stramineus*							3			
Sauger *Sander canadensis*							1			
Shorthead Redhorse *Moxostoma macrolepidotum*							24			30
Silver Redhorse *Moxostoma anisurum*							15			
Smallmouth Bass *Micropterus dolomieu*				30			9	29	28	
Sonora Sucker *Catostomus insignis*									18	

EPA Author Manuscript
EPA Author Manuscript

Name	**CLAR**	**COLO**	**GREE**	**JDAY**	**NOPL**	**ROGU**	**SHEY**	**SNAK**	**VERD**	**YELL**
Speckled Dace *Rhinichthys osculus*		29	1					1		
Spotfin Shiner *Cyprinella spiloptera*							21			
Stonecat *Noturus flavus*										18
Tadpole Madtom *Noturus gyrinus*								3		
Threespine Stickleback *Gasterosteus aculeatus*						7				
Torrent Sculpin *Cottus rhotheus*								2		
Trout-perch *Percopsis omiscomaycus*							5			
Umpqua Pikeminnow *Ptychocheilus umpquae*						28				
Walleye *Sander vitreus*							17			
Western Brook Lamprey *Lampetra richardsonii*						3				
White Bass *Morone chrysops*							17			
White Crappie *Pomoxis annularis*								2		
White Sucker *Catostomus commersonii*		27			23		12			30
Yellow perch *Perca flavescens*								4		

Appendix B.

Total number of individuals of each fish species caught in each of the 10 western USA study sites. Scientific names are in Appendix A.

Common Name	CLAR	COLO	GREE	JDAY	NOPL	ROGU	SHEY	SNAK	VERD	YELL
Banded Killifish								24		
Black bullhead				2						
Blacknose dace							3			
Blackside darter							15			
Bluegill									1	
Bluehead Sucker		6								
Bluntnose Minnow							2			
Bridgelip Sucker				2				105		
Brook Trout			2							
Brown Trout		198	3		19					37
Burbot										11
Channel Catfish				7			265	202	2	
Chinook Salmon						64				
Chiselmouth								101		
Coastrange Sculpin						9				
Coho Salmon						1				
Common Carp				8	31		69	792	74	499
Common Shiner							1			
Creek Chub							2			
Cutthroat Trout	10		5		16					

Common Name	**CLAR**	**COLO**	**GREE**	**JDAY**	**NOPL**	**ROGU**	**SHEY**	**SNAK**	**VERD**	**YELL**
Desert Sucker									31	
Emerald Shiner										105
Fathead Minnow								102		8
Flannelmouth Sucker		11								
Flathead Catfish								3	16	
Flathead Chub										8499
Freshwater Drum							17			
Golden Redhorse							111			
Golden Trout					1					1
Goldeye							32			80
Green Sunfish									3	4
Johnny Darter							4			
Klamath Smallscale Sucker						3				
Lake Chub										3
Lake Trout			2							
Largemouth Bass								36	37	7
Largescale Sucker	43			68				802		
Leopard Dace								1		
Longnose Dace	5			19	46		5	7		177
Longnose Sucker		144			150					28
Mooneye							3			

EPA Author Manuscript
EPA Author Manuscript

Common Name	CLAR	COLO	GREE	JDAY	NOPL	ROGU	SHEY	SNAK	VERD	YELL
Mottled Sculpin		136	219			3				
Mountain Sucker			1					195		1284
Mountain Whitefish	87	111	243					16		71
Northern Pike	1									
Northern Pikeminnow	65			1				9		
Pacific Lamprey						30				
Paiute Sculpin								5		
Peamouth								15		
Prickly Sculpin						258				
Pumpkinseed								14		4
Quillback							24			
Rainbow Trout	52	10	65		743	69				58
Razorback Sucker									3	
Red Shiner									5	
Redside Shiner	5					324		6		
Reticulate Sculpin						128				
Riffle Sculpin						45		1		
River Carpsucker										6
River Redhorse							20			
Rock Bass							6			
Roundtail Chub		3							1	

Common Name	CLAR	COLO	GREE	JDAY	NOPL	ROGU	SHEY	SNAK	VERD	YELL
Sand Shiner							4			
Sauger							1			
Shorthead Redhorse							87			1099
Silver Redhorse							18			
Smallmouth Bass				411			15	1803	98	
Sonora Sucker									61	
Speckled Dace		248	1					1		
Spotfin Shiner							73			
Stonecat										212
Tadpole Madtom								6		
Threespine Stickleback						28				
Torrent Sculpin								2		
Trout-perch							7			
Umpqua Pikeminnow						146				
Walleye							25			
Western Brook Lamprey						4				
White Bass							25			
White Crappie								2		
White Sucker		272			257		17			342
Yellow Perch								6		
Total Individuals per Site	268	1139	541	518	1263	1112	851	4256	332	12535

References

Angermeier PL, Schlosser IJ 1989. Species–area relationships for stream fishes. Ecology 70, 1450–1462.

Angermeier PL, Smogor RA 1995. Estimating number of species and relative abundances in stream fish communities: effects of sampling effort and discontinuous spatial distributions. Can. J. Fish. Aquat. Sci 52, 936–949.

Angermeier PL, Winston MR 1998. Local vs. regional influences on local diversity in stream fish communities of Virginia. Ecology 79, 911–922.

Araujo FG, Fichberg I, Pinto BCT, Peixoto MG 2003. A preliminary index of biotic integrity for monitoring the condition of the Rio Paraiba do Sul, southeast Brazil. Environ. Manage. 32, 516–526. [PubMed: 14986900]

Archdeacon TP, Reale JK, Gonzales EJ, Grant JD 2020. Effects of seining effort and site length on variability of small-bodied fish catch-rates in a sand-bed river. Riv. Resear. Appl Doi.org/10.1002/rra.3666.

Blocksom K, Emery E, Thomas J 2009. Sampling effort needed to estimate condition and species richness in the Ohio River, USA. Environ. Monitor. Assess 155, 157–167.

Bonar SA, Contreras-Balderas S, Isles AC 2009. An introduction to standardized sampling, in: Bonar SA, Hubert WA, Willis DW (Eds), Standard Methods for Sampling North American Freshwater Fishes, American Fisheries Society, Bethesda, Maryland, pp 1–12.

Brown BL Sokol ER, Skelton J, Tornwall B 2017. Making sense of metacommunities: dispelling the mythology of a metacommunity typology. Oecologia 183, 643–652. [PubMed: 28008474]

Bryce SA, Lomnicky GA, Kaufmann PR 2010. Protecting sediment-sensitive aquatic species in mountain streams through the application of biologically based streambed sediment criteria. J. N. Amer. Benthol. Soc 29, 657–672.

Cao Y, Hawkins CP, Larsen DP, Van Sickle J 2007. Effects of sample standardization on mean species detectabilities and estimates of relative differences in species richness. Amer. Natur 170, 381–395. [PubMed: 17879189]

Cao Y, Larsen DP, Hughes RM 2001. Evaluating sampling sufficiency in fish assemblage surveys: a similarity-based approach. Can. J. Fish. Aquat. Sci 58, 1782–1793.

Casarim R, Caldeira YM, Pompeu PS 2020. Representativeness of national parks in protecting freshwater biodiversity: a case of Brazilian savanna. Ecol. Freshwat. Fish DOI:10.1111/eff.12547.

Colwell RK 1997. EstimateS, version 5. Statistical estimation of species richness and shared species from samples.

Curry RA, Hughes RM, McMaster M, Zafft D 2009. Coldwater fish in rivers, in: Bonar S, Hubert W, Willis D (Eds.), Standard Methods for Sampling North American Freshwater Fishes, American Fisheries Society, pp. 139–158.

Dala-Corte RB, Melo AS, Siqueira T, Bini LM, Martins RT, Cunico AM, Pes AM, Magalhães ALB, Godoy BS, Leal CG, Monteiro-Júnior CS, Stenert C, Castro DMP, Macedo DR, Lima D, Gubiani EA, Massariol FC, Teresa FB, Becker FG, Souza FN, Valente-Neto F, de Souza FL, Salles FF, Brejão GL, Brito JG, Vitule JRS, Simião-Ferreira J, Dias-Silva K, Albuquerque L, Juen L, Maltchik L, Casatti L IN PRESS. Thresholds of freshwater biodiversity in response to riparian vegetation loss in the neotropical region. J. Appl. Ecol 57, 1391–1402.

Dauwalter DC, Pert EJ 2003. Electrofishing effort and fish species richness and relative abundance in Ozark Highland streams of Arkansas. N. Amer. J. Fish. Manage 23, 1152–1166.

Dunn CG, Paukert CP 2020. A flexible survey design for monitoring spatiotemporal fish richness in nonwadeable rivers: optimizing efficiency by integrating gears. Can. J. Fish. Aquat. Sci dx.doi.org/10.1139/cjfas-2019-0315.

Dußling U, Berg R, Klinger H,Wolter C 2004. Assessing the ecological status of river systems using fish assemblages, in: Steinberg C, Calmano W, Klapper H, Wilken R-D (Eds), Handbuch Angewandte Limnologie, VIII-7.4, 20. Erg.Lfg. 12/04, Ecomed, Landsberg am Lech, Germany, pp. 1–84.

Erõs T 2007. Partitioning the diversity of riverine fish: the roles of habitat types and non-native species. Freshwat. Biol 52, 1400–1415.

Erõs T, Tóth B, Sevcsik A, Schmera D 2008. Comparison of fish assemblage diversity in natural and artificial rip-rap habitats in the littoral zone of a large river (River Danube, Hungary). Internat. Rev. Hydrobiol 93, 88–105.

Fausch KD, Torgersen CE, Baxter CV, Li HW 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. BioSci. 52, 483–498.

Fischer JR, Paukert CP 2009. Effects of sampling effort, assemblage similarity, and habitat heterogeneity on estimates of species richness and relative abundance of stream fishes. Can. J. Fish. Aquat. Sci 66, 277–290.

Flotemersch JE, Stribling JB, Hughes RM, Reynolds L, Paul MJ, Wolter C 2011. Site length for biological assessment of boatable rivers. Riv. Resear. Appl 27, 520–535.

Fritz KM, Johnson BR, Walters DM 2006. Field Operations Manual for Assessing the Hydrologic Permanence and Ecological Condition of Headwater Streams. United States Environmental Protection Agency, Office of Research and Development, Washington, DC.

Galat DL, Berry CR, Gardner WM, Hendrickson JC, Mestl GE, Power GJ, Stone C, Winston MR 2005. Spatiotemporal patterns and changes in Missouri River fishes, in: Rinne JN, Hughes RM, Calamusso B (Eds.), Historical Changes in Large River Fish Assemblages of the Americas, American Fisheries Society Symposium 45, American Fisheries Society, Bethesda, Maryland, pp. 249–291.

Gammon JR 1976. The Fish Populations of the Middle 340 km of the Wabash River, Water Resources Research Center Technical Report 86, Purdue University: West Lafayette, Indiana.

Glowacki L, Penczak T 2005. Species richness estimators applied to fish in a small tropical river sampled by conventional methods and rotenone. Aquat. Liv. Resour 18:159–168.

Guy CS, Braaten PJ, Herzog DP, Pitlo J, Rogers RS 2009. Warmwater fish in rivers, in: Bonar SA, Hubert WA, Willis DW (Eds), Standard Methods for Sampling North American Freshwater Fishes, American Fisheries Society, Bethesda, Maryland, pp. 59–84.

Herlihy AT, Sifneos JC, Hughes RM, Peck DV, Mitchell RM 2020. Relation of lotic fish and benthic macroinvertebrate condition indices to environmental factors across the conterminous USA. Ecol. Indicat 112 (May):105958.

Hitt NP, Angermeier PL 2008. Evidence for fish dispersal from spatial analysis of stream network topology. J. N. Amer. Benthol. Soc 27, 304–320.

Hughes RM, Gammon JR 1987. Longitudinal changes in fish assemblages and water quality in the Willamette River, Oregon. Trans. Amer. Fish. Soc 116, 196–209.

Hughes RM, Herlihy AT 2007. Electrofishing distance needed to estimate consistent IBI scores in raftable Oregon rivers. Trans. Amer. Fish. Soc 136, 135–141.

Hughes RM, Peck DV 2008. Acquiring data for large aquatic resource surveys: the art of compromise among science, logistics, and reality. J. N. Amer. Benthol. Soc 27, 837–859.

Hughes RM, Boxall G, Herlihy AT, Adams J, Young DB 2020. A complete fisheries inventory of the Chulitna River Basin, Lake Clark National Park and Preserve, Alaska: example of a minimally disturbed basin. Trans. Amer. Fish. Soc 149, 14–26.

Hughes RM, Herlihy AT, Gerth WJ, Pan Y 2012. Estimating vertebrate, benthic macroinvertebrate and diatom taxa richness in raftable Pacific Northwest rivers for bioassessment purposes. Environ. Monitor. Assess 184, 3185–3198.

Hughes RM, Kaufmann PR, Herlihy AT, Intelmann SS, Corbett SC, Arbogast MC, Hjort RC 2002. Electrofishing distance needed to estimate fish species richness in raftable Oregon rivers. N. Amer. J. Fish. Manage 22, 1229–1240.

Isaak DJ, Luce CH, Horan DL, Chandler GL, Wollrab SP, Nagel DE 2018. Global warming of salmon and trout rivers in the northwestern U.S.: road to ruin or path through purgatory? Trans. Amer. Fish. Soc 147, 566–587.

Kanno Y, Vokoun JC, Dauwalter DC, Hughes RM, Herlihy AT, Maret TR, Patton TM 2009. Influence of rare species on electrofishing distance– species richness relationships at stream reaches. Trans. Amer. Fish. Soc 138, 1240–1251.

Karr JR 1981. Assessment of biotic integrity using fish communities. Fisheries 6(6), 21–27.

Kaufmann PR, Hughes RM, Paulsen SG, Peck DV, Seeliger C, Mitchell R In Review. Quantitative assessment of stream and river physical habitat condition. Ecol. Indic

Kimmel WG, Argent DG 2006. Efficacy of two-pass electrofishing employing multiple units to assess stream fish species richness. Fish. Resear 82, 14–18.

LaVigne HR, Hughes RM, Herlihy AT 2008b. Bioassessments to detect changes in Pacific Northwest river fish assemblages: a Malheur River case study. Northwest Sci. 82. 251–258.

LaVigne HR, Hughes RM, Wildman RC, Gregory SV, Herlihy AT 2008a. Summer distribution and species richness of non-native fishes in the mainstem Willamette River, Oregon, 1944–2006. Northwest Sci. 82, 83–93.

Leal CG, Barlow J, Gardner T, Hughes RM, Leitão RP, MacNally R, Kaufmann P, Ferraz SFB, Zuanon J, de Paula FR, Ferreira J, Thomson JR, Lennox GD,. Dary EP,. Röpke CP, Pompeu PS 2018. Is environmental legislation conserving tropical stream faunas? A large-scale assessment of local, riparian and catchment-scale influences on Amazonian fish. J. Appl. Ecol 55, 1312–1326. [PubMed: 32831394]

Leibold MA, Holyoak M, Mouquet N, Amarasekare P, Chase M, Hoppes MF, Holt RD, Shurin JB, Law SR, Tilman D, Loreau M, Gonzalez A 2004. The metacommunity concept: a framework for multi-scale community ecology. Ecol. Lett 7, 601–613.

Leitão RP, Zuanon J, Mouillot D, Leal CG, Hughes RM, Kaufmann PR, Villéger S, Pompeu PS, Kasper D, de Paula FR, Ferraz SFB, Gardner T 2018. Disentangling the pathways of land use impacts on the functional structure of fish assemblages in Amazon streams. Ecography 41, 219–232. [PubMed: 29910537]

Leitão RP, Zuanon J, Villéger S, Williams SE, Baraloto C, Fortunel C, Mendonça FP, Mouillot D 2016. Rare species contribute disproportionately to the functional structure of species assemblages. Proc. R. Soc. B 283, 20160084.

Lomnicky GA, Whittier TR, Hughes RM, Peck DV 2007. Distribution of nonnative aquatic vertebrates in western U.S. streams and rivers. N. Amer. J. Fish. Manage 27, 1082–1093.

Lyons J 1992. The length of stream to sample with a towed electrofishing unit when fish species richness is estimated. N. Amer. J. Fish. Manage 12, 198–203.

Lyons J, Piette RR, Niermeyer KW 2001. Development, validation, and application of a fish-based index of biotic integrity for Wisconsin's large warmwater rivers. Trans. Amer. Fish. Soc 130, 1077–1094.

Meador MR, McIntyre JP 2003. Effects of electrofishing gear type on spatial and temporal variability in fish community sampling. Trans. Amer. Fish. Soc 132, 700–716.

Mebane CA, Maret TR, Hughes RM 2003. An index of biological integrity (IBI) for Pacific Northwest rivers. Trans. Amer. Fish. Soc 132, 239–261.

Paller MH 1995. Relationships among number of fish species sampled, reach length surveyed, and sampling effort in South Carolina coastal plain streams. N. Amer. J. Fish. Manage 15, 110–120.

Patton TM, Hubert WA, Rahel FJ, Gerow KG 2000. Effort needed to estimate species richness in small streams on the Great Plains in Wyoming. N. Amer. J. Fish. Manage 20, 394–398.

Pearson MS, Angradi TR, Bolgrien DW, Jicha TM, Taylor DL, Moffett MF, Hill BH 2011. Multimetric fish indices for midcontinent (USA) great rivers. Trans. Amer. Fish. Soc 140, 1547–1564.

Pompeu PS, Leal CG, Carvalho DR, Junqueira NT, Castro MA, Hughes RM 2019. Effects of catchment land use on stream fish assemblages in the Brazilian savanna, in: Hughes RM Infante DM, Wang L, Chen K, Terra BF (Eds.), Advances in Understanding Landscape Influences on Freshwater Habitats and Biological Assemblages. American Fisheries Society, Symposium 90, Bethesda, Maryland, pp. 303–320.

Pont D, Hughes RM, Whittier TR, Schmutz S 2009. A predictive index of biotic integrity model for aquatic vertebrate assemblages of western U.S. streams. Trans. Amer. Fish. Soc. 138, 292–305.

Reynolds L, Herlihy AT, Kaufmann PR, Gregory SV, Hughes RM 2003. Electrofishing effort requirements for assessing species richness and biotic integrity in western Oregon streams. N. Amer. J. Fish. Manage. 23, 450–461.

Robinson WA, Lintermans M, Harris JH, Guarino F 2019. A landscape-scale electrofishing monitoring program can evaluate fish responses to climatic conditions in the Murray-Darling River system, Australia, in: Hughes RM, Infante DM, Wang L, Chen K, Terra BF, (Eds.), Advances in Understanding Landscape Influences on Freshwater Habitats and Biological Assemblages, American Fisheries Society, Symposium 90, Bethesda, Maryland, pp. 179–201.

Simon TP 1998. Assessing the Sustainability and Biological Integrity of Water Resources using Fish Communities. CRC Press, Boca Raton, Florida.

Smith KL, Jones ML 2005. Watershed-level sampling effort requirements for determining riverine fish species composition. Can. J. Fish. Aquat. Sci 62, 1580–1588.

Smith KL, Jones ML 2008. Allocation of sampling effort to optimize efficiency of watershed-level ichthyofaunal inventories. Trans. Amer. Fish. Soc 137, 1500–1506.

Stoddard JL, Peck DV, Paulsen SG, Van Sickle J, Hawkins CP, Herlihy AT, Hughes RM, Kaufmann PR, Larsen DP, Lomnicky G, Olsen AR, Peterson SA, Ringold PL, Whittier TR 2005. An ecological assessment of western streams and rivers. EPA 620/R-05/005, U.S. Environmental Protection Agency, Washington, DC.

Stranko S, Hilderbrand RH, Morgan II RP, Staley MW, Becker AJ, Roseberry-Lincoln A, Perry ES, Jacobson PT 2008. Brook trout declines with land cover and temperature changes in Maryland. N. Amer. J. Fish. Manage 28, 1223–1232.

Szalóky Z, György AI, Tóth B, Sevcsik A, Specziár A, Csányi B, Szekeres J, Erõs T 2014. Application of an electrified benthic frame trawl for sampling fish in a very large European river (the Danube River)—is offshore monitoring necessary? Fish. Resear 151, 12–19.

Terra BDF, Hughes RM, Araujo FG 2013. Sampling sufficiency for fish assemblage surveys of Atlantic Forest streams, southeastern Brazil. Fisheries 38, 150–158.

Trautwein C, Schinegger R, Schmutz S 2012. Cumulative effects of land use on fish metrics in different types of running waters in Austria. Aquat. Sci 74, 329–341. [PubMed: 25983526]

USEPA (U. S. Environmental Protection Agency). 2016a. National Rivers and Streams Assessment 2008–2009: a Collaborative Survey. EPA/841/R-16/007. Office of Water and Office of Research and Development, Washington, DC. http://www.epa.gov/national-aquatic-resource-surveys/nrsa

USEPA (United States Environmental Protection Agency), 2016b. National Rivers and Streams Assessment 2008–2009 technical report. EPA 841/R-16/008, Office of Water and Office of Research and Development, US Environmental Protection Agency, Washington, DC. . http://www.epa.gov/national-aquatic-resource-surveys/nrsa

Whittier TR, Hughes RM, Stoddard JL, Lomnicky GA, Peck DV, Herlihy AT 2007. A structured approach to developing indices of biotic integrity: three examples from western USA streams and rivers. Trans. Amer. Fish. Soc 136, 718–735.

Wolter C, Bischoff A, Faller M, Schomaker C, Wysujack K 2004. Sampling design and site selection in large rivers, in: Steinberg C, Calmano W, Klapper H, Wilken R-D (Eds), Handbuch Angewandte Limnologie, VIII-7.4, 20. Erg.Lfg. 12/04 Ecomed, Landsberg am Lech, Germany, pp. 38–57.

Yoder CO, Rankin ET, Gordon VL, Hersha LE, Boucher CE 2019. Degradation and recovery of the Scioto River (Ohio, USA) fish assemblage from presettlement to present-day conditions, in: Krueger CC, Taylor WW, Youn S (Eds), From Catastrophe to Recovery: Stories of Fishery Management Success, American Fisheries Society, Bethesda, Maryland, pp. 233–265.

Zajicek P Wolter C 2018. The gain of additional sampling methods for the fish-based assessment of large rivers. Fish. Resear 197, 15–24.

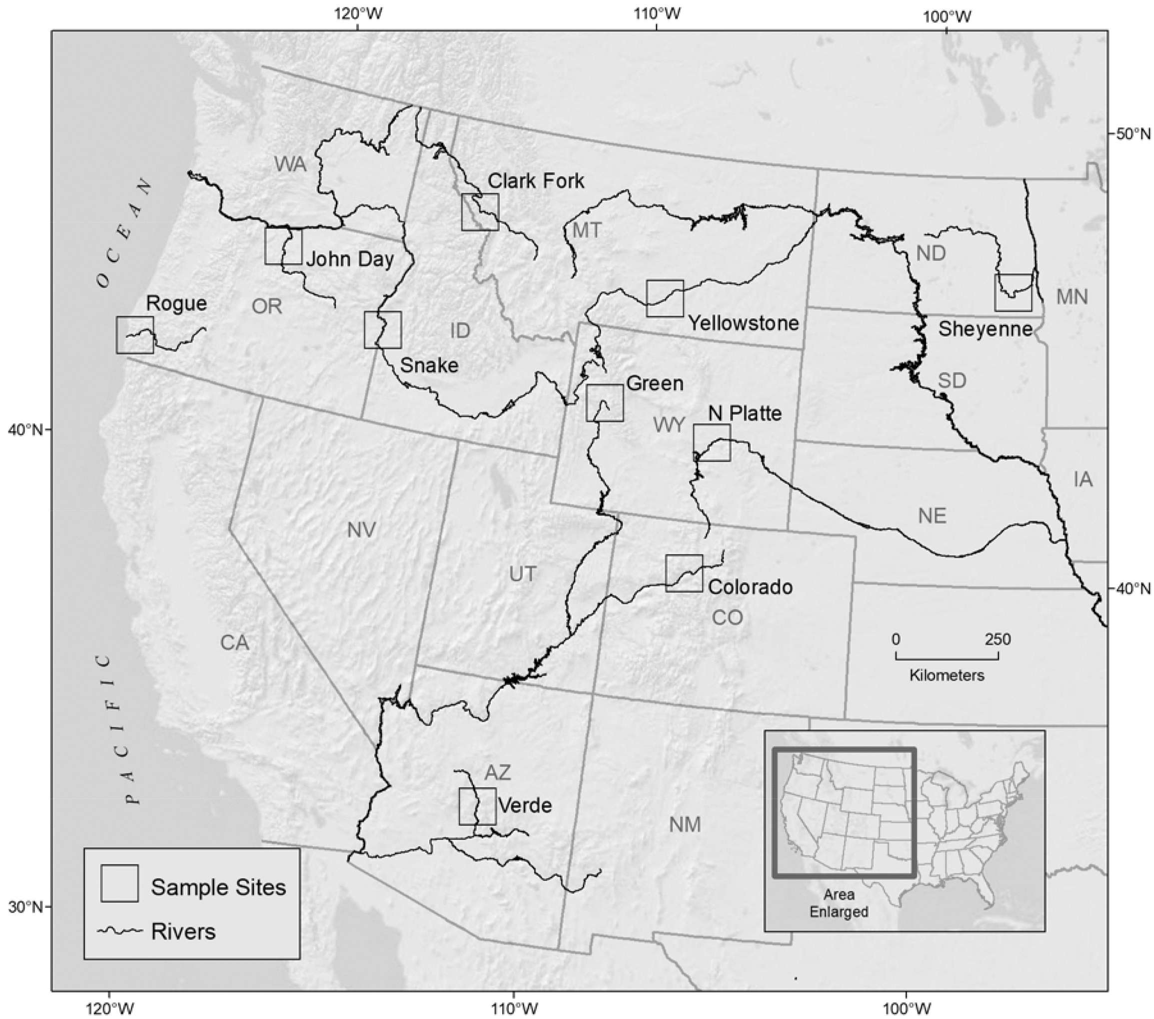

Figure 1.
Locations of the 10 large river sampling sites in the western USA.

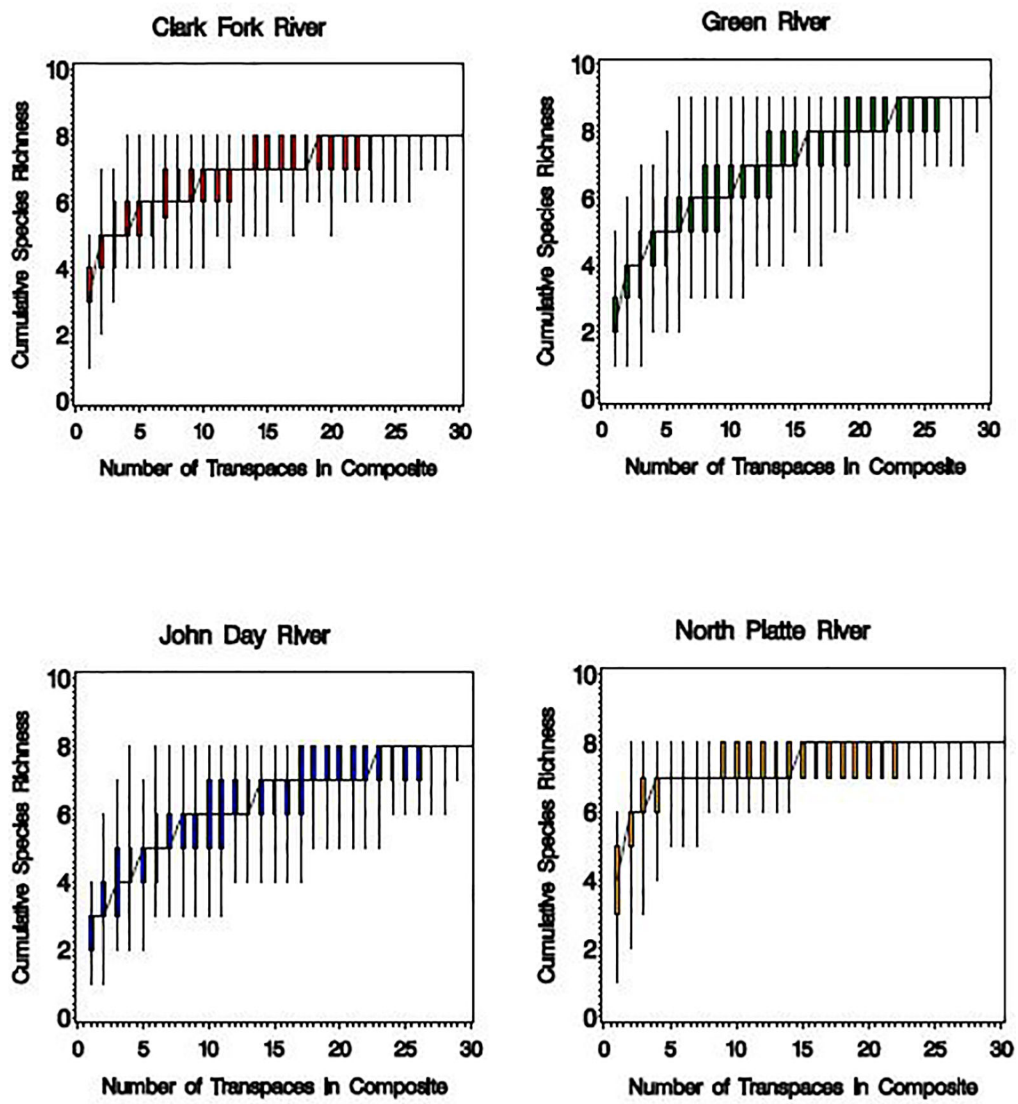

Figure 2.

Monte Carlo estimates (1000 simulations per composite) of cumulative fish species richness in species-poor sites (<10 species collected) as a function of the number of transects (transpaces) sampled. Ten transects equal 100 mean channel widths, which typically required one day of sampling. Boxes delimit interquartile ranges and whiskers are the ranges in the 1000 simulations for each composite; the line connects transect median values.

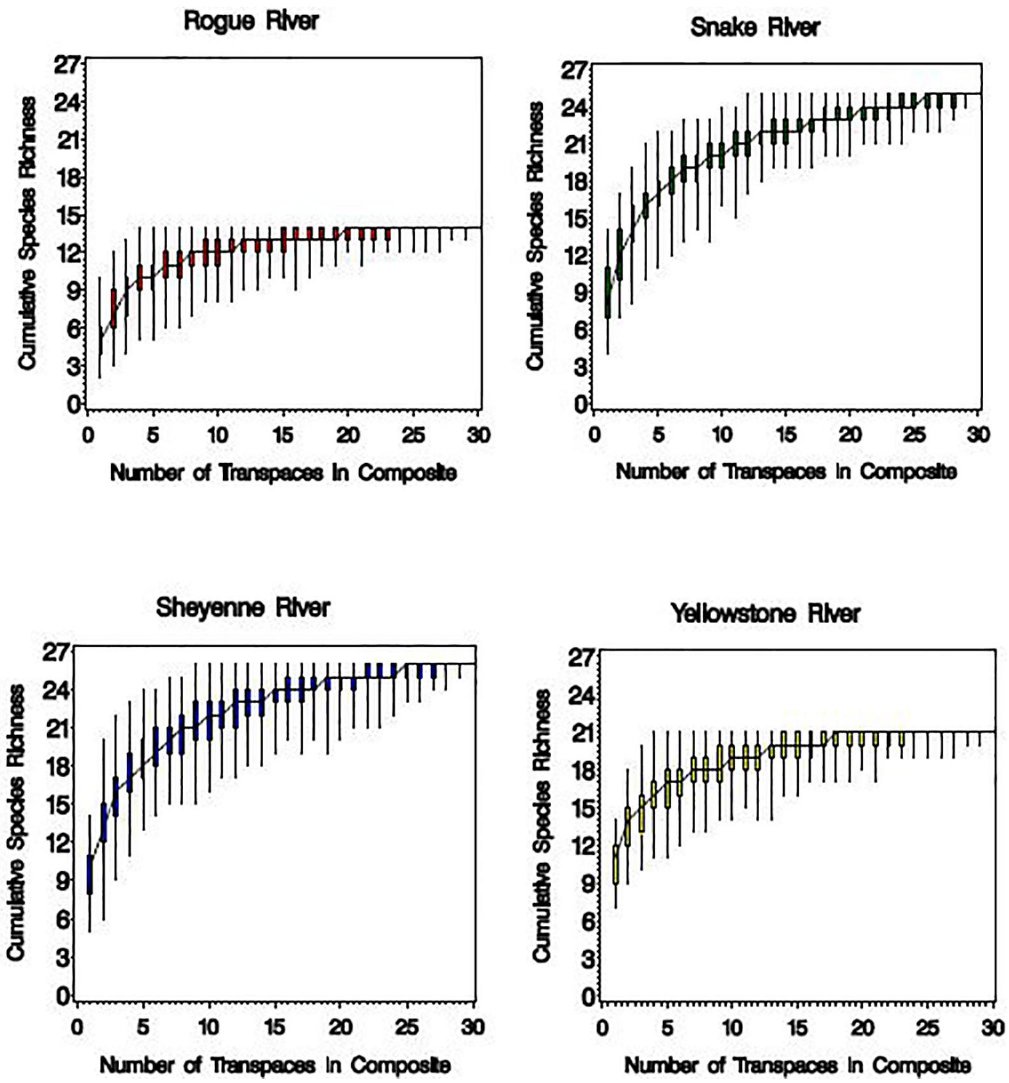

Figure 3.

Monte Carlo estimates (1000 simulations per composite) of cumulative fish species richness in the most species-rich sites (14–20 species collected) as a function of the number of transects (transpaces) sampled. Ten transects equal 100 mean channel widths, which typically required one day of sampling. Boxes delimit interquartile ranges and whiskers are the ranges in the 1000 simulations for each composite; the line connects transect median values.

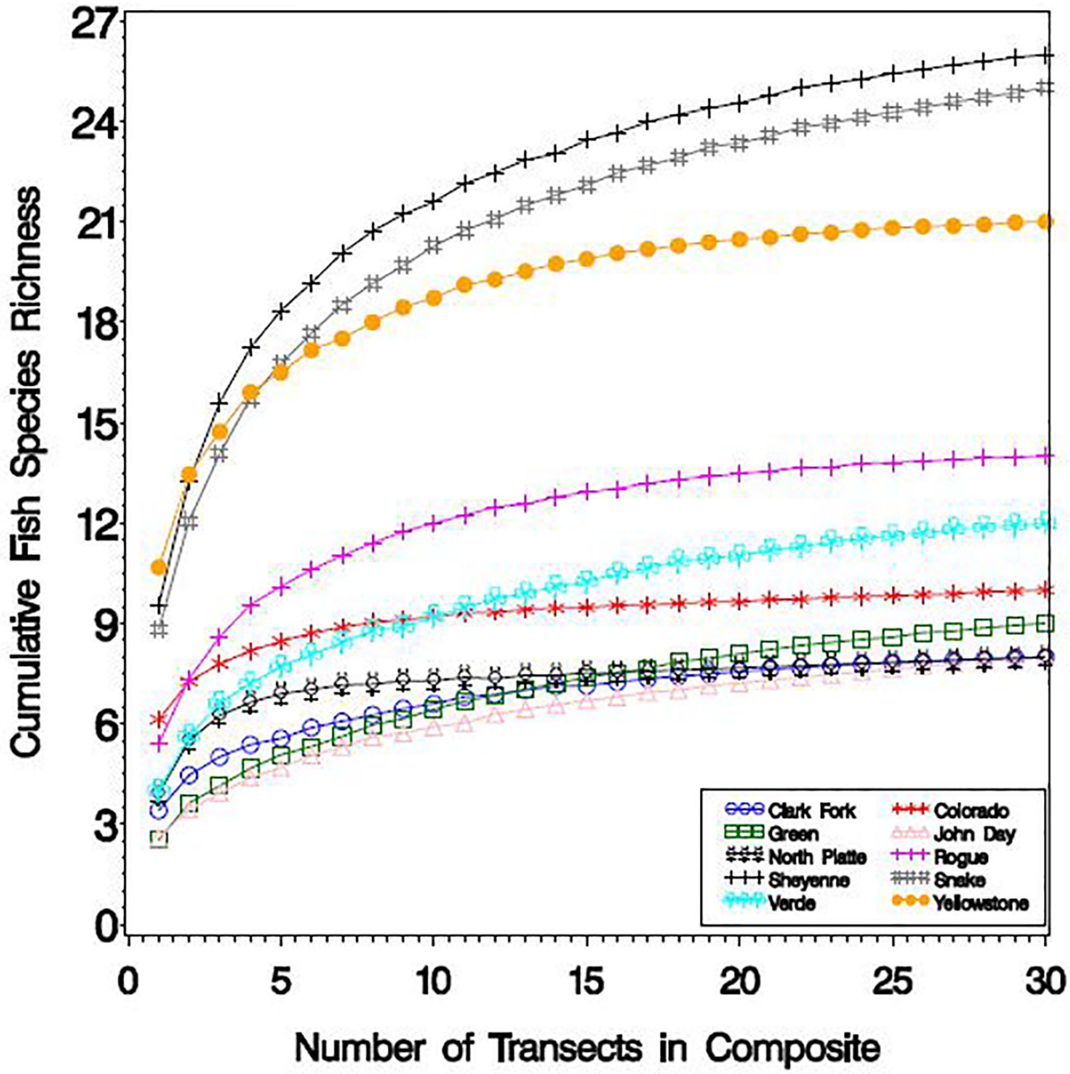

Figure 4.
Cumulative fish species richness versus number of transects in composite at 10 western USA river sites. Values are the means of 1000 random simulations for each composite size. Each transect is 10 MCW long.

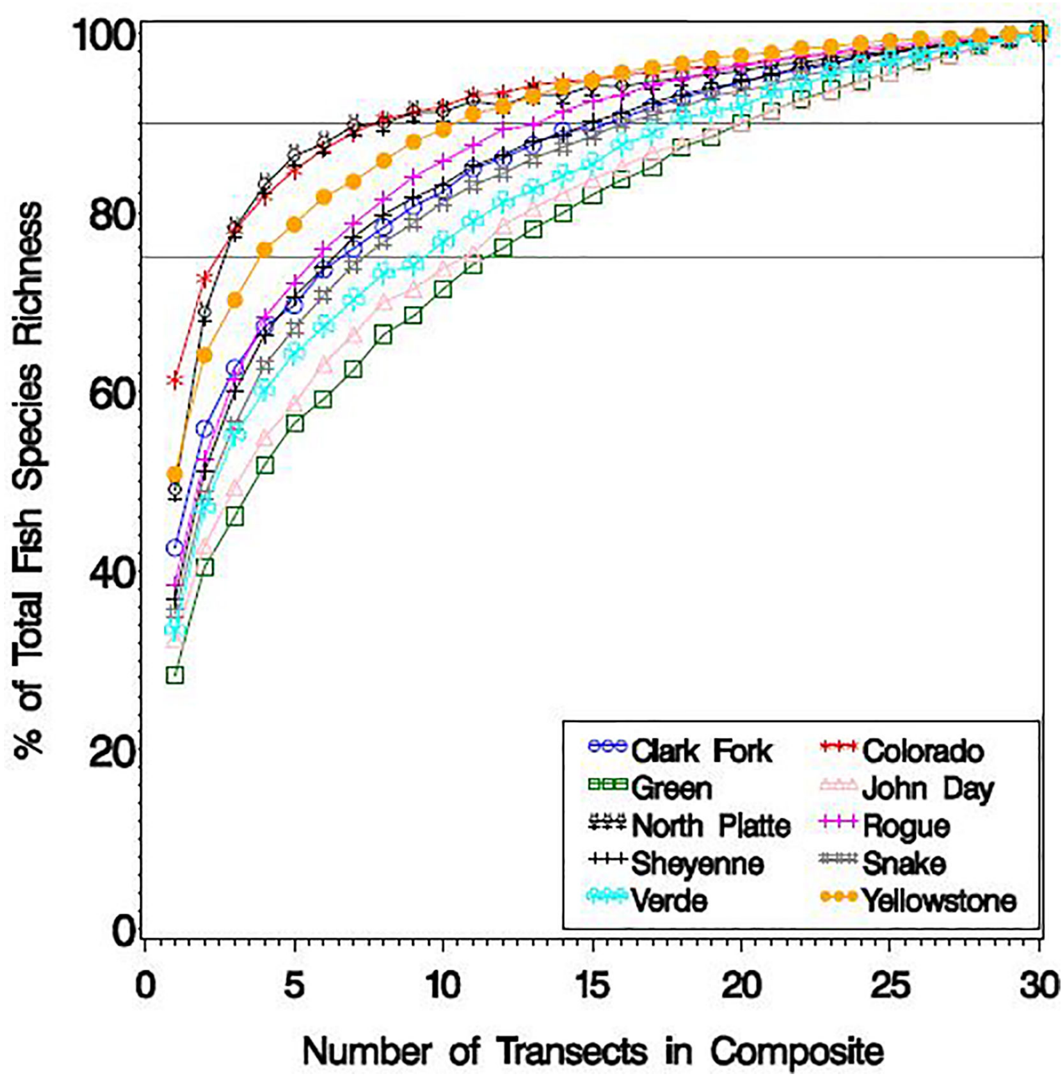

Figure 5.

Cumulative fish species richness expressed as a percent of total site fish species richness versus number of transects in composite at 10 western USA river sites. Values are the means of 1000 random simulations for each composite size. Each transect is 10 MCW long. Reference lines show 75% and 90% of total fish species richness.

Table 1.

Environmental characteristics of 10 western USA study rivers. See Figure 1 for locations.

River	Channel* width (m)	Mean Depth (m)	Conductivity (μS/cm)	Slope (%)	Turbidity (NTU)	Omernik Ecoregion
Clark Fork	65	4.42	227	0.52	0.56	N. Rockies
Colorado	40	1.38	382	1.0	24.4	S. Rockies
Green	60	1.29	46	0.28	0.63	M. Rockies
John Day	60	1.15	150	0.34	0.90	Col. Plateau
North Platte	75	1.09	536	0.70	2.11	WY Basin
Rogue	80	3.72	92	0.11	0.61	Klam. Mts.
Sheyenne	25	0.55	1190	0.03	25.8	N. Plains
Snake	160	1.98	542	0.52	NA	Snake Plains
Verde	40	1.14	633	0.63	5.37	AZ/NM Mts.
Yellowstone	100	1.43	386	1.2	4.80	NW Plains

*The initially determined channel width was used as the unit of sampling effort. Total site length sampled was 300 times that width.

Table 2.

Fish species observed in three or more of the 10 western USA study sites. The numbers in the table indicate the number of transects (30 possible) in which the species was present. See Figure 1 for full river names and locations and Appendix A for fish scientific names

Name	CLAR	COLO	GREE	JDAY	NOPL	ROGU	SHEY	SNAK	VERD	YELL
Common Carp				5	12		24	30	22	29
Longnose Dace	4			12	17		4	6		25
Rainbow Trout	22	8	14		23	9				18
Mountain Whitefish	25	24	24					10		23
Smallmouth Bass				30			9	29	28	
Brown Trout		30	3		15					20
Channel Catfish				4			28	25	2	
Cutthroat Trout	5		5		8					
Largemouth Bass								12	16	3
Largescale Sucker	20			22				29		
Mountain Sucker			1					19		30
Northern Pikeminnow	21			1				5		
Redside Shiner	2					28		4		
Speckled Dace		29	1					1		
White Sucker		27			23		12			30
Longnose Sucker		30			17					12
Mottled Sculpin		21	25			2				

Table 3.

Monte Carlo analysis of electrofishing distance to collect 75% and 90% of the total observed fish species richness in 10 western USA study sites.

River	Total Observed Richness	Estimated Total Richness#	Singleton & Doubleton Richness*	Mean Channel Widths Sampled to Collect:	
				75% of Species	90% of Species
Clark Fork	8	8.5–9.0	2	70	160
Colorado	10	10.4–11.9	1	30	80
Green	9	10.0–11.0	4	120	210
John Day	8	8.9–10.9	3	110	200
North Platte	8	8.4–9.9	1	30	90
Rogue	14	14.6–15.0	2	60	140
Sheyenne	26	27.6–29.0	6	70	150
Snake	25	26.8–30.8	6	80	170
Verde	12	13.1–14.0	4	100	180
Yellowstone	21	21.6–22.0	2	40	110

#Estimated richness as calculated using the bootstrap (lower estimate) and Jacknife2 (higher estimate) methods using EstimateS software (Colwell, 1997).

*Singletons and doubletons are those species only present in one or two, respectively, of the 30 transects sampled in each site.