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Assessing the Use of Existing Data to Compare Plains Fish Assemblages Collected from Random and Fixed Sites in Colorado

By Robert E. Zuellig and Harry J. Crockett

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Conversion Factors and Datum

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer (km)
millimeter (mm)	0.03937	inch

Horizontal coordinate information is North American Datum of 1983 (NAD 83)”

Initialisms Used in This Report

ANOSIM analysis of similarity

CPW Colorado Parks and Wildlife

Assessing the Use of Existing Data to Compare Plains Fish Assemblages Collected from Random and Fixed Sites in Colorado

By Robert E. Zuellig[1] and Harry J. Crockett[2]

Abstract

The U.S. Geological Survey, in cooperation with Colorado Parks and Wildlife, assessed the potential use of combining recently (2007 to 2010) and formerly (1992 to 1996) collected data to compare plains fish assemblages sampled from random and fixed sites located in the South Platte and Arkansas River Basins in Colorado. The first step was to determine if fish assemblages collected between 1992 and 1996 were comparable to samples collected at the same sites between 2007 and 2010. If samples from the two time periods were comparable, then it was considered reasonable that the combined time-period data could be used to make comparisons between random and fixed sites. In contrast, if differences were found between the two time periods, then it was considered unreasonable to use these data to make comparisons between random and fixed sites. One-hundred samples collected during the 1990s and 2000s from 50 sites dispersed among 19 streams in both basins were compiled from a database maintained by Colorado Parks and Wildlife. Nonparametric multivariate two-way analysis of similarities was used to test for fish-assemblage differences between time periods while accounting for stream-to-stream differences. Results indicated relatively weak but significant time-period differences in fish assemblages. Weak time-period differences in this case possibly were related to changes in fish assemblages associated with environmental factors; however, it is difficult to separate other possible explanations such as limited replication of paired time-period samples in many of the streams or perhaps differences in sampling efficiency and effort between the time periods. Regardless, using the 1990s data to fill data gaps to compare random and fixed-site fish-assemblage data is ill advised based on the significant separation in fish assemblages between time periods and the inability to determine conclusive explanations for these results. These findings indicated that additional sampling will be necessary before unbiased comparisons can be made between fish assemblages collected from random and fixed sites in the South Platte and Arkansas River Basins.

Introduction

Colorado Parks and Wildlife (CPW) conducted fish inventories of the South Platte and Arkansas River Basins during the early to mid-1990s (Nesler and others, 1997; Nesler and others, 1999) to evaluate the status of plains fishes in Colorado and identify species in need of conservation and protective status. Site selection for these inventories was based on the ease of property access

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(convenience) and representativeness (provincial judgment) determined by CPW fisheries-management biologists. Sites with water at road crossings and easily accessible areas such as State-owned properties were targeted. This process resulted in 1,381 and 2,128 site visits in the South Platte and Arkansas River Basins, respectively. Less than 30 percent of the visited sites had water resulting in 534 sites in the South Platte and 416 sites in the Arkansas River Basins. Spatially, sites were sampled roughly from 1.6- to 8-km intervals (0.99- to 4.97-mi) in the South Platte River Basin (Nesler and others, 1997). The linear distance between sites with fish varied considerably in the Arkansas River Basin because of the ephemeral nature of most streams (Nesler and others, 1999).

CPW is considering more statistically rigorous sampling methods accompanied with a statistically based selection of sites to update and monitor the status of plains fishes in Colorado. Statistically based designs use a probabilistic approach to randomly select sampling locations from a targeted population of sites. Additionally, CPW is interested in exploring the possibility of using multivariate methods to monitor changes in fish assemblages in addition to using other methods to monitor changes in individual species occurrence, abundance, and distribution. Although each of these goals and interests could entail different sampling methods or analyses, all require spatially extensive sampling. Incorporating a probabilistic study design will allow managers to extend statistical inference to unsampled locations within the plains portions of the South Platte and Arkansas River Basins (sampling frame) in Colorado. Although extending statistical inference to unsampled locations is desirable, CPW has a strong interest in continuing to sample many of the sites visited during the 1990s inventories for several reasons. First, some State protected species have limited distributions and are reliably found at a few known sites. Second, many CPW fisheries-management biologists have long-term data from sites sampled during the 1990s inventories and want to continue sampling those sites. Third, less logistical effort is needed before and during field sampling because landowner permission is already established at sites sampled during the 1990s inventories. Establishing landowner permission at random sites and gaining stream access can be labor intensive and costly. So before a probabilistic sampling design is adopted, CPW wants to determine the comparability of fish assemblages collected from random and paired nonrandom sites (fixed sites, hereafter) utilizing available data collected during two distinct time periods (1992 to 1996 and 2007 to 2010). At the present time (2012), in order to make this comparison, many of the random sites sampled between 2007 and 2010 will need to be paired with data from a nearby fixed site that was sampled during the 1990s; however, doing so could bias the analysis if fish assemblages differ between the two time periods. To this end, the U.S. Geological Survey, in cooperation with CPW, used nonparametric multivariate analysis to test if plains fish assemblages differed at sites that were sampled during both time periods (1992 to 1996 and 2007 to 2010) in the South Platte and Arkansas River Basins in Colorado.

Purpose and Scope

This report presents the strength of similarity between plains fish assemblages collected during two distinct time periods from the South Platte and Arkansas River Basins in Colorado. Data consisting of 100 samples collected from 50 sites dispersed among 19 streams during the 1990s and 2000s (1992 to 1996 and 2007 to 2010) were compiled from the CPW aquatics database (unpublished data, Aquatics Wildlife Research Group, Colorado Parks and Wildlife, June 2011). These data were used to assess the potential for bias when using existing CPW data to make fish-assemblage comparisons between random and fixed sites by determining the strength of similarity between plains fish assemblages collected during two distinct time periods. Results will help CPW move forward in developing a plan for monitoring the status of plains fish assemblages in Colorado.

Study Area

The study area consists of the Interior Plains (Fenneman and Johnson, 1946) portion of the South Platte and Arkansas River Basins in Colorado (fig. 1). Detailed environmental characteristics of this region as they relate to river systems are described elsewhere (Dennehy and others, 1993; Fausch and Bestgen, 1997; Nadler and Schumm, 1981; Eschner and others, 1983).

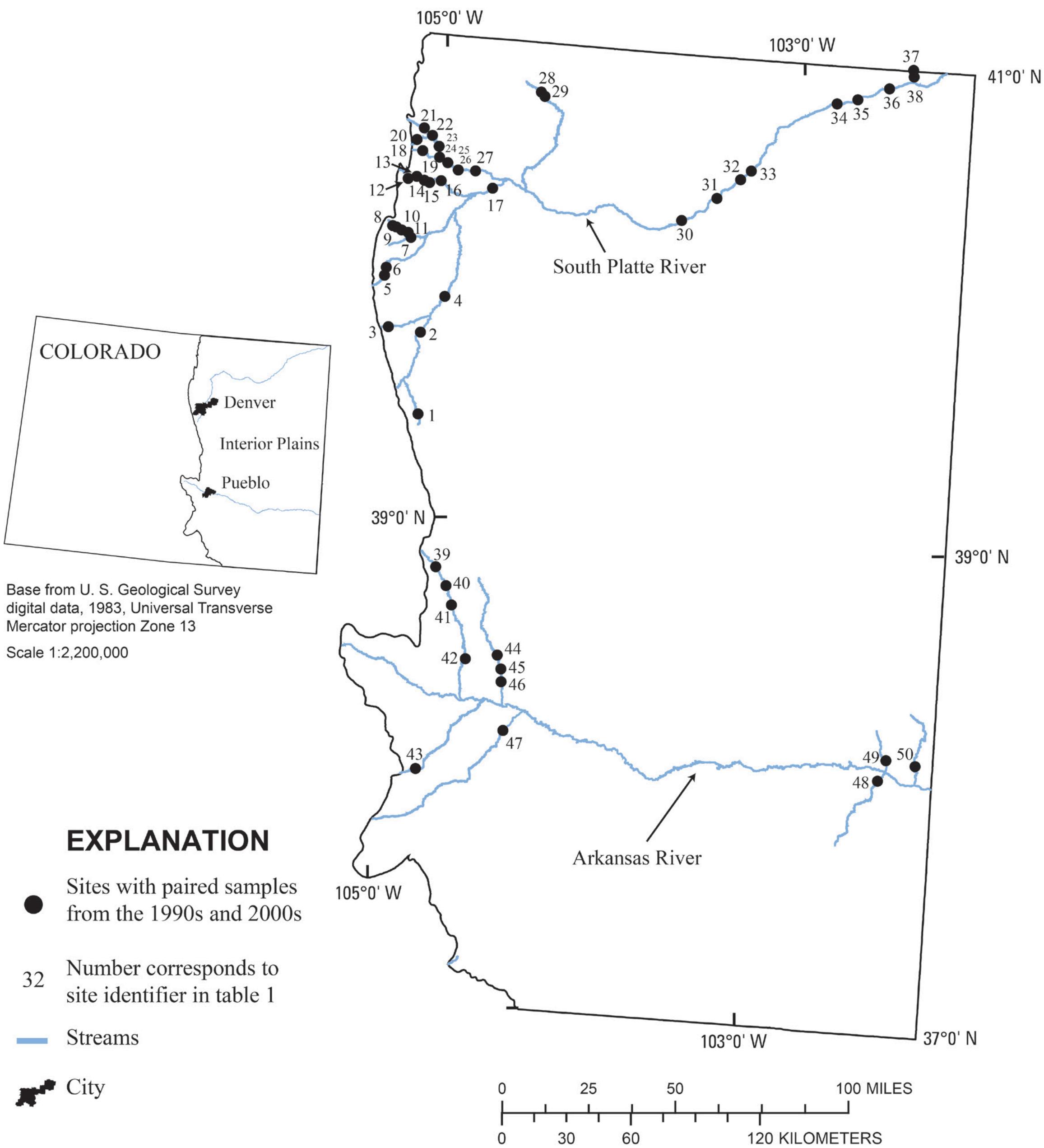

Figure 1. Distribution of selected sites compiled from the Colorado Parks and Wildlife aquatics database with fish-assemblage data collected from the Interior Plains portion of the South Platte and Arkansas River Basins, Colorado, from 1992 to 1996 and 2007 to 2010.

Study Methods

Plains fish community data from the South Platte and Arkansas River Basins were queried from the CPW aquatics database (unpublished data, Aquatics Wildlife Research Group, Colorado Parks and Wildlife, June 2011) for sites that were sampled during two time periods (1992 to 1997 and 2007 to 2010). These data were explored to assess the potential for bias from using existing CPW data to compare fish assemblages collected from random and fixed sites. This process focused on determining if fish assemblages collected during 1992 to1996 were comparable to those collected at the same sites during 2007 to 2010 using nonparametric multivariate methods (PRIMER-E ver. 6.1, Plymouth, United Kingdom; Clarke and Gorley, 2006). If samples from the two time periods were comparable (statistically indistinguishable), then it was considered reasonable that the combined time-period data could later be used to make comparisons between random and fixed sites. In contrast, if statistical differences were found in fish assemblages between the two time periods, then it was considered unreasonable to use these data to make comparisons between random and fixed sites.

Fish Sampling Methods Used for the 1990s Inventories

Nesler and others (1997, 1999) briefly described sampling methods used during the 1990s native fish inventories of the South Platte and Arkansas River Basins. In general, fish were sampled from all habitats present at each site using seining, backpack electrofishing, bank-mounted electrofishing, or a combination of these methods. Electrofishing was not used in the lower Arkansas River due to high specific electrical conductivities. Site selection for these inventories was based on the ease of property access and representativeness as determined by CPW fisheries-management biologists. Sites with water at road crossings and easily accessible areas such as State owned properties were targeted. Site length varied from 165 to 985 feet in order to capture all habitat features present at each site. Very little quantitative information was available regarding sampling efficiency or site-specific effort.

Fish Sampling Methods Used Between 2007 and 2010

A combination of electrofishing, seining, and multipass removal sampling along a predefined reach was used at sites visited between 2007 and 2010. Targeted reach length was 20 times the mean stream width to include multiple riffle, run, and pool sequences (Fitzpatrick and others, 1998; Stanfield and others, 1997) but was constrained to 150 and 500 feet for efficiency and logistical purposes. For most streams (width <30 feet), electrofishing was conducted using two Smith-Root LR-24 backpack electrofishers and a total crew of four. For the largest steams (width >30 feet), a three-electrode barge-electrofishing system was used and supplemented as necessary by one or two backpack electrofishers with the crew expanded as needed. Specific electrical conductivity and temperature were measured prior to sampling and used to determine electrofisher settings in accordance with power transfer theory (Kolz, 1989; Kolz, 2006); effectiveness of calculated settings was confirmed by electrofishing outside the sample reach. Sampling crews were experienced and care was taken to ensure thorough coverage of the entire sample reach and all present habitat types.

Removal sampling consisted of a minimum of three passes but included additional passes when a new species was encountered on the third pass. In these cases additional passes were made until no new species were collected. Typically, reaches were electrofished on the first pass and seined on the second, whereas the third and subsequent passes employed whichever gear type proved most effective from the first two passes. All nets and seines were equipped with 3/16- or 1/4-inch mesh. After each pass, fish were identified to species and individually measured (total length to nearest millimeter). For exceptionally large catches, only the first 50 individuals of each species were measured, but all were identified and enumerated. Except for voucher specimens, all fish were held in live cages upstream of the sample reach and released after all passes were completed. Infrequently, it was necessary to deviate from this protocol in order to effectively sample the site (for example, if ambient conductivity prohibited effective electrofishing); however, these data were excluded from analysis so related sampling details are not included herein.

Data Preparation

After reviewing the methods in Nesler and others (1997, 1999), available information in the database, and speaking with biologists involved in the 1990s inventories, it was apparent that sampling effort varied within the inventory data by necessity and that the inventory methods differed from the methods used between 2007 and 2010. Unfortunately, there was not enough available information within the 1990s inventories data to make adjustments to account for unequal sampling effort or sampling efficiency. For these reasons, data were reduced to presence-absence of species for all analyses to help account for unequal sampling effort among samples and sites. The consequences of using presence-absence data are that all information about abundance is lost, and rare species are given equal weight with common species thereby losing information about species' prevalence and fish-community structure. Additionally, only samples from first-pass electrofishing collected between June and November were considered, and where gear type was unknown, it was assumed that first-pass data were collected using electrofishing equipment. This assumption mostly applied to 1990s inventory data and only accounted for a few samples. Finally, samples collected during 1992 to 1996 were paired with samples collected on the next closest month and day during 2007 to 2010 for each site. This resulted in most samples (45 of 50) being collected within a 90-day index period between June and November. Analysis was completed with and without the remaining five-paired samples collected outside of 90 days. It was found that these samples had little influence on the results, so they were retained to maximize the number of sample pairs. The final dataset consisted of 100 samples collected during the 1990s and 2000s from 50 sites dispersed among 19 streams in both basins (table 1, fig. 1).

Table 1. Description and location of selected sites compiled from the Colorado Parks and Wildlife aquatics database with fish-assemblage data collected from the Interior Plains portion of the South Platte and Arkansas River Basins, Colorado, from 1992 to 1996 and 2007 to 2010.

[ID, identifier; latitude and longitude in degrees, minutes, and seconds]

Site ID (fig. 1)	Station ID[1]	Station name	Latitude	Longitude
		South Platte River		
1	SP0006	West Plum Creek above highway 67	39˚ 25' 43"	104˚ 58' 02"
2	SP0627	South Platte River above 31st Avenue	39˚ 46' 06"	104˚ 59' 02"
3	SP1181	Clear Creek below McIntyre Street above Coors effluent	39˚ 46' 17"	105˚ 10' 22"
4	SP0631	South Platte River above 124th Avenue at Henderson	39˚ 55' 19"	104˚ 52' 07"
5	SP1663	South Boulder Creek 250 feet above South Boulder Road	39˚ 59' 07"	105˚ 13' 17"
6	SP0961	South Boulder Creek 0.38 miles below Baseline Road	40˚ 00' 21"	105˚ 12' 59"
7	SP0766	Left Hand Creek 400 feet above Main Street	40˚ 08' 48"	105˚ 06' 11"
8	SP0771	Saint Vrain Creek above 75th Street	40˚ 10' 10"	105˚ 10' 43"
9	SP0773	Saint Vrain Creek 0.60 miles above North 85th Street 0.68 miles below North 75th Street	40˚ 10' 30"	105˚ 09' 54"
10	SP0774	Saint Vrain Creek above Hover Road	40˚ 09' 59"	105˚ 07' 52"
11	SP0800	Saint Vrain Creek below South main Street	40˚ 09' 17"	105˚ 06' 02"
12	SP1435	Big Thompson River 0.25 miles above Wilson Avenue between gravel pit ponds	40˚ 23' 52"	105˚ 06' 65"
13	SP0805	Big Thompson River 0.17 miles below Taft Avenue, Centennial Park	40˚ 23' 42"	105˚ 05' 35"
14	SP3310	Big Thompson River below River Street bridge	40˚ 23' 01"	105˚ 03' 04"
15	SP1497	Big Thompson River 0.25 miles above County Road 9e	40˚ 22' 59"	105˚ 02' 04"
16	SP1546	Big Thompson River above County Road 3c	40˚ 23' 34"	104˚ 57' 58"
17	SP0362	South Platte River above 37th Street Brower State Wildlife Area	40˚ 22' 43"	104˚ 40' 24"
18	SP3234	Fossil Creek 0.25 miles above South College Avenue at Redtail Grove Open Space	40˚ 30' 35"	105˚ 04' 45"
19	SP0636	Fossil Creek above South County Road 3 at River Bluff Open Space	40˚ 29' 07"	104˚ 57' 50"
20	SP0881	Spring Creek 250 feet above Drake Street	40˚ 33' 09"	105˚ 06' 31"
21	SP1158	Cache La Poudre River above North College Avenue	40˚ 35' 44"	105˚ 04' 41"
22	SP0786	Cache La Poudre River above Riverbend Ponds off Mulberry Road	40˚ 34' 35"	105˚ 02' 06"
23	SP0794	Cache La Poudre River Environmental Learning Center 0.87 miles above Boxelder Creek	40˚ 33' 08"	105˚ 00' 57"
24	SP1511	Cache La Poudre River at sewage disposal ponds	40˚ 33' 02"	105˚ 00' 29"
25	SP0790	Cache La Poudre River above North County Line Road	40˚ 28' 23"	104˚ 56' 37"
26	SP1580	Cache La Poudre River below highway 257 at Windsor sewage outfall	40˚ 26' 14"	104˚ 52' 23"
27	SP3279	Cache La Poudre River above Sheep Draw	40˚ 26' 42"	104˚ 46' 34"
28	SP0317	Willow Creek 0.12 miles above Willow Creek Ponds Pawnee National Grasslands	40˚ 48' 15"	104˚ 27' 58"
		Arkansas River		
39	AR0168	Fountain Creek below Janitell Road below Colorado Springs, Colo. at USGS stream gage 07105500	38˚ 48' 08"	104˚ 47' 39"
40	AR0189	Fountain Creek above highway 16	38˚ 43' 33"	104˚ 43' 50"
41	AR0319	Fountain Creek below diversion dam at Clear Spring Ranch Park	38˚ 38' 52"	104˚ 41' 30"
42	AR0147	Fountain Creek above Pinon Road	38˚ 26' 19"	104˚ 35' 39"
43	AR0077	Greenhorn Creek above interstate 25	37˚ 57' 01"	104˚ 48' 13"
44	AR0093	Chico Creek below Peyton highway	38˚ 27' 31"	104˚ 25' 24"
45	AR0094	Chico Creek below Black Squirrel Creek	38˚ 24' 05"	104˚ 24' 23"
46	AR0149	Chico Creek 0.50 miles below DOT Road	38˚ 21' 21"	104˚ 23' 03"
47	AR0084	Huerfano River below Fields Road	38˚ 08' 45"	104˚ 20' 41"
48	AR0023	Wolf Creek above highway 50	38˚ 03' 52"	102˚ 20' 12"
49	AR0018	Buffalo Creek above highway 385	38˚ 08' 55"	102˚ 18' 43"
50	AR0013	Wild Horse Creek above County Road LL	38˚ 07' 46"	102˚ 08' 13"

[1]Station IDs are from the Colorado Parks and Wildlife aquatics database.

Data Analysis

Most multivariate analysis of ecological communities is based on some measure of community similarity among samples. Legendre and Legendre (1998) define several similarity measures used in ecology. In this case, Bray-Curtis similarity (Bray and Curtis, 1957) calculated from presence-absence data were used for all analyses.

Analysis of similarity (ANOSIM; PRIMER-E ver. 6.1, Plymouth, United Kingdom) was used following details in Clarke and Warwick (2001) and Clarke and Gorley (2006). ANOSIM is based on a multivariate nonparametric-permutation procedure that compares the degree of separation between predefined groups of samples based on the ranks of community similarities underlying a nonparametric multidimensional scaling ordination (Clarke and Warwick, 2001). This procedure does not make assumptions about the distributional properties of the data, variance structure among groups, or about the balance of replicate samples within groups. The degree of separation among predefined groups is determined with the test statistic R, first as a global test to determine if differences among groups exist, then as pair-wise comparisons to determine which groups differ. Values of R near 0 indicate no distinguishable separation between groups, whereas values near 1 indicate complete separation. Statistical significance was determined by a general randomization procedure based on Monte Carlo significance tests described by Hope (1968). Analyses were determined statistically significant when less than 5 percent of the 9,999 permutated values were greater than the global R value.

Testing for Differences Between Time Periods (1990s and 2000s)

Fifty sites dispersed among 19 streams in both river basins (table 1, fig. 1) with fish data collected during both time periods (1992 to 1996 and 2007 to 2010) were used to determine if fish assemblages differed between the two time periods using a two-way ANOSIM analysis for a crossed design. The data structure fit the two-way crossed layout as all levels of factor A (stream) occurred in combination with every level of factor B (time period). The utility for two-way ANOSIM for a crossed design in this effort is that the analysis removes the effects of one factor (stream) while considering the significance of the other (time period). This is important because fish assemblages naturally vary among sites, and it was important to remove stream effects in order to reveal differences, if present, between the two time periods.

Assessing the Use of Existing Data to Compare Fish Assemblages from Random and Fixed Sites—Differences Between Time Periods

Results of two-way ANOSIM indicated significant differences among steams and time periods. Differences in fish assemblages among streams were moderately strong (R = 0.61; significance level = 0.01 percent). However, pairwise comparisons were not investigated as this result was expected because of the spatial extent of the dataset and what is known about the longitudinal distribution of plains fishes in Colorado (Fausch and Bestgen, 1997; Nesler and others, 1997; Nesler and others, 1999). The important part of the analysis was to remove stream effects to determine differences among time periods. After doing so, significant time period differences in fish assemblages were observed, but they were much weaker than differences among streams (R = 0.20; significance level = 0.01 percent). Nonetheless, none of the permutated values exceeded the Global R value testing for time-period differences, which suggests only a 0.01-percent chance of drawing an incorrect conclusion (Type I error in statistical terms). It is possible the low R value in this case was related to there being too few paired time-period samples in nearly half of the stream groups (9 of 19 streams had only one pair of time-period samples). ANOSIM is appropriate for unbalanced designs, but replication within groups is beneficial in most cases (Clarke and Warwick, 2001; Clarke and Gorley, 2006). Collecting additional samples to increase the number of replicates where they were limited and rerunning the analysis would increase confidence in these results.

Although these results suggest some differences exist in fish assemblages between time periods, the difficulty here is revealing what contributed to these differences. For example, it is difficult to separate possible influential factors such as apparent differences in methods, effort, unknown sampling error, or actual decadal changes in fish assemblages in response to various natural or anthropogenic stressors. Regardless, using the 1990s data to fill data gaps to determine if fish assemblages differ between random and fixed sites is not warranted based on the significant separation between time periods, even though the strength of the separation was weak.

Moving Forward

The initial purpose of this study was to use existing CPW data to make comparisons between random- and fixed-site locations to inform decisions about incorporating a probabilistic monitoring design. However, after preliminary efforts, it was determined that using these data could bias the analysis because data collected during the 1990s inventories were needed to compensate for data gaps when pairing recently (2007 to 2010) sampled random sites with nearby fixed-site locations. Some of the influential factors that could bias the analysis included differences in methods, effort, or fish-assemblage response to changes in environmental conditions between time periods. As a result, the initial purpose was modified to determine if using available data to make comparisons between random and fixed sites could bias the analysis by testing for differences in fish assemblages collected during the two distinct time periods (1992 to 1996 and 2007 to 2010). The results indicated discrete separation between time periods making it difficult to justify using existing data to evaluate differences between random and fixed sites. Therefore, additional sampling will be required to make unbiased comparisons between fish assemblages collected from random and fixed sites. This will require pairing contemporary (2007 to present) samples from each random site with a sample collected from a nearby fixed site preferably on the same stream. However, doing so will require substantial effort because less than half of the random sites sampled between 2007 and 2010 (100 sites) could be paired with a nearby fixed-site sample (40 sites), and of those, less than half (13 sites) could be paired with contemporary data (unpublished data, Aquatics Wildlife Research Group, Colorado Parks and Wildlife, June 2011).

Summary

Colorado Parks and Wildlife (CPW) is considering more statistically rigorous sampling methods accompanied with a statistically based selection of sites (sampling design) to update and monitor the status of plains fishes in Colorado. Additionally, CPW is interested in the possibility of using multivariate statistics to monitor changes in fish assemblages. As part of this consideration, CPW seeks to understand the comparability of fish assemblages from random and fixed sites. To this end, the U.S. Geological Survey, in cooperation with CPW, used nonparametric multivariate statistics to test if plains fish assemblages differed at sites that were sampled during two distinct time periods (1992 to 1996 and 2007 to 2010) in the South Platte and Arkansas River Basins in Colorado. Results of two-way Analysis of Similarities indicated significant but relatively weak separation between the two time periods after removing the effects of stream group. Although the analysis was equipped for unbalanced designs, it is possible the weak separation was influenced by the limited replication within many of the streams, temporal change of fish assemblages associated with environmental factors, differences in sampling effort between the time periods, or other unknown factors. Options to further evaluate the comparability of fish-assemblage data from random and fixed sites will require additional sampling to make unbiased comparisons.

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References Cited

Bray, J.R., and Curtis, J.T., 1957, An ordination of the upland forests communities of southern Wisconsin: Ecological Monographs, v. 27, p. 325–349.

Clarke, K.R., and Gorley, R.N., 2006, Primer version 6—User manual/tutorial, Primer-E: Plymouth, United Kingdom, 190 p.

Clarke, K.R., and Warwick, R.M., 2001, Change in marine communities—An approach to statistical analysis and interpretation (1st ed.): Plymouth, United Kingdom, Plymouth Marine Laboratory, 172 p.

Dennehy, K.F., Litke, D.W., Tate, C.M., Qi, S.L., McMahon, P.B., Bruce, B.W., Kimbrough, R.A., and Heiny, J.S., 1993, Water quality in the South Platte River Basin, Colorado, Nebraska, and Wyoming, 1992–95: U.S. Geological Survey Circular 1167, 38 p.

Eschner, T.R., Hadley, R.F., and Crowley, K.D, 1983, Hydrologic and morphologic changes of the Platte River Basin in Colorado, Wyoming, and Nebraska—A historical perspective: U.S. Geological Survey Professional Paper 1277–A, 39 p.

Fausch, K.D., and Bestgen, K.R., 1997, Ecology of fishes indigenous to the central and southwestern Great Plains, *in* Knopf, F.L., and Samson, F.B., eds., Ecology and conservation of Great Plains vertebrates: New York, Springer-Verlag, Inc., p. 131–166.

Fenneman, N.M., and Johnson, D.W., 1946, Physical divisions of the United States: Washington, D.C., U.S. Geological Survey, Special Map Series, scale 1:7,000,000, accessed May 5, 2012, at *http://water.usgs.gov/GIS/metadata/usgswrd/XML/physio.xml*.

Fitzpatrick, F.A., Waite, I.R., D’Arconte, P.J., Meador, M.R., Maupin, M.A., and Gurtz, M.E., 1998, Revised methods for characterizing stream habitat in the National Water-Quality Assessment Program: U.S. Geological Survey Water-Resources Investigations Report 98–4052, 67 p.

Hope, A.C.A., 1968, A simplified Monte Carlo significance test procedure: Journal of the Royal Statistical Society, Series B, Methodological, v. 30, p. 582–598.

Kolz, A.L., 1989, A power transfer theory for electrofishing: U.S. Fish and Wildlife Service Technical Report, v. 22, p. 1–11.

Kolz, A.L., 2006, Electrical conductivity as applied to electrofishing: Transactions of the American Fisheries Society, v. 135, p. 509–518.

Legendre, Pierre, and Legendre, Louis, 1998, Numerical ecology (2nd ed.): New York, Elsevier, 853 p.

Nadler, C.T., and Schumm, S.A., 1981, Metamorphosis of South Platte and Arkansas Rivers, eastern Colorado: Physical Geography, v. 2, p. 95–115.

Nesler, T.P., VanBuren, R., Stanford, J.A., Jones, M., 1997, Inventory and status of South Platte River native fishes in Colorado: Final Report, Aquatic Wildlife Section, Colorado Division Wildlife, p. 111.

Nesler, T.P., Bennett, C., Melby, J., Dowler, G., and Jones, M., 1999, Inventory and status of Arkansas River native fishes in Colorado: Colorado Division of Wildlife, Final Report, 120 p.

Stanfield, L.W., Jones, M., Stoneman, M., Kilgour, B., Parish, J., and Wichert, G., 1997, Stream assessment protocol for Ontario: Peterborough, Ontario, Canada, Ontario Ministry of Natural Resources, Fish and Wildlife Branch, K9J 8M5.