Random versus Fixed-Site Sampling When Monitoring Relative Abundance of Fishes in Headwater Streams of the Upper Colorado River Basin

MICHAEL C. QUIST*[1]

*U.S. Geological Survey, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming,
Department 3166, 1000 East University Avenue, Laramie, Wyoming 82071, USA*

KENNETH G. GEROW

*Department of Statistics, University of Wyoming,
Department 3332, 1000 East University Avenue, Laramie, Wyoming 82071, USA*

MICHAEL R. BOWER[2]

U.S. Bureau of Land Management, Post Office Box 2407, Rawlins, Wyoming 82301, USA

WAYNE A. HUBERT

*U.S. Geological Survey, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming,
Department 3166, 1000 East University Avenue, Laramie, Wyoming 82071, USA*

Abstract.—Native fishes of the upper Colorado River basin (UCRB) have declined in distribution and abundance due to habitat degradation and interactions with nonnative fishes. Consequently, monitoring populations of both native and nonnative fishes is important for conservation of native species. We used data collected from Muddy Creek, Wyoming (2003–2004), to compare sample size estimates using a random and a fixed-site sampling design to monitor changes in catch per unit effort (CPUE) of native bluehead suckers *Catostomus discobolus*, flannelmouth suckers *C. latipinnis*, roundtail chub *Gila robusta*, and speckled dace *Rhinichthys osculus*, as well as nonnative creek chub *Semotilus atromaculatus* and white suckers *C. commersonii*. When one-pass backpack electrofishing was used, detection of 10% or 25% changes in CPUE (fish/100 m) at 60% statistical power required 50–1,000 randomly sampled reaches among species regardless of sampling design. However, use of a fixed-site sampling design with 25–50 reaches greatly enhanced the ability to detect changes in CPUE. The addition of seining did not appreciably reduce required effort. When detection of 25–50% changes in CPUE of native and nonnative fishes is acceptable, we recommend establishment of 25–50 fixed reaches sampled by one-pass electrofishing in Muddy Creek. Because Muddy Creek has habitat and fish assemblages characteristic of other headwater streams in the UCRB, our results are likely to apply to many other streams in the basin.

Fisheries scientists need information on the occurrence and abundance of fishes to guide management

and conservation efforts. For instance, understanding the distributions of native species may identify large-scale factors influencing their occurrence, populations that warrant study, or stream segments that require protection from deleterious anthropogenic activities (Luttrell et al. 1999; Jackson et al. 2001). Information on the distribution of nonnative fishes can be used to identify areas where management activities (e.g., nonnative fish removal efforts, translocation of native species) should be directed (Kruse et al. 1997; Novinger and Rahel 2003). Similarly, information on the abundance of fishes is critical for assessing populations and their response to management activities or anthropogenic disturbances.

Native fishes have declined in distribution and abundance across the upper Colorado River basin (UCRB). Cumulative effects of habitat alterations and interactions with nonnative fishes are cited as the primary mechanisms responsible for declines (Minckley and Deacon 1991; Bezzerides and Bestgen 2002; Minckley et al. 2003). In Wyoming, 11 fish species are native to the UCRB (Baxter and Stone 1995). Three of these species are federally endangered species (i.e., razorback sucker *Xyrauchen texanus*, bonytail *Gila elegans*, and Colorado pikeminnow *Ptychocheilus lucius*) and are probably extirpated from Wyoming. The bluehead sucker *Catostomus discobolus*, flannelmouth sucker *C. latipinnis*, and roundtail chub *Gila robusta* are of particular interest because their distributions have been reduced by about 50% across the Colorado River basin (Bezzerides and Bestgen 2002). Only two small watersheds in Wyoming are currently known to contain sympatric populations of these three species, one of which is Muddy Creek (Little Snake

* Corresponding author: mcquist@iastate.edu

[1] Present address: Department of Natural Resource Ecology and Management, Iowa State University, 339 Science II, Ames, Iowa 50011, USA.

[2] Present address: National Park Service, Death Valley National Park, Post Office Box 579, Death Valley, California 92328, USA.

River drainage). Consequently, studies are occurring to assess their distributions and to monitor their abundance in Muddy Creek (Bower 2005; Beatty 2005).

Conservation of native fishes in small headwater streams is becoming a focus in the UCRB because factors influencing native fishes are often more manageable in small-stream systems. For instance, sampling fish populations in small streams requires less effort and is more effective than in large rivers (e.g., Bayley and Dowling 1990). The most common sampling gears used in small streams are electrofishing and seining (e.g., Wiley and Tsai 1983; Patton et al. 2000). Like all sampling gears, they are biased towards different species and sizes of fish (Parsley et al. 1989; Bayley and Dowling 1990; Pierce et al. 2001; Gries and Letcher 2002). Consequently, these two sampling gears are often used in combination to account for differences in gear selectivity (e.g., Drake and Pereira 2002; Quist et al. 2003). In Wyoming, standardized sampling protocols call for electrofishing of small streams, followed by seining (Quist et al. 2004).

Managers are assuming more responsibilities for native fishes. As such, guidance is needed to help establish efficient sampling protocols. Our purpose was to provide insight on the number of electrofishing samples required to monitor changes in abundance of native and nonnative fishes of a small headwater stream system in the UCRB (i.e., Muddy Creek, Wyoming) using either a random or a fixed-site sampling design. We also sought to determine if seining, in addition to electrofishing, reduced the number of reaches that must be sampled to monitor fish populations. This study focused on fish populations in Muddy Creek, but the approach has widespread application throughout the UCRB and other North American stream systems.

Methods

Study area.—Muddy Creek is a tributary to the Little Snake River in south-central Wyoming. The watershed is about 2,500 km^2 and varies in elevation from 2,500 m in the headwaters to about 1,900 m at its confluence with the Little Snake River. Streams in headwater areas generally have wetted widths less than 2 m and channel gradients of 2–4%. Substrate in headwater streams is usually dominated by gravel with some boulder, cobble, and sand. As streams flow off the mountains and onto the desert, stream width increases to 2–5 m and channel gradients are reduced to less than 1%. Substrates in these areas are dominated by silt and sand in pools and gravel in riffles. Historically, Colorado River cutthroat trout *Oncorhynchus clarkii pleuriticus* occupied headwater areas, but they have been replaced by introduced brook trout *Salvelinus fontinalis*. Native

fishes in downstream areas include bluehead suckers, flannelmouth suckers, roundtail chub, and speckled dace *Rhinichthys osculus*. In addition, nonnative white suckers *C. commersonii* and creek chub *Semotilus atromaculatus* are widespread in downstream areas of Muddy Creek and its tributaries. Mountain suckers *C. platyrhynchus* also occur in the watershed but are generally restricted to stream segments at the transition from the mountains to the desert.

Fish sampling.—Fish were sampled from 49 randomly selected reaches during June–September 2003–2004. Sampling reaches included 10 pool or run habitats or 200 m, whichever was shorter. Fish were sampled by placing block nets at the upstream and downstream end of each channel unit (e.g., pools, runs), conducting one upstream electrofishing pass with a backpack electrofishing unit (Smith-Root, Inc., Vancouver, Washington), and making one upstream seine haul (5 × 1.5 m; 4.7-mm mesh). Fish were identified to species, counted, and released after seining. Catch data were recorded by channel unit and sampling gear. Catch per unit effort (CPUE) was estimated as the number of fish per 100 m of stream in each sampled reach. Age-0 fish were excluded from the analysis because they were not fully recruited to the sampling gear until mid to late August. We estimated CPUE for electrofishing samples and for electrofishing plus seining. Mean CPUE was estimated as the average CPUE across all reaches for each species. Samples focused on warmwater stream segments; therefore, brook trout and mountain suckers were not included in the analysis.

The number of reaches required to detect changes in CPUE at various levels of statistical power $(1 - \beta)$ was estimated as

$$n = \frac{C(t_\alpha + t_\beta)^2(\lambda_0 + \lambda_1)}{(\lambda_0 - \lambda_1)^2},$$

where n is the estimated sample size, C is the variance inflation constant (standard deviation of CPUE/[mean CPUE]) to account for a non-Poisson distribution of CPUE data, t_α is the t-distribution deviate for a one-sided test given α, t_β is the t-distribution deviate for a one-sided test for the given level of statistical power, λ_0 is the mean CPUE at time 0, and λ_1 is the mean CPUE at time 1 (see Gerow in press for details). This equation allows for variation different than a simple Poisson distribution but is otherwise similar to Krueger et al. (1998), Tate et al. (2003), and Paukert (2004). The equation allows estimation of the number of samples necessary for detecting an increase or decrease in CPUE. For example, if the objective is to determine the number of samples required to estimate a 50%

TABLE 1.—Frequency of occurrence (%) of native and nonnative fishes sampled from 49 reaches in Muddy Creek, Wyoming (2003–2004) by means of electrofishing only and electrofishing plus a seine haul.

Species	Electrofishing	Electrofishing plus seining
Bluehead sucker	87.8	87.8
Flannelmouth sucker	69.4	69.4
White sucker	91.8	91.8
Creek chub	95.9	97.9
Roundtail chub	93.9	95.9
Speckled dace	100	100

reduction in mean CPUE (i.e., $\lambda_1 = \lambda_0/2$), then

$$(\lambda_0 + \lambda_1)/(\lambda_0 - \lambda_1)^2 = 1.5\lambda_0/(0.5\lambda_0)^2 = 6/\lambda_0,$$

whereas a 50% increase in CPUE would be different ($10/\lambda_0$). If the same reaches are sampled during two time periods (i.e., paired or fixed samples), the correlation among reaches can be incorporated into the equation as

$$n = \frac{C(t_\alpha + t_\beta)^2(\lambda_0 + \lambda_1 - 2rC\lambda_0\lambda_1)}{(\lambda_0 - \lambda_1)^2},$$

where r is the correlation among reaches (i.e., correlation of CPUE for a species) between time periods.

We estimated the number of reaches necessary to detect a 10, 25, or 50% increase or decrease in CPUE at four levels of statistical power (i.e., 60, 70, 80, and 90%) for each species. Estimates were obtained for electrofishing only and electrofishing plus seining. Differences were compared to provide insight into the potential benefits of seining in addition to electrofishing. Analyses were conducted assuming a simple random sampling design, where n reaches are randomly sampled and an additional n reaches are randomly sampled at a later time. We also conducted analyses assuming a fixed-site sampling design, where n reaches are randomly sampled and the same reaches are sampled at a later time (i.e., paired samples between two time periods). Using a fixed design, we estimated the detectable change in CPUE (i.e., increase and decrease) with 60, 70, 80, and 90% statistical power and four levels of correlation (0.0, 0.2, 0.4, and 0.6). Detectable changes in CPUE were determined by assuming that fisheries scientists could sample 25 or 50 reaches, a realistic assumption given logistical constraints associated with sampling streams in the UCRB (i.e., time, access, physicochemical habitat conditions). All sample size estimates were conducted using a significance level α equal to 0.10.

Results

The speckled dace was the most common species sampled in Muddy Creek and occurred in all of the sampled reaches (Table 1). The roundtail chub, creek chub, and white sucker were sampled in over 90% of the reaches, while the bluehead sucker was sampled in 88% of the reaches. The flannelmouth sucker was the least common species, occurring in approximately 70% of the reaches. Seining did not provide additional occurrence information for the bluehead sucker, flannelmouth sucker, or white sucker, but seining captured creek chub and roundtail chub where they were not collected by electrofishing.

Speckled dace was also the most abundant species (Table 2). The creek chub, white sucker, and roundtail chub had relatively high catch rates, while the flannelmouth sucker had the lowest catch rates. Seining increased the mean CPUEs of all species, particularly creek chub, roundtail chub, and speckled dace.

Assuming a random sampling design, the estimated number of reaches necessary to detect a 10% change in CPUE (i.e., electrofishing only) was greater than 400 reaches for all species except speckled dace (Figure 1). The number of reaches required to detect a 25% change in CPUE was 50–200 among species at low levels of statistical power (60% and 70%). At high levels of power, over 200 reaches were necessary to detect a 25% change in CPUE among species. Detecting a 50%

TABLE 2.—Mean catch per unit effort (fish/100 m), standard deviation (SD), and coefficient of variation (CV = 100 × SD/mean) of native and nonnative fishes sampled from 49 reaches in Muddy Creek, Wyoming (2003–2004) by means of electrofishing only and electrofishing plus a seine haul.

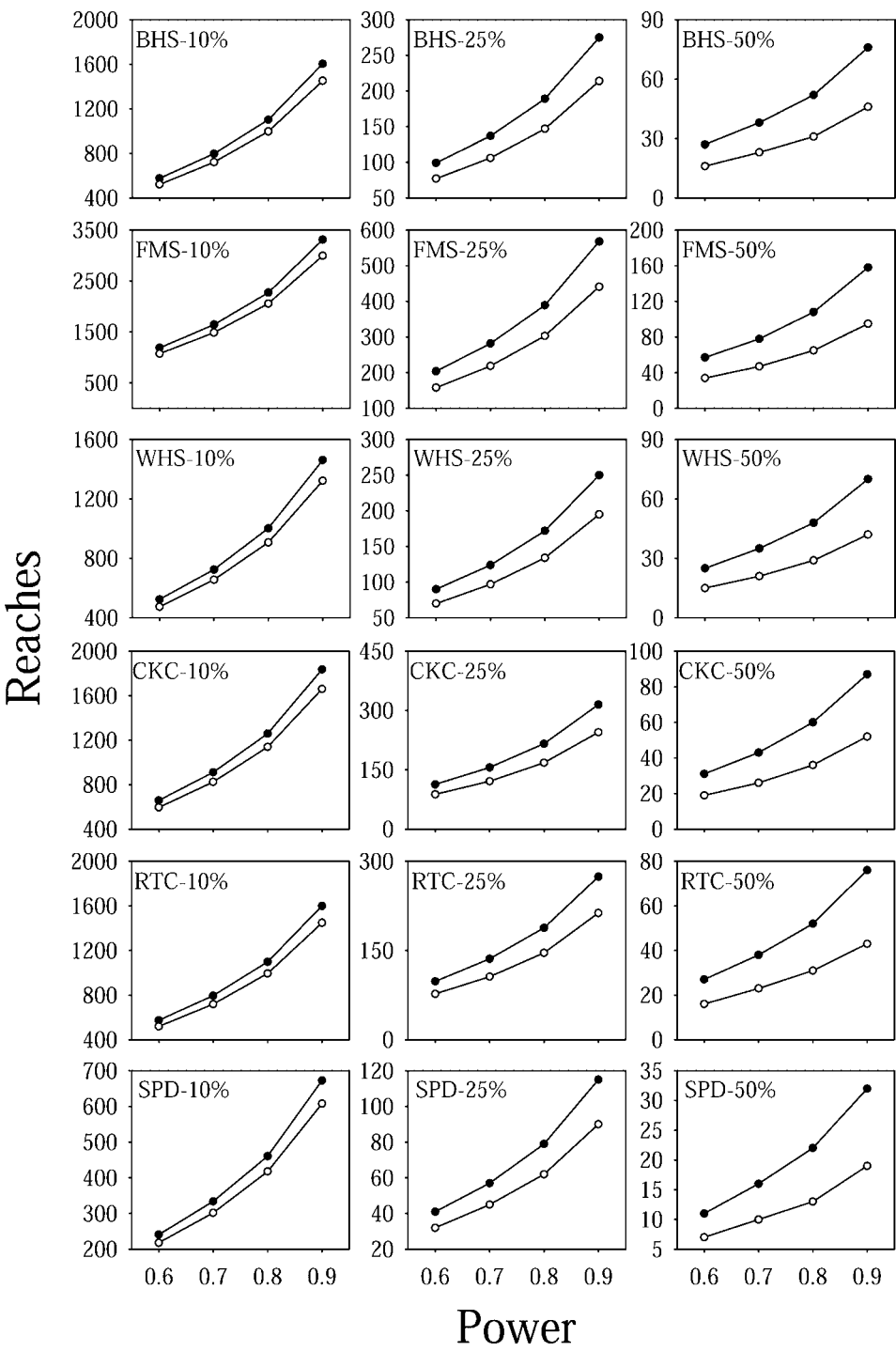| Species	Electrofishing only			Electrofishing plus seining		
	Mean	SD	CV	Mean	SD	CV
Bluehead sucker	3.79	4.08	107.65	4.38	4.49	102.51
Flannelmouth sucker	1.20	1.86	155.00	1.40	2.10	150.00
White sucker	5.78	5.95	102.94	6.48	6.65	102.77
Creek chub	9.51	10.97	115.35	12.41	12.60	101.53
Roundtail chub	8.81	9.10	103.29	14.59	11.96	81.96
Speckled dace	14.40	10.06	69.86	12.13	12.13	61.67

FIGURE 1.—Estimated number of reaches required to detect an increase (solid circle) or decrease (open circle) in catch per unit effort (CPUE; fish/100 m) of bluehead suckers (BHS), flannelmouth suckers (FMS), white suckers (WHS), creek chub (CKC), roundtail chub (RTC), and speckled dace (SPD) at different levels of statistical power in Muddy Creek, Wyoming. The percentage value associated with each figure represents the percentage change in CPUE detected (e.g., BHS-10% represents a 10% increase or decrease in CPUE of bluehead suckers).

change in CPUE generally required less than 80 reaches across species at all levels of statistical power. Regardless of the detection level, the estimated number of reaches was higher for detecting an increase compared with a decrease in CPUE. Sample size requirements increased with increasing statistical power.

Benefits of seining were highly variable among species, detection values, and levels of statistical power (Figure 2). Inclusion of seining reduced the number of reaches necessary to detect a 10% change in CPUE by several hundred reaches, but the estimated number of reaches was still greater than 300 for most species at the lowest level of power. When the detectable change was 25% or 50%, seining did not appreciably reduce the sample size requirements for any species.

Thus far, all analyses have assumed that n reaches are randomly sampled, followed by an additional n randomly sampled reaches. Figure 3 provides detectable levels of change in CPUE (i.e., electrofishing only) plotted against the correlation among fixed reaches. A correlation of zero indicates no relationship among time periods and is analogous to a random-sampling design. For all species, detectable changes in CPUE would be enhanced by using a fixed-site sampling design. For instance, a 50% increase in CPUE of bluehead suckers could be detected at 60% power by randomly sampling 25 reaches. If CPUE is highly correlated among reaches between time periods (e.g., $r = 0.60$), a 30% change in CPUE could be detected by sampling 25 reaches. For some species, an improvement of over 45% in the ability to detect a change in CPUE was observed. Increasing the number of reaches to 50 enhanced the level of change that might be detected. These same patterns were observed for electrofishing plus seining, but differences in detectable change between electrofishing and electrofishing plus seining were less than 15% among species.

Discussion

While the efficiency and selectivity of electrofishing and seining have been studied (e.g., Parsley et al. 1989; Bayley and Dowling 1990; Jackson and Noble 1995), few studies have investigated the use of both gears in the same system. Wiley and Tsai (1983) reported that electrofishing produced more precise population estimates and had higher mean catchabilities (q) for 13 fish species (mean $q = 0.69$) than seining ($q = 0.43$) in small Maryland streams. Patton et al. (2000) studied the effort needed to describe species richness in small Great Plains streams of Wyoming and found that sampling 200 m of stream by electrofishing was required to capture all fish species present, whereas seining required at least 300 m of stream to capture all

species. Our results suggest that seining did not greatly reduce the number of reaches necessary to monitor changes in the CPUE of native and nonnative fishes in Muddy Creek. One likely reason is the small size of Muddy Creek. Although electrofishing efficiency is dependent on a variety of factors (e.g., physical and chemical habitat conditions; Speas et al. 2004), sampling efficiencies are often higher in small streams than in large rivers (Wiley and Tsai 1983; Bayley and Dowling 1990; Speas et al. 2004). In systems where a species is rare or with low electrofishing efficiency (e.g., high conductivity), seining may be advantageous. Because electrofishing tends to sample larger fish than seining (e.g., Wiley and Tsai 1983; Bayley and Dowling 1990), seining may be particularly important when size structure information is needed.

Many analyses focusing on sample size estimation result in sample size requirements that are beyond the capabilities of fisheries scientists or exceed the number of possible sampling sites in a system (e.g., Bayley and Dowling 1990; Cyr et al. 1992; Rodgers et al. 1992; Peterson and Rabeni 1995; Van Den Avyle et al. 1995; Krueger et al. 1998). Paukert (2004) described sample size requirements for bluehead suckers and flannelmouth suckers in the lower Colorado River, Arizona, and found that detecting a 10% or 25% change in CPUE would require nearly 12,000 electrofishing samples and 10,000 trammel net samples depending on statistical power. Although monitoring changes in CPUE of fishes in Muddy Creek required less effort than in the lower Colorado River, sample size requirements with randomly selected reaches were still beyond the capabilities of most scientists and often greater than the number of available reaches in the system.

One method to increase the ability to detect changes in CPUE is to adopt a fixed-site sampling design. A fixed-site sampling design can provide a more sensitive measure of temporal variation, but comparing estimates to other systems can be difficult (King et al. 1981; Fourqurean et al. 2003; Brown et al. 2004). In contrast, randomly selected sites may better capture spatial variation, but spatial heterogeneity can obscure temporal trends (Fourqurean et al. 2003; Brown et al. 2004). The primary objective of sampling fish in Muddy Creek is to monitor whether CPUEs are increasing or decreasing (i.e., temporal variation). A fixed-site sampling design not only meets the objectives of sampling, but it has several advantages not realized with a random-sampling design. Depending on the correlation structure between time periods, relatively small changes in CPUE (up to a 15% change) may be detected by sampling 25–50 fixed sampling reaches in Muddy Creek. A fixed-site design
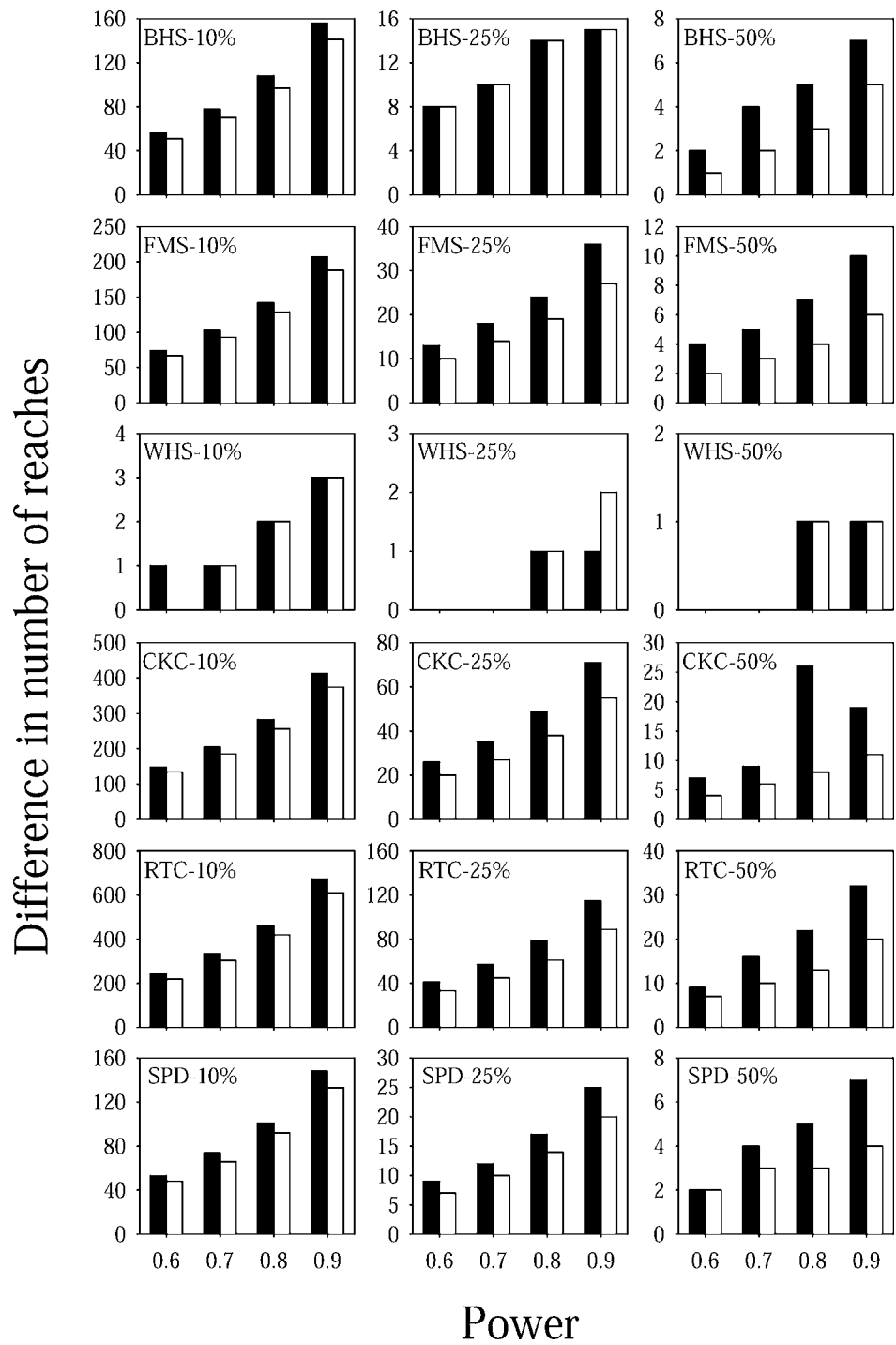
FIGURE 2.—Difference between the estimated number of reaches required to detect an increase (solid bar) or decrease (open bar) in catch per unit effort (CPUE; fish/100 m) of bluehead suckers (BHS), flannelmouth suckers (FMS), white suckers (WHS), creek chub (CKC), roundtail chub (RTC), and speckled dace (SPD) at different levels of statistical power using electrofishing only and electrofishing plus supplemental seining in Muddy Creek, Wyoming. The percentage value associated with each figure represents the percentage change in CPUE detected (e.g., BHS-10% represents a 10% increase or decrease in CPUE of bluehead suckers).
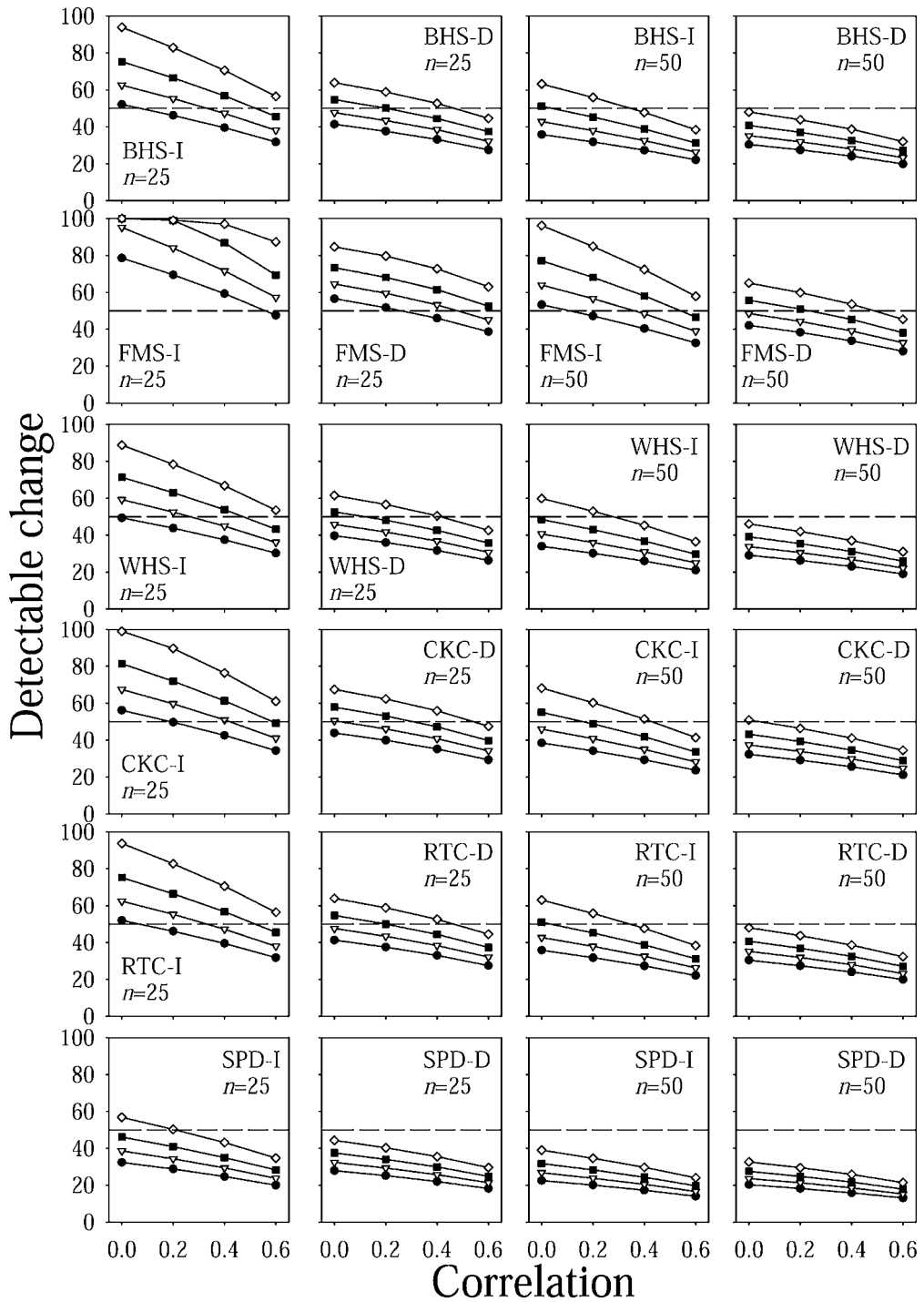
FIGURE 3.—Detectable change in catch per unit effort (CPUE; fish/100 m) of bluehead suckers (BHS), flannelmouth suckers (FMS), white suckers (WHS), creek chub (CKC), roundtail chub (RTC), and speckled dace (SPD) by electrofishing 25 or 50 reaches in Muddy Creek, Wyoming. Detectable changes were estimated at different levels of correlation (0.0–0.6; increments of 0.2) and at four levels of statistical power (60 [circle]; 70 [triangle]; 80 [square]; and 90% [diamond]). An increase (I) or decrease (D) is indicated for each species (e.g., BHS-I presents the detectable increase in CPUE of bluehead suckers).

also has the benefit of allowing long-term trends in CPUE to be evaluated using time-series or regression analyses. Although fixed-site sampling designs have a number of advantages, they may be limited for some species or in some systems. For instance, if a fixed-site sampling design is used, detection of differences in abundance may be hindered by changes in habitat use through time (e.g., Heggenes 2002; Jaeger et al. 2005). Changes in habitat use would result in low correlation between time periods, less statistical power to detect differences at a given detection level (e.g., 10% change in CPUE), and a need for more sampling sites. If the correlation between time periods is extremely low, then fixed-site sampling designs may provide little benefit relative to a random design. Depletion or mark–recapture estimates of population density may also be used to monitor trends in abundance (e.g., Paukert 2004), but these methods have numerous issues and constraints (e.g., Peterson et al. 2004). In headwater streams, such as Muddy Creek, a fixed-site sampling design is probably suitable for monitoring changes in CPUE, particularly if sampling sites are representative of available habitats and the season of sampling is standardized.

We recommend establishment of 25–50 fixed reaches and sampling only by electrofishing to monitor CPUE of fishes in Muddy Creek. Habitat characteristics and fish assemblages in Muddy Creek are similar to other small streams in the UCRB, suggesting that our results have application to a variety of headwater streams in the basin. Moreover, our analytical approach provides a framework for establishing realistic management objectives and monitoring programs in systems outside the Colorado River basin.

Acknowledgments

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