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Comparison of electrofishing and trammel netting variability for sampling native fishes

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The variability in size structure and relative abundance (CPUE; number of fish ≥200 mm total length, L_T, collected per hour of electrofishing or trammel netting) of three native Colorado River fishes, the endangered humpback chub *Gila cypha*, flannelmouth sucker *Catostomus latipinnus* and bluehead sucker *Catostomus discobolus*, collected from electrofishing and trammel nets was assessed to determine which gear was most appropriate to detect trends in relative abundance of adult fishes. Coefficient of variation (CV) of CPUE ranged from 210 to 566 for electrofishing and 128 to 575 for trammel netting, depending on season, diel period and species. Mean CV was lowest for trammel nets for humpback chub ($P = 0{\cdot}004$) and tended to be lower for flannelmouth sucker ($P = 0{\cdot}12$), regardless of season or diel period. Only one bluehead sucker >200 mm was collected with electrofishing. Electrofishing and trammel netting CPUE were not related for humpback chub ($r = -0{\cdot}32$, $P = 0{\cdot}43$) or flannelmouth sucker ($r = -0{\cdot}27$, $P = 0{\cdot}46$) in samples from the same date, location and hour set. Electrofishing collected a higher proportion of smaller (<200 mm L_T) humpback chub ($P < 0{\cdot}001$), flannelmouth suckers ($P < 0{\cdot}001$) and bluehead suckers ($P < 0{\cdot}001$) than trammel netting, suggesting that conclusions derived from one gear may not be the same as from the other gear. This is probably because these gears fished different habitats, which are occupied by different fish life stages. To detect a 25% change in CPUE at a power of 0·9, at least 473 trammel net sets or 1918 electrofishing samples would be needed in this 8 km reach. This unattainable amount of samples for both trammel netting and electrofishing indicates that detecting annual changes in CPUE may not be practical and analysis of long-term data or stock assessment models using mark-recapture methods may be needed to assess trends in abundance of Colorado River native fishes, and probably other rare fishes as well.

Key words: bluehead sucker; Colorado River; flannelmouth sucker; humpback chub; sampling.

INTRODUCTION

Fisheries researchers need precise estimates of fish population statistics (*e.g.* abundance and size structure) to adequately assess the status of fish populations. Previous research has suggested that gear bias is evident for many fish species and habitats (Hubert, 1996; Reynolds, 1996). Relative abundance and size structure indices are often different between gear types (Guy *et al.*, 1996;

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Hanchin *et al.*, 2002; Tate *et al.*, 2003), and variability in relative abundance within a gear type (Allen *et al.*, 1999; Tate *et al.*, 2003) can often mask year to year differences in relative abundance indices. Nonetheless, relative abundance estimates are often used in fisheries and are assumed to be an index of overall abundance (Hubert, 1996); however, this assumption is often not met (Harley *et al.*, 2001). In the mainstem Colorado River, Grand Canyon, various sampling gears are used because of the biases inherent in each gear in different habitats. Trammel nets and electrofishing, however, are two of the most common gear types used to collect native fishes (Valdez & Ryel, 1995).

There has been recent concern about the status of native fishes in the Grand Canyon, particularly the humpback chub *Gila cypha* Miller, which has been identified by the U.S. Government of being in danger of extinction (USFWS, 2002). The status and trends of other large-river native fishes, flannelmouth sucker *Catostomus latipinnus* Baird & Girard and bluehead sucker *Catostomus discobolus* Cope, are also monitored. Native fishes in the Grand Canyon have declined in abundance since impoundment of the Colorado River by the Glen Canyon Dam in 1963, and the fish populations currently may still be declining or are relatively stable at lower than historic abundances (Minckley, 1991). Recently, the U.S. Fish and Wildlife Service (USFWS) suggested that the humpback chub in the Grand Canyon could be downlisted if (in part) the trend in abundance of fish $\geq$200 mm did not decline over a 5 year period (USFWS, 2002). Therefore, sampling methodologies that allow for detection of trends in relative abundance and size structure (total length, L_T) over time would be beneficial (Tate *et al.*, 2003). There is a need to determine the most reliable sampling gears for native fishes in the Grand Canyon so population trends can be assessed and gear bias minimized.

The objectives of this study were to determine the precision of trammel netting and electrofishing in the Colorado River to assess relative abundance and size structure of humpback chub, flannelmouth sucker and bluehead sucker. High variability in relative abundance indices, which is common in native fish populations with low abundance (Counihan *et al.*, 1999; Paukert & Fisher, 1999) leads to low statistical power and reduces the utility of these indices to make management decisions (Peterman & Bradford, 1987). Therefore, this study was used to assess variability between gears in relative abundance indices, the length frequency for each native fish species and the samples size required to detect changes in relative abundance for each gear.

MATERIALS AND METHODS

Sampling was conducted as part of an ongoing monitoring programme of fish populations in the Grand Canyon. This study focused on sampling conducted in 1992 and 1993 in the Colorado River between rkm 96·6 and 104·7 (36°22′ N; 111°53′ W), near the confluence of the Little Colorado River (LCR). This 8 km area was chosen because of its higher density of native Colorado River fishes compared to other areas (Valdez & Ryel, 1995). The LCR, the largest tributary to the Colorado River in the Grand Canyon, enters the Colorado River at rkm 98·7. This tributary is the primary spawning area for native fishes (Childs *et al.*, 1998) and is the reason why there typically is a higher concentration of native fishes in the mainstem Colorado River in this area. Low and patchy catches of native fishes, however, are very common throughout the mainstem, including the reach near the LCR, probably because of alterations caused by Glen Canyon Dam (124 km upstream of the LCR confluence) and non-native species interactions (Minckley, 1991). Trammel nets were 22·9 m long, 1·8 m deep, and consisted of two outer walls of 30·5 cm multifilament netting and one inner wall of 2·5 cm multifilament netting. Nets were primarily tied to the shore and stretched across the river channel, but were occasionally suspended in the mid-water column of the river (Valdez & Ryel, 1995), usually in deepwater eddies or other areas previously known to be frequented by humpback chub, flannelmouth suckers and bluehead suckers (Hoffnagle *et al.*, 1999). To minimize fish mortality, nets were checked about every 2 h (median = 2·21 h, range: 1·5–3·35 h), but remained in the water throughout several sets (total soak time mean: 4·9 h, range: 1·6 to 12·1 h). Each 2 h check was treated as one sampling effort. Electrofishing was conducted along the shoreline using a 5 m Achilles inflatable boat equipped with pulsed-DC current using a Coffelt Mark XX Complex Pulse System (CPS) used to minimize injuries to native fishes (Valdez & Ryel, 1995; Hoffnagle *et al.*, 1999). Output typically ranged from 200 to 250 V and 8 to 10 A (Valdez & Ryel, 1995). Sampling stations consisted of only one general habitat type (*e.g.* sand bar) and therefore sampling times were variable because of different habitat lengths. Variation in CPUE tends to increase with sample time duration (Miranda *et al.*, 1996). To minimize this effect, only electrofishing samples that were between 0·15 and 0·75 h in duration and trammel net samples between 1·5 and 3·5 h were used in the analysis. Catch per unit effort (CPUE) was calculated as the number of fish $\geq$200 mm L_T (for each species) collected per hour of trammel netting or electrofishing. A minimum size of 200 mm was used because this is the minimum size of adult humpback chub defined in the U.S. Fish and Wildlife Service recovery goals (USFWS, 2002). This same size was used for flannelmouth and bluehead suckers for consistency.

To ensure that the analysis included sampling from both all gear types and diel periods, the samples were grouped by seasons (February, March and April: spring; May, June and July: summer; August, September and October: autumn). November, December and January were not used in the analyses because of limited sampling conducted during these months. Samples were also categorized by diel periods. Night samples were samples started from 1 h prior to sunset to 1 h prior to sunrise and day samples were samples started at 1 h prior to sunrise to 1 h prior to sunset. In addition, results were limited to the years 1992 and 1993, in which all gear types were used in all diel periods and seasons.

STATISTICAL ANALYSIS

Trammel net and electrofishing relative variability in CPUE were compared by using the coefficient of variation (CV, $CV = 100\text{S.D.}\,\bar{x}^{-1}$; Zar, 1996) calculated for each gear type, season, diel period and year for the entire 8 km area. An analysis of covariance (ANCOVA) was then used to determine the effects of gear type, diel period and season (with year as a covariate) on mean CV of CPUE for each species. Prior to analysis, homogeneity of variances was determined by Levene's test (Zar, 1996). The sample size needed to detect a 10 and 25% difference in mean CPUE for each gear was estimated using methods described by Allen *et al.* (1999) and Tate *et al.* (2003). To estimate the required sample sizes, the mean and S.D. estimates of CPUE for both years combined were used. Spearman rank correlations were used to compare 'paired' CPUE indices for trammel nets and electrofishing. This was done by using only trammel nets and electrofishing stations that were conducted during the same date, year, month and hour at the same 0·16 rkm. In this analysis, only samples that did not have 0 CPUE for both gears were used. Although these samples were not intentionally 'paired', the samples were collected at the same time and location and offered insight into gear difference by minimizing spatial and temporal differences in sampling. To determine if the proportion of fishes collected $\geq$200 mm L_T differed between gear types, diel periods and among seasons for each species, a likelihood-ratio χ^2 test (SAS, 1996) was used. In this analysis, only the gear type, season and diel period combinations where at least 10 fish of each species were collected were used. When the low numbers of fishes collected precluded the analysis by diel period and season (which occurred in all but one of the flannelmouth sucker and bluehead sucker analyses), diel periods and seasons were combined and a Kolmogorov–Smirnov test was used (Zar, 1996). A α level $P = 0{\cdot}10$ was set for all tests (including the power analysis).

RESULTS

A total of 272 electrofishing stations and 303 trammel net sets were used from February to October, 1992 and 1993. Electrofishing collected a total of only 20 humpback chub, 17 flannelmouth suckers and one bluehead sucker ≥200 mm L_T, whereas trammel netting captured 222 humpback chub, 85 flannelmouth suckers and 31 bluehead suckers ≥200 mm L_T. Mean CPUE values for electrofishing across all years, seasons and diel periods was <0·27, depending on species (Table I). Mean trammel netting CPUE was also low across all years, seasons and diel periods, ranging from 0·05 to 0·34, depending on species (Table I). The variability about the mean CPUE was not related to the duration of electrofishing (categorized at 0·05 h intervals) for humpback chub ($r = 0{\cdot}10$, $n = 9$, $P = 0{\cdot}80$), flannelmouth sucker ($r = -0{\cdot}35$, $n = 9$, $P = 0{\cdot}35$) or bluehead sucker ($r = -0{\cdot}14$, $n = 9$, $P = 0{\cdot}73$). Similarly, there were no relationships between variability about the mean CPUE for trammel netting (categorized in 0·1 h intervals) for humpback chub ($r = -0{\cdot}33$, $n = 17$, $P = 0{\cdot}20$), flannelmouth sucker ($r = 0{\cdot}001$, $n = 17$, $P = 0{\cdot}99$) or bluehead sucker ($r = -0{\cdot}37$, $n = 17$, $P = 0{\cdot}14$).

CPUE VARIABILITY

There were no two-or three-way interactions between gear type, season or diel period in the humpback chub ANCOVA of the CV ($P > 0{\cdot}15$). Mean CV was higher in electrofishing compared to trammel netting ($F_{1,6}$, $P = 0{\cdot}004$) (Table I).

TABLE I. Catch statistics (mean ± S.D.) of native fishes collected between rkm 96·6 and 104·7 in the Colorado River, Grand Canyon, Arizona, between February and October, 1992 and 1993

	CPUE			CV		
Species and gear	Mean ± S.D.	Range	*n*	Mean ± S.D.	Range	*n*
Humpback chub						
Electrofishing	0·25 ± 1·08	0–8·70	272	338 ± 104	210–529	7
Trammel netting	0·34 ± 0·72	0–7·13	303	197 ± 49	128–283	11
Flannelmouth sucker						
Electrofishing	0·26 ± 1·11	0–8·47	272	383 ± 116	242–566	8
Trammel netting	0·12 ± 0·34	0–2·73	303	268 ± 116	128–469	10
Bluehead sucker						
Trammel netting	0·05 ± 0·18	0–1·54	272	347 ± 114	229–575	8

CPUE, the number of fish ≥200 mm L_T collected per hour of electrofishing or trammel netting; CV, coefficient of variation ($100\text{S.D.}\,\bar{x}^{-1}$) is an index of variability in CPUE values; *n*, number of trammel nets or electrofishing stations for CPUE and number of CV observations for CV (*i.e.* season, diel period and year combinations).

The mean CV, however, did not differ among seasons ($F_{2,6}$, $P=0{\cdot}53$) or between diel periods ($F_{1,6}$, $P=0{\cdot}16$). There was higher variability in CPUE of humpback chub $\geq$200 mm L_T using electrofishing, regardless of season or diel period.

There were no two or three-way interactions among effects (*i.e.* diel period, gear type and season; $P \geq 0{\cdot}40$) in the flannelmouth sucker ANCOVA of the CV. In addition, mean CV did not differ among seasons ($F_{2,6}$, $P=0{\cdot}53$), between diel periods ($F_{1,6}$, $P=0{\cdot}40$), but tended to differ between gear types ($F_{1,6}$, $P=0{\cdot}12$) (Table I). There tended to be higher variability in CPUE of flannelmouth suckers $\geq$200 mm L_T by electrofishing compared to trammel netting, regardless of season or diel period.

An analysis of gear types could not be conducted on bluehead sucker CPUE because of electrofishing produced only one bluehead sucker $\geq$200 mm L_T. The CPUE comparisons, however, were made between diel periods and among seasons for trammel nets. There was no difference in mean CV of bluehead suckers among seasons ($F_{2,2}$, $P=0{\cdot}95$) or diel periods ($F_{1,2}$, $P=0{\cdot}90$), or the interaction between season and diel period ($F_{1,2}$, $P=0{\cdot}50$). Very few trammel nets, however, collected bluehead suckers (278 of 303 trammel net sets had no fish).

CPUE RELATIONSHIPS IN 'PAIRED' SAMPLES

Trammel net and electrofishing CPUE for samples collected at the same location, date and hour were not positively related for humpback chub ($r=-0{\cdot}31$, $n=9$, $P=0{\cdot}43$) and flannelmouth suckers ($r=-0{\cdot}27$, $n=10$, $P=0{\cdot}46$). In many instances, one gear collected fishes whereas the other gear collected no fishes in these 'paired' samples. Bluehead sucker CPUE comparisons were not made because only one sample collected at least one bluehead sucker in the trammel net and electrofishing. Clearly, CPUE of native fishes from trammel nets does not necessarily reflect the CPUE of electrofishing.

ESTIMATES OF SAMPLE SIZES REQUIRED

Trammel netting required lower sample sizes to detect changes in CPUE for both humpback chub and flannelmouth suckers. To detect a 10% change in CPUE with a power of 0·9, however, trammel netting still required up to 3844 net sets for humpback chub and up to 5279 for flannelmouth suckers (Fig. 1). Sample sizes required to detect a 25% change in CPUE for humpback chub ranged from 170 (trammel netting at power = 0·6) to 2944 samples (electrofishing at power = 0·9). To detect a 25% change in flannelmouth sucker CPUE, a minimum of 304 samples were need for trammel netting at a power = 0·6 (Fig. 1). The samples size needed for trammel netting bluehead suckers ranged from 489 (25% change at 0·6 power) to 8521 (10% change at 0·9 power). In general, samples sizes to detect changes in CPUE in this Colorado River reach were lower for trammel nets, but still constituted a very high and logistically impractical amount of effort that probably would sample the entire reach completely.

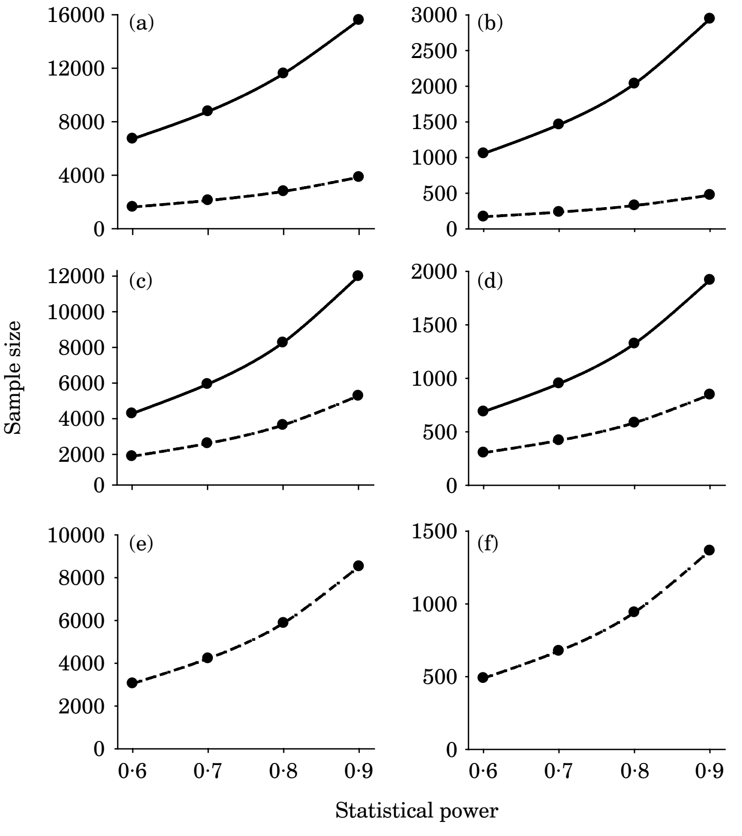

FIG. 1. Sample size needed to detect (a), (c), (e) 10 or (b), (d), (f) 25% change in CPUE for (a), (b) humpback chub and (c), (d) flannelmouth sucker collected with electrofishing (–●–) and trammel netting (--●--), and (e), (f) bluehead suckers with trammel nets (--●--) at four levels of power.

SIZE STRUCTURE

The proportion of humpback chub ≥200 mm L_T collected by electrofishing ranged from 1 (daytime during the autumn) to 6% (night-time during the spring), whereas the proportion of humpback chub ≥200 mm L_T collected by trammel netting ranged from 89 (night-time during the spring) to 97% (night-time during the summer). The proportion of fish ≥200 mm L_T differed by gear type (χ^2, d.f. = 1, $P < 0{\cdot}001$) but not season (χ^2, d.f. = 2, $P = 0{\cdot}40$) or diel period (χ^2, d.f. = 1, $P = 0{\cdot}11$). A higher proportion of large humpback chub were collected with trammel nets compared to electrofishing (Fig. 2).

In only one instance (night-time during the autumn) there were at least 10 flannelmouth sucker collected by electrofishing ($n = 11$) so analysis of size structure could not be conducted for different diel periods and seasons. The proportion of flannelmouth suckers ≥200 mm L_T collected by electrofishing (49%), however, was lower than from trammel netting (100%). There was a higher proportion of smaller fish collected by electrofishing compared to trammel netting (KSa = 2·85, $P < 0{\cdot}001$) (Fig. 2). For bluehead suckers, only trammel netting in the spring during the daytime collected at least 10 fish ($n = 13$). Only

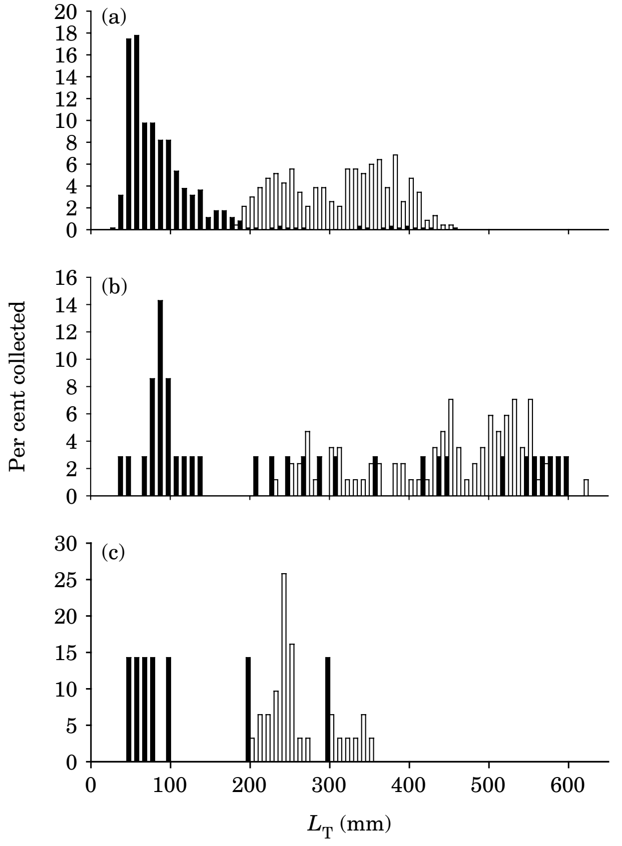

FIG. 2. Total length distributions of (a) humpback chub, (b) flannelmouth sucker and (c) bluehead sucker collected by trammel netting (□) and electrofishing (■) in February to October, 1992 and 1993, from rkm 96·6 to 104·7, the Colorado River, Grand Canyon. (a) $n = 636$ for electrofishing and 234 for trammel netting, (b) $n = 35$ for electrofishing and 85 for trammel netting and (c) $n = 7$ for electrofishing and 31 for trammel netting.

one of seven bluehead suckers collected by electrofishing was $\geq$200 mm L_T, whereas only one of 31 bluehead sucker collected by trammel netting was <200 mm L_T. Electrofishing collected a higher proportion of smaller fish compared to trammel netting (KSa = 1·97, $P < 0{\cdot}001$) (Fig. 2).

DISCUSSION

Trammel netting for native fishes in the Grand Canyon produced lower variability in CPUE and a higher proportion of larger fishes than electrofishing, regardless of season and diel period. Low catches of all three native fish species, however, led to high variability in both trammel nets and electrofishing, even though sampling was conducted in areas believed to be occupied by native fishes (Hoffnagle *et al.*, 1999). Both gears are commonly used to collect native Colorado River fishes (Keading & Zimmerman, 1983; McAda & Wydoski, 1985; Chart & Bergersen, 1992; Valdez & Ryel, 1995; McKinney *et al.*, 1999) and both have been criticized for sampling bias (Hubert, 1996; Reynolds, 1996). Nonetheless, these gears are two of the most common and potentially effective gears in these large river habitats. Fisheries researchers, however, need to consider their target size of fishes when selecting the appropriate gear. The present results suggest that trammel net and electrofishing CPUE for adult ($\geq$200 mm L_T) native fishes was not related and conclusions about the population from one gear may not be the same as conclusions from the other gear.

The disparity of fish sizes collected by electrofishing and trammel netting is probably due to the unique habitats where these gears are fished as well as the life stages of native fishes in these habitats. Electrofishing was conducted primarily in nearshore habitats whereas trammel nets were primarily used in deepwater pools and eddies (Valdez & Ryel, 1995). Juvenile humpback chub, flannelmouth suckers and bluehead suckers (<200 mm L_T) typically use shoreline areas (Tyus *et al*., 1982; Minckley, 1991; Converse *et al*., 1999), possibly with more vegetation or other cover (Converse *et al*., 1999), which are more difficult to sample with trammel nets than electrofishing. Adults of these same species typically occupy deepwater eddies, tributary mouths and offshore habitats (Tyus *et al*., 1982; Minckley, 1991; Valdez & Ryel, 1995; Valdez & Hoffnagle, 1999), which are more easily sampled with trammel nets than electrofishing. Therefore, the present results may not only be explained by gear bias, but also by location of sampling gears and fish life stages.

Although trammel netting produced the lowest variability of adult CPUE for native fishes, variability was still very high and may have precluded the detection of CPUE changes on an annual basis, and therefore CPUE may not be an appropriate index of abundance for these rare fishes. The sample sizes needed probably require a higher effort than would be possible (*i.e.* sample sizes encompassed the entire sampling universe of sample locations; Thompson, 2002). All three native fishes are relatively rare in the mainstem Colorado River when compared to the warmer water tributaries (*e.g.* Little Colorado River, Havasu Creek and Paria River; Keading & Zimmerman, 1983; Weiss *et al*., 1998; Douglas & Douglas, 2000). The CV estimates ranged from 128 to 575, suggesting very high variability in catches of these native fishes even when sampling concentrated on native fish habitats. Based on this high variability, at least 1057 trammel net sets would be needed in this 8 km reach to detect a 10% change in annual CPUE. This amount of effort is logistically not feasible and therefore suggests that using annual point estimates of relative abundance are not adequate to detect changes in native fish relative abundance. Given an appropriate sampling design, analysis of long-term CPUE trends using trammel nets may be more appropriate than electrofishing for adult native fishes in the mainstem Colorado River in the Grand Canyon.

Trammel nets in the mainstem Colorado River may provide more precise estimates of relative abundance of adult native fishes when compared to electrofishing. Both gears, however, are inherently biased to habitats and life stages of fishes where these gears can be effectively fished. Because the U.S. Government have developed criteria that determine 200 mm L_T is the minimum size of an adult humpback club (USFWS, 2002), the use of trammel nets is recommended over electrofishing in the mainstem as this gear collected a higher proportion of fish $\geq$200 mm L_T and variability of this gear was lower than electrofishing. As diel period and season did not affect variability, sampling should be conducted when logistically feasible, but sampling should be consistent with regards to season and diel period. High variability in CPUE of both gears suggest that analysis of long-term trends are more appropriate to determine trends in CPUE of native fish populations than individual CPUE point estimates, and this is probably true for other rare or endangered fishes in riverine environments. Because of the high variability in CPUE, intensive mark recapture estimates using stock assessment models may be more appropriate to determine population trends than CPUE for these rare fishes. Trammel nets in the mainstem Colorado River is recommended over electrofishing for long-term monitoring of adult native fishes relative abundance. Sampling nearshore habitats by electrofishing or some other gear not analysed in this study (*e.g.* seines, hoop nets or trammel nets with smaller mesh sizes), however, may be more appropriate for detecting juvenile relative abundance or recruitment variability.

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