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Relative Length Frequency: A Simple, Visual Technique to Evaluate Size Structure in Fish Populations

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Abstract.—I developed a way to rapidly evaluate the size structure of fish populations designed to be readily understood by a wide audience. Relative length frequency compares the length frequency of fish from a particular water body with an average developed for a region. This technique is analogous to relative weight, relative condition, or relative growth, which are used to compare the condition or growth of fish in a particular water body with rangewide or regional standards. Relative length frequency can be used in conjunction with relative weight or relative growth to rapidly identify factors potentially limiting fish production. I demonstrate this method with data on largemouth bass *Micropterus salmoides* from Washington State and roundtail chub *Gila robusta* from Arizona that were collected during standardized electrofishing surveys.

Length-frequency histograms are among the oldest methods used to assess size structure in fish populations (Everhart and Youngs 1981). Although a length-frequency histogram is simple and inexpensive to construct, it often can be difficult to interpret given the few standards by which to assess whether the length frequency is optimal or expected for a given situation.

Proportional stock density (PSD), relative stock density (RSD), and young–adult ratio are indices used widely to assess size structure in freshwater sport fish populations (Anderson 1976, 1980; Reynolds and Babb 1978; Wege and Anderson 1978). Comparing the structural index of a stock with a standard developed from ''balanced'' populations (e.g., PSDs of 40–70 for largemouth bass *Micropterus salmoides* in central U.S. areas) can help evaluate the status of the particular population. A stock density index compresses the entire length-frequency distribution into a single number, which can result in the loss of much information from an entire length-frequency histogram (Gabelhouse 1984). Therefore, two other types of indices have been developed; based on five-cell length categories, they provide means to evaluate the length distribution in greater detail (Gabelhouse 1984). Traditional RSDs (e.g., RSD-P, RSD-Q, RSD-M, RSD-T) are the percentage of stock-length and larger fish exceeding a particular length (e.g., trophy, T; memorable, M; preferred, P; quality, Q; and stock, S). Incremental RSDs (e.g., RSD S-Q, RSD Q-P, RSD P-M, RSD M-T) are the percentage of stock-length and larger fish that fall between two length categories.

One limitation to stock density indices is the restriction of their application only to sport fishes. Gabelhouse (1984) recommended that his length-categorization system be only for fishes regularly caught by anglers because the fish lengths used in his five-cell categories and for PSD are based on angling records. A method that could be used to analyze length frequency data for all fishes, both sport and nongame, would be useful to fisheries managers.

Even for sport fish populations, information provided by current stock density indices is often not enough. In some systems, obtaining the necessary sample size for precise estimates of PSD or RSD can be difficult because of low catch rates of stock size and larger fish (Serns 1985; Divens et al. 1998). A method with the option to incorporate a greater proportion of the length-frequency distribution of fish from these systems, such as fish smaller than stock length, would increase sample size and statistical power.

Because stock density indices are derived from numbers of fish of harvestable size, they can be ineffective at providing interpretive information on overharvested sport fish populations (Willis et al. 1993). Overharvesting is common in many water bodies that are intensively managed for sport and commercial fisheries, especially popular sites near urban centers. The ability to incorporate fish lengths below that commonly harvested would allow for easier recognition of overharvesting.

Length-frequency information can be difficult to interpret and explain, especially to audiences with

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little training in fisheries. Support of commissioners, legislators, sports groups, commercial fisheries groups, and the general public is usually necessary for successful implementation of fisheries management decisions. It is crucial that the length-frequency information often used for these decisions is clearly presented for such audiences.

To complement information available from length-frequency indices and provide a rapid, visual means of evaluating a length-frequency histogram for both sport and nonsport fishes, I developed the method relative length frequency (RLF). This procedure compares the length-frequency distribution obtained from a sample of fish from a water body with an ''average'' length-frequency distribution (ALF) for that particular region, state, or water type. Relative length frequency compares the length structure of a population with a standard for that population, similar to the way that relative weight (W_r; Wege and Anderson 1978), relative condition (Swingle and Shell 1971), and relative growth (Hubert 1999) compare the weight or growth of individual fish with a respective standard. When used in combination with condition indexes, catch per unit effort (CPUE), or growth data, RLF can be used to visualize the degree of mortality, recruitment in relation to available food, or growth of individuals relative to an average for the region, state, or type of water body. The RLF procedure is simple and rapid to conduct, is easy to understand, and is best suited for rapid, standardized surveys of sport and nongame fishes. The RLF procedure is flexible enough to use established length-groups (e.g., Gabelhouse [1984] five-cell categories) if comparison between regions is the objective. However, other length-groups can also be used to include a greater proportion of the lengths or to address other objectives.

The objectives of this study were to (1) describe RLF and discuss how it was developed; (2) illustrate how RLF can complement the information provided by traditional indexes of stock structure, using largemouth bass *Micropterus salmoides* in Washington State and roundtail chub *Gila robusta* in Arizona as examples; and (3) discuss general management implications of RLF.

Methods

Relative length frequency compares the length-frequency distribution of a particular population of fish with an average for the region. Therefore, the first step of this procedure is to develop a standard against which an individual population is compared, an ALF. This average can be developed for a variety of fish species from a range of water bodies. As examples I demonstrate how I developed ALFs for largemouth bass in Washington State and roundtail chub in Arizona.

First, various populations of the fish species of interest must be sampled to obtain length data. For largemouth bass, I obtained length data from populations in 39 Washington lakes sampled by the Washington Department of Fish and Wildlife (WDFW; Zook 1978; Fletcher 1982, 1983; Bonar et al. 1995; WDFW, unpublished data). These lakes were not chosen randomly; however, they represented a broad cross section of lakes from 1-ha ponds to 11,429-ha reservoirs (median size = 65 ha) representing the range of habitats of largemouth bass populations in Washington. Largemouth bass in some lakes were fished heavily; others received little or no angling effort. Lakes were surveyed between 1978 and 1994 by boat electrofishing. Two anodes were used, each consisting of a Wisconsin ring and cable droppers, and the boat served as the cathode. Electrofishing started after dark and was generally conducted for 0.5–2 h. Lakes were generally electrofished one to three nights; all sizes of largemouth bass were netted, and the total length (TL, mm) of each fish was measured. Gillnetting and electrofishing data were combined in 14 of the original data sets, which were designed as standard surveys of the lakes' fish communities. Almost no largemouth bass were caught in gill nets (D. H. Fletcher, WDFW, personal communication; W. Zook, WDFW, personal communication; S. Bonar, unpublished data), so I concluded that length frequencies developed from these surveys were based primarily on electrofishing data, and size-biased data from gill-net samples had little effect.

For roundtail chub, I obtained length-frequency data collected between 1962 and 2001 in more than 70 river and stream surveys from the Arizona Game and Fish Department. To ensure sampling methods were consistent, I averaged only length data from the fall daytime electrofishing surveys. Only recently were headwaters chub *G. nigra*, which closely resemble roundtail chub, declared a separate species (Minckley and DeMarais 2000). Previously, therefore, any headwaters chub were likely identified as roundtail chub. Because I felt that length-frequency information from the two species would be different, I excluded from my analysis surveys in which headwaters chub were likely to be captured. Arizona streams and rivers are often perennial in upper elevations and then disappear below ground as the streams flow to lower elevations. This provides some degree of separation among populations and I assumed each stream or river would be a distinct unit for management. Therefore, for my analysis I grouped fish by stream. The resulting 11 streams and rivers I used to develop the ALF had long-term median flows ranging from slightly more than 0 to 9 m^3/s. Shallow pools and riffles were sampled with Colfelt or Smith–Root Backpack electrofishers. Deep pools, glides, and rapids were sampled by canoe electrofishers. Canoe electrofishers consisted of a Smith–Root GPP5 or a Colfelt VVP15 and a generator mounted in a 5.2-m-long canoe. Two colanders fastened together served as the anode, and cables or metal plates attached to the hull of the canoe served as cathodes.

Next, I chose length-groups for the analysis. The size and number of these length-groups is arbitrary; however, using length-groups for freshwater sport fishes based on Gabelhouse's (1984) five-cell length categories would facilitate comparisons with other regions. For nongame fishes, to incorporate a greater proportion of the length-frequency distribution, or in areas where overharvesting is a serious concern, another set of length-groups can be chosen. The five length-groups I chose for the Washington largemouth bass example (100–200, 201–300, 301–375, 376–450, and >450 mm TL) were not based on Gabelhouse's (1984) five-cell categories because a majority of largemouth bass in Washington lakes were smaller than stock size, but larger than age 0 (i.e., between 100 and 200 mm). Five groups were chosen because further subdivision of the histogram emphasized variability in the individual lake histograms, preventing simple comparisons with statewide averages (Sokal and Rohlf 1969). I also selected five length categories (0–100, 101–200, 201–300, 301–400, >400 mm TL) for the roundtail chub data.

In most instances, the minimum length selected for the ALF should exclude age-0 fish. Age-0 fish can experience high mortalities, especially during the first winter. Because of their large, fluctuating numbers, age-0 fish included in an ALF can mask the dynamics of the adult population. Data presented in Fletcher et al. (1993) suggested age-0 largemouth bass in Washington were usually larger than 100 mm. Therefore, I set the minimum size of the Washington State largemouth bass example at 100 mm to include all fish age 1 and older. The roundtail chub I considered not to be subject to this rule. Extreme conditions are uncommon in southern desert rivers during the winter months, and roundtail chub mortalities are unlikely to be greater in winter than at other times of the year. Therefore, age-0 fish were included in the roundtail chub ALF. At the time of the fall surveys, age-0 roundtail chub were several months old and were larger than the fry stage, where substantial mortality occurs.

The percentage of fish in each length-group from each water body is then averaged to construct the ALF. For the largemouth bass and the roundtail chub examples, I averaged the percentage in each size-group over 39 lakes and 11 streams and rivers, respectively.

Next, a length-frequency histogram from an individual water body is plotted adjacent to the ALF to estimate how that population compares with the average. This plot can be combined with an analysis of W_r, relative growth, or CPUE data to identify potential limiting factors of the population. For largemouth bass, I demonstrated this by comparing their populations from three Washington lakes (North Gissberg Pond, Clementine Lake, and Trails End Lake) with the ALF for Washington largemouth bass. Largemouth bass were the dominant piscivore in each lake, but available forage and angling pressure differed among the lakes. Fish in all three lakes were sampled in October 1994 with night boat electrofishing techniques identical to those used to sample lakes for the ALF. Total length (mm) and weight (g) were obtained for each largemouth bass captured. Total length data were plotted as a length-frequency histogram next to the Washington State ALF. Weight data from individual fish were converted to W_r values by using the procedures of Henson (1991). Relative weights were then plotted against total length.

For roundtail chub, I compared populations from the Lower Verde River and West Clear Creek with the Arizona roundtail chub ALF. Fish in both sites were sampled in September 1998 and 1999, respectively, with day electrofishing techniques identical to those used to sample streams and rivers for the ALF. Total length (mm) was obtained for each roundtail chub captured. Total length data were plotted as a length-frequency histogram next to the Arizona ALF.

Results and Discussion

The ALF developed for Washington State largemouth bass found that, on average, 62% (range = 6–98%) of the electrofishing catch was 100–200 mm TL; 26% (range = 1–61%) was 201–300 mm TL; 7% (range = 0–35%) was 301–375 mm TL; 4% (range = 0–15%) was 376–450 mm TL; and

2% (range = 0–15%) was greater than 450 mm TL. The ALF developed for Arizona roundtail chub found that, on average, 46% (range = 0–84%) of the electrofishing catch was 0–100 mm TL; 25% (range = 0–60%) was 101–200 mm TL; 14% (range = 0–41%) was 201–300; 7% (range = 0–50%) was 301–400; and 8% (range = 0–53%) was 401–500 mm TL.

Comparing the length-frequency histogram of an individual lake or river with the corresponding ALF histogram enables the researcher to determine whether the size structure of the population is average or contains a greater percentage than average of smaller or larger fish for the region. Individual lake histograms that are skewed to the left (i.e., display a greater percentage of small fish than large fish) when compared with the state or regional ALF may represent populations experiencing above-average exploitation or other forms of mortality or populations where availability of prey is limiting growth of small fish (Figure 1A). Conversely, those histograms that are skewed to the right (i.e., display a greater percentage of large fish than small fish) when compared with the state or regional ALF, may represent populations experiencing lower than average mortality (e.g., those that are exploited less than average) or those with low recruitment (Figure 1B). Populations with histograms close to ALF values are average for the region (Figure 1C). Not shown in Figure 1 are populations that may be experiencing high mortality of both young and older fish, such as a largemouth bass population consisting of overfished adults and young that compete with and are eaten by panfishes such as bluegills *Lepomis macrochirus*. These populations do not express a standard relationship with ALF and are often better identified by low CPUE values for all size groups.

The degree and direction of skew (g_1) can be quantified (e.g., Zar 1984). The ALF g_1 values for Washington State largemouth bass and Arizona roundtail chub were 1.83 and 1.35, respectively. The plot for an individual lake is skewed to the left when its g_1 is greater than g_1 of the ALF. Conversely, it is skewed to the right if its g_1 is less than g_1 of the ALF.

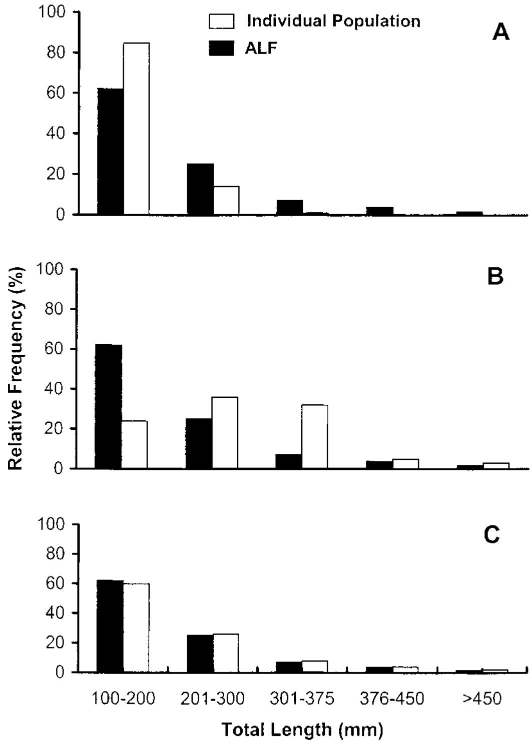

FIGURE 1.—Hypothetical length-frequency distributions of a fish species from individual water bodies compared with the statewide or regionwide average length frequency (ALF). The degree and direction of skewness is represented by g_1. A water body, such as that in panel **A,** that displays a greater than average percentage of small fish (individual population g_1 > ALF g_1) can represent populations that are experiencing higher than average exploitation or other forms of mortality or populations where lack of prey is limiting the growth of the smaller fish. Water bodies, such as that in panel **B,** that display a greater than average percentage of large fish (individual g_1 < ALF g_1) can represent populations that are exhibiting lower than average mortality or those that have low recruitment. Populations, such as that in panel **C,** for which the individual lake histogram is close to the ALF are average for the region (individual population g_1 = ALF g_1).

Largemouth Bass Examples

Using RLF plots in conjunction with W_r data allows rapid identification of potential bottlenecks experienced by largemouth bass populations in the three individual lakes.

North Gissberg Pond.—North Gissberg Pond (3.6 ha) is located in a county park north of Marysville, Washington, close to urban centers. The lake receives intense fishing effort, and the entire shoreline is accessible to anglers. Approximately 2% of the lake's volume is occupied by aquatic macrophytes. Bluegills, pumpkinseed sunfish *Lepomis gibbosus*, prickly sculpin *Cottus asper*, and crayfish *Pacifastacus* spp. provide forage for largemouth bass. The lake was stocked annually with catchable-sized trout *Oncorhynchus* spp. and occasionally with channel catfish *Ictalurus punctatus*. Most of the 104 largemouth bass collected that

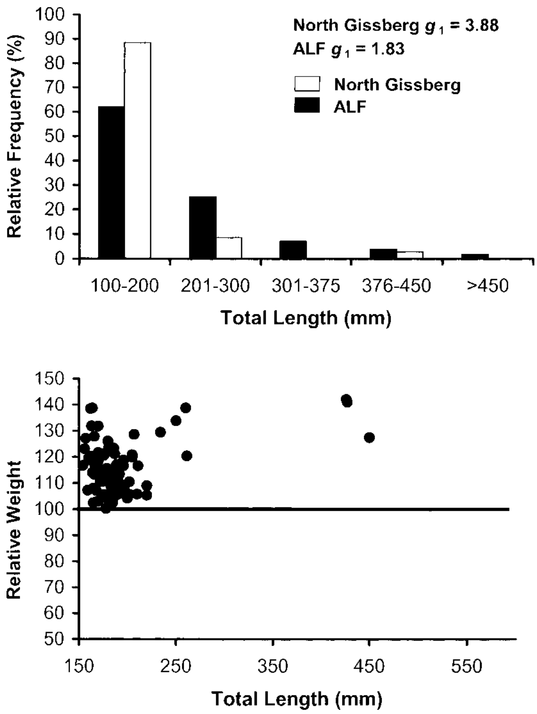

FIGURE 2.—Relative length frequency and relative weight plots for largemouth bass captured by night electrofishing in North Gissberg Pond, Washington, October 1994. The North Gissberg Pond length frequency is plotted next to the average length frequency (ALF) for Washington State. The degree and direction of skewness are represented by g_1.

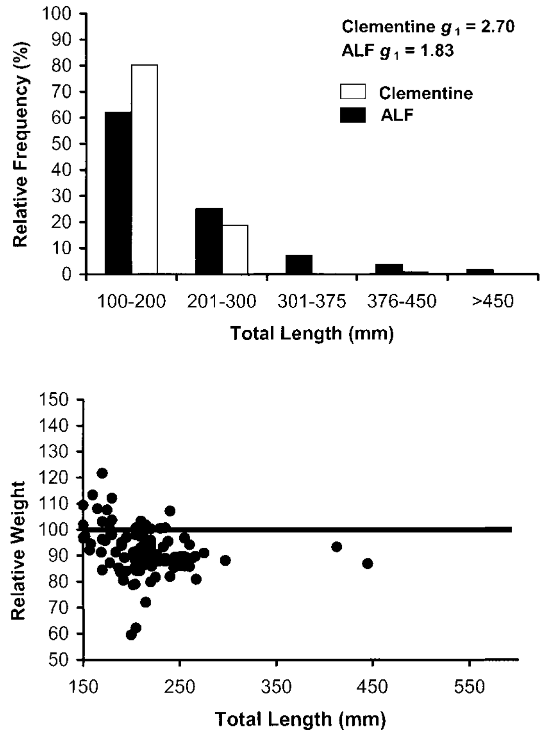

FIGURE 3.—Plots of relative length frequency and relative weight for largemouth bass captured by night electrofishing in Clementine Lake, Washington, October 1994. The Clementine Lake length frequency is plotted next to the average length frequency (ALF) for Washington state. The degree and direction of skewness are represented by g_1.

were larger than 100 mm TL were small compared with the ALF (Figure 2; g_1 = 3.88). The W_r values for all largemouth bass were high, suggesting that food abundance was not limiting growth into larger size classes (Figure 2). This evidence suggests that angling pressure may be removing many of the larger fish, and more restrictive regulations might increase the proportions of large largemouth bass.

Clementine Lake.—Clementine Lake (1.3 ha) is located in the arid shrub-steppe region of eastern Washington. Approximately 20% of the volume of the lake is occupied by aquatic macrophytes. The lake is isolated and receives little angling effort. The electrofishing survey yielded 329 largemouth bass larger than 100 mm TL. At the time of the survey, no other fish species were present in the lake. The RLF plot indicates few fish were in the larger length-groups relative to the ALF (Figure 3; g_1 = 2.70). However, W_r values that declined with TL and the presence of a high proportion of low W_r values suggest that intermediate-length bass may be competing for available prey. Aquatic macrophyte habitat appeared not to be dense enough to affect foraging efficiency of largemouth bass. Therefore, growth of fish into larger size groups probably could be improved by removing some of the intermediate-sized largemouth bass or enhancing forage.

Trail's End Lake.—Trail's End Lake (5.2 ha) is located in the Puget Sound lowlands. Approximately 14% of the volume of the lake is occupied by aquatic macrophytes. Because the lake is on private property, angling is monitored closely. Trail's End Lake receives light angling effort, and all largemouth bass caught are released. The electrofishing survey yielded 61 largemouth bass larger than 100 mm TL. Other fish species in the lake included bluegills, black crappie *Pomoxis nigromaculatus*, bullhead *Ameiurus* spp., and channel catfish. Trail's End Lake contained a greater proportion than average of large largemouth bass (Figure 4; g_1 = 1.13). A plot of W_r versus TL

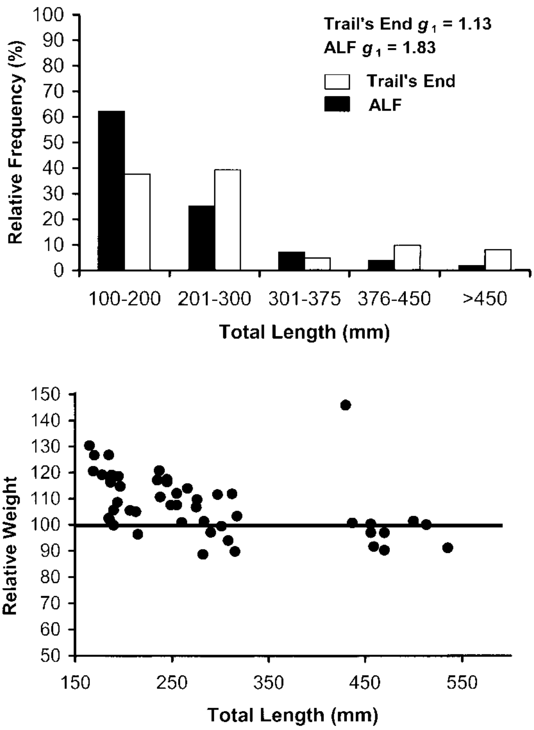

FIGURE 4.—Plots of relative length frequency and relative weight for largemouth bass captured by night electrofishing in Trail's End Lake, Washington, October 1994. The Trail's End Lake length frequency is plotted next to the average length frequency (ALF) for Washington State. The degree and direction of skewness are represented by g_1.

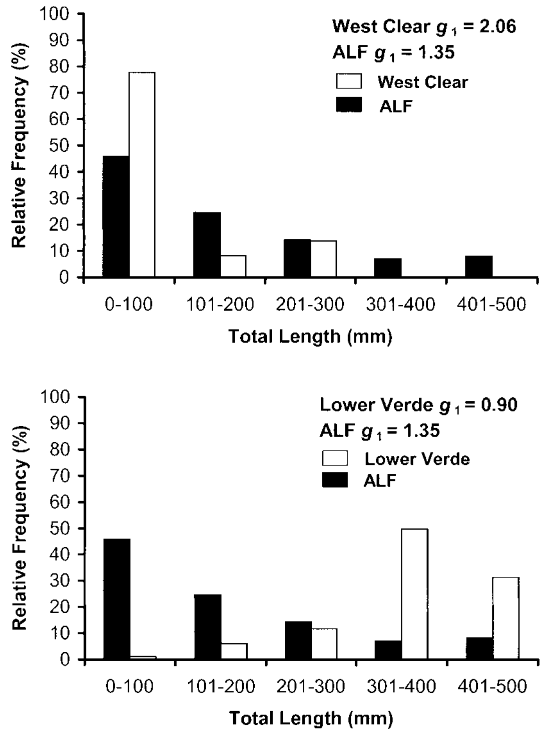

FIGURE 5.—Relative length frequency for roundtail chub captured by day electrofishing in West Clear Creek, Arizona, September 1998, and in the Lower Verde River, Arizona, September 1999. The length frequency of each stream is plotted next to the average length frequency (ALF) for Arizona. The degree and direction of skewness are represented by g_1.

reveals that larger bass are competing for food but not enough to cause a growth bottleneck like that observed in Clementine Lake. Trail's End Lake exhibits a slight surplus of large largemouth bass, which probably could support a light harvest and certainly would provide a nice location for quality catch-and-release angling.

Roundtail Chub Examples

In contrast to the largemouth bass, the roundtail chub is rarely of interest to anglers, even though the Arizona Game and Fish Department promotes the fish for sport. Only 3% of Arizona anglers statewide have specifically targeted the species (Brouder et al. 2000), making it unlikely that overharvesting currently limits any populations. Standard weight equations were not available for roundtail chub so only the RLF plot was used to make inferences about any bottlenecks in production that may be occurring in Arizona rivers and streams.

West Clear Creek.—West Clear Creek is a tributary to the Verde River, located in central Arizona. It is unregulated, has a high gradient, and flows through a deeply incised gorge (Brouder et al. 2000). The creek is isolated and relatively undisturbed. Long-term median flow of West Clear Creek is 0.5 m^3/s. The majority (84%) of fish collected in recent surveys were native (Brouder et al. 2000). Most of the 36 roundtail chub collected in West Clear Creek were small compared with the ALF (Figure 5; g_1 = 2.06). No large roundtail chub were captured. The presence of a high proportion of small fish suggests recruitment is higher than average. A strong positive relationship exists between maximum mean daily discharge and roundtail chub recruitment, possibly because floods clear spawning substrates of fine materials (Brouder 2001). Examination of hydrographs for West Clear Creek shows numerous flood events, so the unregulated flow in the creek may allow for successful spawning and recruitment. Growth of the fish into larger size classes may be constrained by available habitat in West Clear Creek. Preserving the current flow regime of West Clear Creek probably would sustain reasonably steady recruitment, but lack of large riverine habitat will probably preclude growth of roundtail chub into larger size groups.

Lower Verde River.—The Lower Verde River in central Arizona is large, has many access points, and has undergone numerous anthropogenic impacts. Long-term median flow of the Lower Verde River is 9.0 m^3/s. A comparison of the length frequency of the 179 fish captured in the Lower Verde River with the ALF shows that the Lower Verde contains more large fish and fewer young recruits than is average for the state. The flow of the Lower Verde River is regulated upstream from Bartlett Dam and is relatively constant. Lack of flood events, which are positively associated with recruitment, may limit successful roundtail chub reproduction and recruitment in the Lower Verde River. Introduced fishes may also remove many of the young. However, availability of suitable habitat may allow the roundtail chub that are produced to grow larger than those upstream. Encouraging hydroelectric operations to mimic natural flow regimes when possible may aid successful spawning and recruitment of roundtail chub in this section of river. Removal of introduced piscivores may also increase survival of young.

Management Implications

Surveys required to collect the above samples were rapid and represent 1–3 nights or days of electrofishing effort. Simple surveys such as these may be sufficient for small lakes, ponds, and small low-gradient streams, which could be sampled rapidly, treated by adaptive management procedures (Holling 1978), and monitored for changes. For systems in which recruitment can fluctuate widely because of abiotic factors (e.g., Aggus 1979), such as large reservoirs or northern lakes, several years of sampling and use of a wider variety of statistics may be required before management decisions are made. In addition, different areas or coves in larger systems should be sampled because length-frequency distributions can differ significantly between sites within large lakes or reservoirs (Hubbard and Miranda 1988; Mesa et al. 1990).

The number of fish that must be captured to obtain a length-frequency distribution at a particular precision can be calculated (Thompson 1987). In some regions, RLF could be designed to use a larger proportion of fish lengths than do stock density indices. This may be an advantage in oligotrophic or mesotrophic systems, northern systems, or those with great species diversity, where capturing enough fish of stock length and larger to provide precise estimates may be difficult. Thus, it may be easier to collect a sufficient sample size for a given degree of precision than for indices such as PSD and RSD. For example, in 30 night electrofishing surveys in Washington State, an average of 26 stock-length fish were caught per hour, and an average of 1.02 h of pedal-down electrofishing time was used per night (Divens et al. 1998). Therefore, on average, 2.07 nights of electrofishing would have been required to capture the 55 largemouth bass larger than 200 mm that would be necessary to ensure a PSD estimate of ± 10 with 80% confidence (Gustafson 1988; Divens et al. 1998). To estimate the percentage of largemouth bass in each length-group in a length-frequency distribution with the same precision, 75 largemouth bass larger than 100 mm are required (Thompson 1987). Because 62% of the mean electrofishing catch of largemouth bass in Washington ranged between 100 and 200 mm, an average of 68 fish larger than 100 mm should be caught per hour. Therefore, to capture 75 largemouth bass larger than 100 mm should require on average 1.08 nights of electrofishing. Sampling effort for an RLF procedure of largemouth bass in Washington State thus would be 50% less than that required for PSD or RSD.

Many researchers have demonstrated size-related bias in sampling gears, which affects the estimates of stock structure obtained (Willis et al. 1993). Therefore, gear types and collection techniques should be standardized, both in the development of the ALFand in comparisons between the ALF and length-frequency distributions for individual populations. I used electrofishing data to develop the ALFs for largemouth bass and roundtail chub. However, for those species not susceptible to electrofishing, length-frequency distributions developed using trap-net, gill-net, or angling data can be compared with ALFs that have been developed using the same respective gear.

Further research could help identify the optimal number of length-groups to use in this procedure. Subdividing the length frequency into many groups provides more information about populations, but subdividing into only a few groups smoothes noise out of the length-frequency histogram, allowing for easier comparisons with the ALF.

To effectively use this technique, investigators need to develop ALFs based on data from a wide range of water bodies of a particular type in the region of interest. Knowledge of the sample of populations used to develop the ALF is particularly important. Lakes and streams used to develop the ALFs in my study varied considerably in habitat, degree of exploitation, and size. Development of the ALF using data from water bodies that are the most popular fishing sites, or that are all affected by some habitat factor as those intensively monitored by most agencies, may result in an ALF that under- or overestimates proportions of fish in the larger length-groups than would be desired by managers. Conversely, development of the ALF by using data from systems that are unexploited or contain pristine habitat could result in an ALF that well represents ''best conditions'' but rarely may be obtainable.

The RLF procedure could easily be adapted to a variety of sport fishes and nongame fishes in numerous regions. It is flexible enough to be used with already established length-groups, such as Gabelhouse's (1984) five-cell categories, or different length-groups, depending on the application. Finally, the plots are easily understood by an audience that has a wide variety of backgrounds and training in fisheries.

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