Chapter 14

Length, Weight, and Associated Indices

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14.1 INTRODUCTION

Length and weight data provide statistics that are cornerstones in the foundation of fisheries research and management. The objectives of this chapter are to present information on the uses of length and weight data as well as the calculation and interpretation of structural indices from such data.

The numbers and sizes of fish in a population determine its potential to provide benefits for commercial and recreational fisheries. Length and weight data also provide the basis for estimating growth, standing crop, and production (tissue growth) of fishes in natural waters as well as in fish hatcheries and laboratories. The rate of annual production is determined by the rate of reproduction (number of viable offspring each year), the rate of growth (change in weight of individuals), and the rate of mortality (loss of numbers in an age-group). These functional rates determine population dynamics over time, as well as structural attributes such as density, biomass, and length frequency at any point in time.

One challenge for a fisheries manager is to identify problems and opportunities presented by existing population structures. Effective adjustments of functional attributes, such as altering mortality rates with length-limit regulations, can achieve a more favorable population structure to meet the management objectives for that fish population and community.

Homer S. Swingle and Richard O. Anderson provided the primary impetus for understanding the utility of weight and length data in fisheries assessment. These scientists showed us what could be learned from assessment of fish communities in small impoundments. Small impoundments are convenient experimental mesocosms for basic research on ecological concepts and principles as well as for applied research on fish population dynamics and fisheries management. Beginning in the 1940s, state and federal programs stimulated the construction of many small impoundments in the southern USA for soil conservation, irrigation, or wildlife needs. An entomologist at Auburn University, Swingle was concerned about these waters as habitats for mosquitoes that could cause the spread of malaria. His early observations led to the conclusion that ponds with fish had few or no mosquitoes. This led to further studies of how these waters might best be used to produce fish as food for rural populations. The results of management efforts in experimental ponds were often evaluated by census of the fish communities after the ponds were drained.

A good or balanced fish population was defined by Swingle (1950) as a population that could sustain a harvest of good-size fish in proportion to the productivity of the water. His initial work on structural fish community characteristics was based on biomass values and developed empirically for fish populations in small impoundments. Later he delved into an index of relative plumpness for fishes that was based on Alabama statewide averages (Swingle and Shell 1971). Anderson continued Swingle's work but recognized that biomass data are expensive to obtain, especially as fisheries professionals were continually being asked to do more with less. Thus, Anderson (1976) developed the concept of size structure indices based on fish length rather than biomass. In reality, his size structure index (proportional stock density; section 14.3.1) was based on one of Swingle's biomass indices (A_T; section 14.6). Similarly, Wege and Anderson (1978) proposed the concept of rangewide standards for fish condition (relative weight; section 14.5.3), which actually was based on Swingle's concept of a statewide condition index for Alabama fishes (relative condition factor; section 14.5.2). Few inland fisheries management or research biologists can conduct their day-to-day work without extensive reliance on the indices and ecological knowledge provided by Anderson and Swingle. As a result of their work, assessments of length and weight provide a cornerstone for freshwater fish population and community analyses.

The development and early applications of stock assessment indices, such as proportional size distribution (PSD; section 14.3) and relative weight (W_r; section 14.5), were undertaken on sport fishes in small impoundments of the southern and midwestern USA. The research led to an understanding of the value of these indices not only as simple tools for describing fish population structure but also as tools for assessing dynamics (recruitment, growth, and mortality) of populations and interactions in fish communities. Use of these indices has expanded to natural lakes and reservoirs (Willis et al. 1993; Blackwell et al. 2000), nongame and riverine species (Beamesderfer 1993; Quist et al. 1998; Bister et al. 2000), species of special concern (e.g., federally endangered pallid sturgeon; Shuman et al. 2006), fisheries outside North America (Baigun and Anderson 1993; Gassner et al. 2003; Zick et al. 2007), and, only rarely, to marine fisheries. Proportional size distribution has been used to assess weakfish stocks (ASMFC 2006), and body condition was used as an index to describe a striped marlin fishery (Kopf et al. 2005). Proportional size distribution also has been evaluated as a potential size-based indicator in marine ecosystems (Shin et al. 2005). The uncommon use of some of these indices in marine fisheries could be a reflection of their freshwater origins, evolving in relative isolation from marine stock assessment procedures. Application of these structural indices as stock descriptors could be further broadened to marine fisheries but would require development of new standards (e.g., length categories for PSD and standard weight equations for W_r).

The utility of an index such as PSD applies to all fish populations in both freshwater and marine systems because in its simplest form it serves as a descriptor of size structure, making it possible to index length-frequency data. However, the ability to predict or draw conclusions about population dynamics based on the structural indices described in this chapter is not as straightforward in larger waters or in systems with more complex fish communities. In these instances, stock assessments and management decisions should be further grounded in other procedures, such as relative abundance (Hubert and Fabrizio 2007), recruitment (Maceina and Pereira 2007), growth (Isely and Grabowski 2007), mortality (Miranda and Bettoli 2007), and other specific assessment techniques (Guy and Brown 2007). Continued research will further expand the understanding of the strengths and weaknesses of structural indices.

14.1.1 Uses of Length Measurements

Length is important to the recreational angler. In many fisheries, length is used to define legal size for harvest. Weithman and Anderson (1978) and Weithman and Katti (1979) developed a fish quality index that describes the angling value of a captured fish in terms of the world record length for that species. Gabelhouse (1984a) used this fish quality index to define length categories, for a variety of species, that are used to calculate size structure indices. Fisheries managers use length-frequency data and size structure indices to assess fish populations and to monitor fish populations over time in response to management strategies. Length data also are important for determining growth rates, whether by measuring length of fish of known age or estimating growth based on back-calculated lengths (Chapter 15). Describing growth through the use of models, such as von Bertalanffy growth relationships, also requires length-at-age data.

14.1.2 Uses of Weight Measurements

Weights of individuals and biomasses of populations are also key attributes of fish populations. The production process results in the creation of tissue by individuals and populations. Although production can be expressed as calories or weights of carbon, protein, or dried tissue, all of these measures typically are based on a measurement of wet weight. Total weight or weight per unit of area is the statistic typically reported for harvest or standing stock in fisheries applications. Weight is the common basis for reporting catches, whether made by anglers or by commercial fishers.

Weight at age and annual weight increments are other statistics that describe the growth process. Annual weight increments (change in weight over a year) reflect growth and thus how fish of various sizes are gaining in value (size and biomass) to the fishery; annual weight gains combined with growth efficiency values can be used to estimate consumption of prey. Length and weight data can also be used to calculate indices of condition (section 14.5).

14.1.3 Biases Associated with Length and Weight Data

Fisheries biologists use standardized techniques to sample and measure fish (Bonar et al. 2009). The intent of standardization is to remove effects of bias associated with sampling and measuring so that data (e.g., size structure and body condition) can be directly compared among samples collected over time, among locations, or among other treatments of interest.

In many instances, the lengths of fish sampled are influenced by the gear type used, time of year (seasonal behavioral effects), and location within a water body (Pope and Willis 1996; Neumann and Allen 2007). Thus, for a sample collected with a particular gear type, the size structure may not truly reflect the actual size structure in the population; samples collected across seasons are typically not comparable. For routine fisheries management surveys (including comparisons of size structure among water bodies) and for tracking the effects of management strategies (e.g., length-limit regulations, habitat enhancements, and stocking) over time, standardized sampling is recommended. In general, standardized sampling requires that similar gears be used at similar times of year and locations to obtain long-term trend data.

Weights of individual fish sampled appear to be less affected by gear type than do lengths. Gears such as electrofishing or trap netting, for example, are not selective for plumper or thinner fish, but a length bias may exist. However, weights and associated body condition measures can differ substantially over an annual period (Pope and Willis 1996; Blackwell et al. 2000). Seasonal variations in weight can be attributed to physiological changes such as the release of gametes during spawning and somatic mass changes associated with growth.

14.2 LENGTH-FREQUENCY HISTOGRAMS

Length-frequency distributions reflect an interaction of rates of reproduction, recruitment, growth, and mortality of the age-groups that are present. These distributions and changes in them with time can provide an understanding of the dynamics of populations and can identify problems such as weak or missing year-classes, slow growth, or excessive annual mortality.

A common type of length-frequency histogram displays the absolute number of fish collected on the *y*-axis and fish length categories on the *x*-axis (Figure 14.1). Another type displays relative frequency (proportion of all fish represented in each length category) on the *y*-axis. Relative-frequency histograms are useful for comparing length-frequency data sets that contain different sample sizes, which may result from variable effort (Neumann and Allen 2007). An alternative length-frequency histogram is based on catch per unit effort, *C/f*, which is used to indicate relative abundance of fish in each length category. Examples of *C/f* include the number collected per hour of electrofishing or the number captured per trap-net night.

When constructing length-frequency histograms, the use of length-group intervals that are too broad will mask length-frequency details; intervals that are too narrow can result in low sample sizes within each length-group. The width of length-groups for a length-frequency histogram generally depends on maximum fish length. For example, consider using 1-cm intervals for species that reach 30 cm, 2-cm intervals for species that reach 60 cm, and 5-cm intervals for those that reach 150 cm.

The sample size necessary to describe the size structure of a fish population adequately can be quite large. However, when conducting management surveys, such as a 1-year point estimate that is part of a multiyear trend analysis or annual surveys among multiple water bodies, a sample of 100 fish greater than stock length (section 14.3.1) is often adequate. Gilliland (1987) compared length frequencies based on various sample sizes of largemouth bass that were sampled by electrofishing in Oklahoma reservoirs and concluded that a sample size of 150 largemouth bass was adequate to estimate size structure whereas a sample of 50 was not. For more quantitatively rigorous

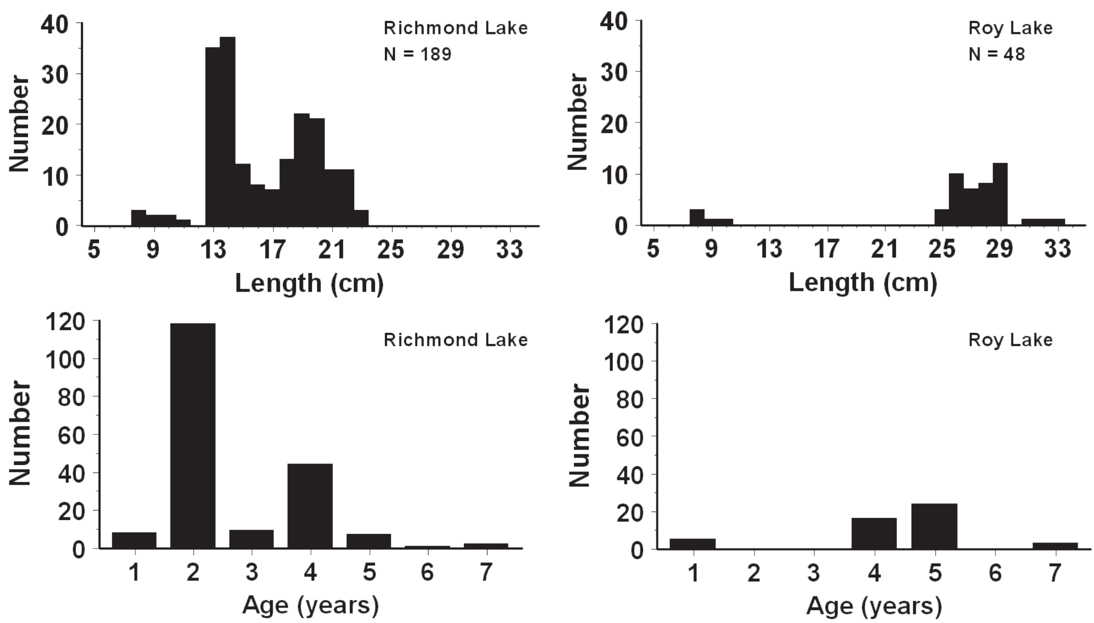

Figure 14.1 Length frequencies and age structures of two black crappie populations sampled with modified fyke nets in South Dakota during May 1991 (C. Guy and D. Willis, unpublished data).

analyses requiring high precision, and when juvenile fish also are sampled, greater sample sizes are typically required. Vokoun et al. (2001) estimated the sample size necessary to construct length-frequency distributions with a given accuracy and precision for bluegill and channel catfish. They compared the length-frequency histogram from a known sample to computer-generated length-frequency histograms by means of bootstrapping methods. They recommended use of at least 300–400 individuals whenever possible.

Consider population characteristics, species-specific maximum lengths, and precision required for conducting analyses when determining sample size requirements (Miranda 2007). Length-frequency histograms with 1-cm intervals require 375–1,200 fish to estimate within 10% precision with 80% confidence, histograms with 2.5-cm intervals require 150–425 fish, PSD (section 14.3) requires 75–140 fish, and mean length requires 75–160 fish (Miranda 2007). In general, smaller species, smaller populations, populations with higher mortality, and simpler length statistics require fewer fish to construct length-frequency histograms.

14.2.1 Population Comparisons

Length-frequency histograms are ideal for comparing populations. The two length-frequency distributions of black crappie depicted in Figure 14.1 have obvious differences. These samples were obtained with modified fyke nets (Chapter 6). At Roy Lake there is a substantial gap in the population size structure between 11 and 24 cm. What is the reason for this gap? The most likely explanation is low or nonexistent recruitment in some years leading to weak or missing year-classes. A few likely age-1 (8–10 cm) black crappies were caught, and, because we know that age-1 black crappies typically do not fully recruit to this gear, we can assume that these few fish may represent a reasonable-size year-class. Large fish (e.g., fish > 30 cm) are present in the sample, indicating that growth must at least be moderate or fast by the standards of this particular geographic location. Harvest mortality is not excessive at Roy Lake as indicated by the presence of large fish.

The length-frequency histogram for Richmond Lake depicts a different set of rate functions. Again, the age-1 black crappies were sampled in low numbers. From 13–23 cm, all length-groups were captured with no gap in the length frequency. However, few fish in this population sample exceeded 20 cm. What is the explanation for this truncated age structure? Could this be a high-density, slow-growing population in which few fish reach larger sizes? Or perhaps this is a lower-density population with fast growth from which anglers have excessively harvested the older, large fish? Only additional information can answer these questions.

Additional or corroborative information is collected after biologists have completed a preliminary assessment. At Roy Lake, biologists determined the age structure (Figure 14.1) and growth rates of the population sample. No 2- or 3-year-old black crappies were sampled, corroborating the suspicion of erratic recruitment. Fish in the sample had a mean total length of 269 mm at age 4, compared with a statewide average of 229 mm at age 4, thus corroborating the assumption of moderate to fast growth. In contrast, the black crappies at Richmond Lake exhibited more consistent recruitment (Figure 14.1). Although year-class abundance was variable, all age-groups from 1 to 7 were present. Biologists also determined that black crappies in this water body averaged 200 mm at age 4 compared with the statewide average of 229 mm. Thus, the truncated size structure of black crappies at Richmond Lake was likely caused by slow growth rather than by overharvest of larger black crappies by anglers.

The above case is a good example of how other types of assessments can strengthen interpretation of length-frequency data. In this case, the analysis was enhanced with growth data (see Chapter 15) and also through the recruitment assessment allowed by age-structure data. Combining additional data types such as mortality, recruitment, and relative abundance can provide stronger assessments than can single descriptors.

14.2.2 Relative Length Frequency

Bonar (2002) developed a simple method to assess the size structure of a fish population quickly by comparing its sampled length frequency with an average developed for the particular geographic region. Importantly, this method requires a standard for comparison, such as a statewide or regionwide average length frequency (Figure 14.2). However, after a standard is available, both visual and statistical comparisons can be made. Both degree and direction of skew between the population sample and the standard are quantified for statistical analysis. In practice, this technique provides comparisons of length-frequency distributions based on relatively broad length categories. The use of statewide or regionwide standards allows comparison to what length distributions can be attained by a species in a particular geographic location.

14.3 SIZE STRUCTURE INDICES

Evaluating size structure of a fish population is one of the most common analyses conducted by fisheries biologists. Size structure indices are calculated based on length data, so they inherently share the same fundamental advantages as length-frequency histograms in population assessments (section 14.2). Data for size structure indices also are easily obtainable and do not require sacrifice of fish, which is not always the case with indices. A benefit of size structure indices is that length-frequency information is indexed by use of easily calculated values. Much as with length-frequency histograms, size structure indices can provide insight into the dynamic rate functions (i.e., recruitment, growth, and mortality) of populations, but they also should be accompanied by other assessment techniques to evaluate the populations thoroughly (section 14.2). In some cases, inspection of length-frequency histograms can provide detail that may be lost when length data are summarized in wide length categories or by an index. Proportional size distribution has been refined over the years to address this issue. As with length-frequency histograms, correct interpretation of size structure indices can occur only with knowledge of how, when, and where the data were collected (Neumann and Allen 2007).

14.3.1 STOCK DENSITY INDICES

Stock density indices provide an easily calculated numerical descriptor of length-frequency data. In some situations, especially in small impoundments, stock density indices provide insight about population dynamics. Proportional stock density (Anderson 1976) was formerly calculated as

$$\text{PSD} = \frac{\text{Number of fish} \geq \text{minimum quality length}}{\text{Number of fish} \geq \text{minimum stock length}} \times 100. \tag{14.1}$$

Stock length has been variously defined as the approximate length at maturity, minimum length effectively sampled by traditional fisheries gear, and the minimum length of fish that provide recreational value. Quality length was defined by Anderson (1978) as the minimum size of fish most anglers like to catch. For largemouth bass, minimum stock length is 20 cm and quality length is 30 cm. The PSD for a largemouth bass sample is the percentage of 20-cm and

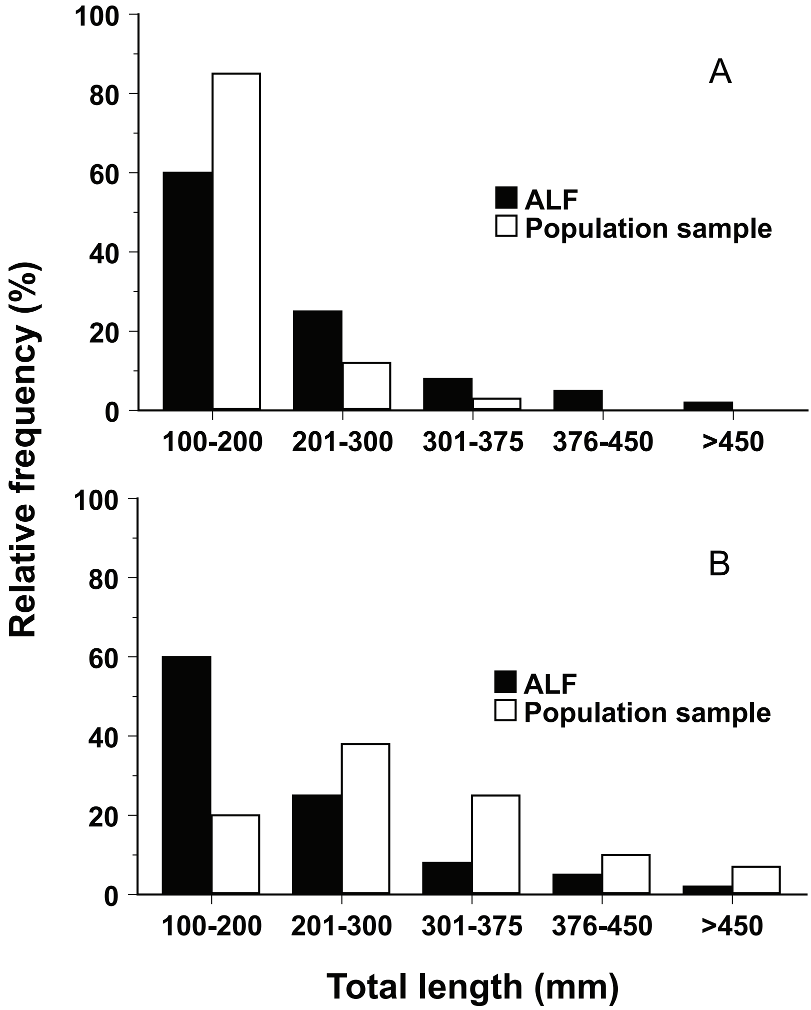

Figure 14.2 Relative length-frequency analysis allows comparison of length distribution of fish from an individual water body to a statewide or regionwide average length frequency (ALF). A hypothetical fish population, such as that in panel **(A)**, which displays a greater than average percentage of 100–200-mm fish than does the ALF, could represent a population that is experiencing (1) higher than average exploitation or other form of mortality or (2) slow growth caused by high abundance (i.e., density dependence). The population in panel **(B)**, which displays a greater than average percentage of 200-mm and longer fish, could represent a population with (1) lower than average mortality or (2) low recruitment (modified from Bonar 2002).

longer fish that are also longer than 30 cm. Anderson and Weithman (1978) defined stock and quality length as percentages of world record lengths (e.g., stock length as 20–26% of record length). They recommended application of this approach to coolwater fishes such as yellow perch, walleye, smallmouth bass, northern pike, and muskellunge.

Relative stock density (RSD; Wege and Anderson 1978) is the percentage of fish of any designated length-group in a sample and was formerly calculated as

$$\text{RSD} = \frac{\text{Number of fish} \geq \text{specified length}}{\text{Number of fish} \geq \text{minimum stock length}} \times 100. \tag{14.2}$$

Relative stock density was first used for largemouth bass; the specified length was 15 in (38 cm), and the percentage of stock-length fish that was 15-in long also came to be known as RSD-15. Gabelhouse (1984a) noted the need for more than a two-cell (stock and quality lengths) model for size structure analysis. His example involved the discussion of two bluegill populations. Both populations had a PSD of 60, meaning that 60% of stock-length bluegills (8 cm) were also quality length (≥15 cm). However, one population contained no bluegills over 18 cm whereas the other contained numerous bluegills over 20 cm and even a few that exceeded 25 cm. He therefore developed a five-cell length-categorization system based on Weithman's (1978) fish quality index and percentages of world record lengths (Figure 14.3). The cells were defined as stock (S), quality (Q), preferred (P), memorable (M), and trophy (T) lengths, and the minimum lengths for the Q, P, M, and T categories corresponded to near 36–41, 45–55, 59–64, and 74–80% of world record lengths, respectively.

Relative stock density calculations can be traditional (as described above) or incremental (Gabelhouse 1984a). Traditional RSD values are calculated as the percentages of stock-length fish that are also longer than the defined minimum lengths for size categories: quality (PSD), preferred (RSD-P), memorable (RSD-M), or trophy (RSD-T). Incremental RSD values are calculated as the percentage of stock-length fish between the minimum lengths for size categories. Thus, incremental RSD values are relative stock density of stock- to quality-length (RSD S-Q), quality- to preferred-length (RSD Q-P), preferred- to memorable-length (RSD P-M), memorable- to trophy-length (RSD M-T), and trophy-length (RSD-T) fish. The sum of incremental values is 100.

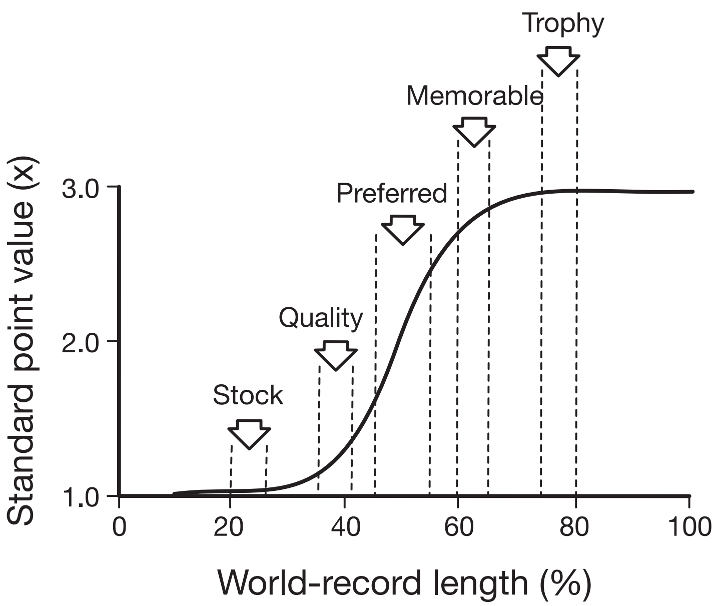

Figure 14.3 Gabelhouse's adoption of Weithman's (1978) fish quality index to identify length ranges from which (or near to which) minimum stock, quality, preferred, memorable, and trophy lengths were selected (from Gabelhouse 1984a).

14.3.2 Proportional Size Distribution—A New Terminology

Despite the widespread use of PSD and RSD, some confusion continues to exist regarding the utility and meaning of stock density indices. This confusion is caused mostly by a lack of understanding of the utility of length-frequency indices and terminology, particularly the inclusion of "density" in the nomenclature for PSD and RSD.

Anderson (1980) stated that individual growth rates and density determine length frequency. Proportional stock density and RSD should reflect density, and hence the term density appeared in the original PSD and RSD nomenclature. Both PSD and RSD can be correlated with density, especially for largemouth bass in small impoundments (see Willis et al. 1993 for correlation data). However, in larger, more complex systems or where habitat is not well suited to a particular species, PSD and RSD often do not reflect population density (Willis et al. 1993). So although PSD and RSD reflect density in some situations, they are not true measures of density but involve only length data in calculations. Another confusing issue was that PSD and RSD-Q were redundant terms. To facilitate communication and name the index more accurately, proportional stock density was changed to proportional size distribution (PSD) and the use of RSD was discontinued (Guy et al. 2007). The calculation of PSD is the same as RSD:

$$\text{PSD-}X = \frac{\text{Number of fish} \geq \text{specified length}}{\text{Number of fish} \geq \text{minimum stock length}} \times 100, \tag{14.3}$$

where X indicates the length category of interest (i.e., specified length). Incremental RSDs now are also termed PSD, and the letters following PSD define the increment used (Table 14.1). The change to proportional size distribution is reflected throughout the rest of this chapter. Values of PSD range from 0 to 100. All expressions of PSD should be rounded to the nearest whole number and reported without the percent symbol; decimals represent significant digits beyond the original data (Box 14.1). Willis et al. (1993) encouraged fisheries biologists to use values as established in either English or metric units rather than converting from English to metric units. For example, stock length for white crappie is either 5 in or 13 cm, not 12.5 cm. Small differences in index values can be created by combining different measurement units. Proposed standards in both English and metric units are presented for 55 taxa in Table 14.2.

Table 14.1 Terminology for former proportional stock density (PSD) and relative stock density (RSD) indices and corresponding revised terminology for proportional size distribution (PSD) index. Note that under the former terminology PSD and RSD-Q were equivalent. Suffixes are stock (S), quality (Q), preferred (P), memorable (M), and trophy (T) lengths.

Former terminology	Current terminology
PSD	PSD
RSD-P	PSD-P
RSD-M	PSD-M
RSD-T	PSD-T
RSD S-Q	PSD S-Q
RSD Q-P	PSD Q-P
RSD P-M	PSD P-M
RSD M-T	PSD M-T

Box 14.1 Calculation of Proportional Size Distribution

Proportional size distribution (PSD) is a numerical descriptor of length-frequency data (section 14.3.2). These examples show how to calculate traditional and incremental PSD values based on length-frequency data from a sample of largemouth bass collected by electrofishing.

Table Numbers of largemouth bass sampled by length-group.

Length-group (cm)	Number of fish sampled
20.0–29.9	50
30.0–37.9	30
38.0–50.9	10
51.0–62.9	7
≥63.0	3

Step 1: The formula for calculating PSD

$$\text{PSD-}X = \frac{\text{Number of fish} \geq \text{specified length}}{\text{Number of fish} \geq \text{minimum stock length}} \times 100,$$

where X indicates the length of interest (i.e., specified length or increment length). When quality length is the specified length (i.e., X = Q), the term PSD is used, not PSD-Q.

Step 2: The length-category designations

Length categories for largemouth bass		
Minimum stock (S) length	=	20 cm
Minimum quality (Q) length	=	30 cm
Minimum preferred (P) length	=	38 cm
Minimum memorable (M) length	=	51 cm
Minimum trophy (T) length	=	63 cm

Step 3: The calculations

(1) Traditional PSD

PSD = [(number > 30 cm)/(number > 20 cm)] × 100
= [(30 + 10 + 7 + 3)/(50 + 30 + 10 + 7 + 3)] × 100
= (50/100) × 100 = 50

PSD-P = [(number > 38 cm)/(number > 20 cm)] × 100
= [(10 + 7 + 3)/100] × 100 = 20

PSD-M = [(number > 51 cm)/(number > 20 cm)] × 100
= [(7 + 3)/100] × 100 = 10

(Box continues)

Box 14.1 Calculation of Proportional Size Distribution

PSD-T = [(number > 63 cm)/(number > 20 cm)] × 100
= (3/100) × 100 = 3

(2) Incremental PSD

PSD S-Q = [(number 20–29.9 cm)/(number > 20 cm)] × 100
= (50/100) × 100 = 50

PSD Q-P = [(number 30–37.9 cm)/(number > 20 cm)] × 100
= (30/100) × 100 = 30

PSD P-M = [(number 38–50.9 cm) / (number > 20 cm)] × 100
= (10/100) × 100 = 10

PSD M-T = [(number 51–62.9 cm)/(number > 20 cm)] × 100
= (7/100) × 100 = 7

PSD-T = [(number > 63 cm)/(number > 20 cm)] × 100
= (3/100) × 100 = 3

Note:
(PSD Q-P) + (PSD P-M) + (PSD M-T) + (PSD-T)
= 30 + 10 + 7 + 3 = 50 = PSD
(PSD S-Q) + (PSD Q-P) + (PSD P-M) + (PSD M-T) + (PSD-T)
= 50 + 30 + 10 + 7 + 3 = 100

As with the former terminology, traditional PSD calculations are more commonly used, easier to communicate, and more useful for first-time assessments or analysis of long-term data sets than are incremental calculations (Box 14.2). Procedures exist to determine whether population PSD is within a given interval (Weithman et al. 1980), to determine what sample sizes are needed to achieve selected levels of precision (Miranda 1993), and to calculate confidence intervals for PSD (Gustafson 1988).

14.3.3 Proportional Size Distribution and Management Targets

Proportional size distribution values can provide insight or predictive ability about population dynamics. Highly variable recruitment can influence PSD values (Carline et al. 1984). However, PSD is less sensitive to variable recruitment when specific lengths (e.g., PSD-P) or increments (e.g., PSD M-T) are used. Both high and low values and wide variation in PSD over time are indicative of populations with functional problems such as unstable recruitment, growth, or mortality. Relationships existed between PSD and mean length at age 3, annual length increments, and mortality of age-1 fish in 38 bluegill populations (Novinger and Legler 1978). Populations with PSD near 0 had maximum densities of stock- to quality-length bluegills. Highly variable year-class strength of bluegills was evident in other populations with low PSD (Anderson 1973; Price 1977). Both population density and biomass of largemouth bass and brook trout can be related to values of PSD (Figure 14.4).

Table 14.2 Proposed PSD length categories for various fish species. Measurements are minimum total lengths for each category except where noted. English units (E) are in inches and metric units (M) are in centimeters. Table is updated from Anderson and Neumann (1996).

	Stock		Quality		Preferred		Memorable		Trophy		
Species	E	M	E	M	E	M	E	M	E	M	Source
Arctic grayling	8	20	12	30	16	40	20	50	22	55	Hyatt 2000
Bigmouth buffalo	11	28	18	46	24	61	30	76	37	94	Bister et al. 2000
Black bullhead	6	15	9	23	12	30	15	39	18	46	Gabelhouse 1984a
Black crappie	5	13	8	20	10	25	12	30	15	38	Gabelhouse 1984a
Blue catfish	12	30	20	51	30	76	35	89	45	114	Gabelhouse 1984a
Bluegill	3	8	6	15	8	20	10	25	12	30	Gabelhouse 1984a
Brook trout											
Lotic	5	13	8	20							Anderson 1980
Lentic and lotic	8	20	12	30	16	40	20	50	24	60	Hyatt 2000
Brown bullhead	5	13	8	20	11	28	14	36	17	43	Bister et al. 2000
Brown trout											
Lentic	8	20	12	30	16	40	20	50	24	60	Hyatt and Hubert 2001a
Lotic	6	15	9	23	12	30	15	38	18	46	Milewski and Brown 1994
Bull trout	8	20	16	40	20	50	26	65	31	80	Hyatt 2000
Burbot	8	20	15	38	21	53	26	67	32	82	Fisher et al. 1996
Chain pickerel	10	25	15	38	20	51	25	63	30	76	Gabelhouse 1984a
Channel catfish	11	28	16	41	24	61	28	71	36	91	Gabelhouse 1984a
Chinook salmon[a]	11	28	18	46	24	61	30	76	37	94	Hill and Duffy 1993
Common carp	11	28	16	41	21	53	26	66	33	84	Gabelhouse 1984a
Cutthroat trout	8	20	14	35	18	45	24	60	30	75	Kruse and Hubert 1997
Flathead catfish	14	35	20	51	28	71	34	86	40	102	Quinn 1991
Freshwater drum	8	20	12	30	15	38	20	51	25	63	Gabelhouse 1984a
Gizzard shad	7	18	11	28							Anderson and Gutreuter 1983
Golden trout	8	20	10	25	14	35	18	45	22	55	Hyatt 2000
Green sunfish	3	8	6	15	8	20	10	25	12	30	Gabelhouse 1984a
Kokanee	8	12	10	25	12	30	16	40	20	50	Hyatt 2000
Lake trout	12	30	20	50	26	65	31	80	39	100	Hubert et al. 1994
Largemouth bass	8	20	12	30	15	38	20	51	25	63	Gabelhouse 1984a
Longnose gar	16	41	27	69	36	91	45	114	55	140	Bister et al. 2000
Muskellunge	20	51	30	76	38	97	42	107	50	127	Gabelhouse 1984a
Northern pike	14	35	21	53	28	71	34	86	44	112	Gabelhouse 1984a
Paddlefish[b]	16	41	26	66	33	84	41	104	51	130	Brown and Murphy 1993
Pallid sturgeon[c]	33	13	63	25	84	33	104	41	127	50	Shuman et al. 2006
Palmetto bass	8	20	12	30	15	38	20	51	25	63	Gabelhouse 1984a

Table 14.2 Continued.

	Stock		Quality		Preferred		Memorable		Trophy		
Species	E	M	E	M	E	M	E	M	E	M	Source
Pumpkinseed	3	8	6	15	8	20	10	25	12	30	Gabelhouse 1984a
Rainbow trout	10	25	16	40	20	50	26	65	31	80	Simpkins and Hubert 1996
Redear sunfish	4	10	7	18	9	23	11	28	13	33	Gabelhouse 1984a
River carpsucker	7	18	11	28	14	36	18	46	22	56	Bister et al. 2000
Rock bass	4	10	7	18	9	23	11	28	13	33	Gabelhouse 1984a
Sauger	8	20	12	30	15	38	20	51	25	63	Gabelhouse 1984a
Saugeye	9	23	14	35	15	46	22	56	27	69	Gabelhouse 1984a
Shorthead redhorse	6	15	10	25	13	33	16	41	20	51	Bister et al. 2000
Shovelnose sturgeon[c]	10	25	15	38	20	51	25	64	32	81	Quist et al. 1998
Smallmouth bass	7	18	11	28	14	35	17	43	20	51	Gabelhouse 1984a
Smallmouth buffalo	11	28	18	46	24	61	30	76	37	94	Bister et al. 2000
Splake	8	20	10	25	14	35	16	40	22	55	Hyatt 2000
Spotted bass	7	18	11	28	14	35	17	43	20	51	Gabelhouse 1984a
Spotted gar	12	30	19	48	25	64	31	79	39	99	Bister et al. 2000
Striped bass[a]	12	30	20	51	30	76	35	89	45	114	Gabelhouse 1984a
Walleye	10	25	15	38	20	51	25	63	30	76	Gabelhouse 1984a
Warmouth	3	8	6	15	8	20	10	25	12	30	Gabelhouse 1984a
White bass	6	15	9	23	12	30	15	38	18	46	Gabelhouse 1984a
White catfish	8	20	13	33	17	43	21	53	26	66	Bister et al. 2000
White crappie	5	13	8	20	10	25	12	30	15	38	Gabelhouse 1984a
White perch	5	13	8	20	10	25	12	30	15	38	Gabelhouse 1984a
White sucker	6	15	10	25	13	33	16	41	20	51	Bister et al. 2000
Yellow perch	5	13	8	20	10	25	12	30	15	38	Gabelhouse 1984a
Yellow bass	4	10	7	18	9	23	11	28	13	33	Anderson and Gutreuter 1983
Yellow bullhead	4	10	7	18	9	23	11	28	14	36	Anderson 1980

[a] Landlocked.
[b] Body length measured as anterior edge of eye to fork of tail.
[c] Body length measured as fork length.

Generally accepted objective ranges of PSD values have been developed for fisheries managers wishing to maintain or create balanced fish populations (Table 14.3). A balanced fish population is one that is intermediate between the extremes of a large number of small fish and a small number of large fish and therefore may have satisfactory rates of recruitment, growth, and mortality (Anderson and Weithman 1978). In most cases, objective ranges were developed from simple models that used recruitment, growth, and mortality rates to predict population size structure (e.g., Gabelhouse 1984b).

In special cases, fisheries managers desire to manage simple largemouth bass–bluegill communities in small impoundments with PSD values that fall outside the objective range of balanced populations for each species. Objective ranges for largemouth bass–bluegill communities man-

Box 14.2 Long-Term Data Sets and Size Structure Indices

Size structure indices can be useful when evaluating and conveying length-frequency data in long-term data sets. Think about writing a report or giving a presentation and having to show multiple length-frequency histograms—it could get tedious. The attractiveness of size structure indices is that they convey length-frequency data efficiently in a numeric value. Thus, the communication of results among biologists is simplified and standardized. Below are 9 years of brown trout data from the Missouri River in Montana that were collected during the spring. Numbers of fish are listed by length category and year. Compare the length-frequency table (or create length-frequency histograms from the data) with the PSD values tabulated and plotted below. What if you needed to report length-frequency information from 30 or 50 years of data? Tables or histograms would be tiresome, but plotted PSD values can efficiently synthesize and convey such information.

Table Number of brown trout per length-group sampled from the Missouri River, Montana, spring 1993–2001 (data courtesy of Montana Fish, Wildlife and Parks).

Length category (mm)	Year								
	1993	1994	1995	1996	1997	1998	1999	2000	2001
150–159	13	19	7	18	5	16	23	14	10
160–169	13	27	14	14	10	21	27	15	5
170–179	21	44	13	21	5	55	50	26	13
180–189	10	32	25	25	11	60	65	16	7
190–199	7	41	25	19	4	77	73	32	8
200–209	13	24	14	20	1	61	82	17	14
210–219	7	20	6	3	1	42	87	15	14
220–229	5	12	11	5	2	22	67	13	15
230–239	7	4	10	8	2	12	45	14	20
240–249	7	7	5	3	1	2	26	16	25
250–259	9	10	10	6	1	7	6	27	30
260–269	12	12	6	17	2	6	7	18	21
270–279	8	23	8	24	6	11	10	21	32
280–289	9	45	35	39	22	21	19	29	14
290–299	16	84	80	61	32	23	32	39	17
300–309	31	138	120	97	51	27	46	64	35
310–319	22	117	123	59	51	37	44	57	30
320–329	43	163	153	72	79	43	84	146	77
330–339	93	163	141	60	57	38	109	160	62
340–349	129	141	131	51	63	35	109	224	79
350–359	127	83	118	46	60	15	140	221	79
360–369	119	43	134	55	68	19	166	236	71
370–379	93	36	91	70	70	22	132	196	101
380–389	54	37	82	98	72	23	101	201	175

(Box continues)

Box 14.2 Continued

Table Continued.

Length category (mm)	Year 1993	1994	1995	1996	1997	1998	1999	2000	2001
390–399	57	42	87	128	104	48	80	161	208
400–409	61	61	71	119	121	58	55	109	251
410–419	44	45	97	111	96	75	38	98	308
420–429	80	44	88	102	87	94	29	85	295
430–439	64	59	69	71	87	69	33	65	273
440–449	65	48	78	56	72	52	28	82	255
450–459	43	44	69	42	64	44	29	68	193
460–469	37	22	64	32	34	40	29	67	129
470–479	20	20	43	9	16	17	22	42	100
480–489	34	23	38	25	32	29	19	48	99
490–499	24	14	31	14	22	13	24	32	65
500–509	18	14	31	8	10	8	20	22	48
510–519	8	15	20	8	13	11	11	19	33
520–529	9	3	13	9	5	5	10	13	32
530–539	4	6	19	5	4	3	6	10	16
540–549	3	3	12	3	4	3	3	10	14
550+	8	5	20	10	9	6	11	15	24

Table Proportional size distribution (PSD) values for the brown trout length-frequency data shown above (see section 14.3 for definition of PSD terms).

Proportional size distribution	Year 1993	1994	1995	1996	1997	1998	1999	2000	2001
PSD	94	88	95	92	97	72	76	95	97
PSD-P	89	77	88	83	93	66	69	89	93
PSD-M	44	28	42	52	59	47	27	42	76
PSD-T	11	7	13	7	10	11	8	10	17

(Box continues)

aged under various options, such as "big bass" and "panfish" options, are summarized in Table 14.4. For example, the bluegill PSD objective range of 50–80 for the panfish option is higher than the range of 20–60 for balanced bluegill populations. Harvest regulations are often used to adjust largemouth bass size structure to meet specific PSD target ranges (Flickinger et al. 1999).

Management targets for size structure indices typically depend on the management objective for a body of water. Fish populations managed for trophy fishing might be subject to differ-

Box 14.2 Continued

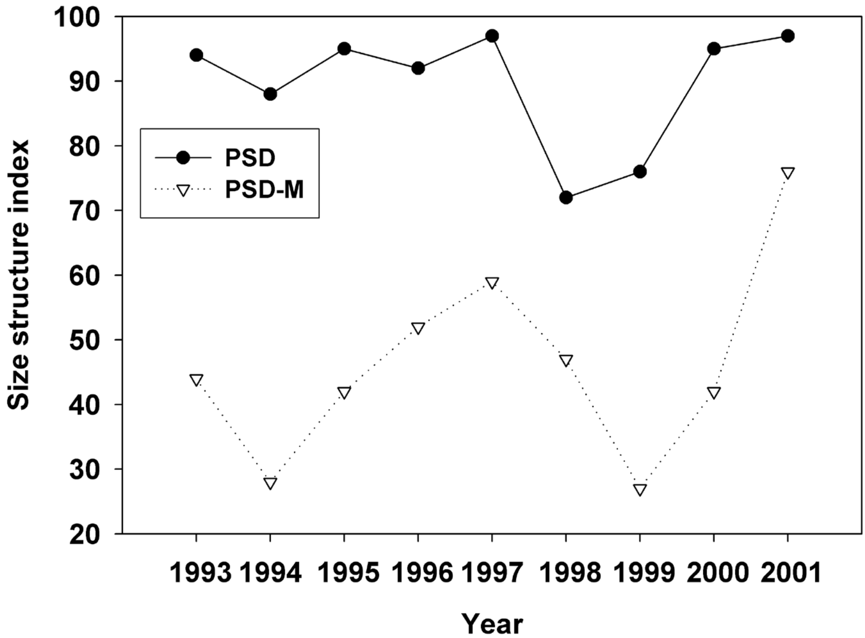

Figure Plot of PSD and PSD-M values calculated from the multiyear brown trout length-frequency data.

ent management targets than are populations managed to maximize catch rates for smaller fish. Similarly, the type of habitat also can determine management targets. For example, low-density brook trout populations in productive lakes can attain lengths and weights not possible in small headwater streams. Thus, management targets need to be set based on the management objectives for a water body as dictated by the feasible management options that may exist for that species in that particular habitat type (Box 14.3).

14.3.4 Young–Adult Ratio

The young–adult ratio (YAR) was developed to provide a relative measure of reproductive success and population structure of largemouth bass (Reynolds and Babb 1978). The ratio of numbers of fish in length-groups is used to calculate the index. In samples of largemouth bass collected in late summer or autumn, YAR is defined as the number 15.0 cm or less divided by the number 30.0 cm or greater. When adult density was low (<25 adults/ha) in small, midwestern U.S. impoundments, the index varied from less than 1 to greater than 60; at moderate adult densities (50–75 adults/ha) the expected index ranged from 1 to 10 (Reynolds and Babb 1978). These ratios suggest that overharvested or depleted stocks of largemouth bass can result in reproduction that is too low (YAR < 1) or excessive (YAR > 60). Whereas YAR is not a common assessment tool today, it was recently used to examine temporal differences in population size structure of salmonids in response to wildfires in the Bitterroot Basin, Montana (Sestrich 2005).

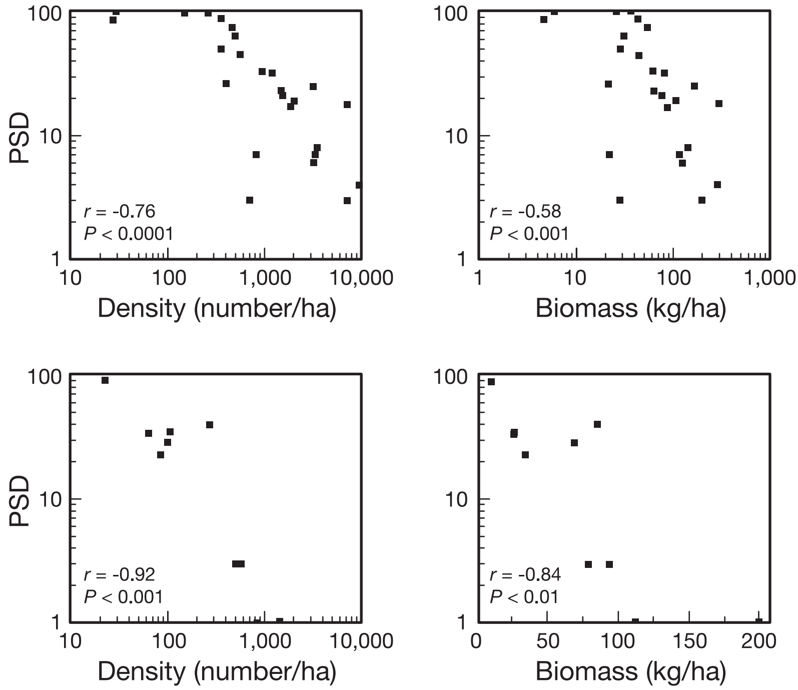

Figure 14.4 Relationships between proportional size distribution (PSD) of quality-length fish and density and between PSD and biomass of brook trout in Wyoming beaver ponds (top; from Johnson et al. 1992) and largemouth bass in small South Dakota impoundments (bottom; from Hill and Willis 1993).

14.4 WEIGHT–LENGTH RELATIONS

Le Cren (1951) stated, "The analysis of length–weight data has usually been directed towards two rather different objectives. First, towards describing mathematically the relationship between length and weight, primarily so that one can be converted to the other. Secondly, to measure the variation from the expected weight for length of individual fish or relevant group of individuals as indications of fatness, general 'well-being,' gonad development, etc." The term condition was applied to analyses of the second type.

Table 14.3 Generally accepted PSD index values for balanced fish populations (from Willis et al. 1993). Indices for crappies are based on fish from midwestern U.S. ponds.

Species	PSD	PSD-P	PSD-M	Source
Bluegill	20–60	5–20	0–10	Anderson (1985)
Crappies	30–60	>10		Gabelhouse (1984b)
Largemouth bass	40–70	10–40	0–10	Gabelhouse (1984a)
Northern pike	30–60			Anderson and Weithman (1978)
Walleye	30–60			Anderson and Weithman (1978)
Yellow perch	30–50			Anderson and Weithman (1978)

Table 14.4 Proportional size distribution values for largemouth bass and bluegill under three different management strategies described in section 14.3.3 (from Willis et al. 1993).

Management strategy	Largemouth bass			Bluegill	
	PSD	PSD-P	PSD-M	PSD	PSD-P
Panfish	20–40	0–10	0	50–80	10–30
Balanced	40–70	10–40	0–10	20–60	5–20
Big bass	50–80	30–60	10–25	10–50	0–10

The relationship between length and weight can be described by the power function

$$W = aL^b, \tag{14.4}$$

where W is weight, L is length, and a and b are parameters. It has proven to be a useful model for weight as a function of length (Figure 14.5). In general, b less than 3.0 represents fish that become less rotund as length increases and b greater than 3.0 represents fish that become more rotund as length increases. For most species and populations, b is greater than 3.0. If b equals 3.0, growth may be isometric, meaning that the shape does not change as fish grow.

The parameters a and b in equation (14.4) can be estimated by linear regression of transformed (common logarithmic transformation) weight–length data (Chapter 2). When weight–length data are transformed, the curvilinear relation between weight and length becomes “straightened” and allows for estimation of a and b by means of linear regression procedures (Figure 14.5). Weight–length relations based on transformed data are usually reported in the form

$$\log_{10}(W) = a' + b \cdot \log_{10}(L), \tag{14.5}$$

where a' is $\log_{10}(a)$ and is the y-axis intercept and b is the slope of the equation. The intercept (a) in equation (14.4) is estimated by taking the anti-logarithm of a' in equation (14.5); b is the same in both equations (14.4) and (14.5).

When collecting data for weight–length relations, measure individual fish to the nearest millimeter and weigh carefully with appropriately sized balances to achieve precision and accuracy (Gutreuter and Krzoska 1994). Five fish per length interval (e.g., 1 cm) usually make an adequate sample. Measure more fish if males and females have different weight–length relationships. Use appropriate equipment and technique to weigh and measure small fish. Do not include small fish in weight–length analyses if weights are inaccurate or precision is low.

14.5 INDICES OF CONDITION

Length is the primary determinant of weight of fishes. However, a wide variation in weight can exist among fish of the same length both within and among populations (Figure 14.5). Indices of condition, or well-being, are more easily interpreted and compared than are a and b in weight–length relations. The three basic variations of indices of condition for whole fish are the Fulton condition factor (K and C), relative condition factor (K_n), and relative weight (W_r).

14.5.1 Fulton Condition Factors

Fulton-type condition factors are of the form

Box 14.3 Management Targets for Size Structure Indices

Assume that you are a biologist working in the Black Hills National Forest in South Dakota and Wyoming. During early September you used backpack electrofishers (Chapter 8) to collect samples of brook trout from two streams, Castle Creek and South Iron Creek. Visually assess the length-frequency histograms for these two population samples.

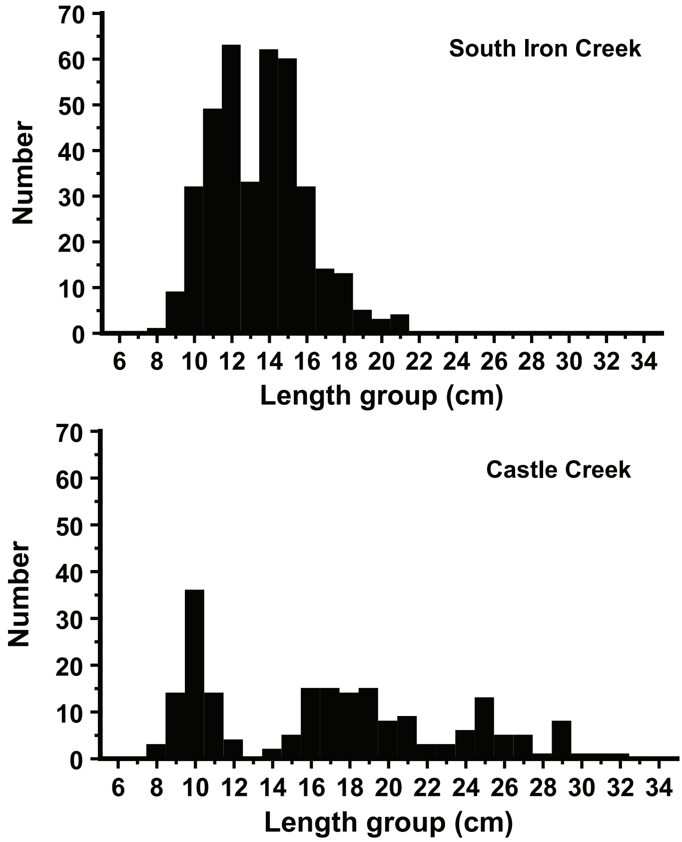

Figure Number of brook trout per length-group (all lengths are total length).

It should be immediately apparent that the size structure is more extended in the Castle Creek population sample than in the South Iron Creek sample. Stock and quality lengths of lotic brook trout populations are 13 and 20 cm, respectively (Table 14.2). Proportional size distribution of quality-length fish (i.e., PSD) for the South Iron Creek sample is 3 ([7/226] · 100 = 3). The PSD of the Castle Creek sample is 49 ([64/130] · 100 = 49). In other words, 49% of all brook trout 13 cm and longer in the Castle Creek sample are also 20 cm or longer.

Johnson et al. (1992) found that in small systems with simple fish communities, Wyoming beaver ponds, brook trout size structure was inversely related to population density and biomass. We might assume that similar density-dependent relationships exist in

(Box continues)

Box 14.3 Continued

nearby, small Black Hills streams. The PSD of 3 in the South Iron Creek population sample indicates relatively low quality for sport angling. Conversely, the PSD of 49 in the Castle Creek population sample indicates that anglers would prefer to fish there. Management targets can be set based upon expected patterns in recruitment, growth, and mortality (e.g., Anderson and Weithman 1978; Gabelhouse 1984b). These authors constructed simple length-based models based on consistent or variable recruitment and known rates of growth and mortality. If such data are not available, then relationships between PSD and relative weight (W_r, section 14.5.3) may be informative. For example, Johnson et al. (1992) found a positive relationship between brook trout PSD and W_r in Wyoming beaver ponds. When brook trout mean W_r was 95, PSD was 19. When brook trout mean W_r was 105, PSD was 59. Thus, a reasonable initial PSD objective range for brook trout in small ponds and streams might be 20–60. A PSD objective range of 20–60 was recommended for balanced populations of bluegill (Willis et al. 1993), which is also an insectivorous species with a tendency to overpopulate and become stunted.

$$K = (W/L^3)\cdot 100{,}000, \tag{14.6}$$

when metric units (millimeters and grams) are used, and

$$C = (W/L^3)\cdot 10{,}000, \tag{14.7}$$

when English units (inches and pounds) are used; W is weight and L is length. The constants 100,000 and 10,000 used in each equation are simply scaling constants to convert small decimals to mixed numbers so that the numbers can be more easily comprehended. A standard convention of subscript symbols is used to designate if K or C was calculated based on measurements of maximum total length (K_{TL} or C_{TL}), fork length (K_{FL} or C_{FL}), or standard length (K_{SL} or C_{SL}). An example of Fulton condition factor calculation is presented in Box 14.4.

Fulton condition factors calculated with metric or English units differ for the same fish and are therefore not comparable. Also, because K and C increase with length for fish with b greater than 3, comparisons should be limited to fish of similar lengths. Comparison of K or C between species is usually impossible because different fishes have different shapes. For example, Bennett (1970) suggested that largemouth bass are in "normal" or "average" condition when C is as low as 4.6 to as high as 5.5, but C of similarly described bluegills is 7.1–8.0 (Box 14.5). Despite these limitations, K and C are useful for indexing body condition of species for which standards are not available for calculation of relative weight (W_r; section 14.5.3).

14.5.2 Relative Condition Factor

Relative condition factor (K_n) compensates for allometric growth; that is, when shape changes as fish grow (Le Cren 1951). It is calculated for each individual fish as

$$K_n = (W / W'), \tag{14.8}$$

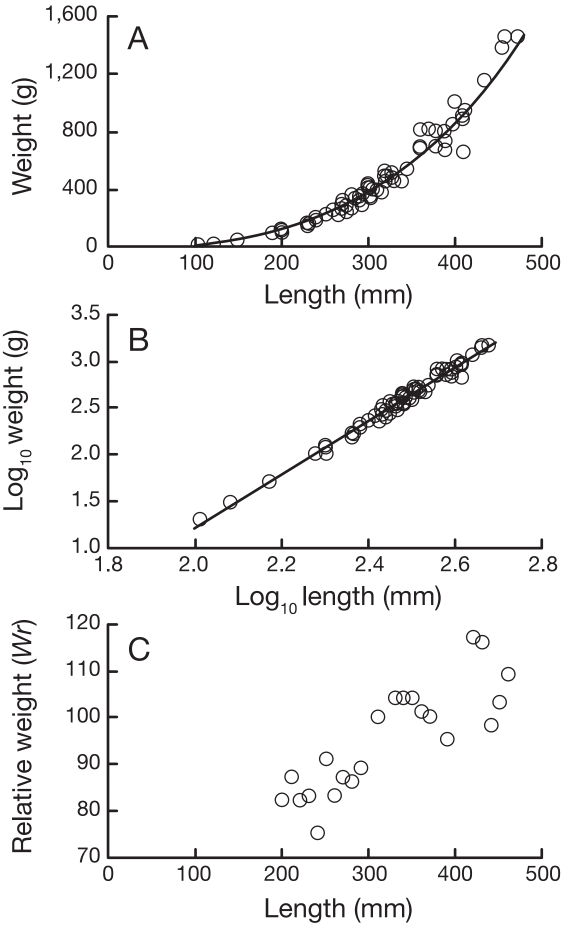

Figure 14.5 Weight–length relationships and relative weight (W_r) plotted as a function of length of largemouth bass collected from Murdo Lake, South Dakota. **(A)** The curvilinear relationship ($W = aL^b$) between weight (W) and length (L). **(B)** The weight–length relationship for the data in (A) logarithmically transformed ($\log_{10}[W] = a' + \mathrm{b} \cdot \log_{10}[L]$). **(C)** The mean W_r per centimeter length-group for 20-cm and longer largemouth bass collected by spring electrofishing (W_r data from Lindgren 1991).

where W is weight of the individual and W' is the length-specific mean weight of a fish in the population under study as predicted by a weight–length equation calculated for that population. Note that K_n thus is a decimal fraction and not a percentage. An example of K_n calculation is presented in Box 14.4.

Relative condition was used by Le Cren (1951) to compare male and female Eurasian perch collected in different seasons within one population. The concept of K_n was expanded by Swingle (1965) and Swingle and Shell (1971) by establishing state-average weight–length relationships for several fishes in Alabama. A practical advantage of K_n is that average fish of all lengths and species have a value of 1.0, regardless of the species or units of measurement. Disadvantages of K_n are that population averages may not describe fish in good condition (but rather just average condition) and averages can vary from one geographic location to another. Comparison and communication are difficult when different weight–length equations are used to obtain W'.

Box 14.4 Calculation and Interpretation of Condition Indices

Calculations of Fulton condition factor based on total length (K_{TL}), relative weight (W_r), and relative condition factor (K_n) are shown below for four largemouth bass in the following table. Relative condition factor was calculated based on Alabama statewide average weight–length data for largemouth bass provided in tabular format by Swingle and Shell (1971). We converted the tabular length and weight data to an Alabama standard weight–length regression for calculation purposes here, but one could simply use their tabular data. Relative weight values were calculated based on the Henson (1991) W_s equation.

Table Total lengths and weights of four largemouth bass with corresponding values of Fulton condition factor (K_{TL}), relative weight (W_r), and relative condition factor (K_n) based on Alabama statewide data.

Length (mm)	Weight (g)	K_{TL}	W_r	K_n
200	101	1.26	100	0.93
300	380	1.41	100	1.02
380	823	1.50	100	1.08
510	2,157	1.63	100	1.15

Fulton Condition Factor (K_{TL})

Because metric units are used for length and weight measurements in this example, the Fulton condition factor is calculated as

$$K_{TL} = (W/L^3) \cdot 100{,}000,$$

where W is weight and L is total length (equation 14.6). Thus, for the first fish in this example,

$$K_{TL} = (101/200^3) \cdot 100{,}000 = 1.26.$$

Relative Weight (W_r)

The standard weight (W_s) equation for largemouth bass based on metric units is

$$\log_{10}(W_s) = -5.528 + 3.273 \cdot \log_{10}(L).$$

Thus,

$$\begin{aligned} \log_{10}(W_s) &= -5.528 + 3.273 \cdot \log_{10}(200) \\ &= -5.528 + 3.273(2.301) = 2.003 \end{aligned}$$

The antilog of 2.003 gives a W_s value of 101 g. Next W_r is calculated as

$$W_r = (W/W_s) \cdot 100 = (101/101) \cdot 100 = 100.$$

Note that W_r is always rounded to the nearest whole number.

(Box continues)

Box 14.4 Continued

Relative Condition Factor (K_n)

The Alabama statewide-average weight–length relationship is

$$\log_{10}(W') = -5.000 + 3.056 \cdot \log_{10}(L),$$

where W' is the predicted average weight. Thus, for the 200-mm-long fish

$$\begin{aligned}\log_{10}(W') &= -5.000 + 3.056 \cdot \log_{10}(200) \\ &= -5.000 + 3.056(2.301) = 2.032.\end{aligned}$$

The antilog of 2.032 gives a W' value of 108 g. Then, K_n is calculated as

$$K_n = (W/W') = (101/108) = 0.94.$$

Each index produces a different interpretation of the condition of these four fish. The K_{TL} values increase with increasing fish length, possibly leading to the incorrect conclusion that longer fish are in better condition. However, K_{TL} values inherently increase with fish length, and comparisons should therefore be limited to only fish of similar lengths. Moreover, K values vary among species and are not comparable (see section 14.5.1).

When an appropriate standard weight (W_s) equation is available, W_r values are based on a comparison of the weight of the fish being measured to the standard weight of a fish of that same species and length across the species' range and during all times of year (i.e., a species-wide standard). Use of K_n values allows a biologist to compare the weight at length of a fish to some other standard, such as a previous weight–length regression from the same population or perhaps a statewide average equation, as in this example. Neither technique is necessarily more correct or superior to the other. In fact, calculation of both W_r values and K_n values based on regional averages might be useful. One might want to compare fish plumpness in a particular population with a species-wide standard and also with a standard derived specifically for one's region.

It should also be noted that the Alabama K_n values also increase with length in this example. Some of this trend may simply be related to a difference in the body form of fish from Alabama and those from populations from across the range of the species. Moreover, the Alabama standards were based on average weights at length (i.e., the 50th percentile), whereas W_s values were based on the 75th percentile (see section 14.5.4). Thus, W_s sets an above-average benchmark.

14.5.3 Relative Weight

Relative weight (W_r) represents refinement of the K_n concept (Wege and Anderson 1978); it is calculated as

$$W_r = (W / W_s) \cdot 100, \tag{14.9}$$

Box 14.5 Comparison of Relative Weight (W_r) and Fulton-Type Condition Factors (C)

Bennett (1970) suggested a range of C_{TL} values for largemouth bass in "poor" condition (3.5–4.5), "average" or "normal" condition (4.6–5.5), and "very fat" or "good plumpness" condition (5.6–6.4). We calculated largemouth bass weights at selected lengths for both the high and low values of each C_{TL} range. These weights were then used to calculate relative weights (W_r) of fish of those lengths as shown in the table below. The descriptive C_{TL} values were in general agreement with expectations of W_r for 300-mm largemouth bass but were inconsistent for other lengths. For example, W_r values of 69 to 88 for 300-mm fish corresponded well with Bennett's poor condition classification, but W_r values of 88 to 113 are not indicative of poor condition for 125-mm fish. Fulton-type condition factors are difficult to compare among sizes because the body shapes of many species change with increasing length; C or K values typically increase correspondingly. Assuming that an appropriate standard weight (W_s) equation is available (Henson 1991), a W_r of 100 indicates that a fish is in above-average condition regardless of length.

Table Fulton condition factor (C_{TL}) ranges of three condition classes of largemouth bass described by Bennett (1970), with corresponding relative weight (W_r) values over a range of lengths (total length in millimeters).

Bennett's classification	Range of C_{TL}	Relative weight (W_r) at length (mm) 125	200	300	380
Poor condition	3.5	88	77	69	65
	4.5	113	99	88	83
Average condition	4.6	115	101	91	85
	5.5	138	121	108	102
Very fat condition	5.6	140	123	110	103
	6.4	163	143	128	120

where W is the weight of an individual and W_s is a length-specific standard weight predicted by a weight–length regression constructed to represent the species. Note that even though W_r is a percentage, it is unitless, and no percentage symbol should be used. The standard weight W_s is calculated as

$$\log_{10}(W_s) = a' + b \cdot \log_{10}(L), \tag{14.10}$$

where a' is the intercept value, b is the slope of the $\log_{10}$(weight)–$\log_{10}$(length) regression equation, and L is the length of the fish. Note that the form of a W_s equation is the same as that for a typical weight–length equation (equation 14.5). A basic concept of W_r is that the standard should describe the inherent shape of a fish in good condition. When W_r values are well below 100 for an individual or a size-group, problems may exist in food or feeding conditions; when W_r values are well above 100, fish may not be making the best use of a surplus of prey.

Standard weight equations have been proposed for a variety of fishes (Table 14.5). The procedure for obtaining W_s and calculating W_r is presented in Box 14.4. Alternatively, tables of W_s

Table 14.5 Intercept (*a'*) and slope (*b*) parameters of standard weight (W_s) equations proposed for various fish species and minimum total lengths (mm) recommended for application. The standard weight equation format is $\log_{10}(W_s) = a' + b \cdot \log_{10}(L)$. Length (*L*) is total length unless indicated otherwise. Metric (M) equations are in millimeters and grams; English (E) equations are in inches and pounds (updated from Murphy et al. 1991, Anderson and Neumann 1996, and Blackwell et al. 2000).

Species	Intercept (*a'*)		Slope (*b*)	Minimum total length (mm)	Source
	M	E			
Bigmouth buffalo	–5.069	–3.346	3.118	150	Bister et al. 2000
Black bullhead	–4.974	–3.297	3.085	130	Bister et al. 2000
Black crappie	–5.618	–3.576	3.345	100	Neumann and Murphy 1991
Blue catfish	–6.067	–3.950	3.400	160	Muoneke and Pope 1999
Bluegill[a]	–5.374	–3.371	3.316	80	Hillman 1982
Brook trout	–5.186	–3.483	3.103	120	Hyatt and Hubert 2001b
Brown bullhead	–5.076	–3.371	3.105	130	Bister et al. 2000
Brown trout					
Lentic	–5.422	–3.592	3.194	140	Hyatt and Hubert 2001a
Lotic	–4.867	–3.366	2.960	140	Milewski and Brown 1994
Bull trout	–5.327	–3.608	3.115	120	Hyatt and Hubert 2000
Burbot	–4.868	–3.454	2.898	200	Fisher et al. 1996
Chain pickerel	–5.824	–3.923	3.243	150	Neumann and Flammang 1997
Channel catfish	–5.800	–3.829	3.294	70	Brown et al. 1995
Chinook salmon	–4.661	–3.243	2.901	200	Halseth et al. 1990
Cisco	–5.517	–3.644	3.224	100	Fisher and Fielder 1998
Common carp	–4.639	–3.194	2.920	200	Bister et al. 2000
Cutthroat trout					
Lentic	–5.192	–3.514	3.086	130	Kruse and Hubert 1997
Lotic	–5.189	–3.492	3.099	130	Kruse and Hubert 1997
Flannelmouth sucker	–5.180	–3.527	3.068	100	Didenko et al. 2004
Flathead catfish	–5.542	–3.661	3.230	130	Bister et al. 2000
Freshwater drum	–5.419	–3.575	3.204	100	Blackwell et al. 1995
Gizzard shad[a]	–5.376	–3.580	3.170	180	Anderson and Gutreuter 1983
Golden shiner	–5.593	–3.611	3.302	50	Liao et al. 1995
Golden trout	–5.088	–3.473	3.041	120	Hyatt and Hubert 2000
Green sunfish	–4.915	–3.216	3.101	60	Bister et al. 2000
Humpback chub	–5.278	–3.586	3.096	120	Didenko et al. 2004
Kokanee	–5.062	–3.458	3.033	120	Hyatt and Hubert 2000
Lake trout	–5.681	–3.778	3.246	280	Piccolo et al. 1993
Largemouth bass	–5.528	–3.587	3.273	150	Henson 1991
Longnose gar	–6.811	–4.623	3.449	200	Bister et al. 2000
Mountain whitefish	–5.086	–3.478	3.036	140	Rogers et al. 1996

Table 14.5 Continued.

Species	Intercept (a') M	Intercept (a') E	Slope (b)	Minimum total length (mm)	Source
Muskellunge					
Overall	–6.066	–4.052	3.325	380	Neumann and Willis 1994
Female	–6.105	–4.070	3.340	380	Neumann and Willis 1994
Male	–5.823	–3.921	3.245	380	Neumann and Willis 1994
Northern pike	–5.437	–3.745	3.096	100	Anderson and Neumann 1996
Northern pikeminnow[b]	–4.886	–3.328	2.986	250	Parker et al. 1995
Paddlefish					
Overall[c]	–5.027	–3.340	3.092	280	Brown and Murphy 1993
Female[c]	–4.073	–2.822	2.782	280	Brown and Murphy 1993
Male[c]	–4.494	–3.063	2.910	280	Brown and Murphy 1993
Palmetto bass	–5.201	–3.448	3.139	115	Brown and Murphy 1991b
Pumpkinseed	–5.179	–3.289	3.237	50	Liao et al. 1995
Pejerrey	–5.345	–3.651	3.097	250	Baigun and Anderson 1993
Rainbow trout					
Lentic	–4.898	–3.354	2.990	120	Simpkins and Hubert 1996
Lotic	–5.023	–3.432	3.024	120	Simpkins and Hubert 1996
Razorback sucker	–4.886	–3.350	2.985	110	Didenko et al. 2004
Redear sunfish	–4.968	–3.263	3.119	70	Pope et al. 1995
River carpsucker	–4.839	–3.293	2.992	130	Bister et al. 2000
Rock bass	–4.827	–3.166	3.074	80	Bister et al. 2000
Roundtail chub	–5.065	–3.486	3.015	100	Didenko et al. 2004
Sauger	–5.492	–3.671	3.187	70	Anderson and Neumann 1996
Saugeye	–5.692	–3.760	3.266	170	Flammang et al. 1993
Shorthead redhorse	–4.841	–3.337	2.962	100	Bister et al. 2000
Shovelnose sturgeon[b]	–6.287	–4.266	3.330	120	Quist et al. 1998
Smallmouth bass	–5.329	–3.491	3.200	150	Kolander et al. 1993
Smallmouth buffalo	–5.298	–3.448	3.208	200	Bister et al. 2000
Spotted bass	–5.392	–3.533	3.215	100	Wiens et al. 1996
Spotted gar	–6.551	–4.388	3.431	250	Bister et al. 2000
Striped bass	–4.924	–3.358	3.007	150	Brown and Murphy 1991b
Tiger muskellunge	–6.126	–4.095	3.337	240	Rogers and Koupal 1997
Walleye	–5.453	–3.642	3.180	150	Murphy et al. 1990
30–149 mm	–4.804	–3.431	2.869	30	Flammang et al. 1999
Warmouth	–5.180	–3.284	3.241	80	Bister et al. 2000

Table 14.5 Continued.

Species	Intercept (a') M	Intercept (a') E	Slope (b)	Minimum total length (mm)	Source
White bass	–5.066	–3.394	3.081	115	Brown and Murphy 1991b
White catfish	–5.851	–3.739	3.395	100	Bister et al. 2000
White crappie	–5.642	–3.618	3.332	100	Neumann and Murphy 1991
White perch	–5.122	–3.373	3.136	80	Bister et al. 2000
White sturgeon[b]	–5.795	–3.912	3.232	700	Beamesderfer 1993
White sucker	–4.755	–3.282	2.940	100	Bister et al. 2000
Yellow bass	–5.142	–3.398	3.133	70	Bister et al. 2000
Yellow bullhead	–5.374	–3.491	3.232	60	Bister et al. 2000
Yellow perch	–5.386	–3.506	3.230	100	Willis et al. 1991

[a] W_s equation was developed by method other than the regression-line-percentile (RLP) technique.
[b] Body length measured as fork length.
[c] Body length measured as anterior edge of eye to fork of tail.

values can be prepared or W_r and W_s can be calculated with computer programs. Consistency in the use of any standard promotes communication and understanding.

Trends or patterns in W_r can be evaluated by plotting individual W_r values by fish length or mean W_r values for length-groups (Figure 14.5C). Calculation of mean W_r for an entire sample can mask important length-related trends in fish condition (Murphy et al. 1991). The length-groups defined by the five-cell PSD model (Table 14.2) provide a convenient basis for determination of W_r values. Fish of the same length may be considered ecological equivalents even if they differ in age (Gutreuter 1987). Body size can provide a more interpretable basis than age for expression of growth rates (Larkin et al. 1956). Low W_r for a length-group could be evidence of competition influencing growth.

14.5.4 Development and Evaluation of Standard Weight Equations

The key to valid use of W_r is the availability of reliable W_s equations for various fish species. The original method (Wege and Anderson 1978) involved use of species weight–length summaries provided by Carlander (1969, 1977). Carlander reported a central 50% range of mean weights by 25-mm (1-in) length-groups; the upper end of this 50% range was termed the 75th percentile weight by Wege and Anderson (1978). Use of 75th percentile weight (i.e., not the average or mean) for W_s equation development has been maintained in subsequent techniques. Thus, a W_r value of 100 represents a fish in above-average (i.e., 75th percentile) condition compared with fish of that length across the species range and at various times of year. The Carlander-based summaries often provided W_s equations that were length biased, meaning that W_r had a tendency to increase or decrease consistently with increasing fish length (Neumann and Murphy 1991). The regression-line-percentile (RLP) technique (Murphy et al. 1990) has been the most useful method developed to date to determine W_s equations. Most of the W_s equations in Table 14.5 were developed by this method, with noted exceptions.

Gerow et al. (2004) used a different method for detecting length-related biases in W_s equations and found that many RLP-based equations resulted in biased W_r values. Gerow et al. (2005) proposed a new method to compute W_s equations that reduces length-related bias. The best available W_s equations are provided in Table 14.5, and we recommend their use. Much of the reported bias in W_r values occurs for small and large individuals of most fish species (Gerow et al. 2004). Neely et al. (2008) proposed a W_s equation for blue suckers based on the empirical percentile technique (EMP) from Gerow et al. (2004, 2005). However, Rennie and Verdon (2008) found that EMP-generated equations were no better than, and not always as good as, RLP-based W_s equations for lake whitefish. Therefore, we recommend that W_r analyses be interpreted with caution for small and large fish until improved W_s equations become available. A constructive suggestion would be to use both methods and select the resulting equation with the least length-related bias.

14.5.5 Management Targets for Relative Weight

In concept, a mean W_r of 100 for a broad range of size-groups of a population should reflect ecological and physiological optimality because W_s equations typically are based on the 75th percentile of weights at a given length, not the average (section 14.5.4). Anderson (1980) recommended a W_r target range of 95–105 for balanced fish populations. McComish (1971) fed midge larvae to bluegills over a range of daily rations in laboratory experiments and found growth efficiency was highest when W_r was near 100.

The difficulty in defining optimal or even good condition for any species has led to the suggestion that W_s should be thought of simply as a benchmark for comparison of samples and populations (Murphy et al. 1990). Murphy et al. (1991) suggested that it is appropriate to model W_s to represent better-than-average populations of a given species, but targets for specific applications may need to be adjusted depending on specific management objectives. For example, when managing for large bluegills in small impoundments, Gabelhouse (1987) recommended a W_r target range of 105–115 for bluegills and 85–95 for largemouth bass (i.e., the panfish option). In this case, the W_r target range for largemouth bass is lower than the generic target of 95–105 because maintaining a high density of largemouth bass (to control bluegill recruitment) should reduce largemouth bass condition.

For some species, average body condition varies among regions, reflecting large-scale environmental differences. For example, mean W_r values of populations of yellow perch in the Great Plains states were 100 or more, whereas W_r values of few populations elsewhere exceeded 100 (Willis et al. 1991). Mean W_r of yellow perch populations in Georgia ranged from 56 to 71. Because of such geographic variability, managers might choose to create region-specific target ranges for W_r or opt for regional standards (i.e., K_n); however, a species-wide standard such as W_s, in addition to regional standards, allows widespread data comparison and communication among fisheries biologists.

Because average W_r ranges of some species differ among water body types, biologists might choose to adjust target ranges accordingly. For example, W_r values of burbot differ between lentic and lotic populations (Fisher et al. 1996). Fisher and Fielder (1998) reported that W_r values of Lake Superior cisco were lower than those of other North American populations and attributed the difference to body shape rather than condition. They suggested target W_r ranges of 70–80 for Lake Superior and other oligotrophic waters and 95–105 for other populations. Seasonal variation in condition may also necessitate adjustment of target ranges (Blackwell et al. 2000).

14.5.6 Utility of Condition Indices

Because condition indices provide a measure of the relative plumpness of fish, they should indicate a general state of well-being or health. Ideally, body condition values reflect health parameters and provide a noninvasive shortcut to assess these aspects of fish populations. A comprehensive review of the status of use of W_r in North America (Blackwell et al. 2000) concluded that its uses may go beyond just a measure of fish plumpness. It found that W_r served as a surrogate for estimating fish body composition, as a measure of fish health, and as a tool to assess prey abundance, fish stockings, and management actions.

Demonstrated relationships exist between condition indices and proximate composition of fish (McComish et al. 1974; Rose 1989; Brown and Murphy 1991a; Neumann and Murphy 1992; Pangle and Sutton 2005). Fulton condition factor (K) was positively correlated to whole-body crude lipid, crude protein, and gross energy content of juvenile cisco in laboratory experiments (Pangle and Sutton 2005), indicating that K could be used to estimate temporal changes in proximate composition during winter in Lake Superior. Relative weight was a useful estimator of body composition and gross energy content of juvenile striped bass and palmetto bass in aquarium experiments; significant positive relationships existed between W_r and whole-body crude fat and visceral fat percentage (Brown and Murphy 1991a). Relative weight could be used to assess body condition of immature walleyes (Rose 1989). However, only weak correlations existed between seasonal energy density and condition index values (K and W_r) of age-0 and age-1 muskellunge (Jonas and Kraft 1996); thus, condition indices may not be the best indicators of seasonal fluctuations in total energy of young muskellunge (Jonas and Kraft 1996). Copeland (2004) found that regressions of percentages of lipid, protein, and water content and liver–somatic, gonadosomatic, and viscerosomatic indices on W_r of two wild bluegill populations over a year had little explanatory power. He concluded that relationships between physiological variables and W_r can be confounded in natural environments and that condition indices should be used as qualitative monitoring tools, not omnibus physiological predictors.

Positive relationships often exist between growth rates and W_r. Growth rates of juvenile palmetto bass (Brown and Murphy 1991a) and immature walleyes (Rose 1989) were positively related to W_r in short-term laboratory experiments. Positive relationships existed between measures of growth (e.g., back-calculated length at age and incremental growth) and W_r of wild populations of northern pike (Willis and Scalet 1989; Neumann and Willis 1996), white crappie (Gabelhouse 1991), black crappie (Guy and Willis 1995), yellow perch (Willis et al. 1991), and largemouth bass (Wege and Anderson 1978). In other cases, no meaningful correlations existed between growth and W_r (Gutreuter and Childress 1990; DiCenzo et al. 1995; Hartman and Margraf 2006). DiCenzo et al. (1995) believed that the lack of correlations was because W_r is an instantaneous measure whereas growth occurs over a longer term. Because W_r varies by season and fish size, correlations between growth rates and W_r may be stronger if data are from the same season or time scales are synchronous (Blackwell et al. 2000). For example, significant positive relationships existed between annual growth and W_r of age-2 largemouth bass in midwestern U.S. ponds (Wege and Anderson 1978). Correlations between growth and W_r of yellow perch were stronger when data were limited to single seasons (Willis et al. 1991).

Relative weight can be indicative of prey availability. Mean W_r of stock-to-quality-length largemouth bass was positively related to prey biomass in midwestern U.S. ponds (Wege and Anderson 1978). Pumpkinseed condition was positively correlated with chironomid and gastropod biomass in southern Quebec lakes (Liao et al. 1995). Walleye condition was positively related to stocking densities of trouts in a series of Wyoming reservoirs (Marwitz and Hubert 1997); apparently, the fusiform, soft-rayed trouts were an important food for walleyes. Walleye W_r was related to prey availability in two Nebraska reservoirs (Porath and Peters 1997) and Lake Erie (Hartman and Margraf 2006). Northern pike condition was correlated with prey abundance in Nebraska Sandhill lakes (Paukert and Willis 2003). Positive correlations existed between flannelmouth sucker condition and macroinvertebrate densities in the Colorado River (Paukert and Rogers 2004).

Higher body condition could be expected to result in greater reproductive potential if fish were able to use more energy for gamete production (Blackwell et al. 2000). For example, a positive relationship existed between the percentage of mature eggs and W_r of white crappie, potentially indicating that fish in better condition allocated more energy reserves to egg development (Neumann and Murphy 1992). Relationships existed between gonadosomatic index and W_r of gizzard shad (Willis 1987) and northern pike (Neumann and Willis 1995).

Evidence for the utility of condition indices is inconsistent. Correlations with growth, body composition (such as liver–somatic index and viscerosomatic index), fish health, and RNA:DNA ratios were demonstrated in some studies but not others (Mustafa et al. 1991; Neumann and Murphy 1992; Copeland et al. 2008). Copeland et al. (2008) suggested that W_r is a general indicator of nutritional status and not a precise index to body composition. Consequently, more research in a variety of environments is needed to assess the utility of W_r as predictor of body composition and growth (Blackwell et al. 2000). Fisheries managers using W_r as an index to population metrics such as growth, recruitment, mortality, and density should therefore validate these relationships. Relative weight should not be used as a stand-alone assessment technique but rather as one technique in a suite of population assessment tools.

14.6 WEIGHT RATIOS

Ratios of weights of different components of a fish assemblage can be used to assess trophic conditions. Based on his research in ponds, Swingle (1950) characterized fishes that often feed on fish as carnivores, or *C* species, and those that often feed on invertebrates and serve as food for carnivores as forage, or *F*, species. The *F/C* ratio is the weight of *F* species divided by weight of *C* species. The most desirable range of *F/C* is 3.0–6.0. The *Y/C* ratio was developed because some individuals in the *F* group are too large to be prey. The *Y* value is the total weight of fish in the *F* group small enough to be eaten by the average-size adult in the *C* group. The *Y/C* ratio is the total weight of *Y* divided by the total weight of *C*. The desirable range of *Y/C* is 1.0–3.0.

Swingle's A_T is the percentage of total weight of a fish population composed of harvestable-size fish. The most desirable range of A_T for both largemouth bass and bluegill populations is 60–85%. Swingle's *E* value is the percentage of weight of the entire fish assemblage composed of a specific species or group. The desirable range of *E* for largemouth bass in small impoundments is 14–25%.

Jenkins and Morais (1978) developed the available prey : predator ratio (*AP/P*), which is similar in concept to Swingle's *Y/C* ratio. For the determination of *AP/P*, all sizes of predators are equated to sizes of largemouth bass that can consume the same maximum size of prey. Biomass of prey small enough to be eaten by a particular size of predator is plotted on log–log scales against the cumulative biomass of predators (Figure 14.6). These ratios are typically determined for one point in time, often based on biomass data obtained from cove rotenone samples (Bettoli and Maceina 1996). The *AP/P* ratio has been used successfully in documenting

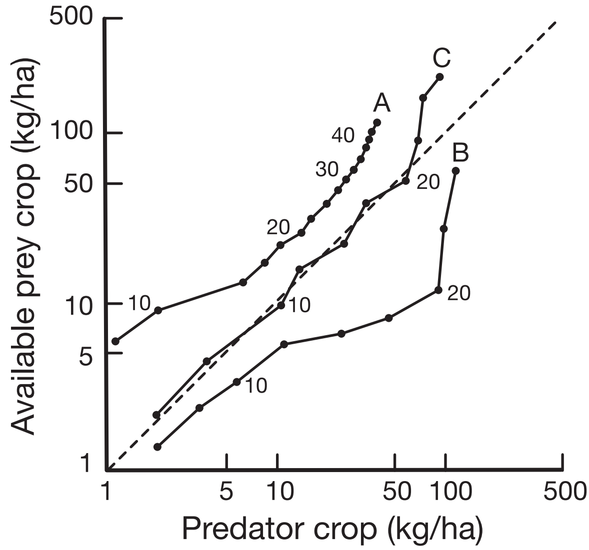

Figure 14.6 Logarithmic plots of available prey : predator (*AP/P*) for three general conditions: (A) excess prey for all lengths of predators; (B) prey deficiencies for all lengths of predators; and (C) prey adequacy for small predators but excess for large predators (>20 cm). Diagonal dashed line indicates the minimum desirable *AP/P* ratio (from Noble 1981). Numbers along the plots are predator lengths (cm), and points represent 2.5-cm length increments.

shortages and surpluses of available prey and for documenting changes in the seasonal availability of prey (Jenkins 1979; Timmons et al. 1980; Stephen 1986; Bettoli et al. 1992; Ney 1999). Buynak et al. (1999) used *AP/P* ratios to determine the minimum size of largemouth bass that should be stocked into a Kentucky reservoir given available prey. Cyterksi and Ney (2005) took the concept one step further by determining an available supply : demand ratio based on bioenergetics modeling.

14.7 INTEGRATION OF SIZE STRUCTURE AND CONDITION INDICES

Size structure information can be integrated with fish condition to assess a fish population more thoroughly. The combined information provided by two indices can often be more interpretive than either index alone. Similarly, fish communities can also be assessed through a combination of size structure and condition indices. A common example is a plot of size structure indices of a prey species as a function of the size structure indices of a predator species (Ney 1999).

14.7.1 Integrated Population Assessment

Size structure indices (section 14.3) and condition indices (section 14.5) can be integrated on a single figure to visualize changes in fish population status over time. For example, both size structure and condition of largemouth bass should improve after successful implementation of a protected slot-length-limit regulation (Noble and Jones 1999). Mean W_r and PSD of a largemouth bass population over a 5-year period in an 18-ha impoundment are plotted in Figure 14.7 to follow changes in body condition and size structure after implementation of a protected slot-length-limit regulation. Under the new regulation, anglers could selectively harvest largemouth

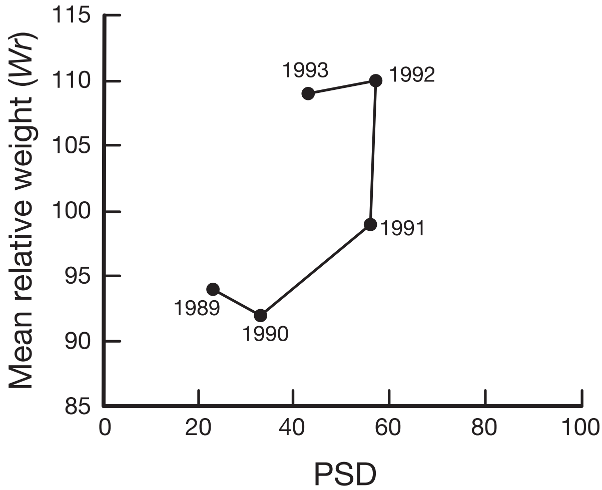

Figure 14.7 Changes in mean W_r and PSD of quality-length largemouth bass collected from 1989 to 1993 in Murdo Lake, South Dakota, after implementation of a 300–380-mm protected slot length limit in 1989 (from Neumann et al. 1994).

bass less than 300 mm. Initially, in 1989, both size structure and body condition were low because of high population density. By 1991, 2 years after the slot limit was implemented, both PSD and W_r values had improved, shifting into the management target ranges of a balanced largemouth bass population for both indices. As anglers continued to harvest smaller largemouth bass selectively, density was further reduced, leading to continued improvements in size structure and body condition. Whereas increases in PSD alone over the 5 years showed improvements in size structure, concurrent examination of W_r strengthened the conclusion that reducing the density of smaller largemouth bass led to faster growth and ultimately a higher-quality fishery.

14.7.2 Integrated Community Assessment

Fish community structure and dynamics can be visualized by plotting PSD values of prey fishes against the PSD values of predatory fishes in both simple and multispecies fisheries (Goedde and Coble 1981). Community structures in the lower left of Figure 14.8 reflect low quality of both predators and prey whereas those in the upper right indicate high quality of both. Mid Lake was opened to angling in 1976 after being closed to angling for the previous 20 years. Size structures of both predator and prey fishes there deteriorated rapidly and soon resembled those in Allen Lake, which had been angled continuously.

14.8 CONCLUSIONS

Indices based on length and weight can be inexpensive and easy to obtain yet provide useful information for monitoring fish populations and assessing communities (Ney 1999). However, as with any index, more information will lead to a better final assessment. Thus, we recommend that biologists, to the extent possible, integrate size structure and condition indices with other tools such as relative abundance (Hubert and Fabrizio 2007), recruitment (Maceina and Pereira 2007),

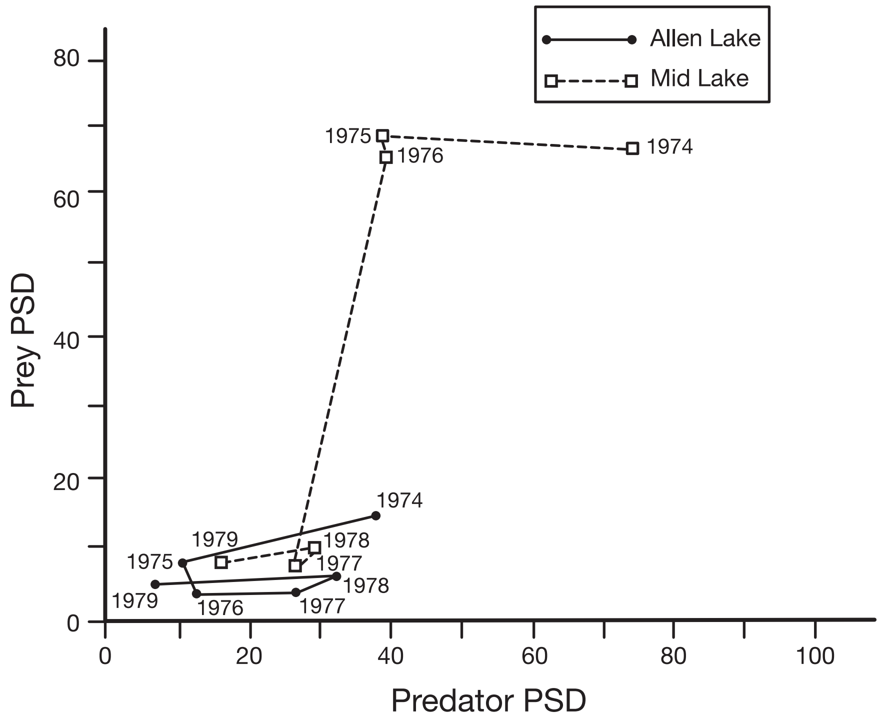

Figure 14.8 The time trajectory of weighted PSD of quality-length game fish (largemouth bass and northern pike) and panfish (bluegill, yellow perch, and pumpkinseed) in two Wisconsin lakes. Mid Lake was opened to angling in 1976 after having been closed for 20 years. Allen Lake had been continuously exploited (from Goedde and Coble 1981).

growth (Isely and Grabowski 2007), mortality (Miranda and Bettoli 2007), and other specific assessment techniques (Van Den Avyle and Hayward 1999; Guy and Brown 2007).

Length, weight, and associated indices are important components of fish population assessments. Whereas more quantitatively complex stock assessment procedures may be necessary at times to address specific questions regarding fish populations and communities, the expanding use of length and weight indices among geographic regions, environments, and species reflects the utility of easily calculable indices to make sound assessments of fish populations and to communicate assessment information readily.

The use of length and weight indices to assess population characteristics of nonsport fishes is gaining popularity, especially as standards become available for more nonsport fishes (e.g., Didenko et al. 2004; Paukert and Rogers 2004; Shuman et al. 2006). For these indices to be useful, standards must first be developed. Such work has occurred, and more is currently ongoing. In addition, improvements in techniques for development of standards will occur, as in the case of improved W_s equation development by Gerow et al. (2004, 2005). Thus, biologists need to be aware of current work and upgrade to more reliable standards if and when they become available. However, changes, no matter how minor, create hardships and should not be made unless evidence indicates that they are indeed necessary and will improve the ability to assess fish populations and communities.

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