10 Condition

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■ 10.3 CONDITION INDICES

Condition indices are widely used to assess many facets of fish populations, including the general health of fish stocks, the effects of management actions, community structure, or environmental influences (Bolger and Connolly 1989; Ney 1993; Neumann and Willis 1995; Ward and Zimmerman 1999; Blackwell et al. 2000). Condition indices are intended to estimate physiological condition (e.g., lipid stores) indirectly based on the premise that a fish of a given species and length should weigh as much as a standard or average for its length, and variations from the standard are taken as an indication of the relative wellness of an individual. Measures of fish condition based on a standard weight have been available since the early 1900s and have undergone an evolution in methodology (Murphy et al. 1991) as well as rigorous reviews regarding their correlation with physiological parameters and statistical merit (e.g., Bolger and Connolly 1989; Patterson 1992; Blackwell et al. 2000; Vila-Gispert and Moreno-Amich 2001; Brenden et al. 2003). They remain popular tools because they are simplistic and noninvasive (only weight–length data needed) and are more easily compared than are the regression parameters in weight–length relationships. Murphy et al. (1990) indicated that an ideal condition index should be consistent, that is, maintain similar statistical properties and meaning across length and species; tractable, that is, analyzable by standard statistics; robust, that is, insensitive to data collection and analysis variations; and efficient, that is, provide precision from relatively small sample sizes. Anderson and Neumann (1996) and Blackwell et al. (2000) provided thorough reviews of the history of condition factors, and here we only briefly describe their history and development.

10.3.1 Fulton's Condition Factor

Traditionally, one of the ways to relate fish length to weight was simply to cube the length of the fish (Spencer 1898; Wootton 1990). However, this basic equation is imprecise because it fails to account for allometric growth (i.e., $b \neq 3$; equation [10.1]; Fulton 1904; Martin 1949). Nonetheless, this basic physical principle has been used extensively in fisheries science and is still used today (e.g., Ratz and Lloret 2003; Stone et al. 2003). For example, Fulton's condition factor (Anderson

and Neumann 1996) is calculated as the ratio between observed and expected weight for a fish of given length:

$$K = (W/L^3) \bullet 100{,}000, \tag{10.8}$$

where W is the weight (g), L is length (mm), and 100,000 is a scaling constant. In application, body form changes with length ($b > 3$) and species ($b_1 \neq b_2$), which results in condition factors that are often length and species dependent (Murphy et al. 1991; Jakob et al. 1996; Blackwell et al. 2000). Thus K increases with increasing length, limiting its application to fish of similar length within the same species.

10.3.2   Relative Condition Factor

Le Cren (1951) attempted to solve the deficiencies of K by comparing the actual weight to a standard predicted by the weight–length regression based on the population from which the fish was sampled. Relative condition is calculated as

$$K_n = (W/W') \bullet 100, \tag{10.9}$$

where W is individual fish weight and W' is the predicted length-specific weight based on $\log_{10}$ transformed data. Average fish of all lengths and species have an average K_n value of 100; however, because weight–length relationships can vary among populations and geographic sites, comparisons of K_n must be confined to those populations with homogenous weight–length parameters. Swingle and Shell (1971) indicated that K_n could be useful as an indicator of physiological stress on a population and expanded the concept by establishing species-specific weight–length relationships across a broader geographical range, which allowed comparisons of condition across populations. This broadened application of condition analyses from a population level to regional scale; however, regional differences still existed, making comparison and communication difficult.

10.3.3   Relative Weight

Relative weight (W_r) was proposed by Wege and Anderson (1978) as a condition analysis tool for largemouth bass and represents further evolution of the K_n concept by allowing comparisons of condition across the geographical occurrence of a species, as well as among species. The W_r index is calculated as

$$W_r = (W/W_s) \bullet 100, \tag{10.10}$$

where W is individual fish weight and W_s is a length-specific standard weight predicted from a weight–length regression developed to represent the body form of the species across its geographical range (see Blackwell et al. 2000 for a list of developed standard weight equations). The W_r index uses 100 (or a range, 95–105) as a benchmark for a fish in good condition—a readily identifiable standard

for fisheries scientists. Fish greater than the target are considered in relatively better condition than a standard fish, whereas those less than the target are considered in worse condition with severity depending on the distance from the benchmark. For example, condition values exceeding 105 may indicate abundant prey and favorable environmental conditions (e.g., Marwitz and Hubert 1997; Porath and Peters 1997).

The estimation of a and b in the standard weight equation (note equation [10.2]),

$$\log_{10}(W_s) = a + b(\log_{10}L), \tag{10.11}$$

has undergone several iterations and review of statistical validity (see Anderson and Neumann 1996). The currently accepted technique for development of W_s equations is the 75th regression-line–percentile (RLP) technique proposed by Murphy et al. (1990), which has consistently provided W_s equations with little or no length-related biases, allowing for comparisons within and across species. Gerow et al. (2004), however, suggested this bias has been incorrectly assessed in the past and may be greater than originally reported for most standard W_s equations. Because standard weight equations are developed based on weight–length relationships across the range of the species, comparison and communications of condition analyses are consistent across the species range. Herein lays the value of W_r relative to other condition indices. Whereas a single W_s equation for each species has generally proven adequate, and is preferred for simplicity, differences in body forms between broad habitat types (e.g., lotic versus lentic habitats) has required maintaining multiple standard weight equations or target goals (i.e., something other than 100) for some species (e.g., burbot, Fisher et al. 1996; inland cutthroat trout, Kruse and Hubert 1997).

It is logical that both environmental and genetic factors influence body form and weight, and, by extension, condition as well. Furthermore, it is possible for an individual to increase energetic fitness without a change in body weight (Booth and Keast 1986). Thus, questions remain whether W_r, or any weight to length ratio, is both a valid and interpretable indicator of the physiological condition in fish or a metric sensitive and relevant enough to assess the effects of changed management or environment on fish condition. Numerous studies have investigated the practical limits in the application of W_r. Liao et al. (1995) and Gutreuter and Childress (1990) found W_r a weak indicator of growth, a relationship that seems intuitive based on the assumption that a fish in better condition can devote more energy to growth. Conversely, Brown and Murphy (1991) and Neumann and Murphy (1992) found W_r was correlated with fat composition in the body, an indication that W_r can be a relative measure of individual energy stores. Blackwell et al. (2000) provided excellent discussion regarding the relationships, or in some cases the lack thereof, between W_r and body composition, growth, and reproductive potential, among other things. Brenden et al. (2003) suggested that the lack of clear relationships in some studies attempting to relate W_r to variables that seem intuitively related to individual condition might be the result of an index

that, in most cases, does not satisfy the theoretical assumptions on which the statistical test is founded.

Most analyses of W_r are either mean comparisons among different populations or length categories (e.g., *t*-test, ANOVA, or nonparametric equivalents) or an assessment of the correlation and regression relationship among condition and other independent variables that might influence fitness (e.g., prey density as a good predictor of condition for a given population or size-class of fish). Sections 10.3.4 and 10.6 describe some of the common statistical procedures used to analyze and compare individual and population level condition as measured by an index.

10.3.4   Application and Common Statistical Analysis of Relative Weight

10.3.4.1   Statistical Analysis of Relative Weight Data

The application of W_r has increased over the last decade and is now commonly used as a condition assessment tool in the majority of the USA (Blackwell et al. 2000); thus, we focus our discussion of statistical analyses on W_r. The appropriateness of W_r, which is a ratio, as a variable in statistical testing has been the subject of several reviews. Numerous authors have recommended against the use of ratios to scale biological data because analyses of ratios may point to treatment effects that do not exist or they may fail to detect major differences that do exist (e.g., Tanner 1949; Atchley et al. 1976; Anderson and Lydic 1977; Atchley 1978; Atchley and Anderson 1978; Reist 1985; Packard and Boardman 1988). Bolgor and Connolly (1989) indicated that the potential for greater variability and nonnormal distributions of ratio data such as W_r might make parametric testing of W_r inappropriate. Furthermore, they indicated that ratio data commonly exhibit heteroscedasticity, skewness, and leptokurtosis (a taller distribution with fatter tails as compared with normal), all of which violate the assumptions of common statistical tests (e.g., regression and ANOVA) and weaken the power of these comparisons. Thus, Hyatt and Hubert (2001) concluded that normality for W_r data cannot be assumed and should be assessed before applying parametric tests. Murphy et al. (1990), when evaluating W_r frequencies in walleye populations, suggested that the use of parametric tests to compare differences in W_r data yields conservative results, which Blackwell et al. (2000) interpreted as a greater probability of type II error (failure to reject the null hypothesis when the alternative is true). Contrarily, Bolger and Connolly (1989) stated that while skewness has minimal effect on significance or power, significant leptokurtosis could lead to greater nominal significance values. Sokal and Rohlf (1981) indicated that a nonnormal distribution is only a minor violation of the assumptions for parametric statistics, thus parametric mean-comparison tests are generally robust to departures from normality. If there is concern over violation of assumptions for parametric tests, an alternative is to use a nonparametric test such as Wilcoxon's rank-sum test or Kruskal–Wallis test for comparison.

Patterson (1992) also recognized the problems of skewed distributions of ratios and suggested, as summarized in section 10.2.3, that it is inappropriate to use

weight–length regression residuals because they are biased estimators of regression error. Likewise, Jakob et al. (1996) noted that residuals from the residual index for condition are not comparable across populations. This is germane because individual values of W_r are essentially the de-transformed residuals. As a solution, Patterson (1992) proposed that all variables assumed to affect weight be directly included in the analyses at the same time as length and the coefficient of each parameter used to assess its effect on condition. For example, when testing for mean monthly differences in condition, include month as a variable in the model:

$$\log_{10}(W_i) = \beta(0) + \beta(m) + \beta_1[\log_{10}(L_i)] + e_i, \qquad (10.12)$$

where $\beta(0)$ is the overall intercept and $\beta(m)$ are monthly adjustments to the overall intercept. Each parameter coefficient is used to measure the effect on fish condition. This is essentially an extension of the ANCOVA analysis.

More recently, based on a derivation of the statistical properties of the index, Brenden et al. (2003) argued that W_r data are not independent and identically distributed, as required by both parametric and nonparametric tests, because the properties are conditionally dependent on fish length. Conventional tests that assume independence and identical distributions increase the likelihood of a type I error (rejecting the null hypothesis when there is no difference) when applied to W_r data. To alleviate this risk, they proposed an *R*-test as the most appropriate and conservative way to test relative weight data (see Brenden et al. [2003] for a more thorough discussion). Of concern is the relative difficulty of computing the *R*-statistic and its associated significance value, especially when the improvement in testing power is moderate. The application of this recently proposed test is probably greatest for researchers attempting to make definitive conclusions regarding patterns in condition but of less utility for management decisions that might include condition as only one component in a decision-making process.

Given these arguments, it is apparent that care should be taken when statistically analyzing W_r values, and the data should be analyzed to ensure that the assumptions of a chosen statistical test are not violated or that the test is robust enough to handle a violation of the assumptions. Transformations to normalize W_r data and homogenize the variances (e.g., Box–Cox transformation; Box and Cox 1964) have generally proven to be of little value (Murphy et al. 1990; Brenden et al. 2003). Alternatively, nonparametric tests can be used if the data will result in misapplication of parametric tests. However, as mentioned, Brenden et al. (2003) argue that their *R*-test is the most appropriate for testing W_r data. Undoubtedly the statistical merit of W_r comparisons will continue to be debated, leading to a better understanding of the statistical properties of this index, as well as a clearer picture of the potential shortcomings and strengths of using established parametric and nonparametric tests and alternative tests for comparisons. We suggest that mean comparisons (*t*-test, ANOVA, Mann–Whitney, and Kruskal–Wallis) and regression relationships can continue to be adequate methods for testing W_r data, as long as the discussion of comparative results includes reference to the potential

shortcomings of the test in relation to the distribution of the data. Results likely can be clarified and strengthened by comparing the results of multiple tests.

10.3.4.2   *Length-Related Patterns in Relative Weight Data*

Because environmentally dependent trends in condition across lengths can be averaged out, mean population condition should not be compared unless it can be demonstrated that length-related patterns or differences are absent in the population. Plotting individual or length-group mean W_r values allows a visual assessment of potential or important patterns such as size-related condition trends resulting from, for example, differences in prey availability, gonad maturity, or density. Murphy et al. (1991) suggested that condition data should be summarized by length-group based on Gabelhouse's (1984) five-cell model (stock-, quality-, preferred-, memorable- and trophy-length fish); others have suggested that this model may not be ecologically relevant depending on the relationship being explored and have summarized W_r differently (e.g., 50-cm length-groups; Porath and Peters 1997). Once W_r values have been classified in a fashion relevant to the question of interest (note that this does not preclude the use of individual fish condition as the unit of interest), individuals or groups can be compared with each other to determine whether one is poorer conditioned than another or whether condition as measured by W_r (as the dependent variable) is statistically related to another variable or suite of variables, such as a habitat attribute. Box 10.3 provides examples of tests comparing W_r among multiple populations.

10.3.4.3   *Relationship of Relative Weight to Physiological and Environmental Measures*

As surrogate indicators of physiological well being, condition index values such as W_r should reflect proximate body composition of individual fish (e.g., lipid content, protein content, or caloric content; Murphy et al. 1991). Strange and Pelton (1987) found a weak relationship between mean condition factor *(K)* and fat percentage in composite samples of prey fishes. However, more recent physiological assessments of W_r have found correlations between W_r and tissue energy content in walleye (Rose 1989), white crappie (Neumann and Murphy 1991), and striped bass and hybrid striped bass (Brown and Murphy 1991). Brown and Murphy (1991) suggested that W_r provided a better estimate of reserve energy than did measures such as the liver–somatic index. Thus, W_r appears to be a reliable index of energy reserves in these species and, as such, might be a good indicator of short-term growth potential or potential for resistance to nutritional stress (Murphy et al. 1991). However, complications such as volume replacement of lipid (fat) reserves by water may confound the relationship between W_r and proximate components (Novinger and Martinez Del Rio 1999).

On the other hand, assessments of relationships between W_r and characteristics that would seem a logical expression of energy use, such as growth, which represents the ultimate expression of individual fitness (Bolger and Connolly 1989), have had mixed results. A common notion is that W_r and other condition indices can be used as indicators of growth: poor condition indicates poor growth and vice versa (e.g., Busacker et al. 1990; Ney 1993). Positive correlations between W_r

and growth have been reported for largemouth bass (Wege and Anderson 1978), northern pike (Willis 1989), yellow perch (Willis et al. 1991), and juvenile striped bass and hybrid striped bass (Brown and Murphy 1991). However, other evidence contradicts the notion that W_r is consistently correlated with growth (Gutreuter and Childress 1990; Gabelhouse 1991). Furthermore, Liao et al. (1995) found no evidence that growth and W_r were correlated for pumpkinseed or golden shiner. Relative weight may reflect growth of some species under certain circumstances, but uncritical use of W_r as a predictor of growth could lead to substantial errors in population assessments.

Another factor commonly linked with W_r is prey availability (Anderson and Gutreuter 1983; Busacker et al. 1990; Flickinger and Bulow 1993; Ney 1993). Poor condition is assumed to reflect prey scarcity, whereas good condition is assumed to reflect an abundance of prey, and both these patterns can be found among size-classes of fish within the same population. Kohler and Kelly (1991) indicated that a quick and cost-effective method for evaluating prey supply was to assess condition of their predators. Porath and Peters (1997) believed that walleye W_r values from standardized fall surveys offer a cost-effective method of detecting prey deficiencies in reservoirs. Small W_r values were reported for lake trout in oligotrophic Wyoming lakes with sparse zooplankton; larger W_r values were found for lake trout in two Wyoming mesotrophic lakes, and the largest W_r values were reported from Flaming Gorge Reservoir, the most productive reservoir in the study (Hubert et al. 1994). Prey availability and W_r values were correlated for pumpkinseed but not for golden shiner; differences in these two species may be related to differences in food habits, with golden shiner having a more flexible and omnivorous diet (Liao et al. 1995). Relative weight may be a good predictor of prey availability especially for species with relatively narrow or specialized diets.

Most of these relationships have been examined through the use of group mean comparisons, bivariate correlations, or linear regression analyses. In Box 10.4 some of these common techniques are applied to the relationship between Yellowstone cutthroat trout W_r and whole-body fat composition.

■ 10.6   FACTORS AFFECTING CONDITION DATA

Seasonal changes occur in fish condition due to changes in fish behavior and physiology that are influenced by many factors (e.g., changes in temperature, turbidity, food supplies, and photoperiod; Pope and Willis 1996). Condition is a short-term indicator of fish health status and is primarily influenced by resource availability and gonadal growth. Typically with spring spawners, fish condition is greatest in the spring just before spawning, declines immediately after spawning, and then increases through the summer and into the fall. Obviously, the seasonal trend in condition for fish species that spawn in the summer (e.g., bluegill) or fall (e.g., brook and brown trout) should be different than spring spawners. Furthermore, differences in gonadal development between males and females may show gender differences in seasonal condition trends. Finally, fish size may also affect the seasonal trend in fish condition (see Pope and Willis 1996 for detailed examples of related studies). Le Cren (1951) noted that seasonal changes in condition of mature fish are often due to changes in gonad weight. However, seasonal changes in the condition of immature fish may be attributable to feeding conditions throughout the winter and spring. For example, Brown (1993) reported that smaller (125–300-mm TL) largemouth bass in Aquilla Lake, Texas, came out of the winter with a low W_r (i.e., 85), and condition remained low until late spring–early summer, when W_r increased (i.e., 105). Gabelhouse (1991) found that small white crappies (130–199-mm TL) in Melvern Reservoir, Kansas, exhibited the greatest W_r in July and that W_r continued to decline throughout the fall and winter. He speculated that the summer peak condition of small white crappies reflected the feeding conditions associated with peak spawning of gizzard shad in mid to late May. Thus, it is inappropriate to combine condition data across seasons. Furthermore, condition data should be reported separately for mature and immature fish and may need to be separated by gender for mature individuals. Generally, W_s

equations are reported for combined sexes; however, Neumann and Willis (1994) provided separate W_s equations for male and female muskellunge (slopes of these two equations were different).

Although general seasonal trends in condition of fish are observed, more specific spatial and temporal patterns of variation in W_r also exist. For example, Liao et al. (1995) observed spatial and temporal differences among lakes for pumpkinseed and golden shiner. Temporal variations in condition have been reported for black crappie (Gabelhouse 1991; Guy and Willis 1991), burbot (Pulliainen and Korhonen 1990), northern pike (Guy and Willis 1991), walleye (Guy and Willis 1991), and yellow perch (Le Cren 1951; Guy and Willis 1991). Many of these studies have resulted in the common practice of sampling during "standard" periods for assessing condition of fishes. However, the temporal asynchrony of pumpkinseed and golden shiner W_r suggests that standard sampling periods might not be as comparable among lakes or among years as previously believed (Liao et al. 1995). This temporal asynchrony illustrates some of the biotic and abiotic variability that fisheries scientists must deal with when assessing fisheries.

Fisheries scientists primarily use condition assessments as a measure of the quality of fish populations, ideally with respect to local environmental and climatic conditions and species potential, and as a means of measuring changes in population quality resulting from management practices (Childress 1991). Thus, comparisons of condition are made on many different scales. Comparisons can be made within populations to assess differences across length-groups or to conduct spatiotemporal comparisons. Theoretically, data on the condition of various sizes of fish within a population can be accumulated over many years to establish a norm for a specific water body. Any deviation from the norm would indicate some fluctuation within the population or some physical or chemical condition interacting with a segment of the population (Swingle and Shell 1971). Comparisons can also be made among populations to evaluate temporal and spatial differences or to evaluate influences of factors (such as parasites) that affect portions of populations (in effect, creating two populations: a population of affected individuals and a population of unaffected individuals; Box 10.6). Prentice (1987) used ANCOVA to test differences in species-specific weight–length relations among river systems and ecological regions within the state of Texas. He found differences among river systems and ecological regions for all species assessed. He also found differences between genders for many of the species he assessed. If a common currency is used to assess condition (such as W_r), comparisons can also be made among species. Condition indices can also indicate changes in environment and ecological processes (e.g., Gabelhouse 1991; Hubert et al. 1994; Liao et al. 1995). Finally, condition assessments are often important in manipulative studies to determine if treatments affect condition.

■ 10.7   CONCLUSION

Condition data have been and will continue to be an important component of ecological assessment in aquatic systems. When combined with other information (e.g., density, prey availability, size structure, community composition, and exploitation), condition data provide fisheries scientists a more complete understanding of population dynamics (recruitment, growth, and mortality) and environmental influences. Several techniques have been used to assess fish condition, and it is clear that there is much debate regarding the most appropriate way to analyze and present condition data, mostly centered on statistical shortcomings of analysis techniques. Appropriately, analytical techniques continue to evolve, as demonstrated by the most recent critique of W_r provided by Brenden et al. (2003).

Because of the relative ease of computation and use, the popularity of condition indices will continue to increase. Condition indices offer fisheries scientists a tool to evaluate effects of various management strategies and, indirectly, ecological interactions in fish populations and communities (Murphy and Willis 1991). More research is necessary to determine both the statistical appropriateness and relativity (to proximate factors and other expressions of fitness) of the condition measure. However, it is apparent that condition indices are useful for assessing fish condition (Blackwell et al. 2000).

Given the limitations discussed herein, controversy about assessment of condition will likely continue as fisheries scientists attempt to separate effects of fish condition from effects of fish size. Detailed assessments of various measures of fish condition that are tested with multiple statistical analyses will provide a clearer picture of relationships among measures of condition and help clarify the usefulness and shortcomings of various techniques. In the meantime, morphometric assessments of condition can be assessed appropriately using graphical display of data in a bivariate plot and ANCOVA with length as a covariate. Further, ratios can be used for descriptive purposes.