
1 Description of condition indicators

Summary: Biologists have developed a wide range of morphological, biochemical and physiological metrics to assess fish condition. This chapter introduces all these indicators and analyzes the simple methods and criteria used to assess the condition of fish, from simple morphometric (weight–length) to morphophysiological (liver, gonad and mesenteric fat weights) indicators. Each method has its pros and cons, along with limits in their application, which are here detailed together with practical recommendations. The utility of each method is shown using examples from different marine fish species around the world.

Key words: Fulton, Le Cren, condition factor, relative weight, liver (hepatosomatic) index, perivisceral (mesenteric) fat index, digestive index

Biologists have developed a wide range of morphological, biochemical, and physiological metrics to assess fish condition and health. These metrics were originally used to quantify aspects of human health, but have also proven useful to address questions in life history, ecology, and resource management of game and commercial animals (Stevenson & Woods, 2006). Condition is an important descriptor of fish health. Fish in good condition are assumed to have larger energy reserves than poor-conditioned fish, as well as optimum health. Here, “fish health” refers to the maintenance of homeostasis, including the normal occurrence of life cycles (primarily growth and reproduction) and the preservation of abundance and productivity of populations (Hochachka & Somero, 1973, 1984, 2002; Nemova & Vysotskaya, 2004; Depledge & Galloway, 2005). The condition of fish can be assessed by a variety of criteria, ranging from simple morphometric indicators based on weight–length data and morphophysiological indicators based on liver and gonad weights (Fig. 1.1) or on mesenteric fat, to physiological and biochemical measures such as lipid or protein content, the concentration of hemoglobin in the blood, the concentration of myoglobin in red muscle, the color and volume of the bile, the enzymatic activity of the tissues, the pH of the muscle after death, and the content of other substances such as glycogen, glucose, lactate, and creatine phosphate (Shulman & Love, 1999). Each of these measurements of fish condition



Figure 1.1 Dissection of a female European hake (*Merluccius merluccius*) showing the liver and ovaries. Photo by Dolors Ferrer.

has its own set of advantages and limitations, depending on the objectives of the particular study. In some cases, samples have to be processed and analyzed in the laboratory, which requires varying degrees of time, specialized training, instrumentation and expense, as in the case of biochemical analyses. In other cases the determination of condition indicators may involve only simple fish length and weight measures. Overall, the choice of condition criteria should be based on the objectives of the particular study, the particularities of each species, population and life stage with regard to body distribution and dynamics of energy reserves, as well as an understanding of the different condition techniques, including a detailed examination of the properties of the dataset as well as available laboratory or sampling facilities and budget. In some cases, integration of the information provided by different morphometric, physiological, and biochemical condition indicators may better reflect the overall physiological condition of the fish. In this chapter, the most used condition indicators in fisheries science are explained.

Some of the best techniques for analyzing fish condition are time-consuming and/or costly (e.g., lipid analysis with gravimetric methods), whereas other techniques that have lower precision are easy to carry out on board or in the laboratory with minimum equipment and cost (e.g., evaluation of morphometric indices). The expert will need to assess which is the best method to use in each case, taking into account the balance between precision, cost, and time. Indicators of the condition of exploited fish are similar to those used to measure condition in medicine and veterinary sciences. The aim of research in this topic is to identify indicators of fish condition that can define the best possible state of organisms and populations, and which can also signal and quantify deviations from it. Here we focus on these indicators that are most suitable and which have been widely used for the evaluation of fish condition for fisheries ecology and management purposes. We must keep in mind, however, that a series of indicators, rather than just one, gives much more information. For example, the protein content of cod muscle decreases during starvation only after the level of liver lipid has dropped below a certain critical value (Black & Love, 1986), so the extent of depletion can be realistically judged only by measuring both. The determination of muscle protein alone fails to detect the early stages of depletion, while liver lipids do not change further during a long series of subsequent stages.

Some authors have argued that, apart from the morphometric, physiological and biochemical indicators described in this book, it is important to establish autopsy-based assessment of the health and condition of fish (Goede & Barton, 1990; Leamon et al., 2000). Several infectious agents, such as viral, bacterial, fungal and parasitic infections, are known to severely affect fish condition, leading to sublethal or lethal effects (Goede & Barton, 1990) and therefore an empirical autopsy-based system of organ and tissue indicators would improve our knowledge regarding fish condition and also the impact of disease(s) on natural fish populations.

Even though simple condition indicators are not always capable of estimating the health status of a given species, Lloret et al. (2012) proposed that those such as morphometric and organosomatic (biometric) indicators (e.g., Le Cren, Fulton, hepatosomatic), and whenever possible total lipid content, are used as a first step for evaluating the amount of energy reserves in fish. This should not be a substitute for standard stock assessment methods but can provide additional information for determining the status of a given stock. Moreover, simple measures of parasite infection such as prevalence, intensity, and abundance could be evaluated (Lloret et al., 2012). For practical purposes, the authors proposed that monitoring could also include the macroparasites (i.e., those large enough to be seen with the naked eye such as cestodes and nematodes) but not the microparasites (e.g., protozoans, which are more difficult to detect) even though they may also have an impact on the condition and reproduction of fish (see for example Kramer-Schadt et al., 2010; Sitjà-Bobadilla, 2009). The monitoring of parasitism will provide therefore a further index of fish health. While no single measurement of fish health uniquely indicates a source of stress (Buckley, 1985), all these simple related energy reserve and parasitism indicators taken together could be used as an index of fish condition (health).

In particular, the analysis of fish health during critical life periods (e.g., prior to spawning or migration, or in early life stages) is important for detecting the effects on stock productivity and thus their availability to the fisheries (Lloret et al., 2012). Several studies suggest that the condition of spawners at or just before the time of spawning would be a better proxy for reproductive potential (Marshall & Frank, 1999). In addition, knowledge of the lipid content in fish species can further enhance our ability to determine the human health benefits of consuming these fish, particularly with regard to essential fatty acids (fish are often promoted as a healthy component of the human diet because of high levels of essential fatty acids). In the following sections of this chapter we focus on simple condition (morphometric and organosomatic) indicators.

1.1 Morphometric indicators

Morphometric condition indicators are the simplest indicators of energy storage in fishery species. They are constructed with simple weight and length data that can be easily obtained from surveys or commercial landings using minimum and affordable equipment such as an ichthyometer (Fig. 1.2) and scale. These indicators assume that heavier fish of a given length are in better condition (Jones et al., 1999). Therefore, they are based on the premise that a fish of a given species and length should weigh as much as a standard for its length, and variations from the standard are taken as an indication of the relative fitness of an individual. These morphometric condition indicators have been available since the early 1900s and have undergone an evolution in methodology (Murphy et al., 1991). They have remained popular tools because they are inexpensive, simplistic, and mostly non-destructive, and are

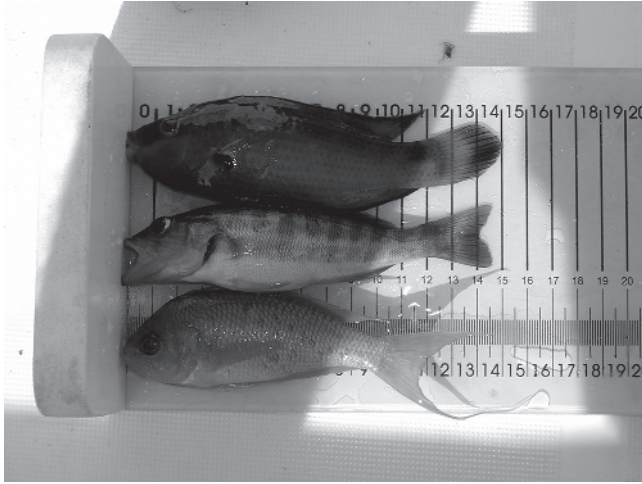


Figure 1.2 Fish length measurement using an ichthyometer. Photo by David Caballero and N ria Zaragoza.

easily calculated from historical datasets that describe the length and weight of individuals (Lambert & Dutil, 1997a; Pope & Kruse, 2001). However, their use has remained sometimes controversial. Blackwell et al. (2000), Pope and Kruse (2001), and Nash et al. (2006) provide thorough reviews of the history of condition factors, together with the controversies surrounding their analysis and interpretation. Stevenson and Woods (2006) argue that morphometric condition factors actually measure the shape (i.e., girth) of a fish rather than being a direct measure of the extent of energy reserves, and several reviews have highlighted the statistical deficiencies of morphometric condition indicators (e.g., Cone, 1989; Hayes & Shonkwiler, 2001). To overcome potential bias and errors, Froese (2006) gives several recommendations for the proper use and presentation of morphometric condition factors, including guidelines for data collection and analysis of weight–length relationships.

For the determination of condition indicators based on length and weight, it is always preferable to use eviscerated weight instead of total weight because the latter is not affected by the viscera and gonad weights. Some authors have even used muscle weight instead of eviscerated weight (e.g., Kurita et al., 2003).

1.1.1 Fulton’s *K* condition factor

K (or Fulton’s) condition factor (Ricker, 1975) was the first morphometric condition factor used in fisheries science. According to Nash et al. (2006) the origin of this condition factor is attributed to Heincke (1908). *K* is computed using the formula:

$$K = (W/L^3) \times 100 \quad (1.1)$$

where *W* is the weight of the individual and *L* its total length. The index uses 1 as a benchmark for the condition of a standard fish: fish above or below 1 are considered in relatively better or worse condition than a standard fish, respectively, depending on their distance from the benchmark. Nevertheless, it is important to note that the stated formula assumes isometric growth in fish, in other words the *b*-value of the weight–length relationship has to be 3 or

very close to 3. In some species such as cod, this assumption is met and therefore a number of studies have used K to evaluate their condition (e.g., Lambert & Dutil, 1997a; Lloret & Rätz, 2000).

However, in other fish species this is often not the case (b -value is not exactly 3 and not close to that value), and there appear to be correlations between the condition factor and length (Bolger & Connolly, 1989; Cone, 1989). Thus K increases with increasing length (b -value >3.0) and decreases with decreasing length (b -value <3.0). In these cases, this limits the application of K to fish of similar length within the same species. Thus the interpretation of the condition factor is prone to error when the growth of fish is not isometric (when b is above or below 3.0). To use K correctly, the assumption of isometric growth must be checked within each stratum (e.g., sex, population) for which comparisons will be made (Cone, 1989). For example, a difference in mean condition between two populations can be caused by different mean lengths in the respective populations. A way to avoid the problems that this could create is to compare individuals of similar length, or populations with similar length structures only (Blackwell et al., 2000). However, one must consider that bathymetric and spatial distribution of a species is often related to length (see for example Macpherson & Duarte, 1991). In order to solve the problem some authors included length as a continuous predictor variable into the model of K (e.g., Lloret et al., 2002). Nevertheless, other indicators have been widely used to overcome the length dependence with accuracy, and these are described here.

1.1.2 Le Cren's relative condition factor (K_n)

Le Cren (1951) attempted to solve the deficiencies of Fulton's K condition factor by comparing the actual weight to a standard predicted by the weight–length regression based on the population from which the fish was sampled. Hence, he introduced the relative condition factor (K_n), which compensates for changes in condition with increase or decrease in length. It measures the deviation of an individual from the average weight for length in the respective sample. This length-independent measure of condition is calculated with the following formula:

$$K_n = W/W_e \quad (1.2)$$

where W is the observed weight of the fish and W_e the estimated weight of that fish. K_n uses 1 as a benchmark for the condition of a standard fish: fish above or below 1 are considered in relatively better or worse condition than a standard fish, respectively, depending on their distance from the benchmark.

However, a disadvantage of K_n is that the mean value of this index is a function of weight–length relationship parameters. Because weight–length relationships can vary among populations and geographic sites, comparisons of K_n must be confined to those populations with homogeneous weight–length parameters (Bolger & Connolly, 1989). The result is that different weight–length equations are needed to compute W_e for each region or population, making comparisons across water bodies difficult.

To solve this problem, one can derive a single weight–length relationship obtained from all individuals to be considered in the analysis, with the formula:

$$K_n = W/W'_e \quad (1.3)$$

where W'_c is computed using the weight–length measurements for all individuals that are to be included in the analysis. This approach is very similar to the analysis of the relative weight (see section 1.1.3) but relies on the availability of the original weight and length data to construct a common weight–length relationship from all samples (populations, regions, sexes, ages, months, years, etc.). Thus, if a single weight–length relationship is estimated for the whole dataset, the K_n will be comparable across all samples in the dataset. The necessity to have original weight–length data from all samples can be a handicap because it is based on cooperation between different agencies/researchers in charge of data collection in order to share weight–length data, and on the need to reevaluate the common weight–length relationship as new data become available. Then, to evaluate interstock differences in fish condition, it would be advantageous to develop stock-level condition indicators from standardized databases on weight and length (Marshall et al., 2004).

Many studies have confirmed the ability of this approach to compare the condition of fish from different samples, always providing that the estimated weights are derived from weight–length relationship representative of all individuals in all samples. K_n has been applied to several species, for example cod (*Gadus morhua*) in the North Atlantic (Bishop & Baird, 1994; Pardoe et al., 2008) and Arctic cod (*Boreogadus saida*) in the Gulf of Alaska (Khan et al., 1997).

1.1.3 Relative weight (W_r)

The relative weight was first proposed by Wege and Anderson (1978) as a fish condition index, and represents further evolution of the K_n concept by allowing comparisons of condition across the geographic occurrence of a species. The W_r index is calculated as:

$$W_r = W/W_s \times 100 \quad (1.4)$$

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 geographic range (see Blackwell et al., 2000 for a list of developed standard weight equations). This index uses 100 as a benchmark for fish in good condition: fish above or below 100 are considered in relatively better or worse condition than a standard fish, respectively, depending on their distance from the benchmark.

The application of W_r has increased over the last decade and has been commonly used as a condition assessment tool in United States freshwater fish surveys (Blackwell et al., 2000). Relative weight can serve as a surrogate for estimating fish energy reserves, as a measure of fish health, and to assess prey abundance, fish stocks and management actions (Blackwell et al., 2000). The analysis of W_r relies on the availability (prior to the analysis) of standard weights equations (W_s) that cover the entire length structure of the species. If this is not the case, problems may arise when determining condition of small and juvenile fishes for example, because many of these individuals are below the minimum applicable length of W_s equations. Thus, the quality of the W_s found in the literature can underpin the analysis of the dataset. This problem will be solved by using Le Cren's K_n condition factor explained in section 1.1.2.

1.1.4 Other methods based on weights and lengths

Other methods have been used to analyze weight and length data but their use has been rather limited in fisheries science. For example, weight–length regression has been used by

several authors to compare condition. Several methods have been proposed for evaluating the weight–length regression including ordinary least-squares regression (Cone, 1989) and analyses of covariance to test differences in weight–length regression lines (García-Berthou & Moreno-Amich, 1993; Blackwell et al., 2000). Another method is the residual analysis (Fechhelm et al., 1995), which is synonymous with the concepts of K_n and W_r in that all three examine the deviation of predicted weight from some common weight–length relationship.

1.1.5 Limits of use of morphometric condition indicators

Many questions remain whether any weight to length ratio is a valid and interpretable indicator of physiological condition in fish. Ideally, any study using morphometric condition indicators should define formally what is being measured by that condition index and validate it against a suitable benchmark, for example a biochemical index (Davidson & Marshall, 2010; McPherson et al., 2011). This type of validation has been carried out for several species and several studies have found positive relationships between morphometric and organosomatic and biochemical indicators in different fish species (Rose, 1989; Brown & Murphy, 1991; Lambert & Dutil, 1997a,b; Pangle & Sutton, 2005; Kaufman et al., 2007). Thus for example, Fulton's K condition factor was positively correlated with crude-lipid content of juvenile lake herring *Coregonus artedii* (Table 1.1; Pangle & Sutton, 2005) whereas the condition factor correlated with the percentage lipid content of somatic tissue of adult Atlantic salmon (Fig. 1.3; Todd et al., 2008). In this case, the poorest condition salmon, which were about 30% underweight, showed lipid reserves reduced by about 80% compared with the highest condition fish. It is also important to note that the strength of the relationships between various condition factors and biochemical condition indicators can vary

Table 1.1 Relationship of Fulton's K condition factor with proximate composition components of juvenile lake herring *Coregonus artedii**

Day of experiment	Linear-regression equation	MS error	SE of K coefficient	r^2	P
75	Crude lipid = $0.599 + 9.845 K$	1.482	1.218	0.612	<0.001
	Crude protein = $12.059 + 2.208 K$	1.644	0.669	0.208	0.076
	Gross energy = $332.8 + 1153.5 K$	38,766.324	196.892	0.453	0.004
	Ash = $4.232 + 1.666 K$	1.152	2.258	0.112	0.642
	Water = $86.417 - 8.888 K$	26.169	1.528	0.435	0.005
150	Crude lipid = $0.305 + 11.222 K$	1.458	1.208	0.615	<0.001
	Crude protein = $10.789 + 7.353 K$	13.995	0.716	0.661	<0.001
	Gross energy = $-339.8 + 2687.9 K$	47,745.583	218.508	0.737	<0.001
	Ash = $4.377 + 0.868 K$	0.154	0.559	0.039	0.496
	Water = $90.704 - 20.687 K$	117.246	1.722	0.748	<0.001
225	Crude lipid = $-1.994 + 15.634 K$	1.781	1.335	0.640	<0.001
	Crude protein = $8.173 + 13.631 K$	13.995	0.716	0.674	<0.001
	Gross energy = $-683.2 + 3577.1 K$	72,530.75	269.315	0.695	<0.001
	Ash = $2.962 + 4.464 K$	3.472	0.894	0.250	0.058
	Water = $93.222 - 27.189 K$	132.963	2.048	0.697	<0.001

*Linear-regression variables of the relationships for crude lipid, crude protein, gross energy, ash and water content and the Fulton condition factor (K) for juvenile lake herring on days 75, 150 and 225 of the laboratory experiment. Crude lipid, crude protein, ash and water content were expressed as percentages of wet body mass, while gross energy was expressed as J/g wet body mass.

Source: Pangle & Sutton (2005).

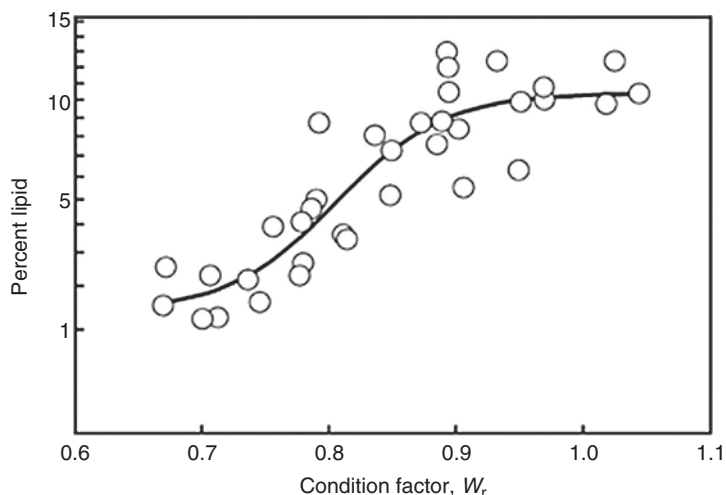


Figure 1.3 Relationship between condition factor and percentage lipid content of somatic tissue of adult Atlantic salmon (*Salmo salar*). From Todd et al. (2008).

considerably among populations, and also between sexes within populations, for example adult walleyes (*Sander vitreus*) in Canadian lakes (Kaufman et al., 2007).

Notwithstanding these examples, the relationship between condition and lipid reserves has not always been observed. Thus for example, the relationships between morphometric condition factors and bioenergetic and biochemical indicators in Atlantic herring (*Clupea harengus*) are inconsistent and often nonexistent, with the correlation dependent on both the maturity stage of the individual fish and the fat depot with which it was being compared (Davidson & Marshall, 2010; McPherson et al., 2011). Whereas Fulton's K was significantly correlated with fatmeter values (Fig. 1.4; Davidson & Marshall, 2010; McPherson et al., 2011), the relationship between K and mesenteric fat was inconsistent and often nonexistent (Fig. 1.5; McPherson et al., 2011). Similar to this, in bluegills (*Lepomis macrochirus*), the relative weight shows an imprecise relationship to body constituents such as lipid and protein (Copeland et al., 2011). It is even possible that the higher weight of a given fish is due to the higher water content in the tissues and not really lipids or any other components of energy stores (Shulman & Love, 1999). Because 60–80% of the fresh weight of a fish consists of water, variations in water content (and not energy reserves) could account for most of the variation in weight. In some cases, the low accuracy of morphometric factors renders them invalid for estimating the impact of factors on fish condition. For example, parasites provoked a twofold to threefold decrease in triacylglycerol in the body of anchovy (Fig. 1.6), while Fulton's condition factor remained unchanged (Shulman & Love, 1999). Furthermore, the relationship between these different indicators may depend on the reproductive stage or the season (Pangle & Sutton, 2005; Copeland et al., 2011; McPherson et al., 2011). For example, Fulton's K was particularly correlated with fatmeter values for fish with inactive gonads (Fig. 1.7; McPherson et al., 2011).

Despite all these facts, many studies use morphometric condition indicators without validation. If morphometric indicators are not validated by being correlated with biochemical indicators, then they should be considered as putative indicators of condition (McPherson et al., 2011). Another aspect to consider is the number of data needed to evaluate these

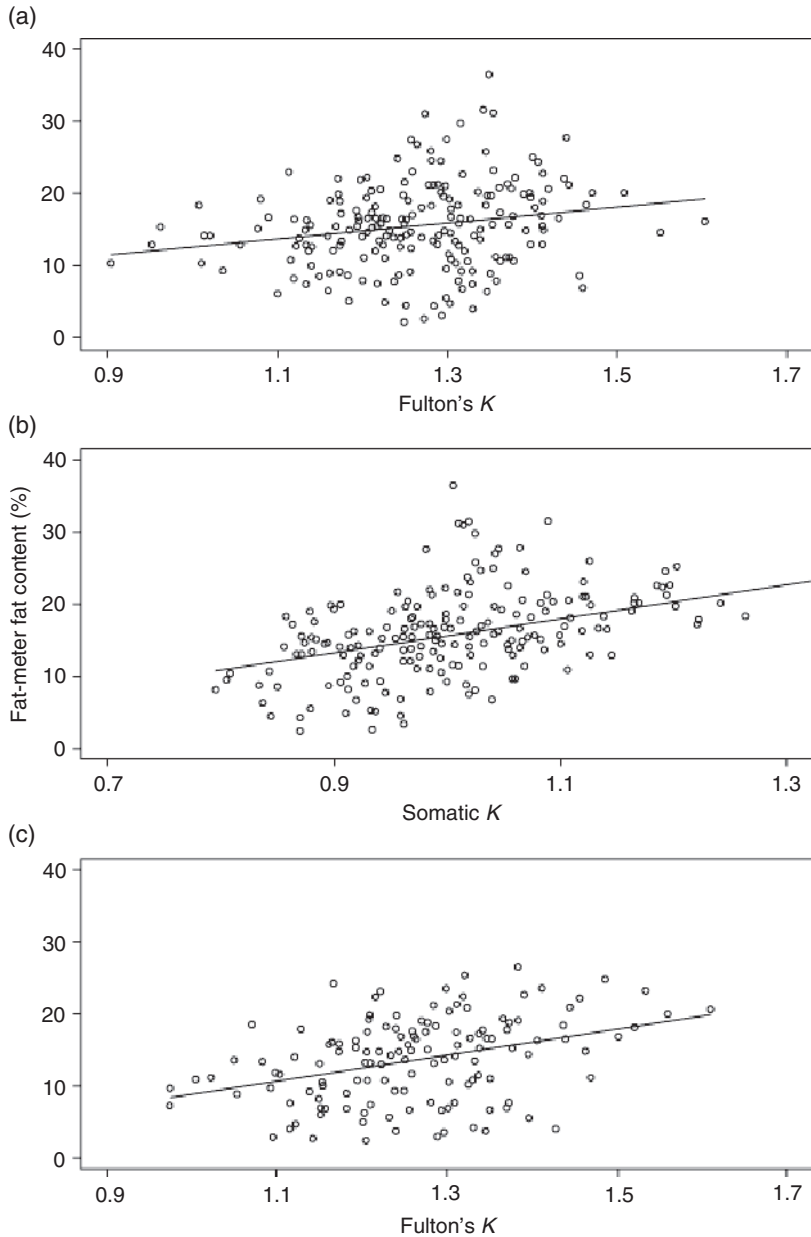


Figure 1.4 Correlation between fatmeter fat content and (a) Fulton's K and (b) somatic K from the 2004 data, and (c) fatmeter fat content and Fulton's K from the 2005 data, in herring *Clupea harengus*. From Davidson & Marshall (2010).

simple condition indices. It only makes sense to use them when there are hundreds or thousands of individuals measured. Indeed, when there are fewer weight–length values, the use of these morphometric condition indices is not recommended, and organosomatic and particularly biochemical indicators must be considered instead.

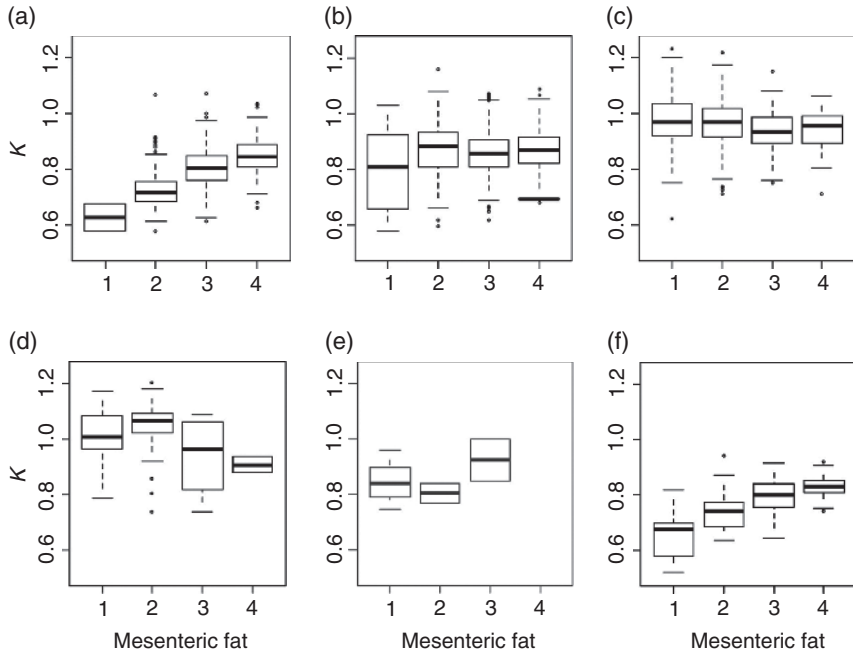


Figure 1.5 Relationship between four mesenteric fat stages and K values across the maturity cycle of Atlantic herring (*Clupea harengus*), including both sexes: (a) immature; (b) maturing 1; (c) maturing 2; (d) maturing 3; (e) spawning; (f) spent/recovering. These six categories (a-f) are related to the degree of gonad development. Boxplots are used to clarify the differences in median and variance between the four mesenteric fat stages. From McPherson et al. (2011).



Figure 1.6 Anchovies (*Engraulis encrasicolus*) captured in the northwest Mediterranean. Photo by Sílvia Vila.

The appropriateness of condition indicators in statistical testing has also been the subject of several reviews. Bolger and Connolly (1989) indicated several statistical difficulties with ratio data such as K_n and W_p , such as increased variability when compared to the variables forming the ratio; biased estimation of the true mean value of the ratio; unusual and non-normal distributions; and a tendency to obscure intervariable relationships. Furthermore,

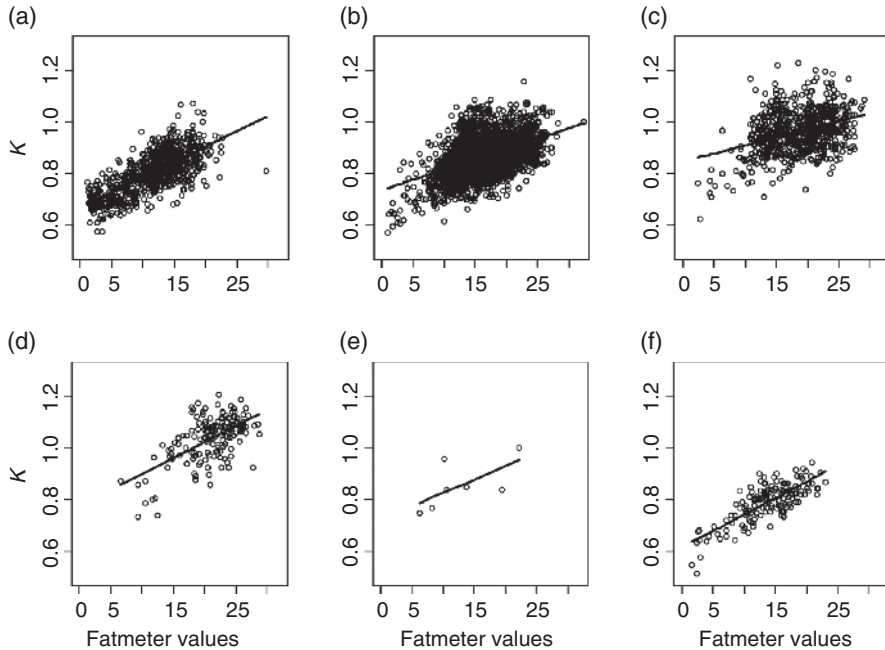


Figure 1.7 Relationship between fatmeter values and K across the maturity cycle of Atlantic herring (*Clupea harengus*), including both sexes: (a) immature; (b) maturing 1; (c) maturing 2; (d) maturing 3; (e) spawning; (f) spent/recovering. These six categories (a–f) are related to the degree of gonad development. Lines indicate linear regression. From McPherson et al. (2011).

they indicate that these types of data commonly exhibit heteroscedasticity, which violates the assumptions of common statistical tests (e.g., regression and analysis of variance) and weakens the power of these comparisons. Given these arguments, it is apparent that care should be taken when statistically analyzing condition indicator values to ensure that the assumptions of each statistical test are not violated.

Furthermore, the interpretation of any morphometric condition index based on individual weights is prone to error when total weights are used. For example, a difference in mean condition between two populations can be caused by differences in the development (weight) of gonads or by differences in the stomach content between the two samples/individuals. Therefore, it is preferable to use eviscerated weights instead of total weights because the latter are not affected by the viscera and gonad weights.

Finally, it is important to note that accurate morphometric condition assessments are dependent on correct length and weight measurements. Length measurements are relatively easy to obtain with fish measuring boards and are generally relatively accurate (Blackwell et al., 2000). It is important to clarify if these are total lengths, fork lengths, or standard lengths (Fig. 1.8). Weighing fish with scales of appropriate precision can be more difficult and time-consuming than measuring fish length and there is increased potential for making errors if appropriate scales are not used (Blackwell et al., 2000). The quality of the scales must be taken into account, especially with regard to variables such as precision, calibration, and motion compensation. Scales with motion compensation allow stable and accurate weights to be obtained while at sea. To keep a scale in top condition, calibrations need to be carried out on a regular basis. Furthermore, the user must check the units (g, kg, cm, mm, etc.) of the weight and length data used to compute these morphometric indicators, as well

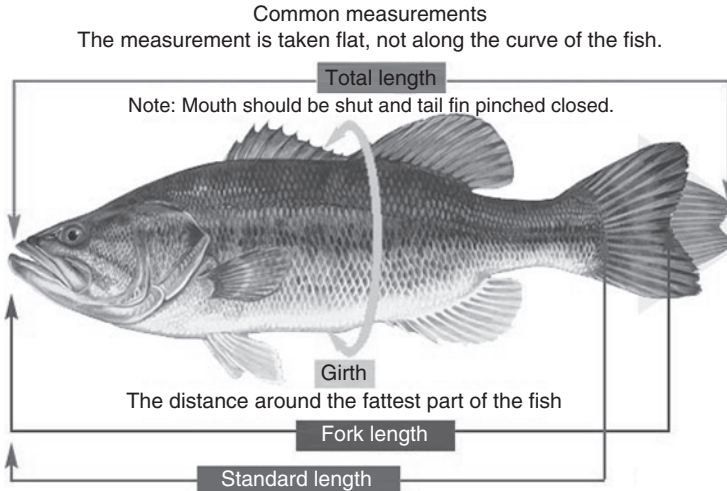


Figure 1.8 Common measures of fish length: standard length, fork length, and total length. Original picture from Duane Raver, United States Fish and Wildlife Service. Modified by Bob Wattendorf, MyFWC.com.

as the transformations (e.g., logarithmic) that are sometimes needed prior to the development of statistical analysis when data do not meet the standard criteria (e.g., normality).

1.2 Organosomatic (bioenergetic or morphophysiological) indicators

Whereas condition indicators attempt to indirectly approximate the energetic fitness based on individual whole body mass, other measures of condition relate directly to the physiological composition of body tissues, providing a more precise measure of actual fitness in terms of stored energy. Organosomatic indicators of condition use an index (ratio) of tissue weights where individuals store energy. Among the available indicators, the liver somatic index (also called hepatosomatic index, liver index, or ratio of liver weight), the mesenteric fat index, and the digestivosomatic index are the most common ones. However, the evaluation of these organosomatic indicators is more time-consuming than the analysis of morphometric indicators because individuals need to be dissected in order to remove and weigh their livers or mesenteric fat.

1.2.1 Hepatosomatic index (liver index or relative liver condition)

The liver (Fig. 1.9) is an important organ for energy storage and is usually the first site for lipid (energy) storage in a number of benthic and demersal species such as gadoids (e.g., Kjesbu et al., 1991; Lambert & Dutil, 1997b; Lloret et al., 2008) and sharks (e.g., Rossouw, 1987; Hoffmayer et al., 2006) as well as deep-sea fish such as macrourids (Drazen, 2002). For example, lipids normally constitute more than 50% of the liver wet weight of cod (Lambert & Dutil, 1997b), up to 66% wet mass (or 82% dry mass) in haddock (Hiddink et al., 2005), nearly 70% of the dry liver of hake (Lloret et al., 2008), and up to 56% lipid (wet liver mass) of the common macrourids *Coryphaenoides armatus* and *Coryphaenoides*



Figure 1.9 The liver, an important organ for energy stores in gadoid species such as hake *Merluccius merluccius*. Photo by Josep Lloret.

acrolepis (Drazen, 2002), confirming the important role of the liver in energy storage in these species. In contrast, only about 1% of the wet weight of the muscle tissue of cod consists of lipids (Yaragina & Marshall, 2000) whereas lipids constituted on average only 3% of the dry muscle of hake (Lloret et al., 2008). For all these species, a liver or hepatosomatic index would more accurately measure the condition of such fish and therefore the periodic evaluation of a liver index would be a more reliable measure of condition than simple morphometric indicators. The hepatosomatic index (HSI) can be calculated as:

$$\text{HSI} = (\text{LW}/\text{EW}) \times 100 \quad (1.5)$$

where LW is liver weight and EW the eviscerated weight of the individual.

For other species the liver is still a key organ because it is the principal site of lipogenesis and in some species (e.g., small pelagics such as sardines) it seems that during feeding periods, excess dietary lipids are exported from the liver and are accumulated and stored in specific long-term storage sites such as mesenteric fat, the fat within the white muscle and between skin and muscle (Tocher, 2003). The relationship between biochemical composition (lipid and energy content) and liver index in gadoid species indicates that the liver condition index is a good indicator of the energetic condition of these species (Lambert & Dutil, 1997b; Hiddink et al., 2005; Lloret et al., 2008). For example, in haddock the hepatosomatic index was strongly correlated with the liver oil content of the liver ($r=0.9$), the energy density of the whole fish ($r=0.9$), and total energy stores per fish ($r=0.8$), whereas liver energy stores correlated with muscle energy stores (Fig. 1.10; Hiddink et al., 2005). In particular, it seems that the liver plays a key role in oogenesis and ovarian development of teleosts (Nicolas, 1999), as indicated by the numerous studies that have linked liver indicators and reproductive activity of fish (e.g., sardine; Ganas et al., 2007).

Among the species for which a liver index has been used as an indicator of fish condition are hake *Merluccius merluccius* in the Mediterranean (e.g., Lloret et al., 2008); cod *Gadus morhua* (e.g., Lambert & Dutil, 1997b; Yaragina & Marshall, 2000; Marshall et al., 2004; Pardoe et al., 2008) and haddock *Melanogrammus aeglefinus* (Hiddink et al., 2005) in the North Atlantic; Arctic cod *Boreogadus saida* in the Gulf of Alaska (e.g., Khan et al., 1997);

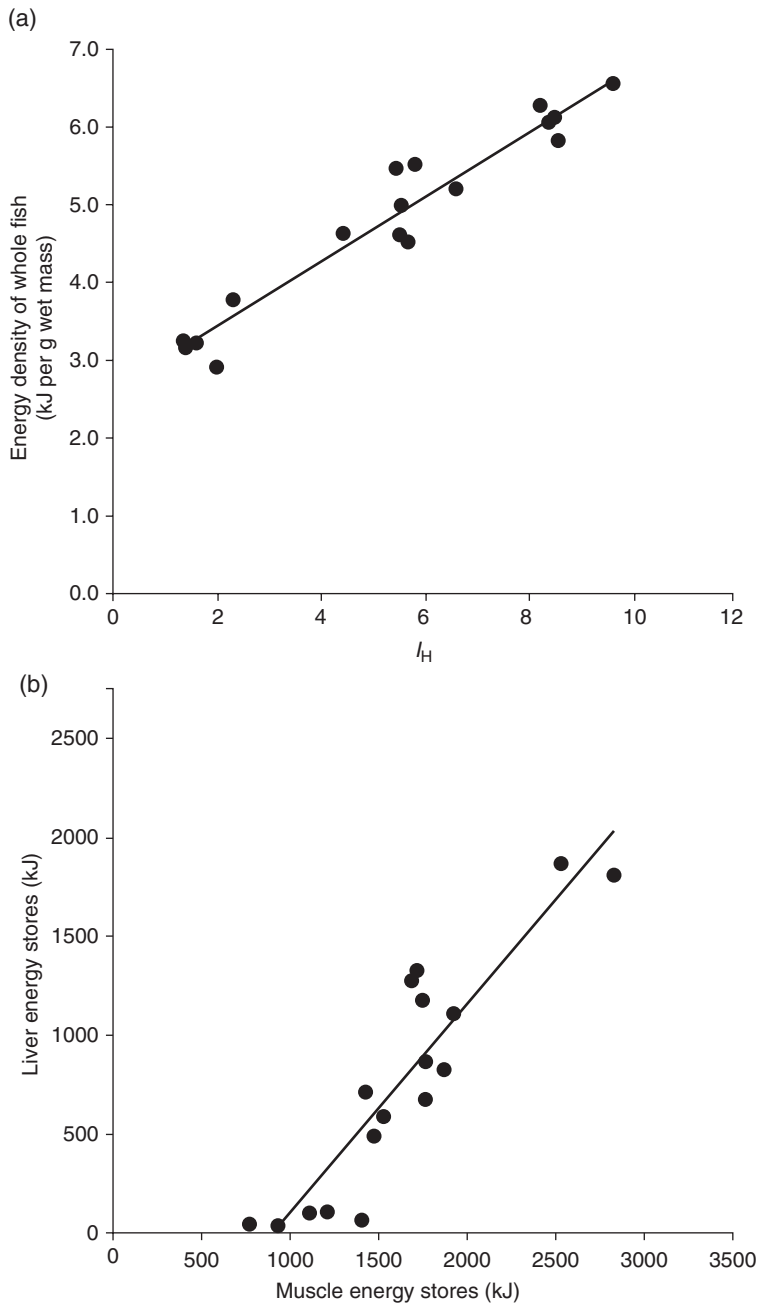


Figure 1.10 The relationship between haddock *Melanogrammus aeglefinus* (a) hepatosomatic index and energy density of whole fish and (b) muscle and liver energy content. From Hiddink et al. (2005).

common macrourids (*Coryphaenoides armatus* and *C. yaquinae*) in the Pacific (e.g. Drazen, 2002); snapper *Pagrus auratus* in New Zealand coastal waters (e.g. Francis, 1997); lesser sand shark *Rhinobatos annulatus* in South African waters (Rossouw, 1987); and pollock *Pollachius virens* in the Pacific (Jensen, 1979).

1.2.2 Mesenteric (adipose or perivisceral) fat index

In some fish species, the perivisceral fat (i.e., mesenteric fat or the adipose tissue surrounding the gastrointestinal tract; Fig. 1.11) develops in particular seasons, constituting important lipid storage. In particular, it seems that mesenteric fat reserves play a key role in the reproductive process of some fish such as bluemouth *Helycolenus dactylopterus* (Muñoz et al., 2010), several small pelagics including *Sardinella aurita* (Ter Hofstede et al., 2007; Mustac & Sinovic, 2012) and sardine *Sardina pilchardus* (Ganias et al., 2007), and several sparids including red porgy *Pagrus pagrus* (Aristizabal, 2007), blackspot seabream *Pagellus bogaraveo* (Costanzo et al., 2011) and white seabream *Diplodus sargus* (Martínez-Pastor & Villegas-Cuadras, 1996). Mesenteric fat is much more labile than other fat stores, such as muscle fat (Slotte, 1999), and therefore mesenteric fat is likely to be the first fat store to become depleted during gonad maturation, migration, or overwintering, and the first fat store to respond to increased food intake.

From the mesenteric fat stores, a perivisceral fat index (PFI) can be calculated as:

$$\text{PFI} = (\text{PF} / \text{EW}) \times 100 \quad (1.6)$$

where PF is the perivisceral fat weight and EW is the eviscerated weight of the individual. Alternatively, visual assessments of the mesenteric fat can be carried out as a gross measure of the magnitude of fat deposited in the mesentery and has been applied routinely to several species of small pelagic fish such as anchovy (*Engraulis encrasicolus*) and sardine (*Sardinops sagax*) in South African waters (van der Lingen & Hutchings, 2005), *Sardinella aurita* in the Adriatic (Mustac & Sinovic, 2012) and northwest Africa (Ter Hofstede et al., 2007), herring (*Clupea harengus*) from the North Sea (Slotte 1999), *Helicolenus dactylopterus* in the Mediterranean (Muñoz et al., 2010), and red porgy (*Pagrus pagrus*) in the southwestern Atlantic coast (Aristizabal, 2007).

This method consists of allocation to a number of fat stages depending on the amount of fat associated with the intestine and stomach (for example in *Sardinella aurita*, Table 1.2; Ter Hofstede et al., 2007). This technique has the advantages of being quick and easy to apply, requires no specialized equipment and is cheap, and is therefore well suited for use at sea for those species that accumulate mesenteric fat (van der Lingen & Hutchings, 2005).

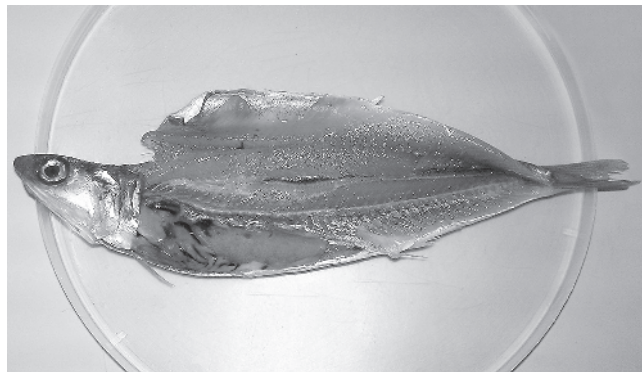


Figure 1.11 Dissected anchovy *Engraulis encrasicolus* showing the mesenteric fat. Photo by Dolors Ferrer.

Table 1.2 Classification of fat content (categories 0–3) of round sardinella (*Sardinella aurita*)

Category	Fat content
0	No fat at all
1	Small chains of fat along intestines
2	Chains of fat cover half of intestines
3	Intestines completely covered with fat

Source: Ter Hofstede et al. (2007).

These factors, together with good reproducibility and accuracy, demonstrate its efficacy as a method for assessing the condition of pelagic fish.

1.2.3 Digestivosomatic index or digestive index

Some authors have evaluated a digestivosomatic index (DSI), which expresses the size of the gut relative to the mass of the body of the animal, as a condition indicator. This index has been computed for example in sea cucumber *Apostichopus japonicus*, a commercially important marine species for aquaculture in China (Gao et al., 2008), and in several demersal fish in the Mediterranean including *Mullus barbatus*, *M. surmuletus*, *Pagellus acarne*, *P. erythrinus* and *Diplodus sargus* (Lloret et al., 2002; Lloret & Planes, 2003). The index can be expressed as:

$$DSI = 100(DW/W) \times 100 \quad (1.7)$$

where DW is the weight of the digestive tract (stomach plus intestine) and W the weight of the whole individual (better eviscerated weight). In some cases the digestive tract has been weighed with food items inside.

1.2.4 Limits of applicability of organosomatic indicators

As was the case with the morphometric condition indicators, ideally any study using bioenergetic condition indicators should formally define what is being measured by that condition index and validate it against a suitable benchmark, such as a biochemical index (McPherson et al., 2011). Although this type of validation has been carried out for several species (reviewed by McPherson et al., 2011), many studies use bioenergetic condition indicators without validation. If bioenergetic indicators are not validated by being correlated with biochemical indicators, then they should be considered as putative indicators of condition (McPherson et al., 2011).