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# Estimating the Girth of Fish by Applying an Elliptic Model

S. RAGONESE and F. BERTOLINO

## Abstract

A new method for estimating the maximum girth of roundfish is proposed and illustrated; this is based on an elliptic approximation of the cross sections of the fish body. Results derived from a small sample of horse mackerel, *Trachurus trachurus*, suggest that maximum girth estimates based on the elliptic model are more precise than the values estimated by applying a conventional method.

## Introduction

Since the pioneering work of F.I. Baranov (Nikolsky 1963; Hamley 1975), measuring the girth in fish has played an important role in fisheries science, particularly for those studies related to gear selection. Inference from girth measurements represents one of the methods for assessing the selectivity pattern of fish, because these estimates usually correlate well with the probabilities of capture which, after all, depends on the shape of the fish body (Hamley 1975; Pauly 1984; Reis and Pawson 1992; Anon. 1993).

Obviously, different measures of girth can be derived depending on what cross section of the fish is considered, but the "greatest" or "maximum girth", i.e., the girth corresponding to the maximum body "height" and "width" ("depth" and "thickness", respectively, according to Holden and Raitt 1974) represents the most important measurement.

Nomograms for a quick estimation of the selection factor in fish from maximum girth and total length relationship are often reported in the literature (for instance, in Pauly 1984). Even though the use of special devices such as "girthometer" has been proposed in order to obtain objective measures of girth in fish (for instance, by Hunter and Wheeler 1972), the most common method of measuring girths consists in using a rope or a metric plastic band as shown in Fig. 1a,b (Cárdenas and Fernandez 1981; Karlsen and Bjarnasson 1986).

The body of the fish is surrounded by the rope at its (assumed) maximum girth and thereafter the measure is directly or indirectly read; the method is functional but inelegant and subjective, and in any case information is lost because it does not take explicitly in consideration the different contributions of "thickness" and of "depth", i.e., of the shape of the fish body.

In this note, a new method is proposed to obtain a more precise and informative measure of maximum girth in fish. The essential assumption of the model consists in considering that the shape of the transverse slices of a fish can be assimilated to an ellipse (Fig. 1c).

## Materials and Methods

Maximum body height ("depth") and width ("thickness") along with the total length ("LT" according to Holden and Raitt 1974) were individually measured in a sample of 17 horse mackerel (*Trachurus trachurus*); "depth" and "thickness" were measured, at 0.1 mm, by using a clock-caliper whereas total length was measured, with a precision of 1 mm, by placing the fish straight on a measuring

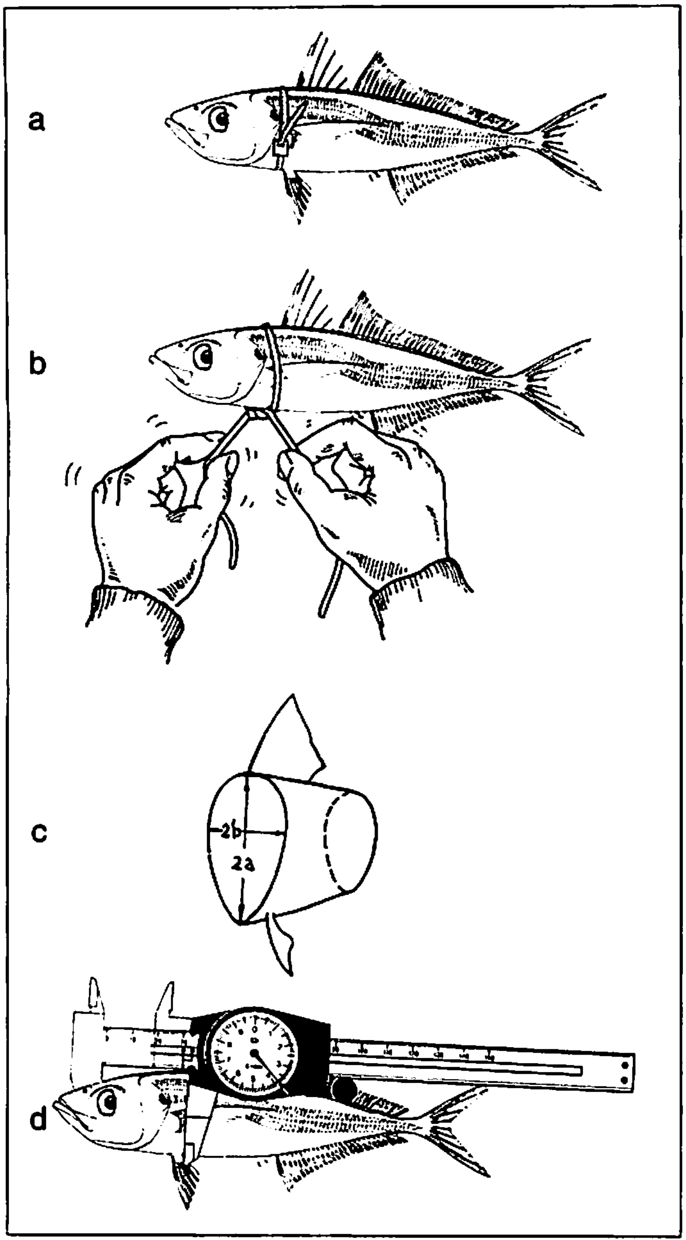

**Fig. 1.** *Schematic representation of girth measurements. Conventional methods (a,b), elliptic based model (c) and measure of the depth and thickness of fish by using a caliper (d).*

board with the head touching the upright headpiece.

Two sets of maximum ("greatest") girth were derived, the first by applying the conventional "rope method", specifically by reading directly the value on a plastic tape measure (hereby defined as "GME"), the second by the elliptical approach (hereby defined as "GES").

An ellipse can be geometrically defined as the locus of all points in the plane at which the sum of the distances from a fixed pair of points, the foci, is constant; its equation can be analytically expressed as:

$$x^2/a^2 + y^2/b^2 = 1 \qquad \text{...1)}$$

where "a" and "b" denote the large and small semiaxes, respectively.

The perimeter of the ellipse, which corresponds to the girth measure (GES), can be computed by solving the definite integral:

$$4b\int_0^{\pi/2}\sqrt{1-k^2\sin^2\theta}\,d\theta \qquad \text{...2)}$$

where k denotes

$$\sqrt{\frac{a^2-b^2}{a}}$$

An alternative formula exists:

$$2\pi\sqrt{\tfrac{1}{2}\,(a^2+b^2)} \qquad \text{...3)}$$

but the result is an approximate solution of the above integral and it should not be used.

The area of the hypothetical elliptical section, hereby defined as "AES", in squared mm, was also computed from $\pi ab$, where $\pi$ is the ratio of the circumference of any circle to its radius: 3.14159... (3.14 in this study).

Each fish was placed on a soft plastic support (in order to prevent distortion of body shape), individually labelled, packed in a plastic envelope and thereafter frozen.

After 48 hours, the frozen fish were individually sliced in cross (transverse) sections, each 0.5-1 cm thick; the series of slices relative to each fish were copied onto transparencies in order to identify the slice corresponding to the maximum width ("maximum thickness") and maximum height ("maximum depth") of body.

Observed maximum girth (hereby defined as "GOB") and area (hereby defined as "AOB"), corresponding to the "maximum slice" were measured and estimated (average of five replicates) by using a curvimeter and a planimeter, respectively, and were assumed as the "true" parameters under investigation.

A paired t-test (Sokal and Rohlf 1981) and a nonparametric test, the Wilcoxon-signed rank test (Wilkinson 1987), were used to compare the two sets of estimated maximum or greatest girth (conventional, GME, and elliptic, GES) and area (AES) with the assumed "true" measures (GOB and AOB).

Coefficients of determinations ($r^2$) and linear or log-linear regressions between the different maximum girth estimates and area estimates and total length of fish were computed and analyzed.

## Results

The biometric data and the measurements are summarized in Table 1; the differences between estimated and true maximum girth clearly indicate that the elliptic measures (GES) are consistently higher than the "true" ones whereas the "rope" estimates (GME) show a more random behavior (columns GOB-GME and GOB-GES in Table 1).

**Table 1. Biometric measurements and differences between observed and estimated measures of girth in *Trachurus trachurus*. Legend: TL - total length; GME - girth measured by rope; a - major semiaxis; b - minor semiaxis; GES - girth estimated by elliptic model; GOB - girth observed by curvimeter; AES - area estimated by elliptic approximation; AOB - area observed by planimeter. See text for details.**

| TL | GME | Elliptic semiaxes a | b | GES | GOB | GOB-GME | GOB-GES | AES | AOB | AOB-AES |
|---|---|---|---|---|---|---|---|---|---|---|
| 336 | 168 | 33.0 | 21.5 | 173.1 | 180.0 | 12.0 | 6.9 | 2,229.0 | 2,253 | 24.6 |
| 212 | 105 | 20.5 | 11.5 | 102.5 | 103.0 | -2.0 | 0.5 | 740.6 | 733 | -7.6 |
| 191 | 95 | 18.0 | 10.5 | 91.1 | 93.3 | -1.7 | 2.2 | 593.8 | 593 | -0.8 |
| 182 | 92 | 18.0 | 9.5 | 88.5 | 95.3 | 3.3 | 6.8 | 537.2 | 566 | 28.8 |
| 186 | 92 | 17.0 | 9.5 | 84.9 | 89.6 | -2.4 | 4.7 | 507.4 | 570 | 62.6 |
| 193 | 109 | 19.0 | 11.5 | 97.3 | 101.0 | -8.0 | 3.7 | 686.4 | 710 | 23.6 |
| 195 | 99 | 18.5 | 10.5 | 92.8 | 91.0 | -8.0 | -1.8 | 610.3 | 565 | -45.3 |
| 191 | 93 | 17.5 | 10.5 | 89.3 | 90.3 | -2.7 | 1.0 | 577.3 | 590 | 12.7 |
| 193 | 99 | 19.0 | 11.0 | 95.9 | 99.3 | 0.3 | 3.4 | 656.6 | 677 | 20.4 |
| 170 | 88 | 16.0 | 9.5 | 81.4 | 85.6 | -2.4 | 4.2 | 477.5 | 513 | 35.5 |
| 162 | 74 | 14.5 | 7.5 | 70.9 | 70.6 | -3.4 | -0.3 | 341.6 | 353 | 11.4 |
| 164 | 85 | 15.5 | 8.5 | 77.0 | 82.0 | -3.0 | 5.0 | 413.9 | 460 | 46.1 |
| 151 | 77 | 14.5 | 7.5 | 70.9 | 71.0 | -6.0 | 0.1 | 341.6 | 330 | -11.6 |
| 48 | 77 | 14.5 | 7.5 | 70.9 | 79.3 | 2.3 | 8.4 | 341.6 | 390 | 48.4 |
| 108 | 58 | 10.0 | 5.0 | 48.4 | 56.0 | -2.0 | 7.6 | 157.1 | 180 | 22.9 |
| Mean difference | | | | | | | | -1.58 | 3.48 | 18.07 |
| Standard error | | | | | | | | 1.27 | 0.81 | 6.96 |

However, a comparison between mean and relative standards error in the two cases (bottom lines in Table 1) reveals a higher precision in the ellipses-based measures (GES) than the "rope" based relatives.

The "t" statistics of the paired t-test resulted to be significant for GES and AES (t = 4.29 and t = 2.59, respectively), i.e., the elliptic approach yields upward biased estimates of both maximum girth (GOB) and area (AOB). In both cases, however, the differences themselves are not normally distributed (as required by the test [Sokal and Rohlf 1981]) and consequently the results of this test are inconclusive.

The Wilcoxon-signed rank tests (two-sided) resulted in highly significant ($p = 0.003$) and nonsignificant ($p = 0.099$) differences from the "true" maximum girth (GOB) for GES and GME, respectively. The estimated area (AES) was also significantly different from AOB ($p = 0.02$). All these measures are consequently biased estimates of the corresponding measures assumed as the true ones.

The plots of the variables *vs.* total length and regressions coefficients and statistics (Fig. 2; Table 2) indicate a good correspondence of the linear (GES, GME) and log-linear (AES) models; the regressions with measures based on the elliptic approach showed the more precise estimates, higher coefficient of determination, and minimum mean square errors (Table 2).

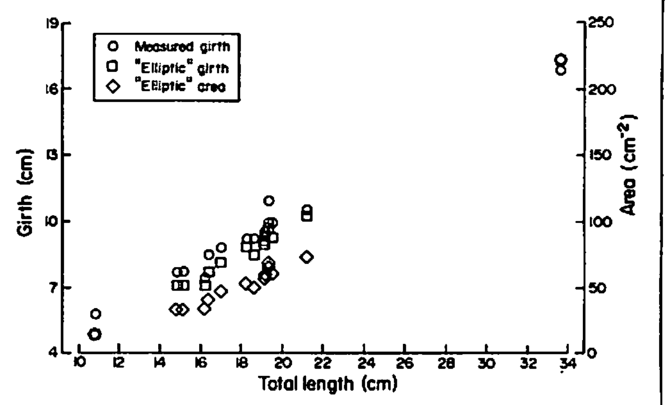

**Fig. 2.** *Scatter plots of the different girth and area values versus total length of* Trachurus trachurus.

**Table 2. Coefficients of linear regressions. Legend: a - intercept on ordinate; b - slope; (s.e. a/b) - standard error of the coefficient; $r^2$ - coefficient of determination; MSE - mean square error; log - natural logarithm. See text for details.**

Independent variable: Total length (TL)

| Dependent variables: | a | (s.e. a) | b | (s.e. b) | $r^2$ | MSE |
|---|---|---|---|---|---|---|
| Girth observed | -9.654 | 5.497 | 0.551 | 0.029 | 0.966 | 27.620 |
| Girth measured | 3.218 | 4.479 | 0.490 | 0.023 | 0.971 | 18.336 |
| Girth estimated | -13.092 | 2.871 | 0.550 | 0.015 | 0.990 | 7.537 |

Independent variable: Log. total length (Log. TL)

| Dependent variables: | a | (s.e. a) | b | (s.e. b) | $r^2$ | MSE |
|---|---|---|---|---|---|---|
| Log. area observed | -5.273 | 0.546 | 2.226 | 0.105 | 0.972 | 0.009 |
| Log. area estimated | -5.964 | 0.410 | 2.351 | 0.079 | 0.986 | 0.006 |

## Discussion

Fish show an incredible variety in shape, but commonly possess a fusiform ("torpedo shaped") body whose cross section approximates quite well an ellipsoid or circular shape, the latter being a special case of an ellipse.

Obviously, many fish species depart moderately to completely from the generalized shape (Lagler et al. 1977) but many others, such as the scombroids and most pelagic species (and generally the so-called "roundfish") maintain the above scheme, meeting the general assumption of an elliptical body section as required, e.g., in many hydrodynamics models (Webb 1978).

Even though based on a small sample size, this study supports the idea of modeling the cross section of fish as an ellipse.

Obviously, the ellipse gives only an approximative description of the parameter investigated but models are built to give a mathematical and less subjective picture of reality (see Chauvelon and Bach 1993). Further studies on large samples and different species of fish may be useful, however, to assess the generous validity of the ellipse-based approach proposed here.

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## Letter to the Editor

**Traditionally, the study of industrial and artisanal fisheries has been undertaken separately. This is probably because of the difference in nature of the two fisheries, the industrial fishery being considered as a sector where economic efficiency and export earnings receive high priority, and the artisanal fishery being regarded as a sector where social concern (e.g., food and employment), and economic factors are important (Charles, A.T. 1988. Fishery socio-economics: a survey. Land Economics 64(3):273-295). Also, the small-scale status of the artisanal fishery has often caused people to underestimate its impact in the whole system. However, the industrial and the artisanal fisheries are always interacting somehow, either directly (e.g., common fishing grounds, technologically or economically), or indirectly (e.g., species interactions).**

**In a case study (Djama, T. 1992. Interactions between the artisanal and the industrial fisheries of Cameroon. Ph.D. thesis, University of Wales. 250 p.), I have been able to show how directly or indirectly the artisanal and the industrial fisheries can significantly affect each other in a way that ignoring one component can lead to biased management options. Global Optimum Management (GOM) considers therefore the optimization of management options pertaining to the global consideration of the interacting fisheries. The advantage of this approach is that of reducing conflicts between fisheries in addition of the other socioeconomic and biological considerations.**

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