

## A simple relationship to calculate eel surface area

PHILIPPE SÉBERT\*, AURELIE VETTIER, MARC BELHOMME

*Laboratoire de Physiologie, EA 2217, Unité Haute Pression et Métabolisme, Faculté de Médecine, 22, Avenue C. Desmoulins, 29200 Brest, France*

**Abstract**—Energy metabolism has a linear relationship with body surface (BS). However, this surface area cannot be easily measured. Consequently, a simple formula including body mass (BM) and body length (BL) is proposed for the eel. The formula  $BS = BL^{0.53} \times BM^{0.49} \times 3.983$  gives BS calculated values which show very low variations compared to the measured values ( $0.16 \pm 1.07\%$ ). The formula may be employed in the study of eel energetics and various aspects of applied aquaculture.

*Keywords:* body surface; eel; energy metabolism; oxygen consumption.

### INTRODUCTION

Although recently criticised (Packard and Boardman, 1999) the use of size-specific indices to normalise physiological data is sometimes very useful. The standardisation of energy metabolism in relation to body mass is a general observation even in fish (Smith, 1984; Oikawa and Itazawa, 1985; Somero and Childress, 1990; Kozłowski and Weiner, 1997). However, when comparing individuals with a wide range of body mass, a logarithmic scale must be used because the relationship between energy metabolism and body mass is not linear: the increase in mass is greater than the increase in energy metabolism, a phenomenon named heteroscedasticity (Nevill, 1994). Sarrus and Rameaux (cited by Kayser, 1951) have proposed their famous “loi des surfaces” (surface law) showing a direct and linear relationship between energy metabolism and body surface. In fish, Hoesslin (1888, cited by Schmidt-Nielsen, 1978) has shown a closer relation of oxygen consumption to surface than to mass. This is easy to understand bearing in mind that energy metabolism corresponds to energy/time ratio, that is to say, the dimension of a flow or a surface (Schulz, 1988). As body surface is not easy to measure, we propose a simple formula to calculate eel body surface from body mass and body length.

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\*Corresponding author, e-mail: [philippe.sebert@univ-brest.fr](mailto:philippe.sebert@univ-brest.fr)

## MATERIAL AND METHODS

### *Animals*

Fifteen freshwater eels, *Anguilla anguilla* L., with body mass ranging from 70 to 1250 g were used. Most of them were at the silver stage but some were at the yellow stage. They were kept in running and aerated tap water in a room open to the outside in order to maintain natural temperature ( $15.3 \pm 0.2^\circ\text{C}$ ) and photoperiod (winter: D/N  $\approx$  9/15 h). At the time of measurements, the eels had fasted for at least 15 days.

### *Measurements*

In order to facilitate the measurements, the fish were slightly anaesthetised using *Eugenia caryophyllata* ( $10^{-5}$ ) and ethanol ( $10^{-3}$ ) in water. Several parameters were considered, including:

- Body mass (BM) and total Body length (BL) were measured with conventional tools.
- Volume (V) was measured by water displacement during the immersion of the fish in a calibrated tank, thereby allowing calculation of density.
- Body surface area (BS) was measured by covering the whole fish with aluminium foil, then weighing it. Care was taken to spread out the fins except for the pectoral one. Body surface was also calculated from the body length and the average circumference of the body measured at ten evenly spaced transverse sections of the body considered as a cylinder (Oikawa and Itazawa, 1985).

### *Calculations*

Calculations were performed using the method described by Dubois and Dubois (1916). A formula based on BM and BL was employed:  $BS = BM \times BL \times C$ , C being a constant depending on units and individuals. As BS is a two-dimensional parameter, exponents for BM (three-dimensional) and BL (one-dimensional, L) must be found in order to obtain BS in two dimensions. There are two simple possibilities. Considering that BS is proportional to  $L^2$ , BL to L and BM to  $L^3$ , BS can be computed:  $BS = (BL \times BM)^{1/2}$  or  $BS = BL \times BM^{1/3}$ . These two possibilities give the same weight to BL and BM. However, the general formula must be  $BS = BL^{1/a} \times BM^{1/b} \times C$ , C being a constant. We used several combinations of a and b values to compute C values from the BS measurements and then we chose the a and b values giving the lower C variations.

## RESULTS

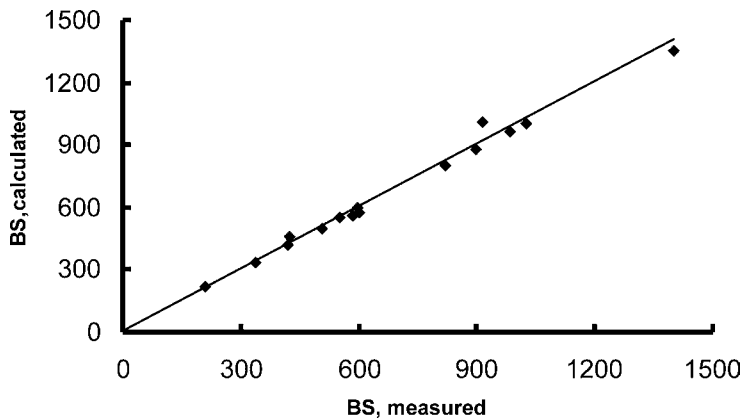
The best formula obtained using different combinations for the exponents of BL and BM was:

$$BS = BL^{0.53} \times BM^{0.49} \times 3.983$$

**Table 1.**

Morphometric data obtained from 15 eels. Results are expressed as the mean  $\pm$  SEM. Condition factor is computed as  $(BM \times BL^{-3})$  with BM in kg and BL in m.

Body mass (BM), g	447.4 $\pm$ 79.6 (71-1231)
Body length (BL), cm	61.4 $\pm$ 3.6 (34-88.8)
Volume (V), cm <sup>3</sup>	476.5 $\pm$ 84.9
Condition factor ( $10^{-1}$ )	0.172 $\pm$ 0.004
Density	1.028 $\pm$ 0.014
Body surface (measurement, BS <sub>M</sub> ), cm <sup>2</sup>	682.2 $\pm$ 79.5 (220-1350)
Body surface (circumference, BS <sub>C</sub> ), cm <sup>2</sup>	681.2 $\pm$ 81.5
Body surface (formula, BS <sub>F</sub> ), cm <sup>2</sup>	685.5 $\pm$ 81.5



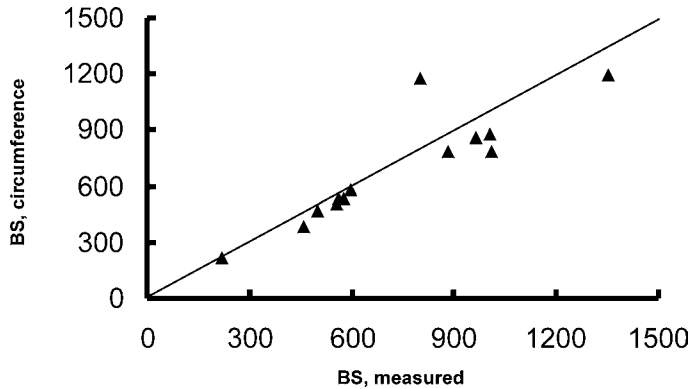
**Figure 1.** Relationship between calculated body surface (BS<sub>F</sub>) vs. measured body surface (BS<sub>M</sub>). The relationship is  $BS_F = 1.02 BS_M - 9.83$  ( $r = 0.994$ ). Only the line of equality is shown.

BS being in cm<sup>2</sup>, BL in cm and BM in g. The mean variation between the value calculated from the formula (BS<sub>F</sub>) and the measured value (BS<sub>M</sub>) was  $0.16 \pm 1.07\%$  (mean  $\pm$  SEM; range  $-9.6\%$  to  $+4.6\%$ ) whereas it was  $-5.9 \pm 4.4\%$  (range  $-22\%$  to  $+46\%$ ) as regards the difference between the values obtained using the circumference method (BS<sub>C</sub>).

Table 1 shows the mean values for the measured or calculated parameters. There is no difference in the BS values obtained by measurements and/or calculations. The relationship between BS<sub>M</sub> and BS<sub>F</sub> or BS<sub>M</sub> and BS<sub>C</sub> are shown in figures 1 and 2, respectively.

## DISCUSSION

The proposed formula provides a good prediction (correlation coefficient = 0.994;  $P < 0.0001$ ) of eel body surface area and is very simple to use. As shown in figure 1, the slope of the regression line is 1.02, which is very close to the line of equality. Circumferences are relatively easy to measure and table 1 shows



**Figure 2.** Relationship between the body surface obtained by circumference method ( $BS_C$ ) vs. measured body surface ( $BS_M$ ). The relationship is  $BS_C = 0.86 BS_M + 52.9$  ( $r = 0.891$ ). Only the line of equality is shown.

that, considering a given population, the obtained result is not different from that obtained by the direct measurement of the surface. However, the individual results do not fit particularly well (fig. 2; regression coefficient = 0.89) and the surfaces are underestimated when the fish size increases. Moreover this method requires repeated measurement which is not the case for the formula where only BM and BL are required and can be determined without anaesthesia. The validity of the proposed formula is highlighted by the great range in body mass and body length and by the fact that yellow and silver eels are considered. Moreover, the body mass range indicates that there are several levels of sexual maturity and/or silvering but no density effect (which decreases when fat content increases) but we are not able to discriminate silvering process level from the body surface (see fig. 1). Furthermore, in another batch (seven eels from 36-57 cm and weighing from 53-238 g, respectively) the measured body surfaces compared to those calculated from the proposed formula gave a variation of  $2.0 \pm 1.0\%$ .

The determination of body surface area has many advantages (Oikawa and Itazawa, 1985) but we will consider only two of them. (1) The standardisation of energy metabolism. As noted in the introduction, the ratio of oxygen consumption (energy demand) to body mass is most often used because it is simple to obtain (see e.g., Schmidt-Nielsen, 1978; Wood, 1989; Prosser, 1991). This is useful for interspecific comparisons and sometimes even for intraspecific ones. Such intraspecific comparisons have been used in fish (Oikawa and Itazawa, 1985; Torres and Somero, 1988; Van Waversveld et al., 1989; Somero and Childress, 1990; Yamamoto, 1991; Goolish, 1993). However, as oxygen consumption varies at the power of 2 whereas body mass varies at the power of 3, body mass increases more than oxygen consumption (heteroscedasticity) and, thus, the largest individuals have a relatively lower respiratory rate than smaller fish. This may well introduce a bias to the results (Batterham et al., 1997). In contrast, the standardisation of energy metabolism to body surface is in accordance with the dimensional system  $L^2/L^2$

**Table 2.**

Comparison of eels from two origins. Note the difference obtained when standardising oxygen consumption ( $MO_2$ ) to body mass (BM) or body surface (BS).

Origin	River Loire	Lake Balaton
N	4	4
Stage	silver	yellow
Body mass, g	649 ± 80	472 ± 51
Body length, cm	71.8 ± 2.6	56.8 ± 5.1 ( $P < 0.05$ )
$MO_2/BM$ , $mmol.h^{-1}.kg^{-1}$	1.5 ± 0.21	1.2 ± 0.02
$MO_2/BS$ , $mmol.h^{-1}.m^{-2}$	9.7 ± 1.3	5.6 ± 0.40 ( $P < 0.01$ )

(and not  $L^2/L^3$  as for body mass) bearing in mind that, in animals, the absorption of food, the diffusion of respiratory gases or ions and waste elimination are surface area-related functions. This probably limit their capacity of serving a metabolism directly proportional to body mass (Hulbert and Else, 2000). This explain why different powers of body mass (0.6-0.9) have been proposed even though “the search for a single unifying cause of so-called “power laws” has been like the search for the Holy Grail” (Hochachka et al., 2003).

By considering two eel populations which differ in stage (yellow or silver), origins (river Loire or Lake Balaton) and fitness (healthy or infested), we have standardised oxygen consumption in relation to body mass and body surface (calculated from the formula). Table 2 summarises the results obtained and shows that there is no difference between the populations in terms of standardisation to body mass. However, there is a significant difference in energy metabolism to body surface ratio. The aim of this work was not to explain the difference (probably due to the stage of the silvering process, Vettier et al., 2003) but to record it. Body length may be more appropriate than body mass in standardising oxygen consumption when body surface is not available because BL and BS are the only parameters able to discriminate the two studied populations (table 2).

(2) The second advantage of knowing body surface is linked to the field of fish farming. In aquaculture, food is normally given to balance energy requirements, based on biomass. However, we have seen that body mass is not always a good index of metabolic intensity, unlike body surface. Another example is the ocular index, which standardises eye surface to body length (Pankhurst, 1982): this index is used to evaluate the silvering process and it would probably be more significant if BS was used instead of BL.

Likewise, tank water volume is an important parameter during the culture of eels and other species such as African catfish, which have cutaneous respiration accounting for 35% of total oxygen consumption (Kirsch and Nonnotte, 1977). Finally, the calculation of body surface could be interesting in terms of pathologies to evaluate, for example, the extent of tumour and/or necrosis or other pathologies. Thus, the proposed formula could also be useful in the standardisation of metabolism and/ or the management of fish farms.

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