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Further evidence of a limiting effect of gill size on the growth of fish: the case of the Philippine goby, Mistichthys luzonensis.* DANIEL PAULY, International Center for Living Aquatic Resources Management, MCC P.O. 1501, Makati, Metro Manila.

In fish, the relationship between oxygen consumption per unit time (Q) and body weight (W) is generally described by the relationship

$$Q = a\,W^{d_Q} \qquad [1]$$

where d_Q is a power that is, in fishes past metamorphosis, always smaller than unity (1, 2). Similarly, the relationship between gill surface area (G) and body weight can be described by the relationship.

$$G = a\,W^{d_G} \qquad [2]$$

where d_G is a power that is, also in fishes past metamorphosis, always smaller than unity (3, 4).

The oxygen consumption of fish larvae is directly proportional to body weight (5). This is possible because of the enormous surface area (per unit weight) available to larvae for respiratory purposes, including their gills, which grow with a power of weight higher than unity (6). (Although fish larvae are included in Fig. 1, they are however excluded from the considerations which follow.)

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Because of the direct proportionality between respiratory surface area and oxygen consumption (3), it follows that

$$d_Q = d_G \qquad [3]$$

i.e., each species has a single value of d which relates its body weight to both its gill size and its oxygen consumption. Using both d_Q and d_G values, I have shown, moreover, that fishes which can grow to large maximum sizes (W_{max}) tend to have high values of d, while fishes which as adults are small tend to have lower values of d (4). The data also allowed the estimation of the relationship

$$d = 0.6742 + 0.03574 \log_{10} W_{max} \qquad [4]$$

(r = 0.83, 20 d.f.), this relationship being based on values of W_{max} ranging from about 10^0g (in the family Cyprinodontidae) to about 10^6g (in bluefin tuna).

Derivation of a new value of d. Recently, data presented by Te Winkel (7) came to my attention, which pertain to gill sizes in the small Philippine goby, *Mistichthys luzonensis*, one of the smallest fishes in the world (8). Analysis of the data (Table 1) allowed the computation of a value of $d_G = 0.60$ in a fish the maximum weight of which is about 10^{-2}g, i.e., about two orders of magnitude smaller than that of the smallest fishes used for the estimation of the relationship in equation [4].

Table 1. Data used in the estimation of the relationship between weight and gill surface area in *Mistichthys luzonensis*. [Adapted from Table 1 in Te Winkel (7).]

No.	Standard length (cm)	Weight (g)[a]	Gill surface (cm^2)
1	1.05	0.0114	0.1509
2	1.20	0.0170	0.1679
3	1.25	0.0193	0.1822
4	1.25	0.0193	0.2132
5	1.30	0.0217	0.1815
6	1.40	0.0271	0.2589
7	1.45	0.0301[b,c]	0.2612

[a]Assuming a condition factor of 0.6 (TL:cm/w:g), total length/standard length = 1.18.

[b]0.0301 g = W_{max}; $\log_{10} W_{max}$ = -1.522.

[c]The estimated relationship between gills (G) and body weight (W) is $G = 2.086\ W^{0.601}$, with $r^2 = 0.82$.

This new value of d_G is of considerable interest for two reasons:

(a) The new value of d suggests that the inclusion of d_G and d_Q values in a same plot on log W_{max} is legitimate. The previous plot was based mainly on low values of d_Q and high values of d_G, while the plot now inclues both high and low values of d_G, thus reducing the chances of a spurious fit (Fig. 1).

(b) The new value closely corresponds to the d value expected (by extrapolation of the earlier plot) from a fish the size of *M. luzonensis,* suggesting that the midpoint values obtained from equation [4] represent reasonable estimates of d.

The range extension presented here for the relationship expressed in equation [4] has two implications related to the theory of growth in fish:

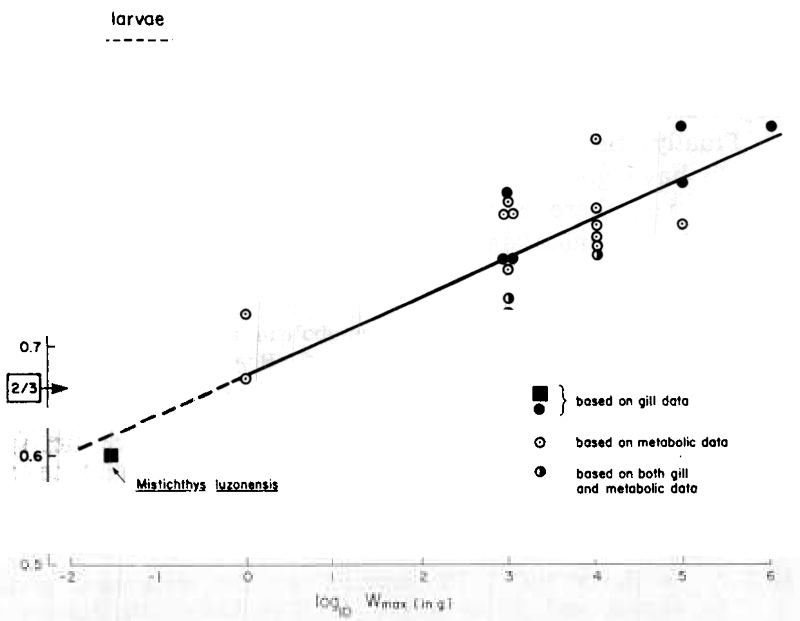

Fig. 1. Relationship between maximum weight reached by the adults of different fish species and power of weight (d) in proportion of gill size increases [Based on data in Pauly (4), Table 2]. Note how new value (black square) corresponds to an extrapolation of relationship established earlier (solid line), and that for larvae (upper left), d = 1.

(a) It disproves the claim for a single value of d (e.g., 2/3 or 3/4) valid for all fish, and suggests that growth models which incorporate values of d must allow for this parameter to range from about 0.6 to 0.95 (4).

(b) It confirms the proposition earlier (4) that smaller fish use only relatively smaller gills and conversely, that relatively large gills are necessary for larger fish.

The points in (b) are non-trivial as they suggest a limiting role of oxygen supply in fish growth (beyond and above any limiting role of food supply), as also recently suggested by Brett & Blackburn (9). A value of d equal to 2/3 implies that the gills of a fish grow isometrically as body mass increases. This value, it now seems, applies only to fishes with a maximum weight of about 1.0 g, as is the case in the Cyprinodontidae from which von Bertalanffy (10, 11) derived the value of 2/3 which he thought applied to all fishes (4).

Fishes capable of reaching larger sizes have gills which grow with a positive allometry (i.e., $d > 2/3$); i.e., optimizing gill growth is an evolutionary method for reaching larger body size.

Finally, fishes whose niche requires small sizes can afford to have gills which grow with a negative allometry ($d < 2/3$); i.e., there is no need for them to invest energy in producing and maintaining larger gills.

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Vertical diurnal migration of Daphnia cucculata and Eudiaptomus graciloides in euthrophic Frederiksborg Castle Lake, Denmark. MANUEL H. CARLOS, Aquaculture Department, Southeast Asian Fisheries Development Center, Binangonan Research Station, Binangonan, Rizal 3106.

Cladocerans and copepods exhibit vertical migration. Theories to explain the phenomenon in Entomostraca and other organisms like phytoplankton have been advanced (1-3). Among the several possible triggering factors, light appears to be the most important (4, 5). Wetzel (6) points out that vertical movement varies considerably with underwater light characteristic, season, and age and sex of the species. The phenomenon is most typical and well-marked in clear oligotrophic lakes (1) but it occurs also, although not as pronounced, under much less transparent conditions in more productive lakes (6).

In euthrophic Frederiksborg Castle Lake, Berg & Nygaard (7) were the first to study vertical migration. They obtained water samples at various time intervals over several days and concluded that the bulk of the population of the zooplankton they were studying shifted from one depth to another.

Daphnia cucculata (Lilljeborg) (Cladocera) and *Eudiaptomus graciloides* (Lilljeborg) (Copepoda) are the two most dominant zooplankters in Frederiksborg Castle Lake (7). The vertical migration of these species was studied, and the observations are reported in this paper.

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