Effects of feeding on the swimming activity and growth of *Ophiocephalus striatus*

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Swimming activity of the obligatory air-breathing fish *Ophiocephalus striatus* reared in cylindrical aquaria on different rations (0–43·3 mg/g/day) increased from 58 m/day for the starving group to 439 m/day for the group fed a maximum ration. Swimming speed also increased from 2·4 cm/sec in the former group to 5·2 cm/sec in the latter group. Owing to sustained swimming activity and the consequent fatigue, the test individuals ' hung ' to the surface for a definite interval. Duration of surface ' hanging ' increased from 3·2 h/day to 15·8 h/day with decreasing ration. The group receiving 25·5 mg/g/day converted most efficiently (28%). The maintenance energy cost is equivalent to 10 mg/g/day and dry substance equivalent to 5 or 12 mg/g/day was expended on the sustained swimming activity by the fish receiving the optimum (25 mg/g/day) or the maximum (43 mg/g/day) ration.

I. INTRODUCTION

Food quantity and quality can affect the growth rate considerably. When growth rate is plotted against ration, one can obtain:

(i) Maintenance ration, in which the fish neither loses nor gains body weight.

(ii) Optimum ration, in which the fish exhibits maximum conversion efficiency.

(iii) Maximum ration, which the fish consumes under the given experimental conditions. To optimize food conversion in fish culture practices, one requires basic knowledge of the metabolic demands of maintenance and other activities. While there are several publications concerning the effect of feeding rates on the growth of fish (Gerking, 1955, 1971; Pandian, 1967*b*; Brett, Shelbourn & Shoop, 1969; Pandian & Raghuraman, 1972), effect of different rations on the swimming activity of fish is lacking.

Kinne (1960) regarded feeding rate and conversion efficiency estimates as better parameters for assessing metabolic rates and efficiencies. Reared in aquaria containing different depths of water, the obligatory air-breathing fish *O. striatus* swam longer or shorter distance to exchange atmospheric air; such a design of experiment permitted Pandian & Vivekanandan (1976) to measure food intake, growth and sustained active metabolism on a long term basis. They found that the fish in deeper waters consumed significantly more food, swam longer distances and dissipated more energy on metabolism and swimming activity. As a continuation of that research, this experiment was carried out to study whether ration level controls the swimming activity or vice versa.

II. MATERIALS AND METHODS

Fingerlings of *Ophiocephalus striatus* (900±65 mg; 4·5±0·8 cm body length) were collected from the Lake Idumban (Palni) while swimming alongside their parents; they therefore

belonged to the same brood. They were brought to the laboratory and acclimatized to laboratory conditions and a feeding schedule. For experiments, cylindrical aquaria (10 cm diameter; capacity: 4·5 l) were chosen to minimize swimming activity in horizontal direction. As the aquaria contained a constant depth of 15·5 cm water, the test individuals travelled about six times their body length, when they returned to the bottom after each surfacing.

O. striatus is known to consume 43 mg dry food/g live fish/day, when fed twice a day for a period of 2+2 h in aquaria containing 15·5 cm water depth at 27° C (Pandian & Vivekanandan, 1975). Six different rations ranging from 0–60 mg dry food/g live fish/day were offered. The test fish groups, each comprising three individuals, were fed twice a day on *Tilapia mossambica* muscle; the groups receiving 6·0–25·5 mg/g/dayconsumed the ration immediately, or in some cases, within 30 min; the last group, which received the maximum ration of 60 mg/g/day for a total period of 4 h (between 09.00 and 11.00 h and 17.00 and 19.00 h), however, consumed only 43·3 mg/g/day. Care was taken to collect the unfed remains with a pipette. Suitable corrections were made for body fluids lost by the muscle pieces during the time they were left in the aquaria.

Faeces were collected by filtering the entire aquaria once every 5 days. ' Sacrifice method ' (Maynard & Loosli, 1962) was used for determining the water content of the test individuals before commencing the experiments. Estimations of dissolved oxygen content and pH of the water in each aquarium were made once every 5 days; the oxygen values ranged between 4·3 and 4·9 ml/l and the pH values between 7·3 and 8·6.

Experiments were conducted in a laboratory where, except for feeding and observations, there was no disturbance. The number of visits to the surface of the water by each test individual was observed for a known period of time (about 15 min), 4 times a day at 07.00 h, 13.00 h, 19.00 h and 23.00 h. The distance travelled per individual per day was estimated multiplying the mean number of visits per unit observation time with twice the depth of water. Observations were made daily for a period of 21 days; since observations were made on three individuals, the average performance is based on a minimum of 250 observations (Table I).

III. RESULTS AND DISCUSSION

As the ration increased, *Ophiocephalus striatus* visited the surface more frequently in order to obtain atmospheric air (Table I, Fig. 1). Correspondingly, the distance travelled by these groups increased from 170·4 m/day–506·9 m/day. Pandian & Vivekanandan (1976), who exposed *O. striatus* (0·75 g) to a water depth of 15·5 cm, reported that the swimming activity increased from 138·4 m/day for a starved group to 468 m/day for a feeding group. The small differences in swimming activity observed among the respective groups studied in this investigation (0·90 g) and that previously described (0·75 g) by Pandian & Vivekanandan (1976) were perhaps due to the size of the fish.

Surfacing by *O. striatus* consists of: (i) A period during which the fish swims upwards, (ii) a short period, usually lasting for some 2 sec, during which time the fish obtains atmospheric air, and (iii) a period, when the fish returns to the bottom. Pandian & Vivekanandan (1976) observed that at times *O. striatus* ' hangs ' to the surface and postpones returning to the bottom. They stated that in addition to the branchial respiration, ' hanging ' to the surface permitted the obligatory air-breathing fish to exchange gas without undertaking vertical movement. Such a period of rest may be regarded as a condition, during which the resulting ' fatigue ' has reached the maximum threshold (Brett, 1972) and the fish is paying off the accumulated ' oxygen debt ', i.e. it exchanges respiratory gases without involving swimming activities.

In order to assess the approximate duration of ' hanging ' in the individuals receiving different rations, simultaneous observations were made on each individual for 60 min per day between 11.00 h–11.30 h and 19.00 h–19.30 h. The duration of ' hanging '

TABLE I. Effects of feeding rates and swimming activity on different metabolic parameters in *Ophiocephalus striatus*. Each value represents the average performance of 3 individuals (mean±SD) maintained for a period of 21 days at 27° C

	Feeding rate (mg/g/day)					
	0	6	11·9	17	25·5	43·3
Number of visits/day	550 ±26·3	569 ±29·7	713 ±50	754 ±28	1589 ±82·3	1635 ±126·9
Distance travelled (m/day)	170·4 ± 8·15	176·5 ± 9·21	220·9 ±15·5	233·8 ± 8·68	492·5 ±25·51	506·9 ± 39·34
' Hanging duration ' (h/day)	15·8 ± 1·15	16·1 ± 1·11	15·1 ± 2·39	8 ± 1·19	2·8 ± 0·81	3·2 ± 0·52
Corrected distance travelled (m/day)	58·2 ± 7·7	58·1 ± 8·78	81·9 ±14	155·9 ± 8·25	435 ±24·70	439·4 ± 37·65
Absorption rate (mg/g/day)	—	5·2 ± 0·20	10·7 ± 0·10	14·4 ± 0·10	21·6 ± 0·20	35·6 ± 2·67
Conversion rate (mg/g/day)	−6·3 ± 0·80	−5·5 ± 1·05	+0·2 ± 0·02	+2·6 ± 0·95	+6·1 ± 0·40	+7·2 ± 1·34
Metabolic rate (mg/g/day)*	6·3 ± 0·80	10·7 ± 1·18	10·5 ± 0·30	11·8 ± 1·04	15·5 ± 0·30	28·4 ± 2·29
(ml O_2/g/h)†	0·25± 0·03	0·42± 0·04	0·42± 0·01	0·46± 0·04	0·60± 0·01	1·11± 0·07
Absorption efficiency (%)	—	86·8 ± 4·06	89·8 ± 0·93	84·5 ± 0·93	84·5 ± 0·87	82·2 ± 2·73
Conversion efficiency (K_2) (%)	—	—	1·3 ± 0·41	17 ± 4·48	28·4 ± 1·54	20·3 ± 3·12

*Calculated subtracting the dry weight equivalents of conversion rate from that of absorption rate
†Calculated considering the expenditure of 4·8 cal energy as equivalent to 1 ml of O_2 uptake (Engelmann, 1966); calorific value of *O. striatus* reported to be 4500 cal/g dry weight (Pandian, 1967a)
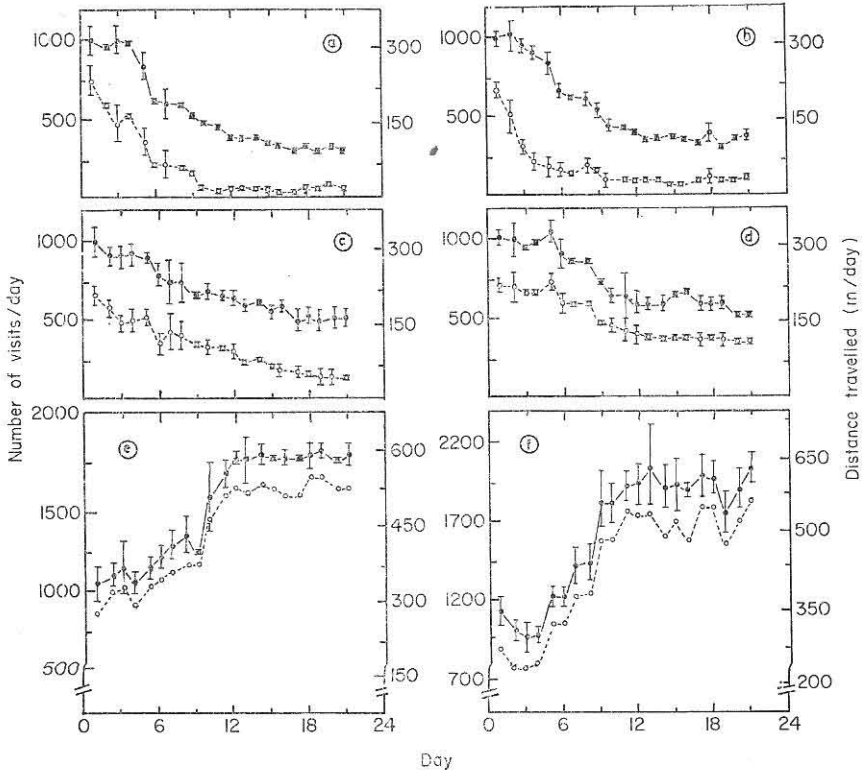
FIG. 1. Effects of feeding rate on the number of visits to the surface for exchange of atmospheric air and the distance travelled by *Ophiocephalus striatus* reared in aquaria containing 15·5 cm depth of water at 27° C. (a)–(f) pertain to the groups receiving 0, 6, 11·9, 17, 25·5 and 43·3 mg dry food/g live fish/day, respectively. Each value represents the average performance of three individuals observed 4 times a day for a total period of 1 h per day. Upper (–●–●–) and lower (– – ○ – – ○ – –) lines indicate the uncorrected and corrected (for hanging durations) distance travelled by the fish. The vertical lines (not indicated in the lower lines of the panels e and f for clarity) indicate SD.

was 3·2 h/day for the group which was fed the maximum ration (Table I). This value compares favourably with the value (3 h/day) reported by Pandian & Vivekanandan (1976) for a feeding group of *O. striatus* exposed to 15·5 cm depth of water. The duration of ' hanging ' increased from 3·2 h/day to 8 h/day in the 17 mg/g/day group, and subsequently to 16 h/day in the groups receiving a ration of 0 or 11·9 mg/g/day (Table I). A ration below 25·5 mg/g/day significantly extended the ' hanging ' periods.

Using the values obtained for the ' hanging ' duration, the actual period during which the fish exhibited swimming activity was assessed (Table I). There was no significant difference in the corrected distance travelled (Fig. 1, lower lines) between the groups receiving 25·5 and 43·3 mg/g/day (Fig. 2); the same was true between the groups receiving 0 and 6 mg/g/day. The swimming activity increased logarithmically from 58 m/day in group receiving 6 mg/g/day to 435 m/day in those feeding 25·5 mg/g/day and levelled off at 440 m/day in the group receiving 43·3 mg/g/day.

On the first day of the experiment, the fish swam an average distance of 320 m/day (Fig. 1). As its mean ' hanging ' duration was 7·1 h/day, the corrected distance
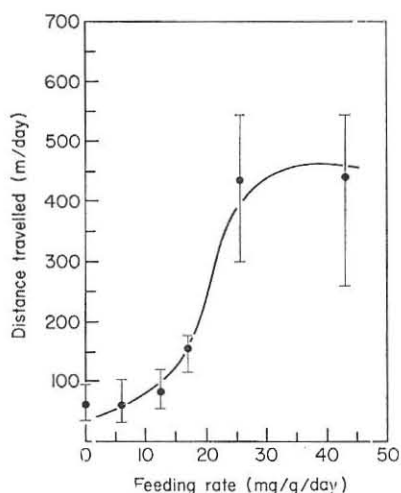
FIG. 2. Effect of feeding rate on the mean distance travelled by the obligatory air-breathing fish *Ophiocephalus striatus* exposed to 15·5 cm depth of water at 27° C. Each value represents the mean of 250 observations. The vertical line indicates the actual range of values recorded.

travelled was only 225 m/day. In the groups receiving rations less than 17 mg/g/day, the ' hanging ' duration increased from 8·2 h/day on the first day of starvation to over 16 h/day on the tenth, fifteenth and eighteenth day in the groups receiving 0, 6, and 11·9 mg/g/day, respectively. The ' hanging ' time remained constant during the rest of the experiment (Fig. 3). On the other hand, the ' hanging ' duration oscillated around 8 h/day in the group receiving 17 mg/g/day and 3 h/day in groups receiving rations over 25·5 mg/g/day. In general, the effect of ration level on duration of ' hanging ' was reflected by the test groups after a period about 7 days.

This delay in the effect of different rations was also observed on swimming activity. The fish receiving a ration of less than 12 mg/g/day swam 240 m/day on the first day of the experiment; the distance rapidly decreased to 75 m/day on the sixth day of the experiment and was constant thereafter. Those receiving over 25·5 mg/g/day increased their swimming activity from 270 m/day on the first day of the experiment to 430 m/day on the ninth day of the experiment and maintained their activity at that level (Fig. 1).

Pandian & Vivekanandan (1976) made similar observations in feeding and starving *O. striatus* exposed to different depths of water. They observed starving *O. striatus* at 31 cm depth decreased their swimming activity from 378 m/day on the first day of the experiment to 316 m/day on the fifth day, whereas feeding fish increased the swimming activity from 1035 m/day on the first day to 1130 m/day on the eighth day of the experiment. Similar observations were made on the swimming abilities of feeding and starving larvae of the largemouth bass *Micropterus salmoides* (Laurence, 1972). They increased their swimming activity from 56 m/day on the first day to 492 m/day on the seventh day of test feeding; conversely an older starving larva swam 400 m/day on the second day of starvation and only 135 m/day on the seventh fasting day. Testing the sustained activity of some marine fish, Beamish (1964) observed a decrease in standard metabolism and swimming capacity.

The increase in the ability of the feeding fish and fish larvae to swim longer distances is understandable, as the conversion of food results in the accumulation of
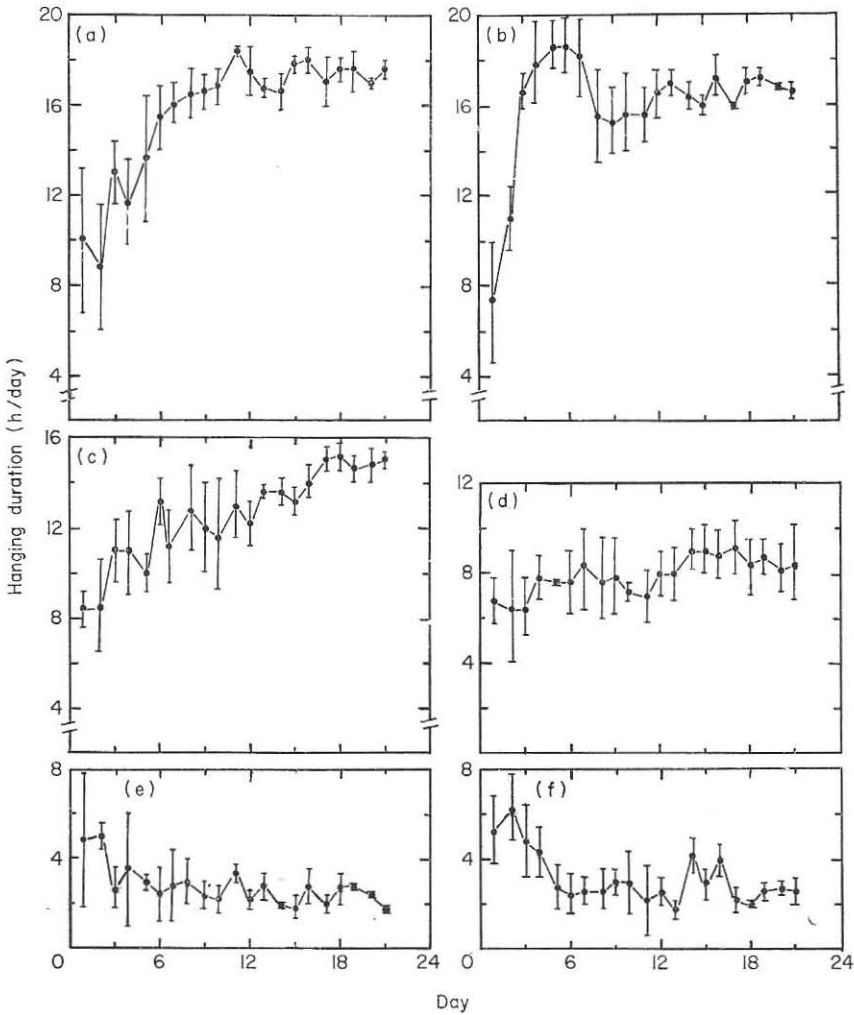
FIG. 3. Effect of feeding rate on the ' hanging ' duration by *Ophiocephalus striatus* reared in aquaria containing 15·5 cm depth of water at 27° C. (a)–(f) pertain to the groups receiving 0, 6, 11·9, 17, 25·5 and 43·3 mg dry food/g live fish/day, respectively. Each value represents the average performance of three individuals observed twice a day for a total period of 1 h per day. The vertical lines indicate SD.

energy-releasing compounds in the muscle fibres. The nature of physiological mechanisms of sustained swimming in fish is determined by the ability of muscles to utilize their energy-releasing substances and by the rates at which these substances can be supplied and waste products removed from the muscles (Johnston & Goldspink, 1973). Apparently, the muscles of starved fish do not have adequate energy-releasing substances to permit sustained swimming activity.

The inadequate store of energy-releasing substances and the inability to remove the waste products of the muscles in starved fish, not only inhibit sustained swimming activity but also decrease the swimming speed (Table II). As indicated previously, the time required for each surfacing increased from 54 sec in groups receiving over 25·5 mg/g/day to 157 sec in groups receiving less than 6 mg/g/day. Correspondingly,

TABLE II. Effect of feeding rates on durations of swimming and resting in the fish *Ophiocephalus striatus* at 27° C. Each mean value is based on 250 observations, each observation lasted for a minimum period of 15 min.

Feeding rate (mg/g/day)	Time required for each surfacing (sec)	'Resting duration' in the bottom (sec)	Swimming duration (sec)	Swimming speed (cm/sec)
43·3	53± 6·8	47± 4	6±2·8	5·2±0·11
25·5	54±11·1	48± 9·5	6±1·6	5·2±0·20
17	115±30·9	105±25·1	10±5·8	3·1±0·53
11·9	121±21·8	112±16·9	9±4·9	3·5±0·63
6	152±29·1	139±23·1	13±6	2·4±0·26
0	157±32·9	144±28·6	13±4·3	2·4±0·70

the duration of rest at the bottom increased from 47 sec in the former groups to 144 in the latter. Furthermore the duration required by the test groups to swim a distance of 31 cm increased from 6 sec in the group feeding the maximum ration to 13 sec in the groups receiving 0 and 6 mg/g/day. In other words, the swimming speed of a well-fed *O. striatus* was 5·2 cm/sec, as against 2·4 cm/sec for a starved fish.

The feeding rate of the test group receiving 60 mg/g/day averaged only 43·3 mg/g/day, a value which confirms closely with the data (43·2 mg/g/day) reported by Pandian & Vivekanandan (1976) for *O. striatus*. An amount of 43·3 mg/g/day may then represent the maximum which a 0·9 g *O. striatus* can consume in the aquaria containing 15·5 cm depth of water at 27° C.

Food absorption efficiency averaged 85·6% and did not appreciably vary between groups receiving different rations. This observation confirms the previous reports of Gerking (1955, 1971), Davies (1964), Pandian (1967*b*) and Pandian & Vivekanandan (1976). Conversion efficiency (K_2) increased progressively from 1·3% for those receiving 11·9 mg/g/day to 28·4% in those receiving 25·5 mg/g/day, and thereafter decreased to 20·3% in those receiving the maximum ration (Table I). Conversion rate increased from 0·2 mg/g/day in the group receiving 11·9 mg/g/day to 7·2 mg/g/day in those receiving the maximum ration [Fig. 4(a)]. Geometric derivation of ration-conversion rate relation obtained for *O. striatus* suggests that 10·5, 28·0 and 43·3 mg/g/day represents the maintenance, optimum and maximum rates, respectively.

The energy cost of maintenance has been determined in two ways; first, either the oxygen uptake (e.g. Beamish, 1964) or the weight loss (e.g. Savitz, 1971; Pandian & Raghuraman, 1972) by the starving fish is estimated. Another method of measurement involves estimating the maintenance energy cost as equivalent to the ration consumed by the fish, which maintains constant body weight (Pentelow, 1939; Brown, 1946; Pandian & Raghuraman, 1972). For instance, the starving *O. striatus* lost 6·3 mg/g/day, which may be considered as the minimum maintenance energy cost; to maintain its body weight without gain or loss, a ration of 10·5 mg/g/day has to be eaten by *O. striatus*, i.e. the group receiving maintenance ration was spending nearly 2 times more energy on metabolism.

Figure 5(a) presents the quantitative relation of food energy absorbed, metabolized for body functions and converted in *O. striatus*. The amount of energy expended by the fish above the maintenance cost of 10·5 mg/g/day is due to the specific dynamic
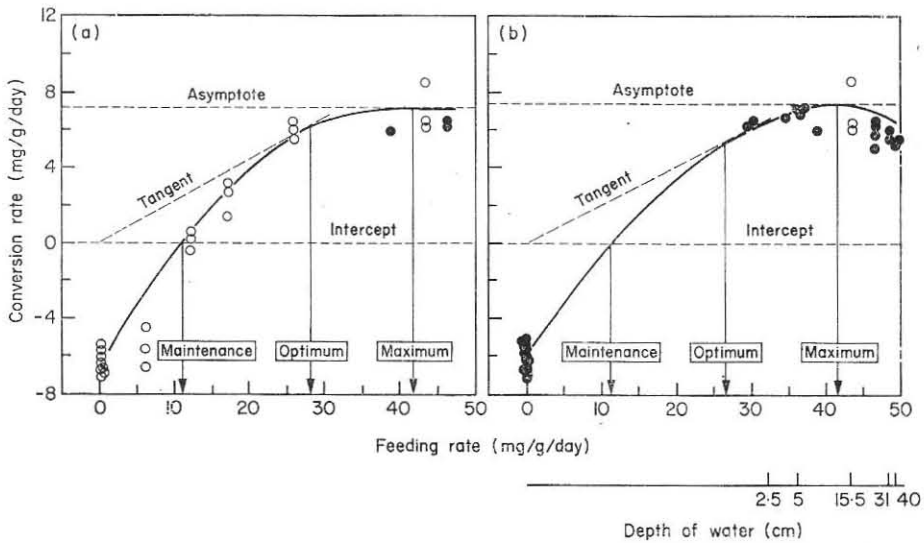
FIG. 4. Geometric derivation of various parameters of conversion rate (= growth) with accompanying feeding rate in the fish *Ophiocephalus striatus* (0·90 g) exposed to 15·5 cm depth of water at 27° C [given in (a)]. For comparison, data reported by Pandian & Vivekanandan (1976) for *O. striatus* (0·75 g) exposed to aquaria containing different depths of water at 27° C are presented in (b). Data obtained by Pandian & Vivekanandan for the group exposed to 15·5 cm water depth are indicated in closed circles in (a); data obtained for the corresponding group in this study are indicated in open circles in panel (b).

action (SDA) and excess swimming activity. The group feeding on the maximum ration of 43·3 mg/g/day expended on the SDA and excess swimming activity 28 mg/ g/day; it swam 439 m/day in comparison to that (82 m/day) exhibited by the group receiving the maintenance ration of 12 mg/g/day. Therefore the excess swimming activity exhibited by the fish receiving the maximum ration is 439−82 = 357 m/day. The group receiving the optimum ration converted 6·1 mg/g/day at an expense of 10·5 mg/g/day on maintenance metabolism and only 5 mg/g/day on the SDA and excess swimming activity. To convert 7·2 mg/g/day, the group receiving the maximum ration expended 10·5 mg/g/day on maintenance metabolism plus 17·9 mg/g/day on the SDA and excess swimming activity, i.e. the total energy cost (maintenance+ SDA+swimming activity) of converting maximum ration is increased by 2 times, or if the SDA alone is considered, it increased nearly by 3½ times.

To assess the energy cost of the SDA and excess swimming activity in the groups receiving more than 25 mg/g/day, the data obtained by Pandian & Vivekanandan (1976) on the quantitative relation of the feeding rate to the food energy absorbed, metabolized for body functions and converted in *O. striatus* exposed to different depths are presented in Fig. 5(b). The fish exposed to over 15·5 cm depth of water exhibited higher feeding rates (to 49·1 mg/g/day) and lower conversion rates (5·5 mg/ g/day) than those exposed to 15·5 cm. In this experiment, the minimum energy cost ranged from 5·8 mg in the starving groups exposed to 2·5 cm depth to 7·4 mg/g/day in those reared in aquaria containing 40 cm depth of water [Fig. 4(b) and 5(b)]. Geometric derivation of ration-conversion rate relation suggests that the maintenance ration is 10·5 mg/g/day, which confirms the value obtained in this experiment. The groups exposed to 31 and 40 cm depth of water consumed 48·5 mg/g/day, converted
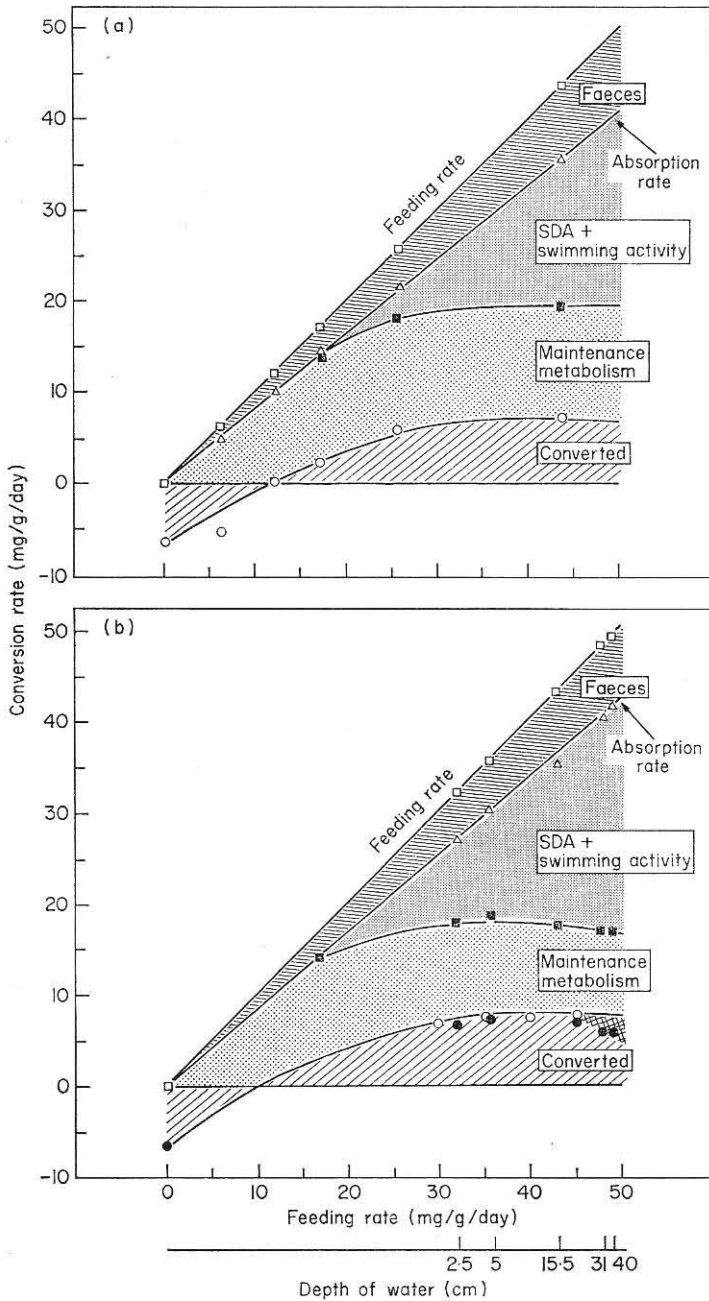
FIG. 5. Effects of feeding rates for scopes for conversion (= growth), metabolism (maintenance+ Specific Dynamic Action and Swimming Activity) and output of faeces in young *Ophiocephalus striatus* fed on *Tilapia mossambica* muscles in aquaria containing 15·5 cm depth of water at 27° C [given in (a)]. For comparison, data obtained by Pandian & Vivekanandan (1976) for *O. striatus* (0·75 g) exposed to aquaria containing different depths of water at 27° C are presented in (b). Data obtained in this study and the eye-fitted line (— o — o —) are also indicated in panel (b). Note the data of Pandian & Vivekanandan for conversion rate in the groups exposed to 31 and 40 cm depth are lower than the expected values indicated by extending the trend obtained (— o — o —) in the present work. Though these groups exposed to 31 and 40 cm depths fed more than 43 mg/g/day, they converted less as they dissipated more energy in swimming longer distance.

5·6 mg/g/day at an energy cost of 35 mg/g/day, whereas the group exposed to 15·5 cm in this experiment as well as in that of Pandian & Vivekanandan (1976) converted 7 mg/g/day at an energy cost of 28·5 mg/g/day. Those exposed to more than 31 cm depth of water expended only 20 mg/g/day on the SDA and excess swimming activity (1158 −116 = 1042 m/day; see Table I, Pandian & Vivekanandan, 1976); the corresponding value for those exposed to 15·5 cm is 15·1 mg/g/day for the SDA and excess swimming activity (357 m/day).

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