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Relation between Food-intake and Growth of Immature Saffron Cod, *Eleginus gracilis* (Tilesius) in Captivity*

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Abstract

Consumption and growth rates of immature saffron cod weighing 26-117 g were measured at 2.7-14.5°C. They were fed squid or sandlance. The net growth efficiencies and maintenance requirements are with these energy sources was ;

$$R = 0.589G \times W^{0.248} + 0.008W^{0.823} \times 10^{0.037T} \text{ g/day}$$

where **R** is food intake (g/day), G is growth (g/day), T is °C and W is body weight (g).

Maintenance rations of saffron cod were similar to those of other immature gadid species. Both feeding rates and growth rates increased under the higher temperature and ration conditions. The caloric value of the laboratory food was twice that of common prey type consumed in nature, thus in situ consumption would potentially be twice the captive estimate.

Introduction

Saffron cod are a small cold-water gadid species that are widely distributed along Alaska's north Pacific Ocean coast, the Bering Sea, the Beaufort Sea, along the coast of the Soviet Union including Kamchatka and Sakhalin, and on the eastern shore of Hokkaido.

They mature at 2 years (Svetovidov, 1948) and have geographical variations in growth rates (Pokrovskaya, 1960 ; Semenenko, 1970b). Spawning usually occurs under coastal sea ice in shallow areas (2-10 m) with a sandy-pebbly substrate. They hatch in early spring. Juveniles don't undertake seasonal migrations and remain in shallow water areas throughout the year (Pokrovskaya, 1960). These biological characteristics are remarkably different from those of other pelagic gadid fish such as cod, haddock, whiting and walleye pollock, which have widespread geographical distribution, prolonged spawning season, etc.

The food-intake, food elimination rate, caloric requirements and growth rate have been examined for many other gadid species in captivity (Edwards et al., 1972 ; Jones and Hislop, 1972, 1978 ; Yoshida and Sakurai, 1984 ; Hawkins et al., 1985 ; Smith et al., 1986, 1988, 1989). However, the measurement of standard metabolism (Chen and Mishima, 1986) is the only experimental bioenergetic information published on saffron cod. The purpose of this paper is to describe the efficiency of food-intake and growth rate of immature saffron cod, and to estimate the food-

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growth relationships of juveniles in nature.

Materials and Methods

Immature saffron cod were caught by small set net or hook and line at Usujiri, Funka Bay, southern Hokkaido in September 1982 through April 1983. Immediately after capture the fish were transported to the Usujiri Fisheries Laboratory, and were acclimated to laboratory conditions for 1-2 weeks. Obviously injured or unhealthy fishes were removed during this period.

The experiment tanks were FRP and circular in shape, about 1,000 l in volume (1.5 m in upper diameter, 1.3 m in lower diameter and 0.7 m in depth), and were provided with running sea water at 6-10 l/min. Water temperature and salinity ranged from 0 to 21.5°C, and 32 to 35‰ respectively throughout the year. The inside of the tanks were divided into several compartments of various sizes by nylon mesh net suitable to fish size in every experiment. The size of fish and feeding intervals are given in Table 1.

No food was given to experimental fish for 72 hrs. before experiments. At the beginning, each fish was measured, weighed and was given identification marks made by inserting plastic tubes of various colors between the 1st and 2nd dorsal fin after anaesthetization by MS 222. In all experiments, the difference in growth rate between sexes was not accounted for because of absence of sex related morphological characteristics. One year old fish (almost or above 20 cm length) were very vulnerable to temperatures above 13°C, and therefore, the experiment for one year old fish was not performed after late May to avoid thermal stress.

During each feeding period, fish were fed a known amount of Japanese common squid (*Todarodes pacificus*) mantle or Japanese sandlance (*Ammodytes personates*) flesh to satiation. Table 1 shows that not all fish were fed every day. Food was

Table 1. Experimental details of immature saffron cod.

Experimental number	Dates (Duration in days)	W.T. (°C) Mean range SD	No. of Fish	Mean BL (range) mm	Mean BW (range) g	Food(*)	Feeding intervals (day)
Exp. 1	17, Oct.-9, Nov. 1982 (25)	14.5 12.9-16.5 1.1	19	14.5 (12.1-17.5)	29.1 (14.7-52.9)	S	0, 1, 3
			21	13.9 (11.6-17.9)	26.1 (14.8-58.8)	SL	
Exp. 2	20, Nov.-19, Dec. 1982 (30)	9.2 6.7-12.2 1.5	23	17.3 (13.8-21.3)	47.2 (21.8-92.5)	S	0, 1, 3, 5
			16	17.1 (13.6-21.3)	51.5 (25.3-101.1)	SL	
Exp. 3	17, Feb.-30, Mar. 1983 (41)	2.7 0.8-5.0 0.9	36	20.0 (17.0-24.0)	76.4 (44.3-135.5)	S	0, 1, 3, 5, 7
			34	20.1 (17.2-23.3)	80.8 (45.6-125.9)	SL	
Exp. 4	7, May-29, May 1983 (22)	9.2 6.4-11.2 1.3	14	22.8 (18.8-26.9)	116.8 (58.7-196.3)	S	0, 1, 3, 5, 7

(*) S: Japanese common squid, SL: Japanese sandlance given at different intervals as listed in Table 1. In each experiment, starvation trials were also performed using 3-8 individuals. After a period of controlled feeding, they were again measured and weighed.

Since these experiments were conducted at different temperatures, each maintenance requirement was standardized to constant temperature. The maintenance coefficients (%BW/day) calculated from each equation were multiplied by the average body weight of the experimental fish, and were adjusted at 10°C by using a temperature correction factor of $10^{0.037(10-T)}$ obtained from Chen and Mishima (1986).

The recorded data was used in calculation of daily feeding rate; $R = F \times 100 / T\{(W_o + W_t)/2\}$ %BW/day, and daily growth rate; $G = (W_t - W_o) \times 100 / T\{(W_o + W_t)/2\}$ %BW/day, where T is feeding period (day), W_o = initial body weight (g), W_t = final body weight (g) T days after, and F = total amount of food taken in (g).

Results

In every experiment, the relationship between growth and food-intake was approximately liner (Fig. 1, Table 2). The slopes of the regressions (a) provide the net growth efficiencies, and the intercepts (b) provide estimates of catabolic rates. The points where the regression lines cross the X axis indicate daily maintenance requirements (b/a: %BW/day).

In Exp 1 and 2, the differences in both the slope and elevation between squid and sandlance were statistically significant (slope; $0.025 < p < 0.05$, elevation; $p < 0.005$). Although there were significant differences in elevation in Exp 3 ($p < 0.005$) non-significance of slope was found ($0.1 < p < 0.2$).

The net growth efficiencies of sandlance were slightly larger than that for squid. Through all experiments, the regressions of net growth efficiencies decline with increasing body weight. The highest catabolic rate was obtained in Exp 3 under lowest experimental temperature (Table 2). The maintenance requirements (g/day) increased with body weight at constant temperature.

The relationship between maintenance requirements adjusted at 10°C (Table 3, M) and body weight was fitted to a straight line on a logarithmic scale (Fig. 2) as $M = 0.018W^{0.823}$

To estimate the daily ration at a given temperature and body weight, the following temperature correction can be used.

$$M = 0.018W^{0.823} \times 10^{0.037(T-10)} = 0.008W^{0.823} \times 10^{0.037T} \text{ g/day at T°C} \qquad (1)$$

Unfortunately I have no strict evidence to prove the relationship between temperature and net growth efficiency. Therefore no attempt has been made to correct the values of "a" for temperature. The values of "a" that were plotted against body weight in Fig. 3 on a logarithmic scale fitted to a straight line as follows.

$$a = 1.697W^{-0.248} \qquad (2)$$

If "M" in equation (1) and "a" in equation (2) are replaced with the equation $G = aR - b$, the following equation is obtained.

$$G = 1.697W^{-0.248} \times R - 0.014W^{0.575} \times 10^{0.037T} \text{ g/day} \qquad (3)$$

$$\text{or } R = 0.589G \times W^{0.248} + 0.008W^{0.823} \times 10^{0.037T} \text{ g/day} \qquad (4)$$

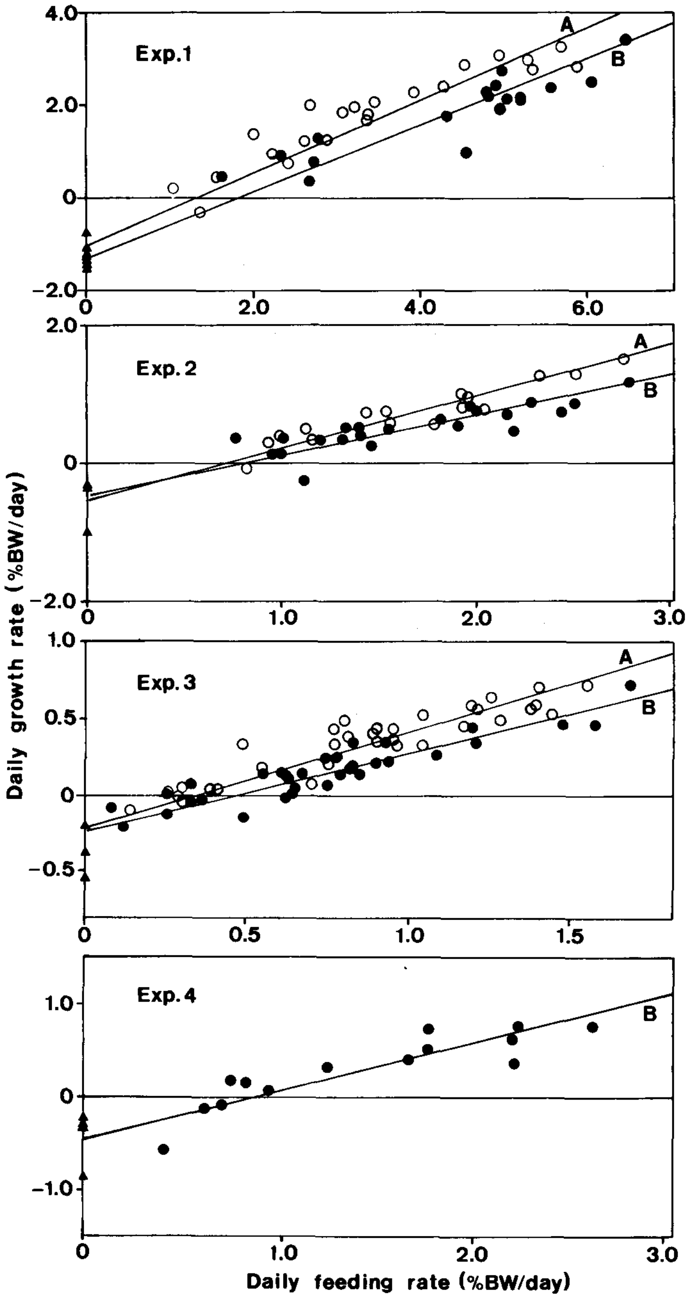

Fig. 1. Relationship between daily feeding rate (%BW/day) and daily growth rate (%BW/day).
open circles: fed with sandlance (line A)
closed circles: fed with squid (line B)
closed triangles: starved condition

Table 2. Regression equations for food-intake (%BW/day) and growth (% BW/day) for different size classes of saffron cod at different temperatures and foods.

Experimental number and food	Mean Weight (g)	Regression equation G=aR−b a	b	r	df	P
Exp. 1, S	29.1	0.689	1.247	0.974	24	0.001
SL	26.1	0.804	1.064	0.964	26	0.001
Exp. 2, S	47.2	0.561	0.452	0.900	24	0.001
SL	51.5	0.737	0.532	0.957	17	0.001
Exp. 3, S	76.4	0.547	0.255	0.921	37	0.001
SL	80.8	0.629	0.219	0.908	35	0.001
Exp. 4, S	116.8	0.502	0.427	0.912	16	0.001

Table 3. Estimates of the coefficients net growth efficiency (a) and maintenance given by this study and Chen and Mishima (1986).

Mean W.T. (°C)	Mean B.W. (g)	a	b/a (%BW/day)	M
14.5	29.1	0.689	0.527	0.359
	26.1	0.804	0.345	0.235
9.2	47.2	0.561	0.380	0.407
	51.5	0.737	0.372	0.398
2.7	76.4	0.547	0.356	0.663
	80.8	0.629	0.281	0.523
9.2	116.8	0.502	0.993	1.063

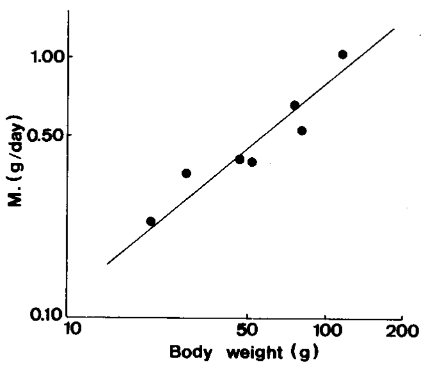

Fig. 2. Relationship between the maintenance requirements (M) and body weight of saffron cod at 10°C.
$M=0.018\,W^{0.823}$, $N=7$, $r=0.937$, $p<0.01$

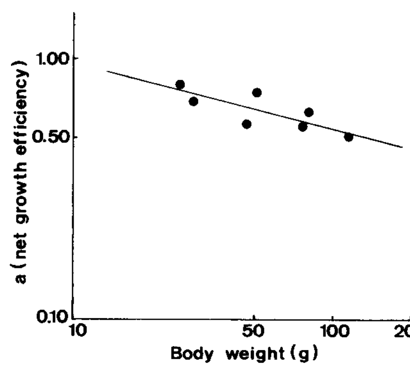

Fig. 3. Relationship between the net growth efficiency (a) and body weight of saffron cod.
$a=1.697\,W^{-0.248}$, $N=7$, $r=0.794$, $p<0.05$

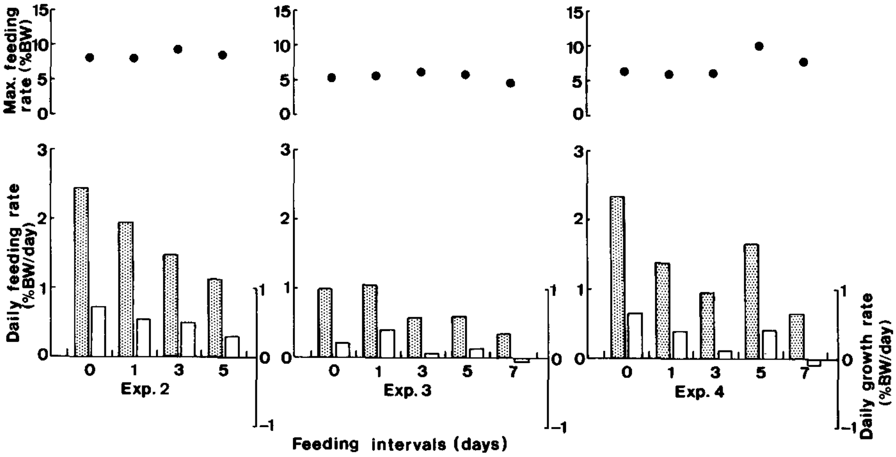

Fig. 4. Comparison of daily feeding rate and growth rate in Exp. 2, 3 and 4 among various intervals. closed bar : daily feeding rate, open bar : daily growth rate, dot : maximum feeding rate

Squid-fed individuals in Exp 2, 3 and 4 show that the feeding rate and growth rate were affected by fish size, water temperature and feeding intervals (Fig. 4). In Exp 2 and 4 at 9.2°C, both feeding and growth rates decreased as the feeding interval increased. On the other hand in Exp 3 at 2.7°C, there was no similar marked decline and slight increases in feeding and growth rates from "daily" to "every other day" groups. Moreover, the maximum food consumption was nearly constant regardless of feeding interval, fish size, and temperature. But at high temperatures both food-intake and growth rate increased regardless of fish size (Exp 2 and 4 in Fig. 4).

Discussion

In this study, no evidence was found that growth rate tailed off at high ration levels (Fig. 1), as has been suggested for feeding experiments with other fish (Warren and Davis, 1967 ; Brett et al., 1969). Condrey (1982) recently concluded that there is more likely a linear relationship rather than a curvilinear one between food-intake and growth.

There are some published reports that indicate that there is no strong relationship between temperature and growth efficiency (Jones and Hislop, 1978 ; Hawkins et al., 1985). So, no attempt in the present study has been made to correct efficiency for temperature. Since the experimental temperatures and fish sizes were similar to those in the area of capture (Chen, 1984), the experimental results should approximate the feeding-growth relationship in nature.

In other works the caloric value is calculated as 1.1 kcal/wet weight for the squid (calculated from Jones and Hislop, 1978 and Suyama et al., 1983) and is assumed to be 1.2 kcal/wet weight for the sandlance (Yoshida and Sakurai, 1984). If average value of 1.15 kcal/wet weight were to be applied to the feeding-growth relationship, equation (4) would be replaced with the following.

$$R = 0.677G \times W^{0.248} + 0.009W^{0.823} \times 10^{0.037T} \text{ kcal/day} \quad (5)$$

From the regressions (Fig. 1 ; Exp 1-3), it is clear that the fish fed sandlance have a higher growth rate than those fed lower calorie squid. The fat content of sandlance is 3.6 times that of squid (calculated from Resource Council, Science and Technology Agency, 1982), and the digestibility of fat is higher than those of protein or carbohydrates (Shirota, 1975). A similar suggestion was reported by Takahashi and Hatanaka (1960) who used anchovy and kuril for feeding-growth experiments of mackerel.

Another energy expenditure for saffron cod is reported in Safronov (1985) who determined their annual ration in Terpeniya Bay, Sakhalin by referring to the Winberg's metabolic equation. Because that report lacks an actual experimental procedure for the feeding-growth relationship, it is considered that the present study better explains feeding energetics of saffron cod than does Safronov (1985).

Both immature and mature saffron cod are epibenthic feeders (Wolotira, 1985). Food organisms cited from other authors are summarised in Table 4, which shows that the main food composition is Crustacean, and that Polychaeta and Fish are of secondary importance. These feeding habits are common for small sized saffron cod (Semenenko, 1970a). At the genus or species level the major food organisms are *Calanus glacialis*, *Metridia ochotensis*, *Parathemisto japonica* (Copepoda) ; *Amperisca* sp, *Gammarus* sp, *Anisogrammaris* sp (Amphipoda) ; *Pandalus* sp, *Crangon septenspinosa* (Decapoda) ; and *Nereis* sp, *Nephthys* sp, and *Onuphis* sp (Polychaeta) (Kozlov, 1959 ; Semenenko, 1970a).

Since the actual caloric values of these organisms has not yet been measured, a rough estimate at the genus level is given in Table 5. These values fall in the 50-100% range of caloric values of squid and sandlance. Consequently, saffron cod in

Table 4. Summary of main organisms of saffron cod which are placed according to the frequency of occurrence within each referred report.

Region	Fish size (cm) or age	Main foods	Authority
Nemuro Bay	1≦	Amphipoda, Decapoda	Irie (1982)
	0	Cladocera, Copepoda, Amphipoda	
	1≦	Mysidacea, Decapoda, Polychaeta	Irie (1981)
	0	Copepoda, Mysidacea, Larvae of Decapoda	
Peter the Great Bay	11-17	Mysidacea, Amphipoda	Markovtsev (1978)
Tatar Strait	26-32(*)	Decapoda, Mysidacea	Kozlov (1959)
Tayiskaya Bay (Okhotsk Sea)	17-20(*)	Copepoda, Amphipoda, Mysidacea	Semenenko (1970a)
Iamskaia Bay (Okhotsk Sea)	21-24(*)	Decapoda, Amphipoda, Polychaeta Copepoda	Semenenko (1970a)
Chukchi Sea	21-24(*)	Polychaeta, Mysidacea, Pisces Amphipoda	Semenenko (1970a)

(*) : including abult fish

Table 5. A rough caloric estimate of food organisms of saffron cod in genus level.

Genus name	Caloric value (cal/wet weight)	Authority
Calanus	853	Nishiyama (1970)
Parathemisto	490-780	calculated from Nishiyama (1975)
Parathemisto	1008	calculated from Percy and Fife (1983)
Gammarus	600-872	calculated from Nilsson (1974)
Anigogrammarus	587	Smith et al. (1986)
Pandalus	1200	Smith et al. (1986)
Neomysis *Anisomysis* *Acetes*	980	Science and Technology Agency (1982)
Nereis	690-960	calculated from Kay and Brafield (1973)

nature potentially may consume up to two times (maximum) the amount of food estimated in equation (5) if they attain the same growth rate.

The increase of feeding and growth rates under the higher temperature and ration conditions (Fig. 4) suggests that growth is greatly influenced by feeding environment. In Hokkaido, saffron cod grow nearly 30 cm in average body length by the first spawning season (Kanamaru, 1980; Chen, 1984). But further north in Okhotsk or along the Bering Sea coast, they attain only 20-25 cm (Kozlov, 1959; Semenenko, 1970b). Hokkaido is located at southern limit of saffron cod distribution and so they have a longer feeding period (warmer temperature) and lower population density than northern populations.

Maintenance rations of saffron cod at various temperatures are comparable to those of other immature gadid fish (Table 6). Though there are differences in prey digestibility, the maintenance ration of saffron cod is still similar to that of other

Table 6. Comparison of maintenance ration values for saffron cod (this study) with those for the juveniles of other gadid fish shown by Smith et al. (1986).

Species	Body weight (g)	Water temp. (°C)	Maintenance ration (kcal/day)
Saffron cod	30-60	3	191-338
		7.5	280-496
		12	411-727
Walleye pollock	30-60	3	225
		7.5	382
		12	649
Atlantic cod	34	10-13	370
	61	12-13	500
	34-61	10-13	435
Haddock	30	10-12	390
	61	10	620
	30-61	10-12	505

gadid fish.

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