

# INGESTION, GROWTH AND CONVERSION EFFICIENCY IN THE BLUE TILAPIA, *OREOCHROMIS AUREUS*, WHEN FED ON THREE AQUATIC MACROPHYTES

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## ABSTRACT

In order to assess food quality of aquatic macrophytes, juvenile and adult blue tilapia, *Oreochromis aureus* (Steindachner) (Teleostei: Cichlidae), were fed three aquatic macrophytes (*Elodea canadensis* St. John, *Myriophyllum spicatum* Jepson and *Potamogeton gramineus* L.) at two temperatures (15°, 25°C). Rates of ingestion and growth were recorded. Juvenile tilapia (45–65 g) consumed more food, in terms of percent of body weight per day, than adult (165–205 g) tilapia. *Elodea* was ingested in greater quantities than *Myriophyllum* and *Potamogeton*, in that order. Juvenile and adult tilapia fed aquatic macrophytes lost weight at both temperatures; the average percent of initial body weight lost in one month was 3.6% and 2.9% for juveniles and 3.9% and 11.3% for adults, at 15° and 25°C, respectively. The maximum conversion efficiencies were -0.03% and +0.03% for juveniles and -0.19% and -0.01% for adults, at 15° and 25°C respectively.

## INTRODUCTION

Despite the use of plant-eating (herbivorous) fishes in fish farming (Bardach *et al.* 1972, Fishelson and Yaron 1983) and for the control of aquatic weeds (Legner 1983), their abilities to grow on natural plant foods are not well documented (Okeyo 1989). Species such as grass carp, *Ctenopharyngodon idella*, frequently used for biological control of aquatic vegetation, have the potential to exert a considerable impact on natural plant communities (Pieterse 1977, Terrell 1982, Fletcher *et al.* 1985). For various herbivorous fishes, information exists on digestion of plants (Moriarty 1973, Van Dyke and Sutton 1977), physiology and energetics (Fischer 1973, Kawshik and Dabrowski 1983), and growth (Fischer 1973, Okeyo 1987, 1989). Nonetheless, our knowledge of these aspects of their biology remains fragmentary due to emphasis on laboratory studies of fishes fed artificial or unusual foods (e.g. kitchen scraps, terrestrial plant cuttings).

Fish growth depends on both the quantity and quality of food eaten (Fischer 1973). Considerable progress has been made in the study of the dietary nutrient requirements of fishes (recent reviews in Jauncey and Ross 1982, Dupree and Huner 1984, Tacon and Cowery 1985, Okeyo 1987, 1989). Dietary protein is important for support of growth, and is probably critical for herbivores feeding on low protein plant foods (Jauncey and Ross 1982). For example, diets recommended for optimal growth of juvenile tilapias include 30–35% protein for 10 to 30 g fish (Jauncey and Ross 1982), and Fischer (1973) suggested that an ideal diet for grass carp would contain 75% animal and 25% plant material.

Despite suggested optimal diets and many records of growth for tilapias and various species of carp in wild populations, protein levels of aquatic plants found in alimentary tracts of herbivorous fishes average only ~10% of dry weight (Boyd 1968, 1979, Fischer 1973, Bowen 1980, De Silva *et al.* 1984). The large

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differences between recommended and available levels of dietary protein suggest that herbivorous fishes must subsidize plant foods with animal matter in nature (Fischer 1972, Legner and Medved 1973, Legner *et al.* 1980).

The apparent subsidy is reflected in the types of foods fed to tilapias by workers interested in enhanced production. Most growth studies performed with cichlid fishes have used artificial foods in laboratory and ponds (De Silva and Perera 1985, Santiago *et al.* 1985, reviews in St. Amant 1966, Lovshin *et al.* 1974, Dupree and Huner 1984). In a rare study using naturally occurring plants as food, Legner and Murray (1981) fed *Tilapia zillii* on *Hydrilla verticillata*, trout pellets, and *Hydrilla* + trout pellets. The greatest increase in length and weight occurred with the combined diet.

In this paper, we present results of studies on two size classes of blue tilapia, *Oreochromis aureus* (Steindachner), designed to measure rates of ingestion and growth on diets of three aquatic macrophytes at two temperatures. This design is a response to three considerations. First, protein supplements may be a practical means of increasing production in carefully controlled culture, but they may be less available in rural areas. For this reason, we were particularly interested in assessing the potential of tilapias to grow or maintain weight on diets composed exclusively of naturally-occurring macrophytes. Second, the greatest problems with processing plant foods may be experienced by young fish with a less massive masticatory apparatus or less well developed gut; both juvenile and adult fish should be examined. Third, we wished to assess effects of temperature on ingestion and growth, as tilapias are used in areas differing greatly from their native habitats in terms of temperature.

## MATERIALS AND METHODS

**SOURCE OF FISH.**—Juvenile (45–65 g) and adult (165–205 g) *Oreochromis aureus* (Teleostei: Cichlidae) were obtained from an aquaculture facility at the Environmental Research Laboratory, University of Arizona, Tucson. The fish were spawned and raised in fiberglass tanks at 25°C, and were fed pelleted foods manufactured at the facility. Pellets were composed of 32.3% crude protein, 8.5% crude fat, 11.4% moisture, and 5.0% ash; carbohydrate content was not reported, but appears to have been greater than 50%.

**FOOD.**—Experimental fish were fed three aquatic macrophytes which occur widely in Arizona lakes. *Myriophyllum spicatum* Jepson and *Elodea canadensis* St. John, were collected from Lower Lake Mary near

Flagstaff, Arizona, and *Potamogeton gramineous* L. came from Peck's Lake near Cottonwood, Arizona. All were collected at depths of 0.5–1.0 m.

Plants were washed in fresh water to remove adhering sediments, invertebrates and encrusting materials. No special efforts were taken to remove all epiphytic algae, if any, and no examinations were made to see if different plants harbored different epiphytes. Macrophytes were held in an aerated plastic tank (~230 l capacity) at 25°C under standard fluorescent room lights. On several occasions, *Potamogeton* was held in a small outdoor pond at Northern Arizona University. All plants were used within a week of collection to insure their relative freshness.

**HOLDING TANKS FOR FISH.**—Fish were held in a round galvanized tank (~525 l capacity) painted with epoxy paint to prevent leaching of toxins from metal surfaces. Water was aerated and continuously pumped through cotton and charcoal filters. Fish were held at room temperature (25 ± 2 C) on a 12 light/12 dark photoperiod, and were acclimated to laboratory conditions for at least one week prior to beginning an experiment.

**INITIATION OF EXPERIMENTS.**—Fish were removed from holding tanks and body weights were determined to the nearest 0.1 g with a K-Tron DS-10 top-loading balance after 24 h starvation and prior to beginning experiments. Fork length (Hubbs and Lagler 1958) was measured to the nearest millimeter. Individual fish were then placed in each of 12 aerated, 40 l aquaria in two experimental rooms at 15°C and 25°C, respectively; both rooms were maintained on a 12 light/12 dark photoperiod. Water in each aquarium was continuously bubbled through cotton and charcoal filters, and feces were siphoned from tanks daily to reduce any opportunity for coprophagy. Fish were acclimated for at least one week in the experimental rooms while being fed *ad libitum* on experimental foods.

All experiments followed the same repetitive timetable of starvation on day 1, weighing and measuring on day 2, and feeding on day 2–6; day 7 began the cycle again with starvation. Although we expect that this recurring handling may have suppressed growth to some degree, fish held under identical conditions and fed dry pelleted foods either maintained weight (on a ration of 0.2% BW·d<sup>-1</sup>) or grew (6.8% of initial body weight added on a ration of 1.5% BW·d<sup>-1</sup> in a 63 d experiment; Okeyo unpublished).

Experiments with three macrophytes, *Elodea canadensis*, *Myriophyllum spicatum* and *Potamogeton gramineous*, ran for 35 days and were repeated twice. During

the 35-day macrophyte experiments, more food was supplied than the fish could eat within 24 hours. Wet weights of plants were measured to the nearest 0.1 g on the K-Tron balance after plants had been blotted with paper towels. The plants were added each day to experimental tanks and attached to rocks with rubber bands, a procedure similar to that employed by Gerking (1984) in his work with a sparid fish, *Sarpa salpa*, in southern Africa. Uneaten plant material was removed and weighed to the nearest 0.1 g. No attempts were made to assay caloric or nutrient contents of foods or feces; published reports of ash, protein, lipid and carbohydrate assays (% dry weight), respectively, include: *E. canadensis*, 21.9%, 26.8%, 3.5%, 15.4%; *M. spicatum*, 40.6%, 9.8%, 1.81%, 18.8%; *Potamogeton* spp., 11.4-17.0%, 8.0-13.4%, 0.9-2.9%, 18.8-37.2% (see Okeyo 1989).

**CALCULATIONS AND ANALYSIS.**—Ration was expressed as percent of body weight (BW) ingested per day:

$$\text{Ration (\% BW}\cdot\text{d}^{-1}) = \frac{\text{g food ingested per day}}{\text{BW (g)}} \times 100\%.$$

Daily growth (loss or gain in weight) was calculated as percent of initial weight (IW):

$$\text{Growth (\% IW}\cdot\text{d}^{-1}) = \frac{\text{change in weight}}{\text{IW}} \times 100\%.$$

Conversion efficiencies were calculated as:

$$\% \text{ conversion efficiency} = \frac{\text{final BW} - \text{IW}}{\text{g food ingested}} \times 100\%.$$

We used two way analysis of variance (F-test,  $p < 0.05$ , Zar 1984) to determine different plant usages by the fish. These analyses showed any significant differences in ingestion, growth rates, and conversion efficiencies among plants by fish of different sizes at 15° and 25°C. We used the two sample t-test ( $p < 0.05$ , Zar 1984) to determine differences between ingestion and growth in the two temperature regimes. We used Biomedical Computer Programs (BMDP) for analysis of variance and MINITAB for the t-test.

RESULTS

**INGESTION OF MACROPHYTES.**—Combined wet weight of all three aquatic macrophytes ingested by juvenile *Oreochromis aureus* (45-65 g) averaged 0.6 g·d<sup>-1</sup> (1.1% BW·d<sup>-1</sup>) at 15°C and 3.9 g·d<sup>-1</sup> (7.0% BW·d<sup>-1</sup>) at 25 C, throughout the one-month experiment (Table 1). In terms of mean percent body weight per day, juveniles appeared to consume more *Elodea* (12.0% BW·d<sup>-1</sup>), than *Myriophyllum* (4.8%) or *Potamogeton* (4.2%) at 25°C (Figure 1). At 15°C, they ate equal amounts of *Elodea* and *Myriophyllum* (1.3% BW·d<sup>-1</sup>), and again ingested less *Potamogeton* (0.7%). Nonetheless, two-way analysis of variance indicated that rates of ingestion of the three plants were not significantly different at 25°C ( $F_{2, 19} = 1.73, p > 0.20$ ). Ingestion was too variable and sporadic at 15°C to allow statistical analysis.

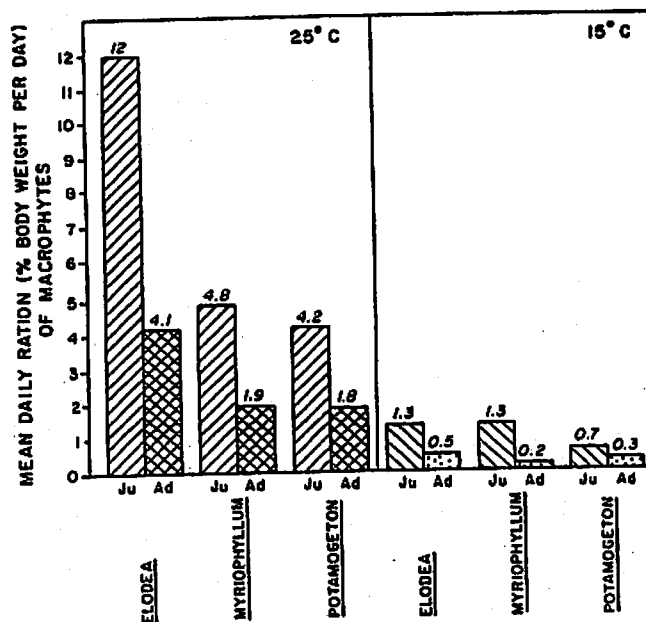


Figure 1. Rates of ingestion (mean % body weight day<sup>-1</sup>) of macrophytes by juvenile and adult *Oreochromis aureus* over the 28 days of feeding experiments at two temperatures. Means are for daily determinations for each of 4 replicates. Ju = juveniles; Ad = adults.

Adult *Oreochromis aureus* (165-205 g) ate an average of 0.6 g·d<sup>-1</sup> (0.3% BW·d<sup>-1</sup>) at 15°C and 4.4 g·d<sup>-1</sup> (2.6% BW·d<sup>-1</sup>) at 25°C (Table 1). Adults, like juveniles, also consumed more *Elodea* (4.1% BW·d<sup>-1</sup>) than *Myriophyllum* (1.9%) and *Potamogeton* (1.8%) at 25°C (Figure 1), and slightly more *Elodea* (0.5%) than *Potamogeton* (0.3%) and *Myriophyllum* (0.2%) at 15°C. Two-way analysis of variance indicated that ingestion

Table 1.—Weights (g; mean, standard deviation, range) of plant material ingested by blue tilapia, *Oreochromis aureus*, during feeding experiments at two temperatures. Means are total amounts of food ingested for each of 4 replicates during the 6 day experiments, giving N = 4 for every entry. Mean weights (g) of experimental fish at the end of each week are also given. Plants used in this experiment included *Elodea canadensis*, *Myriophyllum spicatum*, and *Potamogeton gramineous*. J = juvenile; A = adult.

		15°C											
Days	Age	<i>E. canadensis</i>			(Fish)	<i>M. spicatum</i>			(Fish)	<i>P. gramineous</i>			(Fish)
		$\bar{X}$	SD	Range		$\bar{X}$	SD	Range		$\bar{X}$	SD	Range	
0-7	J	5.2	2.5	1.8-7.4	(60.4)	3.0	1.1	1.8-4.1	(45.8)	1.2	0.9	0-1.9	(66.8)
0-7	A	5.2	1.0	3.7-5.9	(170.6)	2.5	3.1	0.2-7.0	(192.1)	1.6	0.5	1.2-2.3	(192.4)
8-14	J	3.1	1.1	2.1-4.5	(59.9)	5.7	1.5	4.0-7.1	(45.8)	3.2	1.1	2.1-4.7	(66.0)
8-14	A	5.4	1.4	4.1-7.3	(168.9)	2.3	0.6	1.5-2.9	(188.2)	2.1	1.0	1.2-3.4	(186.3)
15-21	J	5.1	1.8	5.3-7.0	(59.6)	2.9	1.2	1.2-3.7	(45.3)	4.3	1.4	2.4-5.6	(64.9)
15-21	A	5.0	3.7	2.5-10.4	(168.5)	3.2	0.4	2.7-3.7	(184.6)	5.3	2.4	2.0-7.7	(182.6)
22-28	J	5.3	1.4	3.5-6.5	(59.4)	2.8	0.5	2.3-3.3	(45.4)	2.8	0.6	2.1-3.5	(64.6)
22-28	A	4.1	3.1	1.6-8.6	(168.1)	2.7	1.8	1.6-5.4	(183.2)	5.4	1.2	4.5-7.1	(181.6)
		25°C											
Days	Age	<i>E. canadensis</i>			(Fish)	<i>M. spicatum</i>			(Fish)	<i>P. gramineous</i>			(Fish)
		$\bar{X}$	SD	Range		$\bar{X}$	SD	Range		$\bar{X}$	SD	Range	
0-7	J	47.1	25.2	33.2-84.8	(57.4)	12.8	2.6	10.4-16.1	(56.0)	21.1	1.0	10.8-13.2	(58.1)
0-7	A	13.2	5.5	11.1-23.1	(173.2)	13.1	4.2	7.0-16.2	(175.0)	14.3	4.1	10.8-13.2	(189.3)
8-14	J	43.4	24.4	27.5-79.6	(56.6)	18.3	5.7	13.2-21.8	(55.0)	16.8	1.6	14.7-18.5	(55.9)
8-14	A	32.7	11.2	22.5-46.9	(170.2)	16.0	1.7	15.0-17.9	(170.6)	19.4	5.8	13.1-27.0	(184.2)
15-21	J	38.6	28.9	21.1-81.7	(56.6)	16.0	4.8	10.7-21.8	(54.6)	14.1	2.7	11.7-17.8	(55.8)
15-21	A	67.4	21.1	54.5-81.3	(170.4)	30.5	4.9	25.6-36.1	(169.4)	26.6	3.0	22.4-29.3	(182.1)
22-28	J	35.2	19.4	22.5-64.0	(57.5)	15.9	3.0	12.6-19.6	(54.1)	13.0	2.4	10.4-15.2	(55.7)
22-28	A	52.2	24.8	21.4-77.3	(169.7)	17.4	1.0	16.1-18.2	(168.4)	16.2	4.5	13.1-22.8	(179.4)

rates of *Elodea* were significantly greater than for *Myriophyllum* and *Potamogeton* at 25°C ( $F_{2, 20} = 3.75$ ,  $p < 0.05$ ), but ingestion was again too variable to detect differences at 15 C.

**GROWTH OF FISH.**—Over the 35-day experiments, juvenile fish fed macrophytes exclusively lost an average of 0.5 g (SD = 0.3 g). No macrophyte used in this study supported any positive growth (weight gain) by juvenile fish (Figure 2). Less weight lost on *Elodea* ( $\bar{X} = -0.2$  g) than on *Myriophyllum* ( $\bar{X} = -0.5$  g) or *Potamogeton* ( $\bar{X} = -0.8$  g), although losses by the fish fed on different plants were not significantly different from each other ( $F_{2, 19} = 2.45$ ,  $p > 0.11$ ). The declines in juvenile fish weight throughout the one-month experiments were significant ( $F_{3, 60} = 5.11$ ,  $p < 0.001$ ),

and the patterns of decline for fish fed on various plants did not differ through time ( $F_{6, 60} = 1.30$ ,  $p > 0.26$ ; Figure 2). No differences in weight loss by juvenile fish were detected at 15°C ( $\bar{X} = -0.5$  g) or 25°C ( $\bar{X} = -0.4$  g), using two-sample t-tests, regardless of the identity of the food plant ( $t = -1.81$ ,  $p > 0.11$ ; Figure 2).

Adult fish fed exclusively on macrophytes lost an average of 3.0 g on all foods throughout the one month experiments. No macrophyte supported any positive growth by adult fish (Figure 2). Less weight was lost on *Elodea* ( $\bar{X} = -0.6$  g) than on *Myriophyllum* ( $\bar{X} = -3.3$  g) or *Potamogeton* ( $\bar{X} = -3.3$  g), although the weights lost by fish fed on the three plants were not significantly different from each other ( $F_{2, 20} = 0.16$ ,

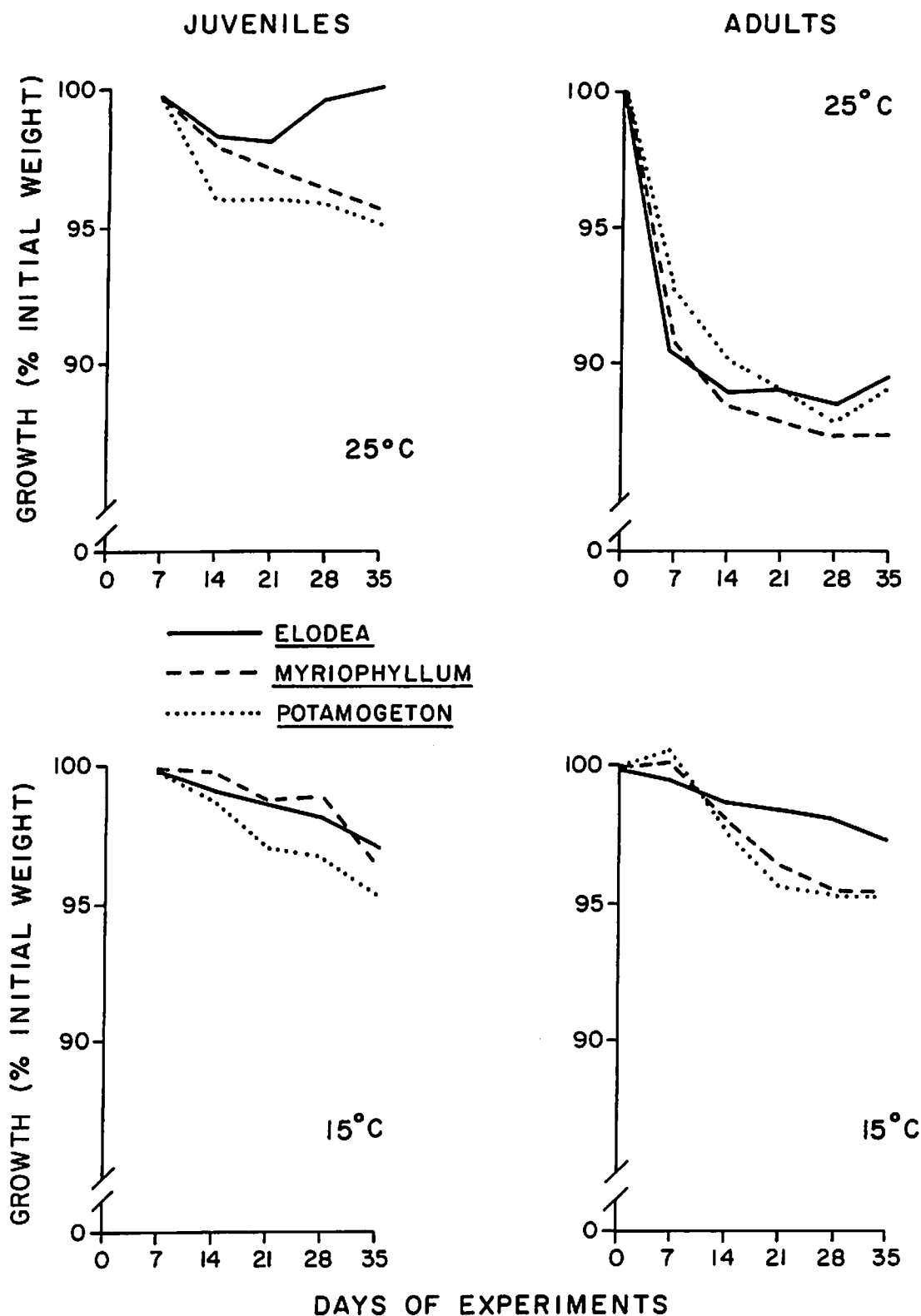


Figure 2. Growth (mean % of initial body weight) of juvenile and adult *Oreochromis aureus* during feeding experiments with three aquatic macrophytes. N = 4 in each case.

$p > 0.85$ ). There were significant changes in adult fish weight throughout the one month experiments ( $F_{8, 84} = 84.4, p < 0.001$ ).

Adult fish lost more weight at 25°C ( $\bar{X} = -4.6$  g) than at 15°C ( $\bar{X} = -1.3$  g), regardless of the plant eaten (Figure 2). However, two-sample t-tests indicate that the weight losses were not significantly different ( $t = -0.92, p > 0.36$ ).

**CONVERSION OF MACROPHYTES.**—The mean conversion efficiency for juvenile *Oreochromis aureus* fed on the three aquatic macrophytes was -0.10%. There was a slightly higher conversion efficiency for *Elodea canadensis* (-0.05%) than *Myriophyllum spicatum* (-0.08%) and *Potamogeton gramineous* (-0.18%), although the differences were not significantly different ( $F_{2, 19} = 1.40, p > 0.27$ , Figure 3). Conversion efficiencies did not change significantly through the one-month experiments ( $F_{2, 4} = 2.94, p > 0.20$ ). Also, conversion efficiencies for different plants did not differ significantly through time ( $F_{4, 40} = 0.52, p > 0.72$ , Figure 3).

Juvenile fish had higher mean conversion efficiency (-0.03%) at 25°C than at 15°C (-0.1%) for all foods (Figure 3). The pattern in mean conversion efficiency was more stable at 25°C than at 15°C for all plants.

The mean conversion efficiency for adult tilapia fed on the three aquatic macrophytes was -0.7%. Adult fish had slightly higher conversion efficiency for *Elodea* (-0.2%) than *Potamogeton* (-0.8%) and *Myriophyllum* (-1.1%), although the differences were not significantly different ( $F_{2, 20} = 1.22, p > 0.31$ , Figure 3). Conversion efficiencies for adult fish fed different macrophytes did not differ through time ( $F_{3, 63} = 1.20, p > 0.31$ ), and the patterns were identical for all three plants (Figure 3). In general, however, conversion was poorest at the beginning of the experiment and increased with time.

Adult fish, like the juveniles, also had higher conversion efficiencies (-0.1%) at 25°C than at 15°C (-1.3%) for all foods. The patterns in conversion efficiencies were more stable at 25°C than at 15°C for all plants.

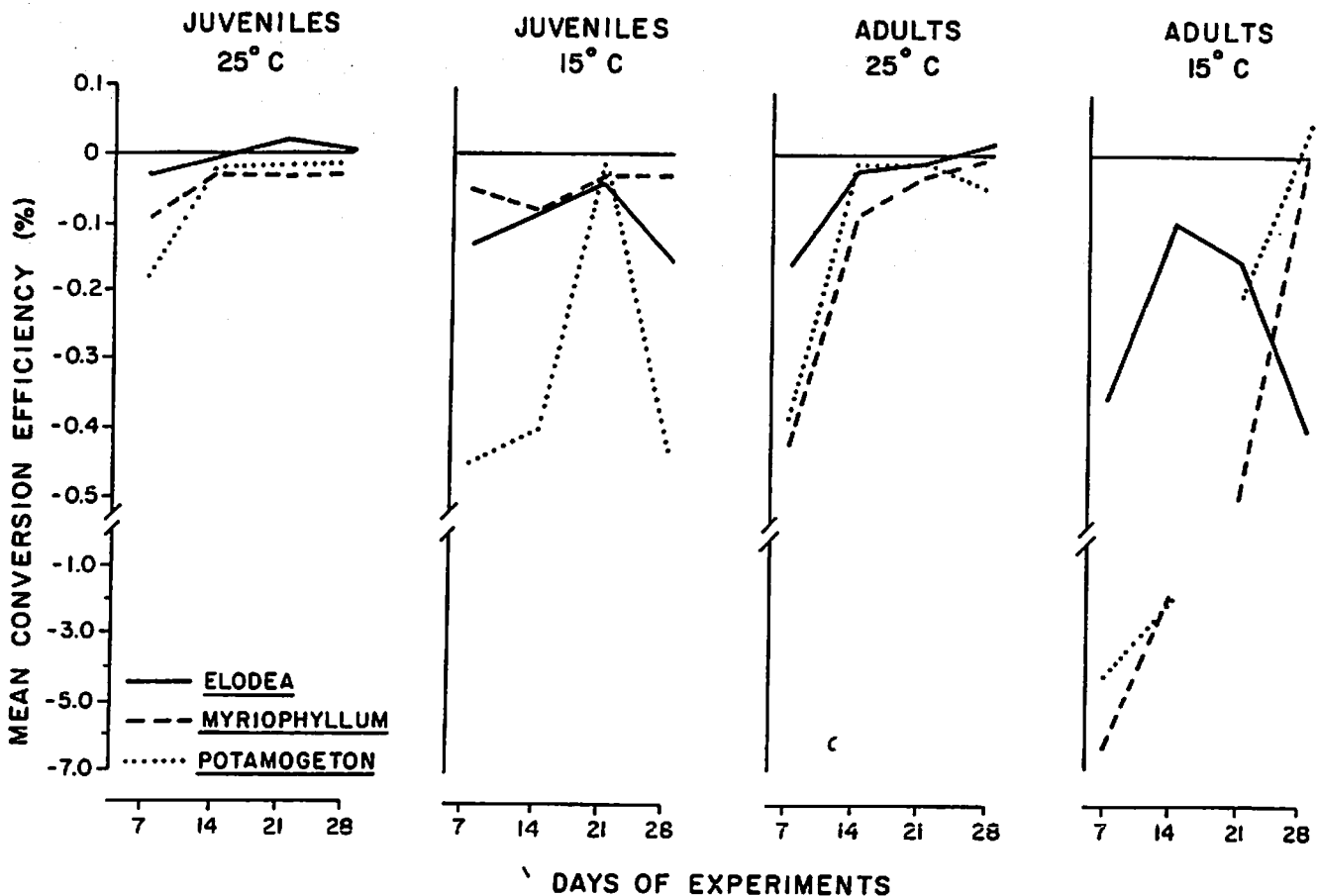


Figure 3. Conversion efficiencies (%) for three aquatic macrophytes eaten by juvenile and adult *Oreochromis aureus*.

## DISCUSSION

**FEEDING RATES ON AQUATIC MACROPHYTES.**— Since growth is generally used as the criterion for estimating dietary requirements, it is essential that food supply not be limiting. Nonetheless, many studies involve predetermined rations rather than *ad libitum* feeding. In this study, fish had food available to them throughout their daily activity period, so that ingestion was a function of fish behavior rather than experimental protocol. Juvenile and adult *Oreochromis aureus* ate more *Elodea canadensis* than *Myriophyllum spicatum* and *Potamogeton gramineus*, in that order. Legner and Murray (1981), who offered *Tilapia zillii* choices of *Hydrilla verticillata*, *Potamogeton pectinatus* and *Myriophyllum spicatum*, found that *Hydrilla* was eaten most frequently, followed by *Potamogeton*. *Myriophyllum* was generally avoided in the laboratory, and was only taken by wild fish if it was the only plant available.

Such selectivity suggests that plants differ in some aspects of palatability or quality. Boyd (1968, 1969) estimated the nutritional values of various aquatic plants in terms of protein: *Elodea*, 20.5%; *Hydrilla*, 17.5%; *Potamogeton*, 10.9%; and *Myriophyllum*, 9.8%. Due to the large quantities of refractory carbohydrates in these aquatic macrophytes (Schuette and Adler 1927, Gortner 1934, Nelson and Palmer 1938, Boyd 1968, 1969, Fischer 1973), and the fact that tilapia do not readily digest cellulose (Fish 1955, Buddington 1979), fish must ingest large quantities of plants in order to obtain sufficient nutrients for body maintenance.

Tilapia generally ingest plants with high food (protein) value (e.g. *Elodea*, *Hydrilla*), rather than those with low food value (e.g. *Potamogeton*, *Myriophyllum*; Legner and Murray 1981). Hofer and Niederholzer (1980), however, found rather contrasting results in their feeding experiments with the minnows *Rutilus rutilus* and *Scardinius erythrophthalmus* in the laboratory. The daily relative consumption of filamentous algae and mealworms, *Tenebrio molitor*, was below 8%, whereas values up to 40% were obtained when food consisted of *Chara* or *Zannichellia*. At this point, it is difficult to identify the factors which control selection of certain plants by fishes. These may include texture, nutrient composition and palatability (Buddington 1979, Horn *et al.* 1982).

In our experiments, juvenile tilapia consumed relatively more of the three plants than did adults at 25° and 15°C. In contrast Mathavan *et al.* (1976) working with *Oreochromis mossambicus* found that when the alga *Spirogyra* was fed to young fish (4–29 mg dry algae/g fish·d<sup>-1</sup>), they could not consume and utilize sufficient algae to meet their metabolic requirements.

Mathavan *et al.* (1976) also compared ingestion and growth on algal food versus high protein food (goat liver). When they supplemented algal food with goat liver, fish consumed not only more plant food (38 mg algae/g fish·d<sup>-1</sup>), but also increased their absorption efficiency to 94%. When fed on goat liver alone, the fish displayed no increase in absorption efficiency (95% over the mixed diet).

During our study, *O. aureus* lost weight on *Elodea* despite the relatively high ingestion rate of the plant. Hofer and Niederholzer (1980) also recorded loss in weight by roach and rudd on *Zannichellia* when it was fed alone, despite high ingestion of the plant by the fish.

We did not calculate exact maintenance ration, but reported the mean % BW ingested by the fish. Buddington (1979) estimated the amount of *Najas* necessary to meet maintenance requirements of *T. zillii* at 24 C in the laboratory as 10.8 g of the plant, or about 20% of the body weight. Buddington's observations indicated that the fish ingested more *Najas* than required, but he did not look at fish growth. De Moor *et al.* (1986) estimated the daily ingestion rate of food (mainly *Microcystis*) for *O. mossambicus* in nature at 453 mg/g of fish. Gerking (1984) also designed experiments to estimate the maintenance ration of *Sarpa salpa* (Sparidae), and suggested that these marine herbivorous fish could maintain their body weight by consuming *Ulva* (Chlorophyta) at a rate of 5.6–9.9% of the body weight day<sup>-1</sup>.

**GROWTH ON PLANT FOOD.**—When juvenile (30–80 g) and adult (150–220 g) *Oreochromis aureus* were fed the three aquatic macrophytes (*Elodea canadensis*, *Myriophyllum spicatum* and *Potamogeton gramineus*), all fish lost weight. If one accepts that the food quality of a given diet is directly proportional to its ability to support growth (Bowen 1982), then the three aquatic macrophytes fed to fish in the present experiments are low quality foods.

Juvenile fish lost less weight (relative to total body weight) and exhibited higher conversion efficiencies than did adults. This may indicate that juvenile fish were better utilizers of aquatic macrophytes than adults, although this result contrasts with those of the authors working with other tilapias. Hauser (1975) indicated that adult *T. zillii* may grow faster than juveniles on a vegetable diet. Growth of *T. zillii* in Hauser's experiment increased in growth rate near the end of test period, i.e. as the fish became larger. Hauser (1975) related his results to possible changes in enzyme production as fish mature. Mironova (1976) believed that reduced digestion of plants by juvenile tilapia was caused by incomplete development, and

thereby function, of the gut and the inability of small fish to utilize foods that are not usually encountered in the natural environment. A transitional size at which dietary shift occurs has been shown in other species (Hickling 1966, Montgomery 1976) and correlates with development of a fully functional digestive system (Tanaka 1972, Tanaka *et al.* 1972, Kawai and Ikeda 1973). Although a size-related change in food habits occurs in tilapia (Pandian and Raghuraman 1972, Moriarty 1973), the development of the digestive system has not been examined closely. It may be possible that small fish feed selectively on more nutritional food resources to compensate for digestive inadequacies, but this has not been fully demonstrated in nature.

**CONVERSION EFFICIENCY.**—Juvenile and adult *O. aureus* exhibited poor conversion efficiencies for all three aquatic macrophytes (*Elodea*, *Myriophyllum* and *Potamogeton*) at both temperatures. Fish of both sizes had similar conversion efficiencies at 25°C, and there were no significant differences in conversion efficiency among the three plants by either juvenile or adult fish at 25°C. The relationship between rate of conversion and rate of feeding is very important (Shell 1968). The relationship is dependent on the species of fish, size of fish, quality of food and water temperature. Shell (1968) examined the relationship between rate of feeding, rate of growth and conversion in feeding trials involving *O. mossambicus* and *O. niloticus* when high protein diets were fed at different intervals. The best conversion rates were obtained at 2% BW day<sup>-1</sup> feeding rate with *O. mossambicus* and at a 1% BW day<sup>-1</sup> feeding rate with *O. niloticus*.

**CONCLUSIONS.**—Juvenile and adult blue tilapia, *Oreochromis aureus*, ate more *Elodea canadensis* than *Myriophyllum spicatum* and *Potamogeton gramineus* at both temperatures (25°, 15°C), and thus exhibited some measure of selectivity or willingness to ingest certain plants over others. Juvenile fish consumed relatively more food than adult fish, yet lost weight on all plant diets, including *Elodea*, despite the relatively high ingestion rate of the latter plant. This may be due to (1) an inability of fish to digest plant materials or (2) relatively low nutrient levels in plant food. Fish of both sizes lost less weight on *Elodea* than on *Myriophyllum* and *Potamogeton*, demonstrating that at least *Elodea*, and probably *Myriophyllum*, provide some positive food value. Such poor performance on plant foods is not surprising, given the generally low levels of protein and lipid, and high levels of refractory carbohydrates, found within macrophytes. Nonetheless, greater attention should be given to digestive

and growth capabilities of such fishes when fed on naturally-occurring aquatic plants, for such fishes may lend themselves to simple and inexpensive culture techniques applicable where additional protein in human diets would be beneficial. Locally-available, rapidly-growing, and partially-digestible plants (like *Elodea* in our experiments) could be used in simple polyculture with tilapias, in permanent or temporary waters. Such plants would provide substrates for epiphytic algae, potentially more digestible than macrophytes, as well as food, shelter and reproductive sites for locally occurring invertebrates (insects, crustaceans). Thus, one could potentially generate simple, productive communities to support useful, if not maximal, growth of omnivorous food fishes. At present, it appears that the greatest weakness to design of such systems may be our lack of knowledge about digestibility and food quality of naturally occurring aquatic macrophytes.

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