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Food Consumption and Growth of Juvenile Arrowtooth Flounders

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ABSTRACT: Food consumption and growth of juvenile arrowtooth flounders *Atheresthes stomias* were examined in the laboratory. Weight gain, Y (in % BW/d) was related linearly to food consumption, X (in J/g/d): $Y = 0.0033X - 0.0564$; $r^2 = 0.75$ at 4°C. Fish 30 to 300 g had similar energy conversion efficiencies. When fed Pacific herring *Clupea pallasi* at 4°C, maintenance ration was estimated to be 17 J/g/d. Minimum estimates for daily ration to achieve growth rates observed in the Gulf of Alaska were approximately 3.0 to 1.0% BW/d for 1- to 4-year-old arrowtooth flounders, respectively, when fed walleye pollock *Theragra chalcogramma*. When feeding on euphausiids, the corresponding consumption rates were 6.9 and 2.4% BW/d.

INTRODUCTION

The arrowtooth flounder *Atheresthes stomias* is a common benthic fish in the Gulf of Alaska and the southeastern Bering Sea. Management agencies are interested in estimating consumption of commercially important species by these flounders (Livingston et al. 1986; Yang and Livingston 1986), but little is known about the arrowtooth flounder's energetic needs. Its primary food is other fishes, especially walleye pollock *Theragra chalcogramma*, but pandalid and crangonid shrimp and euphausiids are commonly eaten (Yang and Livingston 1986). Prey consumption has been estimated from stomach content weights for arrowtooth flounders grouped into categories of < 40 cm and > 40 cm total length (TL; Livingston et al. 1986), but no age-specific consumption estimates are available. The objective of this study was to measure the maintenance ration and energy–growth relationships of captive juvenile arrowtooth flounders to estimate consumption rate.

METHODS

Arrowtooth flounders used in all experiments were captured by hook and line during the spring of 1996 in Resurrection Bay, an embayment of the Gulf of Alaska, near Seward, Alaska. All fish were held in the laboratory for 2 months before starting the feeding trials to ensure they had recovered from capture. Experiments were done at 4.0°C (SD = 0.5), about the average temperature the species normally encounters. In the southeastern Bering Sea, bottom temperatures range from 1° to 3°C (Livingston et al. 1986), but 3° to 6°C is more common in the Gulf of Alaska (Smith et al. 1988). Photoperiod for all experiments was 9 h of light (0.5 lux) and 15 h of darkness.

For weight gain relative to food consumption studies 8 individuals were held in 100-L (fish <100 g) or 400-L tanks (fish >150 g), with one fish in a tank. Seawater exchange rate in the tanks was 100% per hour. Growth rates may change with size, so fish of various weights were included in the feeding–growth trials. Fish were anesthetized with MS 222 and weighed to the nearest gram. The fish weights ranged from 30 to 300 g. Fish were acclimated to captivity and the experimental temperature for 8 weeks before experiments were conducted. Fish were fed fillets of Pacific herring *Clupea pallasi* of known weight and energy content. One box of frozen bait herring, all captured in the same set, was the food used in feeding trials. Ten herring were selected at random for measurement of energy content. Fillets were removed, weighed wet, dried, ground, and blended. For the drying process fillets were freeze dried until no moisture was apparent.

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They were then dried in a convection oven at 60°C until the sample reached a constant weight. The energy content in calories (not adjusted for nitrogen formation) for triplicate samples from each fish was measured with an adiabatic calorimeter. Herring was used because it is a relatively high-energy food likely to produce measurable weight gains during the experiment. Herring fillets averaged 8.336 (SD = 0.3) kJ/g wet weight.

At each feeding several small pieces of fillet were weighed and placed individually on a tray with the weight of each piece noted beside it. Each fish was fed successive pieces of flesh until it was satiated. This method made it possible to know exactly the weight of food an individual consumed each meal. Fish were offered food every other day for 50 d; some were avid feeders, but others were not. Variations in individual feeding intensity provided a variety of food consumption levels. All the fish ate during the feeding trial.

Individual fish growth was calculated using the formula: $G = (\log_e W_T - \log_e W_0)$ x 100/t, where G = growth in % BW/d, W_0 = initial fish weight, W_T = final fish weight, and t = the duration of each experiment (always 50 d). Caloric consumption, in calories per gram of fish weight per day, was calculated by multiplying the summed weight of consumed food by its energy value, and dividing by 50 d and initial fish weight. The energetic equations were converted to Joules (1 cal = 4.184 J), and consumption was expressed as J/g/d.

The average weights of year classes 0–4 from the literature (Bechtol and Yuen 1995; Bouwens et al. 1999) were used to calculate growth rates of the various age classes from the instantaneous growth coefficient equation of Chapman (1978): $G_x = (\log_e W_i - \log_e W_{i-1})/365$, where G_x is the instantaneous growth coefficient, W_i is weight in the ith year, and W_{i-1} is weight in the previous year. These coefficients were expressed as growth in % BW/d. Once the food consumption–growth relationship was developed in the laboratory, it was used to estimate the energy required to achieve the growth rates predicted by Chapman's equation.

RESULTS

There was no strong relationship between fish weight and food consumption during the observation (Figure 1). Four of the fish consumed some food regularly, and 4 others ate infrequent large meals. Consumption rates ranged from 0.0006 to 0.53% BW/d. For the actively feeding fish with consumption ≥ 30 J/g/d, growth rates ranged from 0.01 to 0.1% BW/d. Weight gain (Y = % BW/d) was related to food consumption (X = J/g/d) linearly: $Y = 0.0033X - 0.0564$; $r^2 = 0.75$ at 4°C (Figure 2). The linear relationship between these variables suggests that fish weighing 30 to 300 g had similar energy conversion efficiencies. At 4°C the maintenance ration estimated from the regression equation was 17 J/g/d for arrowtooth flounders weighing 30 to 300 g (Figure 2).

Data from Bechtol and Yuen (1995) and Bouwens et al. (1999) were analyzed using the growth equation of Chapman (1978). Growth rates of arrowtooth flounders from Kachemak Bay ranged from 0.52 to 0.14% BW/d for fishes aged 1–4 years; growth was approaching an asymptotic profile by age 4 (Table 1). The estimated consumption was 160 J/g/d for 1-year-old

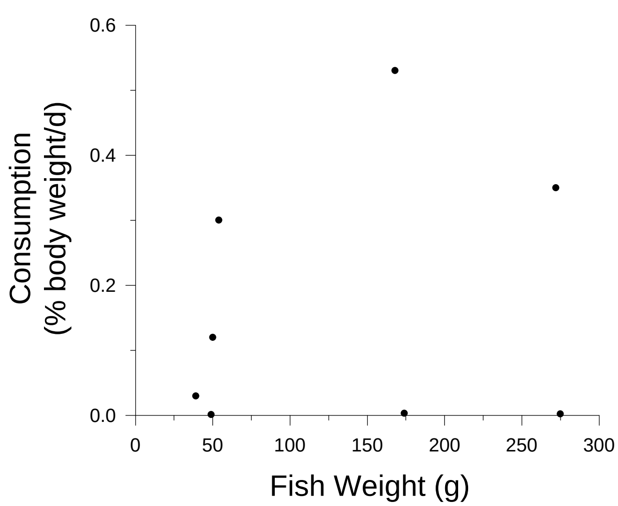

Figure 1. Consumption (% body weight/d) for arrowtooth flounders held at 4°C and fed Pacific herring fillets.

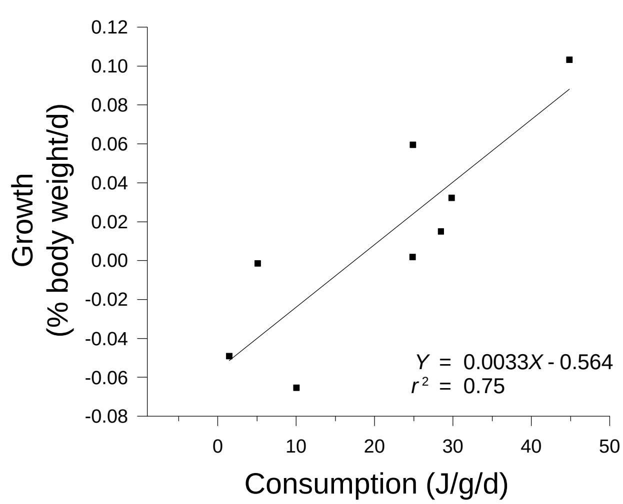

Figure 2. Growth rates (% body weight/d) for arrowtooth flounders held at 4°C and fed Pacific herring fillets.

Table 1. Ration estimates for arrowtooth flounders fed walleye pollock and euphausiids. Rations were derived using the equation in Figure 2.

Arrowtooth Flounders				Ration		
Age (years)	*n*	Growth (% BW/d)	weight (g)	J/g/d	Pollock (% BW/d)	Euphausiids (% BW/d)
0	23		3.6[a]			
1	10	0.46[a]	19[a]	160	2.7	6.2
2	17	0.52[a]	127[a]	180	3.0	7.0
3	21	0.25[b]	313[b]	93	1.6	3.7
4	26	0.14[b]	514[b]	60	1.0	2.4

[a] data from Bouwens et al. (1999).
[b] calculated from Bechtol and Yuen (1995) length-at-age and Bouwens et al. (1999) TL-to-WW regression equation.

flounders, and the comparable value for 4-year-old fish was 60 J/g/d. If they preyed on walleye pollock, with an energy content of about 5.8 kJ/g/d wet weight (Harris et al. 1986), and their maintenance ration was 17 J/g/d, the consumption rate would be 2.7% BW/d for age-1 fish and only 1.0% BW/d for 4-year-old fish. If they were eating euphausiids with an energy content of about 2.5 kJ/g/d wet weight (Paul et al. 1990a), age-1 arrowtooth flounders would need to consume 6.2% BW/d and age-4 fish 2.4% (Table 1).

DISCUSSION

Fisheries management programs are evolving toward manipulating coexisting species rather than treating each species as if it existed alone. Mapping energy flows between species is one method to quantify species interactions. Key measurements in energy flow maps are estimates for consumption and growth. In Alaska arrowtooth flounder populations are high but this low-value fish is not harvested. Thus, from a management perspective, they are currently viewed primarily as predators and prey rather than a harvestable resource. Arrowtooth flounders consume commercially important species like walleye pollock and shrimp, and compete with several other species for prey like euphausiids (Yang and Livingston 1986). Because of their abundance, these flounders must have a considerable effect on food resources, and our preliminary estimates of growth and consumption could be used to ascertain that effect within their food web.

Arrowtooth flounders proved to be difficult to capture without lethal effects. Several attempts to rear trawl-captured specimens were total failures. Even with barbless hooks, there was a high initial mortality, although fish that survived capture adapted well to captivity. Our sample size of 8 fish was small, and 4 fish did not feed on a regular basis; so the results of this laboratory feeding study must be received with caution. Thus, our estimates of growth and consumption need to be verified by other methods. Future attempts to determine consumption rates for arrowtooth flounders might consider using in situ techniques such as time-sequence measurements of stomach contents (Livingston et al. 1986) and whole body energy content (Paul et al. 1993).

The metabolic energy needs of captive juvenile arrowtooth flounders were similar to values reported for other Alaskan flatfishes. Feeding and growth experiments similar to those in this study were completed for juvenile yellowfin sole *Pleuronectes asper* at 3°C (Smith et al. 1991) and flathead sole *Hippoglossoides elassodon* at 4°C (Paul et al. 1992). With a consumption of 30 J/g/d, arrowtooth flounders (4°C), flathead sole (4°C), and yellowfin sole (3°C) would have growth rates of 0.04, 0.05, and 0.05% BW/d, respectively. Comparative studies for flatfish from Atlantic waters have been typically accomplished at temperatures above our experiment at 4°C. The maintenance ration for winter flounders *Pleuronectes americanus* at 7°C is 33 J/g/d (Tyler and Dunn 1976), nearly twice that of arrowtooth flounders at 4°C. Much of this difference probably reflects the temperature at which the measurements were taken. There are no metabolic measurements for arrowtooth flounders at different temperatures, but they exist for yellowfin sole, which have a similar maintenance ration. Oxygen consumption rates for yellowfin sole at 7°C are 160% of those at 4°C (Paul et al. 1990b). If arrowtooth flounders respond similarly to temperature changes, the maintenance ration for *P. americanus* and *A. stomias* are not markedly disparate.

The laboratory estimates of maintenance ration provide a basis for comparing the existing consumption rate estimate based on stomach-content weights (Livingston et al. 1986) with the bioenergetic needs.

At 3.0°C arrowtooth flounders < 40 cm total length (no weights specified) are estimated to feed at rates of 0.61% BW/d during the summer feeding period (Livingston et al. 1986). Our ration estimates (Table 1) suggest the average annual consumption for fishes < 3 years old is much higher, about 1–7% BW/d depending on the prey type.

Typically northern flatfishes feed intensively from spring to fall and reduce feeding in winter (MacKinnon 1972), so the annual average values for consumption rate (Table 1) do not reflect actual feeding activity in a given season. In yellowfin sole the whole body energy content changes by about 35% over the year, with a dramatic increase of 28% between mid May and mid June (Paul et al. 1993). Thus, much of the season's energy is acquired in a very short period of intense feeding. Arrowtooth flounders probably have a similar seasonal somatic energy cycle. Prey consumption estimates for any high-latitude species need to account for temporal variations in feeding intensity but can only do so if the seasonal patterns of energy use and storage are better understood. The energy content of prey species also varies with season and stage of development. Therefore, we need to acquire information on seasonal growth rates and feeding habits of arrowtooth flounders to improve our consumption estimates.

LITERATURE CITED

Bechtol, W. R., and H. Yuen. 1995. Abundance and composition of flatfish in Kachemak Bay, Alaska. Pages 497–522 *in* Proceedings of the international symposium on North Pacific flatfish. University of Alaska Fairbanks, Alaska Sea Grant Report 95-04.

Bouwens, K. A., A. J. Paul, and R. L. Smith. 1999. Growth of juvenile arrowtooth flounders from Kachemak Bay, Alaska. Alaska Fishery Research Bulletin 6(1):35–40.

Chapman, D. W. 1978. Production. Pages 202–217 *in* T. Bagenal, editor. Methods for assessment of fish production in fresh waters. International Biological Program Handbook 3, Blackwell Scientific Publications, Oxford, England.

Harris, R. K., T. Nishiyama, and A. J. Paul. 1986. Carbon, nitrogen and caloric content of eggs, larvae and juveniles of the walleye pollock, *Theragra chalcogramma*. Journal of Fish Biology 29:87–98.

Livingston, P. A., D. A. Dwyer, D. L. Wenker, M. S. Yang, and G. M. Lang. 1986. Trophic interactions of key fish species in the eastern Bering Sea. International North Pacific Fisheries Commission Bulletin 47:49–65.

MacKinnon, J. C. 1972. Summer storage of energy and its use for winter metabolism and gonad maturation in American plaice (*Hippoglossoides platessoides*). Journal of the Fisheries Research Board of Canada 29:1749–1759.

Paul, A. J., J. M. Paul, and R. L. Smith. 1990a. Energy ingestion and conversion rate in pollock (*Theragra chalcogramma)* fed different prey types. Journal du Conseil International pour l'Exploration de la Mer 46(3):232–234.

Paul, A. J., J. M. Paul, and R. L. Smith. 1990b. Rates of oxygen consumption of yellowfin sole (*Limanda aspera* (Pallas)) relative to body size, food intake, and temperature. Journal du Conseil International pour l'Exploration de la Mer 47(2):205–207.

Paul, A. J., J. M. Paul, and R. L. Smith. 1992. Energy and ration requirements of flathead sole (*Hippoglossoides elassodon* Jordan and Gilbert 1880) based on energy consumption and growth. ICES Journal of Marine Science 49(4):413–416.

Paul, A. J., J. M. Paul, and R. L. Smith. 1993. The seasonal changes in somatic energy content of Gulf of Alaska yellowfin sole, *Pleuronectes asper*. Journal of Fish Biology 43(1):131–138.

Smith, R. L., A. J. Paul, and J. M. Paul. 1988. Aspects of energetics of adult walleye pollock, *Theragra chalcogramma* (Pallas), from Alaska. Journal of Fish Biology 33(3):445–454.

Smith, R. L., A. J. Paul, and J. M. Paul. 1991. Daily ration estimates for yellowfin sole, *Limanda aspera* (Pallas), based on laboratory consumption and growth. Journal of Fish Biology 38(2):243–250.

Tyler, A. V., and R. S. Dunn. 1976. Ration, growth and measures of somatic and organ condition in relation to meal frequency in winter flounder, *Pseudopleuronectes americanus*, with hypotheses regarding population homeostasis. Journal of the Fisheries Research Board of Canada 33:63–75.

Yang, M. S., and P. A. Livingston. 1986. Food habits and diet overlap of two congeneric species *Atheresthes stomias* and *Atheresthes evermanni*, in the eastern Bering Sea. Fishery Bulletin 84(3):615–623.