

Food selection and growth of young snakehead *Channa striatus*

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Summary

Food selection and growth of young snakehead *Channa striatus* were studied in the laboratory and in a field trial. In the laboratory, first-feeding snakehead larvae of 6–7 mm total length (TL) with a mouth opening of 0.55 mm selected for *Artemia* nauplii, and against formulated feed. Fish began feeding on formulated feed at 12 mm TL when their mouth width reached 1.0 mm. In both laboratory and field trials, snakehead diets changed as fish size increased. For fish 15–20 mm TL, cladocerans and copepods were 96.5% of their diet. With fish 30–40 mm TL, zooplankton consumption was greatly reduced while benthic organism consumption increased. Fish 45–50 mm TL fed exclusively on benthic invertebrates. Diet shift from zooplankton to benthic invertebrates was not due to reduced zooplankton availability, but was instead related to changes in gill raker structure. Low density of benthic invertebrates in the field trial caused reduced fish growth rates when fish switched diets from zooplankton to benthos. Our results indicate that snakehead can take *Artemia* nauplii as a larval starter food, then accept formulated feed at ≥ 12 mm TL. Zooplankton can serve as food for snakehead < 40 mm, but formulated feed should be provided for larger fish which are unable to catch zooplankton.

Introduction

Snakeheads (genus *Channa*) are one of the best known and most successful predatory freshwater fishes in Southeast Asia (Ng and Lim 1990). They are found in rivers, canals, lakes, swamps, marshes and rice fields (Kilambi 1986). *Channa striatus* is an important food fish, produced from both pond culture and from capture fisheries (Wee 1982). In polyculture, snakehead are used to control unwanted small fish through predation (Cruz and Laudencia 1980). In monoculture, this species is cultured at very high densities made possible by their air breathing ability which allows this fish to live in waters of low oxygen tension (Singh et al. 1986).

Although considerable literature exists for snakehead on their swimming ability (Vivekanandan 1976), respiration (Singh et al. 1986), reproduction strategies (Kilambi 1986; Srivastava and Singh 1991), salinity adaptation (Woo and Tong 1982), starvation tolerance (Pandian and Vivekanandan 1976; Arul 1991), food conversion (Sampath 1985; Qin and Fast 1996), and feeding frequency (Sampath 1984), little is known about their food preferences and needs in early life. Successful larval rearing of snakehead depends on a more full understanding of diet requirements at the first-feeding, and diet requirements as fish grow.

After complete yolk-sac absorption, snakehead need small

live food such as rotifers during first-feeding (Ling 1977). Chen (1990) found that 9 mm snakehead larvae fed on rotifers, nauplii and other organisms of less than 200 μm , but Chen did not document dietary change and prey size as snakehead grew. Snakehead capture prey individually and swallow them intact (Ling 1977), thus allowing easy determination of prey type and size from stomach content analysis. The objective of our present study was to determine prey size and prey selected by snakehead during its early development. We conducted laboratory foraging trials to quantify prey selection, while at the same time we conducted an independent trial in an outdoor tank.

Materials and methods

Broodstock snakehead spawned naturally in an outdoor tank (5.5 m diameter) at the Hawaii Institute of Marine Biology during August 1994. Fish produced from this spawn provided all larval and juvenile snakehead used in this study. Different sizes and types of food were presented to snakehead larvae and juveniles (Table 1). Snakehead and their prey lengths presented here are total length (TL). Chironomid larvae and amphipods were collectively considered benthic invertebrates. Two laboratory trials were conducted to determine diet selection of young snakehead, while an outdoor tank trial was conducted to verify laboratory results. In the first laboratory trial, we provided 6–7 mm larval snakehead, which had just absorbed their yolk-sac, with two diet types: *Artemia* nauplii only, and *Artemia* nauplii plus formulated feed. This trial was conducted in 100-L plastic aquaria (50 \times 50 \times 40 cm) with three replicates per treatment. In each aquarium, 450 larval fish were stocked (4500 fish m^{-3}), and randomly assigned one of the two feeding treatments. Live *Artemia* nauplii were offered daily at about 500 nauplii per fish, while the daily ration of formulated feed

Table 1
 Mean total lengths with ranges of prey species and prepared feed presented to snakehead (*Channa striatus*) in the laboratory rearing trials

Prey	Lengths (mm)	
	Mean	range
Rotifers	0.14	0.10–0.21
Cladocerans	0.50	0.32–0.65
Copepods	0.85	0.30–1.20
Copepod nauplii	0.22	0.18–0.35
<i>Artemia</i> nauplii	0.35	0.30–0.37
Chironomid larvae	6.10	3.50–9.50
Amphipods	6.50	4.50–8.60
Prepared feed ¹	0.69	0.40–1.10

¹ Trout and salmon starter feed No. 1, Rangen Inc., Idaho, USA

was 20 mg per fish. *Artemia* nauplii were offered three times a day at 0800, 1200 and 1700 h, while formulated feed was offered at 1.5 h intervals using automatic feeders. Fish were sampled every 3–4 days for size evaluation. Gill raker length, space between gill rakers, mouth width, and fish TL measurements were used to develop regression equations with these variables. Mouth width was the widest distance across the mouth opening, when the mouth was closed. Trial 1 lasted 35 days with water temperatures of 24–25 °C. Illumination was by fluorescent lights on the ceiling, providing 400–500 lux of light at the water surface. Aquaria were cleaned daily and water exchange was 2–3 times per day.

In the second laboratory trial, a variety of prey species was provided to three fish size groups: 15–20 mm, 30–40 mm, and 45–50 mm. Prey were collected from a freshwater fish pond with a plankton net (60 µm mesh openings). All prey were combined in a 100 l L container from which 4 L of thoroughly mixed water with prey was put into each of nine, 5-L jars. Before and after the feed selection trial, food organisms in jar water were counted using a plankton counting chamber at 200x magnification. Initial densities of cladocerans, copepods, copepoda nauplii, rotifers, benthic invertebrates were 178, 984, 366, 397, 100, and 118 L⁻¹, respectively. Initial prey composition and quantity were assumed similar in each jar. Before starting the trial, all fish were starved for 24 h. Five fish were placed into each jar with three jar replicates for each fish size group. The trial was completed after 24 h at 25 °C and stomach contents of all fish were examined.

Food selection by fish was further evaluated in an outdoor tank (5.5 m diameter; 0.8 m deep), in which larval snakehead (9.0 mm) were stocked at 40 fish m⁻³. The tank was inoculated with zooplankton and benthic invertebrates one week before fish stocking, and fertilized weekly with a commercial fertilizer (N:P = 16:16) at 5.0 mg L⁻¹. The trial started on September 9, 1994 and lasted 35 days. Water temperature was 24–26 °C during the trial. Fish growth and stomach contents were analyzed every 3–4 days. Zooplankton (cladocerans, copepods, copepoda nauplii, and rotifers) and benthic invertebrates (amphipods and chironomids) were collected from four locations in the tank on the same days as fish collection and preserved in 10% formalin. Prey species compositions in the tank and in fish stomachs were quantified using a dissecting microscope at 50–200x magnification. Fish electivity index (ϵ) for each prey was calculated as follows (Chesson 1983):

$$\epsilon_i = \frac{m\alpha_i - 1}{(m-2)\alpha_i + 1}, \quad i = 1, \dots, m$$

Where: ϵ_i is the electivity index for species i ; α_i is the preference for prey type i ; and m is the number of prey taxa. Values of ϵ ranges from -1 to +1, where -1 indicates absence of prey in the stomach. Negative ϵ -values indicate avoidance of those prey types. Positive ϵ -values suggest active selection for these prey types, and zero indicates random selection. Each α_i was calculated as follows (Chesson 1983):

$$\alpha_i = \frac{r_i/n_i}{\sum_{j=1}^m r_j/n_j}, \quad i = 1, \dots, m$$

Where the r_i and n_i are the proportion of prey type i (by number) in fish stomach contents and the tank, respectively.

Wet weights were measured to the nearest 0.01 g, and TL was measured to the nearest 0.1 mm. Fish condition factor (K) was calculated as a function of wet weight (W , g) and TL (L , cm),

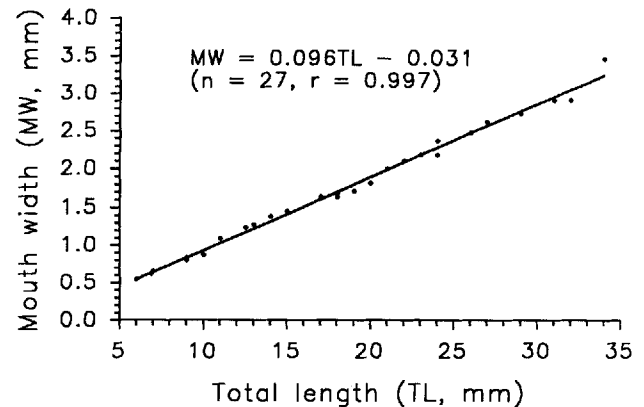


Fig. 1. Relationship between snakehead (*Channa striatus*) mouth width (MW, mm) and fish body total length (TL, mm)

where $K = (W L^{-3}) \times 10^5$ (Anderson and Gutreuter 1983). Instantaneous growth rate (b) was estimated as follows: $b = (\ln W_2 - \ln W_1) / (t_2 - t_1)$. Where, W_1 and W_2 are fish wet weights (g) at times t_1 and t_2 (day), respectively.

Results

Average mouth width of snakehead at first-feeding was 0.55 mm. Mouth width increased linearly with body length (Fig. 1). Gill rakers were short, and their lengths (RL, µm) were not linearly related with fish TL (Fig. 2). Spaces between gill rakers (RS, µm) were also non-linearly related to fish TL (Fig. 2). Gill raker structure and spacing made it difficult for large snakehead to catch small prey.

In our first laboratory food selection trial, first-feeding snakehead larvae consumed only *Artemia* nauplii. After making visual contact with a food item, larvae oriented towards it, bringing it into the visual field of both eyes. Next, larvae slowly approached the particle to within 1–2 mm, at which point they either rejected it and swam away, or swallowed it. *Artemia* consumption by fish < 12 mm was not affected by provision of formulated feed ($P > 0.10$; Fig. 3). Formulated feed consumption began 12 days after yolk absorption, when fish were ≥ 12 mm, with a mouth width of 1.0 mm. At this time the amount of *Artemia* nauplii consumption was reduced in fish provided with both *Artemia* and formulated feed, compared with fish provided with *Artemia* nauplii only ($P < 0.01$). Formulated feed gradually replaced *Artemia* nauplii in fish stomach

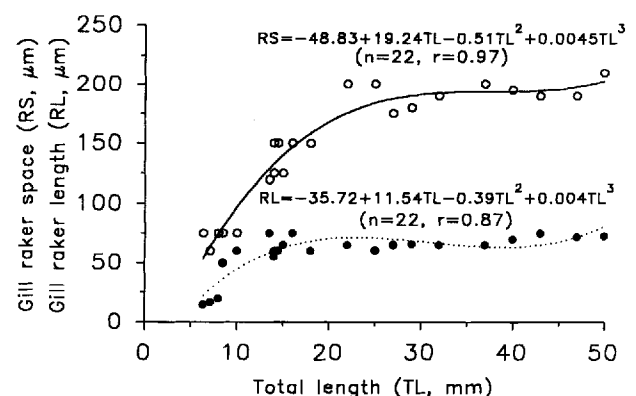


Fig. 2. Relationships of snakehead gill raker length (RL, µm), space between gill rakers (RS, µm), and fish total length (TL, mm)

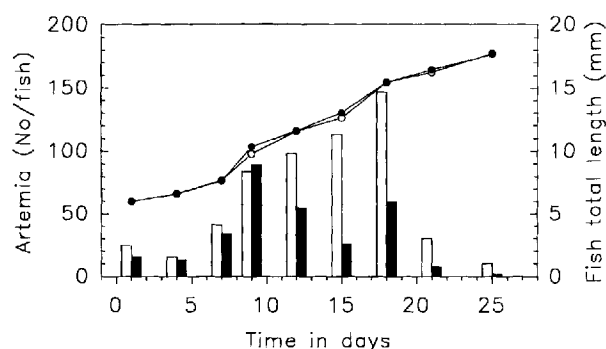


Fig. 3. *Artemia* nauplii consumption by snakehead, and fish total length during the first laboratory feeding trial. Line graphs represent fish lengths, while bar graphs represent number of *Artemia* consumed. Open bars and open circles represent *Artemia* only treatment; while filled bars and circles represent *Artemia* plus formulated feed treatment

contents, while *Artemia* nauplii consumption substantially decreased after 21 days when fish reached 16 mm.

In our second laboratory food selection trial, snakehead diet changed as fish size increased (Fig. 4). For fish of 15–20 mm, cladocerans and copepods were 96.5% of total food consumed,

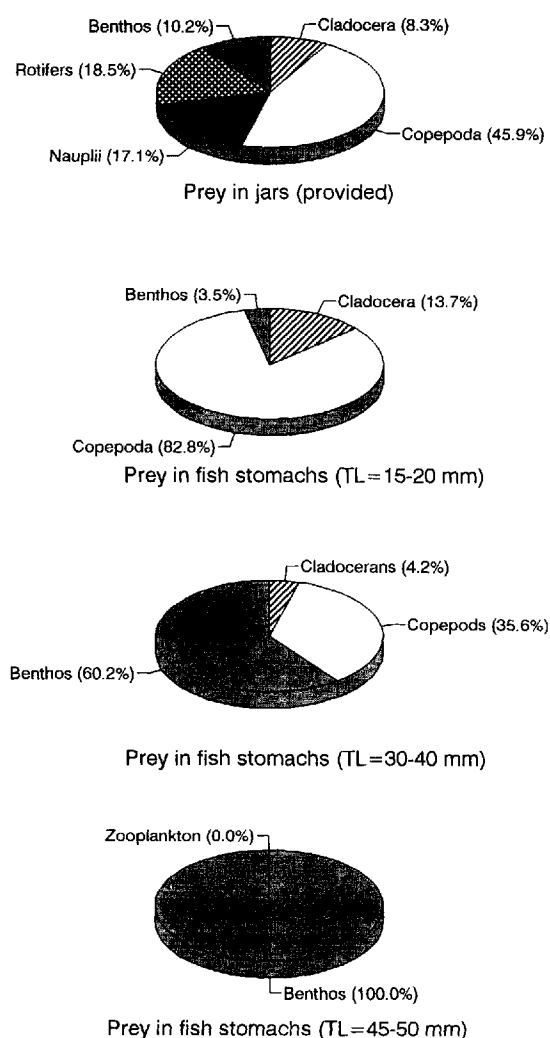


Fig. 4. Prey compositions in rearing jars and fish stomach contents for different sizes of *Channa striatus*. Three fish sizes were: 15–20, 30–40, and 45–50 mm (TL)

however, for fish of 30–40 mm, cladocerans, and copepods were 4.2%, and 35.8%, respectively, while benthic invertebrates were 60.2% of food consumed. Fish 45–50 mm fed exclusively on benthic invertebrates. Although rotifers and copepod nauplii were present in large number, they were not consumed by snakehead of the sizes we evaluated. Food selectivity indices clearly indicated that fish of 15–20 mm selected for cladocerans and copepods, but selected against rotifers, copepod nauplii and benthic invertebrates (Table 2). As fish grew, however, they selected for benthic invertebrates and against rotifers, nauplii, cladocerans and copepods.

Cladocerans and copepods dominated the prey community in the outdoor tank, while copepod nauplii, rotifers and benthic invertebrates were less abundant (Fig. 5). With fish ≤ 35 mm, cladocerans and copepods contributed more than 70% of prey consumed (by number), while benthic invertebrates accounted for less than 30%. The amount of benthic invertebrates in fish stomachs dramatically increased after fish exceeding 35 mm, and accounted for 100% of stomach contents by the time fish reached 43.5 mm. Copepod nauplii accounted for only a small percentage of food consumed at beginning, while no rotifers were found in any fish stomachs even though rotifers were abundant in the tank. In the outdoor tank trial, fish gained both length and weight rapidly during the first 17 days after

Table 2
Prey electivity indices (e) for different sized snakehead (*Channa striatus*) in the jar feeding trials

Prey species	Fish total length (mm)		
	15–20	30–40	45–50
Rotifers	–1.00	–1.00	–1.00
Copepod nauplii	–1.00	–1.00	–1.00
Copepods	0.57	–0.35	–1.00
Cladocerans	0.51	–0.53	–1.00
Benthic invertebrates	–0.43	0.89	1.00

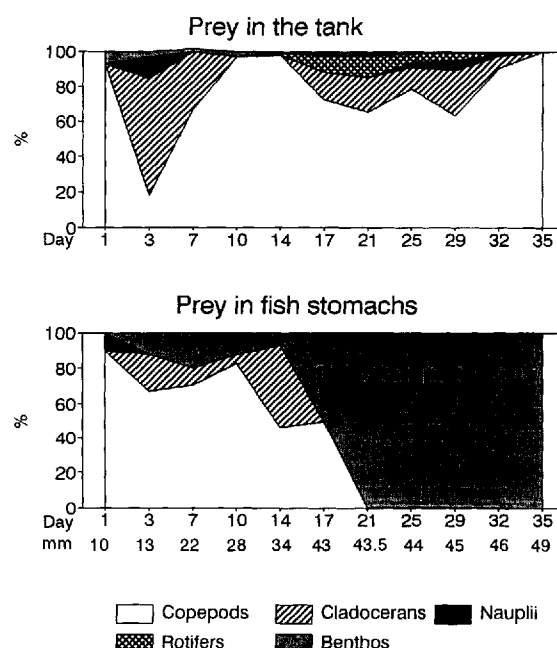


Fig. 5. Prey compositions in the outdoor tank and in snakehead stomachs. The scale on the first line under the abscissa represents time in days, while the scale on the second line refers to fish length (TL, mm)

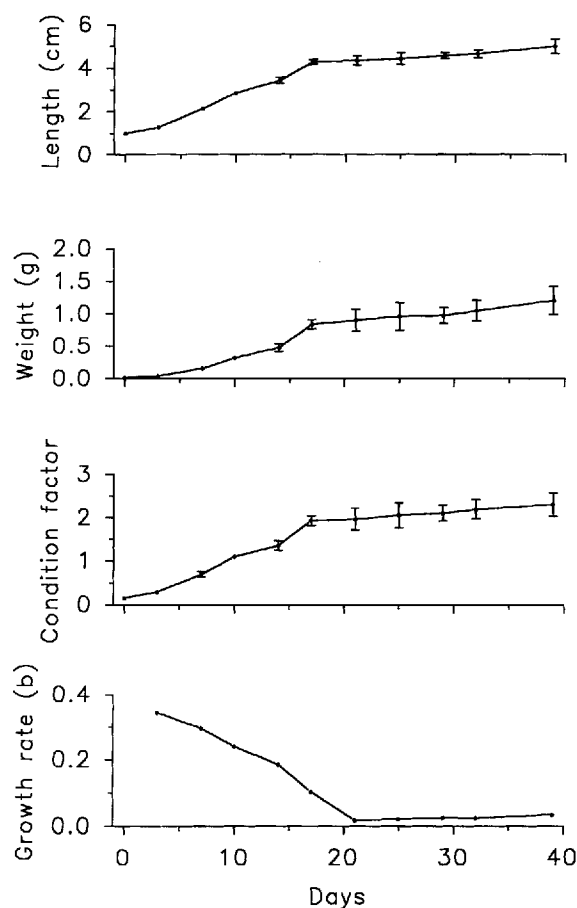


Fig. 6. Total length, wet weight, condition factor (K) and instantaneous growth rate (b) of snakehead fish in the outdoor tank trial. Vertical bars are ± 1 SE ($n = 20$)

stocking (Fig. 6). Instantaneous growth rate (b) declined with increased fish size, and remained at a very low level after 21 days. Condition factor (K) increased quickly through day 17, but increased slightly thereafter.

Discussion

Feeding limitations occur in many fish larvae related to mouth size and gill raker spacing (Wankowski 1979). In our first laboratory trial, snakehead larvae at first-feeding initially selected only *Artemia* nauplii (0.35 mm in size), and did not consume formulated diet until their length exceeded 12 mm. Mouth width of 0.55 mm at first-feeding apparently limited snakehead access to formulated diet (0.69 mm in particle size). Malhotra and Munshi (1985) found that formulated feed might also be physically unsuitable for most first-feeding fish larvae because large food particles that did not pass down the gut could subject larvae to physical or physiological stress. Twelve days after yolk-sac absorption in our trial, when fish length exceeded 12 mm, formulated feed was consumed. As fish grew, the amount of *Artemia* consumed was reduced, while formulated feed increased in the treatment with both *Artemia* and formulated feed offered. After reaching 15 mm, *Artemia* consumption was significantly reduced, indicating that fish preferred larger food particles to *Artemia* nauplii. These results suggest that *Artemia* nauplii should be provided to first-feeding snakehead as a starter food, and formulated feed should be provided when fish approach 12 mm. Our food selectivity trials

in the tank and jars clearly showed that fish of 15–20 mm fed mainly on copepods and cladocerans, while no copepod nauplii and rotifers were consumed even though nauplii and rotifers were abundant (35.6% by number). Our observations on feeding behaviour from the time of first-feeding showed that snakeheads are selective 'strike' feeders similar to walleyes, *Stizostedion vitreum* (Mathias and Li 1982). Snakehead feeding success depends upon vision, its ability to pursue and catch prey, as well as on the ability of prey to escape. Laboratory feeding trials showed that snakehead ability to eat *Artemia* nauplii (0.35 mm in size) declined when fish exceeded 15 mm, which was similar to our tank trial result that fish did not consume copepod nauplii (0.22 mm) after fish reached 13 mm. Fish larvae usually change feeding strategies as they grow, such as eating more or larger prey, and eating different prey (Hartman 1983). These strategies are presumably intended to provide optimal nutrients while minimizing energy expenditures, but they may also be obligatory in some cases due to changes in mouth morphology. As snakehead grew from postlarvae to juveniles, we found that their prey-capture ability became more acute and they shifted from smaller, slow moving prey to larger, faster organisms. By comparison, yellow perch, *Perca flavescens*, usually switch from feeding on zooplankton to feeding mainly on benthic prey during periods of zooplankton decline (Wu and Culver 1992). Unlike yellow perch, snakehead switched from zooplankton to other benthic invertebrate even though zooplankton was still abundant. In the laboratory, we demonstrated that snakehead > 45 mm exclusively fed on benthic invertebrates despite abundant zooplankton. Our tank results demonstrated that snakehead switched from feeding mainly on zooplankton to feeding solely on benthic invertebrates when fish were > 43.5 mm. In both cases, food shifts were not associated with reduced zooplankton abundance. This diet shift can be explained by increases in gill raker spacing and short gill rakers. These changes in gill raker morphology as snakehead grew make it difficult, if not impossible, for large fish to capture small prey.

Significance of diet shift in a trophic niche is related to productivity at each trophic level of the food chain. Fish growth rate is generally related to availability and density of optimal food (Mittelbach 1981). For example, growth of yellow perch in natural lakes was reduced when they shifted from eating zooplankton to benthic organisms which were less abundant after zooplankton populations diminished (Wu and Culver 1992). On the other hand, due to greater abundance of benthic organisms in fertilized ponds, walleye growth increased after they switched their diets from zooplankton to chironomids (Fox et al. 1989). In our study, snakehead growth in the tank could be explained by prey abundance in the tank and prey compositions in the fish's diet. Snakehead growth rate was greatly reduced when they consumed mostly benthic organisms. This reduced growth rate of snakehead was obviously due to an insufficient supply of benthic invertebrates in the tank, and their apparent inability to switch back to a mainly zooplankton diet (Fig. 5). In natural conditions, stunted growth may extend the period of vulnerability to other predators and reduce recruitment, while in aquaculture settings, formulated feed application can be increased to meet diet needs.

Our combined laboratory and field results showed that snakehead selected for small prey such as nauplii until 13–15 mm, and their diet shifted from zooplankton to benthic prey by fish size 40–45 mm. These shifts relate to short gill raker length and large spaces between gill rakers as fish grew. In nursery culture of snakehead, *Artemia* nauplii could be used as a starter feed in

indoor tank culture, and formulated feed should be introduced when fish reach 12 mm. In outdoor pond culture, zooplankton can serve as food for snakehead < 40 mm, but formulated feed should be provided when fish exceed 40 mm.

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