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Population growth, trophic level, and reproductive biology of two congeneric archer fishes (*Toxotes chatareus*, Hamilton 1822 and *Toxotes jaculatrix*, Pallas 1767) inhabiting Malaysian coastal waters*

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Abstract: Population growth, trophic level, and some aspects of reproductive biology of two congeneric archer fish species, *Toxotes chatareus* and *Toxotes jaculatrix*, collected from Johor coastal waters, Malaysia, were studied. Growth pattern by length-weight relationship ($W=aL^b$) for the sexes differed, and exhibited positive allometric growth (male, female and combined sexes of *T. chatareus*; female and combined sexes of *T. jaculatrix*) and isometric growth (male samples of *T. jaculatrix* only). Trophic levels of both species were analyzed based on 128 specimens. The results show that, in both species, crustaceans and insects were the most abundant prey items, and among crustaceans the red clawed crab *Sesarma bidens* and Formicidae family insects were the most represented taxa. The estimated mean trophic levels for *T. chatareus* and *T. jaculatrix* were 3.422±0.009 and 3.420±0.020, respectively, indicating that they are largely carnivores. Fecundity of *T. chatareus* ranged from 38354 to 147185 eggs for females with total length ranging from 14.5 to 22.5 cm and total body weight from 48.7 to 270.2 g, and *T. jaculatrix* 25251 to 150456 eggs for females with total length ranging from 12.2 to 23.0 cm and total body weight from 25.7 to 275.0 g. Differences in values of gonadosomatic and hepatosomatic indexes calculated for both species in this study may have resulted from uneven sample size ranges.

Key words: Archer fish, Toxotidae, Mangrove, Estuary, Predator, Growth, Reproduction
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INTRODUCTION

Seven species in the genus *Toxotes* are commonly referred to as archer fishes (Allen, 2004). They live mainly in the brackish water of mangrove-lined estuaries (Allen, 1978; 2001). These fishes are relatively scarce, swim fast, and have sharp eye vision (Blaber, 2000), which makes collecting specimens with nets in the complex root network of mangrove forests challenging. Therefore, it is not surprising that little is known about the biology and ecology of these fascinating fishes.

Recently, we have reported the length-weight and length-length relationships of archer fishes (combined sex) (Simon and Mazlan, 2008). However, length-weight relationship (LWR) of archer fishes within and between sexes is still lacking. The relationship between length and weight of fish species is important and it is extensively used for: (1) estimation of weight from length due to technical difficulties and

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the amount of time required to record weight in the field (Kolher *et al*., 1995); (2) conversion of growth in length equations to growth in weight for use in stock assessment models (Stergiou and Moutopoulos, 2001; Özaydin and Taskavak, 2007); (3) estimation of the biomass from length observations (Anderson and Gutreuter, 1983; Petrakis and Stergiou, 1995); and (4) estimation of condition factors of the aquatic species (Petrakis and Stergiou, 1995).

The quality and quantity of food are among the most important exogenous factors directly affecting growth and, indirectly, maturation and mortality in fish, thus being ultimately related to fitness (Wootton, 1990). Traditionally, information on the quality and quantity of food consumed by fish can be derived from feeding studies (Jennings *et al*., 2001). Diet composition data are also used for the estimation of trophic levels (Pauly and Christensen, 2000; Pauly and Sa-a, 2000), which is very important for the management of aquatic resources. Despite the key role of trophic levels for fisheries and ecosystem research, up to now the position (trophic level) of archer fish in the food web has never been studied in Malaysia or elsewhere.

Apart from length-weight relationship and trophic level, assessments of fecundity, gonadosomatic index and hepatosomatic index are fundamental indexes in the study of the biology and population dynamics of fish (Hunter *et al*., 1992). Published information on archer fish reproductive biology is scarce. There exist only the reports on the fecundity and egg size of *T. chatareus* (Pethiyagoda, 1991).

Therefore, the aims of this study were to measure some important biological features, e.g., population growth pattern, trophic level, gonadosomatic index, hepatosomatic index, and fecundity, of *T. chatareus* and *T. jaculatrix*, two congeneric archer fishes collected from Malaysia's Johor coastal waters.

MATERIALS AND METHODS

Field sampling and laboratory preparation

Sampling was carried out in the coastal waters of Johor (01°24′53″ N; 104°09′44″ E), the southern part of Peninsular Malaysia, from August 2007 to November 2008. A total of 350 fish (*T. chatareus*, n=145, 35 females and 110 males; *T. jaculatrix*, n=205, 63 females and 142 males) were collected using three-layered trammel net, cast net, scoop net, and trap. The gear was set up randomly throughout the study areas. The mesh sizes (stretched length) of the trammel and cast nets were 4.2, 6.5, 7.5, and 2.0 cm. Mesh size of the scoop net was 1.5 cm. The length of the net was 20 m for trammel net, 250 cm for the cast net, and 40 cm for the scoop net. The size of the trap was 80 cm×80 cm×90 cm (length×width×depth). The mesh size of the net used in the trap was 1 cm^2. Specimen identification was carried out in the field according to the description given by Allen (2001; 2004).

Several individuals of varying sizes were saved for diet studies. In order to prevent further digestion and decomposition of the content, the preservative (4% (w/v) formaldehyde) was injected into fish's body cavity soon after weight measurement.

Length-weight relationship

Population growth of the two species of archer fish was estimated based on the length-weight relationship analysis. In the laboratory, specimens were sorted by sex, measured to the nearest 1 cm (total length), and weighed to the nearest 0.1 g (weight). Total length of individual fish was taken from the tip of the upper jaw to the tip of the caudal fin. The relationship between the length and weight of a fish is usually expressed by the equation $W=aL^b$ (Ricker, 1973), where W is body weight (g), L is total length (cm), a is the intercept, and b is the slope (fish growth rate) (Beverton and Holt, 1996). Determination of a and b values was done using a non-linear regression for which curve fitting was carried out by a non-linear iterative method using Levenberg-Marquardt and Simplex algorithms for obtaining best convergence χ^2 goodness of fit values using a computer programme, Microcal Origin™ Version 6.0 (Simon and Mazlan, 2008). The degree of adjustment of the model studied was assessed by the correlation coefficient (r^2). A t-test was performed to test whether the computed value of b was significantly different from 3.0, indicating the type of growth: isometric (b=3.0), positive allometric (b>3.0), or negative allometric (b<3.0) (Spiegel, 1991). In all cases a statistic significance of 5% was adopted.

Stomach content and trophic level analysis

In the laboratory, the digestive tract was removed and fixed in 70% (v/v) ethanol to provide further and longer preservation in the museum. Diet estimation was achieved by analyses of stomach contents from pre-selected samples (63 *T. chatareus* and 65 *T. jaculatrix*). Stomach fullness was determined according to Joyce *et al.*(2002). Stomach contents were analyzed under the microscope and quantified in accordance with occurrence method (Hyslop, 1980; Gunn and Milward, 1985). Frequency of occurrence (f_o) and percentage weight (wt%) were examined for different length classes.

Finally, diet composition data were also used for the estimation of the trophic levels of *T. chatareus* and *T. jaculatrix*. Trophic level (*TROPH*) expresses the position of organisms within the food webs that largely define aquatic ecosystems (Pauly and Christensen, 1995; 2000; Pauly *et al*., 1995; 1998; Pauly and Palomares, 2000). *TROPH* value was calculated from the dataset using TrophLab (Pauly *et al*., 2000), which is a stand-alone application for estimating *TROPH* and its standard error (*SE*) using the weight or volume contribution and the trophic level of each prey species to the diet (Pauly *et al*., 2001). Real consumers do not usually have *TROPHs* with integer values and the definition of *TROPH* for any consumer species *i* is:

$$TROPH_i = 1 + \sum_{j=1}^{G} DC_{ij} \times TROPH_j,$$

where $TROPH_j$ is the fractional trophic level of prey *j*, DC_{ij} represents the fraction of *j* in the diet of *i*, and *G* is the total number of prey species. Thus defined, the trophic level of aquatic consumers is a measurable entity that can take any value between 2.0 for herbivorous/detrivorous and 5.0 for piscivorous/carnivorous organisms (Pauly *et al*., 1998; Pauly and Palomares, 2000).

Reproductive biology

Each fish was dissected, and the gonad and liver were removed and weighed (wet weight) to the nearest gram. Fecundity, considered as the total number of oocytes present in mature gonad (ripe), was estimated from 49 females (12 *T. chatareus* and 37 *T. jaculatrix*). Briefly, after fixing in formalin, the gonads were carefully dissected and weighed to the nearest 0.1 g. Sub-samples were taken from three different locations of each ovary: near the base, mid part, and apical part, and were weighed to the nearest 0.01 g. Oocytes were loosened from the trabeculae and counted, and the total number of oocytes in the ovary was calculated and is reported here as fecundity (Clavier, 1992). The gonadosomatic index (*GSI*) was calculated as $GSI=(GW/BW)\times100\%$, where *GW* is gonad wet weight (g), and *BW* is body wet weight (g) (excluding gonad weight). The hepatosomatic index (*HSI*) was calculated as $HSI=(LW/BW)\times100\%$, where *LW* is liver wet weight (g) (Mazlan and Rohaya, 2008).

RESULTS

Length-weight relationship

Length-weight relationship was derived from 145 *T. chatareus* and 205 *T. jaculatrix* samples. The *T. chatareus* samples ranged from 9.8 to 22.5 cm in total length and 17.2 to 270.2 g in total body weight for females, and 8.5 to 20.0 cm in total length and 12.0 to 180.2 g in total body weight for males; and the *T. jaculatrix* samples ranged from 8.7 to 23.0 cm in total length and 13.4 to 275.0 g in total body weight for females, and 8.5 to 19.0 cm in total length and 12.0 to 142.8 g in total body weight for males. The intercept *a* for combined sexes of *T. chatareus* and *T. jaculatrix* was 0.007 and 0.012, and correlation coefficient r^2 was 0.971 and 0.959 (Fig.1). Intercept *a* for male *T. chatareus* was 0.01 and for female was 0.005 and correlation coefficient r^2 for male was 0.969 and for female was 0.970, while in *T. jaculatrix* intercept *a* was 0.015 for male and 0.007 for female and coefficient correlation r^2 was 0.958 for male and 0.950 for female (Fig.2). The values of the slope or exponent *b* for males (3.246), females (3.465), and combined sexes (3.353) were significantly ($P<0.05$) higher than 3, exhibiting a positive allometric growth for *T. chatareus*, whereas the exponent *b* value for male (3.076) was close to 3.0 ($P>0.05$), showing isometric growth pattern (i.e., changing the body form following the cube law (volume=L^3)) for *T. jaculatrix*. In contrast, the estimated *b* values for female (3.310) and combined sexes (3.160) were significantly ($P<0.05$) higher than 3 and therefore exhibited a positive allometric growth for *T. jaculatrix*, indicating that weight increases faster than length (Figs.1 and 2b).

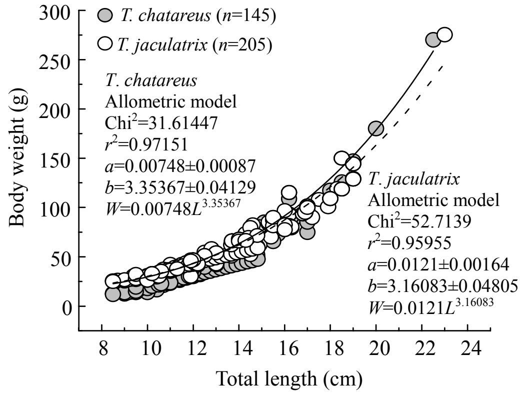

Fig.1 Length-weight relationships of *T. chatareus* and *T. jaculatrix* (combined sex)

Solid regression line represents non-linear fit of *T. chatareus* and dashed regression line represents non-linear fit of *T. jaculatrix*

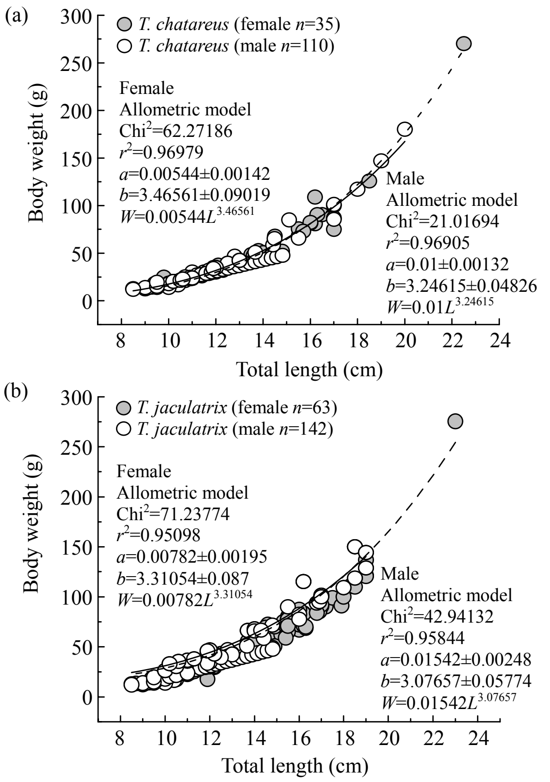

Fig.2 Length-weight relationships between sexes of (a) *T. chatareus* and (b) *T. jaculatrix*

Solid regression line represents non-linear fit of male specimens in both species and dashed regression line represents non-linear fit of female specimens

Stomach content and trophic level

The stomachs of 63 *T. chatareus* samples were examined, and 8% were found empty and 92% contained food items, whereas in 65 *T. jaculatrix* stomachs 11% were empty and 89% contained food items. A total of 2 crustaceans (crab and shrimp), 4 different insect families, and 1 teleost species were identified (Table 1 and Fig.3). After grouping all food items into three categories, crustaceans in particular with the red clawed crab (*Sesarma bidens*) (70%, 67%) were the main prey items observed in both *T. chatareus* and *T. jaculatrix*, followed by insects (namely Formicidae 12%, 13%; Dytiscidae 5%, 6%; Araneidae 3%, 5%; and Cerambycidae 3%, 3%). *Penaeus* sp. occurred in 3% and 2% in *T. chatareus* and *T. jaculatrix* stomachs, respectively. Teleost (*Toxotes* sp.) constituted a tiny proportion of diet (5%) in *T. jaculatrix* while it was not found in *T. chatareus* stomachs (Table 1 and Fig.4). Crustaceans formed the majority of the diet, 73% (f_o=92) and 69% (f_o=89) by weight, followed by insects 23% (f_o=87) and 26% (f_o=69) in *T. chatareus* and *T. jaculatrix*, respectively (Table 1).

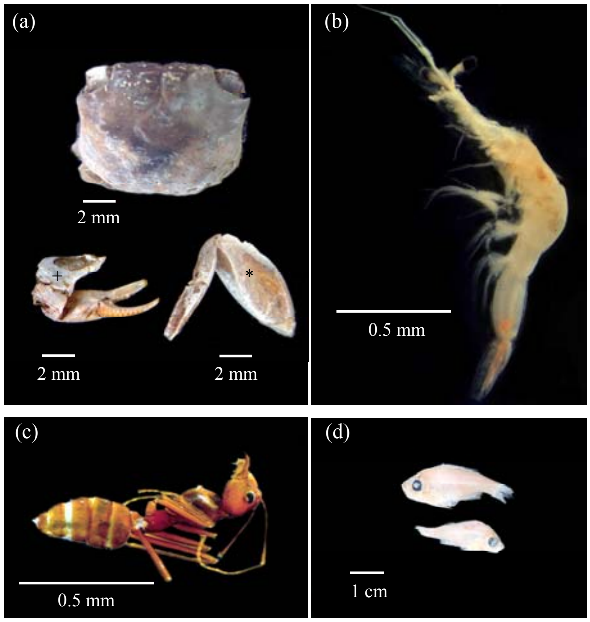

Fig.3 Major food items ingested by two archer fishes *T. chatareus* and *T. jaculatrix* collected from Johor coastal waters, Malaysia

(a) Crab. Plus sign indicates chelate leg and asterisk indicates non-chelate leg; (b) Shrimp; (c) Insect; (d) Teleosts

The estimated trophic levels ranged from 3.230 to 3.590 with mean value of (3.422±0.009) for *T. chatareus* and from 3.24 to 4.39 and mean value of (3.420±0.020) for *T. jaculatrix* (Fig.5). Trophic levels in both species gradually increased with size (Fig.5).

Table 1 Prey items observed in 128 archer fish (63 *T. chatareus* and 65 *T. jaculatrix*) stomachs from Johor, Malaysia, were grouped by major prey categories

Species	Prey category	*N*	*W* (g)	wt%	*n*	f_o	*w* (g)
T. chatareus	Crustaceans	175	46	73	58	92	0.73
	Crab (*S. bidens*)	151	44	70	48	76	0.69
	Shrimp (*Penaeus* sp.)	24	2	3	10	16	0.03
	Insects	328	14	23	55	87	0.22
	Formicidae	153	7	12	29	46	0.11
	Dytiscidae	73	3	5	16	25	0.05
	Araneidae	57	2	3	6	10	0.03
	Cerambycidae	45	2	3	4	6	0.03
	Teleosts	0	0	0	0	0	0.00
	Total	503	60	96			0.95
T. jaculatrix	Crustaceans	184	27	69	58	89	0.42
	Crab (*S. bidens*)	156	26	67	50	77	0.40
	Shrimp (*Penaeus* sp.)	28	1	2	8	12	0.02
	Insects	205	10	26	45	69	0.15
	Formicidae	97	5	13	25	38	0.08
	Dytiscidae	51	2	6	10	15	0.03
	Araneidae	43	2	5	6	9	0.03
	Cerambycidae	14	1	3	3	5	0.02
	Teleosts	2	2	5	2	3	0.03
	Toxotes sp.	2	2	5	1	2	0.03
	Total	391	39	100			0.60

N: number of organisms; *W*: total weight; wt%: percentage weight in g; *n*: number of stomachs with prey item; f_o: frequency of occurrence; *w*: weight per stomach sampled in g

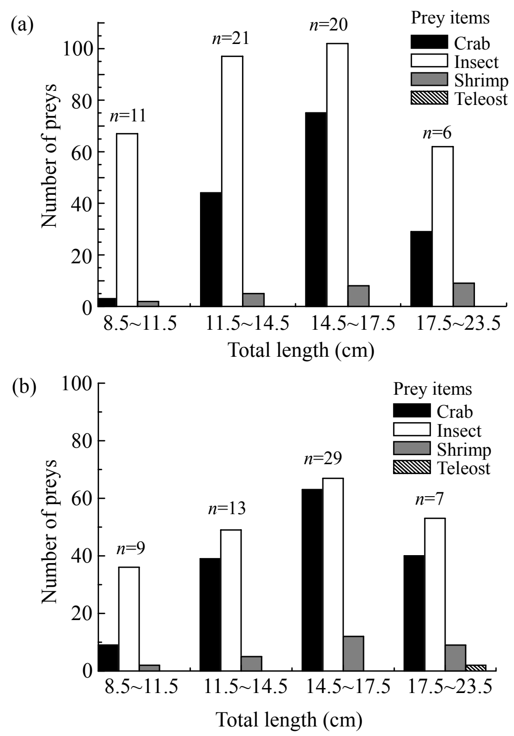

Fig.4 Number of food items ingested by (a) *T. chatareus* and (b) *T. jaculatrix*
n: number of fish in each length class (excluding empty stomach)

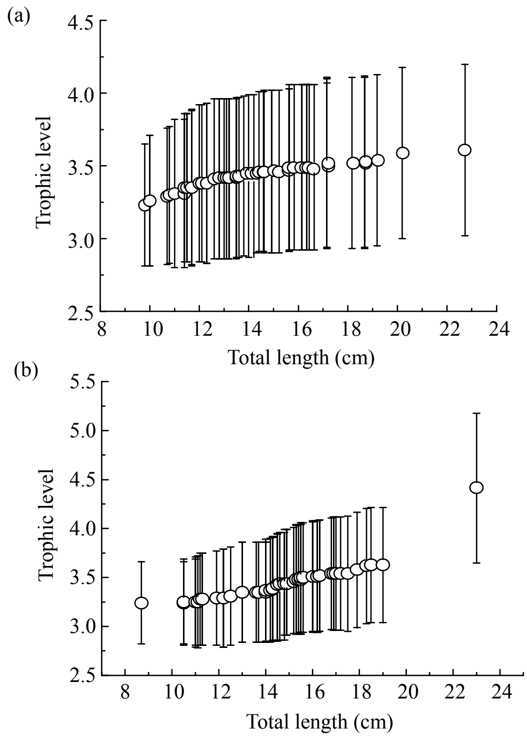

Fig.5 Identification of the trophic levels of (a) *T. chatareus* and (b) *T. jaculatrix*
Open circles represent mean TROPH values/trophic level and solid bars represent variants of prey items

Reproductive biology

Estimated fecundity ranged from 38354 to 147185 eggs for *T. chatareus* females and 25251 to 150456 eggs for *T. jaculatrix* females. The sample size, minimum and maximum numbers of eggs, and mean egg count values are presented in Table 2. The fecundity of mature females increased with total length (TL), total body weight (BW), eviscerated weight (EW) (excluding the stomach and gonad weights) and ovary weight (OW) (Fig.6). The calculated mean gonadosomatic index was (1.061±0.075) for *T. chatareus* and (1.796±0.077) for *T. jaculatrix*, and hepatosomatic index was (1.201±0.080) for *T. chatareus* and (1.332±0.070) for *T. jaculatrix* (Table 2).

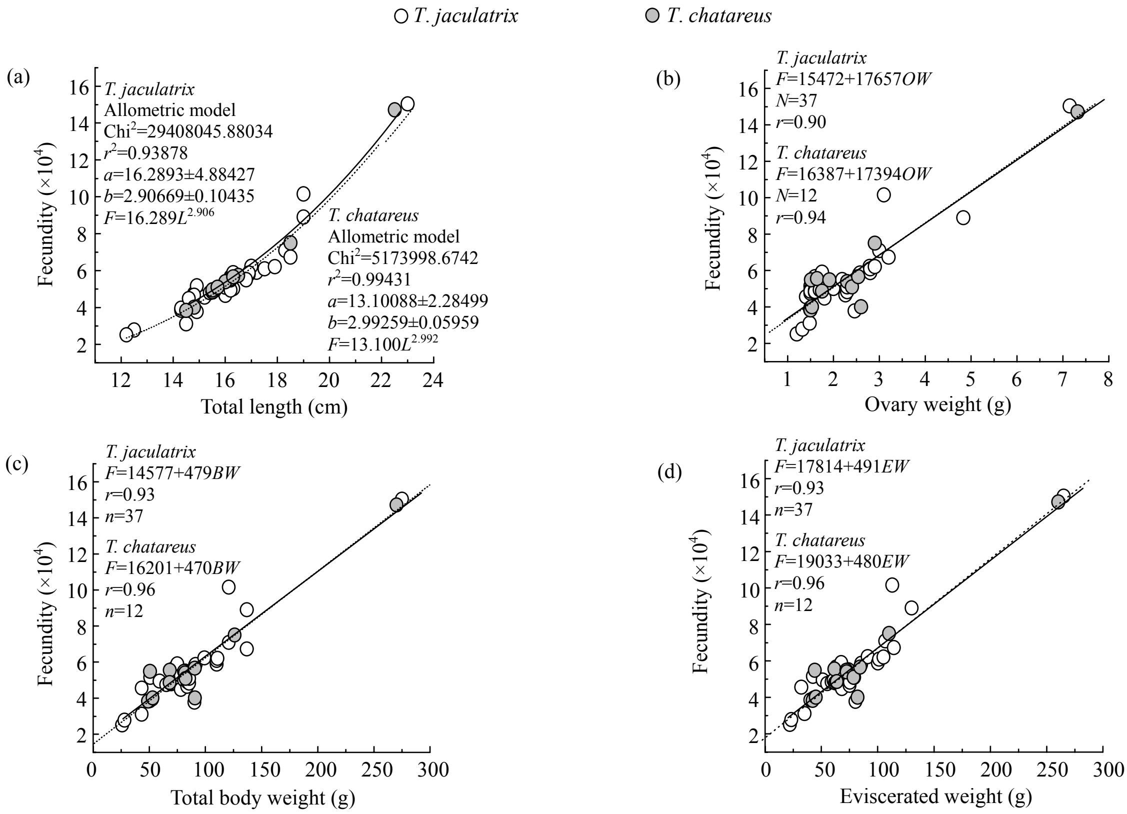

Fig.6 Relationships between fecundity and (a) total length (TL), (b) ovary weight (OW), (c) total body weight (BW), and (d) eviscerated weight (EW) in *T. chatareus* and *T. jaculatrix*
Dot bar represents non-linear fit of *T. jaculatrix* and solid bar represents non-linear fit of *T. chatareus* in (a), while dot bar represents linear fit of *T. jaculatrix* and solid bar represents liner fit of *T. chatareus* in (b)~(d)

Table 2 Total fecundity, gonadosomatic index (GSI) and hepatosomatic index (HSI) and related statistics in archer fishes

Species	Samples (female)	Fecundity			Samples (combined sex)	Gonadosomatic index			Hepatosomatic index		
		Mean	SE	Range		Mean	SE	Range	Mean	SE	Range
T. chatareus	12	60716	±8303.389	38354~147185	145	1.061	±0.075	0.02~7.26	1.201	±0.080	0.130~4.430
T. jaculatrix	37	55063	±3552.849	25251~150456	205	1.796	±0.077	0.03~8.70	1.332	±0.070	0.130~4.680

DISCUSSION

In the current study, we observed that *T. chatareus* and *T. jaculatrix* (except male samples of *T. jaculatrix*) exhibit similar growth patterns (i.e., positive allometry and fish becomes more rotund as length increases), in accordance with a previous study (Simon and Mazlan, 2008). The slopes or exponents (b) for male, female, and both sexes for *T. chatareus* were significantly ($P<0.05$) higher than 3.0, reflecting a positive allometric growth, whereas in *T. jaculatrix* the values of exponent b for males were close to

3.0 (P>0.05), showing isometric growth pattern. The estimates of the parameter b, varying between 2 and 4 (Bagenal and Tesch, 1978), remain within the expected range (3.076~3.465), with a mean b value of 3.268 (±0568) for all the species. A high degree of positive correlation between total length and total weight of both species is indicated by high values of correlation coefficient r^2. The length-weight relationships of *T. chatareus* and *T. jaculatrix* within and between sexes have not been previously recorded in Malaysia or elsewhere. However, as a result of the size-selective characteristics of fishing gears, the samples may not have included all available lengths. For more precise weight estimations, the application of these length-weight relationships should be limited to the observed length ranges; otherwise it may be erroneous (Petrakis and Stergiou, 1995; Froese, 1998).

Even though the change of b value depends primarily on the shape and fatness (size) of the species, various factors may be responsible for the differences in parameters of the length-weight relationships among seasons and years, including temperature, salinity, food (quantity, quality, and size), sex, time of year, and stage of maturity (Pauly, 1984; Sparre, 1992). The parameter b, unlike the parameter a, may vary seasonally, even daily, and between habitats (Bagenal and Tesch, 1978; Gonçalves *et al*., 1997; Taskavak and Bilecenoglu, 2001; Özaydin and Taskavak, 2007). Thus, the length-weight relationship in fish is affected by a number of factors including gonad maturity, sex, diet, stomach fullness, health, and preservation techniques as well as season and habitat; however, none of them were taken into consideration in the present study.

Our results show that the two species of archer fishes in the Johor coastal waters feed primarily on crustaceans (mostly *Sesarma bidens*) and insects (in decreasing order of abundance: Formicidae, Dytiscidae, Araneidae, and Cerambycidae), followed by teleost. Crustaceans (i.e., crabs and shrimps) dominated the stomach content by weight, while insects dominated the diet by number in all length classes of *T. chatareus* and *T. jaculatrix* (Table 1 and Fig.4). It is assumed that insects were captured by the two species through shooting from the overhanging mangrove vegetation in the study area. This feeding mechanism has been well documented (Timmermans, 2000; 2001; Timmermans and Vossen, 2000; Rossel *et al*., 2002; Schuster *et al*., 2004; 2006). Smaller individuals with total length of 8.5~11.5 cm of both species fed on a smaller number of prey items compared to larger length classes. The diet differences among the size classes are probably due to the energy requirements, which vary according to the developmental stage. Indeed, during ontogeny, fishes often change their diet mediated by allometric, morphological changes (Karpouzi and Stergiou, 2003), thus being able to exploit sequentially a series of prey sizes ranging from phytoplankton and small size zooplankton to much larger prey (Wootton, 1998).

Our results show that the diets of *T. chatareus* and *T. jaculatrix* include crabs, shrimps, and insects prey, which is consistent with Blaber (2000)'s results. However, Blaber found that the two fish species also take plant material, which he explained as an occasional behavior. In addition, the similar ontogenetic changes in the diet in *T. chatareus* were reported in the present study and by Blaber (2000) (Figs.4 and 5).

The methods of stomach fullness assessment in the present study allowed observing the prey items in the stomach by dissection. A similar method of assessment has been also reported by Joyce *et al*.(2002). Larger archer fishes appear to develop a higher degree of carnivory by capturing large crabs, shrimps, insects or even to display cannibalistic behavior on juvenile fish.

The estimated trophic levels for *T. chatareus* and *T. jaculatrix* are similar to those calculated by Stergiou and Karpouzi (2001) for other pelagic species such as *Gadiculus argenteus argenteus*, *Trachurus mediterraneus*, and *Trachurus trachurus*. All these species exhibit similar feeding preference, namely, crustaceans, fish larvae, and mysids, and can be considered as largely carnivores. Our results indicate that the two species of archer fishes are largely opportunistic predators feeding on a wide spectrum of prey species such as crustaceans, insects, and, rarely, teleost, depending on the food availability in the environment.

The fecundity estimates of *T. chatareus* and *T. jaculatrix* show that these species have a reproductive strategy common to other fish families (e.g., Carangidae and Scombridae) with lack of parental care: i.e., they produce a high number of smaller size pelagic eggs. These results agree with the findings for *T. chatareus* females in previous studies (Allen *et al*., 2002; Pethiyagoda, 1991). The increase in fecundity with body length and weight is consistent with the observations made in other fish species (Gartner, 1993; Barbin and McCleave, 1997). An increase in gonadosomatic index value is an indication of increased reproductive activity. In contrast, hepatosomatic index is a good indicator of recent feeding activity (Tyler and Dunn, 1976) and hepatosomatic index value decreases during spawning, suggesting that the fishes may decrease its feeding activity during reproduction. In the present study, due to scarcity of samples in each month's sampling programme, we were unable to obtain the monthly gonadosomatic and hepatosomatic indexes of both species. However, differences in values of gonadosomatic index and hepatosomatic index calculated for both species in this study may have resulted from uneven sample size ranges. Moreover, there was no previous study on these reproductive indexes in archer fish to confidently infer real gonadosomatic index and hepatosomatic index values from gonad and liver analyses.

CONCLUSION

In conclusion, we observed that *T. chatareus* (male, female, and combined sexes) exhibited positive allometric growth pattern (species become more rotund as their length increases) and *T. jaculatrix* exhibited both positive allometric (female and combined sexes) and isometric growth (male samples only) patterns (changing the body form following the cube law (volume=L^3)) by the exponent b values derived from the allometric length-weight relationship. The estimated trophic levels indicate that *T. chatareus* and *T. jaculatrix* are opportunistic fish feeders that take a wide spectrum of prey species such as crustaceans, insects, and, rarely, teleost, depending on the food availability in the environment. The estimated fecundity demonstrates that both species are highly fecund and their fecundity increases linearly with body length, body weight, ovary weight, and eviscerated weight. Low gonadosomatic index and hepatosomatic index values obtained from both samples might be as a result of abundant juvenile samples; therefore, further studies are needed to obtain more information about the reproductive biology of this fascinating fish. Our findings will be useful for ecological modeling for a better representation of the trophic flows associated with large, medium, and small pelagic fishes in Malaysian estuaries.

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