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Environmental effect on diet, fecundity and condition of an endangered fish *Neosalanx reganius* (Osmeriformes) in the Chikugo Estuary, in the upper Ariake Bay, Japan

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Abstract – *Neosalanx reganius* is a poorly studied salangid fish restricted to the upper reaches of the Chikugo and the Midori River flowing into the Ariake Bay, Kyushu, Japan. Samples of *N. reganius* were collected from brackish water areas of the Chikugo River by eight cruises in 1998−2004 to characterize the distribution pattern, feeding ecology in relation to ambient prey concentrations, fecundity and condition of the fish. A total of 244 specimens were collected, 36 to 71 mm total length, and 111 to 1301 mg body weight. The catch per unit of effort (CPUE; number of fish collected by towing a larva net for 20 min) correlated positively with turbidity and negatively with salinity. *N. reganius* is a planktivorous fish, fed on a single calanoid copepod species *Sinocalanus sinensis*, which was the single most dominant prey item in all stations during all cruises, contributing as high as 97.0% of the total diet of the fish; the other prey items (other calanoids and cyclopoids, *Daphnia* sp. and decapod mysid) together contributed only 3%. *S. sinensis* also dominated in the environmental copepod composition. The CPUE showed significant correlation with copepod dry biomass which increased upstream ($r = 0.90$; $p < 0.05$). Fecundity ranged 347−995 (mean 583 ± 173) oocytes individual^{-1} and relative fecundities ranged 6.8−15.6 (mean 10.1 ± 2.4) oocytes mm^{-1} TL and 0.8−2.5 (mean 1.6 ± 0.5) oocytes mg^{-1} of net body weight (weight taken after gonad extraction). Fecundity showed significant positive relationship with fish length and body weight. GSI ranged 29.4−58.8% (mean 43.5 ± 7.9%) and had significant relationship with fish length and body weight. Spawning individuals had higher allometry coefficient (b) and condition factor (K) than the non-spawning individuals. The oligohaline upper Chikugo estuary provides important feeding and spawning grounds for the fish with sufficient prey abundance and turbidity maximum that seemed advantageous for feeding and spawning of *N. reganius* in the Chikugo estuary. We suggest that future research should emphasize on the spawning and early life ecology of the fish in order to formulate effective conservation action.

Key words: Feeding habits / Fecundity / Condition factor / Estuarine turbidity / Salangidae / *Neosalanx reganius*

Résumé – Influence environnementale sur l'alimentation, la fécondité et les facteurs de condition d'un poisson menacé d'extinction, *Neosalanx reganius* (Osmériformes), de l'estuaire du Chikugo, baie de Ariake, Japon. *Neosalanx reganius* est un poisson Salangidé peu étudié et dont l'aire de répartition est limitée aux fleuves Chikugo et Midori se déversant dans la baie Ariake, Kyushu, Japan. Des échantillons de *N. reganius* ont été collectés dans les zones à eaux saumâtres du fleuve Chikugo lors de 8 campagnes de 1998 à 2004 afin de caractériser la répartition, l'écologie alimentaire, en relation avec les proies disponibles du milieu, la fécondité et l'indice de condition du poisson. Un total de 244 individus, de 36 à 71 mm (longueur totale) et de 111 à 1301 mg, ont été collectés. Les captures par unité d'effort (CPUE ; nombre de poissons collectés par trait de 20 min) sont correlées positivement avec la turbidité et négativement avec la salinité. *N. reganius* est planctonivore, il se nourrit de copépode calanoïdes *Sinocalanus sinensis*, proie dominante (97 % des proies) à toutes les stations et durant toutes les campagnes ; les autres proies sont d'autres calanoïdes et cyclopoïdes, *Daphnia* sp. et mysidacés. *S. sinensis* est aussi le copépode le plus abondant dans le milieu. Les CPUE montrent un corrélation significative avec la biomasse sèche de copépode qui augmente vers

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l'amont (r = 0,90; p < 0,05). La fécondité est de 347 à 995 ovocytes (moy. 583 ± 173) par individu et la fécondité relative est de 6,8 à 15,6 (moy. 10,1 ± 2,4) ovocytes mm^{-1} TL et 0,8–2,5 (moy. 1,6 ± 0,5) ovocytes mg^{-1} de poids corporel (poids sans les gonades). La fécondité montre une relation significative avec la taille et le poids, de même pour l'indice gonado-somatique (de 29,4 à 58,8 % – moy. 43,5 ± 7,9 %). Les individus prêts à pondre ont un coefficient d'allométrie (b) et un facteur de condition (K) plus élevés que les autres individus. La zone amont oligohaline de l'estuaire du Chikugo présente des aires importantes de ponte et d'alimentation pour ce poisson, avec un maximum de turbidé qui semble avantageux à sa reproduction et à son alimentation. Nous suggérons que de futures recherches mettent en relief la reproduction et le cycle de vie de *N. reganius* afin de formuler une action de conservation effective.

1 Introduction

The salangid fishes (Osmeriformes: Salangidae) are commonly known as the "icefishes" or "noodlefishes". There are more than 20 species of salangid fishes native in China, Russia, Korea and Japan (Roberts 1984; Dou and Chen 1994; Nelson 1994; Zhang and Qiao 1994) but species diversity is greatest in China and Korea (Roberts 1984; Wang et al. 2002 cited in Fu et al. 2005). They inhabit mainly freshwater lakes (Dou and Chen 1994) but there are some estuarine forms residing in the fresh-to-low salinity areas of estuarine transition zones (e.g., *Neosalanx reganius*; Takita et al. 1988) with a few distributed in the tidal flats and surf zones in bays and seas (e.g., *Salanx ariakensis*; Hibino et al. 2002a,b). Some of these fishes are commercially important in the lake and reservoir fisheries in China and Korea. Several species, such as *Protosalanx hyalocranius* and *Neosalanx taihuensis* have been successfully used for commercial stock enhancement in lakes and reservoir fisheries throughout China during the last two decades and have been increasingly introduced into waterbodies for stock enhancement (Liu 2001). The salangids are characterized by a translucent, scaleless body, except for one row above and fin base in adult males, strongly depressed head, and a poorly ossified skeleton (Nelson 1994). They are thought to be possibly neotenic (Roberts 1984; Nelson 1994). In general, very little is known on the biology of the salangid fishes. Previous studies have consistently shown that the salangids are planktivores (Dou and Chen 1994; Liu 2001) and intensive feeding by salangids can contribute tremendously in shaping the population of plankton, and can cause density-dependent growth of the fishes themselves (Liu et al. 2000). However, this scenario may be true particularly for lake and reservoir ecosystems where food is often limited and where different species compete for the same food resource (Liu et al. 2000). This may not be true for estuarine ecosystems with sufficient plankton food supply (Dou and Chen 1994). This lack of knowledge suggests that the biological information about salangid fishes and their prey resources is extremely important before their introduction to a new ecosystem.

Neosalanx reganius is known only in the Chikugo River and the Midori River that flow into the Ariake Bay (32° 27′–33° 11′ N, 130° 6′–37′ E) in Kyushu, Japan (Takita et al. 1988). The fish generally inhabits the tidal areas of the rivers above the saltfront, 16–20 km upstream from the river mouth and sometimes found in areas with low seawater concentrations (Takita et al. 1988). The fish spawns in March and April in a temperature range of 10–14 °C, has an average life span of approximately one year and reaches a maximum size of 63 mm SL (Takita 1996). Previously conducted morphological study revealed that the two populations in the Chikugo and in the Midori River are entirely isolated from each other, indicating that the fish is restricted to the fresh and low salinity regions. The fish is regarded as endemic to these rivers and are also thought to be a "continental relict" species, historically isolated from the original Chinese and Korean population and has been existing only in these habitats. Moreover, *N. reganius* is a critically endangered species and has been placed in the Japanese and the IUCN (International Union for Conservation of Nature) red list of endangered species (Takita 1996). Therefore, the fish is an ecologically important species deserving immediate conservation action, which necessitates the biological information to be understood since *N. reganius* is one of the most poorly studied species among the salangid fishes. A little information exist on the life history, distribution pattern and morphology of the fish (Takita 1966; Takita et al. 1988); however, nothing is known of the length-weight relationships, fecundity and the feeding habits of the fish in relation the natural prey distribution. We conducted eight field surveys during 1998–2004 to characterize the feeding ecology, fecundity, length-weight relationships and condition factor of *N. reganius* in the Chikugo River estuary.

2 Materials and methods

The Chikugo estuary, flowing into the upper part of the Ariake Bay (32° 27′–33° 11′ N, 130° 06′–130° 37′ E), is a large, well-mixed coastal estuarine system. The estuary has very high tidal amplitudes (~6.0 m) and is characterized by a zone of turbidity maximum in its upper part near the saltfront; this zone has higher particulate matter and nutrient concentrations than the other part of the estuary (Islam et al. 2004) influencing tremendously the distribution and feeding of estuarine living resources (Islam et al. in press). Four sampling stations (R1, R2, R3, and R4) were established along the estuarine gradient (Fig. 1); R1 was located at the river mouth and R4 was the uppermost station above the saltfront, 16 km upstream from the mouth. *N. reganius* samples were collected during eight cruises on 12 March 1998, 21 March 2000, 11 March 2001, 23 March 2001, 10 April 2001, 22 April 2001, 16 March 2002 and 19 March 2004. Samples were collected by towing a bongo-type larval ring net (1.5 m mouth diameter, 5 m long, 1 mm mesh at the body, and 0.33 mm mesh at the cod end) against tidal current for 20 min, which was regarded as a unit of fishing effort. Samples were collected during high tide at the morning on each cruise and were immediately preserved in 10% formalin solution. In the laboratory, *N. reganius* was sorted and separated from other fishes for subsequent studies. The total number of fish collected by each fishing effort was expressed as the catch per unit of fishing effort (CPUE).

Guts of the fishes were dissected with fine needles under a stereomicroscope. The guts were opened and food organisms

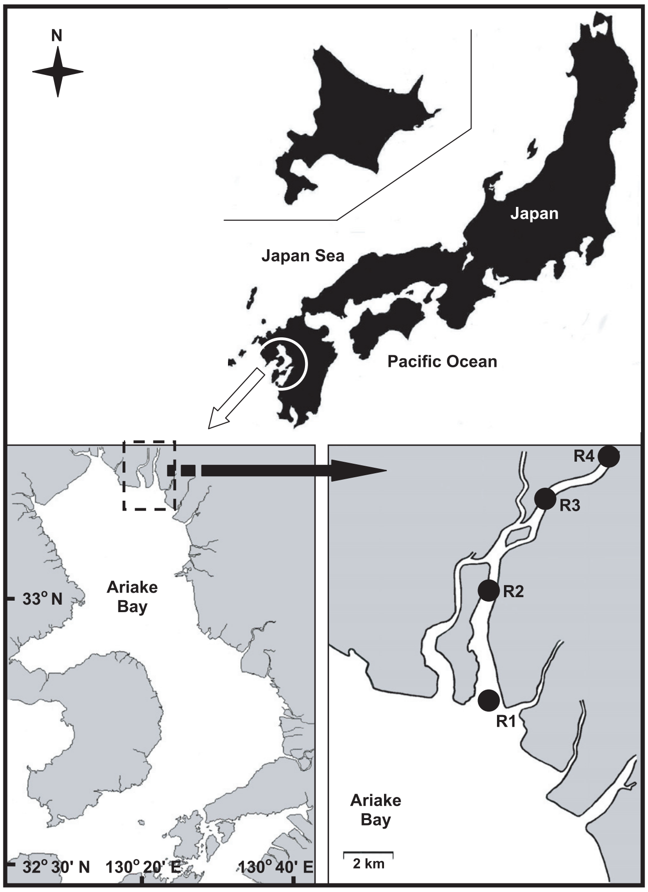

Fig. 1. Map showing the sampling stations in the Chikugo estuary.

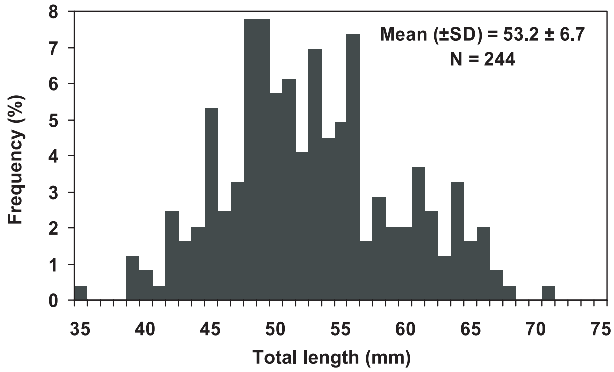

Fig. 2. Total length-frequency distribution of *Neosalanx reganius* collected by eight sampling cruises from the Chikugo River.

were separated from the oesophagus to the rectum and were examined under microscope. Prey organisms were counted and identified. Feeding incidence was calculated as the percentage of the number of fish with foods in relation to the total number analyzed (No. of fish with foods / No. analyzed × 100). Numerical composition, abundance and distribution of copepods in the environment was analyzed by collecting samples simultaneously during each cruise at each station by obliquely towing a plankton net (45 cm mouth diameter; 0.1 mm mesh) equipped with a flow meter. Copepods were identified and were counted; copepod density was expressed as number per m^3 of water filtered. Copepod dry biomass was determined by drying samples at 45 °C for 24 hours in a thermost oven and the dry weight was expressed as $mg\,m^{-3}$. Temperature (°C), salinity and turbidity (nephelometric turbidity unit, NTU) were recorded on the board during each cruise by using an environmental monitoring system (YSI 650 MDS, YSI Incorporated, Ohio, USA).

The total length-weight relationship and condition of the fish were assessed. Total length of each individual fish was measured to nearest mm and total weight (ungutted and gonad unextracted) was taken to nearest mg on a digital electronic balance. The regression line of length-weight relationships was drawn by plotting the body weight data against the total length data. Le Cren's (1961) widely used formula of $W = aL^b$ was used to fit a curvilinear power relationship model between length and weight; using the least square regression method, the formula was modified as $\log W = \log(a) + b\log(L)$ and was used to establish a linear relationship model between the length and the weight, where W is the weight and L is the length, a is a constant and b is the allometric coefficient. The value of $b = 3$ indicates an isometric growth and values greater or lesser than 3 indicate an allometric growth; value of $b > 3$ and $b < 3$ indicate positive and negative allometry respectively (Santos et al. 2002). The slope of the regression line is believed to be an estimate of b (Safran 1992), indicating the isometry or allometry of growth and, therefore, a useful indicator of the condition of fish. Fulton's condition factor (K), which was used to compare length and weight, was calculated for individual fish, and was computed as

$$K = 1000\ W/L^3$$

where W is the weight (mg) and L is the total length (mm).

Fecundity was defined as the number of maturing eggs in an ovary prior to spawning and was estimated from a total of 30 individuals. Relative fecundity was estimated and expressed by two means: number of oocytes per mm of total fish length (TL) and the number of oocytes per mg of net body weight (after extraction of gonad). The ovaries were separated from gravid females and were wet weighed to calculate the gonadosomatic index (GSI) which was computed as: the gonad weight / the whole body weight × 100. For fecundity estimation, all the vitellogenic eggs were counted under a stereomicroscope. Pre-vitellogenic oocytes were not included in fecundity estimates but were included in GSI calculation.

3 Results

A total of 244 fish were collected by eight sampling cruises, ranging in TL from 36 to 71 mm (mean ± SD = 53 ± 7 mm; Fig. 2) and weight from 111 to 1301 mg (mean ± SD = 495 ± 241 mg). *N. reganius* was distributed mainly in the low saline areas at the upper part of the estuary. Almost all the fishes (96.9% of the total catch) were collected from the two uppermost stations (R3−R4) with salinities ranging 0.24−1.67 and only 3.1% of the total catch was collected in R2 and no fish was collected in R1 (Fig. 3). The CPUE correlated negatively with salinity ($r = -0.97$; $p < 0.01$) and positively with turbidity ($r = 0.66$; $p < 0.05$) (Table 1).

Table 1. Correlations among hydrographic variables, catch per unit of fishing effort (CPUE), fish condition factor, copepod density and copepod dry biomass (* $p < 0.05$ ** $p < 0.01$).

	Salinity	Turbidity	CPUE	Condition factor (K)	Copepod density	Copepod biomass
Turbidity	−0.525					
CPUE	−0.972*	0.659				
Condition factor (K)	−0.856**	0.228	0.717			
Copepod density	0.723*	−0.636	−0.658	−0.818*		
Copepod biomass	−0.941**	0.260	0.897**	0.788*	−0.473	
Feeding intensity	−0.872*	0.062	0.743*	0.935**	−0.583	0.919**

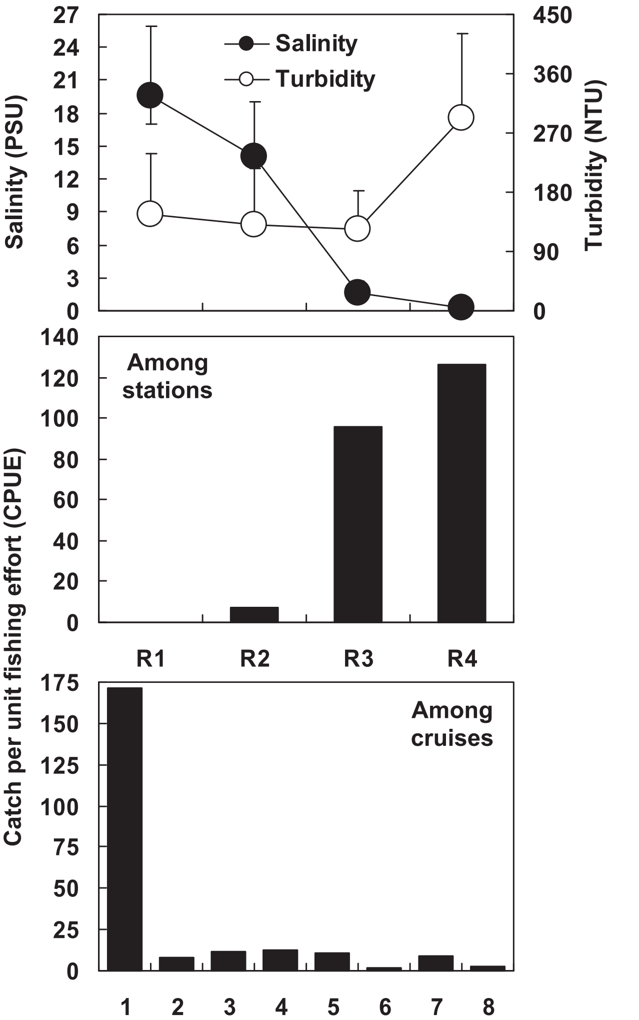

Fig. 3. Distribution of *Neosalanx reganius* in relation to the hydrographic variables in the Chikugo River estuary; upper: spatial variations in salinity and turbidity; middle: spatial variations in CPUE among stations and lower: variation in CPUE among the sampling cruises. PSU = practical salinity unit; NTU = nephelometric turbidity unit; CPUE = catch per unit of effort (number of fish per 20 min tow).

Table 2 shows the number and body size of fish used for gut content study, number of prey and the feeding incidence during each cruise. A total of 125 individuals with a TL range of 41−71 mm were used for gut examination and a total of 1275 preys were recorded. Feeding intensity and feeding incidence ranged 0.33−87.5 preys gut^{-1} and 22.2−100% respectively. Overall feeding incidence was 78.9%, with an average

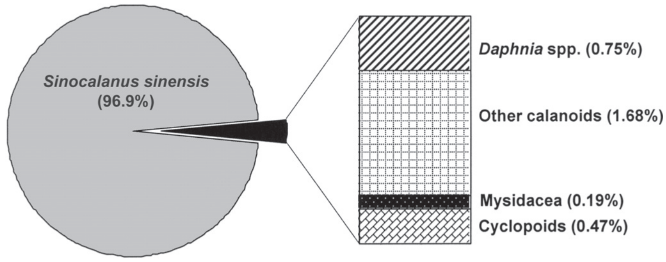

Fig. 4. Numerical composition of the gut content of *Neosalanx reganius* in the Chikugo estuary.

of 10.2 prey items gut^{-1} and the remaining 21.1% of the fish had empty guts. Regression analysis between the number of prey items in the gut and the corresponding fish size revealed a significant positive relation ($p < 0.05$). *Sinocalanus sinensis* was the single most dominant prey item in all stations during all cruises, contributing tremendously in the diet of fish collected in almost all cruises and at all stations (Table 3). Overall, *S. sinensis* contributed as high as 96.9% of the total diet of the fish and the other items, which include other calanoids, cyclopoids, *Daphnia* sp. and mysidacea, contributed only the remaining 3.1% (Fig. 4). *S. sinensis* dominated also in the environmental copepod composition, contributing more than 99% in R3 and R4 (Fig. 5). In contrast, *Oithona davisae* dominated overwhelmingly at R1 (90%) while at R2, *S. sinensis* and *O. davisae* contributed nearly equally (45% and 50% respectively) (Fig. 5). Copepod density and copepod dry biomass showed contrasting spatial pattern, i.e., density increased downstream while dry biomass increased upstream (Fig. 5). The CPUE showed significant correlation with copepod dry biomass ($r = 0.897$; $p < 0.01$). Spatial variations in feeding intensity as well as condition factor of fish showed an exactly similar pattern to that of copepod dry biomass in the ambient water (Fig. 6) and correlated significantly (Table 1).

The total length (TL, mm) and body weight (W, mg) relationships (Fig. 7):

$$W = 0.0003\ \mathrm{TL}^{3.56} \quad \text{with} \quad R^2 = 0.87;\ p < 0.05;\ N = 244.$$

The natural log transformed: $\ln(W) = 3.56\ln(L) - 8.02$

The condition factor (K) ranged from 1.3 to 4.6 (mean ± $SD = 3.0 \pm 0.57$) and had significant relationships with both total length and body weight. A simple linear regression analysis of fish length and weight with corresponding condition factor (K) produced significant relationships ($F = 36.6$; $p < 0.001$; adjusted $R^2 = 0.15$ for length – K relationship and $F = 186.4$; $p < 0.001$; adjusted $R^2 = 0.48$ for weight – K relationship)

Table 2. The number of *Neosalanx reganius* used for gut examination, their size range, number of prey recorded and the feeding incidence during each cruise.

SL No.	Cruise	Station	Number examined	Size range (SL, mm)	Total number of prey	Number of prey per gut	Feeding incidence (%)
1.	12 March 1998	R4	30	45.1−65.5	30	1.0	57.1
		R3	38	44.7−71.3	357	9.4	89.5
		R2	-	-	-		-
2.	21 March 2000	R4	8	57.1−67.3	69	8.6	75
		R3	-	-	-	-	-
		R2	-	-	-	-	-
3.	11 March 2001	R4	9	50.0−56.8	5	0.56	22.2
		R3	3	48.5−64.3	1	0.33	33.3
		R2	-	-	-	-	-
4.	23 March 2001	R4	4	40.5−52.9	59	14.8	100
		R3	9	50.5−64.4	137	15.2	22.2
		R2	-	-	-	-	-
5.	10 April 2001	R4	2	49.9−52.5	21	10.5	100
		R3	6	46.6−56.6	28	4.7	100
		R2	3	45.2−48.4	18	6.0	100
6.	22 April 2001	R4	-	-	-	-	-
		R3	2	49.9−51.2	175	87.5	100
		R2	-	-	-	-	-
7.	16 March 2002	R4	7	48.2−56.4	139	19.9	100
		R3	-	-	-	-	-
		R2	1	57	10	10.0	100
8.	19 March 2004	R4	1	60	20	20.0	100
		R3	-	-	-	-	-
		R2	2	49.2−59.5	6	3.0	100

Table 3. Numerical composition of the gut content of *Neosalanx reganius* collected from the Chikugo estuary.

Cruise	R4		R3		R2	
	S. sinensis	Others	*S. sinensis*	Others	*S. sinensis*	Others
12 March 1998	100	-	100	-	-	-
21 March 2000	62.3	37.7	-	-	-	-
11 March 2001	100	-	100	-	-	-
23 March 2001	94.9	5.1	98.5	1.5	-	-
10 April 2001	100	-	96.4	3.6	94.4	5.6
22 April 2001	-	-	100	-	-	-
16 March 2002	100	-	-	-	100	-
19 March 2004	100	-	-	-	100	-

(Fig. 8). Both the allometry coefficient (b) and the condition factor (K) showed higher values in spawning individuals than in all the other individuals (Fig. 9). Condition factor correlated positively with copepod dry biomass (Table 1).

Fecundity was estimated from 30 individuals ranging in TL from 48 to 64 mm (mean ± SD = 56.8 ± 4.3 mm) and weight from 377 to 1071 mg (mean ± SD = 712 ± 208 mg) (Table 4). Fecundity ranged 347−995 (mean ± SD = 583 ± 173) oocytes individual^{-1} and relative fecundities ranged 6.8−15.6 (mean ± SD = 10.1 ± 2.4) oocytes mm^{-1} TL and 0.8−2.5 (mean ± SD = 1.6±0.5) oocytes mg^{-1} of net body weight (Table 4). Fecundity showed significant positive relationship with TL (F = 67.6; adjusted R^2 = 0.70; $p < 0.001$) and body weight (F = 60.6; adjusted R^2 = 0.68; $p < 0.001$) (Fig. 10). GSI ranged from 29.4 to 58.8% (mean ± SD = 43.5 ± 7.9%); GSI had significant relationship with TL (F = 34.06; adjusted R^2 = 0.54; $p <$ 0.001) and body weight (F = 55.96; adjusted R^2 = 0.66; $p <$ 0.001) (Fig. 10).

4 Discussion

Takita (1996) reported that *N. reganius* inhabits freshwaters of the upper tidal reaches and some are dispersed downstream to oligohaline areas and the result of the present study is in close agreement with the reported pattern of distribution. Our results on the distribution patterns also correspond to other estuarine salangid fishes such as *Salangichthys microdon* (Senta 1973a,b). The correlations of CPUE with salinity and with turbidity apparently indicate that the low saline and highly turbid regions of the estuary are the preferred habitats for the fish. Nevertheless, it is difficult from these relations to predict the role of each factor in shaping the distribution of the fish. The correlation of CPUE with salinity may be simply due to low salinity preference of the fish. However, the correlation of CPUE with turbidity may have been resulted from cause and effect relations, particularly if we consider the feeding ecology of the fish. The fish may concentrate

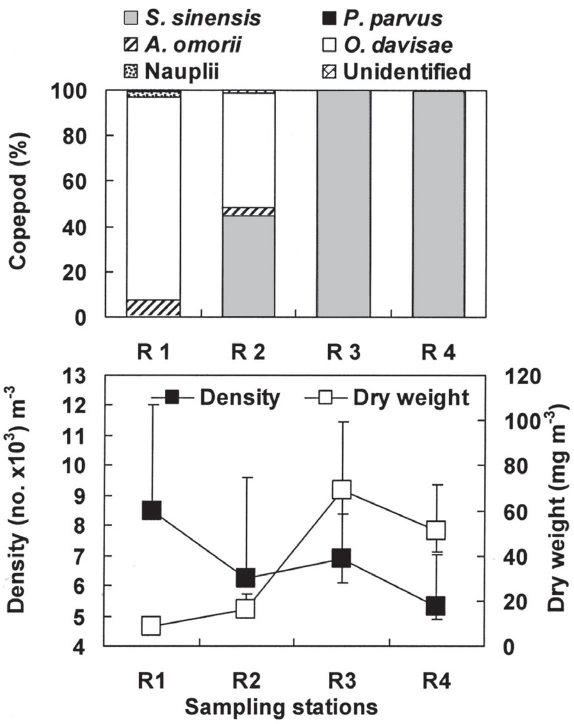

Fig. 5. Numerical composition, density and dry biomass of copepods in the Chikugo estuary; upper: numerical composition of copepods and lower: spatial variations in copepod density and dry biomass.

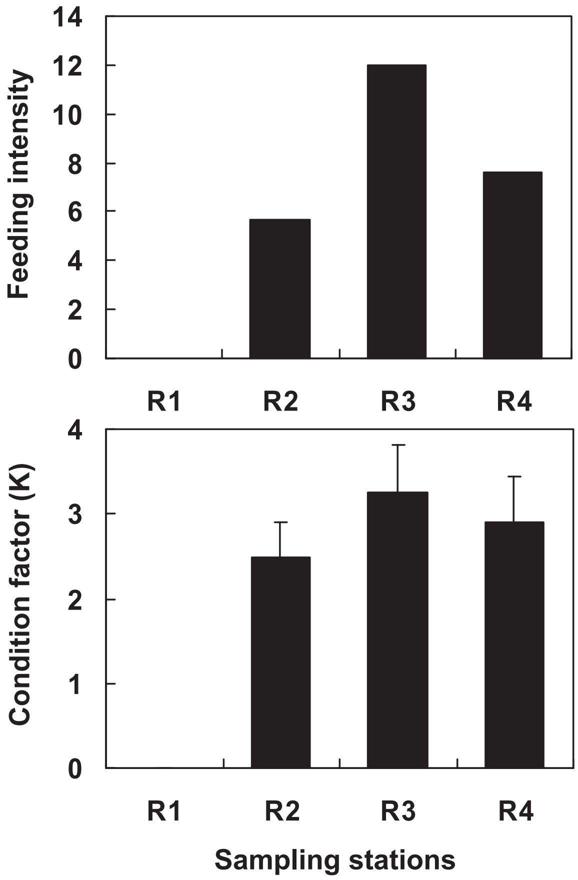

Fig. 6. Spatial variations in feeding intensity (number of prey fish^{-1}) and condition factor of *Neosalanx reganius* in the Chikugo estuary.

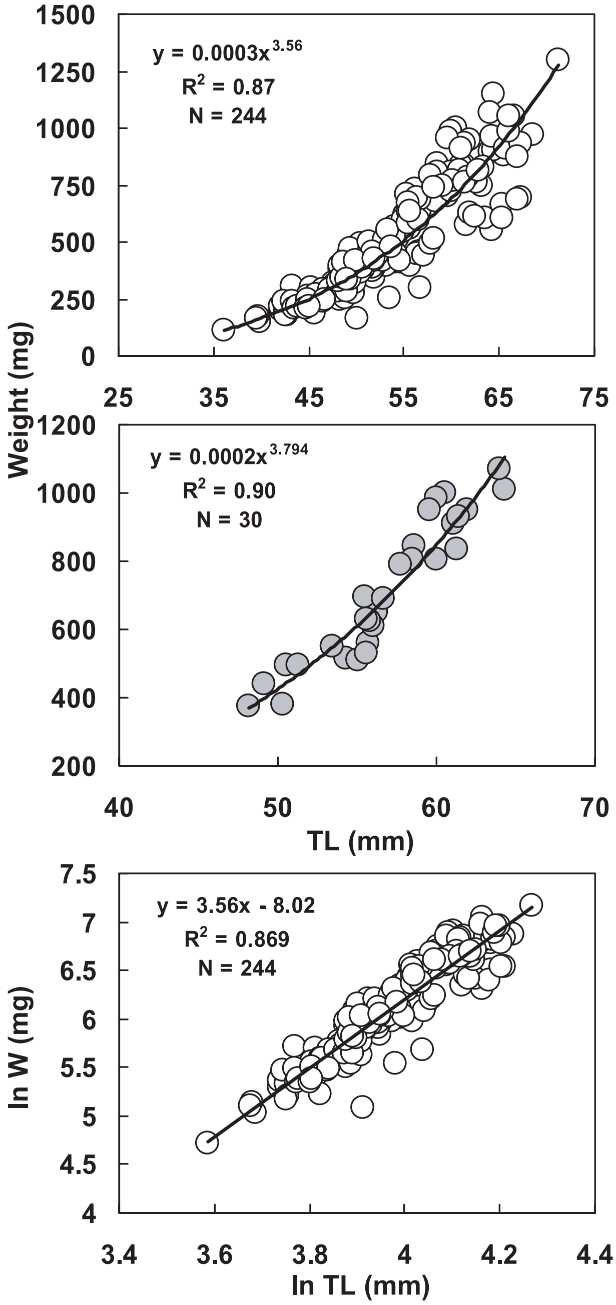

Fig. 7. Length-weight relationships of *Neosalanx reganius* from the Chikugo estuary; upper: showing a curvilinear relationship between length and weight of all individuals with a *b* value of 3.56; middle: curvilinear relationship between length and weight of spawning individuals (those used for fecundity estimates) with a *b* value of 3.79; and lower: a linear relationship between natural log transformed total length (TL, mm) and whole body weight (*W*, mg) of all individuals.

in the highly turbid areas to take advantage of a rich prey resource since highly turbid areas offer a better foraging environment through higher prey concentrations than the upstream and downstream areas (Dodson et al. 1989; Laprise and Dodson 1989; Dauvin and Dodson 1990; Laprise and Dodson 1994; Sirois and Dodson 2000a,b; North and Houde 2003; Shoji et al. 2005). Higher prey concentrations in the highly

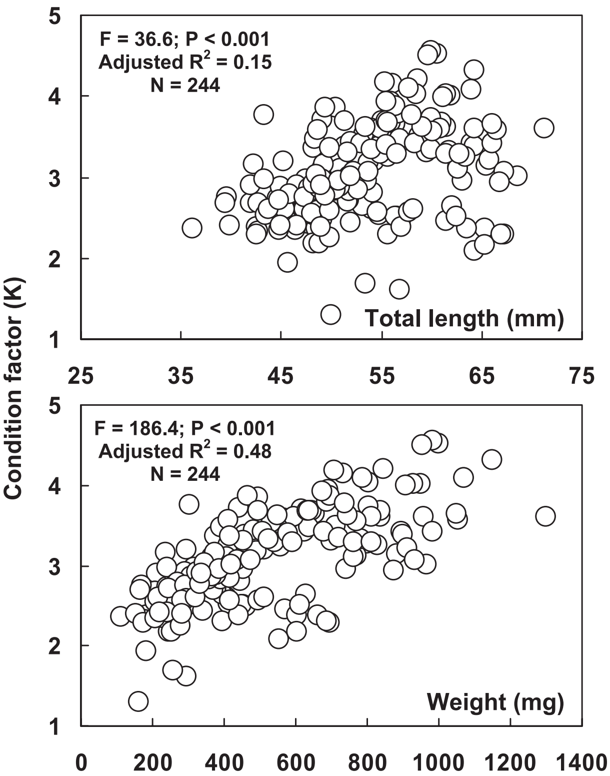

Fig. 8. Relationships between total length, TL (mm) and condition factor, K (F = 36.64; P < 0.001; adjusted R^2 = 0.148) (top) and between weight (mg) and K (F = 186.4; P < 0.001; adjusted R^2 = 0.475) (bottom) for *Neosalanx reganius*.

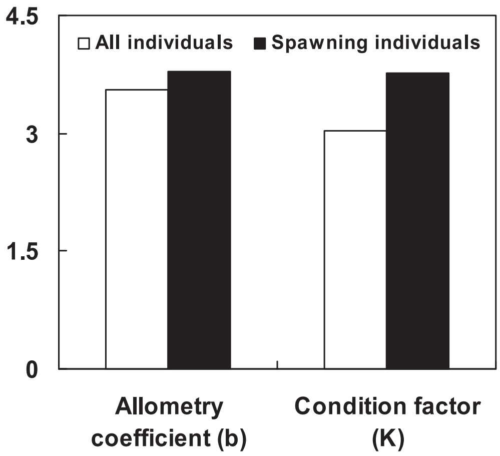

Fig. 9. Variations in the allometry coefficient (b) and condition factor (K) between all individuals and spawning individuals of *Neosalanx reganius* in the Chikugo estuary.

turbid zones may result in enhanced encounter rate between fish and prey, promoting feeding success (Shoji et al. 2005). Encounter rates may be critical factor for feeding success for fishes with delicate morphology and thus having poor swimming ability and visual acuity (Margulies 1990) as in many salangids (Dou and Chen 1994). The importance of prey concentrations in the feeding success of larval and juvenile fishes have been discussed in a number of previous studies. Shoji et al. (2005), for example, reported that prey concentration was the most important small-scale factor affecting feeding success of white perch in the Chesapeake Bay turbidity maximum and Sirois and Dodson (2000b) found that growth of larval rainbow smelt *Osmerus mordax* was enhanced at high turbidities and high prey concentrations. The role of high turbidity in promoting feeding success of fish has also been discussed by several other workers mentioned above. Positive correlations among the CPUE, turbidity, feeding intensity and condition factor in our study essentially indicate the role of turbidity in promoting the feeding and condition of the fish and thus influencing their distribution; this also indicates that prey concentrations is one of the most important small-scale factor influencing the distribution of *N. reganius* in the Chikugo estuary.

Spawning of the fish occurs in March and April (Takita 1966 and 1996); however, no information is available on the ecology of the spawning ground. Occurrence of a considerable number of mature and spawning individuals in the catch indicate that the fish use the low-salinity, turbidity maximum upper estuary as a spawning habitat. In a study on the spawning ecology of an another salangid fish *Salangichthys microdon*, Senta (1973a) reported high densities of naturally spawned eggs from the sand grains of the bottom sediment samples from 5.2 km upstream in Takahashi estuary with salinity ranging 0.8−16.8 ppt. This author reported that the spawning ground of *S. microdon* mainly composed in areas with sand grains nearly equal to the size of the spawned eggs; this feature might be associated with the strategy to avoid predation on the eggs and to increase the egg survival. As in other salangids, the eggs of *N. reganius* are demersal and are attached with bottom objects with adhesive threads on the envelope and are embedded on the bottom of the river (Takita 1996). Although not apparent from our study, it is not unlikely that the turbidity maximum area in the upper Chikugo estuary provides suitable spawning environment and enhances egg survival and hatching success though providing more bottom substrata and shelters for the eggs as this area has higher concentrations of phytobenthos (that cause high turbidity) than the rest of the estuary (Islam et al. 2004).

Dou and Chen (1994) suggested that the icefishes are extremely delicate and are highly vulnerable to environmental changes and to predation by other fishes, resulting in low survival rates particularly during the larvae-juvenile transformation stage; they also suggested that the high fecundity might be compensatory for this low survival rates. Dou and Chen (1994) reported the mean relative fecundity of 9.48, 5.80, 8.24 and 5.52 oocytes mm^{-1} TL and 0.886, 0.275, 0.103 and 0.308 oocytes mg^{-1} of net body weight (after gonad and gut extraction) of *Protosalanx chinensis*, *Neosalanx andersoni*, *Salanx ariakensis*, and *S. prognathus* respectively in the Yellow River estuary, China. Therefore, fecundity of *N. reganius* (10.1 ± 0.24 oocytes mm^{-1} TL and 1.55 ± 0.47 oocytes mg^{-1} of net body weight) is higher than the related species. The fecundity and the GSI both indicate that *N. reganius* is a highly fecund salangid. Despite the high fecundity, CPUE was generally low throughout the experiment except in the first cruise. The generally low catch may be indicative of vulnerability of the fish as an endangered species. The gap between fecundity and CPUE suggests that the fish may either experience poor spawning success or high mortality

Table 4. Mean values and range of fish size, fecundity and GSI of *Neosalanx reganius* collected from the Chikugo estuary.

	Minimum	Maximum	Mean ± *SD*
TL (mm)	48.2	64.4	56.8 ± 4.3
Weight (mg)	377.0	1070.6	711.9 ± 207.9
Fecundity (oocytes)	347	995	583 ± 173
Relative fecundity (oocyte/mm)	6.8	15.6	10.1 ± 2.4
Relative fecundity (oocyte/mg)	0.8	2.5	1.6 ± 0.5
GSI (%)	29.4	58.8	43.5 ± 7.9

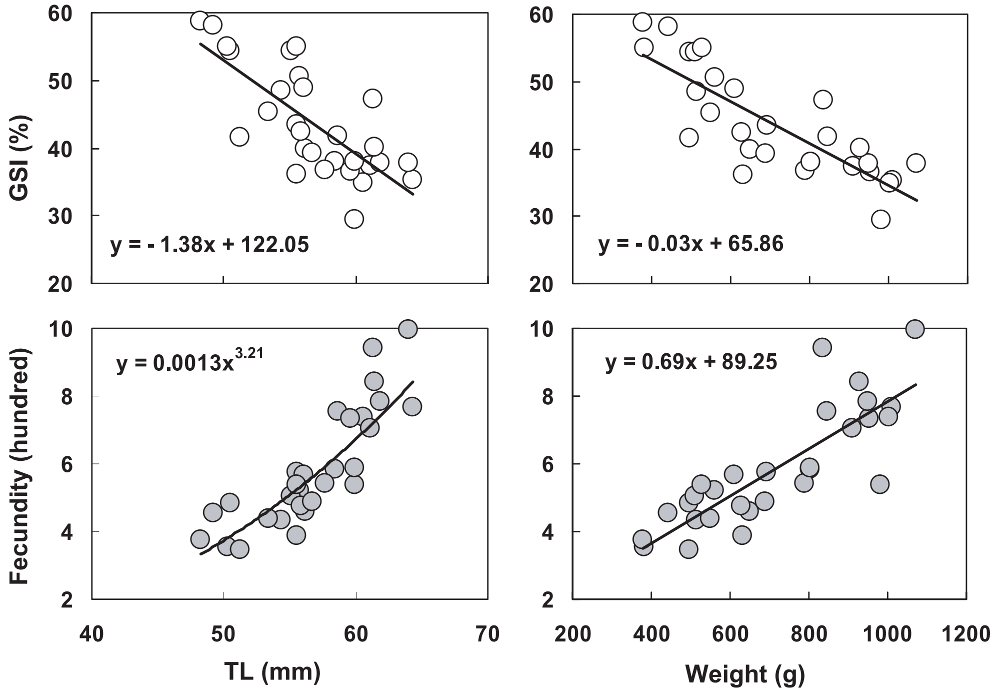

Fig. 10. Relationships of the fecundity and GSI with the total length (TL, mm) and weight (mg) of *Neosalanx reganius*; fecundity and GSI had significant relationships with both total length (F = 67.55; P < 0.001; adjusted R^2 = 0.70 for fecundity and F = 34.06; P < 0.001; adjusted R^2 = 0.54 for GSI) and body weight (F = 60.55 == 79; P < 0.001; adjusted R^2 = 0.68 for fecundity and F = 55.96; P < 0.001; adjusted R^2 = 0.66 for GSI).

that concentrate during early stages of life resulting in recruitment failure. Takita (1996) reported that the fish is threatened by pollution from surrounding agricultural lands and human settlements, destruction of spawning habitats due to sand collections from the river for years and deterioration of overall habitat quality by interrupting the freshwater flow through construction of dam across the river. Therefore, future attempts should be concentrated on the spawning and early life ecology of the fish as well as on the habitat quality.

The diet of *N. reganius* in Chikugo estuary appears similar to other salangid fishes which, in general, are exclusively zooplanktivorous (Dou and Chen 1994; Liu et al. 2000; Liu 2001); obviously, the type of prey items varies depending on geographical location. In our study, *N. reganius* preyed exclusively on copepods occurring in the estuarine environment. A single species, *S. sinensis*, which dominated in the environment and in the guts of the fish, contributed as high as 97% of the total diet. This is consistent with our previous study (Islam et al. submitted) which showed that most of the dominant fish species occurring in the upper Chikugo estuary forage mainly on *S. sinensis*. This indicates that the fish is highly dependent and perhaps feed selectively on this prey item. Selection pattern is apparent when we look at st. R^2 where a greater proportion of ambient copepod was *Oithona davisae* but greater proportion of gut content was *S. sinensis*. The preference on *S. sinensis* was presumably associated with its bigger size than *O. davisae* (1.8 mm and 5.7 μg individual^{-1} of *S. sinensis* vs. 0.45 mm and 0.60 μg individual^{-1} of *O. davisae*). In one of our previous studies (Islam et al. in press), we reported selective feeding of the Japanese temperate bass larvae and juveniles on *S. sinensis* in the same study area. Bigger preys are selected by fish to maximize the growth rate (g) and to minimize the mortality risk (μ) as suggested by the "minimize μ/g hypothesis" (Utne et al. 1993; Dahlgren and Eggleston 2000). Selection of bigger prey would reduce the amount of energy needed for foraging and produce more energy per unit of effort and therefore, higher net benefit. Moreover, the abundance of *S. sinensis* is sufficiently high during most part of the year, particularly during winter and spring.

A relatively high proportion of empty guts were recorded. Nevertheless, this does not essentially indicate an existence of competition for prey. Although *N. reganius* share the same prey resources with some other co-occurring estuarine resident and migrant fish species in the upper Chikugo estuary, competition for food does not occur, presumably because *S. sinensis* is tremendously abundant in these regions for most part of the year (Islam et al. submitted). Greater proportion of empty guts might have been resulted from higher gut evacuation rates caused by the gut morphology (straight guts) of *N. reganius*. Although there is evidence of increasing capture efficiency of icefish *N. pseudotaihuensis* on copepod prey with an increase in fish size Liu (2001) and also there is experimental evidence of increasing prey capture efficiency with fish size in other species such as roach, bleak and blue bream (Hambright and Hall 1992; Wanzenboch 1992), significant relationship between fish size and the corresponding number of prey items in the gut in our study does not essentially indicate an increase in prey capture efficiency but may be simply associated with increased demand for prey with increasing fish size.

Length and weight data are useful and essential for a wide array of fishery studies such as in fish biology, physiology, ecology and fisheries assessment and management. Length–weight regressions have been extensively used to estimate weight from length because of technical difficulties and the amount of time required to record weight in the field. These relationships are often used for estimating growth rates, age structure, condition indices, standing stock biomass and for other aspects of fish population dynamics (Kolher et al. 1995). Length–weight relationships allow life history and morphological comparisons between different fish species, or between fish populations from different habitats and/or regions (Gonçalves et al. 1997). Estimates of the condition factor and allometry coefficient can be related to ecological processes and therefore, can reveal useful life history information. Therefore, data on length-weight relationships and condition factor are useful and essential for fishery managers as well as for conservation biologists. Our results shows that the length and weight of *N. reganius* has significant relationships, and the allometry coefficient (3.56 for all the individuals and 3.79 for spawning individuals) indicate that *N. reganius* has positive allometric growth that implies that the species gains weight fast growing in length. Difference between the *b* values of the spawning individuals and all other individuals (that mostly composed of non-spawning individuals) clearly indicates a variation in the *b* value with spawning condition; similar variation was observed also for mean *K* values between the spawning individuals and all individuals. Obviously, these variations do not necessarily indicate the existence of sexual dimorphism in the length-weight relationships and the values derived from them. Sexual dimorphism in length-weight relationships in fishes may not be a common phenomenon. Morato et al. (2001), for example, found only 2 species showing sexual dimorphism in length-weight relationships among the 21 coastal fish species analyzed in the Northeast Atlantic. Siginificant positive relation of *K* with length and weight indicate that both *b* and *K* are size-dependent; consequently, *b* and *K* are dependent on each other, i.e., variation in one of them is a reflection of the variation of the other. These dependencies indicate that the estimated length and weight and the derived parameters can be potentially biased by the sampling design, e.g., gear selectivity and the catchability of a particular gear used for collecting samples; thus collected samples often do not truly represent a population and, consequently, the estimated parameters can deviate substantially from true estimates of the population parameters (Safran 1992). Our length-weight and condition data also suffer this problem and should be treated with caution because we collected samples with size range of 36.1−71.3 mm and our results should be considered only for this size range. Details on the length-weight relationships and condition factor warrant further studies with smaller sized individuals.

In conclusion, *N. reganius* is distributed in the highly turbid zones of the upper Chikugo estuary at generally low abundance. The fish is supported by a rich prey resource dominated by the key copepod species *S. sinensis* with its tremendously high abundance. From the high fecundity and low CPUE, we assume that the population of *N. reganius* may be limited by poor spawning success, high larval mortality and recruitment failure, indicating that reduction of early mortality possibly through protecting the spawning habitats may be useful tool for conservation of the fish from the existing threat. Therefore, future research should emphasize on the spawning and early life ecology of the fish in order to formulate effective conservation action.

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