

# Life history and ecology of the glowbelly *Acropoma japonicum* in the Uwa Sea, Japan

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**ABSTRACT:** The life history and ecology of the glowbelly *Acropoma japonicum* a commercially important fishery resource, were investigated in the Uwa Sea, Japan. Newly settled juveniles (0<sup>+</sup>) appeared at the end of the breeding season and reached maturity in the next season, i.e. when they became yearlings (1<sup>+</sup>). The yearlings made a gametic effort comparable to that of older fish. During the breeding season, the somatic conditions were more deteriorated for males than for females. That the deterioration of male somatic conditions was not attributable to a sexual difference in energy gain from feeding suggests that the males incurred higher energetic costs of reproduction despite their relatively low gonadosomatic indices. Such an energy depletion may increase the mortality risk, resulting in female-biased sex ratios in the older age classes. Most of the 1<sup>+</sup> fish disappeared in winter following their first breeding. For *A. japonicum*, the observed precocity and short life span is notable because it is a higher consumer that is generally expected to show later maturation and longer life. As possible explanations for their disappearances, predation and postbreeding emaciation were less likely. While fishing is one of the most influential factors, the possibility of age-specific migration toward deeper waters remains to be examined.

**KEY WORDS:** *Acropoma*, age structure, feeding habit, growth, maturity, sex ratio, somatic condition, trawl.

## INTRODUCTION

The glowbelly *Acropoma japonicum* (Pisces: Acropomatidae) inhabits the continental shelf from the West Pacific to the Indian Ocean.<sup>1</sup> In the Uwa Sea fronting the Bungo Channel, Japan, it is a commercially important fishery resource for manufacturing fried fish cake or Jako-Ten, the industrial mainstay in the southern parts of Ehime. This fish is a bottom-dwelling carnivore living in the deep waters of this area, and is caught by some fishing gears. A Buri trawl is a local fishing technique for catching *A. japonicum* exclusively. The name Buri is derived from Teguri, which means the towing of net by hand in Japanese. As the name implies, traditional Buri trawls were operated manually, however, they have been replaced with motor-driven types that have high catch efficiency. In today's trawls, a 100-m wide by 3-m high net is towed on the seabed from offshore (~60 m in depth) verti-

cally toward the shore on which a fishing boat is anchored. The operation of this trawl is limited to within 1 km of the coastline in the northern part of the Uwa Sea (Fig. 1), according to a local fisheries agreement. Its catch is predominantly *A. japonicum* in number and mass, with a minority of such demersal fishes as lizardfishes, cardinalfishes, ponyfishes, gobies, lefteye flounders, and soles.

In spite of its high abundance, there is apprehension that the stock has substantially decreased over the last few decades. In 2002, we embarked on a research program to conserve and manage this fishery resource. However, its ecologic information is considerably limited, except for its luminescent habit.<sup>2</sup> Here we conducted field research to investigate the ecology and life history of this fish. Special attention was paid to its population characteristics and reproductive schedule, which provided basic information necessary for fisheries management.

## MATERIALS AND METHODS

A total of 2023 specimens of *Acropoma japonicum* were collected by Buri trawls with the aid of local

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**Fig. 1** Fishing area (dotted zone) for Buri trawls in the Uwa Sea, Japan.

fishermen. The sample collections were conducted at Hoketsu Bay of the Uwa Sea (Fig. 1), between 06:50 and 12:00 hours, monthly from October 2002 to December 2003, except December 2002. The mesh size of the trawl net was usually 43.3 mm, but a coarser net was used in winter to sift out newly settled juveniles (50.5 mm in November 2002 and 46.6 mm in November–December 2003). Measurements were made of the total length (TL) of fish specimens, to the nearest 0.01 mm, and their wet body weight, to the nearest 0.01 g. Sixty specimens were dissected each month, except October 2002 when 40 specimens were examined, to separate their gut, liver, fat body (i.e. a fatty tissue enveloping the viscera), gonad, and eviscerated body. For each specimen, calculations were made of the hepatosomatic index ( $HSI = 10^2 \times \text{liver weight}/\text{total body weight}$ ), the fat body somatic index ( $FSI = 10^2 \times \text{fat body weight}/\text{total body weight}$ ) and the condition factor ( $K = 10^5 \times \text{total body weight}/\text{TL}^3$ ) as indicators of somatic condition, especially of lipid contents for the former two, and the gonadosomatic index ( $GSI = 10^2 \times \text{gonad weight}/\text{total body weight}$ ) as an indicator of maturation. Their gut contents were also weighed in wet condition, excluding the contents of their intestines, and identified their prey items. After landing, fish often had an empty stomach because the stomach was pushed out of the abdominal cavity through the esophagus due to a drastic change in hydraulic pressure. Without including such specimens, the gut fullness index was calculated ( $GFI = 10^2 \times \text{gut contents weight}/\text{total body weight}$ ) accompanied

by the vacuity index ( $VI = 10^2 \times \text{number of specimens with empty stomach}/\text{total number of specimens}$ ). In October 2002, no data related to FSI and GFI was collected.

Estimates of the age structure of *A. japonicum* were made by fitting its size frequency data to the normal distribution, using cohort analysis with the least squares method (a computer program package, Microsoft Excel, Microsoft Corp., Redmond, WA, USA, according to Aizawa and Takiguchi<sup>3</sup>). The growth curve was delineated based on the monthly changes in the average TL in each estimated age class. Furthermore, the sex ratio in each age class was examined using specimens for which sex determination was made based on gonadal inspection after the dissection. The sex ratio is expressed as the proportion of females to all individuals. A sex ratio of 0.5 indicates an equal number of both sexes, and a ratio approaching 1.0 indicates bias toward females. Tests were performed to determine if the sex ratio significantly deviated from equality (0.5), using the  $\chi^2$ -test for goodness of fit.

To estimate the predation pressure on *A. japonicum*, examination was made of the stomach contents of four dominant large carnivorous fish species caught by the Buri trawls. The lizardfish, *Saurida* sp. (common Japanese name: Maeso), and the pike eel, *Muraenesox cinereus*, are sand dwellers sympatric with *A. japonicum*. The former species shows the next highest catch to *A. japonicum*, suggesting that it is a potential predator predominating in the demersal fish communities. Although the remaining two species, the cutlassfish *Trichiurus japonicus*, and the barracuda *Sphyraena pinguis*, are pelagic species, they are also frequently caught by the Buri trawls. The lizardfish and the pike eel were collected in May, and the cutlassfish and the barracuda, whose catch is increased from late summer, were collected in October. After measuring their TLs to the nearest 1 mm, their stomachs were dissected and their prey items sorted into two dietary categories, fishes and crustaceans. It was also noted if *A. japonicum* was found in their stomachs. The body size range and the sample size were 204–520 mm ( $n = 33$ ) for *Saurida* sp., 600–780 mm ( $n = 6$ ) for *M. cinereus*, 405–582 mm ( $n = 7$ ) for *T. japonicus* and 226–295 mm ( $n = 9$ ) for *S. pinguis*. The sample size corresponded approximately to their relative abundance.

For statistical analysis, parametric tests were used. Data on FSI and GFI were log-transformed because they did not fit a normal distribution. We performed two-factor ANOVA to examine age- or sex-specific differences in the parameters in each month. In all figures, plots and vertical bars represent means and standard deviations, respectively.

## RESULTS

### Life history and population characteristics

In the Uwa Sea, the population of *A. japonicum* consisted of mainly three age classes (Fig. 2). The breeding season was from June to September, judging from the seasonal patterns of the GSIs (Fig. 3). Fish in the youngest age class, whose TLs ranged between 40 and 70 mm, appeared in September (Fig. 2), suggesting that they were newly settled juveniles ( $0^+$ ). The juveniles grew rapidly from autumn to winter (Fig. 4). Their growth leveled off in spring and was accelerated thereafter until winter, reaching nearly an asymptote at the age of two ( $2^+$ ). Fish reached maturity in the season following their settlement, becoming yearlings ( $1^+$ ) (Fig. 3). During the breeding season, the GSIs of  $1^+$  females were as high as those of older females ( $t_{113} = -1.04$ ,  $P = 0.30$ ). In winter, a large number of  $1^+$  fish disappeared from the fishing ground, whereas some rejoined the breeding population in the next season (Fig. 2). Fish that were estimated to be  $3^+$  or older from their body size were rarely

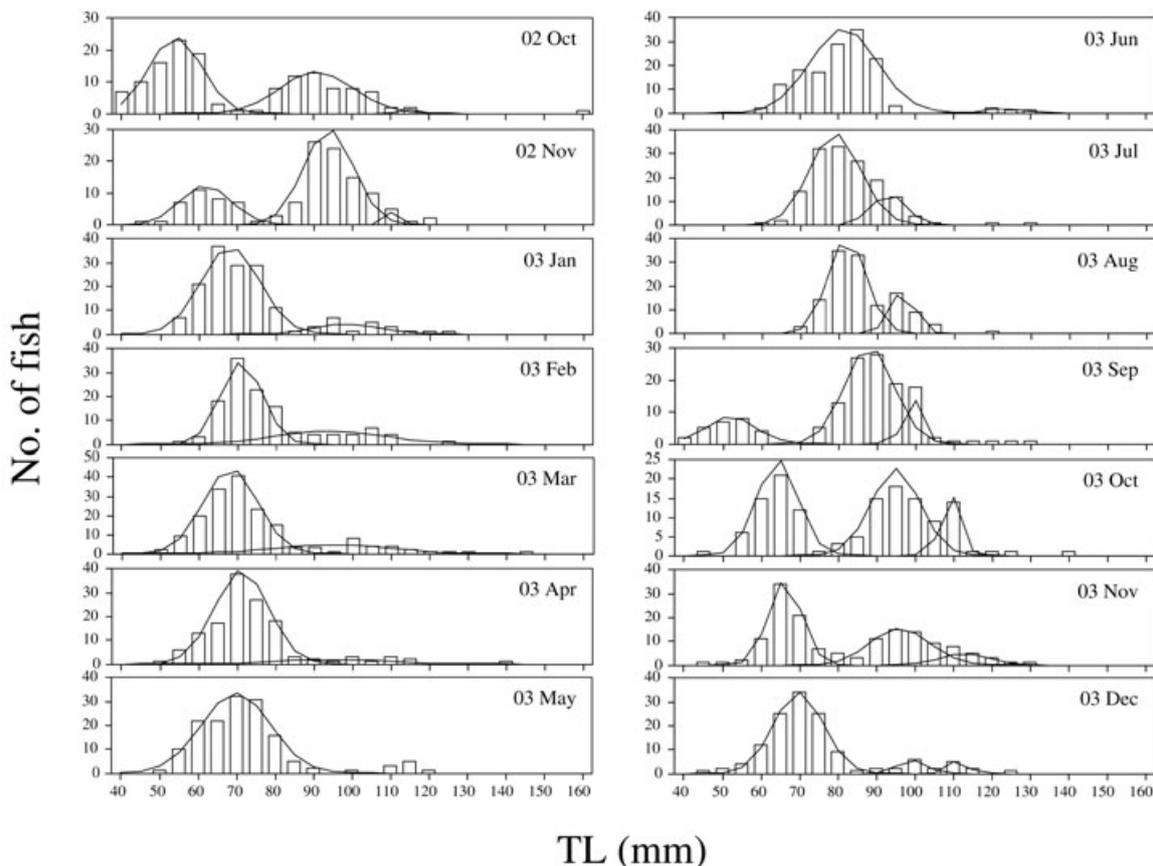
caught by the Buri trawls. The largest fish that was caught in October 2002 had a TL of 157.6 mm (Fig. 2) and was estimated to be more than four year old, according to the cohort analysis.

The sex ratio did not significantly deviate from equality (i.e. 0.5) through the most part of the first year of life, whereas it was biased toward females with increasing age (Fig. 5). The sex ratio of older fish (0.68) was more female-biased than that of  $0^+$  fish (0.58, data were pooled for all months;  $\chi^2 = 8.46$ , d.f. = 1,  $P = 0.004$ ).

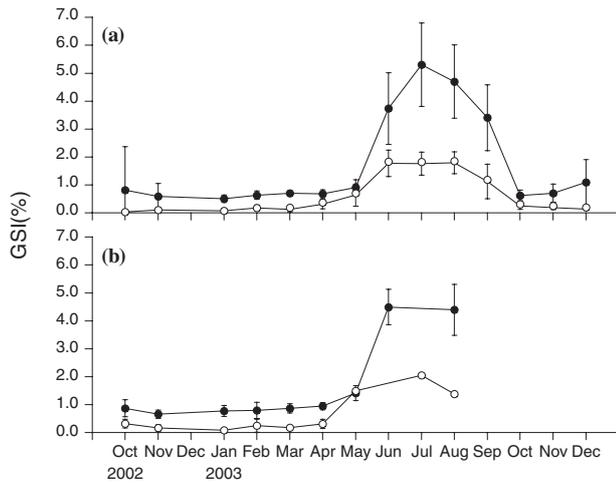
For  $0^+$  fish, there was no sexual difference in their TLs (two-factor ANOVA, sex:  $F_{1,449} = 2.94$ ,  $P = 0.09$ , month:  $F_{13,449} = 26.43$ ,  $P = 0.001$ ). As regards  $1^+$  or older fish, it was not possible to statistically compare the body size between the sexes, because of the small sample size for males.

### Feeding and somatic condition

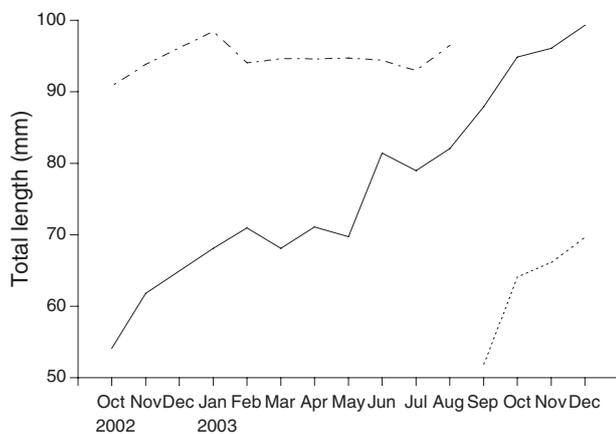
The feeding habits of *A. japonicum* changed as it grew. Small fish fed mainly on small crustaceans, such as copepods, ostracods, mysids, gammarids,



**Fig. 2** Size frequency of *Acropoma japonicum* caught by Buri trawls in the Uwa Sea, Japan. Solid lines represent the age structure estimated from the cohort analysis.



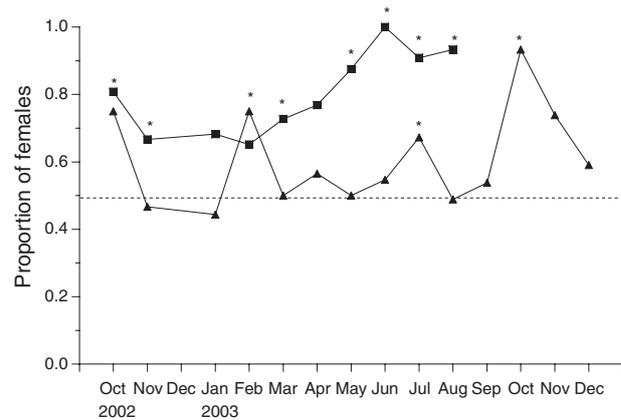
**Fig. 3** Seasonal changes in the gonadosomatic index (GSI) of males (open circles) and females (closed circles) born in (a) 2002 and (b) before 2002. Age classes born before 2002 are pooled.



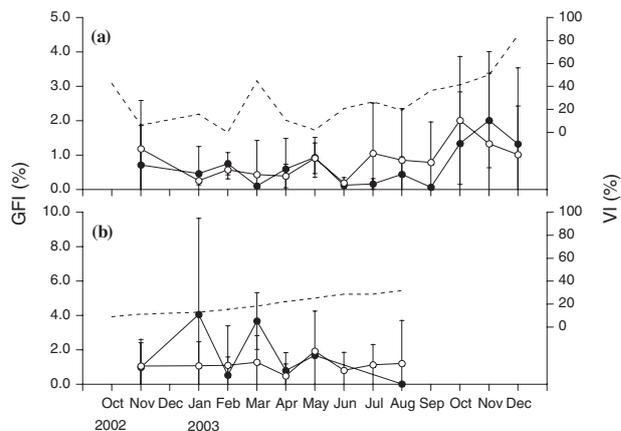
**Fig. 4** Growth curve drawn from monthly changes in the average body size in each age class estimated from Fig. 1. Dashed, solid and dotted lines represent age classes of fish born in 2001, 2002 and 2003, respectively.

euphausiids, and decapod larvae, whereas large fish had relatively large prey items, such as tiny squids, prawns, juvenile gobies, and larval anchovies. The GFIs were significantly higher for 1<sup>+</sup> fish than for 0<sup>+</sup> fish (Fig. 6; two-factor ANOVA, age:  $F_{1,511} = 3.95$ ,  $P = 0.05$ , month:  $F_{12,511} = 1.65$ ,  $P = 0.08$ ). The 1<sup>+</sup> fish showed an increase in GFI in autumn. During this season, they fed mainly on juvenile gobies that were newly settled.<sup>4</sup> There was no sexual difference in the GFI (two-factor ANOVA, sex:  $F_{1,499} = 1.89$ ,  $P = 0.17$ , month:  $F_{12,499} = 6.15$ ,  $P = 0.001$ ).

The condition factors (K) of 0<sup>+</sup> fish were increased in May, the prebreeding season, and

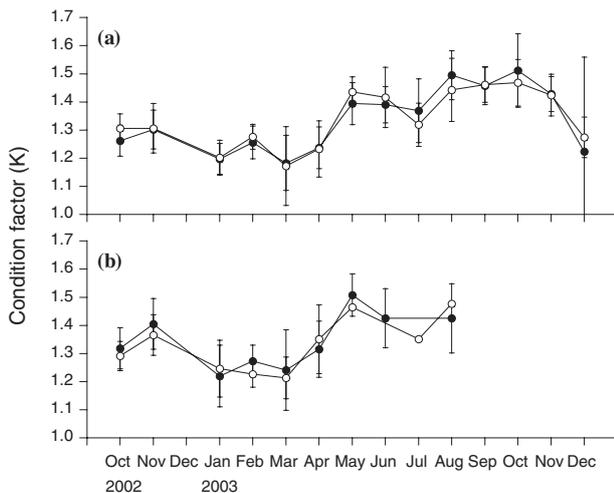


**Fig. 5** Seasonal changes in the sex ratio of age classes of fish born in 2002 (triangles) and before 2002 (squares). Asterisks indicate that the sex ratios significantly deviate from equality.

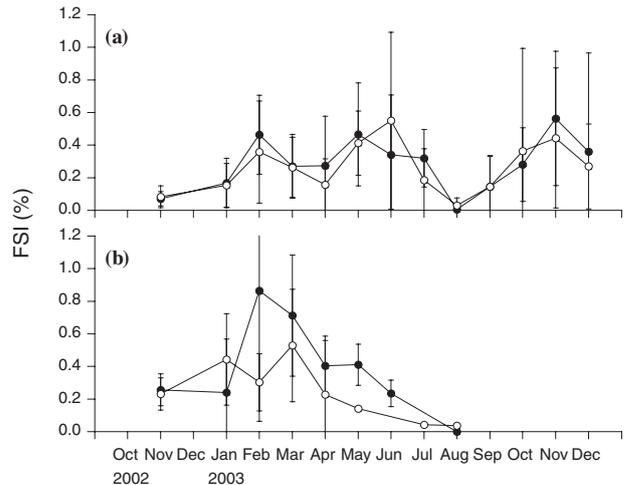


**Fig. 6** Seasonal changes in the gut fullness index (GFI) of males (open circles) and females (closed circles) born in (a) 2002 and (b) before 2002. Age classes of fish born before 2002 are pooled. Dotted lines represent the vacuity index (VI) for each class.

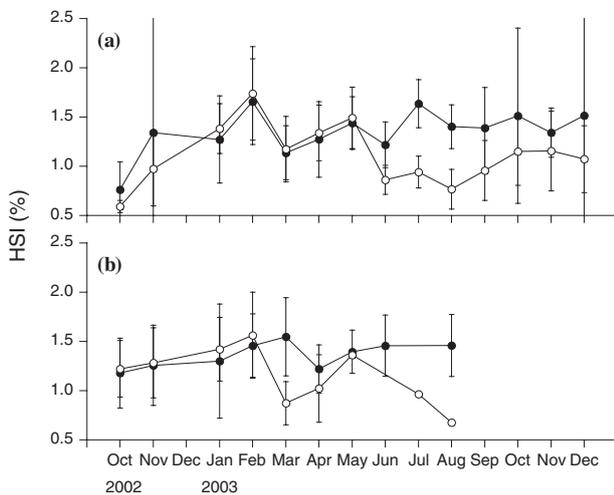
remained high throughout the breeding season (Fig. 7). For 1<sup>+</sup> fish, the Ks were significantly higher than for the 0<sup>+</sup> fish (two-factor ANOVA, age:  $F_{1,775} = 19.88$ ,  $P = 0.001$ , month:  $F_{13,775} = 40.80$ ,  $P = 0.001$ ). There was no significant difference in the K between sexes (two-factor ANOVA, sex:  $F_{1,775} = 2.44$ ,  $P = 0.12$ , month:  $F_{13,775} = 51.19$ ,  $P = 0.001$ , sex  $\times$  month:  $F_{13,775} = 0.73$ ,  $P = 0.73$ ). In contrast, the HSI showed a sexual difference in its seasonal pattern (Fig. 8; two-factor ANOVA, sex:  $F_{1,775} = 37.38$ ,  $P = 0.001$ , month:  $F_{13,775} = 9.21$ ,  $P = 0.001$ ). In both age classes, males showed a decrease in their HSI during the breeding season, whereas females maintained their HSI during this season (sex  $\times$  month:  $F_{13,775} = 5.63$ ,  $P = 0.001$ ). The 1<sup>+</sup> males also exhibited



**Fig. 7** Seasonal changes in the condition factor (K) of males (open circles) and females (closed circles) born in (a) 2002 and (b) before 2002. Age classes of fish born before 2002 are pooled.



**Fig. 9** Seasonal changes in the fat body somatic index (FSI) of males (open circles) and females (closed circles) born in (a) 2002 and (b) before 2002. Age classes of fish born before 2002 are pooled.



**Fig. 8** Seasonal changes in the hepatosomatic index (HSI) of males (open circles) and females (closed circles) born in (a) 2002 and (b) before 2002. Age classes of fish born before 2002 are pooled.

a drastic decrease in their FSI one month after the decrease in their HSI, almost depleting their fat reserves in August (Fig. 9). Although the FSI varied markedly among months, its seasonal pattern did not differ between the sexes (two-factor ANOVA, sex:  $F_{1,701} = 0.16$ ,  $P = 0.69$ , month:  $F_{12,701} = 33.80$ ,  $P = 0.001$ , sex  $\times$  month:  $F_{12,701} = 1.68$ ,  $P = 0.07$ ). The 1<sup>+</sup> fish usually showed higher FSI than the 0<sup>+</sup> fish (two-factor ANOVA, age:  $F_{1,701} = 45.47$ ,  $P = 0.001$ , month:  $F_{12,701} = 33.00$ ,  $P = 0.001$ ).

## Predation

Among four potential predators, the pike eel, *M. cinereus*, was the least piscivorous (Table 1), feeding on macrobenthic crustaceans exclusively, such as portunid crabs and penaeid prawns. The lizardfish, *Saurida* sp., fed mainly on benthic fishes, such as gobiid fishes and small conspecifics, and rarely on *A. japonicum* (Table 1). Two pelagic species, the cutlassfish, *T. japonicus*, and the barracuda, *S. pinguis*, were also piscivorous but were less likely to be the strong predators of *A. japonicum* (Table 1). In a total of 55 predatory fish specimens examined, there were only two cases (3.6%) in which *A. japonicum* was found in their stomachs.

## DISCUSSION

From local fishermen's experience, it is well known that *A. japonicum* shows the distinct social behavior of gathering around inshore spawning grounds (60–70 m in depth) during the breeding season. Although the details of its reproductive biology, particularly its behavioral aspects, have not yet been elucidated, anatomical observation of ovarian tissue has implied that the fish release pelagic spawns. The GSIs were three times higher for females than for males at the peak of the breeding season. However, this does not necessarily mean that females make a greater gametic effort because the gamete production rate is potentially high for

**Table 1** Feeding habits of large carnivorous fishes collected by Buri trawls in the Uwa Sea, Japan. The number of individuals feeding on items of each dietary category is expressed as percentage frequency (%F) with respect to the total number of samples. The %F in cases in which *Acropoma japonicum* was identified as a prey item are shown in parentheses

Species	Sample size	Dietary category	
		Fishes	Crustaceans
Lizardfish ( <i>Saurida</i> sp.)	33	63.6 (3.0)	9.1
Pike eel ( <i>Muraenesox cinereus</i> )	6	0.0 (0.0)	83.3
Cutlassfish ( <i>Trichiurus japonicus</i> )	7	85.7 (0.0)	42.9
Barracuda ( <i>Sphyraena pinguis</i> )	9	66.7 (11.1)	0.0
Total	55	60.0 (3.6)	20.0

males in communal spawners.<sup>5,6</sup> During the breeding season, the males of *A. japonicum* deplete their fat body and decrease their liver weight much more than the females. In fish, the fat body and the liver serve as important energy reserves for reproduction, storing energy in the form of lipids.<sup>7-9</sup> The more depleted energy reserves for the breeding male *A. japonicum* cannot be attributed to a sexual difference in energy gain because the food intake as indicated by the GFI did not differ between the two sexes. It is therefore suggested that the overall energetic cost of reproduction, whether gametic or behavioral, is higher for males than for females in *A. japonicum*.

The sex ratio was nearly equal for 0<sup>+</sup> fish and skewed toward females with increasing age. As has been reported for many fish species, energy depletion entailed by reproductive activities may be a cause of increased mortality risk<sup>10-13</sup> and its sexual difference often accounts for selective mortality between the sexes.<sup>14-16</sup> For *A. japonicum*, the female-biased sex ratio may be a consequence of the higher mortality for males that incur greater energetic loss during the breeding season.

Examination of the GSI indicated that yearlings usually reached maturity, making their gametic effort comparable to that of older fish. Moreover, the cohort analysis revealed that most of them did not survive to the second year of their lives. That *A. japonicum* shows such precocity and short life span is notable because it is considered to be a higher consumer in the coastal food web of the Uwa Sea.<sup>17</sup> As a rule, organisms at the higher trophic levels tend to have larger body sizes, which are also related to later maturation and longer life span<sup>18,19</sup> In the case of *A. japonicum*, its life span is nearly equivalent to that of the main prey item, anchovy *Engraulis japonicus*.<sup>20</sup> It is worth discussing why *A. japonicum* has a life history characteristic of short-lived species. In this fish, particularly in the larger size class, the mass disappearance occurred in winter (Fig. 2). Some possible explana-

tions of this phenomenon have been presented: predation, postbreeding emaciation, overfishing, and seasonal migration. Predation is not considered to be a crucial factor for determining the adult mortality of *A. japonicum* because sympatric large carnivorous fishes rarely prey on it. In addition, the size-selective disappearance found in this fish does not accord with the general pattern in which smaller fish are subject to higher predation pressure. Post-breeding emaciation is often considered to be the primary cause of winter mortality in fishes.<sup>10,13</sup> In *A. japonicum*, the emaciation was remarkable during the breeding season. However, the somatic condition was quickly recovered in the postbreeding season when food availability was relatively high. As older fish had higher energy reserves than the younger fish, the postbreeding emaciation was less likely to cause the winter disappearance of older fish.

In general, fishing may be a selective force that alters the life history traits of exploited fish. The most representative response in harvested populations is a shift toward earlier maturation and reduced body size.<sup>21-23</sup> Such life history alterations might also have been caused by a reduction in trawl mesh size.<sup>24</sup> Although we have no scientific data on the long-term population trend of *A. japonicum* from the Uwa Sea, local fishermen have narrated that the fish size has been substantially reduced in the last several decades (K. Yakushijin, Uwajima Fish-Paste Cooperative Association, pers. comm., 2002). To our surprise, their anecdote says that the past largest fish reached approximately 25 cm, which is much larger than the maximum size recorded (157.6 mm) in the present study, implying that a size reduction took place in the Uwa Sea population. Although the existence of some extremely large individuals in the present population suggests that *A. japonicum* has the potential to live longer than expected from its life table, it remains unclear to what extent the observed short life span can be accounted for by

the effect of Buri trawls and whether such a phenotypic shift is based on genetic changes due to fishing pressure.

As an alternative explanation of the winter disappearance, older fish might have emigrated seasonally from inshore to offshore. Since the operation of the Buri trawls is limited to within 1 km of the shore, this could not be verified in the present study. However, if the size distributions of fish captured by the inshore Buri trawls and the offshore beam trawls were compared all year round, it would be possible to obtain useful information on the size- or age-specific habitat shift of *A. japonicum*. The discrimination of the fishing effects from the migratory nature, although these two are not mutually exclusive, will be of great significance in the future fisheries management of this fish.

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