

# Age and growth of the yellowbelly threadfin bream *Nemipterus bathybius* in Kagoshima Bay, southern Japan

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**ABSTRACT:** Age and growth of the yellowbelly threadfin bream *Nemipterus bathybius* in Kagoshima Bay, southern Japan were examined using sectioned otoliths of 1359 fishes collected from April 1998 to November 2000. Monthly changes in marginal growth increments indicated that ring marks (outer edge of opaque zone) were formed once a year between May and August. Assuming a birth date of 1 July from the monthly change of gonadosomatic index, ages were assigned to every individual according to the number of ring marks. Length-at-age and weight-at-age data were best fitted to the von Bertalanffy among the three growth models. Equations obtained were  $FL_t = 274.7(1 - \exp(-0.341(t + 0.762)))$  for males and  $FL_t = 231.0(1 - \exp(-0.161(t + 4.405)))$  for females, where  $t$  is age (year) and  $FL_t$  is the fork length (mm) at age  $t$ , and they were significantly different (i.e. males grew faster than females). Maximum age observed was approximately 8 years for males and approximately 10 years for females.

**KEY WORDS:** age, growth, Kagoshima Bay, *Nemipterus bathybius*, otolith, southern Japan, yellowbelly threadfin bream.

## INTRODUCTION

The threadfin breams of the genus *Nemipterus* are widespread throughout the tropical and subtropical Indo-West Pacific region and more than 20 species are recognized.<sup>1</sup> They are small to moderate-sized fishes and most inhabit shallow sand or mud bottoms, and are taken commercially by hook-and-line and bottom trawl.<sup>2</sup>

Many biological studies have been done for the genus *Nemipterus*. Eggleston studied the fisheries biology of some nemipterid fishes in Hong Kong.<sup>3</sup> Russell summarized the diagnostic morphology, geographic distribution, habitat and general biology of nemipterid fishes of the world.<sup>1</sup> He also reviewed the threadfin breams of the genus *Nemipterus* from Japan and Taiwan.<sup>2</sup> Young and Martin examined the sex ratios and hermaphroditism in nemipterid fishes from northern Australia.<sup>4</sup> Lau and Sadovy studied the gonad structure and sexual pattern in two threadfin breams and possible function of the dorsal accessory duct.<sup>5</sup>

The threadfin breams of the genus *Nemipterus* are commercially important in many parts of the

world; therefore, stock parameters such as for age, growth and mortality have been examined to manage them properly. The age and growth parameters of the following species have been examined: *N. peronii* from the north-west shelf of Australia using otoliths,<sup>6</sup> *N. peronii* on the east coast of peninsular Malaysia by length frequency analysis,<sup>7</sup> *N. japonicus* in the north-west continental shelf of India by length frequency analysis,<sup>8</sup> *N. japonicus* off Kuwait using otoliths,<sup>9</sup> *N. virgatus* off Fukuoka, Japan by scale reading,<sup>10</sup> *N. virgatus* from the East and South China Seas using otoliths,<sup>11</sup> *N. furcosus* from north-west Australia using otoliths and length frequency analysis.<sup>12</sup> For *N. peronii*<sup>6</sup> and *N. japonicus*,<sup>9</sup> total or natural mortality were also estimated, and for *N. peronii* the stock status and management scheme were proposed.<sup>7</sup>

In Kagoshima Bay, located in southern Kyushu, Japan, the following two species of the genus *Nemipterus* are distributed: *N. bathybius* in the entire bay and *N. virgatus* in the entrance area of the bay (Vladimir Puentes Granada, unpubl. data, 2002). Of these two species, *N. bathybius* is captured in large quantities by fishing gear such as Danish seine, longline, gill net, and hook-and-line in Kagoshima Bay, and proper stock management is needed. There are many sources of information on the age and growth of *N. virgatus* as described above, but very little for *N. bathybius*.

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In the present study, the age and growth of *N. bathybius* in Kagoshima Bay was examined using transverse sections of otoliths, which is the best method for age determination of fish at present.

## MATERIALS AND METHODS

A total of 1818 specimens (536 males and 1282 females) of *N. bathybius* were collected at Iwamoto Fishermen's Cooperative (IFC), Ibusuki city and Kagoshima fish market, Kagoshima city, Japan, from April 1998 to November 2000. Samples from the IFC were mostly from Danish seine catches, while those from the Kagoshima fish market were from longline or gill net, all being caught at depths less than 100 m (Fig. 1).

Fork length (*FL*) and body weight (*BW*) were measured to the nearest millimeter and to the nearest gram for every fish sampled. Gonads were also measured to the nearest 0.01 g (*GW*) and then

preserved in Bouin's solution for subsequent histological observations. Sex was checked by the naked eye or by microscope. Gonadosomatic index (*GSI*) was calculated as follows:

$$GSI = 100 \times GW / (BW - GW) \quad (1)$$

Based on preliminary observations of both scales and otoliths (sagittae), sectioned otoliths revealed clear ring marks as shown in Fig. 2, while scales were difficult to read and offered no reliable data. Therefore, the right sagittae were used for age determination; the left sagittae were used if the right sagittae were damaged when extracted from the fish or during the sectioning process. Otoliths of 1563 fish specimens were embedded in epoxy resin, cut with a microcutter (type MC-201; Maruto Co., Ltd, Tokyo, Japan) and polished using a grinder (type 9820; Makita Co., Ltd, Tokyo, Japan) in order to make transverse sections crossing the focus, leaving a thin slice of approximately 0.2 mm thick, and mounted on a glass slide and coated with nail enamel.<sup>13</sup>

The number of ring marks (outer edge of opaque zone) on sectioned otoliths was counted by two readers using a microscope (LEICA MZ 12.5; Leica Microsystems, Heerbrugg, Switzerland) with transmitted light under a black background at 40× magnification. Otoliths difficult to read were taken out; then, if there was an agreement between both readers, the resulting counts of the ring marks were adopted. Distances from the focus to the outer edge of each opaque zone (ring radius,  $r_i$ ) and to the periphery of the otolith (otolith radius,  $R$ ) were measured with the built-in micrometer of the microscope along the dorsal tip of sulcus acusticus (Fig. 3), as this area showed the clearest ring marks among other areas within the otolith section, and marks increased steadily. The marginal growth increment (*MGI*) is expressed as the following equation and was used to establish the period of ring formation:

$$MGI = (R - r_n) / (r_n - r_{n-1}) \quad (2)$$

where  $R$  is the otolith radius,  $r_n$  is the distance from the focus to the outer edge of outermost opaque zone, and  $r_{n-1}$  is the distance from the focus to the outer edge of the immediately preceding opaque zone.

The following power equation was used to relate fork length (*FL*) to otolith radius ( $R$ ) at capture:

$$FL = aR^b \quad (3)$$

Assuming a birth date of 1 July, which approximately corresponded to the peak spawning season, ages were assigned to every individual according to the number of ring marks (outer edge of opaque zone). A new ring mark found on the otolith of a

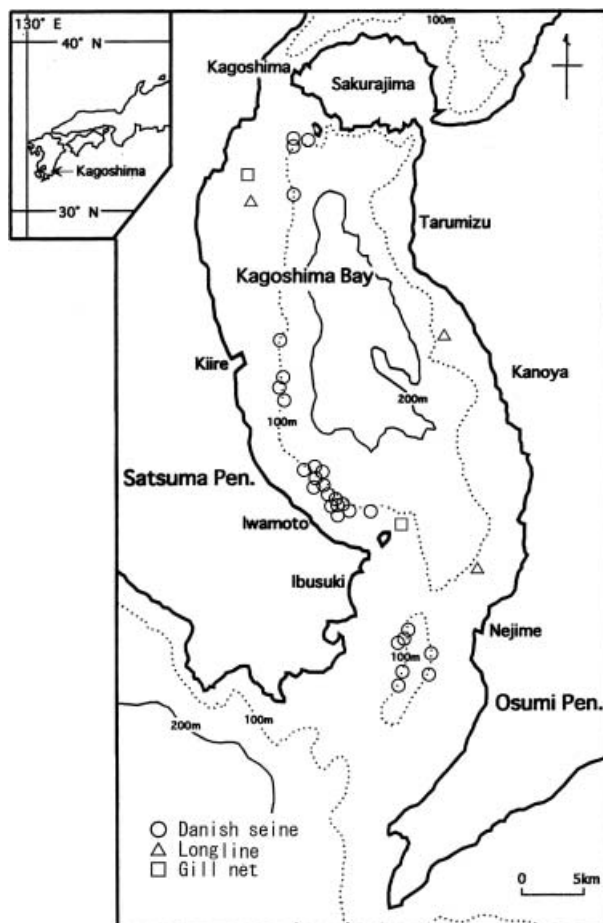
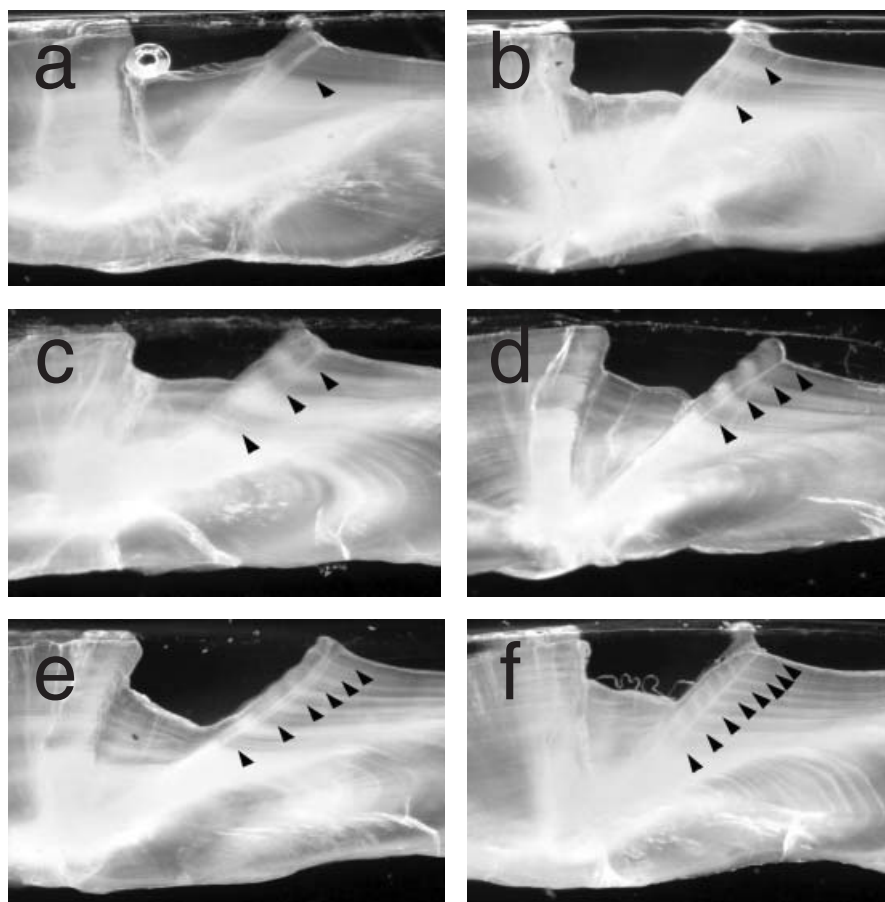
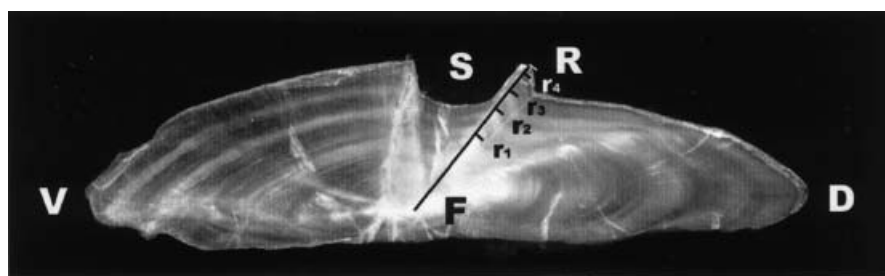


Fig. 1 Sampling sites of *Nemipterus bathybius* in Kagoshima Bay, southern Japan.



**Fig. 2** Ring marks ( $\blacktriangle$ ) on transverse sections of otoliths of the six representative specimens of *Nemipterus bathybius* sampled in Kagoshima Bay. (a) a 145-mm FL female with one ring mark, (b) a 174-mm FL male with two ring marks, (c) a 152-mm FL female with three ring marks, (d) a 184-mm FL male with four ring marks, (e) a 193-mm FL female with six ring marks, (f) a 187-mm FL female with eight ring marks.



**Fig. 3** Measurement axis of sectioned otolith of *Nemipterus bathybius*. F, focus;  $r_1$ – $r_4$ , annual ring radii 1–4; R, otolith radius; S, sulcus acusticus; V, ventral side; D, dorsal side.

fish captured before 1 July was not considered as an annulus in age assignment, whereas when a fish sampled after the assumed birth date had no new ring mark, an annulus that was supposed to form was considered in age estimation. The time elapsed from July to the sampling month was also considered in assignment of ages.<sup>13</sup>

The following three growth models (von Bertalanffy, Gompertz and Logistic) in terms of length were used for the analysis:

$$\text{Von Bertalanffy: } L_t = L_\infty (1 - \exp(-K(t - t_0))) \quad (4)$$

$$\text{Gompertz: } L_t = L_\infty \exp(-\exp(-K(t - t_0))) \quad (5)$$

$$\text{Logistic: } L_t = L_\infty / (1 + \exp(-K(t - t_0))) \quad (6)$$

where  $L_t$  (mm) is the fork length at age  $t$  (years),  $L_\infty$  (mm) is the asymptotic fork length,  $K$  is the growth coefficient, and  $t_0$  (year) is the hypothetical age when the fork length would be zero.

In terms of weight, the following von Bertalanffy growth model was used:

$$W_t = W_\infty (1 - \exp(-K(t - t_0)))^3 \quad (7)$$

where  $W_t$  (g) is the body weight at age  $t$  (years) and  $W_\infty$  (g) is the asymptotic body weight. For the Gompertz and Logistic models in terms of weight,  $L_t$  and  $L_\infty$  in equations 5 and 6 were replaced with  $W_t$  and  $W_\infty$ , respectively.

These growth curves were fitted to the unweighted length-at-age or weight-at-age data by non-linear regression analysis (Levenberg–Marquardt method)<sup>14</sup> using the curve-fitting function of the personal computer software Delta Graph 4.5 (Delta Point Inc., Monterey, CA, USA). The best-fitting model was selected on the basis of the *AIC* (Akaike's Information Criterion) values:<sup>15</sup>

$$AIC = n \ln Y_{\min} + 2p \quad (8)$$

where  $n$  is the number of specimens used for the analysis,  $Y_{\min}$  is the minimum value of the residual sum of squares, and  $p$  is the number of estimated parameters. The minimum value of *AIC* shows the best fitting of the model. The statistical tests of the non-linear fork length–otolith radius relationships and the growth equations between sexes were followed by Chen *et al.*<sup>16</sup>

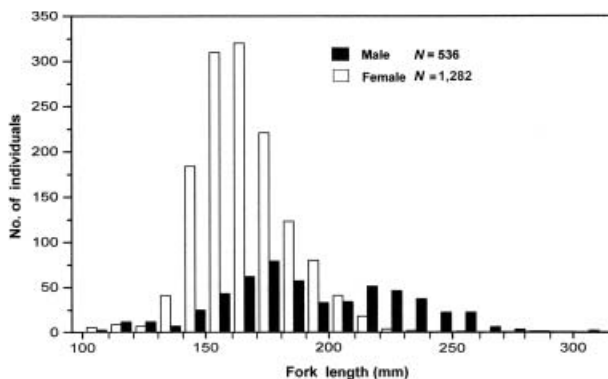
## RESULTS

### Length frequency distribution

Males ( $N=536$ ) were significantly larger than females ( $N=1282$ ) in fork length (*FL*) (Mann–Whitney *U*-test,  $P < 0.01$ ; Fig. 4). Length frequency distributions clearly showed differences in the range of sizes between sexes: most females ranged from 130 to 210 mm *FL* and males from 140 to 260 mm *FL*.

### Ring formation period

Ring marks of 204 otoliths (13%) out of 1563 examined were not clear and difficult to read or, if readable, gave disagreements between two readers. The remaining 1359 otoliths (87%) showed clear ring marks (Fig. 2) and were used for the following growth analysis.



**Fig. 4** Length frequency distribution of *Nemipterus bathybius* in Kagoshima Bay.  $N$ , number of fish examined.

In order to estimate the period of ring mark (outer edge of opaque zone) formation, monthly changes of the marginal growth increment (*MGI*) were examined by sex and by the number of ring marks (i.e. by ring group) (Figs 5,6). In *MGI* analysis, an appearance of low *MGI* values suggests that new rings were recently completed, and an appearance of high *MGI* values suggests that new rings were not completed. The period of coexistence of low and high *MGI* values, therefore, is considered as the ring formation period. In male *N. bathybius* (Fig. 5), the ring formation period was from May to July in the one-ring group, June to July in the two-ring group, August in the three-ring group, June to August in the four-ring group, and August in the five- to seven-ring group. In females, (Fig. 6), ring formation period in each ring group also ranged from May to August, indicating that ring marks were formed once a year during these months (i.e. considered as an annual mark).

Figure 7 shows the monthly changes in gonadosomatic index (*GSI*) by sex. For both sexes *GSI* started to increase from May, and maintained high values from July to September, then dropped in October. This trend was notable for females and the spawning season of *N. bathybius* was considered to be from May to October, with a peak occurring during July to September in Kagoshima Bay. The *MGI* analysis showed that the ring formation season was from May to August, corresponding to the early spawning season.

### Fork length–otolith radius relationship

The fork length (*FL*, mm)–otolith radius (*R*, mm) relationship for each sex was represented by the following equations (Fig. 8):

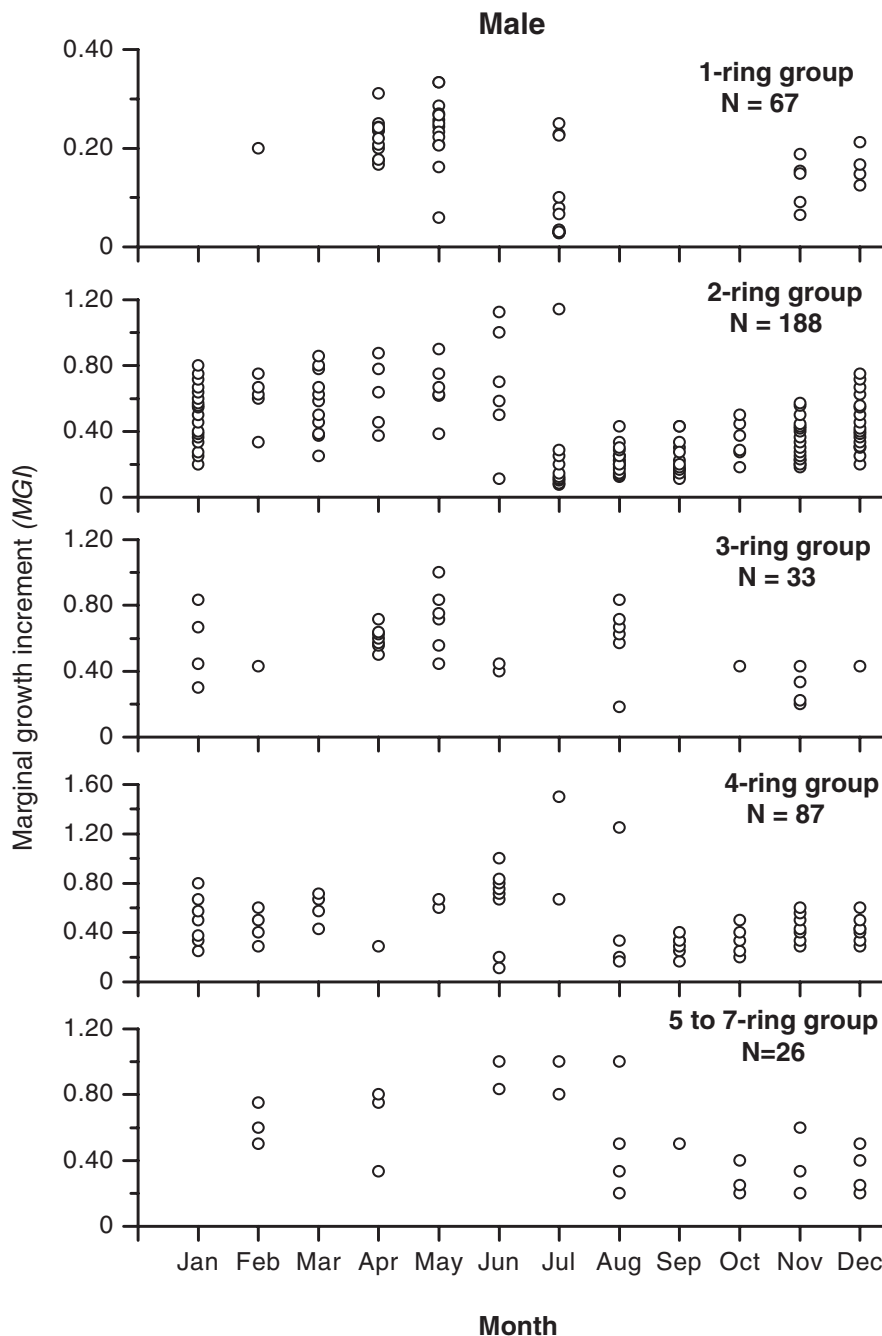
$$\text{Male: } FL = 167.655 R^{0.797} \quad (N = 401; r^2 = 0.659) \quad (9)$$

$$\text{Female: } FL = 148.827 R^{0.480} \quad (N = 958; r^2 = 0.551) \quad (10)$$

These two curves significantly differed in the residual sum of squares ( $P < 0.01$ ). In both curves, coefficient of determination ( $r^2$ ) was not high, so that back-calculation method was not used for growth analysis. In the present study, the age assignment method to every individual (i.e. length-at-age and weight-at-age data) was used for the analysis.

### Growth

The growth curves fitted to the length-at-age data were as follows:



**Fig. 5** Monthly changes in marginal growth increment (MGI) for sectioned otoliths of males.

Von Bertalanffy:

Male:  $FL_t = 274.7 (1 - \exp(-0.341(t + 0.762)))$   
 $(r^2 = 0.804; AIC = 4591.2)$  (11)

Female:  $FL_t = 231.0 (1 - \exp(-0.161(t + 4.405)))$   
 $(r^2 = 0.628; AIC = 11182.8)$  (12)

Gompertz:

Male:  $FL_t = 263.7 \exp(-\exp(-0.476(t - 0.346)))$   
 $(r^2 = 0.802; AIC = 4595.3)$  (13)

Female:  $FL_t = 226.0 \exp(-\exp(-0.204(t + 2.269)))$   
 $(r^2 = 0.626; AIC = 11187.5)$  (14)

Logistic:

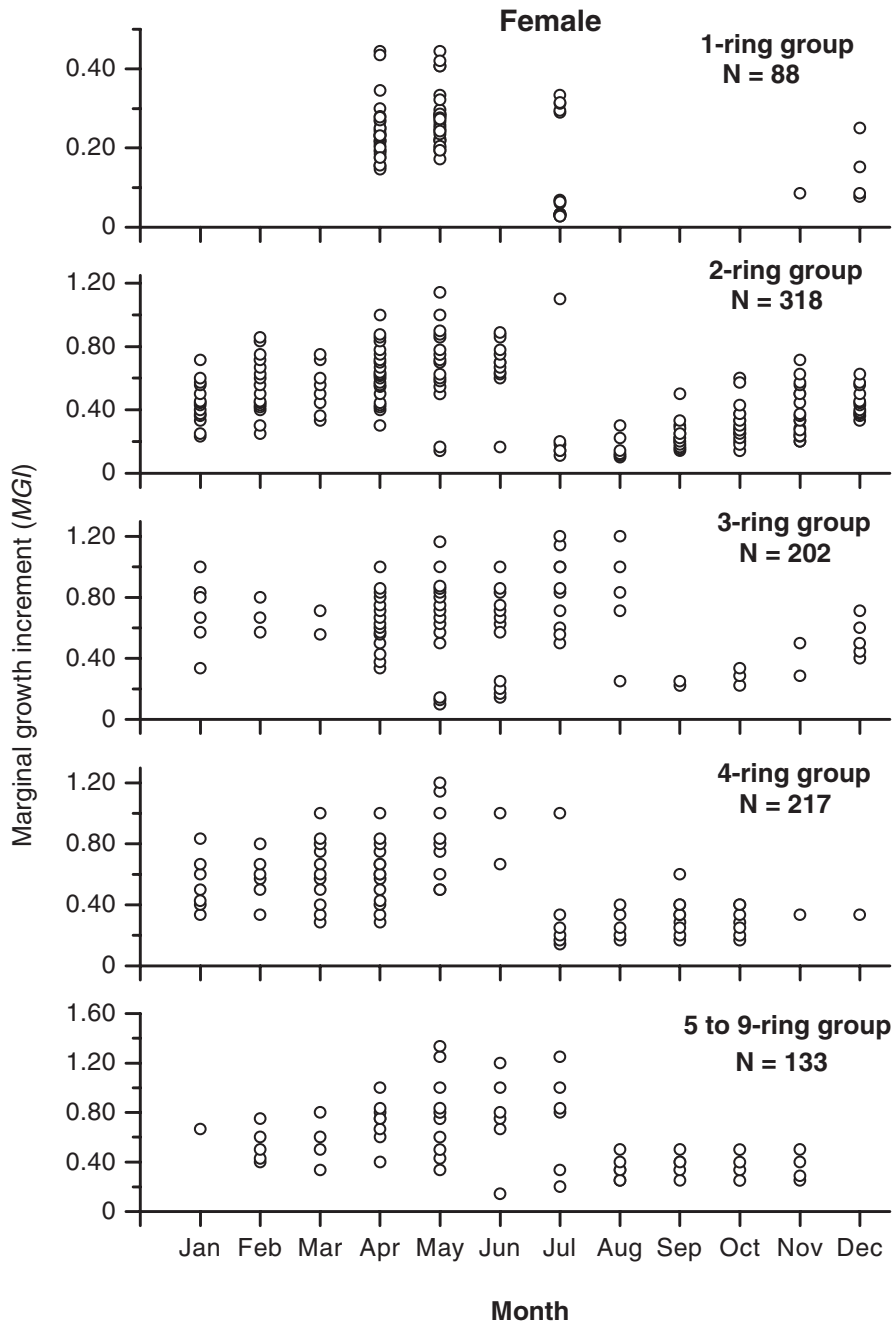
Male:  $FL_t = 257.2 / (1 + \exp(-0.608(t - 0.986)))$   
 $(r^2 = 0.800; AIC = 4600.2)$  (15)

Female:  $FL_t = 222.4 / (1 + \exp(-0.248(t + 0.843)))$   
 $(r^2 = 0.624; AIC = 11191.8)$  (16)

The growth curves fitted to the weight-at-age data were:

Von Bertalanffy:

Male:  $W_t = 408.2 (1 - \exp(-0.292(t + 1.120)))^3$   
 $(r^2 = 0.766; AIC = 5256.6)$  (17)



**Fig. 6** Monthly changes in marginal growth increment (MGI) for sectioned otoliths of females.

Female:  $W_t = 294.0 (1 - \exp(-0.118 (t + 5.726)))^3$   
 $(r^2 = 0.578; AIC = 12265.6)$  (18)

Gompertz:

Male:  $W_t = 374.2 \exp(-\exp(-0.384(t - 2.982)))$   
 $(r^2 = 0.765; AIC = 5258.4)$  (19)

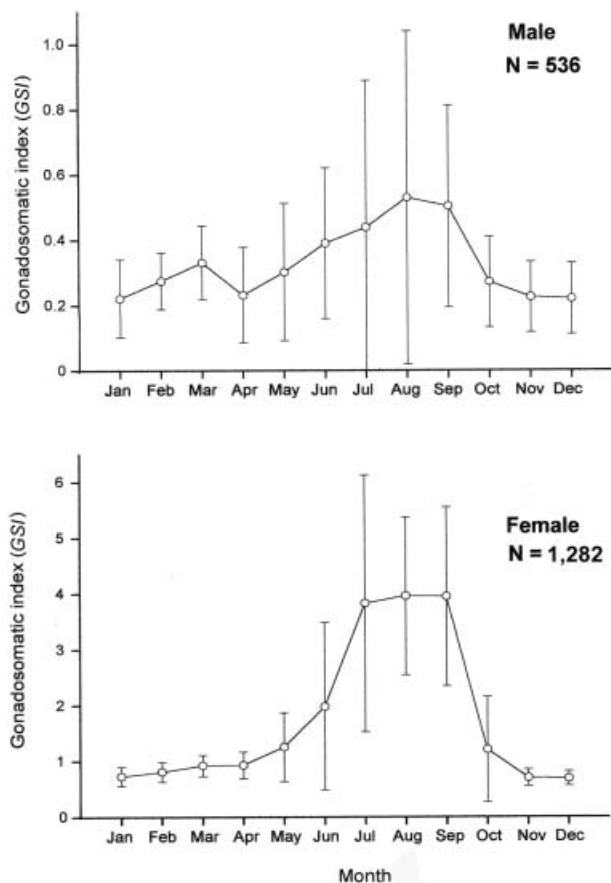
Female:  $W_t = 256.3 \exp(-\exp(-0.164(t - 4.055)))$   
 $(r^2 = 0.577; AIC = 12267.3)$  (20)

Logistic:

Male:  $W_t = 331.7 / (1 + \exp(-0.650(t - 3.565)))$   
 $(r^2 = 0.762; AIC = 5264.7)$  (21)

Female:  $W_t = 207.8 / (1 + \exp(-0.304(t - 4.689)))$   
 $(r^2 = 0.575; AIC = 12271.9)$  (22)

In all models, growth of males and females significantly differed in the residual sum of squares ( $P < 0.01$ ), male being bigger than female. The

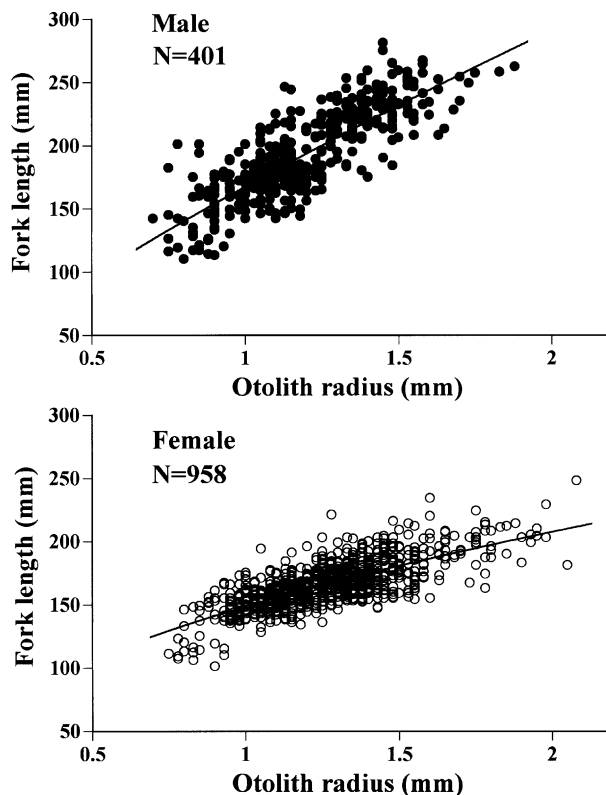


**Fig. 7** Monthly changes in mean gonadosomatic index (GSI) for male and female *Nemipterus bathybius* in Kagoshima Bay. Vertical bars indicate standard deviations. N, number of fish examined.

minimum value of *AIC* was found in the von Bertalanffy model, for both males and females and for both length-at-age and weight-at-age data, showing the best fitting of the curves (Figs 9,10).

## DISCUSSION

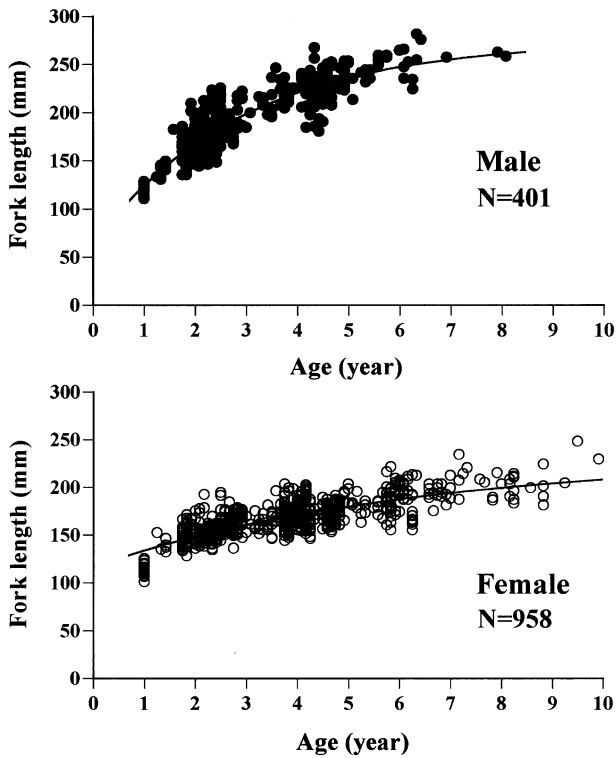
Preliminarily, we examined the suitability of scale and/or otolith of *N. bathybius* for age determination. Clear age marks were observed in otoliths (Fig. 2), but not in scales. The suitability of otoliths for age determination in nemipterid fishes has already been suggested by Eggleston,<sup>3</sup> Sainsbury and Whitelaw,<sup>6</sup> Samuel,<sup>9</sup> and Kao and Liu.<sup>11</sup> However, most of them used whole otoliths. Only Samuel<sup>9</sup> used sectioned otoliths for older and larger fishes. The superiority of sectioned otoliths to whole otoliths has been demonstrated in Pacific hake *Merluccius productus*<sup>17</sup> and flathead *Platycephalus speculator*<sup>18</sup> and, therefore, sectioned otoliths were used in the present study. Our



**Fig. 8** Relationship between fork length and otolith radius for males and females of *Nemipterus bathybius*. N, number of fish examined.

data showed a relatively high percentage (87%) of readable otoliths.

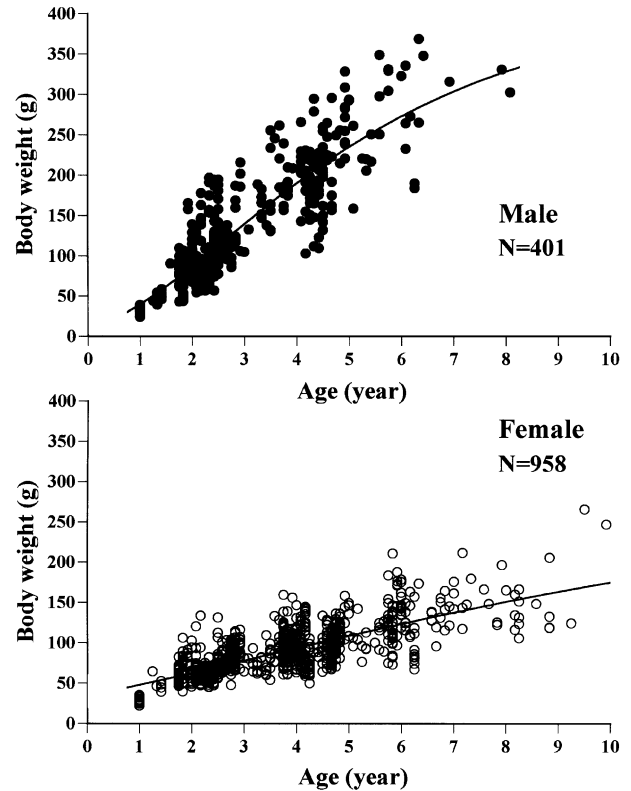
The von Bertalanffy growth model showed the best fit among the three models. In terms of length (Fig. 9), males grew gradually from 1 to 8 years of age and fitted well to the curve, as did females of more than about 2 years of age, although growth was very slow. The model, however, could not describe well the growth of females at a younger age. Beckman *et al.*<sup>19</sup> observed a similar trend in the black drum *Pogonias cromis* in the Gulf of Mexico, where the sharp decrease in growth rate at 4–5 years of age was attributed to the reallocation of energy from growth to reproduction, as black drums mature at approximately this age. In the case of *N. bathybius*, females start to spawn at about 1–2 years of age (Vladimir Puentes Granada, unpubl. data, 2003) and this may cause the decrease in growth rate at this age. The von Bertalanffy growth curve passing through the origin ( $t_0 = 0$ ) fitted better with the younger female fishes, but yielded a maximum length at about 4 years of age and, after that, the curve did not fit well to the length-at-age data. Therefore, it is necessary to describe the growth of *N. bathybius* with at least two growth curves through further studies on young fishes.



**Fig. 9** Von Bertalanffy growth curves fitted to length-at-age data of male and female *Nemipterus bathybius* in Kagoshima Bay. N, number of fish examined.

The fork length–otolith radius relationship (power curve) did not fit well in female *N. bathybius* of less than approximately 120 mm FL (Fig. 8). This relationship seems to change at the boundary of about 120 mm FL in females and this may relate to the decrease in growth rate after this body size, as described above. In addition, Fig. 8 shows a wide range of otolith radius for a certain body length in females (e.g. approximately 0.8–1.6 mm otolith radius to 150 mm FL). Beamish and McFarlane<sup>20</sup> reported that otoliths continue to grow predominantly towards the proximal side (towards the sulcus side) as the fish ages (i.e. even when a fish shows no or reduced body growth). In female *N. bathybius*, continuous otolith growth (Fig. 2) and slow down of body growth (Fig. 9) may cause a low slope of the curve and a wide range of otolith radius (i.e. a wide range of year class) in a certain body size.

The von Bertalanffy growth equations estimated for *N. bathybius* in Kagoshima Bay showed growth curves in which males grew faster and larger than females (Figs 9,10). Eggleston's data for *N. bathybius* and *N. virgatus* showed the same length for both sexes during the first year, then male fish grew faster and larger than female fish.<sup>3</sup>



**Fig. 10** Von Bertalanffy growth curves fitted to weight-at-age data of male and female *Nemipterus bathybius* in Kagoshima Bay. N, number of fish examined.

Kao and Liu<sup>11</sup> observed the same trend in *N. virgatus*. For *N. japonicus*, males and females grew more or less at the same rate until 2 years of age old; after that, males started to grow faster than females.<sup>9</sup> Thus, there seems to be a trend in which males grow faster and larger than females for many *Nemipterus* species. This trend might have evolved from the high reproductive success in larger males, where the following two cases may be considered:<sup>21</sup> (i) females directly prefer larger males such as in the mottled sculpin *cottus bairdi*;<sup>22</sup> and (ii) results of male–male competition such as the exclusive possession of females or female's preferred resources by large males in Cortez damselfish *Stegastes rectifraenum*.<sup>23</sup> The reproductive behavior of *N. bathybius* and other *Nemipterus* species is hardly known; a harem polygyny mating system, which often generates larger males, may occur in these *Nemipterus* species.

Length–frequency distribution for all specimens in *N. bathybius* showed a bimodal size–frequency distribution in which males reach larger sizes than females (Fig. 4). This is common in protogynous hermaphroditic species; however, *N. bathybius* is known to be a rudimentary hermaphrodite, where males have functional testes with rudimentary



**Table 1** Fork lengths (mm) at each age of *Nemipterus bathybius* in Eggleston's work and the present study

Age	Eggleston <sup>3</sup>		Present study <sup>†</sup>	
	Male	Female	Male	Female
1	120	120	124	134
2	150	140	168	149
3	190	160	199	161
4	210	160	221	171
5			236	180
6			247	188
7			255	194
8			261	200
9				204
10				208

<sup>†</sup>Calculated from equations 11 and 12.

ovarian portions throughout their life.<sup>24</sup> Lau and Sadovy<sup>5</sup> also confirmed that *N. virgatus* and *N. japonicus* are functionally gonochoristic species while the ovarian affinities of the dorsal accessory duct in males mean that they are also developmentally, but not functionally, hermaphrodites. This disparity in size between males (larger) and females (smaller) in these three *Nemipterus* species is mainly explained on the basis of different growth rates between sexes. However, the following other factors can also cause a bimodal length frequency distribution:<sup>5,25</sup> (i) differential mortalities between sexes; (ii) differential migration or spatial segregation by sex; and (iii) size-biased selectivity in fishing methods. To clarify whether these factors have an effect on size disparity or not, further field and experimental studies must be undertaken.

As shown in Table 1, the lengths of *N. bathybius* in Kagoshima Bay seem to be bigger than those in Hong Kong<sup>3</sup> at each age. The largest size difference is seen in males 2 years of age, in which fish from Kagoshima Bay are 18 mm larger than those from Hong Kong. Size differences in females are around 10 mm, except at 3 years of age in which mean lengths are quite similar. These differences in size in both regions may be caused by ecological differences, such as an abundance of *N. bathybius* itself and/or their prey or predator species, or by artificial differences such as fishing intensity, or by genetic differences between local populations. To clarify this, further studies on these factors may be needed.

Eggleston reported that there was no evidence for any differences in longevity for *N. virgatus* and *N. bathybius*, even though males grew faster than females.<sup>3</sup> His analyses, however, only extended to age 4 years for *N. bathybius* and to age 6 years for *N. virgatus*. Our findings, in contrast, indicated how females (up to about 10 years) live longer than males (up to about 8 years), even though males

grew faster and larger. Kao and Liu reported that *N. virgatus* reached a maximum of 5 years in females and 4 years in males in the East and South China Seas, showing a difference in longevity and also suggesting that males grew faster and larger than females.<sup>11</sup> A recent study for *N. virgatus* around Kagoshima prefecture, southern Japan showed females with a maximum of eight rings, and males with a maximum of five rings in otolith readings (Miagao S, pers. comm., 2002). A study on *N. japonicus*<sup>9</sup> and *N. peronii*<sup>7</sup> suggested a maximum age of 6 years in both species. Thus, *Nemipterus* species appear not to live beyond 10 years, where females may live a few years older than males. Differences in longevity between sexes may be explained by the following factors, but it is still unclear at present which has a predominant effect: (i) intrinsic factors, such as a high natural mortality in males caused by a more energetic consumption in reproductive strategy, like male–male competition, if present; and/or (ii) extrinsic factors, such as a high fishing mortality in large males caused by fishing gear selectivity or a high natural mortality in large males through predation. Future field and experimental studies on these factors must be undertaken.

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