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Age and Growth of the Starspotted Dogfish *Mustelus manazo* from Tokyo Bay, Japan

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Age and growth of the starspotted dogfish *Mustelus manazo* in Tokyo Bay were examined from centrum analysis using soft x-radiography. Based upon seasonal centrum edge analysis, a dark ring was formed annually, mostly in June. The von Bertalanffy growth equations were described as follows, male; $L_t = 1241[1 - \exp\{-0.120(t+2.59)\}]$, female; $L_t = 1341[1 - \exp\{-0.113(t+2.55)\}]$, where L_t is total length in mm and t is age in years. The maximum age was 8 years old for males and 10 years old for females. The growth until 2 years was similar in both sexes, but over 2 years females tended to grow larger than males. Sex ratios were approximately 1:1 until age class 4; after age class 5 the proportion of males was reduced.

Key words: Tokyo Bay, *Mustelus manazo*, age, growth, x-radiography, sex ratio

In recent years, the depletion of shark resources has become a serious problem all over the world. To prevent resource depletion, stock assessment is essential, so it is indispensable to clarify the traits needed for stock assessment.

The starspotted dogfish, *Mustelus manazo*, is commonly found along the coast of Japan[1] and is an important fishery resource. However, as is often the case with many shark species, there is not sufficient information on this species for population structure analysis.

Some studies on age and growth,[2-4] reproduction[3,5,6] and feeding habit[7] of M. manazo have been carried out in other areas. Taniuchi *et al.*[3] pointed out that several stocks may be recognized around Japan judging from the differences in growth parameters between the East China Sea and off Choshi. However, Cailliet *et al.*[4] conducted cross-exchange and comparative readings of vertebral centra used by Tanaka and Mizue[2] and Taniuchi *et al.*[3] and found that there were no statistically significant differences. To clarify whether differences are real and some unique stocks exist, more detailed studies on age and growth of *M. manazo* in Japan are needed. In the present study, we clarified the age and growth of *M. manazo* in Tokyo Bay to provide essential information on stock structure.

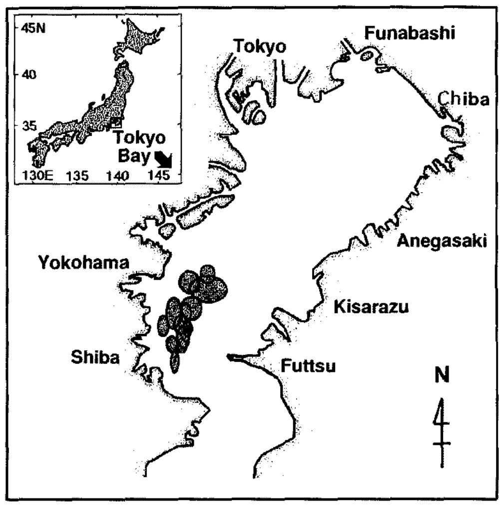

Fig. 1. Sampling location in Tokyo Bay, central Japan.

Materials and Methods

The sampling surveys were carried out in Tokyo Bay, from May 1994 to October 1995 (Fig. 1). Specimens were collected monthly in the muddy substrata at depths between 20 and 50 m in the southern part of the bay, because their distribution was almost limited to this area. Towing at about 2 knots for 40 to 90 minutes using a commercial bottom-trawl net (trap entrance 0.6 m high, 5.5 m wide, 5 cm mesh size, 3 cm mesh size of cod end) was repeated 5 to 10 times a day (500 and 1600 h). On occasions when insufficient numbers of specimens were collected, additional specimens of sharks landed at the fish market were to supplemented.

A total of 442 specimens, consisting of 191 males ranging in size from 264 to 946 mm TL and 251 females from 215 to 1070 mm TL, were collected during this study period (Table 1).

For age determination, the largest centra around the 32nd to 40th were used. After trimming off the excess connective tissues and preserving in 70% ethanol for several days, they were sectioned into half or about a thickness of 1-2 mm along the central longitudinal axis and ground with a revolving whetstone. Several techniques, such as Mayer's hematoxylin staining, silver nitrate staining, and soft X-radiography, were tried, as Yudin and Cailliet[8] did, to elucidate more calcified rings for 30 specimens selected at random. Ring counts agreed on small-sized specimens processed with all three techniques, but on large-sized

Table 1. Size distribution of specimens

Total length (mm)	Number of specimens		
	male	female	Total
201-300	5	8	13
301-400	57	57	114
401-500	25	22	47
501-600	24	23	47
601-700	24	23	47
701-800	37	35	72
801-900	16	41	57
901-1000	3	30	33
1001-1100	0	12	12
Total	191	251	442

specimens, particularly those with more than 5 rings, staining methods failed to distinguish the peripheral rings, while the soft X-radiography method could distinguish the periphery clearly. Therefore, counts were made by two readers using the soft X-radiography method. Each radius was measured by calipers from the focus to the distal margin of the dark rings (Fig. 2).

The period of annual formation was determined by monthly changes in percentage occurrence of the centra with dark rings.

The von Bertalanffy growth equations were obtained by Akamine's program.[9]

Results

Of 442 centra examined, 406 (91.9%) were readable, the remaining 36 centra (unreadable) had obscure rings. The monthly change in percentage occurrence of the centra with dark ring (Fig. 3) indicated that dark rings were formed mostly in June in both years. In addition, none of the 23 full-term embryos (218-304 mm TL) in April and May that were investigated had a ring on their centrum, while very small, free-swimming specimens (215-322 mm TL, n=9) captured in May and July had one ring. This suggests that the first ring was formed soon after birth. It also means that N years old specimens had N+1 rings.

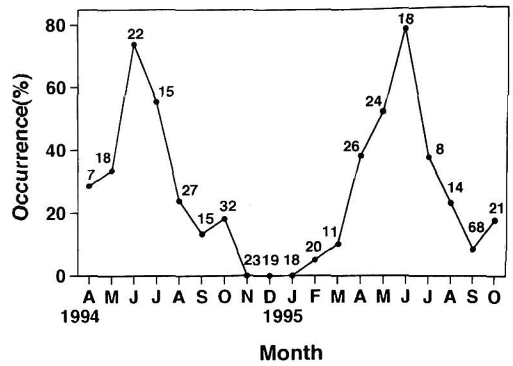

Fig. 3. Monthly changes in percentage occurrence of centrum with dark ring.

The numbers in the figure denote the number of readable specimens.

There was a good agreement in band counts between readers, especially on young specimens, with the percent agreement of exact counts, ±1 band, and ±2 bands, being 83%, 14%, 3%, respectively.

Total length and centrum radius were found to have a statistically significant relationship (Fig. 4). Analysis of covariance showed no significant difference between sexes, therefore, these data were combined. The equations are as follows,

$$y=190.8x^{0.797} \quad [r^2=0.974, n=442],$$

where y is total length in mm and x is centrum radius in mm.

The mean radii of each ring at each estimated age for males and females were very predictable, had low standard deviations, and were used to estimate the back-calculated length at age (Table 2). Neither Lee's nor reversed Lee's phenomenon was found for the mean centrum ring radii.

The von Bertalanffy growth equations derived from the back-calculated lengths are as follows;

$$\text{male:} \quad L_t=1241[1-\exp\{-0.120(t+2.59)\}]$$

$$\text{female:} \quad L_t=1341[1-\exp\{-0.113(t+2.55)\}]$$

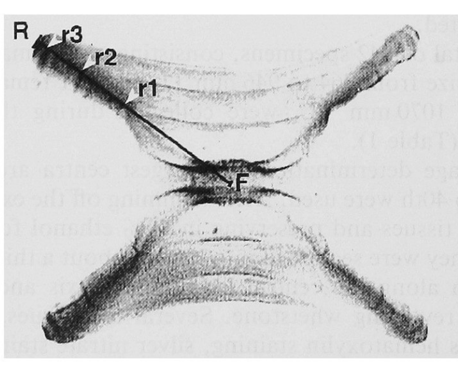

Fig. 2. Soft X-radiograph of centrum of *Mustelus manazo*, male, 517 mm TL, collected in August 1994.

R: centrum radius, r_1-r_3: annual ring radii, F: focus.

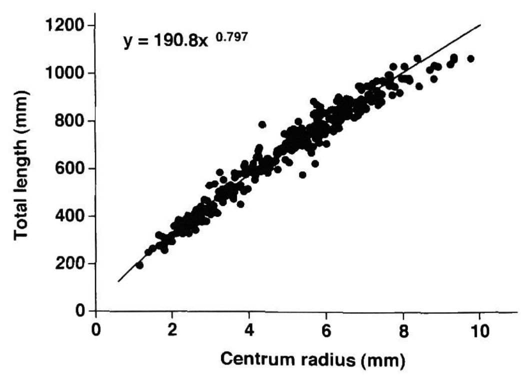

Fig. 4. Relationship between total length and centrum radius in *M. manazo*.

The curve and points in the figure indicate the regression one and data, respectively.

Table 2. Mean centrum ring radii (±SD) for each age group of *Mustelus manazo*

Age groups	N	Ring radii (mm) r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}
Male												
0	68	1.95±0.32										
1	16	1.93±0.18	2.58±0.30									
2	24	2.06±0.23	2.89±0.38	3.40±0.41								
3	23	2.06±0.46	3.16±0.27	3.93±0.36	4.51±0.42							
4	25	2.07±0.29	3.09±0.45	3.86±0.51	4.53±0.47	5.16±0.45						
5	17	2.07±0.28	2.98±0.41	3.63±0.33	4.17±0.38	4.67±0.40	5.30±0.40					
6	3	1.87±0.04	2.77±0.17	3.46±0.27	4.15±0.18	4.92±0.11	5.59±0.06	6.14±0.06				
7	2	2.01±0.08	2.93±0.00	3.54±0.06	4.19±0.08	4.81±0.12	5.38±0.09	5.93±0.05	6.55±0.00			
8	2	2.05±0.00	2.69±0.81	3.40±0.04	4.12±0.09	4.67±0.01	5.23±0.07	5.77±0.05	6.64±0.25	6.94±0.04		
Weighted mean	180	2.02±0.32	2.92±0.40	3.67±0.45	4.38±0.44	4.97±0.46	5.40±0.35	6.02±0.17	6.64±0.21	6.94±0.04		
Back-calculated length (mm)		334	448	538	619	684	732	797	862	893		
Female												
0	64	1.97±0.36										
1	19	1.98±0.27	2.61±0.42									
2	25	2.02±0.31	2.74±0.40	3.40±0.53								
3	26	2.03±0.27	3.07±0.39	3.91±0.49	4.52±0.57							
4	20	2.06±0.27	3.08±0.38	3.91±0.43	4.69±0.46	5.26±0.54						
5	31	2.04±0.30	2.99±0.41	3.73±0.42	4.51±0.44	5.16±0.48	5.71±0.50					
6	10	2.05±0.16	2.88±0.16	3.73±0.18	4.45±0.23	5.13±0.21	5.58±0.46	5.88±1.21				
7	7	2.05±0.15	2.84±0.16	3.57±0.25	4.38±0.35	5.09±0.38	5.82±0.36	6.46±0.34	7.04±0.32			
8	12	2.01±0.17	2.75±0.15	3.51±0.17	4.40±0.23	4.94±0.27	5.62±0.30	6.24±0.34	6.83±0.35	7.39±0.37		
9	9	2.01±0.11	2.76±0.10	3.56±0.12	4.30±0.17	4.99±0.29	5.67±0.36	6.31±0.36	6.94±0.42	7.55±0.43	7.99±0.44	
10	3	1.95±0.52	2.71±0.75	3.46±0.02	4.19±0.20	4.78±0.38	5.28±0.54	5.73±0.93	6.41±0.92	7.12±0.60	7.57±0.92	8.07±0.35
Weighted mean	226	2.02±0.30	2.89±0.42	3.68±0.47	4.48±0.47	5.13±0.46	5.72±0.46	6.32±0.77	6.92±0.40	7.44±0.43	7.88±0.62	8.07±0.35
Back-calculated length (mm)		334	444	539	630	703	766	829	891	944	988	1007

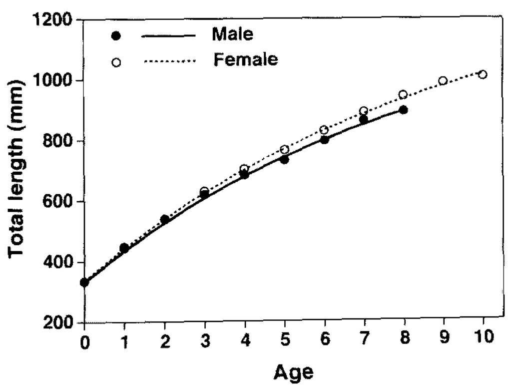

Fig. 5. von Bertalanffy growth curves in male and female *M. manazo*. Circles are the back-calculated length at age in years.

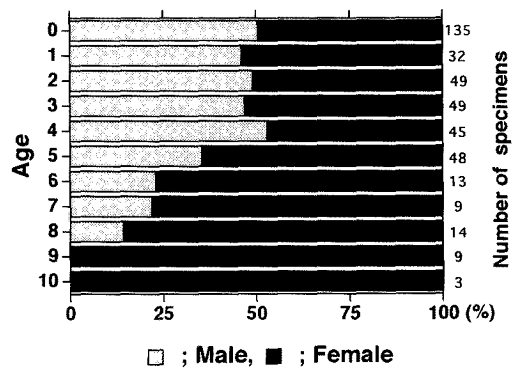

Fig. 6. Sex ratios for each age class of *M. manazo*.

where t is age in years and L_t is total length in mm at age t (Fig. 5).

The maximum ages in the specimens were 8 years old for males and 10 years old for females. The growth until 2 years was similar in both sexes, but over 2 years females tended to grow larger than males.

Sex ratios were approximately 1:1 until age class 4 (Fig. 6). After age class 5 the proportion of males was reduced (χ^2 test, age class 5, $p=0.043$; 6, $p=0.046$; 7, $p=0.090$; 8, $p=0.007$).

Discussion

In this study, we found that opaque (dark) rings were formed mostly in June, suggesting annual deposition. Similar estimates have been reported from two other areas for *M. manazo*.[2,3] Taniuchi *et al.*[3] suggested that in *M. manazo* collected from off Choshi the vertebral rings were formed during the period from March to April, but may be formed not regularly. The von Bertalanffy growth equations from the other two areas[2,3] were obtained by Allen's method,[10] since the relationships between total length and centrum radius or each centrum ring radius were rather variable. However, in the present study, Allen's method was not used because we could measure the distance of the focus to each ring.

According to Tanaka and Mizue[2] in the East China Sea, males grew slower than females over 2 years old, and the same trend was found in Tokyo Bay. In *Mustelus antarcticus* from southern Australian waters,[11] females grew larger than males over 3 years. Francis *et al.*[12] also suggested that in most, if not all, species of *Mustelus*, females grow larger and live longer than males.

Growth coefficient, K value (M, 0.120; F, 0.113), was the lowest for males in Tokyo Bay when compared those that from the East China Sea[2] and off Choshi.[3] In females K was lower in Tokyo Bay than in the East China Sea and higher than off Choshi. Furthermore K values in Tokyo Bay were lower than for any other species of the Genus *Mustelus* estimated by Francis.[13] That is, in Tokyo Bay, the growth rate of *M. manazo* was relatively low. The maximum ages of 8 years for males and 10 years for females of *M. manazo* suggest that the life span is relatively longer than that of *M. manazo* from other areas.[1,2] The maximum total length for males and females was higher than that in the East China Sea (912 mm TL, 957 mm TL) and lower than that of off Choshi (1002 mm TL, 1238 mm TL).

It is usually suggested that sharks show faster growth and smaller size in warmer water. Tokyo Bay is warmer than off Choshi where the catch depth is relatively deep, but colder than the East China Sea. The same trend in the bonnethead shark *Sphyrna tiburo* was reported.[14] These trends might be ascribed to the differences of food availability or environmental conditions as mentioned,[14] but need further study. Therefore, the difference in growth rates should be discussed with care.

Cailliet *et al.*[4] pointed out that the apparent differences in the growth rate between populations might not be real, and might be influenced by other factors. They commented that when studying possible differences in growth, several additional factors should be considered, for example, sample sizes, preparation techniques, reading precision, and statistical analysis. Similarly, the study[15] on differences in growth of the blue shark *Prionace glauca* from two areas in the Pacific indicated that apparent differences might be procedurally and statistically invalid. Therefore, to clarify the intra-specific difference of traits in age and growth characteristics, the same readers must conduct the comparison using the same method to minimize the errors.

Sex ratios in Tokyo Bay indicated that older females were predominant. Klimley[16] suggested that there is an adaptive advantage for females of many shark species to be spatially segregated from males so that they can feed more efficiently and grow more rapidly to maturity size. In the present case, however, this tendency toward female dominance for older ages may be a consequence of a rapid decrease in the number of males over 4 years old, rather than of sexual segregation. However no information on *M. manazo* for the nearby area off the entrance of Tokyo Bay is available, which needs further study.

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