Age and growth of big skate (Raja binoculata) and longnose skate (R. rhina) in the Gulf of Alaska

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SPECIAL ISSUE SKATES

Age and growth of big skate (*Raja binoculata*) and longnose skate (*R. rhina*) in the Gulf of Alaska

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Abstract In 2003, big skates, *Raja binoculata*, and longnose skates, *Raja rhina*, were the target of a commercial fishery around Kodiak Island in the Gulf of Alaska (GOA) for the first time. The sudden development of a fishery for these species prompted the need for improved life history information to better inform fishery managers. Due to the selective nature of the skate fishery, mostly larger individuals were captured. Back-calculation from skate vertebral measurements was used to estimate size-at-age for younger skates. Because back-calculated age-length data within individuals were highly correlated, bootstrap resampling methods were used to test for differences between male and female growth curves. Results from bootstrapping indicated that differences between male and female growth were statistically significant for both species. This investigation indicates that growth of big skates in the GOA (max size 178 cm total length, max age 15 years) is similar to that in California, but different from that in British Columbia. For longnose skates, our GOA results agree with those reported in British Columbia, but were considerably older (max size 130 cm, max age 25 years) than those reported in California, which may not be surprising because longnose skates in the present study were generally larger. This life history information suggests that both big and longnose skates are at risk of unsustainable exploitation by targeted fisheries.

Keywords Alaska skate fisheries · Age determination · Back-calculation · Rajidae

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Introduction

In the Gulf of Alaska (GOA) the most common skate species are the big skate, *Raja binoculata*, longnose skate, *Raja rhina*, Aleutian skate, *Bathyraja aleutica*, Bering skate, *Bathyraja interrupta*, and the Alaska skate, *Bathyraja parmifera* (Gaichas et al. 2003, 2005). The range of the big skate extends from the Bering Sea to southern Baja California in depths ranging from 2 to 800 m (Love et al. 2005). The longnose skate has a similar biogeographical range, from the southeastern Bering Sea to Baja California from 9 to 1,069 m depths (Love et al. 2005). While these two species have wide depth ranges, they are generally found in continental shelf waters (0–200 m) in the GOA. The greatest biomass of skates is found in depths less than 100 m and is dominated by the big skate (Fig. 1). Longnose

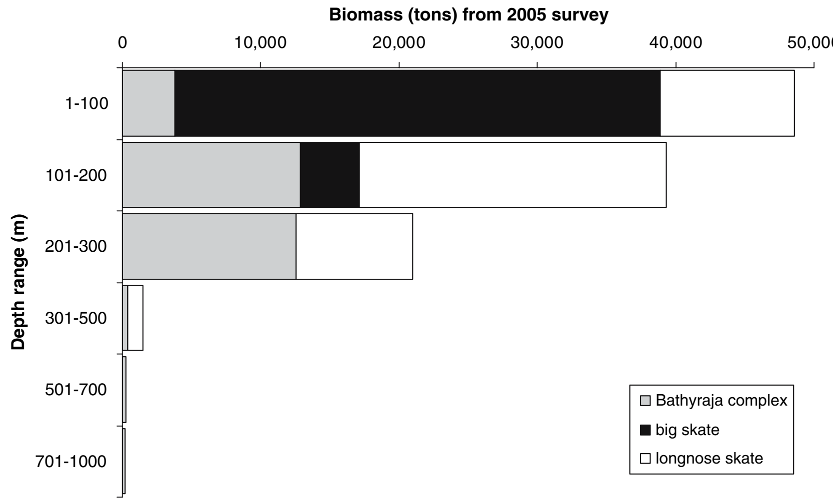

Fig. 1 Biomass at depth for major GOA skate species (big, longnose, and *Bathyraja* spp) (Gaichas et al. 2003, 2005)

skate is the dominant skate species at depths of 100–200 m, and *Bathyraja* spp are dominant in deeper waters (200 to >1,000 m) (Fig. 1). In the eastern Bering Sea, *Bathyraja* spp dominate the skate biomass in continental slope waters (Ebert 2005; Gaichas et al. 2003, 2005).

In 2002, markets for skates in the GOA developed (Bang and Bolton, Alaska Fisheries Inc, personal communication), and the resource became economically valuable in 2003 when the ex-vessel price became equivalent to that of Pacific cod, *Gadus macrocephalus*. In 2003, vessels began retaining and delivering skates as target species in federal waters partly because the market for skates had improved and partly because Pacific cod could be retained as bycatch in a skate 'Other species' target fishery, even though directed fishing for cod was seasonally closed (Gaichas et al. 2003, 2005). The result was a dramatic increase in skate landings around Kodiak Island in the GOA (Fig. 2; Gaichas et al. 2003, 2005). Moreover, in recent years (2003–2005) over half the annual catch was composed of *R. binoculata* and *R. rhina* (Gaichas et al. 2003, 2005).

In response to skate fisheries in other regions, age, and growth studies have been applied by Sulikowski et al. (2003, 2005a) for more informed management of the winter skate, *Leucoraja ocellata*, and the thorny skate, *Amblyraja radiata*, in the western Gulf of Maine (Sulikowski et al. 2005b). Two previous studies, Zeiner and Wolf (1993) and McFarlane and King (2006) studied age and growth of big and longnose skates in California waters and off the west coast of British Columbia, Canada, respectively, and a third age and growth study of the longnose skate was completed by Thompson (2006) on the US west coast. The purpose of the current study is to provide biological information on the age and growth of big and longnose skates in the GOA, in response to the development of the directed skate fishery.

Materials and methods

Specimen collection and preparation

Big and longnose skates were obtained from the directed fishery by longline in the surrounding waters of Kodiak Island, Alaska (57°45′N and 153°29′W), from February 2003 to June 2003 and in February 2004 to May 2004 (Fig. 2). Six thoracic vertebrae were excised from each skate by the Alaska Department of Fish and Game (ADFG) port sampling program in Kodiak, stored frozen and shipped to the Alaska Fisheries Science Center (AFSC) for later examination. All skates were identified, sexed, and measured for either total or pectoral length (±1 cm) at the port.

In this study, a total of 100 big skates (43 males and 57 females) and 103 longnose skates (48 males and 55 females) were examined. At the

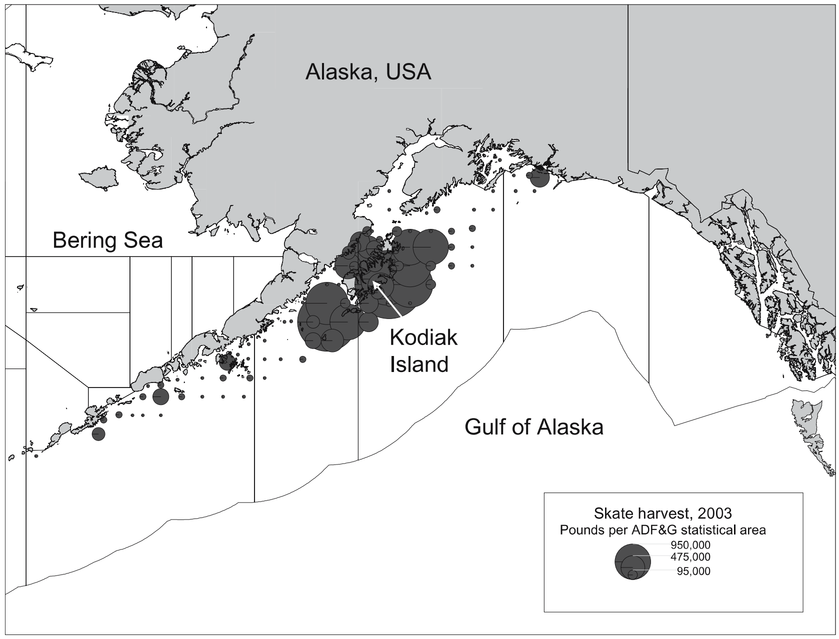

Fig. 2 Skate catch from Alaska Department of Fish and Game (*ADFG*) fish ticket database in 2003, data courtesy of Michael Ruccio, ADFG. Vertebrae used for our study were collected from skates in the waters surrounding Kodiak Island

AFSC, excess vertebral tissues, along with the neural and haemal arches, were removed from each vertebra with a scalpel. Individual vertebrae were stored in vials containing 70% ethanol. After initial processing, vertebrae were embedded in polyester resin (Artificial Water™) and mounted in a slotted block attachment on an Isomet™ low speed saw. Each vertebra was cut along the sagittal (i.e., longitudinal) axis at a speed of ~200 rpm using two Norton™ 4-in. diamond blades. Sections were mounted on a microscope slide with UV-light cured Loctite™ 349 adhesive. After curing, each mounted thin section (≈0.30 mm thick) was sanded and polished using an Ecomet™ table sander and 800 to 1,200 grit sandpaper. Mounted thin sections were viewed under a dissecting microscope to determine the optimal thickness for readability by examining the degree of translucence through the thin section. Section thickness was adjusted with further polishing.

Skate ageing methodology

Growth bands were examined under a Leica™ MZ 95 dissecting microscope with reflected light from a fiber optic light source (Fig. 3). Mineral oil was applied to the thin sections to enhance bands. Opaque and translucent bands were followed from one corpus calcareum 'arm' across the intermedialia to the corpus calcareum 'arm' on the opposite side (Cailliet and Goldman 2004). Growth bands, which could be followed in this manner were interpreted as annual marks. The angle of each growth band changes where the intermedialia intersects the corpus calcareum and was the region which was used for counting (Fig. 3a). An hourglass-shaped constriction at age zero was assumed to correspond to the event of hatching from the egg case (Fig. 3a). The next translucent band was considered the first year (Cailliet and Goldman 2004). Thin sections were assigned a readability code according to the following scale: 1-clear thin section; 2-a single age can be generated with variable level of confidence; or 3-very difficult, where the reader can only assign a minimum age or age range.

Precision and bias

Band counts were made independently by two readers for each specimen without prior knowledge of total length or sex. Inter-reader precision was calculated by using the coefficient of variation (CV) (Chang 1982) and percent agreement between readers. Discrepancies between the two readers were resolved using a teaching (double)

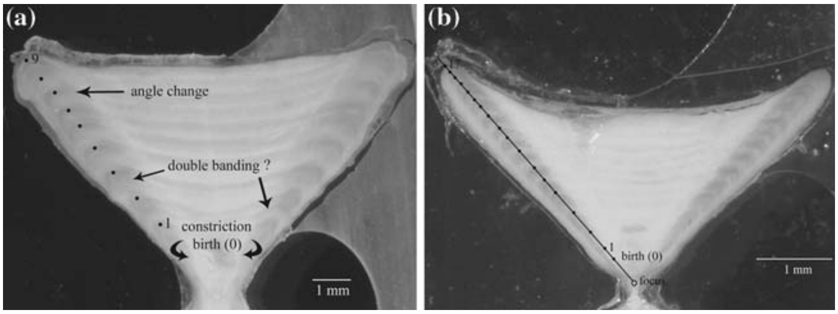

Fig. 3 (a) Big skate vertebral thin section with an estimated age of 9 years, showing angle change, potential double banding (*checks*), first year and constriction used to locate the birth mark (age 0). (b) Longnose skate vertebral thin section showing *annular rings* with an estimated age of 17 years. Back-calculation measurements are indicated along the *line* from focus to the outer-most edge

microscope. Age bias plots were constructed for each species to evaluate any potential bias between reader 1 age estimates and the resolved ages. A matched pairs *t*-test was performed between reader 1 and reader 2 ages and reader 1 and resolved ages.

Back-calculation, growth parameter estimation, and sample bootstrapping

Back-calculation was used to estimate the size-at-age for all age classes, since small skates were not targeted by the commercial fishery. Vertebral measurements (V_i) were measured from the focus of the V-shaped vertebral section, along the corpus calcareum, to the distal side of each presumed annual mark (Fig. 3b). The simple Dahl-Lea method (Francis 1990) was used, which assumes an isometric relationship between linear measurements in the skate vertebra and skate total length:

$$L_{\mathrm{i}} = (V_{\mathrm{i}}/V_A)L_A,$$

where L refers to skate total length, V refers to the vertebral measurement, i is the presumed ith annual ring, and A is the age at capture at the time of formation of the Ath presumed annual ring.

Although back-calculation allowed us to easily generate large amounts of age-length data, it must be recognized that these data were highly correlated within each of the individual specimens. To test differences between male and female growth curves, bootstrap resampling methods were used (Efron 1982). Length-at-age data were fit with a von Bertalanffy growth function:

$$L_{\mathrm{t}} = L_{\infty}(1 - \exp(-K(t - t_0))),$$

where L_{t} is the total length at time t (age in years), L_∞ the theoretical asymptotic length, K the Brody growth coefficient, and t_0 is the theoretical age at zero length. The usual F-statistic to test between the male and female von Bertalanffy growth curves (Kimura 1980, 1990; Quinn and Deriso 1999) uses probabilities, which are usually drawn from the F-distribution. To bootstrap the null distribution for this statistic, the male and female data were combined into one sample. The same sample sizes that were present in the original male and female samples were randomly sampled, with replacement. When a specimen was selected, all back-calculated age-length data from that specimen were also selected. Note that each of the bootstrapped samples actually contained a mixture of males and females (e.g., if $n = 43$ specimens are selected, this would include both males and females). The F-statistic was calculated in the same way as the original male and female samples, and was bootstrapped 10,000 times to approximate the sampling distribution of the F-statistic under the null hypothesis that there is no difference between male and female growth curves. The proportion of these bootstrapped F-statistics greater than or equal to the original F-statistic calculated for testing between the male and female growth curves was determined. This proportion equals the estimated probability of the *F*-statistic for testing between male and female growth curves, and is more realistic than the probability calculated from the *F*-distribution.

Estimation of the natural mortality rate (M)

Hoenig's (1983) equation is commonly used in fishery stock assessment work to estimate the natural mortality rate from maximum age.

Natural mortality was estimated using the equation:

$$M = 4.306/t^{1.01},$$

where M is the natural mortality rate on an annual basis and t is the maximum age measured in years.

Results

Sample analysis

The size range of collected specimens varied from 84 to 141 cm TL for male big skates (n = 43) and 67–178 cm TL for female big skates (n = 57), and 100–129 cm TL for male longnose skates (n = 48) and 98–140 cm TL for female longnose skates (n = 55) (Fig. 4).

A similar isometric relationship was observed between vertebral radius and total length for both the big skate ($\hat{\beta} = 22.1$) and for the longnose skate ($\hat{\beta} = 21.5$) (Fig. 5). Isometry was also supported by statistical tests, which indicated the hypothesis of a slope intercept of zero could not be rejected for either species (P = 0.66 for big skate; P = 0.15 for longnose skate) (Fig. 5).

For big skates, a comparison of age estimates between the two readers showed a 38% total agreement (±0) with a slight overall bias where the second reader tended to overestimate the primary reader's ages. The inter-reader CV was 9.35% (n = 50). For longnose skates, a comparison of age estimates between the two readers showed a 14.3% total agreement (±0) with a much greater bias where the second reader tended to underestimate the primary reader's ages. The inter-reader CV was 11.85% (n = 49). A matched pairs t-test (Zar 1999) showed the overall bias between reader 1 and reader 2 was not significant for big skates (t = 1.07, df = 46, and P = 0.29) or longnose skates (t = –1.93, df = 46, and P = 0.06).

Discrepancies between reader 1 and reader 2 were investigated and potential ageing criteria differences were resolved. An age bias plot between reader 1 and resolved ages showed that differences in ageing criteria between readers was successfully resolved (Fig. 6). Because there was no significant age bias between readers, the primary reader's ages were used as final ages in this study. Verification was not performed since vertebrae were only sampled from the directed skate fishery over a 4–5-month period of time. Based on results of other skate age and growth studies, we assumed that each opaque and translucent band pair for big and longnose skates represented 1 year's growth.

Observed ages ranged from 4 to 15 years for big skates and 13–25 years for longnose skates, indicating that the maximum age of longnose skates may be 10 years greater than the maximum age of big skate (Table 1, Fig. 4). Due to the lack of small skates, back-calculation was used to estimate the size and age of skates that were missing from our samples. The inclusion of this technique greatly increased the sample sizes available for fitting the von Bertalanffy growth curves (Table 2). Average back-calculated length-at-age data are plotted along with the von Bertalanffy growth curves estimated from the individual back-calculated data (Fig. 7). The von Bertalanffy growth parameters for big skates were L_∞ = 153.3 cm TL, K = 0.1524 year^{-1} and t_0 = –0.632 year (R^2 = 0.88, males) and L_∞ = 247.5 cm TL, K = 0.0796 year^{-1} and t_0 = –1.075 year (R^2 = 0.82, females) (Table 2). For longnose skates, the von Bertalanffy growth parameters were L_∞ = 168.8 cm TL, K = 0.0561 year^{-1} and t_0 = –1.671 years (R^2 = 0.92, males) and L_∞ = 234.1 cm TL, K = 0.0368 year^{-1} and t_0 = –1.993 years (R^2 = 0.94, females) (Table 2). Plots of average length-at-age (Fig. 7) suggest that female skates of both species continue to grow after the length at maturity of 110 cm for big skate and 60 cm for

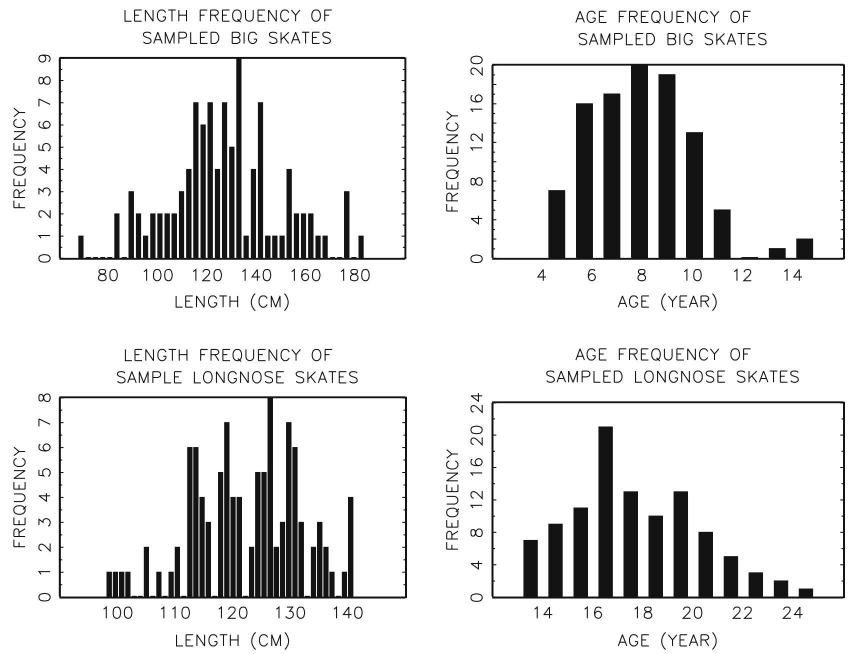

Fig. 4 Frequency histograms of total length and age for sampled big and longnose skates, sexes combined

longnose skate estimated by Zeiner and Wolf (1993) and Martin and Zorzi (1993). Bootstrapping the F-statistic indicates that the difference between male and female growth curves is highly significant for big skate ($F = 28.96$, $P < 0.0004$) and longnose skate ($F = 45.93$, $P < 0.0001$) (Table 2).

Based on maximum age (Hoenig 1983) the instantaneous natural mortality rate for big skates was estimated to be 0.28, and the natural mortality rate for longnose skates was 0.17.

In order to compare ageing results from specific regional studies, we plotted and compared the size-at-age from growth curves estimated by Zeiner and Wolf (1993) for California, by Thompson (2006) for the US west coast longnose skates, by McFarlane and King (2006) for British Columbia and in our study for the GOA (Table 3, Fig. 8). Since Zeiner and Wolf (1993) used the logistic growth curve when fitting data from big skates, these data were plotted in Fig. 8 but were omitted from Table 3 to avoid confusion. Thompson (2006) forced the von Bertalanffy curve through an estimated length at birth. It is clear from all four studies that female big and longnose skates grow larger than males (Table 3). This is also reflected in estimated L_∞ (Table 3, Fig. 8).

Discussion

The relationship between TL and vertebral radius demonstrated that vertebrae grow isometrically with respect to the rest of the body in the big skate ($n = 100$) and the longnose skate ($n = 103$). However, sampling restrictions for both species limited the body size range (67–178 cm TL for the big skate and 98–140 cm TL for the longnose skate) from which vertebral age estimates could be obtained. The isometric relationship between total length and vertebral radius was useful for back-calculation and consequently expanding the size range and number of samples. Back-calculation is a common practice used to supplement the lack of small individuals from a data set (Cailliet and Goldman 2004). The accuracy of ages produced using this technique was illustrated by the back-calculated size at hatching for both big and longnose skates, which compared well with available size at birth data from specimens previously collected in the GOA (Gerald Hoff, Alaska Fisheries Science Center, personal communication 2006), California[1] and data reported by Zeiner and Wolf (1993).

[1] K. Cox and C. Hitz, unpublished data.

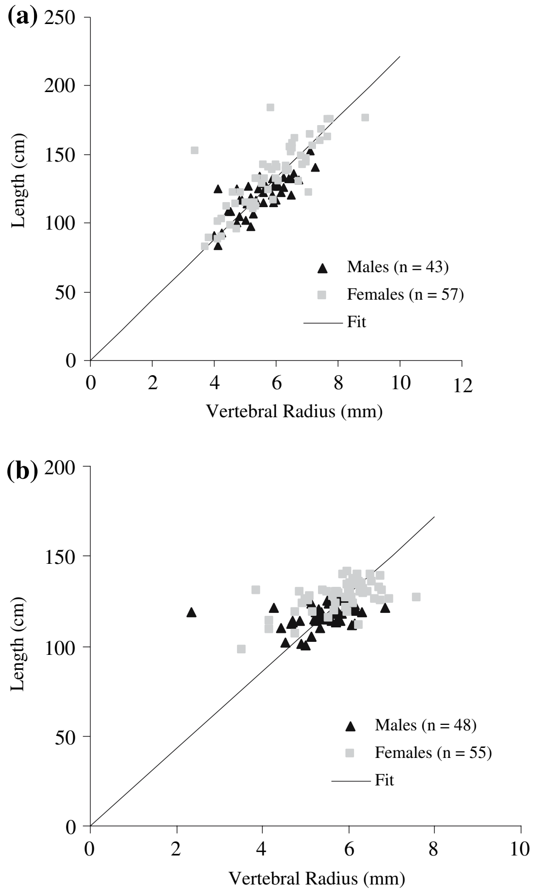

Fig. 5 The isometric relationship between vertebral radius and skate total length for big skate (a) and longnose skate (b), sexes combined. For the big skate, the slope and SE were $\hat{\beta} = 22.1, \mathrm{SE}(\hat{\beta}) = 0.25$; for longnose skate the slope and SE were $\hat{\beta} = 21.5, \mathrm{SE}(\hat{\beta}) = 0.25$. All regressions were through the origin

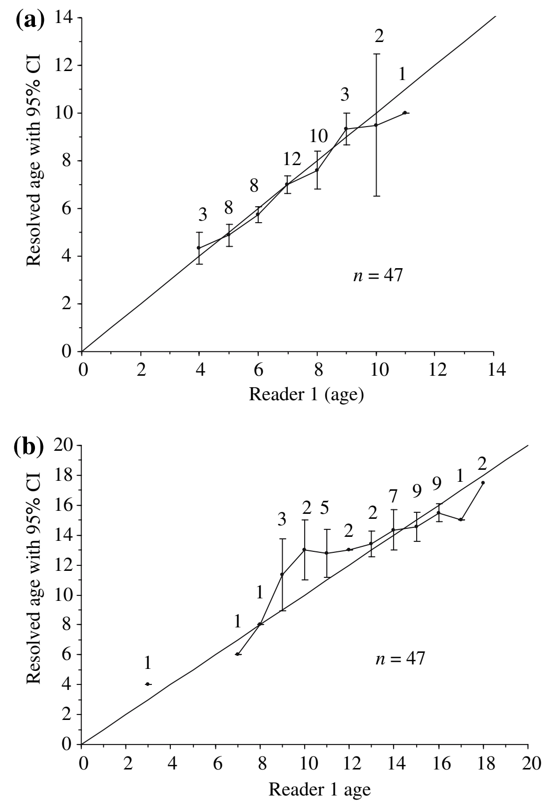

Fig. 6 Age bias graphs for (a) big skate (n = 47) and (b) longnose skate (n = 47) vertebral band counts by reader 1 and corresponding mean resolved ages. Each *error bar* represents the 95% confidence interval for the mean resolved age to all fish assigned a given age by reader 1. The *diagonal line* represents the one-to-one equivalence line. Sample sizes are given above each corresponding age

The primary criterion for determining that a growth ring is an annual mark was the consistency of growth zones across the thin section (Cailliet and Goldman 2004). Technically, some species of skates can be difficult to age due to faint annuli or inconsistent growth patterns. This is suggested in recent age and growth studies for the longnose skate (Thompson 2006) and the Alaska skate, *B. parmifera* (Matta 2006). Thompson (2006) indicated a CV of 13.75% for the longnose skate, while Matta (2006) described a CV of 10.89% for the Alaska skate. Variation in growth patterns have been found within the *Raja* spp by McFarlane and King (2006), who observed that thin sections of big skate centra produced a clearer pattern of dark bands than longnose skate centra. Precision from inter-reader age comparisons for the big skate (n = 50) resulted in a 38% (±0) agreement and a CV of 9.35% versus the longnose skate (n = 49) with a 14.3% (±0) agreement and a CV of 11.85%. The CV's from vertebral studies of sharks have frequently exceeded 10% (Campana 2001), and thus we considered our level of precision acceptable. In our study, the level of precision and the presence of bias are likely due to differences in growth band interpretation between readers. The higher agreement and lower CV for the big skate may be attributed to readability differences between species. Growth bands became constricted approaching the vertebral thin section edge for the longnose skate, whereas big skate thin

Table 1 Maximum and mean total lengths and ages observed for GOA big and longnose skates

Species	Sex	Sample size	Max length (cm)	Max age (year)	Mean length (cm)	Mean age (year)
R. binoculata	Male	43	141	15	119.6	8.02
R. binoculata	Female	57	178	14	132.4	8.09
R. rhina	Male	48	129	25	116.6	17.50
R. rhina	Female	55	140	24	127.7	18.6

Table 2 Back-calculated sample sizes and estimated von Bertalanffy parameters for big and longnose skates in the GOA

Species	Sex	Back-calculated sample size	L_∞ (cm TL)	*K*	t_0 (year)	F	*P*
R. binoculata	Male	388	153.3	0.1524	–0.632	28.96	0.0004
R. binoculata	Female	518	247.5	0.0796	–1.075		
R. binoculata	Combined	906	189.6	0.1145	–0.835		
R. rhina	Male	888	168.8	0.0561	–1.671	45.93	0.0001
R. rhina	Female	1,083	234.1	0.0368	–1.993		
R. rhina	Combined	1,971	203.8	0.0437	–1.868		

F-statistics refer to the standard *F*-statistic for testing between male and female growth curves, and *P* is the bootstrapped probability of the *F*-statistics

sections remained more consistent in growth band spacing. Thompson (2006) indicated this band constriction for the longnose skate led to difficulties in age estimation for this species. Similarly, Cailliet and Goldman (2004) suggest that ageing vertebrae from older animals can be problematic due to bands being tightly grouped. Overall, the big skate age estimates had greater inter-reader precision, with a higher agreement, lower CV and less bias compared to the longnose skate. The matched pairs *t*-test showed bias between reader 1 and resolved ages not to be significant ($P > 0.05$), and thus reader 1 ages were used as the final ages to estimate growth parameters

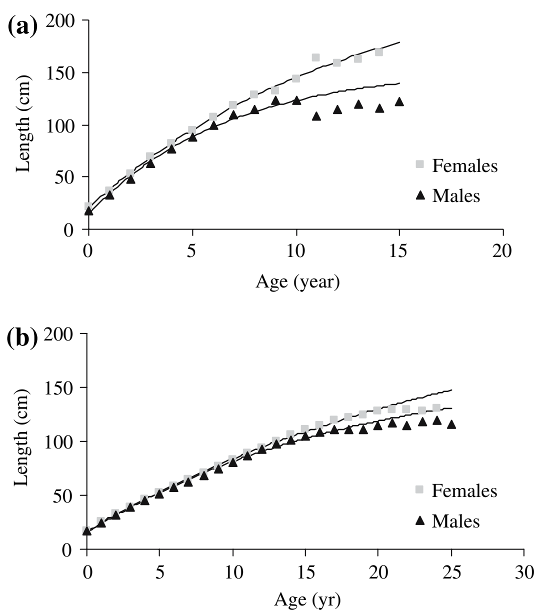

Fig. 7 Average total length-at-age for male and female big skate (a) and longnose skate (b) with von Bertalanffy growth curves. Big skate: males (L_∞ = 153.3 cm TL, K = 0.1524 year^{-1}, t_0 = –0.632 year, R^2 = 0.88), females (L_∞ = 247.5 cm TL, K = 0.0796 year^{-1}, t_0 = –1.075 year, R^2 = 0.82). Longnose skate: males (L_∞ = 168.8.3 cm TL, K = 0.0561 year^{-1}, t_0 = –1.671 year, R^2 = 0.92), females (L_∞ = 234.1 cm TL, K = 0.0368 year^{-1}, t_0 = –1.993 years, R^2 = 0.94)

Brander and Palmer (1985) suggest that seasonal changes including environmental conditions, migrations, and spawning can affect growth. For the bull shark, *Carcharhinus leucas*, it was implied that ring deposition may be attributed to the spring pupping season (Neer et al. 2005). Checks, sometimes associated with presumed annual marks, may be due to these seasonal changes or may be randomly occurring. Opaque growth bands are wide and are typically laid down during the summer or productive growth periods (Cailliet and Goldman 2004). Translucent growth bands are narrower, signifying less growth during the winter months or less productive growth periods. Longnose skates appear to have more constricted growth patterns compared to big skates, which may be the result of potential differences between the two species in depth preference or reproductive events. Generally,

Table 3 A comparison of three age and growth studies of big skates and four age and growth studies of longnose skates, which took place in four geographic regions

Species	Region/source	Sex	Length range TL (cm)	Max age (year)	L_∞ (cm)	*K*	t_0 (year)
R. binoculata	California	Male	17.5–132.1	11	N/A	N/A	N/A
R. binoculata	California	Female	22.7–160.7	12	N/A	N/A	N/A
R. binoculata	British Columbia	Male	16.6–183.6	25	233.0	0.05	–2.10
R. binoculata	British Columbia	Female	16.9–203.9	26	293.5	0.04	–1.60
R. binoculata	GOA	Male	84–141	15	153.3	0.152	–0.632
R. binoculata	GOA	Female	67–178	14	247.5	0.080	–1.075
R. rhina	California	Male	35.9–132.2	13	96.7	0.25	0.73
R. rhina	California	Female	30.3–106.8	12	106.9	0.16	–0.30
R. rhina	West coast	Male	19–129	20	207.2	0.042	0
R. rhina	West coast	Female	18–142	22	180.9	0.051	0
R. rhina	British Columbia	Male	18.6–122.0	23	131.5	0.07	–2.17
R. rhina	British Columbia	Female	18.4–124.6	26	137.2	0.06	–1.80
R. rhina	GOA	Male	100–129	25	168.8	0.056	–1.67
R. rhina	GOA	Female	98–140	24	234.1	0.037	–1.99

growth zones, which did not follow the horizontal pattern across the thin section, or were faint, were dismissed as non-annual marks in our study. The attributes contributing to the growth pattern of each species could be the focus of a future study.

The lack of age validation presents a limitation to this study. However, based on previous studies of other elasmobranchs, including the longnose skate, we believe that one opaque and translucent band pair is deposited annually. Thompson (2006) performed MIA on the longnose skate and found annual periodicity of band pair formation and evidence that opaque bands typically form in the winter and spring. Other skate studies support annual periodicity in band pair formation including Sulikowski et al. (2003,2005a) for the winter skate, Sulikowski et al. (2005b) for the thorny skate and Matta (2006) for the Alaska skate. Conrath et al. (2002) performed edge analysis on the smooth dogfish, *Mustelus canis*, and found

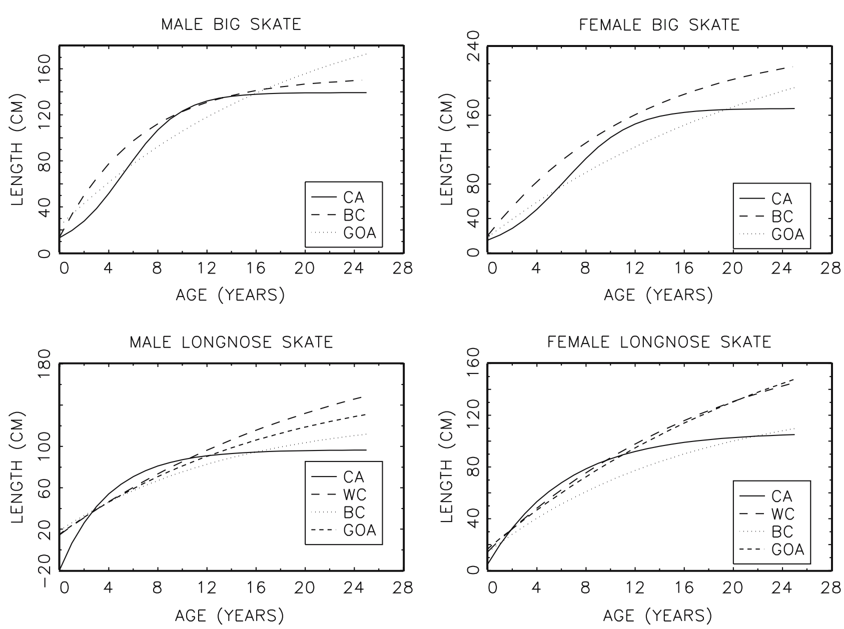

Fig. 8 Age-total length growth curves from four studies of male and female big and longnose skates [*GOA* Gulf of Alaska, *BC* British Columbia, *CA* California, *WC* US west coast (Cape Flattery, WA to Cape Mendocino, CA, USA)]. Growth curves are all von Bertalanffy except for the CA big skate data, which was fit with a logistic curve

MIA conclusive for juvenile-size animals. Annual periodicity was also indicated by the marginal increment analysis for the salmon shark, *Lamna ditopis* (Goldman and Musick 2006).

Big skate growth rates were different between the sexes in our study. Longnose skate growth rates were more similar between the sexes. Females of both species had slower growth rates than males. McFarlane and King (2006) also reported a slightly slower growth rate for females when compared to males for big and longnose skates. In other elasmobranchs, like the salmon shark, females tend to exhibit larger maximum sizes and slower growth rates than males (Goldman and Musick 2006). Female big and longnose skates may be at a higher risk to over-fishing than males because they grow more slowly to larger sizes. The larger body size of big and longnose skates compared to other skate species may make them more vulnerable to over-fishing (Dulvy and Reynolds 2002).

When examining the L_∞ parameter estimates, it should be understood that this is an *average* theoretical maximum size. Some individuals may never attain the age required to reach this maximum size, and large individuals may exceed L_∞ because it is an average. It should be noted that for our study, the von Bertalanffy parameters were estimated from the individual data, while the mean length at each back-calculated age appears on the plots. The result is that the von Bertalanffy curve does not follow the means at older ages because these are based on fewer data points. This was evident in the age and growth of the dusky shark, *Carcharhinus obscurus*, where the lack of larger specimens prevented an accurate estimation of L_∞ (Simpfendorfer et al. 2002).

The natural mortality rate for longnose skates (M = 0.17) from our study was somewhat lower than Thompson's (2006) natural mortality rate for longnose skates (M = 0.26). The big skate natural mortality rate (M = 0.28) derived from the maximum age was somewhat higher than that of the longnose skate. Since the big skate and the longnose skate have not been previously aged in Alaskan waters, this study presents the first estimates of natural mortality based on maximum age from that region.

Comparing skate growth data from California, the US West Coast, British Columbia, and GOA (present study)

The four age and growth studies of big and longnose skates have been largely regional in nature (Zeiner and Wolf 1993; McFarlane and King 2006; Thompson 2006; our study). Each has had their set of limitations. For instance, the study by Zeiner and Wolf (1993) in waters off the coast of California (Santa Cruz to Monterey) lacked the larger body sizes, especially for longnose skates. In our study, the GOA commercial fishery selected for larger specimens and inadequately sampled smaller sizes, resulting in fewer young specimens. The maximum age of longnose skates off California (Zeiner and Wolf 1993) was much younger compared to GOA longnose skates, most likely because more large-bodied longnose skates were collected in the GOA. The maximum ages of longnose skates from British Columbia (Dixon entrance to the northwest coast of Vancouver Island) by McFarlane and King (2006) and from the GOA were very similar and longnose skates from the US west coast (Coos Bay, Oregon to the US/Mexico Border) by Thompson (2006) were only slightly younger.

Comparisons between the four studies suggest differences in life history parameters. These differences could be truly geographical in nature, or they could be the result of differences in sampling or age estimation criteria between the studies. For example, an 11 years difference in maximum ages existed between British Columbia (26 years, ≈190 cm TL, female) and GOA (15 years, 141 cm TL, female) big skates. Since the GOA sampling for big skate included large individuals, it was expected that GOA maximum ages would be similar to McFarlane and King's (2006) age results. Limitations in our study's sample size (n = 100) when compared to McFarlane and King (2006; n = 242) may have contributed to the discrepancy in maximum ages. Additionally, a 60 cm difference in maximum length between our study and McFarlane and King (2006) may have still resulted in age differences. Differences between British Columbia and GOA maximum ages may potentially be related to the different ageing methodologies between the studies. McFarlane and King (2006) estimated the position of the first 3 years by using vertebral measurements from younger specimens and applying them to older specimens even when presumed annual marks were not clearly visible. The GOA big skate ages resembled those of Zeiner and Wolf (1993), who employed similar ageing criteria where bands were assumed to be annual only when visible on the thin section. Their maximum age of 12 years (161 cm TL) compared well with our maximum age of 15 years (141 cm TL). In our study, big skate centra produced clearer growth zones compared to longnose skates, though a majority of thin sections from both species were assigned a readability code of 2 by the primary age reader. Clarity differences also existed between specimens within species.

Maximum ages of longnose skate collected from the US west coast, British Columbia, and the GOA appear reasonably consistent. The maximum age of longnose skate collected off the US west coast (22 years) by Thompson (2006) was similar to our results from the GOA (25 years). Ageing methodologies of Thompson (2006) and our study were similar due to technical assistance provided to both studies by Moss Landing Marine Laboratories. Our maximum ages for longnose skates caught in the GOA were much older compared to those from California (13 years) (Zeiner and Wolf 1993). Longnose skates caught in the GOA were generally larger compared with those caught off California (Table 3). Studies of other skate species also suggests the possibility that maximum ages for longnose skates can be older than previously reported (Frisk et al. 2001, 2004).

Age and growth studies have been found useful in the management of skate fisheries in the northeast Atlantic Ocean. The thorny skate, *A. radiata*, in the western Gulf of Maine has decreased in biomass, requiring biological data to assist managers in rebuilding these stocks (Sulikowski et al. 2005b). Sulikowski et al. (2003, 2005a) suggests the susceptibility of the winter skate, *L. ocellata*, to over-fishing, particularly when large individuals are selectively removed from the population. Body size can be a predictor of vulnerability since most skate fisheries select for larger individuals, and many skate species mature at a large body size (Dulvy and Reynolds 2002). Comparing age and growth of the same species on a regional level may help fisheries managers monitor populations and identify potential detrimental effects of fishing pressure on different stocks.

It is important to better understand the life history traits of big and longnose skates through age and growth studies because these species are being targeted by commercial fisheries in the GOA (Gaichas et al. 2003, 2005). Future studies and long-term monitoring by the AFSC will help ensure that these skate populations can be managed properly; in particular, age validation will be performed to verify annual vertebral band pair periodicity for big and longnose skates in Alaska waters. Skates in other parts of the world have been over-fished (Brander 1981; Dulvy et al. 2000; Sulikowski et al. 2003, 2005a). This study is a direct response to the initiation of a directed skate fishery to avoid a similar situation in the GOA. The growth characteristics of these species suggest that they could not sustain high levels of catch (Hoenig and Gruber 1990; Musick et al. 2000; King and McFarlane 2003), and this study will help fisheries managers determine appropriate strategies of management and conservation for big and longnose skates.

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