SHORT NOTE

REVISED AGE AND GROWTH ESTIMATES FOR ANTARCTIC STARRY SKATE (*AMBLYRAJA GEORGIANA)* FROM THE ROSS SEA

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Abstract

A previous study on the age and growth of *Amblyraja georgiana* in the Ross Sea suggested that these skates initially grow very rapidly for about five years, after which growth almost ceases (Francis and Ó Maolagáin, 2005). An alternative interpretation of age and growth in *A. georgiana* that is radically different from the published interpretation is presented. By counting fine growth bands in the caudal thorns instead of broad diffuse bands, growth curves have been generated that suggest much slower growth, greater ages-at-maturity (about 20 years compared with 6–11 years) and greater maximum ages (28–37 years compared with 14 years). Several pieces of circumstantial evidence support the new interpretation, but a validation study is required to determine which growth scenario is correct.

Résumé

Dans une étude précédente sur l'âge et la croissance de *Amblyraja georgiana* dans la mer de Ross, il est suggéré que ces raies ont une croissance initiale très rapide pendant environ cinq ans, et que celle-ci cesse pratiquement par la suite (Francis et Ó Maolagáin, 2005). Nous présentons une autre interprétation de l'âge et de la croissance chez *A. georgiana* qui est radicalement différente de la version publiée. Les courbes de croissance générées en comptant les stries fines d'accroissement sur les épines caudales plutôt que les larges anneaux diffus, semblent indiquer que la croissance est nettement plus lente, que les âges à la maturité sont plus élevés (20 ans environ par rapport à 6–11 ans) et que les âges maximum le seraient aussi (28–37 ans par rapport à 14 ans). La nouvelle interprétation est étayée par plusieurs preuves indirectes, mais une étude de validation est nécessaire pour déterminer lequel des scénarios de croissance est le bon.

Резюме

В предыдущем исследовании возраста и роста *Amblyraja georgiana* в море Росса было высказано предположение, что эти скаты сначала растут очень быстро на протяжении примерно пяти лет, после чего их рост почти прекращается (Francis and Ó Maolagáin, 2005). Представлена альтернативная интерпретация возраста и роста *A. georgiana*, которая радикально отличается от опубликованной интерпретации. Путем подсчета тонких зон роста в хвостовых шипах вместо широких размытых зон были сгенерированы кривые роста, которые говорят о намного более медленных темпах роста, большем возрасте при достижении половозрелости (около 20 лет по сравнению с 6–11 годами) и бóльших максимальных возрастах (28–37 лет по сравнению с 14 годами). Несколько косвенных доказательств поддерживают эту новую интерпретацию, но требуется провести анализ достоверности, чтобы определить, какой из сценариев роста является правильным.

Resumen

Un estudio previo sobre la edad y crecimiento de *Amblyraja georgiana* en el Mar de Ross da a entender que estas rayas crecen rápidamente por un período aproximado de cinco años, y luego el crecimiento cesa casi por completo (Francis y Ó Maolagáin, 2005). Se presenta otra interpretación sobre la edad y el crecimiento de *A. georgiana* que difiere radicalmente de la interpretación publicada. Al contar los anillos finos de crecimiento en los aguijones caudales en vez de los anillos gruesos y difusos, se han generado curvas de crecimiento que apuntan a un crecimiento mucho más lento, mayores edades de madurez (unos 20 años comparado con 6–11 años) y edades de máxima longevidad (28–37 años comparado con 14 años). Varias pruebas indirectas apoyan la nueva interpretación, pero se deberá realizar un estudio de validación para determinar cuál hipótesis de crecimiento es la correcta.

Keywords: age, growth, longevity, natural mortality, maturity, CCAMLR

Introduction

The Antarctic starry skate (*Amblyraja georgiana*) is frequently taken as by-catch in the Ross Sea fishery for Antarctic toothfish (*Dissostichus mawsoni*) (Ballara and O'Driscoll, 2005). In an effort to assess the potential impact of fishing on this species, research has been directed at understanding its biology and productivity (Francis and Smith, 2002; Francis, 2003; Francis and Ó Maolagáin, 2005; Francis, 2006; Francis and Mormede, 2008). Francis and Ó Maolagáin (2005) estimated growth parameters for *A. georgiana* by counting growth bands on caudal thorns. However, they found that age estimation was difficult: 'Some bands were clear and unambiguous, while others were diffuse and indistinct; frequently it was difficult to determine whether a thorn zone comprised a small number of broad bands or a larger number of narrow bands'. They counted the broad diffuse bands, and ignored the more numerous fine bands. This resulted in a growth curve that suggested rapid initial growth for about five years, followed by a near cessation of growth. They estimated the age-at-sexual-maturity to be 6–7 years for males and 8–11 years for females, and their maximum observed age was 14 years. However, no ageing validation study was conducted, so their results were preliminary, and further studies are required to confirm them.

In this paper, the ageing of *A. georgiana*, using a larger sample size and an alternative approach of counting the fine thorn bands instead of the broad diffuse bands, is re-visited. Two readers, one of whom has had previous experience ageing Falkland Islands' skates from their thorns, enabled an assessment of between-reader variability. The revised age and growth estimates for this species lead to different estimates of age-at-maturity, longevity and growth rate from those suggested by Francis and Ó Maolagáin (2005).

Methods

Caudal thorns were obtained from Ross Sea *A. georgiana* by observers on board commercial longliners. Thorns were collected from skates caught in CCAMLR Subarea 88.1, with most coming from small-scale research units (SSRUs) 881H and 881I centred on about 72°S and 180°. Thorns were mainly removed from the base of the tail near the pelvic fins, or the pelvic region. Where thorns were eroded or otherwise damaged, samples were taken from elsewhere on the tail. Most of the thorns in the study had been examined previously by Francis and Ó Maolagáin (2005), and were augmented with new thorns from skates collected during the 2000/01 to 2006/07 seasons, giving a total of 239 thorns. Specimens were labelled by observers with pelvic length (distance between the tip of the snout and the rear edge of the pelvic fins; PL), sex and station. Thorns were soaked in a solution of ca. 3% trypsin at 35–37°C, and the adhering skin and cartilaginous plug inside each thorn were removed with forceps.

Thorn growth bands were read by two readers. Reader 1 (M.P. Francis) aged the thorns in the previous study by Francis and Ó Maolagáin (2005). Reader 2 (M.J. Gallagher) developed the thorn-ageing technique in skates, and applied it to a number of other species, including several from the Falkland Islands (Gallagher and Nolan, 1999; Gallagher et al., 2005, 2006). Reader 1 aged the whole set of 239 thorns once and a subset of 135 of these a second time, with the two readings being five months apart. Reader 1's first reading was taken as his age estimate, since it contained a larger sample size. Reader 2 aged a subset of 100 thorns four times: the first reading was considered a familiarisation reading, and the other three readings were carried out over a period of 10 days. These last three readings were not considered independent, as the reader was able to 'remember' some of his previous counts. Reader 2's fourth reading was used as his age estimate.

Counting began below the apical protothorn, which forms before the skate hatches from its egg case (Francis and Ó Maolagáin, 2005). The two readers counted growth bands independently, without knowledge of each other's readings, or an agreed counting protocol. All readings were made without knowledge of the size, sex or date of capture of the skate, although thorn size provided some indication of skate size. Band readability was scored subjectively on a scale from 1 (excellent) to 5 (unreadable).

Band counts were assessed for within-reader and between-reader ageing bias using age-bias plots (Campana et al., 1995). The index of average percentage error (APE) and mean coefficient of variation (CV) for each skate were calculated to assess ageing precision (Campana et al., 1995). Von Bertalanffy growth curves were fitted to length-at-age data using non-linear least squares regression:

$$L_t = L_\infty \left(1 - e^{-K[t-t_0]}\right)$$

where L_t is the expected length at age t years, L_∞ is the asymptotic maximum length, K is the von Bertalanffy growth constant, and t_0 is the theoretical age at zero length. An age-standardised randomisation test for differences between male and female growth curves was used (see Francis et al., 2007).

Results

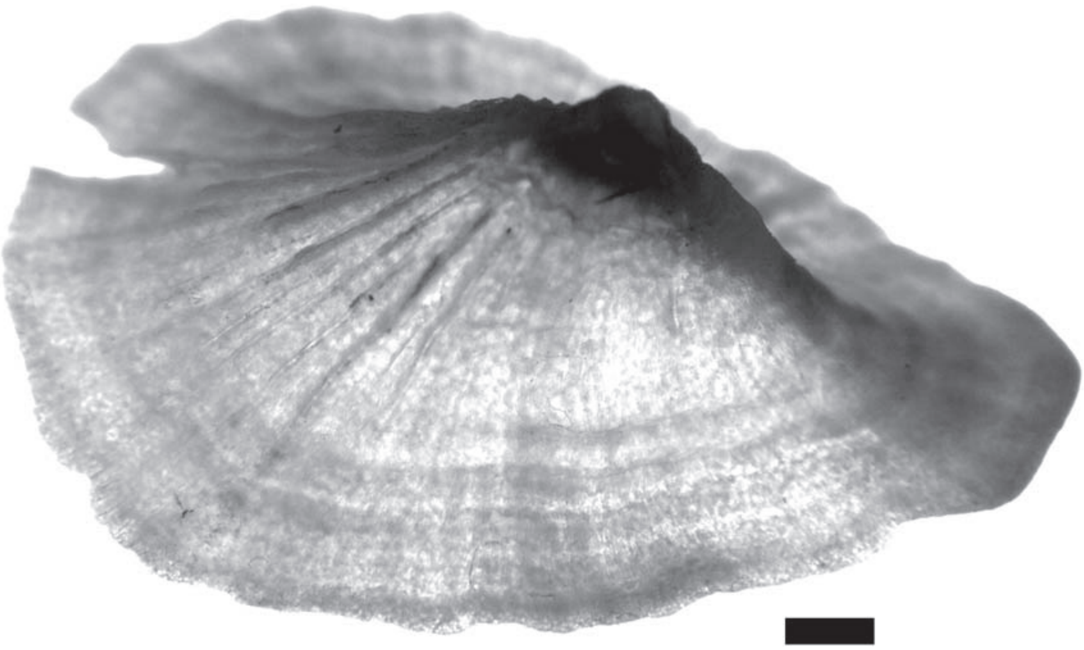
Both readers counted the fine growth bands that were visible within and between the broader diffuse bands counted by Francis and Ó Maolagáin (2005) (Figure 1). They found the thorns difficult to count, though confidence improved with experience. Only a small proportion (7.5%) were rejected as unreadable, but most (61.5%) were scored as readability 4 (bands very unclear over at least part of the thorn, and count subject to considerable interpretational uncertainty) or readability 3 (24.7%) (some regions of the thorn unclear, producing moderate uncertainty in the count). Only 6.2% of thorns were regarded as clear and unambiguous (readability 1 or 2).

Within-reader comparison indicated a high precision (APE 3.4%, CV 4.8%) for counts by reader 2 taken eight days apart. APE and CV were both about twice as high (7.6% and 10.7% respectively) for reader 1 on counts taken five months apart, and were probably more realistic measures of counting precision in this species. The CV for reader 1 (10.7%) compares favourably with those for shark age estimates, for which the CV is usually higher than 10% (Campana, 2001). There was no apparent bias between the two readings of reader 1, although individual variability was high with some significant discrepancies (Figure 2). A between-reader comparison produced lower precision (APE 11.6%, CV 16.4%), but these values were inflated by the presence of between-reader bias (see Campana, 2001). Both readers obtained similar age estimates, on average, for skates aged up to about 20 years (Figure 2). However, beyond 20 years, reader 1 consistently aged skates considerably older than reader 2.

Discussion between the readers revealed that reader 1 counted more fine growth bands near the thorn margin than reader 2. The finest bands were usually not visible around the entire margin and could often be counted only in isolated portions of the margin. Reader 2 re-examined thorns from eight skates that had some of the largest between-reader discrepancies. He concluded that he had underestimated band counts in the outer one-quarter of the thorn, and provided revised age estimates for these eight fish (Figure 2). However, his revised estimates were still lower than those by reader 1 for the oldest skates.

Randomisation tests showed no significant difference between the growth curves for the two sexes (p = 0.52 and p = 0.73 for readers 1 and 2 respectively) so the data for subsequent analyses were pooled. The growth curves fitted to the age estimates for the two readers were similar up to about 18 years, after which they diverged (Figure 3, Table 1). A cluster of outliers with positive residuals, centred on about 75 cm and 18 years, was apparent for both readers, suggesting that these individuals may have been under-aged. A second, less distinct, cluster of outliers with negative residuals, centred on about 38 cm and 12 years, suggested some over-ageing by both readers. Reader 1 generally produced the greatest outliers for ages greater than 15 years, indicating that counting the fine marginal bands in older fish was difficult.

(a)



(b)

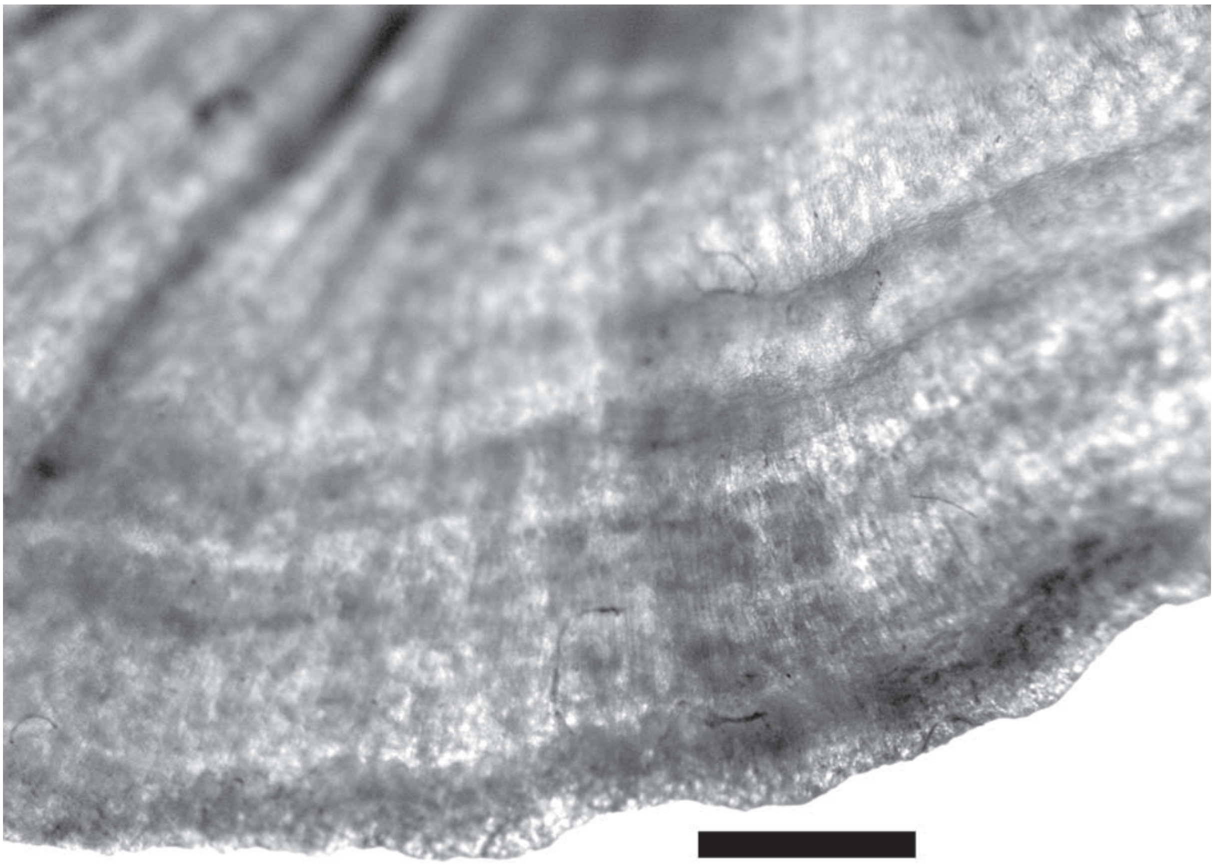


Figure 1: Caudal thorn from a 71 cm pelvic length female *Amblyraja georgiana* viewed in transmitted white light, showing broad diffuse bands on whole thorns (a) and finer bands at the outer edge of the thorn (b). Age estimates were 6 years (Francis and Ó Maolagáin, 2005), 27 and 23 years (reader 1, first and second readings), and 16 and 23 years (reader 2, fourth and revised readings). Scale bar = 1 mm.

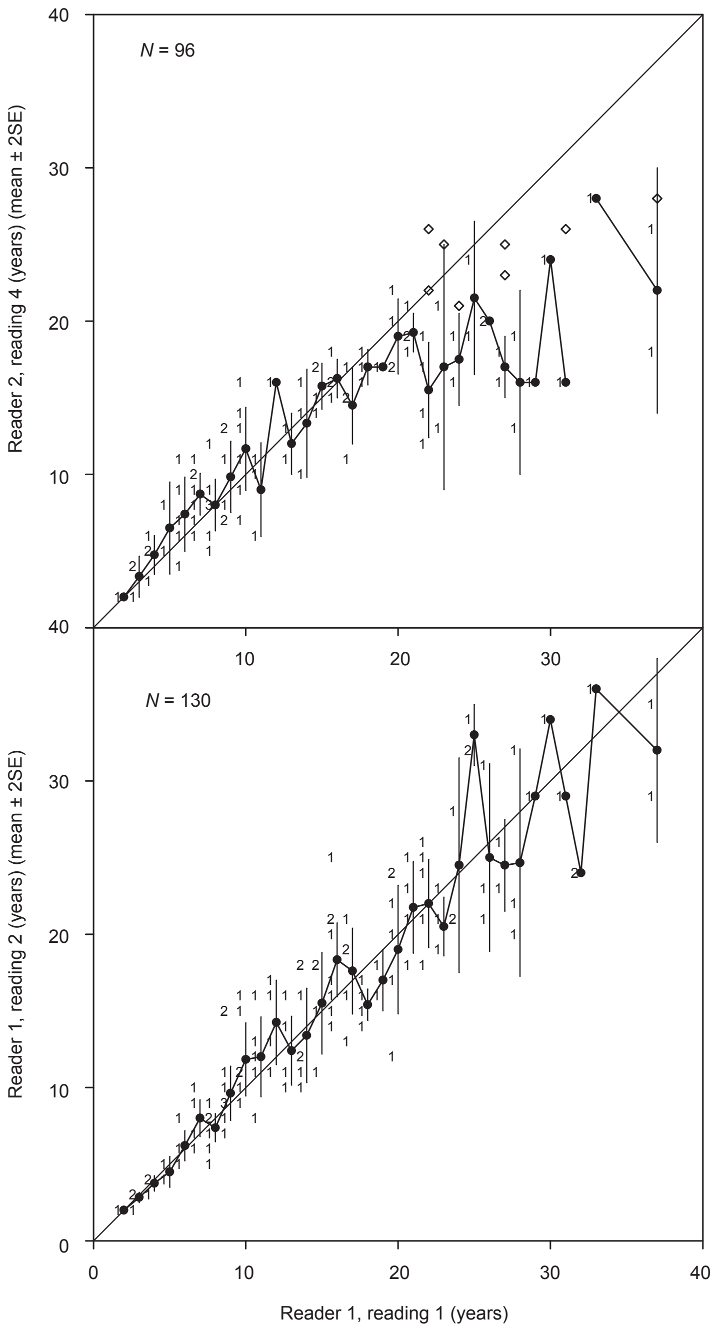


Figure 2: Age-bias plots comparing thorn band counts between readers (top) and within reader (bottom). Numerals indicate sample frequency, and dots and error bars indicate the mean and two standard errors for readings on the y-axis relative to the reading on the x-axis. Diamonds in the top panel indicate revised ages by reader 2 for skates having large discrepancies between the two readers.

Table 1: Von Bertalanffy growth parameters for *Amblyraja georgiana* from two readers (both sexes combined). SE = standard error.

Reader	N	L_∞	SE	K	SE	t_0	SE
1	216	78.79	2.76	0.085	0.011	–1.19	0.70
2	98	112.76	27.90	0.041	0.019	–3.08	1.74

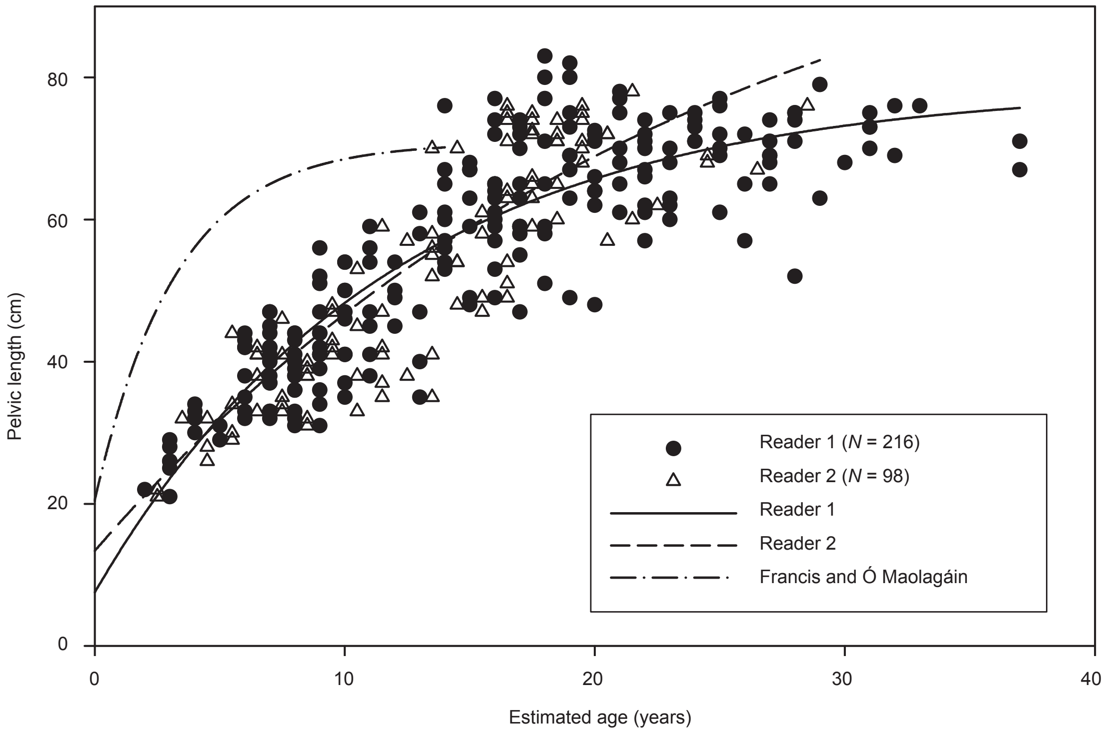


Figure 3: Comparison of *Amblyraja georgiana* length-at-age from two readers with fitted von Bertalanffy growth curves. Also shown is the growth curve developed previously by Francis and Ó Maolagáin (2005). Reader 2's ages were increased by 0.5 years for clarity.

The growth curves of both readers indicated slow but steady growth with skates reaching about 48 cm in 10 years and 66–69 cm in 20 years (Figure 3). Thereafter, reader 2's growth curve fitted the data poorly, with most skates having negative residuals. This curve also had an implausibly high estimate of L_∞ (113 cm) with a very large standard error and an implausibly low value of t_0 (Table 1). Reader 1's growth curve fitted the data at the upper end better and had more plausible parameter estimates, but had a predominance of negative residuals over about 25 years. The intercepts on the y-axis were 8.0 cm for reader 1 and 13.8 cm for reader 2.

The greatest age recorded by reader 1 was 37 years compared with 28 years by reader 2. Reader 2's ages increased for all eight skates that were re-examined, but this did not increase his maximum age estimate. Based on these age estimates, longevity in *A. georgiana* is probably at least 30 years, and possibly greater than 40 years. Using Hoenig's (1983) regression equation which related longevity and natural mortality rate for all taxa combined, the natural mortality rate M is estimated to be 0.12 (longevity of 37 years) to 0.16 (longevity of 28 years). Using a median length-at-sexual-maturity of 67.3 cm (Francis and Mormede, 2008), calculated ages-at-maturity were 21 years for reader 1 and 19 years for reader 2. Thus, maturity is estimated to occur at about 20 years in this species, albeit with a potentially wide variation: 67 cm PL skates ranged from 14 to 37 years of age (Figure 3).

Discussion and conclusions

An alternative interpretation of age and growth for *A. georgiana* that is radically different from the published interpretation (Francis and Ó Maolagáin, 2005) is presented. By counting fine growth bands in the caudal thorns instead of broad diffuse bands, growth curves have been generated that suggest

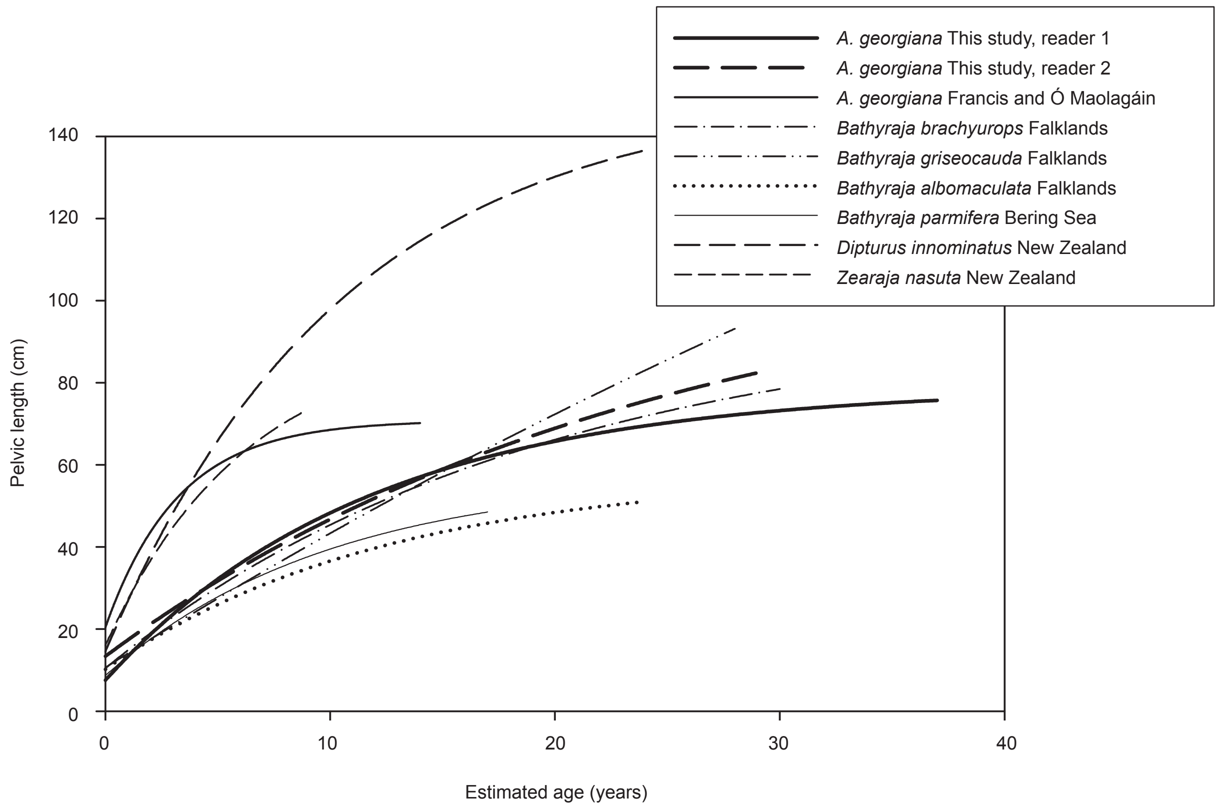


Figure 4: Comparison of *Amblyraja georgiana* growth curves with those for other skates from New Zealand (Francis et al., 2001), the Falkland Islands (Henderson et al., 2005; Arkhipkin et al., 2008) and the eastern Bering Sea, Alaska (Matta and Gunderson, 2007). For the three Falklands skates and the Alaska skate, the growth curves were converted from total length to pelvic length using PL:TL ratios estimated from images (0.70, 0.62, 0.61 and 0.64 for *Bathyraja brachyurops, B. griseocauda, B. albomaculata* and *B. parmifera* respectively).

much slower growth, greater ages at maturity (about 20 years compared with 6–11 years) and greater maximum ages (28–37 years compared with 14 years).

Weak circumstantial evidence supports the new age and growth estimates presented here:

(i) The new ageing technique counts all visible growth bands instead of grouping them into broad diffuse bands, and therefore seems more objective.

(ii) The shape of the new growth curves, with their slow steady rise to an asymptote, appears more plausible than the previous growth curve which had a very rapid rise to an abrupt asymptote (Figure 3).

(iii) The new growth curves have y-axis intercepts (8.0 and 13.8 cm) that are closer to the estimated length-at-hatching (10–12 cm; Francis and Ó Maolagáin, 2005) than was the intercept for the previous growth curve (20 cm; Francis and Ó Maolagáin, 2005).

(iv) The new growth curves are more similar to growth curves (Figure 4) for skates that live in cold deep water, although no other skate aged so far lives in water as cold or as deep as *A. georgiana*.

Tagged and recaptured *Bathyraja* cf. *eatonii* from Heard Island and McDonald Island grew 1.0 cm per year over the length range 64–104 cm TL (van Wijk and Williams, 2005; Francis, 2006), or about 0.6 cm per year at 38–62 cm PL assuming isometric growth of disc and tail. Based on the growth curves from the present study, *A. georgiana* is estimated to grow an average of 2.3 cm per year (reader 1) or 2.6 cm per year (reader 2) over this length range. Surprisingly, the previous 'fast' growth curve for *A. georgiana* (Francis and Ó Maolagáin, 2005) produces an annual growth rate of only 1.4 cm over this length range, because growth under that interpretation has virtually ceased over the latter part of the length range.

Of the two growth curves presented in this study, reader 1's curve seems more plausible because it fits the data better, and because reader 2 underestimated the ages of the older skates. A more defined reading protocol that included band count criteria may have reduced inter-reader variability, and will be developed in future studies. However, despite this variability, there is little difference between the curves up to 18 years, and the estimated age-at-maturity is barely affected by the choice of curve. Longevity and natural mortality differ slightly between the two curves. Compression of growth bands at the margin may have caused reader 1 to underestimate ages as well, so the estimates here of longevity may still be too low, and estimates of natural mortality too high. This is especially true if the exploitation rate of Ross Sea skates has been high enough to selectively reduce the frequency of the largest, oldest skates in the population, resulting in them being absent from the relatively small sample in this study.

Two very different approaches to ageing *A. georgiana* are now available, but strong support for either is still lacking. The very different parameter estimates derived from the two approaches indicate an urgent need for a validation study to identify the best one. Validation or verification techniques that have some promise include injection with fluorochemical markers such as oxytetracycline (Gallagher and Nolan, 1999), estimation of growth of tagged and released skates, radiometric dating and thorn scans for seasonal variation in stable isotope composition. The first two techniques have high potential, as long as capture, tagging and injection do not increase mortality rates or reduce growth rates of skates. The other two techniques require further investigation to determine whether they would be suitable for application to Antarctic skates. In addition, understanding the dynamics of thorn growth, principally through sectioning, may provide insight into band formation processes and lead to more accurate band counts (Gallagher et al., 2005).

Acknowledgements

We thank Caoimhghin Ó Maolagáin for preparing and photographing the thorn specimens. New Zealand members of CCAMLR's Working Group on Fish Stock Assessment, P. Brickle and an anonymous reviewer made many useful comments on an earlier version of this work.

References

Arkhipkin, A.I., N. Baumgartner, P. Brickle, V.V. Laptikhovsky, J.H.W. Pompert and Z.N. Shcherbich. 2008. Biology of the skates *Bathyraja brachyurops* and *B. griseocauda* in waters around the Falkland Islands, Southwest Atlantic. *ICES J. Mar. Sci.*, 65 (4): 560–570.

Ballara, S.L. and R.L. O'Driscoll. 2005. A review of rattail (*Macrourus* spp.) and skate by-catch, and analysis of standardised CPUE, for the exploratory fishery in the Ross Sea (CCAMLR Subareas 88.1 and 88.2) from 1997/98 to 2004/05. Document *WG-FSA-05/24*. CCAMLR, Hobart, Australia: 33 pp.

Campana, S.E. 2001. Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. *J. Fish Biol.*, 59 (2): 197–242.

Campana, S.E., M.C. Annand and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. *Trans. Am. Fish. Soc.*, 124: 131–138.

Francis, M.P. 2003. Length at maturity of the Antarctic skates *Amblyraja georgiana* and *Bathyraja eatonii* in the Ross Sea. Documents *WG-FSA-03/42*. CCAMLR, Hobart, Australia: 8 pp.

Francis, M.P. 2006. Review of biological parameters for Ross Sea skates. Document *WG-FSA-06/31*. CCAMLR, Hobart, Australia: 18 pp.

Francis, M.P. and N.W.M. Smith. 2002. Morphometrics, maturity, and movement of the Antarctic skates *Amblyraja georgiana* and *Bathyraja eatonii* in the Ross Sea. Document *WG-FSA-02/42*. CCAMLR, Hobart, Australia: 15 pp.

Francis, M.P. and C. Ó Maolagáin. 2005. Age and growth of the Antarctic skate (*Amblyraja georgiana*) in the Ross Sea. *CCAMLR Science*, 12: 183–194.

Francis, M.P. and S. Mormede. 2008. Updated biological parameters for the Antarctic starry skate (*Amblyraja georgiana*) from the Ross Sea. Document *WG-FSA-08/20*. CCAMLR, Hobart, Australia: 15 pp.

Francis, M.P., C. Ó Maolagáin and D. Stevens. 2001. Age, growth, maturity, and mortality of rough and smooth skates (*Dipturus nasutus* and *D. innominatus*). *NZ Fish. Assess. Rep. 2001/17*: 21 pp.

Francis, M.P., S.E. Campana and C.M. Jones. 2007. Age under-estimation in New Zealand porbeagle sharks (*Lamna nasus*): is there an upper limit to ages that can be determined from shark vertebrae? *Mar. Freshw. Res.*, 58: 10–23.

Gallagher, M. and C.P. Nolan. 1999. A novel method for the estimation of age and growth in rajids using caudal thorns. *Can. J. Fish. Aquat. Sci.*, 56 (9): 1590–1599.

Gallagher, M.J., C.P. Nolan and F. Jeal. 2005. The structure and growth processes of caudal thorns. *J. Northw. Atl. Fish. Sci.*, 35: 125–129.

Gallagher, M.J., M.J. Green and C.P. Nolan. 2006. The potential use of caudal thorns as a non-invasive ageing structure in the thorny skate (*Amblyraja radiata* Donovan, 1808). *Env. Biol. Fish.*, 77: 265–272.

Henderson, A.C., A.I. Arkhipkin and J.N. Chtcherbich. 2005. Distribution, growth and reproduction of the white-spotted skate *Bathyraja albomaculata* (Norman, 1937) around the Falkland Islands. *J. Northw. Atl. Fish. Sci.*, 35: 79–87.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. *Fish. Bull.*, 81 (4): 898–903.

Matta, M.E. and D.R. Gunderson. 2007. Age, growth, maturity, and mortality of the Alaska skate, *Bathyraja parmifera*, in the eastern Bering Sea. *Env. Biol. Fish.*, 80: 309–323.

van Wijk, E.M. and R. Williams. 2005. Biological and fishery information for skates in Division 58.5.2. Document *WG-FSA-05/70*. CCAMLR, Hobart, Australia: 21 pp.

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras