J. Northw. Atl. Fish. Sci., Vol. 35: 79–87 Publication (Upload) date: 29 September 2004

Distribution, Growth and Reproduction of the White-spotted Skate *Bathyraja albomaculata* (Norman, 1937) Around the Falkland Islands

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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. doi:10.2960/J.v35.m503

Abstract

Specimens of *Bathyraja albomaculata* collected on-board commercial and research vessels operating within the Falkland Islands Interim Conservation and Management Zone ranged in size between 7–73 cm disc width (DW), with the sexes evenly distributed throughout the depth-range studied. Both sexes displayed a negatively-skewed unimodal size-distribution above 200 m while at deeper depths the size-distribution of both sexes was bimodal, with smaller individuals accounting for an increased proportion of the population. Females matured between 29–46 cm DW, and males between 35–46 cm DW, with the size at 50% maturity occurring at 40.0 cm and 41.6 cm in males and females respectively. Gravid and post-partum females were observed year-round and throughout the species' depth range. However, there was an increase in the proportion of gravid/post-partum females during autumn and winter (March–August). Specimens were aged by incremental analysis of the dorsal thorns and the results were used to generate the von Bertalanffy equations $DW_t = 70.6\ (1 - e^{-0.07(t+2.39)})$ and $DW_t = 64.9\ (1 - e^{-0.09(t+1.94)})$ for males and females respectively.

Key words: *Bathyraja albomaculata*, distribution, Falkland Islands, growth, reproduction, skate

Introduction

Records of commercial rajid catches in Falkland Islands waters extend back to 1987, when the Falkland Islands Interim Conservation and management Zone (FICZ) was established. The group was initially taken in relatively small amounts (less than 1 500 tons annually) in a mixed groundfish fishery, but since 1989 they have been targeted by a Korean fleet utilising demersal trawls, with a subsequent increase in catches. The fishery initially concentrated on two main areas, one located on the shelf edge to the north of the Islands, and the other to the south of the Islands where there is an indentation of the shelf. However, the southern area was closed to the Korean fleet in 1996 due to concerns over the sustainability of the fishery. Rajids are also taken as bycatch in the demersal finfish and squid (*Loligo gahi*) fisheries operating around the Falkland Islands, in addition to a small bycatch in the Patagonian toothfish (*Dissostichus eleginoides*) longline fishery operating in the deeper waters of the Falklands Outer Conservation and management Zone (FOCZ).

Although approximately 11 rajid species are regularly taken, commercial catches are dominated by four species in particular: *Bathyraja griseocauda*, *B. albomaculata*, *B. brachyurops* and *Raja flavirostris*. With the exception of an investigation into the use of caudal thorns as a method of ageing (Gallagher and Nolan, 1999), work has so far been limited to the assessment and management of the fishery (Agnew *et al.*, 1999, 2000), and very little is known of the biology of any of these species. It was therefore decided to address this matter by investigating the age composition, growth and reproductive biology of one of these species, with a view to extending the work to additional species at a future date. Because of its convenient size and common nature, the white-spotted skate *Bathyraja albomaculata* (Norman, 1937) was identified as an ideal candidate for such an exploratory investigation.

Materials and Methods

Data were sourced from the existing scientific observer database in addition to being collected aboard commercial and research vessels (demersal trawls) operating within the FICZ during the study period (February–December). Information gleaned from the database was typically concerned with size, maturity and capture location, while specimens examined at sea during the study were processed as follows: Total length and disc width were measured to the nearest cm and, in the case of males, clasper length was measured to the nearest 0.1 cm following Hubbs and Ishiyama (1968). After exposing the body cavity, each specimen was assigned a maturity stage following the sampling protocol of the Falkland Islands Fisheries Department (FIFD) (Table 1)[1] and, in the case of females, oviducal gland width was measured to the nearest 0.1 cm, in addition to the number and maximum diameter of oocytes in each ovary being noted. For the purpose of age estimation approximately four caudal thorns were collected and stored frozen. The reproductive tracts from a non-random sub-sample of the specimens caught were removed and fixed in a 10% buffered formol saline solution, for a separate histology study.

TABLE 1. Falkland Islands Fisheries Department maturity scales for male and female rajids.

Maturity stage	Condition
	Female
I: Juvenile	Ovaries leaf-like, thin. No obvious eggs or eggs present in leaf-like opaque zone within ovary with gelatinous or granular appearance (grains of sugar). Oviducal glands undeveloped, present as opaque bulge in oviduct. Oviducts small and thread-like.
II: Adolescent, maturing	Ovary/Ovaries containing small eggs. Oviducal glands small and developing. Usually cream in colour with obvious white ends. Oviducts small and thread-like.
III: Adult, developing	Ovary/Ovaries containing developing eggs some of which are very large. Oviducal glands fully developed, uniformly white. Oviduct walls thickened.
IV: Adult, mature	Ovary/Ovaries containing large egg/eggs. Large eggs present in fallopian tubes, or already passing through to oviducal gland. Oviducal glands fully developed. Egg cases, if present, only partially extruded. Oviducts developed, walls thick and venous.
V: Adult, laying	Ovary/Ovaries containing large egg/eggs. Oviducal glands fully developed, uniformly white. Fully formed egg cases present. Oviducts developed, walls thick and venous or may appear stretched (following extrusion).
V: Adult, resting	Ovaries containing a variety of eggs in different stages of development. No extremely large eggs present. Oviducal glands fully developed. No eggs present in fallopian tubes or oviducts. No egg cases present. Oviducts venous and stretched.
	Male
I: Juvenile	Claspers less then length of the pelvic fins. Testis undeveloped, thread or leaf-like. Spermatophoric area evident as leaf-like zone within the testis. Sperm duct undeveloped.
II: Adolescent, maturing	Claspers longer than tips of pelvic fins. Clasper tips (glans) already structured but skeleton still flexible. Testis swollen with developing spermatophoric spheres. Sperm ducts with obvious structure and of uniform size throughout. Kidneys slightly obscured by developing sperm duct.
III: Adult, mature	Claspers rigid and much longer than the pelvic fins, glans structures fully formed. Testis swollen with developing spermatophoric spheres. Sperm ducts with obvious structure separated into two distinct structures and filled with flowing sperm. Sperm duct obscuring at least half of the kidneys.
IV: Adult, running	Same as IV, except that sperm is present in the glans.

[1] It should be noted that two different maturity scales have been used for male rajids by FIFD, an older four-stage scale and a newer five-stage scale. As the latter can be converted to the former, but not *vice versa*, the four-stage scale was employed in all data analyses so as to maximise the number of existing records that could be utilised by the present study.

Thorn samples were cleaned in a trypsin solution incubated at 37°C, oven/air dried, etched in a 5% EDTA solution for approximately 10 minutes, rinsed in water, and then microwaved on full power for ~3 minutes to enhance etching and dehydration. Thorns were placed in a 1% silver nitrate solution for 45–60 minutes, rinsed in water, then blotted dry and exposed to a UV light source until suitably blackened. The process was halted by a 10-minute immersion in a 5% sodium thiosulphate solution, after which the thorns were left to air dry (Fig. 1).

Each of the thorns in the entire sample was independently read by a primary and secondary reader, during which time all biological data was disregarded. Where readings disagreed by ± 1 year, the age assigned to the specimens alternated between the primary and secondary reading, and where readings disagreed by ± 2 years the mean reading was assigned. In the event of disagreements of ± 3 years or more, the thorns were re-read by the primary and secondary readers, and if this failed to resolve the issue, a third reader was employed. Where the

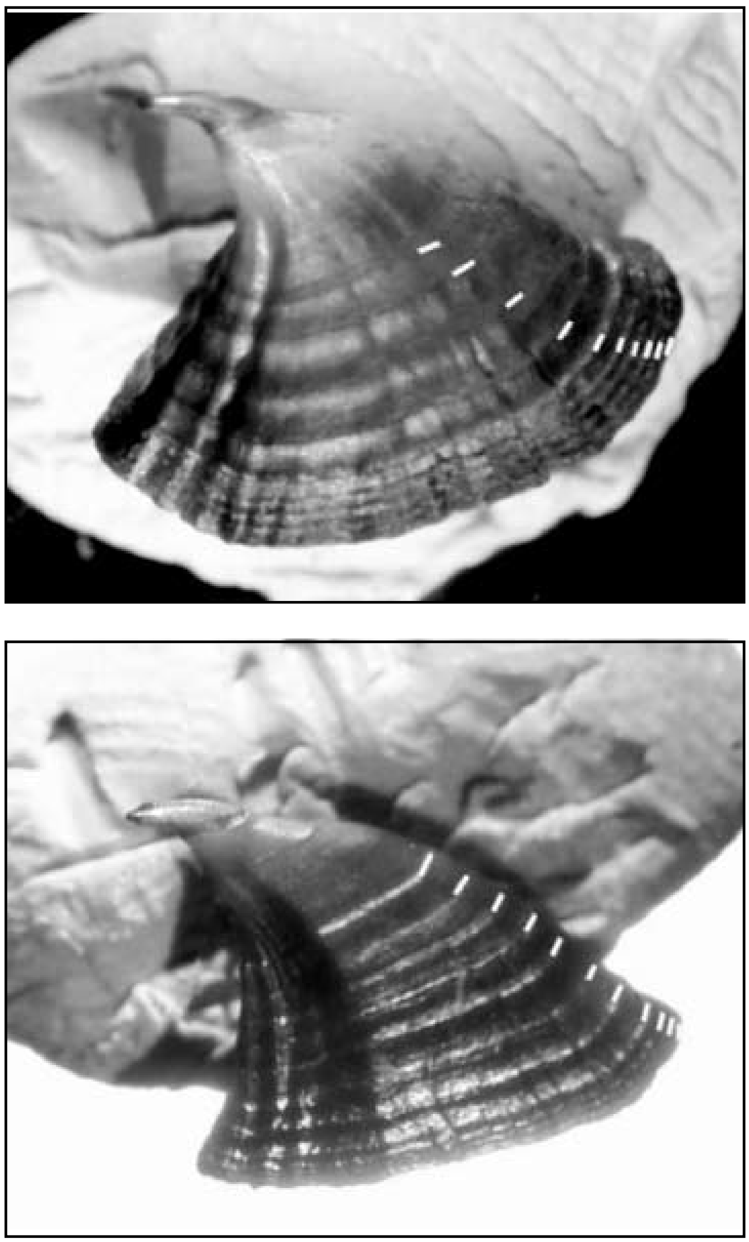

Fig. 1. Example of a 10-year-old (top) and 11-year-old (bottom) thorn, processed using the silver nitrate method (see text).

latter showed close agreement with either the primary or secondary reading, these two readings were treated as above for readings of ± 2 years or less. If a discrepancy of ± 3 years or more still remained, the thorn was disregarded from further analyses. The first apical mark on the thorns of adults was considered as the birthmark as it matched completely with the total thorn height from hatchling skates. As the validation of the annual rings on the thorns was not accomplished for *B. albomaculata*, all age estimates should be considered as putative in this report. Growth curves were generated with the Simply Growth program (PISCES Conservation Ltd), which estimates parameters by non-linear regression using the Levenberg-Marquardt method.

Results

Catches of *B. albomaculata* were concentrated along the shelf edge to the east and south of the Islands (Fig. 2). A total of 430 specimens were dissected during the study (February–December 2001), supplemented by a further 2 073 records from the observer database. The sex ratio within each 100 m depth stratum between 100–400 m was approximately 1:1, although fractionally more males were recorded in each case. Although the database contained records of specimens from 7–73 cm DW, the vast majority (99.8%) of specimens ranged from 9–60 cm DW. Catch records display a bimodal size distribution (Fig. 3). When this information is viewed with respect to depth it can be seen that both sexes display a negatively skewed unimodal size distribution above 200 m, while at deeper depths the size-distribution becomes bimodal (Fig. 4).

A total of 480 specimens were aged from caudal thorn analysis. Of these, only 5.6% had to be discarded due to a difference greater than ± 2 years between the primary and secondary readers, with 41.7% in complete agreement, 42.5% disagreeing by ± 1 year and 10.2% disagreeing by ± 2 years. The maximum age assigned to a thorn by an individual reader was 18, although the highest agreed age assigned was 17 (see Table 2). The age-class distribution is presented graphically for each sex in Fig. 5.

In an effort to minimise the effect of extreme (and therefore possibly erroneous) data on the resultant growth curve, boxplots of disc width against age were constructed, with a view to eliminating outliers from further analyses. The growth equations thus obtained were:

Female: $DW_t = 64.9\ (1 - e^{-0.09(t + 1.94)})$

Male: $DW_t = 70.6\ (1 - e^{-0.07(t + 2.39)})$

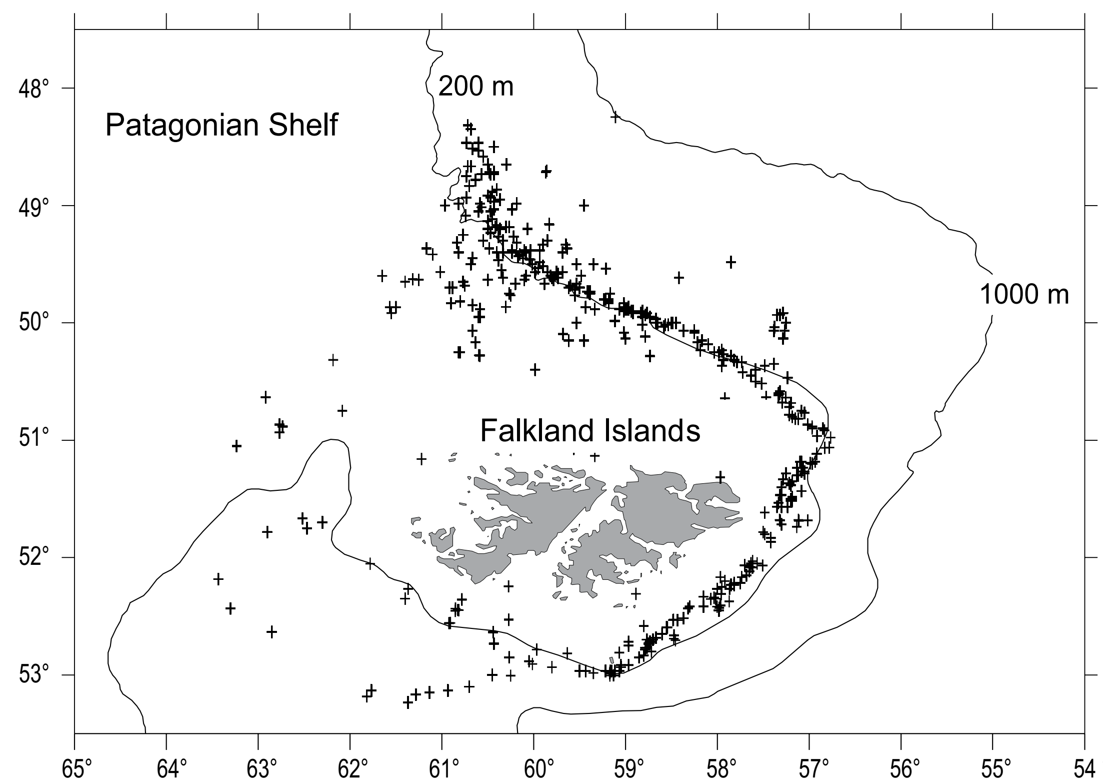

Fig. 2. Catch distribution of *Bathyraja albomaculata* around the Falkland Islands.

Using these equations, growth curves were constructed (Fig. 6a), and size at hatching was estimated to be 9.8 and 10.5 cm DW for females and males respectively.

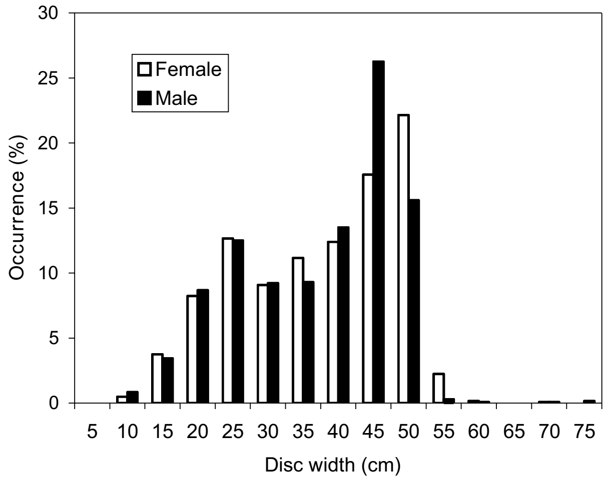

Fig. 3. Size distribution of male and female *Bathyraja albomaculata* in Falkland Islands waters.

Because of the high degree of similarity between the male and female growth curves, age and size data for both sexes were pooled to construct a common growth model for the species as a whole (Fig. 6b). The von Bertalanffy equation obtained was:

$$\text{Sexes combined: } DW_t = 67.6\,(1 - e^{-0.08(t+2.14)})$$

The size ranges within assigned maturity stages are presented for males and females in Fig. 7. A one-way analysis of variance determined that the mean size differed significantly between maturity stages in both sexes (P <0.001), and *post-hoc* analysis (Scheffé) further determined that these significant differences only occurred between immature and mature groups – *i.e.* there was neither significant difference in the mean size of stage III and stage IV males, nor between stages III, IV, V, and VI in females.

Figure 8 presents the percentage of mature individuals at each length, as determined by visual inspection. As can be seen, the smallest mature female measured 29 cm DW, the largest immature female measured 46 cm, and

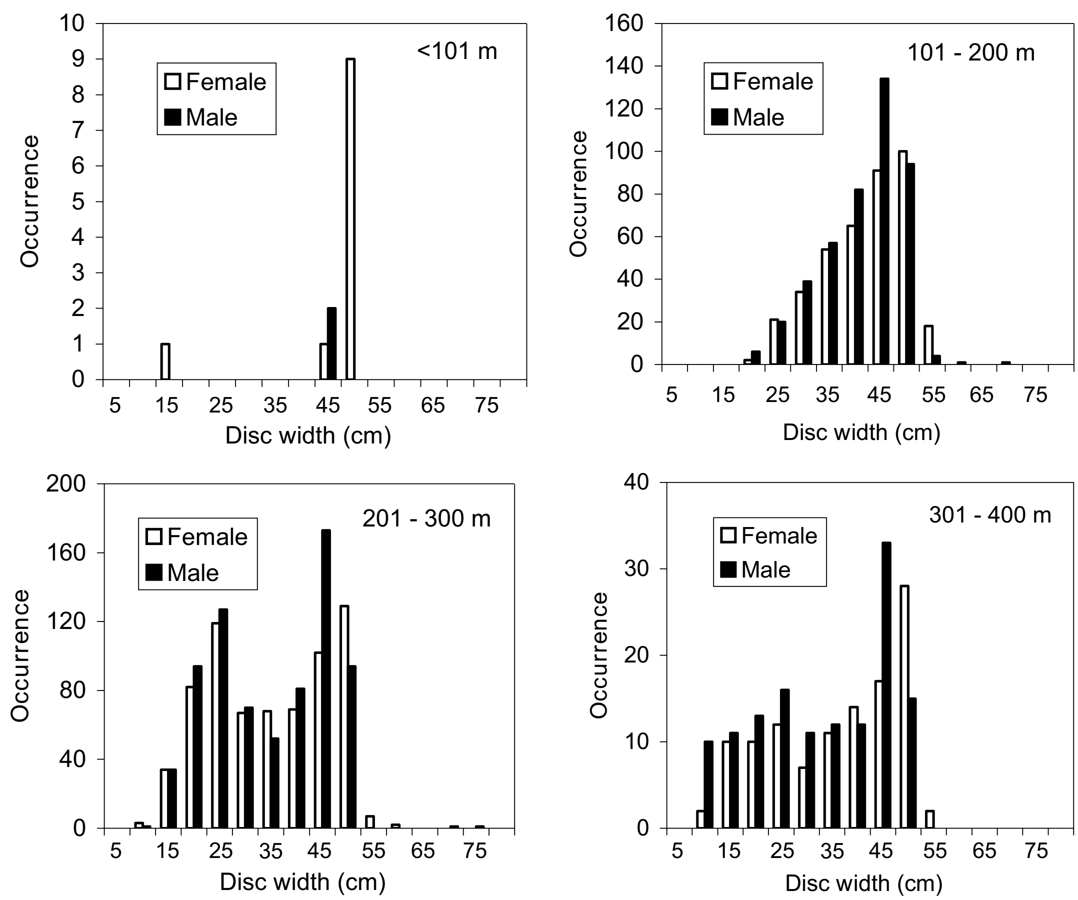

Fig. 4. Size distribution of male and female *Bathyraja albomaculata* within 100 m depth strata.

TABLE 2. Summary statistics on the age distribution of male and female *Bathyraja albomaculata* from around the Falkland Islands.

Statistic	Female	Male
Mean	8.9	7.4
Standard Error	0.28	0.32
Median	10	8
Mode	11	12
Standard Deviation	4.3	4.3
Kurtosis	-0.82	-1.14
Skewness	-0.45	-0.31
Minimum	0	0
Maximum	17	17

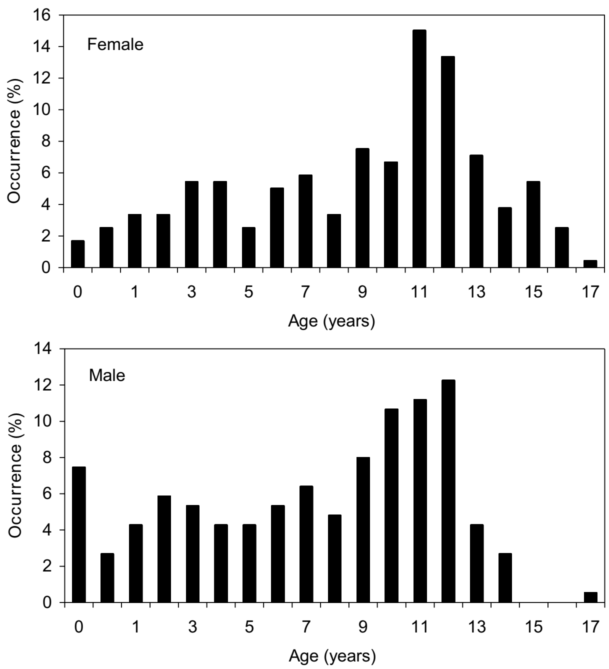

Fig. 5. Age distribution of male and female *Bathyraja albomaculata*. 0 age-class presents hatchlings, and 0.5 age-class presents animals of age <1 year.

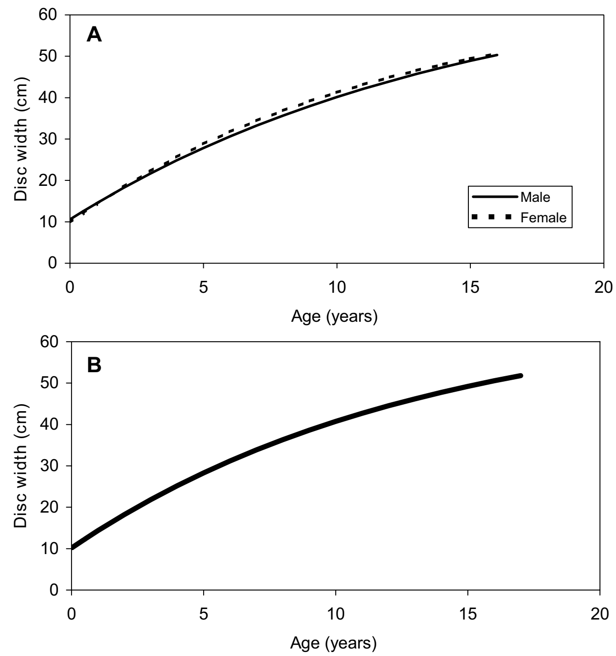

Fig. 6. Von Bertalanffy growth curves for (**A**) male and female *Bathyraja albomaculata*, and (**B**) sexes combined.

50% maturity occurred at 40.0 cm. Extrapolating from the von Bertalanffy growth curve, these lengths correspond to ages of six years (first maturity) and 10 years (50% maturity). The relationship between disc width and oviducal gland width is presented in Fig. 9, in which the trendline inflections associated with the first mature and last immature individuals show close agreement with the visual assessment of maturity.

From Fig. 8 it can be seen that the smallest mature male occurred at 35 cm, while the largest immature male occurred at 46 cm. The size at 50% maturity was estimated as 41.6 cm. These sizes indicate first maturity and 50% maturity at the slightly older ages of eight and 11 years respectively, when compared with females. Figure 9 presents the relationship between clasper length and disc width, and as can be seen from this, the range of clasper lengths increases dramatically between these lengths, again concurrent with the gross visual maturity assessment.

The depth distributions of male and female maturity stages are presented in Fig. 10, showing that there was considerable overlap between groups. Although a one-way

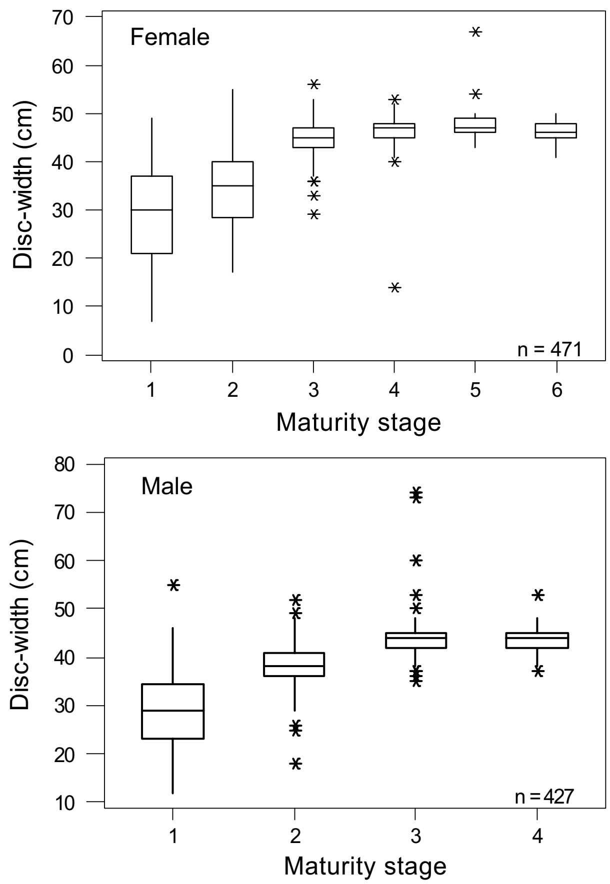

Fig. 7. Size range within assigned maturity stages for male and female *Bathyraja albomaculata*.

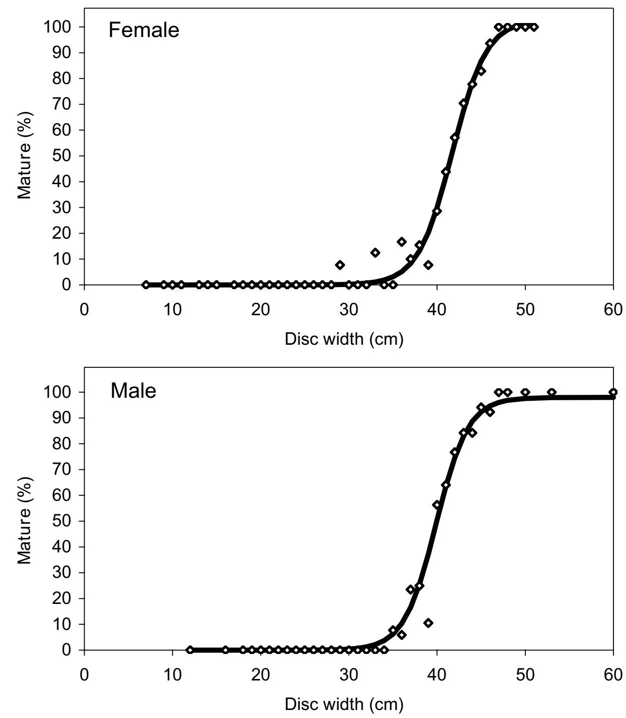

Fig. 8. Relationship between disc width and maturity in male and female *Bathyraja albomaculata*.

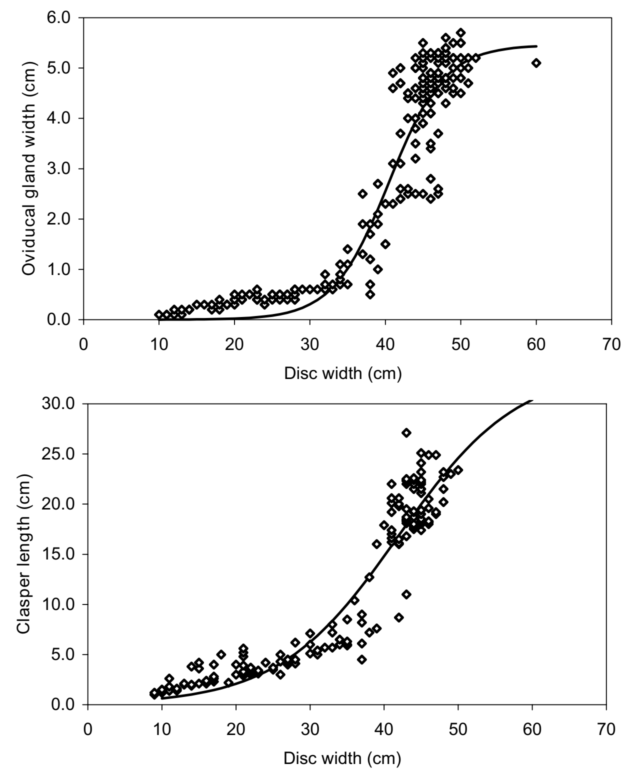

Fig. 9. Relationship between disc width and (**A**) oviducal gland width, (**B**) clasper length, in *Bathyraja albomaculata*.

analysis of variance determined that the depth distributions of the various male maturity stages did not differ ($P > 0.05$), the same analysis determined that the depth distribution of the female maturity stages did differ significantly ($P < 0.05$). However, *post-hoc* analysis ascertained that only the depth distributions of post-partum and wholly immature (*i.e.* stage VI and stage I) individuals differed from each other significantly, the former displaying a slight propensity for shallower depths when compared with the latter (Scheffé test, $P < 0.05$). The proportion of mature females accounted for by stage V and stage VI (*i.e.* gravid and post-partum) individuals in each season is presented in Fig. 11, showing a notable increase in their occurrence during autumn and winter. Ovarian fecundity ranged from four, in a 46 cm DW individual, to 32, in a 50 cm DW individual. Mean fecundity was 14, with a modal fecundity of 12, and fecundity was only loosely correlated with female size (partial correlation, $P < 0.05$). Oocytes were ovulated at a diameter of 3.5–3.8 cm.

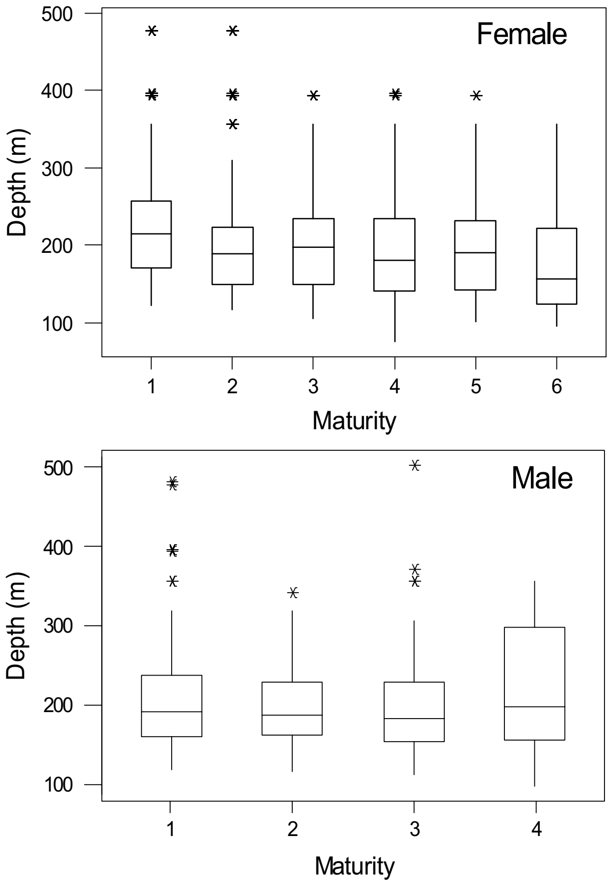

Fig. 10. Depth distributions of the various maturity stages.

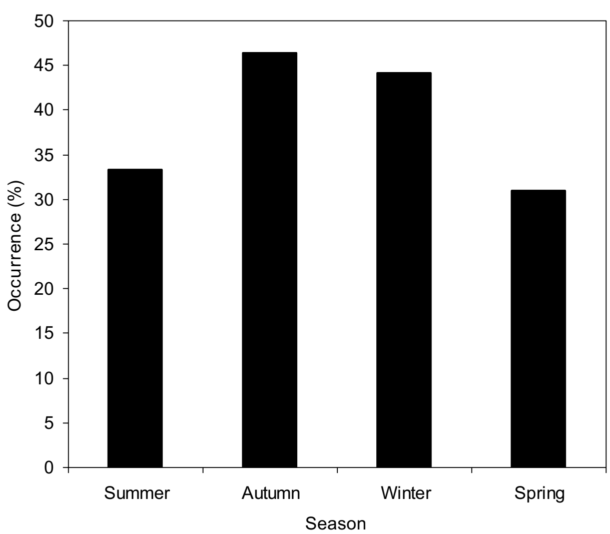

Fig. 11. Percentage of mature females accounted for by gravid and post-partum individuals.

Discussion

Bathyraja albomaculata displays a rather dispersed distribution around the Falkland Islands, occurring in both shelf and slope waters. While Agnew *et al.* (1999) have shown local variations in the species composition of rajid catches around the Islands, possibly indicating habitat preference, the catch distribution presented here is more likely to be a reflection of fishing effort rather than specimen abundance – the eastern edge of the shelf being the primary location of the intensive *Loligo* fishery. While the results here may initially indicate a lack of sexual segregation, it is important to remember that not all segregations are overtly depth stratified, and gender-related movements may occur within depth strata (*e.g.* Ryland and Ajaya, 1984; Rousset, 1990).

Depth-related size segregations are commonly reported in elasmobranch studies. While in its simplest form there is a gradient of smaller to larger individuals with increasing depth, this is not always the case, and depth-related movements are often attributed to the reproductive cycle (*e.g.* Olsen, 1954; Tanaka *et al.*, 1990; Girard and Du Buit, 1999). Unlike many studies in which there is a modal progression with increasing depth, the modes of the present study remained static, it being their markedness that varied. The main adult mode is clearly evident in the three primary depth strata (101–400 m), indicating that adults do not confine themselves to deeper or shallower waters. The emergence of a strong juvenile mode between 201 m and 300 m, however, clearly indicates a preference for upper slope waters in this section of the population (males and females). Beyond 300 m the occurrence of these juveniles is less pronounced, although these depths are still clearly preferred over the shallower (<200 m) waters.

The small number of specimen records exceeding 60 cm DW would appear to be erroneous, most probably a matter of species misidentification. At the other end of the size range it is unclear if the smallest records are of free-ranging individuals or near-term embryos which have been excised from their egg-cases. Based on observations during the study period and during previous research cruises, it seems very likely that the few records below 9–10 cm DW are of excised embryos.

The range in age and size at age values reported here are very similar to those reported by Gallagher (2000), lending credence to the accuracy of both studies. As this is the first independent study to employ Gallagher and Nolan's (1999) ageing method, it also confirms the applicability the technique. The growth coefficient determined by Gallagher (2000) for male *B. albomaculata* is almost identical to that determined here, but Gallagher's (2000) female growth coefficient is considerably lower. As Gallagher himself points out, his female growth coefficient is most probably an underestimate due to small sample size, and the results of the present study would appear to confirm this. The same applies to the rather large asymptotic length and high t_0 reported for females in that study, as well as the difference in size at 50% female maturity.

The females of many rajid species are known to move into shallower waters in order to deposit their eggs (Steven, 1936; Wheeler, 1969). However, both gravid females of *B. albomaculata* and small juveniles were concentrated at a slightly deeper depth, which may indicate that this species spawns at deeper waters (200–300 m). Stage IV males occurred throughout the depth range, suggesting that mating occurs at all depths.

Bathyraja albomaculata displays quite a low fecundity (max = 32) relative to other rajid species that have been studied, *e.g. R. radiata* (max = 88; Abdel-Aziz *et al.*, 1987), *R. clavata* (max = 74), *R. brachyura* (max = 61; Ryland and Ajaya, 1984). Combined with its slow growth and late maturity, this data clearly indicates that this species could be susceptible to over-fishing if not monitored closely.

Acknowledgements

We are grateful to the many FIFD and IEO observers who collected the data used here. Joost Pompert (FIFD) assisted with thorn reading which is greatly appreciated. We thank the FIFD Director of Fisheries, John Barton, for supporting this work.

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