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Diet of the white-dotted skate, *Bathyraja albomaculata*, in waters of Argentina

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Summary

The present paper analyzes the diet, feeding strategy and niche width of *Bathyraja albomaculata* over the Patagonian continental shelf and upper slope. The diet comprised a variety of 14 small invertebrates, although the most important prey were polychaete worms. The opheliid polychaete *Travisia* sp. and the gammarid amphipod *Cirolana* sp. were the main prey present in stomach contents of *B. albomaculata*. No differences were found between the diets of males and females, however ontogenetic changes were detected. Skates < 40 cm of disk width (DW) preyed on amphipods, and sizes > 40 cm DW largely consumed polychaetes. As size increased, polychaetes became more important and the importance of amphipods decreased. *B. albomaculata* showed a narrow food niche and a marked specialization towards polychaetes.

Introduction

The white-dotted skate, *Bathyraja albomaculata* (Norman, 1937), is widely distributed over the Argentine continental shelf and upper slope between 37° and 55°S, and from 72 to 945 m depth (Cousseau et al., 2000; Menni and Stehmann, 2000; Brickle et al., 2003). This species has been also referred to as *Rhinoraja albomaculata* based on the putative presence of a basal joint in the rostral cartilage typical of the genus *Rhinoraja* (Compagno, 1999). However, we failed to find such a joint; pending any formal generic re-assignation of the species, we prefer to refer to it as belonging in the genus *Bathyraja*. Its highest abundances have been reported in northern and southern Patagonian waters (Ruocco et al., 2006), and it is regarded as one of the most abundant skates in the Islas Malvinas rajid fishery (Agnew et al., 1999). This species has traditionally been caught as bycatch in trawling fisheries targeting Argentine hake, *Merluccius hubbsi* (Coscarella et al., 1997), southern blue whiting, *Micromesistius australis*, hoki, *Macruronus magellanicus* (Brickle et al., 2003), and in the Patagonian red shrimp, *Pleoticus muelleri* (Cedrola et al., 2005). In recent years the commercial importance of this species has increased (García de la Rosa et al., 2000), and it is now one of the most valuable bycatch in southwest Atlantic fisheries (Paesch and Meneses, 1999; Agnew et al., 2000) contributing *c.* 28% of the estimated total rajid catch around Islas Malvinas, where it is the second most commonly caught skate (Agnew et al., 1999) and one of the four rajid species regularly taken on commercial catches in this fishery (Henderson et al., 2004). Despite its recognized commercial importance, the biology of *B. albomaculata* is poorly known.

Previous studies on *B. albomaculata* focused primarily on taxonomy (Stehmann, 1978; Menni et al., 1984), and distribution (Bellisio et al., 1979; Menni and Gosztonyi, 1982; Pequeño and Lamilla, 1993; Cousseau et al., 2000), and gave little or no information on the basic biology. The only studies on *B. albomaculata* life history are by Henderson et al. (2004), in waters around Islas Malvinas, and Ruocco et al. (2006) on the Patagonian and northern Argentine shelf. The diet of *B. albomaculata* has only been analyzed in multispecies studies comparing food habits of several species over a restricted part of the species geographic range, which precludes detailed intraspecific comparisons (i.e. Sánchez and Mabragaña, 2002; Brickle et al., 2003). Those studies have shown that *B. albomaculata* has a rather restricted niche breadth with a diet specializing on polychaetes. Our objective was to analyze the composition of the *B. albomaculata* diet over most of its geographic range on the Argentine continental shelf and upper slope, and to evaluate the diet in relation to size and sex.

Materials and methods

Samples used in this paper were obtained from three research cruises conducted in the southwest Atlantic between 41°S and 54°S, over a depth range of 43–440 m, by the RVs 'Capitán Oca Balda' and 'Doctor Eduardo Holmberg' of the Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP, Argentina) between 2000 and 2003. The sampling scheme was randomly stratified and designed for assessment of hake, *Merluccius hubbsi*, southern blue whiting, *Micromesistius australis*, hoki, *Macruronus magellanicus* and Argentine squid, *Illex argentinus*. A 59-m Engel-type bottom trawl net, with a stretched mesh size of 200 mm in the wings and 103 mm in the codend, a vertical height of 4 m, and a horizontal opening of 15 m was used in all research cruises. Haul duration was 30 min at a trawling speed of 3.6 knots.

For each specimen, disk width (DW), total length (TL) and sex were recorded. Maturity stage was assessed according to macroscopic observation of the uteri, oviducal glands, ovarian follicles and eggs in females, and the degree of calcification of the claspers and shape of efferent ducts in males (Ruocco et al., 2006).

The stomachs were removed, frozen and subsequently analyzed in the laboratory. Prey were identified to the lowest possible taxonomic level, using keys, field guides and specific catalogues (Bastida and Torti, 1973; Moreira, 1973; Boschi et al., 1992). Prey were categorized into four groups, Polychaeta, Amphipoda, Isopoda and Others (i.e. cirripeds, unidentified crustaceans, crabs and cumaceans), for statistical analyses.

The number and the wet weight of each prey were recorded using a digital scale accurate to 0.01 g. For both sexes cumulative curves were used to determine whether enough samples had been collected to describe the diet precisely and for subsequent comparisons (Ferry and Cailliet, 1996). The order of stomachs sampled was randomized 100 times and the mean number of new prey categories (± 1 SD) was plotted as a function of sample size. Cumulative curves were separately built for males and females using the four prey groups. The asymptote of the curve indicated the minimum sample size required to describe the diet (Ferry and Cailliet, 1996).

The importance of each prey was determined by calculating the index of relative importance:

$$\mathrm{IRI} = \%F \times (\%N + \%W)$$

where $\%F$ is the percent frequency of occurrence (i.e. the number of stomachs in which a given prey was found as percentage of the number of stomachs with food) of each prey taxa; $\%N$ is the number of a given prey as percentage of the total number of prey; and $\%W$ is the number of a given prey as percentage of the total weight of prey. The index of relative prey importance was expressed as a percentage (%IRI), where:

$$\%\mathrm{IRI}_i = 100 \times \mathrm{IRI}_i / \sum_{i=1}^{n} \mathrm{IRI}_i$$

n is the total number of food categories considered at a given taxonomic level (Cortés, 1997).

A two-way non-parametric multivariate analysis of variance (NPMANOVA) was used to describe variation in stomach contents owing to sex and size (Anderson, 2001). The number of the main prey groups and the Bray–Curtis distance were used to test sexual and ontogenetic effects on the diet of *B. albomaculata*. The specimens were grouped in four size classes: < 33; 33–40; 40.1–47 and > 47 cm DW. These classes were based on the approximate size at maturity of *B. albomaculata*. According to Ruocco et al. (2006) length at first maturity of *B. albomaculata* in the study area was 62.8 and 65.3 cm TL for males and females, respectively, which corresponds to 43.9 and 45.6 cm DW, respectively. Thus, specimens > 47 cm DW are mostly mature, and specimens below 40 cm DW are mostly juveniles. A posteriori, we performed a Kruskal–Wallis test for each prey group comparing all sizes; if significant differences were detected, we conducted pair-wise comparisons between length classes with a Wilcoxon paired rank test to locate the significant differences. In all *a-posteriori* tests, a correction control for the false discovery rate was used to avoid inflation of type-I error (Benjamini and Hochberg, 1995).

The prey importance (dominant or rare), feeding strategy (specialist or generalist) and niche width contribution were assessed by means of the graphic method of Amundsen et al. (1996). The parameters used were P_i (i.e. the prey-specific abundance of prey i), S_i the stomach content (total number of the prey i) and S_{ti} the total stomach content in only those predators with prey i in their stomach.

$$P_i = \left(\sum S_i / \sum S_{ti}\right) \times 100$$

This analysis consists on a two dimensional representation where each point represents the specific abundance of the prey and the frequency of occurrence.

Results

Of a total of 89 stomachs examined, only 11 were empty. Digeneans were observed in 44.9% (40 individuals) of the samples. Females (17 immature and 18 mature) ranged from 30.8 to 53.0 cm DW, and males (17 immature and 26 mature) ranged from 25.9 to 55.1 cm DW. In both sexes, the four most important prey found were polychaetes, present in 95.5% of the stomachs, amphipods in 56.7%, isopods in 41.79% and cirripeds, unidentified crustaceans, crabs and cumaceans in 19.4%.

Fourteen prey taxa were identified (Table 1). Cumulative prey curves reached an asymptote, indicating that the sample sizes (n = 35 and n = 43 for females and males, respectively) were sufficient to describe the diet of *B. albomaculata*. The estimate of the minimum sample size needed were 13 in females and 20 in males (Fig. 1).

Among the four different prey categories found, polychaetes had the highest importance (IRI% = 56.8); the opheliid polychaete *Travisia* sp. was the main prey ingested; in second place were amphipods (IRI% = 26.7) and in third place isopods (IRI% = 15.2), with *Cirolana* as the most important isopod genus consumed. The Others category had a much lower importance in the diet (%IRI < 1) (Table 1).

Polychaetes were the main prey in both sexes, followed by amphipods. There were no significant differences between the diets of males and females (NPMANOVA, F = 214.75, d.f. = 1, P = 0.129). Size had a significant effect: large and small skates showed differences in the number of the major prey groups consumed (NPMANOVA, F = 605.52, d.f. = 3, P = 0.0002); however there was no significant multivariate interaction between sex and size (NPMANOVA, F = 166.481, d.f. = 3, P = 0.086).

Significant differences among size groups were detected only for amphipods (Kruskal–Wallis, χ^2 = 30.68, d.f. = 3,

Table 1
Diet composition of 78 white-dotted skates, *Bathyraja albomaculata*, from Patagonian shelf and upper slope (both sexes combined); expressed as percentage by number (%*N*), weight (%*W*), frequency of occurrence (%*F*), and index of relative importance (%IRI) for individual prey and prey group (in brackets) categories. Observed number of each prey taxa (n) is given

Prey items	%*N*	%*W*	%*F*	n	%IRI
Polychaeta	(38.55)	(45.52)	(83.14)		(56.83)
Glyceridae	0.96	2.69	1.49	9	0.058
Lumbrineridae	3.84	3.31	8.95	36	0.68
Nephtyidae	1.6	1.46	17.9	15	0.58
Onuphidae	1.7	2.44	7.46	16	0.33
Opheliidae					
Travisia sp	12.59	15.8	38.8	118	11.7
Terebellidae	2.02	1.88	16.41	19	0.68
Unidentified Polychaetes	22.09	17.7	86.56		36.75
Crustaceans					
Amphipoda	(44.09)	(15.53)	(55.05)		(26.68)
Gammaridea	37.67	13.99	56.7	353	31.21
Isopoda	(14.08)	(33.4)	(39.32)		(15.2)
Cirolana sp	11.21	33.19	35.8	105	16.95
Serolis schythei	0.2	0.058	2.98	2	0.01
Macrochiridothea stebbingi	1.71	0.81	5.97	16	0.162
Antarcturidae ?	0.53	0.66	4.47	5	0.06
Others	(3.26)	(5.47)	(17.97)		(1.27)
Decapoda					
Peltarion spinosulum	0.11	1.3	1.49	1	0.022
Cumaceans	0.21	0.073	2.98	2	0.01
Lepadidae	2.35	2.78	4.47	22	0.24
Unidentified Crustaceans	1.17	1.72	16.4	11	0.51

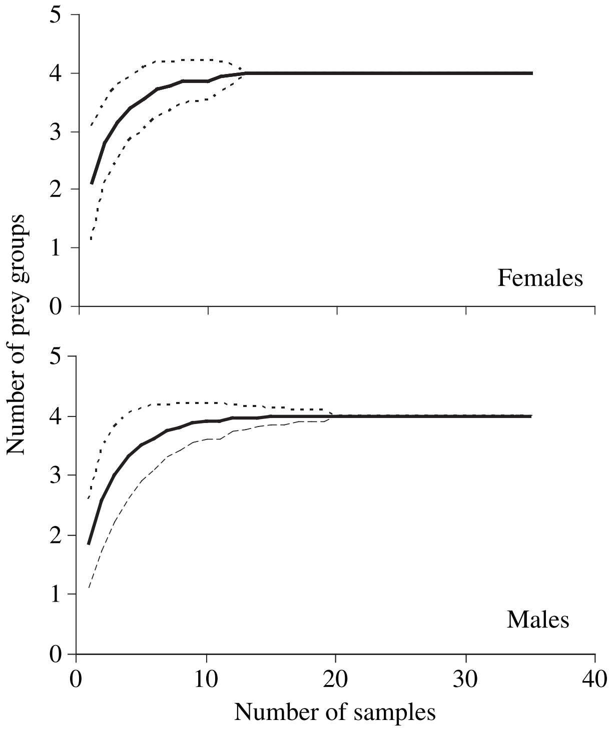

Fig. 1. Cumulative prey curves for stomachs of white-dotted skates, *Bathyraja albomaculata*, from Patagonian shelf and upper slope, considering four prey groups (Amphipoda, Isopoda, Polychaeta and Others) used in the statistical analyses. Bold line = mean number of new prey, broken lines = standard deviations, after 100 permutations

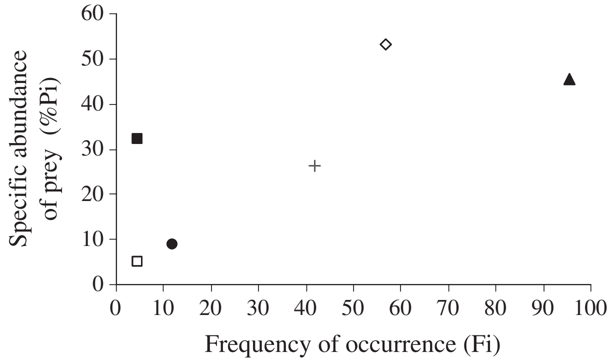

Fig. 3. Prey-specific abundance plotted against frequency of occurrence of prey of white-dotted skates, *Bathyraja albomaculata*, from Patagonian shelf and upper slope. □ Cumaceans, ■ Cirripeds, ● Crustaceans, + Isopods, ◇Amphipods, and ▲ Polychaetes

$P = 0.0001$), while all other prey did not differ significantly. In specimens with DW < 40 cm, amphipods were the group with the highest %IRI values, and in individuals > 40 cm DW, polychaetes had the highest %IRI.

Results of the pair-wise comparisons in amphipod consumption were not significant within the smallest (Pairwise Wilcoxon test, < 33 vs 33–40 cm DW, $P = 0.929$), and the largest (40.1–47 vs > 47 cm DW, $P = 0.766$) size classes, although there were differences between the smallest and the largest size classes (< 33 vs 40.1–47 cm DW, $P = 0.073$; < 33 vs > 47 cm DW, $P = 0.008$; 33–40 vs 40.1–47 cm DW, $P = 0.002$; 33–40 vs > 47 cm DW, $P = 0.004$) (Fig. 2).

Plotting prey-specific abundance against frequency of occurrence showed that polychaetes were the dominant prey, followed by amphipods and isopods, the latter with a value of $F\%$ and P_i lower than 50%. Cirripeds, decapods, unidentified crustaceans and cumaceans were included within the category of rare species (Fig. 3).

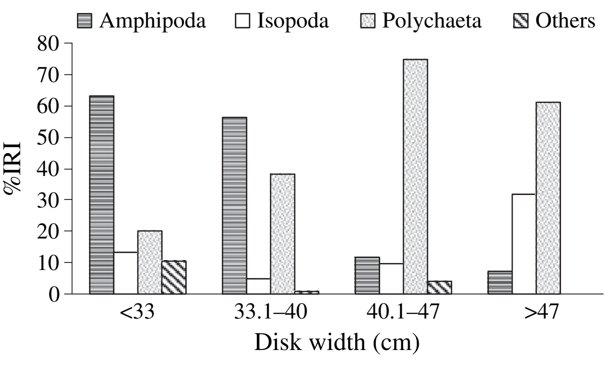

Fig. 2. Diet composition of four size classes of white-dotted skates, *Bathyraja albomaculata*, from Patagonian shelf and upper slope. Sample sizes for each size class: 11 (< 33 cm disc width, DW), 23 (33.1–40 cm DW), 24 (40.1–47 cm DW), and 20 (> 47 cm DW). %IRI: Percent index of relative importance

Discussion

The results of the present paper show that *B. albomaculata* feed on benthic prey, mainly polychaetes, and have a narrow food niche and a marked specialization on polychaetes, followed by amphipods and isopods in decreasing order of importance.

A specialist predator has a narrow dietary niche, in contrast to the large variety of prey found in the stomach contents of a generalist predator (Pianka, 1988). The analysis of the prey-specific abundance against frequency of occurrence shows that *B. albomaculata* is a specialized feeder, polychaetes being the dominant prey. Similarly, in *B. albomaculata* collected around Islas Malvinas (Brickle et al., 2003) and on the southwest Atlantic continental shelf (Sánchez and Mabragaña, 2002; Mabragaña et al., 2005), polychaetes were the dominant prey. The specialist nature of the feeding habits in *B. albomaculata* are reflected in the lower diversity of the prey consumed in comparison to other congeners, like *B. griseocauda* and *B. brachyurops* (Brickle et al., 2003).

Our results on ontogenetic shifts in the *B. albomaculata* diet agree with those of Brickle et al. (2003) who observed that, around Islas Malvinas, juveniles fed upon benthic amphipods and as they increased in size, polychaetes and isopods became important. In the present paper the opheliid polychaete *Travisia* sp. was the main prey found in the diet of *B. albomaculata*. The family Opheliidae reached the highest frequency of occurrence in benthic samples of the southwest Atlantic continental shelf (Bremec et al., 2000), which suggests that these polychaetes may be highly available to skate predators searching for polychaetes.

No differences in diet between sexes were found in *B. albomaculata*, however, a dental sexual dimorphism was observed; juvenile males present a tooth morphology similar to that of adult females (grinding blunt teeth), but mature males have pointed conical cusps. Dental sexual dimorphism was originally proposed as a result of feeding segregation among sexes (DuBuit, 1978). Feduccia and Slaughter (1974) suggested that sexually dimorphic skate dentition implies differential foraging by males and females, reducing intraspecific competition for food. However it is well known that elasmobranchs exhibit a complex reproductive behavior in which the teeth are used by the male for firmly gripping the female during copulation (Price, 1967; McEachran, 1977; Kajiura et al., 2000). McEachran (1977) suggested that if tooth dimorphism is related to ecological niche segregation, it should appear prior to sexual maturation. Here we show that male and female *B. albomaculata* have a similar diet, suggesting that differences in tooth morphology could be more related to reproductive behaviour than to feeding.

Our results suggest that *B. albomaculata* has a specialized polychaetes diet over its entire Atlantic geographic range. Given that the polychaetes consumed are most abundant on soft bottoms (Bremec et al., 2000) that are also best trawlable, its specialized diet can make *B. albomaculata* especially vulnerable to trawl fisheries over most of its geographic range.

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