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Feeding ecology of the apron ray *Discopyge tschudii* (Elasmobranchii, Narcinidae) in San Jorge Gulf, Patagonia, Argentina

M. CECILIA SPATH, GABRIELA DELPIANI AND DANIEL E. FIGUEROA

Laboratorio de Ictiología, Facultad de Ciencias Exactas y Naturales, Instituto de Investigaciones Marinas y Costeras (IIMyC), Universidad Nacional de Mar del Plata, Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Deán Funes 3350, Mar del Plata, Argentina

The study of the feeding habits of elasmobranch populations should help to elucidate the ecological role of these fishes in the marine ecosystem. Feeding habits of the apron ray, Discopyge tschudii *from San Jorge Gulf were investigated. An evaluation of whether the diet of* D. tschudii *changes with body size, seasons, maturity stage and sex was performed using a multiple-hypothesis modelling approach.* Discopyge tschudii *preyed mainly on polychaetes. The consumption of polychaetes was higher in males. Also, amphipods and siphons of clams were preyed more heavily in the cold season and* Munida gregaria *in the warm season. Stomatopods were consumed more with increasing body size. All prey categories were independent of maturity stage. We concluded that* D. tschudii *is a benthic feeder.*

Keywords: diet variation, predation, Magellanic province, GLM, Akaike's weight

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INTRODUCTION

Feeding is one of the most important functions of organisms, since other basic functions such as growth, development and reproduction depend on the energy obtained through feeding (Nikolsky, 1963). Chiefly, diet information is crucial to understanding the species ecology, trophic inter-relationships, food webs, and ultimately, the flow of energy through ecosystems (Brown *et al*., 2012).

The study of the feeding habits of elasmobranch populations should help to elucidate the ecological role of these fishes in the marine system. Despite this, batoids have received considerably less attention than sharks and little is known about the feeding ecology of these species (Bizzarro *et al*., 2007). The reasons for the lack of quantitative studies include a scarcity of adequate systematic knowledge of the group and a lack of interest in studying non-target species or those of little economic value (Ebert & Bizzarro, 2007).

In general, most batoids are benthic predators and consume a wide range of prey found near the sea floor, with invertebrates being the most important food component for many species (Muto *et al*., 2001; Bizzarro, 2005; Scenna *et al*., 2006; Ruocco *et al*., 2007; Bornatowski *et al*., 2010; Navia *et al*., 2011; Delpiani *et al*., 2013; Spath *et al*., 2013). Torpediniformes in particular show marked differences in diet between Narcinidae and Torpedinidae families. While the first feed primarily on fish, crabs and small invertebrates (Bigelow & Schroeder, 1948; Cousseau & Bastida, 1982; Abdel-Aziz, 1994; Capapé *et al*., 2007; Belleggia *et al*., 2008), the second, consume smaller benthic invertebrates (Valadez *et al*., 2000; Valadez-Gonzalez, 2007; Moreno *et al*., 2009; Yick *et al*., 2011). These differences could be attributed mainly to the size of the mouth in each family, since Narcinidae presents a narrow, transverse and protractile mouth and in Torpedinidae the mouth is broad, transverse and only slightly protractile (McEachran & Fechhelm, 1998).

The apron ray, *Discopyge tschudii* (Narcinidae) is found mainly in coastal waters below 120 m (Menni & Stehmann, 2000; Cousseau *et al*., 2007), being endemic to South America. It inhabits the South-west Atlantic, from southern Brazil to southern Argentina, and the South-east Pacific, from Peru to southern Chile (Figuereido, 1977; Menni & Gosztonyi, 1982; Menni & López, 1984; Pequeño *et al*., 1988; Cousseau *et al*., 2007). According to the zoogeographic scheme proposed for the South-west Atlantic, *D. tschudii* belongs to the fauna of the Magellanic Province and it is grouped with the fish assemblage that composes the mixed fauna of the inner shelf (Menni & Gosztonyi, 1982; Menni & López, 1984; Menni *et al*., 2010). The International Union for Conservation of Nature (IUCN) categorized *D. tschudii* as 'Near Threatened' (Massa *et al*., 2004a). Moreover, the population inhabiting the South-west Atlantic is considered 'Vulnerable' due to the remarkable decrease in its abundance during 1994–1999 (Massa *et al*., 2004b).

The aims of this study are to provide a quantitative analysis of the diet composition of *D. tschudii* and to assess the effects of sex, maturity stage, body size and season on the diet.

Corresponding author:
M.C. Spath
Email: ceciliaspath@gmail.com

MATERIALS AND METHODS

Study area and sampling

Individuals of *D. tschudii* were collected from scientific trawl surveys (N = 58) conducted by the Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP, Argentina) during January and August 2012 and by scientific observers on commercial vessels (N = 32, Figure 1) during September and October 2010.

The study area, encompassing the San Jorge Gulf and surroundings (44.5–47.5°S and 65.5°W), is the largest semi-open basin in the South-west Atlantic (Fernandez *et al.*, 2005; Vinuesa, 2005) and is one of the most important fishing grounds in Argentina. These waters belong to shelf waters, as amended by the contributions of coastal waters from the Strait of Magellan.

Stomach contents analysis and sample size sufficiency

For each individual, total length (TL, mm), sex and maturity stage were recorded. Maturity stage (immature or mature) was determined according to the degree of calcification of the claspers and development of testes and reproductive ducts in males, and observation of the uteri and ovarian follicles in females (Colonello, 2009). The stomachs were excised and frozen at −20°C for subsequent analyses in the laboratory.

Stomach contents were sorted and identified to the lowest possible taxonomic level, using a published catalogue (Boschi *et al.*, 1992) and reference collections preserved at the Laboratorio de Ictiología, Universidad Nacional de Mar del Plata, Argentina. Prey were counted and their wet weights recorded (±0.01 g).

To determine whether a sufficient number of *D. tschudii* was sampled, the stomachs sampled were randomized 1000 times and the sample size was plotted against the mean cumulative Shannon–Wiener diversity index (Magurran, 2004). Sample size was considered sufficient to describe diet and to conduct statistical analyses if the curve reached an asymptote.

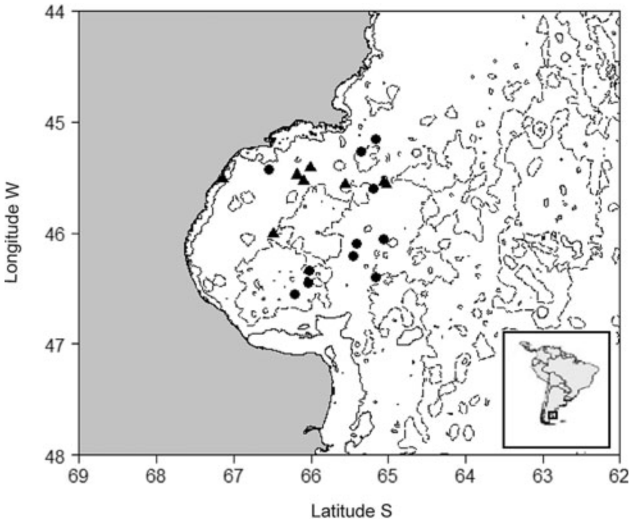

Fig. 1. Map of study area showing positions of trawl station where individuals of *Discopyge tschudii* were collected from San Jorge Gulf, Argentina. The black triangles and circles represent commercial vessels and scientific trawl respectively. The solid line represents the 50 m isobath and the dotted line the 100 m isobaths.

Statistical analysis of diet variation

Prey were grouped into five categories: polychaetes, clam siphons (*Amiantis purpurata*), amphipods, lobster krill (*Munida gregaria*) and stomatopods.

To evaluate the importance of each prey and allow for comparison with other studies the composition of diet was presented as percentage by number (%N), percentage by mass (%M), percentage frequency of occurrence (%FO) and index of relative importance (IRI) (Pinkas *et al.*, 1971). The IRI was expressed in percentage (%IRI; Cortés, 1997).

Dietary variability of *D. tschudii* with sex, maturity stage (immature and mature), TL and season (warm = October–March; cold = April–September) were evaluated using generalized linear models (GLM; Venables & Ripley, 2002). For each prey category, models were built where response variable was the number of prey consumed and the independent variables were sex, maturity stage, TL and season. Also, a model without any of the independent variables (i.e. null model) was fitted to test the hypothesis that none of the variables tested had an effect on the consumption of the prey category (Lucifora *et al.*, 2009). The response variable as number of prey had a large variance because of the great number of zero values in the samples; therefore a negative binomial error distribution was specified (Crawley, 2005). A log link was used in the models since response variables could only take zero or positive values (Crawley, 2005).

A multiple-hypothesis model approach was used to identify the best model explaining the consumption of a given prey (Anderson *et al.*, 2000; Franklin *et al.*, 2001; Johnson & Omland, 2004). For each competing model, the Akaike Information Criterion (AIC) was calculated and the model with the lowest AIC was selected as the best model (Crawley, 2005). Also, the Akaike's weight (*w*) was calculated to obtain the likelihood of each competing model given the data (Franklin *et al.*, 2001; Johnson & Omland, 2004).

RESULTS

Sampling description

A total of 90 stomachs of *D. tschudii* were examined. Of all specimens with stomach contents, 43 were females (96–411 mm TL) and 38 were males (141–495 mm TL). Overall, 243 prey with a total weight of 138.78 g were found in the stomachs. The cumulative curves of prey diversity reached an asymptote for all groups, except for 'Female-Warm', indicating that sample size was sufficient to describe the diet (Figure 2).

Diet description

Polychaetes were the most important prey in terms of %N, %M, %FO and %IRI in the diet composition of *D. tschudii*. Less important were clam siphons, amphipods, lobster krill and stomatopods (Table 1). Nine families of polychaetes were identified: five families of errant polychaetes and four

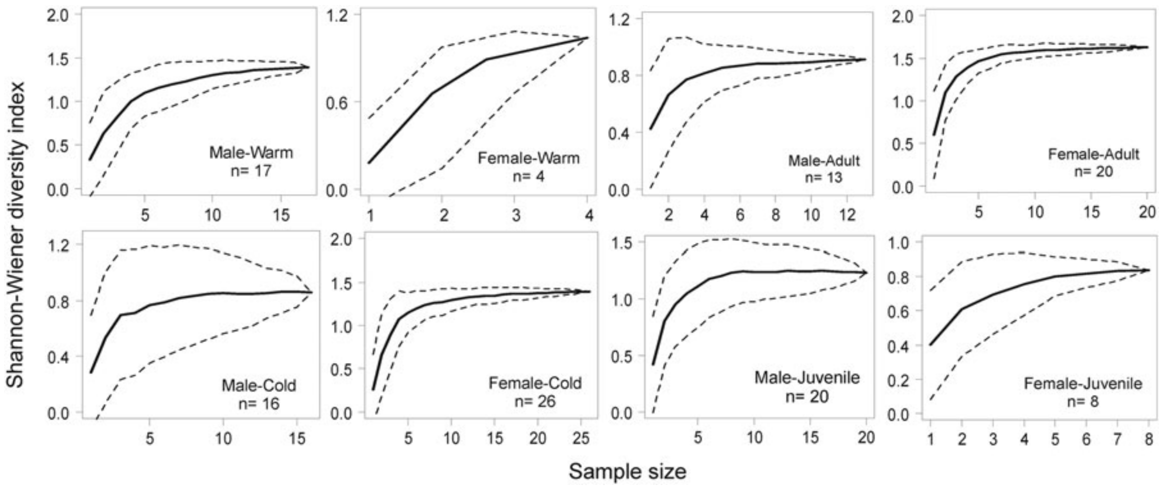

Fig. 2. Cumulative mean Shannon–Wiener diversity index (continuous lines) and standard deviation (dashed lines) as a function of sample size of *Discopyge tschudii* from the San Jorge Gulf, Argentina.

families of burying polychaetes. Among errant polychaetes, Glyceridae was the main family consumed followed by Lumbrineridae. Orbiniidae were the most important burying polychaetes followed by Flabelligeridae.

Several patterns were found in the relationships between number of prey consumed with TL and season (Table 2). The consumption of polychaetes was higher in males than females (Figure 3A). The number of siphons of *Amiantis purpurata* and amphipods consumed was higher in the cold season than in the warm season (Figure 3B, C). On the other hand, *M. gregaria* was predated more heavily in the warm season than in the cold season (Figure 3D). The consumption of stomatopods increased as *D. tschudii* increased its size. Sexual maturity of *D. tschudii* was not related to the comsumption of any prey.

DISCUSSION

It was observed that in the San Jorge Gulf, *Discopyge tschudii* was a benthic feeder, preying mainly on benthic invertebrates such as polychaetes, siphons of clams, amphipods, lobster krill and stomatopods. The diet composition of *D. tschudii* showed changes between sexes, seasons and also with increasing body size.

The ecology of *D. tschudii* is poorly known and there are only a few studies on their feeding habits (García, 1984; Arrighetti *et al.*, 2005; Spath *et al.*, 2013). García (1984) and Spath *et al.* (2013) observed that the diet of *D. tschudii* was characterized mainly by the consumption of polychaetes, followed by a variety of invertebrates. In contrast, Arrighetti *et al.* (2005) found that the diet of *D. tschudii* was dominated by the presence of siphons of *A. purpurata*. These differences in the most important prey may be due to two factors: the season when the work was done, and the study area. Concerning the first and most important factor, Arrighetti *et al.* (2005) conducted the study almost exclusively in the cold season, when the consumption of clam siphons is higher according to the present results. With regard to the second factor, the extent of the study area (38°20′S – 57°37′W, Mar del Plata, Argentina) in which Arrighetti *et al.* (2005) did their work was very restricted. In agreement with García (1984) and Spath *et al.* (2013) our results showed that the most important prey were polychaetes.

Previous studies about the diet of Narcinidae showed that the family preys mostly on benthic invertebrates such as crustaceans, polychaetes, amphipods, molluscs and stomatopods (Valadez *et al.*, 2000; Bornatowski *et al.*, 2006; Valadez-Gonzalez, 2007; Payán *et al.*, 2010). These results suggest that this group of electric rays is highly specialized in its feeding habits. Additionally, diet and foraging behaviour may differ between individuals of different sex, reproductive status or age (Begg *et al.*, 2003). Sexual differences in prey preferences have been previously observed in elasmobranchs (Ezzart *et al.*, 1987; Klimley, 1987; Sims *et al.*, 2001; Bohórquez-Herrera, 2006; Delpiani *et al.*, 2013). The variation

Table 1. Diet composition of *Discopyge tschudii* from the San Jorge Gulf, Argentina. %N, percentage by number; %M, percentage by mass; %FO, percentage of frequency of occurrence; IRI, the index of relative importance; %IRI, percentage of IRI.

	%N	%M	%FO	IRI	%IRI
Polychaeta	72.43	57.64	61.05	7940.87	97.11
Unidentified remains	13.36	3.58	13.36	226.35	
Errant polychaetes	17.69	31.93	21.85	1084.21	
Lumbrineridae	9.051	4.93	4.74	66.30	
Goniadidae	0.43	0.013	0.43	0.19	
Glyceridae	5.17	13.83	4.31	81.91	
Onuphiidae	2.59	0.24	1.72	4.88	
Nephtyidae	1.29	0.08	1.29	1.77	
Burried polychaetes	41.97	19.73	21.01	1296.31	
Orbiniidae	24.57	1.22	7.33	188.97	
Opheliidae *Travesia spp*	14.22	0.77	0.43	6.46	
Trochochaetidae	1.29	6.52	0.86	6.74	
Flabelligueridae	3.017	1.87	2.15	10.52	
Sabellidae	0.86	1.43	0.86	1.97	
Mollusca					0.27
Siphons of *Amiantis purpurata*	5.60	0.14	3.88	22.27	
Crustacea					2.41
Amphipods	15.52	0.98	5.60	92.45	1.13
Munida gregaria remains	5.60	16.48	4.74	104.70	1.28
Stomatopoda					0.21
Unidentified remains	2.15	7.74	1.72	17.06	

Table 2. Best models explaining the consumption of prey categories in number of *Discopyge tschudii* from the San Jorge Gulf, Argentina. The intercept and coefficient for the variables are given. TL, total length (mm); AIC, Akaike information criterion; w, Akaike's weights; standard errors in parentheses.

Prey categories	Intercept	Coefficient	AIC	w
Polychaetes	1.9218 (0.5673)	−0.8388 (0.3667) Female	342.87	0.7362
Siphon of *Amiantis purpurata*	−1.979 (1.975)	1.862 (1.975) Cold	73.577	0.7756
Amphipods	−1.8458 (0.7346)	1.6047 (0.8280) Cold	113.46	0.2953
Munida gregaria	−0.5465 (0.1682)	−2.2452 (2.001) Cold	45.035	0.99549
Stomatopods	−8.8045 (2.5131)	0.016863 (0.006046) TL	33.585	0.5571

in the diet of chondrichthyans can be attributed to intrinsic and extrinsic factors (Di Giacomo & Perier, 1996; Lucifora, 2003). Intrinsic factors are features of the predator, such as sex, stage of maturity and body size and extrinsic ones are characteristic of the prey or the environment that affects the availability of prey. The diet of predators may differ between the sexes due to sexual dimorphism by size (Begg *et al.*, 2003), differences in the predatory ability of males and females (Floeter & Temming, 2003), spatial-temporal differences in foraging activity of males and females (Braccini *et al.*, 2005) and/or habitat use (Wetherbee & Cortés, 2004). In *D. tschudii*, polychaetes were more consumed by males than females. In support of the hypothesis that sexual size dimorphism reduced intersexual resource competition, in *D. tschudii* males have larger sizes than females (Cousseau *et al.*, 2007), and consequently could have more capability to take polychaetes from the substrate than females. Alternatively, these differences might be a consequence of sexual differences in the spatial distribution. This sexual segregation was previously reported in *D. tschudii* (Menni *et al.*, 1981; Cousseau *et al.*, 2007; Estalles *et al.*, 2011) and may have an effect on their feeding habits.

The diet composition of *D. tschudii* showed seasonal variation. This seasonal pattern is characterized by a higher consumption of siphons of *A. purpurata* and amphipods in the cold season and high consumption of *M. gregaria* in the warm season. Similar seasonal shifts in diet have been previously documented in *D. tschudii* (Spath *et al.*, 2013). Diet composition will differ seasonally between alternative prey species depending on which are currently more available (Taylor, 1984), in response to the decreased availability of preferred food types (Perry & Pianka, 1997). Another explanation could be related to the migration pattern of the predator (Muto *et al.*, 2001). Seasonal migrations are common in

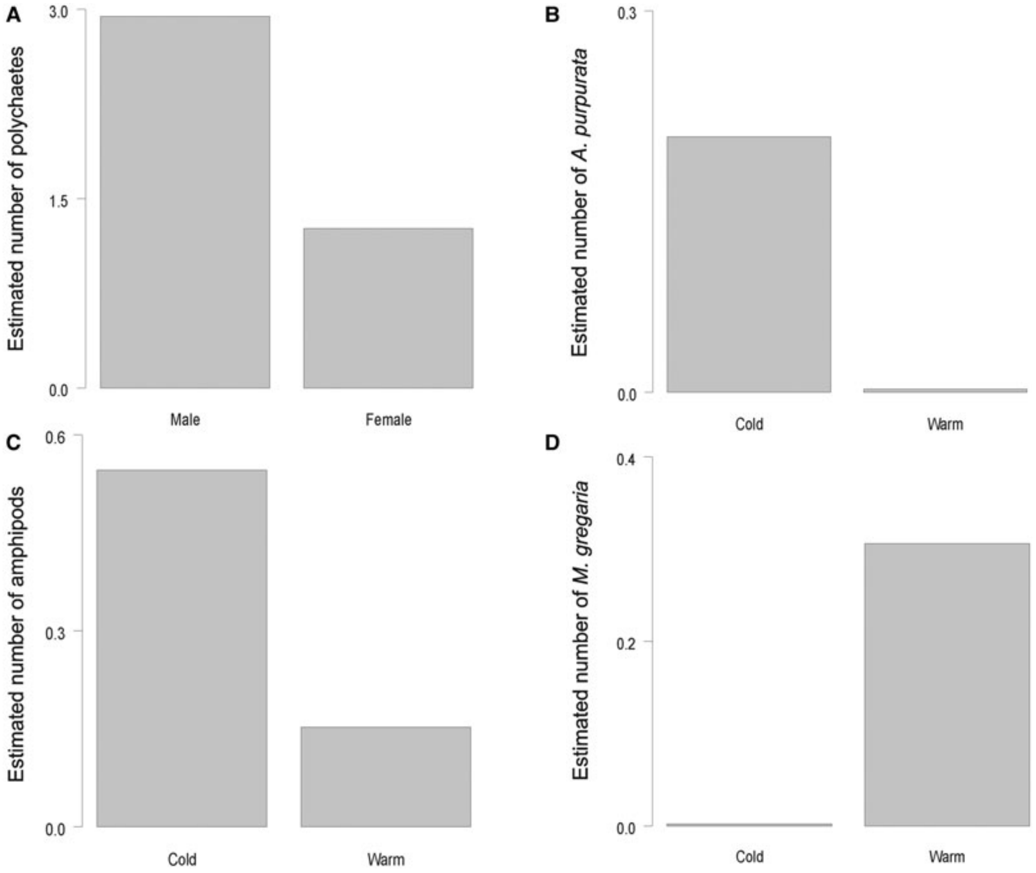

Fig. 3. Changes in the consumption of (A) polychaetes (in number), (B) siphons of *Amiantis purpurata*, (C) amphipods and (D) *Munida gregaria* (in number) by *Discopyge tschudii* from San Jorge Gulf, Argentina, estimated by generalized linear models. The models had a log link and a negative binomial distribution.

elasmobranchs and can be driven by temperature, reproduction or foraging needs (Heithaus, 2004). Related to this, Cortés *et al.* (2011) found that *D. tschudii* makes onshore-offshore movements related to change in salinity and temperature in the South-west Atlantic. These onshore-offshore movements could explain the seasonal pattern observed in the diet composition. However, specific studies are needed in the area to test this hypothesis.

The protrusible jaw apparatus present in electric rays (Rudloe, 1989; Rudloe & Rudloe, 1993) generates negative pressures in the oral cavity to suck the food into the mouth (Dean & Motta, 2004). Some phases during feeding, like capture, clamping force or suction of prey improve as a predator increases its size (Scharf *et al.*, 2000). This could explain the rise in the consumption of stomatopods in *D. tschudii* with increasing body size.

Finally, several factors may influence the feeding of *D. tschudii*. This species occurs sympatrically with other species of elasmobranchs (e.g. *Bathyraja macloviana*, Scenna *et al.*, 2006, Ruocco *et al.*, 2012; *Psammobatis normani* and *P. rudis*, Mabragaña & Giberto, 2007, Sánchez & Prenski, 1996; *Callorhinchus callorhynchus*, Di Giácomo & Perier, 1996) and bony fishes (e.g. *Cheilodactylus bergi*, Bruno *et al.*, 2000) that consumed the same prey categories, and they could be competitors for trophic resources.

The San Jorge Gulf is an important fishing ground in Argentina. *Discopyge tschudii* is not a commercial resource but it is captured as bycatch together with other species and discarded on board (Massa *et al.*, 2004b; Tamini *et al.*, 2006), which has resulted in a significant decrease in abundance. The fisheries affect marine populations both directly through removal of individuals and indirectly though loss of habitat and modification of the trophic structure (Stevens *et al.*, 2000). Since our results showed that the diet of *D. tschudii* is composed exclusively of benthic prey, it is very important to study in detail the damage to the bottom caused by commercial fisheries in order to analyse the possible consequences on benthic populations.

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Correspondence should be addressed to:

M.C. Spath
Laboratorio de Ictiología, Facultad de Ciencias Exactas y Naturales, Instituto de Investigaciones Marinas y Costeras (IIMyC), Universidad Nacional de Mar del Plata, Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Deán Funes 3350, Mar del Plata B7602AYL, Argentina
email: ceciliaspath@gmail.com