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The diet of the South American Tern: the Argentine Anchovy as key prey in the non-breeding season

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Abstract. The Argentine Anchovy (*Engraulis anchoita*) is one of the most important pelagic fishery resources of the Patagonian Shelf and is known to be an important prey item for several seabirds of the northern Argentine coast. The South American Tern (*Sterna hirundinacea*) is endemic to the Atlantic and Pacific coasts of South America and, on the Atlantic coast, breeds from central Brazil to southern Argentina. Large non-breeding flocks form during the austral winter and spring from southern Brazil to northern Patagonia. The diet of the South American Tern was studied over three consecutive non-breeding seasons through the analysis of regurgitated pellets. The Argentine Anchovy comprised >80% (index of relative importance) of fish prey in the diet, and remained important throughout the study period. Other important fish prey were Cornalito Silverside (*Odonthestes incisa*), Pejerrey Silverside (*O. argentinensis*) and Stripped Weakfish (*Cynoscion guatucupa*). The growing interest in commercially fishing Argentine Anchovies makes it important that studies are conducted to determine the potential effect of the harvest of Anchovies on South American Terns and other top predators.

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Introduction

The South American Tern (*Sterna hirundinacea*) is endemic to the Atlantic and Pacific coasts of South America. In the Atlantic, the species has a disjunct breeding distribution extending from central Brazil to Tierra del Fuego and the Malvinas (Falkland) Islands (Gochfeld and Burger 1996; Yorio 2005), interrupted at intermediate latitudes along the coast of southern Brazil (Bugoni and Vooren 2005), Uruguay (Alfaro and Clara 2007) and northern Argentina (Favero *et al*. 2000; Silva Rodríguez *et al*. 2005), where only non-breeding populations occur. Non-breeding flocks of ~2000 birds are common in southern Brazil and Uruguay during the austral winter (June–August) and in Argentina in early austral spring (September–October) (Bugoni and Vooren 2005; Silva Rodríguez *et al*. 2005; Alfaro and Clara 2007). The breeding phenology of the populations of the Atlantic coast varies with latitude: in central Brazil, breeding occurs during the austral winter (April–September), whereas in Argentinian Patagonia breeding occurs in the austral summer (November–January) (Yorio 2005; Faria *et al*. 2010). However, despite this temporal segregation, there are only low levels of genetic differentiation between populations (Faria *et al*. 2010). Although migratory routes of the South American Tern are not well known, the available information suggests that birds wintering in northern Argentina are breeding later in the year in Patagonia (Bugoni and Vooren 2005; Faria *et al*. 2010).

With a total biomass estimated at $>3 \times 10^6$ t, the Argentine Anchovy (*Engraulis anchoita*) is the most abundant pelagic fish of continental shelf waters of the south-western Atlantic Ocean (Hansen *et al*. 2009*a*, 2009*b*). It is distributed between 23°S, off Cabo Frio, Brazil, and 48°S, off Patagonia in southern Argentina. South of 34°S two different stocks have been identified. The northern stock concentrates in the north of the range during winter, then moves south, where spawning occurs, during spring and disperses offshore during summer, migrating back to their northern wintering areas following offshore currents (Castello and Castello 2003; Cousseau and Perrota 2004). Movements of the southern population are not well known. The Argentine Anchovy plays an important role in the marine ecosystem as it is the prevailing resource for many fish, marine mammals and seabird species, such as the South American Tern (Sánchez and Ciechomski 1995; Castello and Castello 2003; Silva Rodríguez *et al*. 2005).

Despite coastal and offshore fisheries targeting the Argentine Anchovy for parts of the year in Argentina and Uruguay, the Argentine Anchovy is considered an under-exploited resource, with catches of $<30\,000$ t year^{-1}, although catches increased

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slightly after 2003 (Castello and Castello 2003; Skewgar *et al.* 2007; see SAGPyA 2009). Mar del Plata harbour, in south-eastern Buenos Aires Province, is one of the most important commercial harbours in Argentina, receiving almost 90% of Argentine Anchovy catches between 1998 and 2009 (up to 99% in 2006). The fleet targeting this fish (classified as mid-water pair-trawl fisheries by Nédelec and Prado 1990) comprises a minimum of 100 ice-trawl vessels as well as several coastal and offshore trawlers fishing in waters off northern Patagonia (Cousseau and Perrota 2004; SAGPyA 2009).

Previous studies on the diet of seabird species during the non-breeding season in Argentina were based on the analysis of regurgitated pellets (see review in Silva Rodríguez *et al.* 2005). Studies on the South American Tern focussed on the comparison between neighbouring wintering areas but did not examine temporal variation in the diet (Favero *et al.* 2000). Of the methodologies to determine the diet of seabirds, analysis of regurgitated pellets has been widely used since it provides valuable information with little effort and little disturbance to the birds in the field. There are, however, several caveats regarding the use of this methodology, such as biases in the estimation of number, length and mass of ingested fish owing to the erosion and digestion of otoliths in the gastrointestinal tract, over-representation of hard parts of some types of food and the under-representation of prey that do not leave hard parts (see Barrett *et al.* 2007). However, some of these shortcomings can be overcome by the use of complementary methodologies or the analysis of large number of samples distributed spatially or temporally. The aim of this study was to determine the diet of South American Terns over three consecutive non-breeding seasons.

Materials and methods

Regurgitated pellets of South American Terns were collected monthly between August and October of 1998, 1999 and 2000 ($n = 93$, 399 and 193 respectively) at roosting sites on the most important wintering areas in Argentina, between the village of Mar Chiquita (37°40′S, 57°22′W) and Mar del Plata city (38°00′S, 57°34′W). Pellets were dried at room temperature, dissected and the hard remains identified using a stereo microscope (20×). Otoliths were identified to species using reference material from our own collections of juvenile and adult fish sampled in the vicinity of the study area. Quantities were determined by minimum number (i.e. otoliths were separated into right and left, and the most abundant was considered as representing the number of fish of each species in the sample). Length of the otolith (OL, mm) was used to estimate total length of fish (TL, mm) and mass (M, g) by regression equations used in previous studies (Favero *et al.* 2000; Mariano-Jelicich and Favero 2006). Owing to a high degree of erosion or digestion, a proportion of otoliths were only identified to family level (Engraulidae and Atherinopsidae). Crustaceans and insects were identified to the lowest taxonomic level using our own reference collections.

The importance of prey categories was quantified as: frequency of occurrence (F%, the percentage of samples as a proportion of all samples for which diagnostic remains were found) and numerical abundance (N%, the percentage of prey items of one type as a proportion of all prey items). Dietary importance, particularly for fish, was also quantified by mass (M%, percentage of biomass provided by one prey item as a proportion of the total biomass consumed) (Barrett *et al.* 2007). In order to overcome the shortcomings of using any of the former parameters alone as representing a predator's diet, those parameters were combined in an index of relative importance ($IRI = F_i\% (N_i\% + M_i\%)$, and $IRI\% = (IRI_i \times 100)/IRI_{total}$) for each prey category (i) (Sanger 1987). Total length data are expressed as mean ± one standard deviation.

Similarities in dietary composition of fish species between years, in terms of abundance and biomass, were determined with multivariate techniques included in the PRIMER software package version 5.2 (Clarke and Gorley 2001). A Bray–Curtis similarity matrix was generated to assess similarities in fish prey-composition between samples using non-parametric multi-dimensional scaling (MDS). The multivariate analysis of similarities (ANOSIM) was used to test for significant differences in diet composition between years. This procedure uses the Bray–Curtis similarity matrix to compute a test statistic R that takes a value of 1 when all samples within a group are more similar to each other than any sample from other groups, and is approximately 0 when there are no differences between groups. A randomisation process is used to find the probability of gaining particular values of R by chance (Clarke and Warwick 2001). Fish prey species most responsible for the multivariate pattern were identified using similarity percentages analysis (SIMPER). In the comparison between years, species contributing at least 10% dissimilarity were considered important (e.g. Bulleri *et al.* 2005).

Results

Overall, fish were the main prey in all years sampled (F% > 90%, N% > 97%) followed in numerical importance by Insecta (mainly Coleoptera, N% = 5%) and Crustacea (N% < 5%); cephalopod beaks (Mollusca) were found in only a small percentage of pellets in only a single year (N% < 1%). More than 52% of samples (i.e. F%) contained otoliths. The 816 otoliths found represented 675 individual fish, of which >96% were identified to familial or specific level. Of the identified otoliths, 56% allowed the estimation of total length and mass of fish.

Ten species of fish were identified through pellet analysis. The Argentine Anchovy constituted the bulk of the diet (IRI% = 85.2%, all years pooled), followed by Cornalito Silverside (*Odonthestes incisa*, 4.7%), Anchovy (*Anchoa marinii*, 2.6%), Pejerrey Silverside (*O. argentinensis*, 1.2%) and Stripped Weakfish (*Cynoscion guatucupa*, 0.4%). Other prey were neither recorded frequently nor did they constitute a significant percentage by mass (overall IRI% < 0.1%), so they were regarded as occasional and not considered in further analyses (Table 1). The Argentine Anchovy and Cornalito Silverside were consistently important in the diet throughout the study period. Other important prey, such as the Pejerrey Silverside and Stripped Weakfish, were present through the study period but their frequency in the diet varied much between years (Table 1).

The dietary composition in terms of abundance by number and biomass showed a high level of overlap between years (MDS: stress = 0.01, indicating that the axis is an excellent representation of the data; see Clarke and Warwick 2001). Significant differ-

Table 1. Importance as percentage number (N%), frequency of occurrence (F%), percentage mass (M%) and index of relative importance (IRI%) of fish prey in the diet of South American Terns (regurgitated pellets) over 3 years

In parentheses, n_F, total number of fish prey; n_O, total number of samples containing otoliths. Blank cells denote no presence of a given item in a year

	1998				1999				2000			
	N% (n_F = 133)	F% (n_O = 58)	M% (n_F = 133)	IRI%	N% (n_F = 445)	F% (n_O = 230)	M% (n_F = 445)	IRI%	N% (n_F = 97)	F% (n_O = 72)	M% (n_F = 97)	IRI%
Argentine Anchovy (*Engraulis anchoita*)	45.9	56.9	82.4	86.2	38.2	54.8	67.7	81.8	40.2	40.3	67.0	75.9
Anchovy (*Anchoa marinii*)					14.0	18.3	6.9	5.4	2.1	2.8	1.1	0.2
Unidentified Engraulidae					9.9	15.6	11.9	4.8	14.4	18.1	17.2	10.1
Pejerrey Silverside (*Odonthestes argentinensis*)	20.3	22.4	2.7	6.1	6.6	7.4	1.3	0.8	1.0	1.4	0.2	<0.05
Cornalito Silverside (*Odonthestes incisa*)	9.8	6.9	2.1	1.0	17.2	17.0	5.3	5.4	17.5	16.7	6.6	7.1
Unidentified Atherinopsidae					7.2	9.6	1.5	1.2	15.7	18.1	3.1	5.9
Stripped Weakfish (*Cynoscion guatucupa*)	16.5	20.7	7.4	5.9	0.7	1.3	0.2	<0.05	3.1	4.2	1.0	0.3
Surel (*Trachurus lathami*)					0.9	1.3	1.1	<0.05	3.1	4.2	2.5	0.4
Whitemouth Croaker (*Micropogonias furnieri*)	3.8	5.2	2.2	0.4	0.7	1.3	0.3	<0.05	2.1	2.8	0.9	0.3
Toadfish (*Porichthys porosissimus*)					0.7	0.9	0.6	<0.05				
Banded Cusk Eel (*Raneya fluminensis*)					0.4	0.4	0.4	<0.05	1.0	1.4	0.8	<0.05
King Weakfish (*Macrodon ancylodon*)	0.8	1.7	0.3	<0.05								
Unidentified fish	3.0	6.9	3.0	0.5	3.6	6.1	3.0	0.6				

ences were observed in the ANOSIM analysis, although R values were small, meaning that samples were highly similar (R global = 0.06, $P < 0.01$ when comparing both abundance by number and biomass). Five of the ten species of fish identified contributed to dissimilarities between years in abundance. The Argentine Anchovy (>32.8%) and Cornalito Silverside (11.3–15.8%) made important contributions in all years. Other species contributing to differentiation between 1998 and 1999 and 2000 were Pejerrey Silverside (15.2 and 13.9% respectively) and Stripped Weakfish (11.6 and 12.6% respectively), whereas the Anchovy (10%), unidentified Engraulidae (14.5%) and unidentified Atherinopsidae (11.6%) contributed to differences between 1999 and 2000. In terms of dietary composition by biomass, four species of fish contributed to the dissimilarities between years. The Argentine Anchovy (>35%) and Cornalito Silverside (between 11.2% and 20.4%) made important contributions in all years, whereas Stripped Weakfish (>12.6%) contributed to differentiation of between 1998 and 1999 and 2000, and Pejerrey Silverside (11.6%) contributed to differences between 1998 and 1999.

Average length of Argentine Anchovies eaten by Terns during the study period was 103.7 ± 38.2 mm (range 10.9–168.9 mm, n = 179; Fig. 1). No significant differences were observed in the size of Argentine Anchovies eaten in different years ($F_{2,176}$ = 1.45, P = 0.24).

Discussion

Throughout the years of the study, the Argentine Anchovy constituted the main component of the diet of South American Terns, a result consistent with previous studies of the Terns, in both their breeding and non-breeding range (Favero *et al*. 2000; Gatto 2009). Silversides were also important, but their contribution varied between years. Previous studies found Pejerrey and Cornalito Silverside as important prey items, with the former more important both in number and biomass (Favero *et al*. 2000).

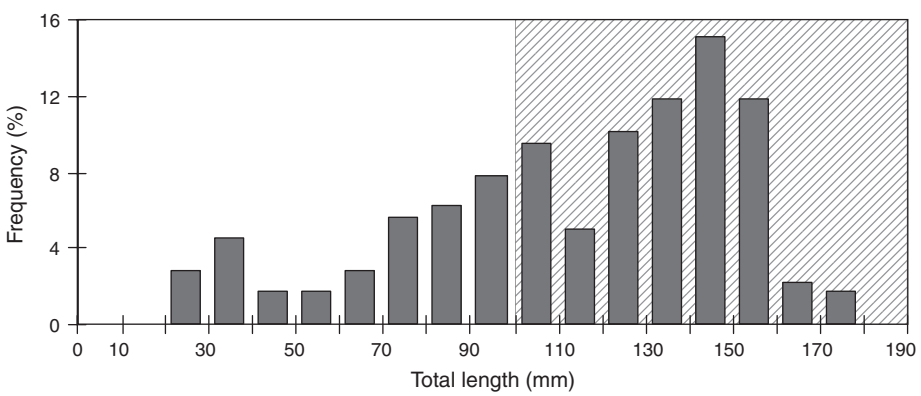

Fig. 1. Frequency distribution of total length of Argentine Anchovies eaten by South American Terns. The hatched area shows the sizes of Argentine Anchovy targeted by commercial fisheries.

However, in the present study, Pejerrey Silverside varied in frequency of occurrence and number over the three seasons of the study whereas Cornalito Silverside was more important in the diet, with greater frequency number and occurrence and greater biomass (with the exception of 1998) in the diet than Pejerrey Silverside. Moreover, the Stripped Weakfish, considered the second most important fish prey in a previous study (Favero *et al*. 2000), was recorded only occasionally in the present study, except for 1998. Variations between studies may be a result of the timeframes over which they were conducted. Although Favero *et al*. (2000) conducted a study over 2 years, samplings were basically conducted *ad libitum* without any provision of information on the temporal distribution of samples. The present study highlights the value of conducting medium- or long-term monitoring to allow an adequate interpretation of the existence and functioning of predator–prey relationships over time both within and between seasons. A proportion of samples analysed in this study contained no or eroded otoliths, which precluded the identification of samples to species level. However, this problem was overcome through the large number of samples analysed and the temporal distribution of the sampling effort. In line with the observed consistency in the importance of the Argentine Anchovy in the diet, preliminary information coming from a long-term study on stable isotope signatures of predators and prey in coastal Argentina indicate that the Argentine Anchovy and Pejerrey Silverside are major contributors to the isotope mixture of South American Terns (50–58% and 41–48% respectively; R. Mariano-Jelicich, unpubl. data).

The consistency in the importance of Argentine Anchovy in the diet of South American Terns suggests an important predator–prey relationship in the study area. The northern boundary of the breeding distribution of South American Terns at Cabo Frio and the distribution of breeding sites along the Brazilian coast have been linked to the availability of small fish (mainly *Engraulis* anchovies) associated with the influence of coastal fronts and cold-water upwellings (Antas 1991). Information on the temporal variation of Tern populations in their non-breeding range suggests that movements between the winter quarters in Buenos Aires and breeding areas in Patagonia could be at some extent regulated by high local and seasonal abundances of the Argentine Anchovy. Moreover, recent studies in Patagonia highlight the importance of this food resource for breeding South American Terns (Gatto 2009). Such dependence on engraulid fish has been reported for other species of tern from North America (Schaffner 1986) and South Africa (Crawford and Dyer 1995). Our results suggest that it is possible that there is a coupled migratory mechanism, with South American Terns using wintering and breeding areas with high abundances of anchovies (see Favero *et al*. 2000). Such a mechanism could also include Terns following key prey in their migratory movements between breeding areas in Patagonia and non-breeding areas in northern Argentina, Uruguay and southern Brazil. These matters should be subject of further investigations.

Terns are considered vulnerable to commercial fishing (Yorio 2005). In breeding areas of Patagonia, and other populations at the South Atlantic, South American Terns has been reported associating with coastal and offshore fishing operations (González-Zevallos and Yorio 2006). Preliminary studies between July and October 2007 showed South American Terns regularly attended coastal trawlers off non-breeding sites in Argentina. Up to 25 Terns were sighted in association with other seabirds and marine top predators commonly attending vessels, such as Kelp Gulls (*Larus dominicanus*), Brown-hooded Gulls (*Chroicocephalus maculipennis*), Common Terns (*Sterna hirundo*) and South American Sea-lions (*Otaria flavescens*). Although South American Terns were often observed plunge-diving over the trawling area, no interaction with the fishing gear or incidental capture was recorded (J. P. Seco Pon, unpubl. data).

Even though the Argentine Anchovy is caught throughout the year, the main fishing effort (over 1000 t landed) is between June–July and November, a pattern that has been consistent since 1992 (SAGPyA 2009). The occurrence of Argentine Anchovies in the diet of South American Terns was observed between 4 and 8 weeks before the peak of this fishing effort, which suggests that the Anchovies constitute a key natural prey for these Terns and that its importance in the diet is not merely an association with fisheries. Although the Argentine Anchovy and other midwater species of fish can be taken directly by Terns, other typical demersal species of fish present in the diet, such as the Stripped Weakfish, could primarily be eaten as the result of association with coastal trawlers and allied facilitation mechanisms, since juvenile non-commercial fish can easily escape during the hauling operations and also be an important component of discards (e.g. reported minimum landing size of the Stripped Weakfish ranges from 350 to 450 mm; Cousseau and Perrota 2004).

The estimated size of Argentine Anchovies eaten in the present study (11–169 mm) was consistent with sizes eaten reported for this Tern wintering along the Atlantic coast (Favero *et al*. 2000). The size of Argentine Anchovies captured by commercial fisheries range from 90 to 195 mm, with the most important between 140 and 190 mm (Garciarena and Hansen 2007; Hansen *et al*. 2009*b*; Fig. 1). This shows an important overlap between fisheries and Tern catches during the study period, at least over the upper range of sizes of Anchovies eaten by Terns. Anchovies and silversides are currently considered commercially important, and the northern Argentine Anchovy stock constitutes an important target species for fisheries (Hansen *et al*. 2009*b*). Even though the southern Argentine Anchovy stock has not been significantly exploited yet, it might be an attractive alternative resource and has recently been experimentally fished in order to evaluate its potential (Skewgar *et al*. 2007). Several authors have emphasised the negative effect that pelagic fisheries may have on seabird populations (Furness 2002; Skewgar *et al*. 2007). With a total biomass estimated in the order of 2.0×10^6 and 1.2×10^6 tonnes (t) for the northern and southern stocks, respectively, the current captures of Argentine Anchovy are well below the recommended maximum catches (biologically allowable catch) of 120 000 t for the northern stock and 100 000 t for the southern stock (Hansen *et al*. 2009*a*, 2009*b*). However, since 1998 there have been several attempts to expand the Argentine Anchovy fishery, partly as an alternative to Common Hake (*Merluccius hubbsi*) and partly for fish-meal production, and as an export product (Skewgar *et al*. 2007; Hansen *et al*. 2009*b*). An increased fishing effort for Argentine Anchovies raises a number of questions about the effect of exploitation of the resource on several top predators, including seabirds like the Magellanic Penguin (*Spheniscus magellanicus*) (e.g. Wilson *et al*. 2005; Schiavini *et al*. 2005)

and the South American Terns, that are heavily and directly dependent on this resource throughout their annual cycle.

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