

Low seasonal variation in the diet of Rock Shags (*Phalacrocorax magellanicus*) at a Patagonian colony in Argentina

Alexandra Sapoznikow^{A,C}, Flavio Quintana^{A,B} and Luisa Kuba^A

^ACentro Nacional Patagónico (Conicet), Boulevard Brown 3600 (9120), Puerto Madryn, Chubut, Argentina.

^BWildlife Conservation Society, 2300 Southern Boulevard, Bronx, NY 10460, USA.

^CCorresponding author. Present address: Paso 348, 9120, Puerto Madryn, Chubut, Argentina.

Email: alexamadryn@yahoo.com.ar

Abstract. The characteristics of the food sources exploited by seabirds are one of the main factors determining the abundance and distribution of those birds. Determination of the diet over the year and between breeding and non-breeding seasons is important in understanding the food sources and their potential relationship with seabird population dynamics. We studied seasonality in the diet of the Rock Shag (*Phalacrocorax magellanicus*), a seabird endemic to southern Argentina and Chile, at a colony at Punta Loma, Chubut, by analysis of pellets (regurgitated casts) collected weekly during two consecutive non-breeding and breeding seasons in 2002 and 2003. We identified 19 prey-types in the diet. Polychaetes were the most common item, being present in 80–90% of the samples. Fish were also dominant in both non-breeding and breeding seasons (present in 60–80% of the pellets), especially species of *Patagonotothen*, *Riberoclinus* and *Helcogrammoides*. Crustaceans and cephalopods were also present in the diet, but to a lesser extent. There was a high overlap in dietary composition between non-breeding and breeding seasons, although more crustaceans and cephalopods were consumed during the non-breeding season in 2002. Results indicate that the food sources of Rock Shags are present in their feeding areas throughout the year, although many of these species are restricted in their availability, are of small size and have low energy content.

Additional keywords: Cormorants, foraging ecology.

Introduction

Rock Shags (*Phalacrocorax magellanicus*) are foot-propelled pursuit-divers, endemic to the Atlantic and Pacific coasts of Patagonia (Argentina and Chile). The total population on the Atlantic coast of Patagonia is only 7000 pairs (Yorio *et al.* 1998; Frere *et al.* 2005). Rock Shags have a distinctive pattern of abundance and distribution on the Atlantic coast of Patagonia, with a large number of small colonies (143 colonies of 5–377 pairs) (Yorio *et al.* 1998; Frere *et al.* 2005), which birds occupy throughout the year (Sapoznikow and Quintana 2005). The diet and foraging ecology of Rock Shags has been studied at a few colonies during the breeding season (Punta *et al.* 1993, 2003; Malacalza *et al.* 1997; Quintana 1999, 2001; Quintana *et al.* 2002) but there is little information for the non-breeding season. Results of a qualitative study of a small sample of regurgitated pellets from a colony at Punta Loma, Chubut, in Argentina, suggested that birds eat the same prey during the breeding and non-breeding seasons (Malacalza *et al.* 1997). However, there have been no quantitative studies of seasonal diet. As part of a broader study of the foraging ecology and diving behaviour of Rock Shags, we studied annual and seasonal diets to determine if diet varied over the year, to improve our knowledge of the biology of the species and to describe the main food sources.

Materials and methods

We studied the diet of Rock Shags at Punta Loma colony (42°49'S, 64°53'W), one of the largest colonies in Argentina (280 pairs) (Yorio *et al.* 1998; Frere *et al.* 2005). At this colony, Rock Shags remain throughout the year, occupying the same nest-site (Sapoznikow and Quintana 2005, 2008). We analysed composition of pellets (regurgitated casts) collected weekly during both the non-breeding (March–September) and breeding seasons (October–February) in 2002 and 2003.

It has been noted that analysis of pellets may not provide an accurate representation of diet, because pellets fail to show remains of soft-bodied prey and other prey that do not leave remains after digestion (Duffy and Jackson 1986; Jobling and Breiby 1986; Johnstone *et al.* 1990). Nevertheless, we used this method because it is simple, non-invasive, provides large samples over time and is useful to compare diet between seasons (Duffy and Laurenson 1983; Duffy and Jackson 1986; Barrett *et al.* 1990; Harris and Wanless 1993). As Rock Shags breed on sea-cliffs, regurgitated pellets usually fall into the water below. We designed nets to collect pellets. We placed aluminum nets immediately below 30 nests in different areas of the colony. The nets (mesh size of 2 mm) measured 1.20 × 0.40 m, and were fastened perpendicular to the face of the cliff by means of iron bars.

We installed the nets during the non-breeding season in order to minimise potential impacts and used the same net through the year. We did not observe any evidence of the nets affecting the normal behaviour of the birds in the breeding or non-breeding season. The size of the mesh was too small for the birds to become entangled even if they occasionally roosted on them. The nets were generally resistant to bad weather, corrosion or damage by roosting birds, though some had to be replaced or refurbished during the second winter season. We collected 68 pellets during the non-breeding season of 2002 and 53 in 2003, and 131 and 108 pellets, respectively, during the last days of incubation and the first weeks of the chick-rearing periods of the same years.

Pellets were placed in separate polythene bags and frozen pending examination. Once at the laboratory, they were fixed with 10% formalin and stained with alizarin red solution following Gosztanyi (1984) to facilitate the recognition and separation of bony or calcified materials. Fish bones, otoliths, cephalopod beaks, polychaete mandibles, crustacean chelae and other structures present in the samples were identified to the lowest taxonomic level possible using illustrations and guides by Orenzan (1975), Fauchald (1979), Boschi *et al.* (1992) and Gosztanyi and Kuba (1996), and by comparison with reference collections at the Centro Nacional Patagónico. We sorted the main prey into four groups: fish, polychaetes, crustaceans and cephalopods for the analysis. Non-cephalopod molluscs were not included in the analysis as shells could serve as gastroliths in a manner similar to the stones found in many pellets (Velando and Freire 1999). We calculated the percentage occurrence for each group of prey (Ashmole and Ashmole 1967).

Variation in the composition of the diet between seasons was studied with multivariate techniques included in the PRIMER suite of programs (Clarke 1993). We performed separated analyses for each year as there were significant differences between years for breeding and non-breeding seasons (ANOSIM, $P < 0.05$). We generated a Bray–Curtis similarity matrix (Bray and Curtis 1957) to assess similarities in prey-group composition among samples. We tested for significant differences in dietary composition between seasons using a multivariate analysis of similarities (ANOSIM) (Clarke and Warwick 2001), which is analogous to a univariate analysis of variance (ANOVA). This procedure uses the Bray–Curtis similarity matrix to compute a test statistic, R . R is standardised so that a value of one means that all the samples within a group are more similar than any sample from the other group. R is approximately zero if there are no differences between the groups. A randomisation process is used to find the probability of gaining particular values of R by chance. The contribution of each prey-group to differences between seasons was examined using the similarity percentages breakdown (SIMPER) (Clarke and Warwick 2001).

We used the same methods to study the contributions of individual taxa (family, genus or species) to the composition of the diet.

Results

General description

The analysis of pellets showed that Rock Shags fed on a wide variety of prey, consisting of at least 19 different prey-types, during

both seasons and years. The main prey during both breeding and non-breeding seasons were polychaetes (Eunicidae), present in 79–96% of the samples, and fish, present in 61–83% of samples. We identified eight species of fish, of which the most frequently occurring were *Patagonotothen* species, and *Riberoclinus eigenmani* and *Helcogrammoides cunninghami*. Two species of *Patagonotothen* – *P. sima* and *P. cornucola* – were grouped together, and we also had to group *Helcogrammoides cunninghami* and *Riberoclinus eigenmani* together owing to the difficulty in identifying their otoliths after extensive digestion.

The percentage occurrence of crustaceans and cephalopods in pellets was comparatively low, occurring in 24–79% and 22–54% respectively (Table 1). The dominant crustacean was *Betaeus truncatus*, present in pellets collected in all seasons; other species occurred at only low percentages in only some seasons (Table 1). It was not possible to identify cephalopods to lower taxonomic levels because the beaks were small, and there are no morphological descriptions of small beaks for the species present in the Punta Loma area.

Seasonal comparison

Dietary composition (by prey-group) showed a high level of overlap between seasons. We found significant differences between breeding and non-breeding seasons in 2002, but the R value was very low, which indicates considerable overlap ($R = 0.151$; $P < 0.001$). In 2003, we found no differences between the breeding and non-breeding seasons and a high degree of dietary overlap ($R = 0.048$, $P = 0.06$).

SIMPER analysis revealed that crustaceans and cephalopods were the groups that contributed most to the seasonal differences found in 2002, because they were more frequently consumed during the non-breeding season (Table 2). Of these, the crustacean *Betaeus truncatus* was the species that contributed most to the observed differences (contribution to average dissimilarities = 18.3%, SIMPER analysis). Fish also contributed to the differences, as they were more frequently consumed during the breeding season (Table 2).

Discussion

The diet of Rock Shags at Punta Loma was dominated by benthic species and mainly comprised polychaetes belonging to the families Eunicidae and Nereidae, and the fish *Patagonotothen* spp., *Riberoclinus eigenmanni* and *Helcogrammoides cunninghami*. Our results are consistent with a preliminary study in the area (Malacalza *et al.* 1997) and with those from other Patagonian colonies (see Frere *et al.* 2005 for a review), in which fish and polychaetes were the main prey-items, followed by crustaceans and cephalopods.

Rock Shags and Imperial Cormorants (*Phalacrocorax atriceps*) are species that are widely distributed along the Patagonian coast of Argentina, and breeding colonies of the two often occur at the same locations (Yorio *et al.* 1998; Frere *et al.* 2005). Both these species share most of the identified prey-items during the breeding season, though Imperial Cormorants fed on a wider variety of prey species than Rock Shags. Moreover, Rock Shags feed mainly on demersal and benthic species of fish, whereas Imperial Cormorants also incorporate pelagic fish such as hake (*Merluccius hubbsi*) and anchovy (*Engraulis anchoita*)

Table 1. Percentage occurrence of prey items in regurgitated pellets of Rock Shags collected during the non-breeding and breeding seasons of 2002 and 2003

Prey-group and taxa	Non-breeding season		Breeding season	
	2002 (n = 68)	2003 (n = 53)	2002 (n = 131)	2003 (n = 108)
Fish	75.00	81.13	83.21	61.11
<i>Patagonotothen</i> spp. (<i>P. sima</i> and <i>P. cornucola</i>)	60.29	69.81	53.44	29.63
<i>Helcogrammoide scunnighami</i> – <i>Ribeiroclinus eigenmanni</i>	57.35	56.60	65.65	49.00
<i>Agonopsis chiloensis</i>	1.47	5.66	23.66	7.41
<i>Triathalassothia argentina</i>	0.00	3.77	8.40	2.78
<i>Raneya brasiliensis</i>	0.00	0.00	1.53	0.00
<i>Bovichtys argentinus</i>	0.00	0.00	0.76	0.00
<i>Engraulis anchoita</i>	1.47	0.00	0.00	0.00
Unidentified	19.12	7.55	7.63	7.41
Polychaetes	94.12	79.25	96.18	94.44
<i>Eunicidae</i>	89.71	73.58	84.73	88.89
<i>Nereidae</i>	61.76	41.51	62.60	37.96
<i>Polynoidae</i>	33.82	15.09	38.17	17.59
Unidentified	1.47	1.89	0.76	0.93
Cephalopods	54.41	22.64	38.17	46.30
Crustaceans	79.41	41.51	24.43	35.19
<i>Betaeus truncatus</i>	66.18	32.08	12.98	20.37
<i>Munida</i> sp.	0.00	3.77	0.76	4.63
<i>Peltarion spinosolum</i>	2.94	5.66	0.76	0.00
<i>Nauticariscus magellanica</i>	4.41	0.00	0.76	0.00
<i>Halyscarinus planatus</i>	2.94	0.00	0.00	1.85
<i>Peisos petrunkevitchi</i>	0.00	0.00	0.00	1.85
Isopoda	0.00	1.89	6.11	0.93
Brachiura	0.00	1.89	3.82	0.93
Unidentified	23.53	0.00	2.29	4.63
Unidentified items	2.94	3.77	3.82	2.78

Table 2. The frequency of occurrence of each of the main groups of prey in the diets of the Rock Shags in the non-breeding and breeding seasons, and its percentage contribution to average dissimilarities in diet composition of year 2002

Prey-group	Non-breeding frequency	Breeding frequency	Contribution to difference (%)
Crustaceans	0.79	0.25	39.90
Cephalopods	0.54	0.38	30.33
Fish	0.75	0.83	22.66
Polychaetes	0.94	0.96	7.11

in their diet (Punta *et al.* 2003; Frere *et al.* 2005; Bulgarella *et al.* 2008). Along the coast of Patagonia, the Red-legged Cormorant (*Phalacrocorax gaimardi*) also breeds sympatrically with the Rock Shag but only at eight breeding sites (Yorio *et al.* 1998; Frere *et al.* 2005). Like the Rock Shag, the Red-legged Cormorant also feeds mainly inshore on benthic or demersal fish (*Patagonotothen* spp.) and invertebrates (Quintana 1999, 2001; Frere *et al.* 2002; Gandini *et al.* 2005; Millones *et al.* 2005) during the breeding season, but includes sardines (*Sprattus fuegensis*) during the non-breeding season (Millones *et al.* 2005).

Our results showed a high degree of overlap in the dietary composition of Rock Shags between breeding and non-breeding seasons at Punta Loma. The seasonal similarities may provide indirect evidence for highly stable levels over time and space of the food resources exploited by Rock Shags in the vicinity of

Punta Loma. This possible stability is also suggested by other recent studies of the pattern of colony attendance through the year, in which we found a stable number of adults attending the colony, and the same daily abundance of birds during spring, summer, autumn and winter (Sapoznikow and Quintana 2005), a high degree of fidelity to colonies and nesting sites between seasons (Sapoznikow and Quintana 2008), and equal time spent foraging at sea by adults at the same areas during breeding and non-breeding seasons (Sapoznikow 2006; A. Sapoznikow and F. Quintana, unpubl. data). However, our data for 2002 suggest some minor seasonal differences potentially related to natural fluctuations of the populations of the main prey. Crustaceans, mainly *Betaeus truncatus*, and cephalopods, were the groups that mostly contributed to these differences, having a higher occurrence in winter. There are no studies of *Betaeus truncatus* in Argentina, but studies of this species in Chile found ovigerous females were more abundant in winter and spring (Lardies 1995), suggesting that ovigerous females of *B. truncatus* might be an abundant source of food of high energetic value for Rock Shags during the non-breeding season. *Octopus tehuelchus* is the most common cephalopod in the area and is present all year in the intertidal area, but it would be less commonly available when they are breeding and females are incubating and hidden in caves or shells (Ré 1998).

The two main groups of prey (fish and polychaetes) present in the breeding and non-breeding diet of the Rock Shag live in benthic habitats and exhibit notably sedentary behaviours (Hureau 1970; Orenzans 1975). Such characteristics highlight

the idea of a fairly predictable and spatially stable source of food (as above). Unfortunately, there is no information about the ecology or reproductive cycle of the fish present in the diet of Rock Shags, but it is known that notothenids are, in general, sedentary and long-lived species that remain in the same area for life (Hureau 1970). Moreover, different studies have shown that, in general, intertidal fish assemblages are highly stable over time (Grossman 1982; Beckley 1985; Collette 1986). Considering these facts, the main prey fish of Rock Shags appear to be present in their feeding areas through the year, and extreme fluctuations in their abundance are not expected. Also, complementary studies have shown that abundance and distribution of fish in the foraging areas of Rock Shags in Punta Loma were similar though the year (Sapoznikow 2006).

Rock Shags appear to exploit restricted or low-energy prey-items, or both: all species recorded in the diet of Rock Shags either live in caves (cephalopods and fish), hidden among rocks or algae (fish and polychaetes) or totally or partly underground (crustaceans and polychaetes), and thus represent a restricted or hard-to-access food source. The high foraging effort (diving time per foraging trip) and diving efficiency (ratio between diving time and recovery time) recorded during this and previous studies (Quintana 1999, 2001; Quintana *et al.* 2002; Sapoznikow 2006) may be associated with these difficult foraging conditions. The main prey species also have low energy content, compared with other fish species in the area, such as anchovies (*Engraulis anchoita*). Whereas anchovies have an energetic value of 7.1 kJ g^{-1} , the benthic fish *Riberoclinus eigenmanni* has a value of only 3.7 kJ g^{-1} , polychaetes in the family Eunicidae 5.8 kJ g^{-1} and the octopus *Octopus tehuelchus* 5.1 kJ g^{-1} (Gonzalez Miri 1995).

Polychaetes were frequently recorded in the diet of Rock Shags but their importance has been questioned in previous studies: experimental studies have shown that polychaete mandibles could come from fish stomachs (Casaux *et al.* 1995; Johnson *et al.* 1997). However, evidence of pellets containing only polychaete mandibles in other species of cormorant and shag suggests that polychaetes could well form part of the diet of Rock Shags (Green and Williams 1997; Leopold and Van Damme 2003). The maximum number of polychaetes that we found in any one pellet was 81, and 23% of the pellets we collected had only polychaetes in them. It is thus highly probable that polychaetes were genuine prey-items and did not represent secondary consumption. Polychaetes are interesting from an energetic perspective, as they have similar energy content to the other prey, or even higher than some of the main species of prey, such as the fish *Riberoclinus eigenmanni*.

In summary, the data collected in this study indicate that the food sources of Rock Shags are present in their feeding areas, and exploited, throughout the year. However, they also appear to include mainly species that are restricted in their availability, of small size and low energy content, which may have implications for the population dynamics of the species and could be associated with the small colony sizes in coastal Patagonia.

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