CHANGES IN DIET OF CORY'S SHEARWATERS *CALONECTRIS DIOMEDEA* BREEDING IN THE AZORES

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SUMMARY

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The Cory's Shearwater *Calonectris diomedea borealis* breeds in the subtropical northeast Atlantic and is one of the most important consumers in the pelagic system of the mid-North Atlantic. Stomach samples collected in the Azores in 2005 indicated that the blue jack mackerel *Trachurus picturatus* (68.7% of individuals and 72.1% of overall mass) constituted most of the Cory's shearwater diet during the breeding season, in strong contrast with findings of a study in 1994, when their diet comprised mainly boarfish *Capros aper,* trumpetfish *Macroramphosus* sp. and Atlantic saury *Scomberesox saurus/Nanichthys simulans.* No differences were found in diet between sexes and between islands in 2005. Blue jack mackerel were probably caught in the Azores islands shelf area, during both short and long foraging trips. Prey availability may have changed in response to changes in sea-surface temperatures and/or the frequency of feeding associations with other top predators in the region.

Key words: Cory's Shearwaters, fisheries interactions, feeding ecology, Azores

INTRODUCTION

Determining the food and feeding ecology of seabirds is important for bird conservation, as it clarifies relationships among seabirds, prey accessibility and fisheries (Montevecchi & Myers 1995, Karpouzi *et al*. 2007). Modelling such causal relationships with fisheries requires detailed information on the biology of seabirds and of their prey, both of which are still scarce in some regions of the world. Information on the diet of key marine predators is often limited, making it difficult to assess trophic and operational overlap between fisheries. Furthermore, the vast expansion of fisheries worldwide has resulted in the collapse of many fish stocks (Pauly *et al*. 2002), which may negatively affect seabirds (Wanless *et al*. 2005, Karpouzi *et al*. 2007).

The sub-tropical North Atlantic oceanic waters of the Azores archipelago (36–39°N, 25–31°W) support well-managed fisheries that exploit around 50 of the 500 species living in the ecosystem, but landings are dominated by the tuna fishing fleet (Santos *et al*. 1995, Granadeiro *et al*. 1998, Morato *et al*. 2001). Tuna catches (of bigeye tuna *Thunnus obesus*, skipjack tuna *Katsuwonus pelamis*, bluefin tuna *T. thynnus* and yellowfin tuna *T. albacares*) vary from year to year, but in a good year catches can reach 5 000 tonnes (Morato *et al*. 2001). The tuna are fished with pole-and-line (with unbaited hooks), usually with water spray and live bait. Fishermen throw the bait into the water to attract tuna to the hooks. The estimates of fish species caught for bait for the tuna fishery are about 200 tonnes per year, mainly blue jack mackerel (*Trachurus picturatus*, 70% of bait caught by weight) but also the European pilchard (*Sardina pilchardus*, 10%), chub mackerel (*Scomber japonicus*, 10%) and blackspot seabream (*Pagellus bogaraveo*, 10%) (Morato *et al*. 2001). As these fish species are abundant in the Azores' waters, particularly blue jack mackerel in shelf waters, natural predators such as seabirds may depend on them as an important food source (Martin 1986).

The Cory's Shearwater is the most abundant breeding seabird and one of the most important consumers in the pelagic system of the mid-North Atlantic, including in the Azores (Monteiro 2000). Cory's Shearwaters forage over extensive areas in the Atlantic Ocean (Mougin & Jouanin 1997, Magalhães *et al*. 2008, Navarro *et al*. 2009, Paiva *et al*. 2010a,b), with long trips of up to 1800 km but also short trips within 75 km of the Azores breeding site, in shelf areas where blue jack mackerel are known to be abundant (Magalhães *et al*. 2008, Paiva *et al*. 2010a). Shearwaters can be used as bio-indicators in marine ecosystems and have proved useful indicators of fish and squid stocks in coastal and oceanic surface waters that are difficult to assess by conventional means (Ristow *et al*. 2000, Xavier *et al*. 2006, Paiva *et al*. 2010b).

Previous studies of Cory's Shearwaters in the Azores conducted in 1994 indicated that they fed primarily on small fish, mainly trumpet fish *Macrorhamposus* sp., boarfish *Capros aper* and sauries *Scomberesox saurus* and *Nanychthys simulans* (Monteiro *et al*. 1996; Granadeiro *et al*. 1998) during the pre-laying and chick-rearing periods, with blue jack mackerel constituting <10% (by weight) of the diet.

This study investigates the diet of Cory's Shearwaters at various islands of the Azores archipelago in 2005, and any changes in diet and foraging behaviour since 1994. The possibility of differences in diet between males and female Cory's Shearwaters are also explored, and conservation implications are discussed.

MATERIALS AND METHODS

Fieldwork was carried out in the Azores Archipelago between 28 June and 22 August 2005, on the islands of Corvo, Santa Maria and Graciosa. Adult Cory's Shearwaters were captured by hand at their breeding grounds when entering their burrows during incubation and chick-rearing periods. The sex of each adult was assessed by vocalization (James & Robertson 1985) when possible (75% of the birds in Corvo; 77%, in Santa Maria and 67%, in Graciosa). Food samples were obtained using Wilson's (1984) water off-loading technique. After examining for the presence of fish, squid or crustaceans, the excess salt water was removed and all solid remains were preserved in 70% alcohol or frozen for subsequent analyses. In the laboratory, the solid fraction was separated into categories (fish, cephalopods or crustaceans). Fish otoliths were identified according to Härkönen (1986) and Assis (2004), and reference collections at the Department of Oceanography and Fisheries (DOP, University of Azores), Centre of Marine Sciences (CCMAR,University of Algarve) and Institute of Oceanography (University of Lisbon). The otolith–fish size relationships (C. Assis, unpublished data) are presented below:

Boarfish

$SL = 34.73\ OL^{0.87}$, r = 0.94, n = 77 (SL = 35–120 mm)

$M = 4.47 \times 10^{-5}\ SL^{2.95}$, r = 0.98, n = 77 (M = 2–77 g)

Blue jack mackerel

$SL = 20.95\ OL^{1.19}$, r = 0.96, n = 34 (SL = 134–270 mm)

$M = 2.8 \times 10^{-6}\ SL^{3.29}$, r = 0.96, n = 34 (M = 27–277 g)

where OL = otolith length (mm), SL = standard length (mm) and M = body mass (g) of the fish. The number of fish was estimated from the number of intact crania containing both sagittal otoliths and loose otoliths. The loose otoliths were, when possible, paired by size and degree of erosion (Xavier *et al*. 2003).

Cephalopod beaks were identified using Clarke (1986) and beak collections held at the Department of Oceanography and Fisheries (DOP, University of Azores). Allometric equations of mantle length (ML) and estimated mass (W), based on cephalopod beak measurements, were taken from Clarke (1986) and Lu & Ickergill (2002). Eroded beaks were not included in the dietary analyses that included fresh prey (Table 1).

Dietary information is presented in terms of frequency of occurrence (% of samples with a given prey item), by number (number of specimens of each prey type, expressed as % of the total number of prey found) and proportion by mass (mass contribution of a component, as % of total mass). The component "Osteichthyes" denotes highly digested fish that could not be identified. Some birds had empty stomachs, and these were not considered here. The dietary statistics involving mass are restricted to the fish species that could be identified. The data were tested for normality and, if necessary, transformed. In cases where normality was not achieved, non-parametric tests were used. General linear models (GLMs) were used to test whether the diet of Cory's Shearwaters varied significantly between islands and by sex.

RESULTS

A total of 79 stomach contents from Cory's Shearwaters were collected in 2005 from colonies on Corvo, Santa Maria and Graciosa islands (Table 1). The mean mass of food samples was 15.3 (standard error [SE] 2.6) g with no significant differences between islands (Corvo = 11.6 [SE 5.6] g; Santa Maria = 20.1 [SE 4.1] g; Graciosa = 15.3 [SE 2.6] g; ANOVA, $F = 2.2$, $P = 0.10$). Nor were there significant differences between the masses of food samples between sexes on the same islands (GLM, $F = 2.5$, $P = 0.09$ for island; $F = 2.2$, $P = 0.14$ for sex; and $F = 0.2$, $P = 0.84$ for the interaction between island and sex).

Overall, when samples from all islands were combined, Cory's Shearwaters consumed mainly fish (98.5 [SE 0.7]% by mass; Table 1), with no significant differences between the proportions of fish (the main diet component) between islands (Kruskall–Wallis, $H = 0.4$, $P = 0.8$) nor between sexes (females versus males: Corvo — Mann–Whitney test, $W = 37$, $P = 0.66$, Santa Maria — Mann–Whitney test, $W = 102$, $P = 0.07$, Graciosa — Mann–Whitney test, $W = 283$, $P = 0.70$, all — Mann–Whitney test, $W = 1056$, $P = 0.20$).

TABLE 1
Component of the diet of Cory's Shearwaters in the Azores Islands in 2005

Location, prey species	Frequency of occurrence within samples, no. (%)		Specimens of each prey type, no. (%)		Estimated mass, %
Overall (n = 79)					
Fish[a]	79	(100.0)			98.5 ± 0.7
Trachurus picturatus	28	(35.4)	46	(68.7)	72.1
Macroramphosus sp.	2	(2.5)	2	(3.0)	15.3
Capros aper	1	(1.3)	1	(1.5)	8.6
Osteichthyes	48	(60.8)	17	(25.4)	4.0
Crustacea	1	(1.3)	1	(1.5)	< 0.1
Corvo Island (n = 12)					
Fish[a]	12	(100.0)			100.0
Osteichthyes	12	(8.0)	2	(100.0)	100.0
Graciosa Island (n = 24)					
Fish[a]	24	(100.0)			98.2±1.4
Trachurus picturatus	6	(25.0)	7	(58.3)	98.2
Osteichthyes	18	(75.0)	5	(41.7)	1.8±1.4
Crustacea	1		1		< 0.1
Santa Maria Island (n = 43)					
Fish[a]	43	(100.0)			98.6±0.9
Trachurus picturatus	20	(46.5)	39	(75.0)	73.5
Macroramphosus sp.	2	(4.7)	2	(3.8)	15.8
Capros aper	1	(2.3)	1	(1.9)	8.9
Osteichthyes	23	(53.5)	10	(19.2)	1.7±0.9

[a] For the fish component, allometric equations were applied only to species that were identified.

Within the diet components, the fish species blue jack mackerel was the most important prey species (68.7% by number of individuals and 72.1% of overall mass, Table 1), with the second most important species, trumpet fish, representing only 3% by number individuals and 15.3% of mass (Table 1). The size of blue jack mackerel in the samples ranged between 40.8 and 142.2 mm (Table 2). Although cephalopod flesh was not found in the samples, eroded cephalopod beaks were identified (Table 3). The most numerous identifiable taxa were the squid *Neoteuthis* sp. (30.8% by number of individuals), followed by *Histioteuthis arcturi, H. reversa* and *Taonius pavo* (each representing 3.8% by number of individuals; Table 3). Other components (pieces of plastic) occurred in eight food samples.

DISCUSSION

Diet and feeding ecology of Cory's Shearwaters

Cory's Shearwaters are surface-feeders, apparently unable to capture prey deeper than 6 m (Mougin & Mougin 1998). Previous studies have shown that they adopt a dual strategy, feeding on epipelagic shelf prey in shallow waters during short trips and on oceanic prey items, normally associated with different water masses, during long trips (Weimerskirch & Cherel 1998, Paiva *et al*. 2010a).

Blue jack mackerel dominated the diet of Cory's Shearwaters in 2005, in contrast to observations in the 1990s, when small fish such as trumpet fish and boarfish constituted 75% of diet by mass, and squid made up most of the remainder (Granadeiro *et al*. 1998).

Cephalopods are also known to be consumed by Cory's Shearwaters (Granadeiro *et al*. 1998, Paiva *et al*. 2010b) but in this study only eroded squid beaks were found (Table 3), which may have been consumed during the long trips or when migrating/foraging before breeding (see Paiva *et al*. 2010b). Nevertheless, important information can be obtained from these data, as the diversity, distribution and biology of mid-Atlantic cephalopods are still poorly known. Of the beaks that were possible to identify, histioteuthids, neoteuthids and cranchiids are known to occur in Azorean waters. The Neoteuthid *Neoteuthis* sp. was numerically the most important cephalopod species (Table 3), but its biology is poorly known (Nesis 1987). Although *Histioteuthis arcturi* and *H. reversa* are generally found in deep waters, to below 1000 m, they may become available close to the surface either through diel vertical migrations or as a result of post-spawning mortality (Voss *et al*. 1998). As the only *H. arcturi* caught had an estimated ML of 66.4 mm (Table 3) and this species starts to mature at 72 mm ML (Voss *et al*. 1998), the individual was probably caught alive.

Potential causes of changes in diet of Cory's Shearwaters between 1994 and 2005

Variability in the diet of seabirds can be attributed to a wide range of factors, but, overall, change in diet generally reflects a change in prey abundance or access to prey. Neither boarfish nor trumpet fish are commercially exploited in the Azores (they are only caught to be used as live bait to catch tuna), and there are no independent stock assessments for either species. Both are, nevertheless, reported to be extremely abundant in the area between the Azores, the south of Portugal and the Canary Islands (Ehrich 1975). Data collected just south of the Azores Islands, at the Great Meteor seamount (30°N, 28.5°W), showed that trumpet fish, boarfish and blue jack mackerel are among the most abundant fish in the region (Fock *et al*. 2002). Furthermore, the first two fish species are thought to have increased in abundance by a factor of approximately 50 to 100 between 1967 and 1998 (Fock *et al*. 2002). With no more recent data on the abundance as well as vertical and horizontal distribution of the three species in the region, it is impossible to critically evaluate changes in their abundance and accessibility as prey for Cory's Shearwaters.

TABLE 2
Fish prey found in the diet of Cory's Shearwaters in the Azores Islands

Species	Specimens of each prey type	Mean (range) [SE]								
		Otolith, mm			Standard length, mm			Estimated mass, g		
Trachurus picturatus	46	3.6	(1.8–5.0)	[0.2]	96.1	(40.8–142.2)	[7.4]	12.3	(0.6–33.9)	[2.5]
Macroramphosus sp.	2	1.1	(1.0–1.2)	[0.1]	97.4	(87.9–106.8)	[9.5]	5.6	(3.9–7.3)	[1.7]
Capros aper	1	1.5			49.4			4.1		

TABLE 3
Eroded beaks of cephalopods found in the diet of Cory's Shearwaters in the Azores Islands

Cephalopod species	Frequency of occurrence within samples, no.	(%)	Specimens of each type of prey, no.	(%)	Mean (range) [SE]								
					Lower rostral length, mm			Mantle length, mm			Estimated mass, g		
Histioteuthis arcturi	1	(1.3)	1	(3.8)	3.6			66.4			94.9		
Histioteuthis reversa	1	(1.3)	1	(3.8)									
Neoteuthis sp.	5	(6.3)	8	(30.8)	4.0	(2.8–5.6)	[0.6]	122.4	(85.7–171.4)	[19.4]	246.6	(68.6–549.1)	[109.7]
Taonius pavo	1	(1.3)	1	(3.8)	5.7			337.9			99.2		
Others (eroded)	9	(11.4)	15	(57.7)									

Previous observers have, however, witnessed adult Cory's Shearwaters feeding on blue jack mackerel and the trumpet fish *M. scolopax* that were driven to the surface by dolphins and tuna; such feeding associations are now common around the Azores in summer (Martin 1986, Clua & Grosvalet 2001, Steiner 1995, Morato *et al*. 2008). As the catches of tuna can reach 5 000 tonnes in a year (Morato *et al*. 2001), and the catch of bigeye tuna was the highest in 2005 since 1998 (Miguel Machete, pers. obs.), interactions between Cory's Shearwaters and other predators may have enhanced access to food for Cory's Shearwaters, at least in 2005.

Cory's Shearwaters breeding in the Azores in 2004–7 again demonstrated a dual-foraging strategy in which they exploited feeding areas up to 1800 km from the nest, with short trips used to catch prey for their chicks and long trips for self-feeding (Magalhães *et al*. 2008, Paiva *et al*. 2010a). Although the frequencies of fish prey did not differ between the short and long trips, the frequency of cephalopods and amount of food delivered to chicks were higher after long trips (Magalhães *et al*. 2008, Paiva *et al*. 2010b). As blue jack mackerel are confined to the shallow neritic zones of island shelves, banks and seamounts (Smith-Vaniz 1986, Froese & Pauly 2007), in 2005 they were likely obtained either on short trips or when returning from long trips (see Paiva *et al*. 2010b).

The contribution, by mass, of blue jack mackerel to the diet of Cory's Shearwaters was related to environmental conditions, with sea surface temperature anomaly (SSTa, for July, from http://coastwatch.pfel.noaa.gov/coastwatch/CWBrowserWW360.jsp) close to the Azores Islands (area chosen: 39°N, 29°W) differing markedly between 1994 (SSTa = -1.43 °C; the third most negative SSTa in the last 27 years) and 2005 (SSTa = -0.23 °C), with the latter slightly warmer (Table 4). Moreover, diet data from 2006 and 2007, which also show a prevalence of blue jack mackerel dominating the diet of Cory's Shearwaters, showed similar SSTa values (Table 4).

Studies of the diet of terns in the Azores have documented that in 1994 boarfish, trumpet fish and blue jack mackerel were also very abundant, as opposed to years (e.g. 1995) when the number of other prey, such as Myctophidae, were higher (Granadeiro *et al*. 2002, Ramos *et al*. 1998).

In summary, this study showed very different diets of Cory's Shearwaters in 1994 and 2005, with suggestions that increased feeding associations with other large predators in the region and/or differences in surface sea temperatures were among the causal factors. To fully understand the functional role of island shelves and seamounts, and how breeding seabirds associate with other predators at these sites, further studies of the spatial and temporal variation in fish availability, diet and feeding areas at a finer scale in relation to Cory's Shearwater breeding performance are necessary.

Implications for seabird conservation

The blue jack mackerel is a well-known source of live fish bait for tuna fishing in the region (Santos *et al*. 1995). Although there are no current signs of over-exploitation (Miguel Machete pers. obs.), our results highlight the need for further investigation of the potentially negative impacts on Cory's Shearwater population caused by tuna fisheries and fishing vessels (either directly, from competition for blue jack mackerel, or indirectly, from tuna overfishing and a concomitant reduction in feeding associations between birds and tuna within Azorean waters). Fisheries in the Azores Islands are characterized by small-scale operations using coastal surface gillnets, traps and various forms of hook and line (Morato *et al*. 2001). Cory's Shearwaters are known to follow fishing vessels, but there are no known records of them being incidentally caught on long lines (M.C. Magalhães, pers. comm.). Cory's Shearwaters very rarely get hooked during the tuna fishery, and any that do are immediately released with no evidence of mortality (M.C. Magalhães, pers. comm.). However, although local fisheries in the Azores have little impact on incidental mortality of Cory's Shearwater populations, concerns have been expressed over incidental mortality of adult Cory's Shearwaters in longline fisheries elsewhere during overwintering and migration periods (Gonzáles-Solís *et al*. 2007, Magalhães *et al*. 2008). Furthermore, it is crucial to continue monitoring the Azorean Cory's Shearwater population, their breeding success and foraging ecology in view of the fact that this archipelago is known to hold more than 50% of the world population. This is particularly important as Cory's Shearwaters can be affected by the accessibility of food around Azores islands, particularly when foraging in shallow waters during their short trips. Moreover, as feeding associations with other predators appear to play a key role in the population dynamics of Cory's Shearwater, conservation issues in the Azores marine ecosystem need to be approached in a broader perspective.

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TABLE 4
Diets of Cory's Shearwaters in the Azores islands and sea surface temperature around the Azores archipelago (39°N, 29°W) and in short trip (ST; 37–41°N and 27–31°W) and long trip (LT; between 47–51°N and 27–31°W) core areas

Year	Main diet	Main prey species (by mass)	Sea surface temperature (°C)	ST	LT	Reference for diets
1994	Fish (69.8%)	*Scomberesox/Nanychthys, simulans* (25%)	-1.43	-1.05	-1.91	Granadeiro et al. 1998
2005	Fish (98.5%)	Blue jack mackerel (72.1%)	-0.23	0.22	0.28	This study
2006	Fish (91.8%)	Blue jack mackerel (90.1%)	-0.08	0.41	0.13	DOP, unpublished data
2007	Fish (96.3%)	Blue jack mackerel (86.5%)	-0.53	-0.06	-0.62	DOP, unpublished data
1982–2008			-0.18 (SE 0.16)	-0.18 (SE 0.16)	-0.10 (SE 0.84)	

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