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DIET OF BREEDING OSPREYS IN THE CAPE VERDE ARCHIPELAGO, NORTHWESTERN AFRICA

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ABSTRACT.—We studied the diet of breeding Ospreys (*Pandion haliaetus*) in the Cape Verde archipelago during 2006, using prey remains recovered at 21 nests and perches on the islands of São Vicente, Santiago, Santa Luzia, Boavista, Branco, and Raso. We identified a total of 1264 individual fish prey items of 35 species. Diet was dominated (>80%) by only six fish species, including *Trachinotus ovatus*, *Exocoetus volitans*, *Aulostomus strigosus*, *Sparisoma cretense*, *Sardinella maderensis*, and *Tylosurus acus*. Dominant prey species varied among islands, but diet similarity was greater between nearby islands. Pelagic species were consumed most frequently (>60%) in Boavista and Santa Luzia, whereas demersal reef fish dominated (>50%) in the other islands. The fish consumed were generally large, though there was wide variation in estimated length (20.7–62.2 cm) and weight (49–1117 g). A comparison of Osprey diet with Cape Verde fisheries suggested that the potential for conflict is low, due to minimal overlap in the primary species caught. Changes in marine productivity associated with the ongoing moderate warming of the Canary Current System may represent a threat, though there is considerable uncertainty about the type and magnitude of these effects. Monitoring of Osprey numbers, breeding success, and diet is required to detect any changes associated with availability of food sources, and such monitoring may also provide a relatively simple and inexpensive method to track long-term changes in littoral fish assemblages.

KEY WORDS: *Osprey*; Pandion haliaetus; *Cape Verde*; *diet*; *foraging ecology*; *piscivory*.

DIETA DE INDIVIDUOS REPRODUCTIVOS DE *PANDION HALIAETUS* EN EL ARCHIPIÉLAGO CABO VERDE, NOROESTE DE AFRICA

RESUMEN.—Estudiamos la dieta de individuos reproductivos de *Pandion haliaetus* en el archipiélago de Cabo Verde durante 2006, usando restos de presas recolectados en 21 nidos y perchas en las islas São Vicente, Santiago, Santa Luzia, Boavista, Branco y Raso. Identificamos un total de 1264 presas de peces correspondientes a 35 especies. La dieta estuvo dominada (>80%) por sólo seis especies de peces, incluyendo *Trachinotus ovatus*, *Exocoetus volitans*, *Aulostomus strigosus*, *Sparisoma cretense*, *Sardinella maderensis* y *Tylosurus acus*. Las especies dominantes de presas variaron entre las islas, pero la similitud de las dietas fue mayor entre las islas cercanas. Las especies pelágicas fueron consumidas con mayor frecuencia (>60%) en Boavista y Santa Luzia, mientras que los peces de fondo de los arrecifes dominaron (>50%) en otras islas. Los peces consumidos fueron generalmente grandes, aunque hubo gran variación en el largo (20.7–62.2 cm) y peso (49–1117 g) estimado. Una comparación de la dieta de *P. haliaetus* con las pesqueras de Cabo Verde sugirió que existe poco potencial de conflicto, debido a la baja superposición en la principal especie capturada. Los cambios en la productividad marina asociados con el calentamiento moderado en curso del Sistema de Corriente de las Canarias pueden representar una amenaza, aunque hay una incertidumbre considerable sobre el tipo y la magnitud de estos efectos. Se requiere el monitoreo de los números, del éxito reproductivo y de la dieta de *P. haliaetus* para detectar cualquier cambio asociado con la disponibilidad de las fuentes de alimento, y este monitoreo también puede brindar un método relativamente simple y barato para seguir los cambios a largo plazo en los ensambles de peces de litoral.

[Traducción del equipo editorial]

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The Osprey (*Pandion haliaetus*) has a nearly worldwide distribution and large population sizes (Poole 1989), despite dramatic, but transitory, reductions in range and numbers due to organochlorine-induced reproductive suppression during the second half of the twentieth century (Watts and Paxton 2007, Bai et al. 2009). The global conservation status of Ospreys is thus of Least Concern (BirdLife International 2010), though there is evidence that some local populations are highly vulnerable to extermination. This is the case for small and isolated populations in the Mediterranean and Macaronesia, where the species is restricted to the islands of Corsica and the Baleares, the North African coast, and the Atlantic archipelagos of the Canaries and Cape Verde (Thibault et al. 1996, Palacios 2004, Palma et al. 2004). Protection of peripheral populations such as these may be important for the long-term conservation of even geographically widespread species (Lessica and Allendorf 1995).

With about 70–80 breeding pairs, the Cape Verde archipelago holds the largest Osprey population in the whole of the Mediterranean and Macaronesia (Palma et al. 2004). Ospreys are largely concentrated in the northern *Barlavento* (windward) islands group (Santo Antão, São Vicente, Santa Luzia, São Nicolau, Branco, Raso, Boavista, and Sal), where the population appears to be recovering from past declines due to overharvesting of eggs and nestlings for human consumption (Palma et al. 2004). In the southern *Sotavento* (leeward) islands (Maio, Santiago, Fogo, Rombos, and Brava) the species is scarce and seemingly still declining (Palma et al. 2004). Reasons for these contrasting population sizes and trends are poorly known, but may be related at least partly to differences in prey availability (Naurois 1987). The *Barlavento* islands are influenced by the Canary Current System, which brings relatively cold waters rich in nutrients from upwelling areas in northern Africa (Roy and Cury 2003). This creates the conditions for high marine productivity and fish abundance (Roy and Cury 2003), which in turn may influence Osprey population distribution, density, and breeding success (Harmata et al. 2007, Bai et al. 2009, Glass and Watts 2009).

Despite the value of foraging ecology for understanding population dynamics and spatial distribution patterns, little is known about Osprey diet in the Cape Verde islands. Early reports described the comber (*Serranus cabrilla*) as the most important prey of Ospreys in the archipelago (Bannerman and Bannerman 1968), but this species was not mentioned in later studies (Naurois 1987, Ontiveros 2003). Instead, fish of the families Carangidae, Acanthuridae, Scombridae, and Exocoetidae were obtained from nests in Santa Luzia and Raso (Naurois 1987), and parrotfish of the genus *Sparisoma* were by far the most important prey recorded in Boavista (Ontiveros 2003). These preliminary data suggest that Ospreys in the Cape Verdes may exploit a wide range of marine fish, though there may be strong spatial variation in the most important prey species. We here provide a comprehensive account of Osprey diet in the Cape Verde archipelago. Specifically, we describe: (1) prey species and sizes most frequently consumed by Ospreys, (2) dietary variation across islands, and (3) the fish habitats (pelagic vs. demersal) most often exploited by Ospreys. We use our results to identify key trophic resources for Ospreys in the Cape Verde islands and to discuss the conservation implications of potential variations in resource availability due to fisheries and climate change.

Methods

Study Area. The Cape Verde archipelago is made up of 10 islands and several islets of volcanic origin (surface: 4026 km²; coastline: 1050 km) between 14°50′–17°20′N and 22°40′–25°30′W, about 600 km west of the African mainland (Senegal). Maximum distance between islands (Santo Antão–Maio) is about 280 km. All islands are inhabited except Santa Luzia and the islets. Cape Verde is included in the African Sahelian arid and semiarid climate regions and in the Macaronesian biogeographic region (Duarte and Romeiras 2009). The climate is dry tropical, with roughly three main seasons: warm dry (May–July), warm wet (August–September), and cold dry (December–April; Medina et al. 2007). Ospreys breed during the cold dry season (Naurois 1987), when water surface temperature is lowest (Medina et al. 2007).

Dietary Analysis. We collected fish remains recovered from 21 nests and perch sites in January 2006 (Branco and Raso islets) and between April and June 2006 (islands of São Vicente, Santiago, Santa Luzia, and Boavista). Sampling was limited by the number of nests in each island (Palma et al. 2004), by difficulties of access of remote nests and perches, and by travel constraints between and within islands. Fish remains collected at each sampling site were stored in plastic bags, labeled, and frozen for future analysis. We identified remains using a reference collection of bones and scales of fish occurring

in the Cape Verde archipelago (e.g., Reiner 1996), obtained from local fishermen and marine biologists. We then estimated the minimum number of individuals of each species represented in a sample from the number and sizes of diagnostic bones (e.g., maxillae, premaxillae, operculae, etc.). We also used bones to estimate the size of fish captured by Ospreys, from regression equations relating bone size (e.g., width, breadth, maximum length) to fish length and length-weight regressions (S. Martins unpubl. data).

Data Analysis. We quantified diet as the numeric frequency of each prey type, computed as the number of individuals of that prey type relative to the total number of individuals identified (e.g., Beja 1997). To assess whether Ospreys were feeding on fish living mainly in the water column or near the sea bottom, we classified species as either pelagic or demersal according to their main habitat type (Froese and Pauly 2010). We used contingency tables (Legendre and Legendre 1998) to assess variation in diet composition among islands. We also used correspondence analysis (CA) to summarize the spatial patterns of dietary variation (Legendre and Legendre 1998). Before CA, we square-root-transformed proportional diet composition data to reduce the influence of a few prey species that were taken very frequently (Legendre and Legendre 1998). We estimated diet diversity using Shannon's entropy H (Legendre and Legendre 1998).

RESULTS

Overall Diet Patterns. We recovered prey remains from Osprey nests and perches representing 1264 individual fishes and 32 species of 24 families (Table 1). Most remains originated from the islands of Boavista (38.3%), São Vicente (37.0%), and Santa Luzia (18.4%), whereas few were gathered on Santiago (1.5%), Raso (4.0%), and Branco (0.7%). Despite the large number of families recorded, nearly 80% of fish prey belonged to just five families: Carangidae (26.8%), Exocoetidae (16.6%), Aulostomidae (14.6%), Scaridae (11.2%), and Clupeidae (10.2%). Likewise, six species with numeric frequencies >5% accounted for 83.5% of fish identified, including the pompano (*Trachinotus ovatus*), the tropical two-wing flying fish (*Exocoetus volitans*), the Atlantic cornetfish (*Aulostomus strigosus*), the parrotfish (*Sparisoma cretense*), the Madeiran sardinelle (*Sardinella maderensis*), and the agujon needlefish (*Tylosurus acus*; Table 1). Pelagic fish were far more frequently consumed (65.2%; 95% CI: 62.6–67.8%) than demersal species (32.2%; 95% CI: 32.2–37.4%). The only non-fish items recorded were one juvenile cat (*Felis catus*), one Bulwer's Petrel (*Bulweria bulwerii*), and one Little Shearwater (*Puffinus assimilis boydi*), although it was uncertain whether these items were taken as prey or as nest material.

Comparisons Among Islands. The number of prey species recorded per island varied widely across the archipelago (Table 2), but there was a tendency for this to be correlated with variation in sample sizes among islands, albeit not significantly so ($r = 0.80$, $n = 5$, $P = 0.105$). Diet diversity was uncorrelated with sample sizes ($r = 0.29$, $n = 5$, $P = 0.633$), with the lowest value on Santiago and the highest in the northern group of islands, particularly on Santa Luzia and Branco/Raso (Table 2).

For further analyses of diet composition, we combined fish with percentage numbers <5% in the category ''other fish'' (16.6% of individuals identified). We also combined data from the nearby islets of Branco and Raso (about 6 km), due to small sample sizes. Analysis revealed a significant dietary variation ($\chi^2 = 639.0$, df = 24, $P < 0.001$), with major differences among islands in dominant prey species (Table 2). The first two axes extracted from correspondence analysis accounted for 79% of variation in the data, showing a strong segregation between the southern (Santiago), central (Boavista), and northern (São Vicente, Santa Luzia, and Branco/Raso) islands (Fig. 1).

Santiago was characterized by a diet largely dominated by *A. strigosus*, with *T. ovatus* and *Sardinella maderensis* also making an important dietary contribution. More than half the fish consumed at Boavista were *T. ovatus*, though *E. volitans* and several minor prey species (18) also were taken frequently. Diet in the northern group was mostly characterized by the high contribution of prey species that were generally less represented on Boavista and Santiago, including *E. volitans*, *S. cretense*, and *T. acus*. However, there were important dietary differences within the northern group, with *A. strigosus* dominating on São Vicente, *S. cretense* and *T. acus* in Santa Luzia, and the ''other fish'' in Branco/Raso.

The proportion of pelagic versus demersal species consumed also varied among islands ($\chi^2 = 172.6$, df = 4, $P < 0.001$), with pelagic fish dominating in Boavista (86.0%) and Santa Luzia (64.8%). Pelagic fish were less important than demersal fish on São Vicente (47.9%), Santiago (42.1%), and the islets of Raso and Branco (41.7%).

Table 1. Fish prey species recorded in the diet of Ospreys in the Cape Verde archipelago (January–June 2006), indicating fish family, the main habitat type (P = pelagic; D = demersal), the percentage of islands where it occurred in the diet (% islands), and the frequency in the diet (% numbers).

SPECIES	FAMILY	HABITAT	OCCURRENCE (% ISLANDS) (n = 6)	FREQUENCY (% NUMBERS) (n = 1264)
Trachinotus ovatus	Carangidae	P	83.3	24.1
Exocoetus volitans	Exocoetidae	P	83.3	16.6
Aulostomus strigosus	Aulostomidae	D	83.3	14.6
Sparisoma cretense	Scaridae	D	66.7	11.2
Sardinella maderensis	Clupeidae	P	66.7	10.2
Tylosurus acus	Belonidae	P	100.0	6.8
Selar crumenophthalmus	Carangidae	P	50.0	2.7
Hemiramphus balao	Hemiramphidae	P	33.3	2.3
Acanthurus monroviae	Acanthuridae	D	66.7	2.1
Euthynnus alletteratus	Scombridae	P	50.0	2.1
Lithognathus mormyrus	Sparidae	D	16.7	1.1
Aluterus schoepfii	Monocanthidae	D	50.0	0.9
Sargocentron hastatus	Holocentridae	D	50.0	0.9
Galeoides decadactylus	Polynemidae	D	16.7	0.7
Heteropriacanthus cruentatus	Priacanthidae	D	33.3	0.5
Chilomycterus reticulatus	Diodontidae	D	33.3	0.5
Mulloidichthys martinicus	Mullidae	D	16.7	0.4
Diplodus prayensis	Sparidae	D	33.3	0.4
Spicara melanurus	Centracanthidae	P	16.7	0.3
Dactyloperus volitans	Dactylopteridae	D	33.3	0.2
Chelon labrosus	Mugilidae	D	33.3	0.2
Myripristis jacobus	Holocentridae	D	50.0	0.2
Abudefduf luridus	Pomacentridae	D	33.3	0.2
Virididentex acromegalus	Sparidae	D	33.3	0.2
Fistularia petimba	Fistulariidae	D	16.7	0.2
Decapterus macarellus	Carangidae	P	16.7	0.1
Scorpaena scrofa	Scorpaenidae	D	16.7	0.1
Eucinostomus melanopterus	Gerreidae	P	16.7	0.1
Rypticus saponaceus	Grammistidae	D	16.7	0.1
Diplodus sargus	Sparidae	D	16.7	0.1
Diplodus fasciatus	Sparidae	D	16.7	0.1
Diplodus puntazzo	Sparidae	D	16.7	0.1

Fish Sizes. We obtained data on lengths and weights of 162 individual fish prey, including the four most important species and the surgeonfish (*Acanthurus monroviae*; Table 3). Fish sizes varied widely, with estimated lengths between 20.7 and 62.2 cm (mean: 38.6 ± 8.6 cm [SD]), and weights between 49 and 1117 g (mean: 366 ± 211 g [SD]). The longest fish captured tended to be *A. strigosus*, but they usually had a low mass. The heaviest fish tended to be *S. cretense* (Table 3).

DISCUSSION

As in other studies (e.g., Poole 1989, Francour and Thibault 1996, Cartron and Molles 2002, Clancy 2005), Ospreys in the Cape Verde archipelago consumed a wide variety of pelagic and demersal fish, but only a few species were important in the diet.

This was particularly evident at the scale of individual islands, with just 1–3 species accounting for >50% of prey consumed on each island. These key prey species varied greatly across the archipelago, though there was a tendency for higher dietary similarity among nearby islands, probably due to differentiation in fish assemblage structure associated with geographic distance (Medina et al. 2007).

Most fish prey recorded at Cape Verde have been rarely or never found in Osprey diets elsewhere, likely reflecting the specificity of fish communities around the archipelago (Floeter et al. 2008). Nevertheless, the species most frequently consumed at

Table 2. Variation in frequency (% of total numbers), number of prey species, and diversity of Osprey diet among islands of the Cape Verde archipelago (January–June 2006); n = number of fish prey items identified.

	FREQUENCY OF FISH SPECIES IN THE DIET (%) BY ISLAND				
PREY OR STATISTIC	SÃO VICENTE (n = 424)	SANTA LUZIA (n = 194)	BRANCO/RASO (n = 37)	BOAVISTA (n = 382)	SANTIAGO (n = 17)
Prey species					
Trachinotus ovatus	3.8	13.7	11.7	50.2	21.1
Exocoetus volitans	19.0	16.3	20.0	14.7	0.0
Aulostomus strigosus	32.7	5.2	16.7	0.0	47.4
Sparisoma cretense	14.3	22.7	5.0	3.7	0.0
Sardinella maderensis	14.7	5.2	0.0	9.3	15.8
Tylosurus acus	6.0	20.2	8.3	1.0	5.3
Other fish	9.4	16.7	38.3	21.1	10.5
Number of prey species	17	14	14	23	5
Diet diversity (H)	0.854	0.918	0.921	0.807	0.593

Cape Verde shared some ecological and morphological similarities with those taken by Ospreys feeding in other subtropical and tropical marine waters. For example, the fish most commonly captured by Ospreys in the Tiran Island (Red Sea) was the bluespotted cornetfish (*Fistularia commersonii*; Safriel et al. 1985), which is a Syngnathiforme broadly similar to *A. strigosus* which was an important prey on Santiago and São Vicente (Cape Verde). Likewise, needlefish such as *Tylosurus* spp. were consumed frequently in Cape Verde (Santa Luzia), the Red Sea (Safriel et al. 1985), the Gulf of California (Cartron and Molles 2002), and the Arabian Gulf (Beech 2003). In contrast to these species, it is noteworthy that mullets (Mugilidade) were very rarely consumed at Cape Verde, though they are an important part of Osprey diet along the nearby coast of Senegal (Prevost 1982), as they are for many Ospreys feeding along tropical and subtropical coasts (Cartron and Molles 2002, Clancy 2005), and in the Mediterranean (Francour and Thibault 1996). This was probably due to the scarcity of mullets in the Cape Verde archipelago.

Factors influencing prey selection by Ospreys in Cape Verde are unknown at present, due to the limited information about coastal fish abundance and distribution (but see Medina et al. 2007). However, a combination of abundance and susceptibility to capture probably influenced diet composition, as found elsewhere (Poole 1989). For instance, cornetfish may be easily captured because they occur in shallow reefs and rocky habitats, where they rest, immobile, near the bottom to ambush their prey (Safriel et al. 1985). These fish may be particularly abundant where the rocky coast plunges abruptly to the depths (Safriel et al. 1985), which may explain their high consumption in islands with very narrow rocky platforms such as São Vicente and Santiago. Parrotfish (*S. cretense*) and surgeonfish (*Acanthurus* spp.) are slow-swimming fish that also occur in shallow water along rocky shores, which may make them highly vulnerable to Ospreys. Among the pelagic species, the high consumption of needlefish is likely explained by the habit of this predator of remaining close to the water surface, nearly motionless, with the body pointing slightly downwards (Safriel et al. 1985).

The estimated mass of fish taken most frequently by Ospreys at the Cape Verdes Islands was generally large compared to that in other inland and marine areas (Poole 1989). For example, in Corsica, 94% of mullet weighed 180–310 g (mean = 235 g; Francour and Thibault 1996), whereas 45.1% of fish prey weighed >300 g in the present study. The greater proportion of large fish observed in this study is closer to that recorded in the Red Sea (Safriel et al. 1985) and, to a lesser extent, in New South Wales, Australia (Clancy 2005). This result suggests that feeding conditions may be particularly favorable in the Cape Verde archipelago, as large prey is generally believed to be the most profitable for breeding Ospreys (Glass and Watts 2009). Despite this general pattern, diet on Santiago was largely dominated by *A. strigosus*, which is a fish with a long body but with low mass. This, together with the low dietary diversity recorded, may indicate that food resources may be less favorable on Santiago than elsewhere, which was in agreement with the small size of the Osprey population there (Palma et al. 2004).

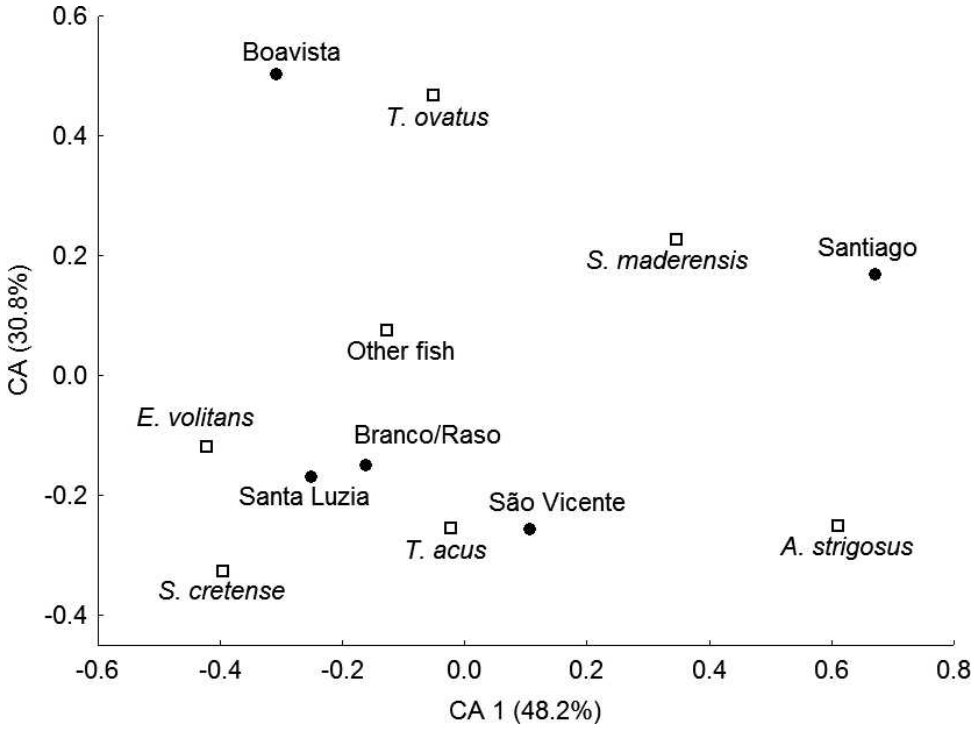

Figure 1. Biplot of a correspondence analysis (CA) of Osprey diet composition in the Cape Verde archipelago (January–June 2006). Species matrix includes species with >50 identified individuals, and combines the remaining prey in an ''other fish'' category. Data from the nearby islets of Raso and Branco were combined due to small sample sizes. Islands are represented by filled circles; fish species by open squares.

Conservation Implications. A sustainable Osprey population requires the maintenance of an abundant food supply, as this strongly influences population density and breeding success (Harmata et al. 2007, Bai et al. 2009, Glass and Watts 2009). In Cape Verde, where large reef and littoral pelagic fish make up the bulk of Osprey diet, maintenance of large stocks of these species will help preserve the Osprey population. One of the potential threats to Ospreys could thus be overfishing (e.g., Safriel et al. 1985, Clancy 2005). We compared the primary species of demersal fish caught by Cape Verde commercial fisheries (Medina et al. 2007) to Osprey diet documented in our study, and found the only overlap to be *A. monroviae*, a fish species that contributed only 2.1% to the overall Osprey diet. Thus, overfishing is unlikely to threaten the population at present, although concentration of fishing effort at the local scale could still influence prey availability for particular Osprey pairs.

Table 3. Estimated mean (±SD) and range of lengths and masses of fish prey species recorded in the diet of Ospreys in the Cape Verde archipelago (January–June 2006).

Fish Prey Species	*n*	Mean Length ± SD (cm)	Range	Mean Mass ± SD (g)	Range
Trachinotus ovatus	13	38.9 ± 2.3	34.9–42.8	486.7 ± 90.6	343–647
Exocoetus volitans	27	35.9 ± 2.0	31.7–39.1	347.9 ± 39.3	266–413
Aulostomus strigosus	63	47.0 ± 6.3	31.5–62.2	187.9 ± 80.2	49–436
Sparisoma cretense	48	30.1 ± 4.5	20.7–39.1	519.1 ± 231.1	144–1117
Acanthurus monroviae	11	33.5 ± 1.3	31.2–36.1	619.9 ± 80.6	482–796

Climate change may represent a potentially more serious threat for the Osprey in Cape Verde, due to potential reductions in marine productivity and fish biomass associated with the ongoing moderate warming of the Canary Current System (Behrenfeld et al. 2006, Sherman et al. 2009). Negative effects on marine productivity may be greater in the *Barlavento* group of islands (Roy and Cury 2003), thereby affecting the Osprey stronghold in the Cape Verde archipelago (Palma et al. 2004). Thus, there is a need for long-term monitoring of Osprey population densities, breeding success, and diet, to detect Osprey responses to any changes in food resources. Monitoring of Osprey and other generalist piscivorous birds could be a relatively simple and inexpensive approach to track temporal and spatial variations in littoral fish assemblages across the Cape Verde archipelago. This might provide early warnings for changes associated with environmental insults such as overfishing and global warming (e.g., Einoder 2009).

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