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Original article

Inter-insular variation of the diet of osprey *Pandion haliaetus* in the Canarian archipelago

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We studied the diet of the osprey *Pandion haliaetus* in the Canary Islands during 1997-2008 using prey remains under perches and nests, and direct observations. We collected data both in breeding territories and in non-breeding areas. We counted a minimum of 307 fish individuals as prey remains (both during breeding and non-breeding seasons), and identified another 78 during 433 hours of field observations. According to our results, ospreys consumed at least 15 taxa belonging to 12 families. We found slight differences in the spatial (both intra and inter insular) and temporal diet composition. During the breeding season, the main prey species were flying fishes (belonging to the family Exocoetidae) and needlefishes (belonging to the family Belonidae) according to the two employed methods (i.e. prey remains and direct observations). In the non-breeding period, the diet was composed primarily of non-autochthones freshwater fishes such as common carp *Cyprinus carpio* and goldfish *Carassius auratus*. In general, the diet diversity was similar to the diversity reported in other breeding populations of subtropical areas, and being less diverse than those of tropical areas. More precise studies evaluating the effect of fish availability in marine reserves, overfishing areas or fish farms on the demographic parameters are necessary for the management and conservation of threatened Canarian ospreys.

Key words: Belonidae, Canary Islands, diet, direct observations, Exocoetidae, osprey, Pandion haliaetus, prey remains

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The osprey *Pandion haliaetus* is a top predator specialised on fish. Its diet composition is greatly influenced by seasonal and geographical fish prey distributions (Poole 1994). Several methods have been employed to assess its diet worldwide: direct or video recording observations of foraging birds or fish deliveries to the nests (Häkkinen 1977, Edwards 1988, Eriksson 1988, Chubbs & Trimper 1998, Glass & Watts 2009), identification of prey remains collected under nests or feeding perches (Häkkinen 1978, Swenson 1978, Carss & Brockie 1994, Gil-Sánchez 1995, Fisher et al. 2001, Cartron & Molles 2002, Clancy 2005) or the combination of both (McKlein & Byrd 1991, Carss & Godfrey 1996). As only flesh and easily broken bones are ingested, pellets are not useful for assessing osprey diet (Francour & Thibault 1996).

Breeding sites of osprey in the Macaronesian archipelagos (i.e. in the northeastern Atlantic) are currently limited to the Canary and the Cape Verde Islands, where 14 and ca 80 pairs occur, respectively (Palma et al. 2004, Siverio 2008). Despite its delicate conservation status (catalogued as Critically Endangered by the Red List of Spanish birds; Triay & Siverio 2004), specific ecological aspects of the Canarian population remain poorly known, with

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only a few surveys conducted regarding status, distribution and breeding parameters (Siverio & Rodríguez 2007 and references therein). The available quantitative information on the food habits of osprey in Macaronesia is limited to the Cape Verde population (de Naurois 1987, Den Hartog 1990, Ontiveros 2003, Martins 2006), with a few isolated observations on the subject from the Canarian population (Martín & Lorenzo 2001). In our study we quantify, for the first time, composition and inter-insular variation of the osprey diet in the Canary Islands, mainly during the nesting period. We do this by prey remains analysis (PRA) compared with direct observations (DO) on foraging birds and birds delivering fish to the nests.

Material and methods

The Canarian archipelago (27°-29°N and 13°-18°W) is located 96-100 km from the northwestern Atlantic coast of Africa. It is composed of seven major islands and some small islets and rocks. The current osprey breeding distribution comprises the islands of Lanzarote (including its related islets Montaña Clara and Alegranza belonging to the Chinijo archipelago), Tenerife, La Gomera and El Hierro (Fig. 1). Some individuals are regularly observed in the remaining islands, but no successful breeding attempts have been recorded there (Siverio & Rodríguez 2007).

We assessed diet composition during breeding (i.e. January-July; Siverio 2006) in 2003-2007, by vi-

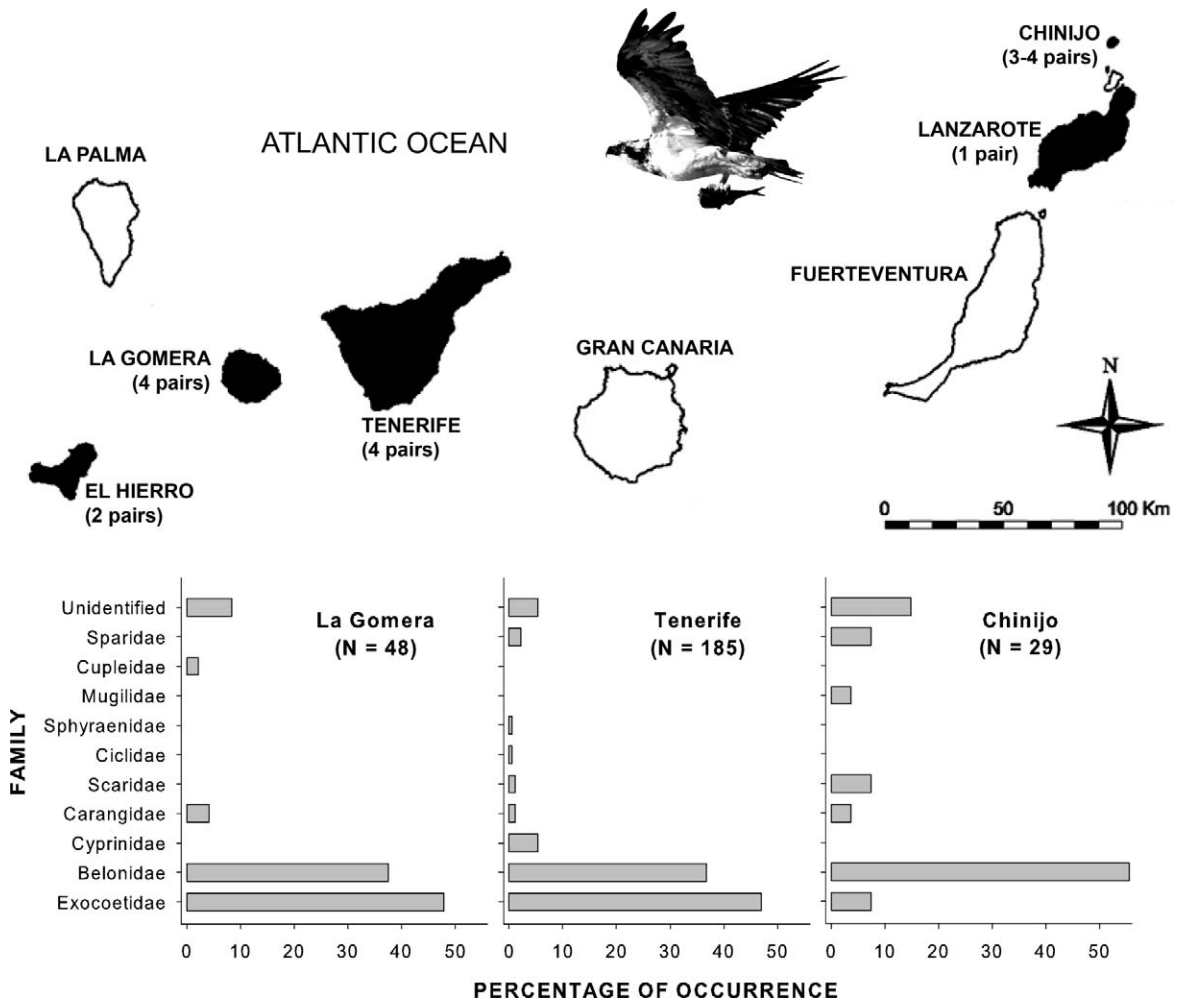


Figure 1. Current breeding distribution of osprey in the Canarian archipelago (occupied islands are shown in black and the numbers of breeding pairs are also given according to Siverio 2008). The histogrammes show the prey frequencies and sample sizes (N) on the three studied islands.

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siting 22 perch or nest sites (five in Chinijo islets in North Lanzarote, 12 on Tenerife and five on La Gomera; see Fig. 1) of 12 of the 14 current breeding territories of the archipelago (Siverio 2008), and by collecting prey remains. To avoid disturbances, we mainly collected prey remains during July-August, just after fledglings leave the nests. We also collected material at non-breeding sites (one on Gran Canaria and two on Tenerife), where local breeding adults were regularly sighted, but also European visitors (colour-ringed) have been recorded (M. Siverio & B. Rodríguez, pers. obs.). This non-breeding season material was presented and analysed independently. We placed emphasis on key fish parts that provided taxonomic identification, and we considered only fresh prey remains (i.e. estimated to be < 2 months old). We assessed the minimum number of fish individuals in prey remains based on the most commonly found fins, whole tails, jaws, different bones or body parts representing an individual (Marti et al. 2007). Whenever possible, we identified prey items at the species level using a reference collection and fish guides (Whitehead et al. 1986, Fischer et al. 1987, González et al. 2000, Brito et al. 2002, Miranda & Escala 2002). We estimated sizes and weights of common carp *Cyprinus carpio* according to formulas relating opercula size and the measurements published by Gil-Sánchez (1995) referred to a population of the Iberian Peninsula. For the other prey species identified in our study, similar formulas were not available in the literature. We also tried to identify all fishes delivered to nests and being carried by flying birds, using binoculars and telescopes (10-60 magnifications), during the 1997-2008 breeding seasons. For this phase of our study, we employed a total of 433 observation hours at different breeding territories and its nearest feeding areas (mainly located on Tenerife and La Gomera). As it has been reported that estimating length size from direct observations entails important biases (Carss & Godfrey 1996), we did not consider this direct method to estimate the size of prey. Niche breath and diet diversity were calculated using the standardised Levin's (B_{sta}) and Shannon (H') indexes (Krebs 1999) applied to the items consumed. The Levin's index formula is:

$$B = 1/\sum p_i^2,$$

where p_i is the frequency of each food category consumed. The standardised Levin's index formula is:

$$B_{sta} = \frac{B - 1}{B_{max} - 1},$$

where B is the Levin's index and B_{max} is the total number of food categories recognised (lowest niche breadth $= 0$ and greatest niche breadth $= 1$).

The Shannon index (in which higher values refer to higher diversity) formula is:

$$H' = -\sum p_i \log p_i.$$

We measured the diet overlap between islands using percentage of food items through the Pianka's index (O):

$$O_{jk} = \frac{\sum_{i=1}^{n} p_{ij} p_{ik}}{\sqrt{\sum_{i=1}^{n} p_{ij}^2 \sum_{i=1}^{n} p_{ik}^2}},$$

where p_i is the percentage of prey item 'i' in the diet of islands 'j' and 'k'. Pianka's index varies between 0 (total separation) and 1 (total overlap).

To study insular variation of the most important prey (belonging to the families Exocoetidae and Belonidae), we applied likelihood ratio tests (G-tests), comparing a certain prey item with the total number of the remaining prey items. We conducted analyses using SPSS (version 17.0).

Results

During the breeding season, we counted a minimum of 262 and 78 fish individuals in prey remains and direct observation, respectively, including at least 15 taxa (belonging to 12 families; Table 1). The most frequently consumed prey was flying fishes (belonging to the family Exocoetidae; 42.7 and 19.2% according to PRA and DO, respectively) and needlefish (belonging to the family Belonidae; 38.5 and 6.4% according to PRA and DO, respectively). At least six species were represented by only one individual in the PRA and DO (see Table 1). We found some remains of red rock crabs *Grapsus grapsus* at two feeding perches on Tenerife, but they were not considered in the analysis as we were not confident that they were consumed by ospreys. Diet composition varied slightly between the islands (La Gomera: $B_{sta} = 0.35$ and $H' = 0.53$, Tenerife: $B_{sta} = 0.21$ and $H' = 0.59$ and Chinijo: $B_{sta} = 0.42$ and $H' = 0.63$; see Fig. 1). Only on Tenerife, fresh-water fishes were caught, and the percentage of captures of flying

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Table 1. Breeding diet composition of osprey in the Canary Islands according to prey remains analysis (PRA) and direct observations (DO) during the periods 2003-2007 and 1997-2008, respectively (see details in text). MNI = Minimum number of individuals.

Prey taxa		PRA		DO	
Family	Species	MNI	%	MNI	%
Marine fish					
Cupleidae	Unidentified	1	0.4	-	-
Mugilidae	Unidentified	1	0.4	1	1.3
Belonidae	*Tylosurus acus**	96	36.6	5	6.4
Belonidae	Unidenfied	5	1.9	-	-
Exocoetidae	*Cheilopogon heterurus**	112	42.7	15	19.2
Aulostomidae	*Aulostomus strigosus*	-	-	1	1.3
Moronidae	*Dicentrarchus labrax*	-	-	1	1.3
Carangidae	*Trachinotus ovatus*	5	1.9	2	2.6
Sparidae	*Sparus auratus*	4	1.5	2	2.6
Sparidae	*Diplodus* sp.	2	0.8	-	-
Scaridae	*Sparisoma cretense*	4	1.5	-	-
Sphyraenidae	*Sphyraena viridensis*	1	0.4	-	-
Freshwater fish					
Cichlidae	*Oreochromis mossambicus*	1	0.4	-	-
Cyprinidae	*Carassius auratus*	-	-	7	9.0
Cyprinidae	*Cyprinus carpio*	10	3.8	-	-
Unidentified	Unidentified	20	7.6	44	56.4
Total		262		78	
B_{sta}		0.15		0.38	
H'		0.55		0.70	

* includes primarily this species but possibly others too.

fishes (belonging to the family Excoetidae) in Chinijo was lower than on La Gomera and Tenerife (see Fig. 1). Diet overlap (O), expressed as Pianka's index, between La Gomera and Tenerife was 0.99, between Tenerife and Chinijo 0.66 and between Chinijo and La Gomera 0.68. The two most important groups of prey showed different patterns. Thus, the species belonging to the family Exocoetidae were significantly more consumed on Tenerife and La Gomera than in Chinijo ($G_2 = 20.85$, $P < 0.001$), but for species belonging to the family Belonidae it did not vary between the islands ($G_2 = 2.33$, $P = 0.31$).

In the non-breeding areas (all associated with large artificial ponds), all identified prey was freshwater fishes. Of a total of 45 fish individuals, the common carp (belonging to the family Cyprinidae; 71.1%, N = 32) was the most common species followed by goldfish *Carassius auratus* (belonging to the family Cyprinidae; 8.9%, N = 4), tilapia *Oreochromis mossambicus* (belonging to the family Cichlidae; 6.7%, N = 3) and large mouth bass *Micropterus salmoides* (belonging to the family Centrarchidae; 2.2%, N = 1), whereas the rest remainded unidentified (11.1%, N = 5). Estimated mean size and weight of common carp (N = 35) captured by osprey were 25.9 cm ± 2.6 (range: 21.5-32.3) and 223.3 g ± 43.4 (range: 147.4-329.3), respectively (Fig. 2).

Discussion

We found only small differences between prey remain analysis and direct observations (see Table 1), so both methods could be considered complementary, though some limitations and biases are present (see Marti et al. 2007). Direct observation is time consuming, and the percentage of correct identifications is highly biased and related to several factors such as size, colour and morphology of the fish, and by the distance of the observation (Carss & Godfrey 1996). Fish identification is also impeded, because often fish are partially eaten when observations commence. In the case of prey remains analysis, some biases are associated with identifiable, conspicuous and lasting body pieces, so usually the smallest fish are more prone to be undetected compared to bigger fish (Carss & Brockie 1994). The presence of scavengers that may affect the durability of larger prey remains, could represent a

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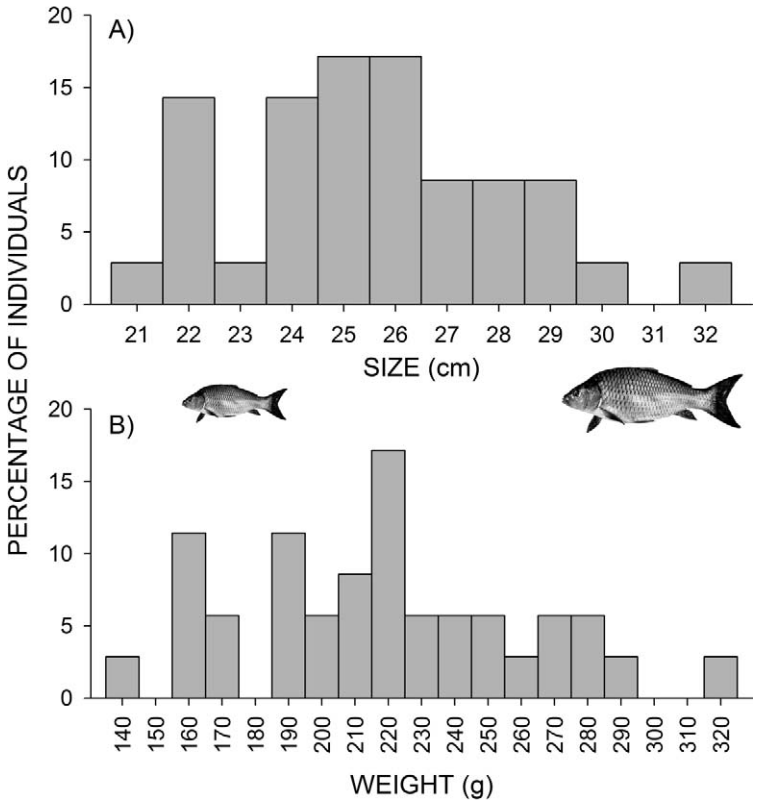


Figure 2. Estimated size (A) and weight (B) of common carps (N = 35) consumed by osprey on the Canary Islands based on the opercula size according to equations described in Gil-Sánchez (1995).

small bias in our study as we collected remains at the end of the nesting season. In this sense, we noticed that some prey remains were probably moved into cracks by the black rat *Rattus rattus*. Furthermore, yellow legged gull *Larus michahellis* and common raven *Corvus corax* usually occur in the vicinity of the osprey feeding perches or nests, apparently searching for food (M. Siverio & B. Rodríguez, pers. obs.).

Taking into account the quantitative data from our study and the addition of saddled seabream *Oblada melanura* (belonging to the family Sparidae), quoted as an occasional item (Martín & Lorenzo 2001), the diet of osprey in the Canary Islands is composed of a minimum of 16 fish taxa (belonging to 12 families). This diet diversity is comparable to reports from other Palearctic populations, but lower than reported in tropical waters such as the southern Red Sea or Cape Verde (Table 2). Reviewing osprey dietary studies during breeding in the western Palearctic, northern populations feed mainly on freshwater fishes, while southern populations feed mainly on marine fishes, and it seems that diet diversity increases in a latitudinal gradient southward (see Table 2). It has been suggested that sea surface temperature is the main proximate factor affecting surface fish availability (both factors related positively), and consequently, osprey feeding behaviour selection into marine or freshwater environments (Marquiss et al. 2007). However, the proportion of marine items in the osprey diet must also be influenced by local factors such as availability of foraging areas (e.g. freshwater body masses are scarce and small on the Canary Islands) and human disturbances. In this sense, it is well-known that ospreys are generalist and opportunistic foragers on fish, depending greatly on locally available resources (Poole 1994, Martins 2006). This behaviour also explains the observed spatial differences within the Canarian archipelago. According to the Pianka's index, the diets of ospreys from La Gomera and Tenerife overlap more (0.99) than the osprey diet from Chinijo compared with La Gomera (0.68) or Tenerife (0.66). These differences are probably related to fish availability as Canarian coastal fish assemblages vary greatly within and between the islands according to the particular habitat features and human pressure (Falcón et al. 1996, Tuya et al. 2004, Clemente et al. 2010).

During the breeding season, freshwater fishes (belonging to the families Cichlidae and Cyprinidae) were only consumed in low numbers on Tenerife (see

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Table 2. Comparison of diet of selected osprey breeding populations across the western Palearctic based on prey remains. The Behaviour/main foraging ground abbreviations are M-Fe = migratory and freshwater environment and S-Me = sedentary and marine environment.

Location	Latitude	Longitude	Behaviour/main foraging ground	N° prey	Species/taxa	B_{sta}	H'	Source
Finland (inland)	60.5°N	23.8°E	M-Fe	716	12	0.13[a]	0.58[a]	Häkkinen (1978)
Finland (coastal)	60.3°N	21.3°E	M-Fe	198	10	0.33[a]	0.71[a]	Häkkinen (1978)
Scotland (north)	56.6°N	3.6°W	M-Fe	104	6	0.63	0.67	Carss & Brockie (1994)
Scotland (south)	54.9°N	4.4°W	M-Fe	239	9	0.36	0.69	Marquiss et al. (2007)
Germany (north-east)	51.5°N	13.5°E	M-Fe	562	6	0.47	0.22	Müller et al. (2005)
France (south)[b]	47.1°N	2.5°E	M-Fe	90	14	0.60	1.02	Thiollay & Wahl (1998)
Corsica (inland)[c]	41.8°N	8.7°E	S-Me	258	12	0.46	0.87	Francour & Thibault (1996)
Portugal (south)[d]	37.1°N	8.6°W	S-Me	49	9	0.21	0.62	Cancela & Palma (1984)
Canary Islands	28.2°N	15.3°W	S-Me	262	13[e]	0.15	0.55	Our study
Red Sea (south)	16.8°N	42.0°E	S-Me	688	56	0.30[f]	-	Fisher et al. (2001)
Cape Verde Islands	16.1°N	22.8°W	S-Me	1264	32	0.20	1.01	Martins (2006)

[a] calculated using number of key bones per species;
[b] study based on direct observation;
[c] considering also some direct observations;
[d] currently extinct population;
[e] 16 considering prey remains analysis, direct observations and bibliographic sources (Martín & Lorenzo 2001);
[f] mean value of four studied islands.

Fig. 1), and thus the relative high level of diet diversity there (H' = 0.59) could be related to their consumption. Both on Tenerife and La Gomera, although more abundant on Tenerife (Siverio et al. 2008, M. Siverio & B. Rodríguez, pers. obs.), the breeding territories are situated close to water ponds used for agriculture. Many of these reservoirs contain domesticated fishes which make up potential prey for ospreys. However, according to our observations on Tenerife, the domesticated fishes seem to be consumed mainly during the non-breeding season or by non-breeding or migratory birds. Given the lack of native freshwater fish in the Canary Islands, the artificial fish source may be crucial when weather conditions (strong winds or rough sea) impede fishing at sea (Grubbs 1977). It is known that birds also forage on fish farms of gilthead seabream *Sparus auratus* and European seabass *Dicentrarchus labrax* (M. Siverio & B. Rodríguez, pers. obs.), of which some are close to nesting sites of Tenerife.

Although several non-fish prey have been reported worldwide (see Wiley & Lohrer 1973), in the Canaries only lizards (two Caesar's lizard *Gallotia caesaris* individuals captured on El Hierro; Díaz et al. 1986) and crabs (without any more information; Martín & Lorenzo 2001) have been recorded. Curiously, recent observations have indicated that some ospreys ingested algae (*Rhizoclonium* sp. belonging to the family Cladophoraceae) and slime near the banks of an agricultural water reservoir, but the reason for this behaviour remains unknown (Siverio et al. 2008).

The estimated mean length (25.9 cm) and weight (223.3 g) of the common carp consumed by ospreys in the Canaries are within the range recorded elsewhere (Häkkinen 1978, Poole 1989, Francour & Thibault 1996). It has been observed that the size and weight of fish captured by ospreys vary according to its availability, and it has been suggested that neither species nor size are selected for by this raptor (Swenson 1978, Poole 1989, Carss & Godfrey 1996, Francour & Thibault 1996).

Our study indicates that during the breeding season, the osprey diet in the Canaries is mainly composed of flying fishes (belonging to the family Exocoetidae) and needlefish (belonging to the family Belonidae), species whose abundance is probably related to their very low commercial fisheries value (G. González-Lorenzo, pers. com.). The slightly higher diet diversity observed in the Chinijo islets compared to Tenerife and La Gomera could be influenced by the fact that the former present a better conservation state of coastal fish assemblages as they were declared as a Marine Reserve by the Spanish Government in 1986. At this site, protection measures against overfishing have contributed to the increase and/or the maintenance of the populations of certain heavily exploited species, such as for example the parrot fish *Sparisoma cretense* (García-Charton et al. 2008). The differences in the management re-

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gimes could be affecting the diet composition of osprey in Chinijo (a marine reserve) vs Tenerife and La Gomera (unprotected and overfishing areas). More precise studies to assess the effect of availability of fish (under natural conditions such as marine protected areas, or at artificial sources such as water ponds or fish farms) on the breeding success and demographic parameters of populations are necessary for the management and conservation of threatened Canarian ospreys.

The use of fish farms as artificial sources of food by osprey could also represent an additional source of mortality as ospreys may entangle in the nets that cover the cages (Siverio & Rodríguez 2007). As it is suspected that the maintenance staff of these farms, to avoid legal problems, may easily hide dead birds if found, competent authorities should inspect these installations to detect and correct potential risks to the raptor species.

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