

Conservation implications of past and present nesting habitat selection of the endangered Osprey *Pandion haliaetus* population of the Canary Islands

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We studied nesting habitat selection of the endangered non-migratory Osprey *Pandion haliaetus* population of the Canary Islands and evaluated the effect of human expansion in recent decades. Compared with randomly selected potential nest-sites, Osprey nests were more frequently found on taller, southwest-facing cliffs, characterized by lower human pressure and closer to Yellow-legged Gull *Larus michahellis* colonies and Barbary Falcon *Falco pelegrinoides* breeding sites. Furthermore, changes in some breeding habitat features have been detected in recent decades. According to our predictive models, large areas of suitable habitat are available but unoccupied in the Canaries, and human activities are probably limiting the settlement and dispersion of new pairs.

Keywords: density, development, human disturbance, management, sea cliffs, sedentary.

Current distributions of threatened populations do not necessarily reflect optimal habitat choice (Richardson & Miller 1997). Detailed knowledge of habitat selection both before and after emergence of threats is necessary

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to develop effective conservation management (Underhill & Gibbons 2002, Toschik *et al.* 2006), including reintroduction programmes (Stamps & Swaisgood 2007).

The Osprey *Pandion haliaetus* is a fish-eating raptor with a worldwide distribution. In the Western Palearctic, northern populations are migratory and nest on trees or, more rarely, on artificial structures, whereas southern populations, mainly confined to islands, are sedentary and usually breed on coastal cliffs, or occasionally inland (Poole 1989a, Thibault *et al.* 2001, Palma *et al.* 2004). These southern populations are threatened by human activities (Palma 2001, Thibault *et al.* 2001, Palma *et al.* 2004, Siverio & Rodríguez 2005), and the species is categorized as critically endangered in Spain (Triay & Siverio 2008).

Most studies of human influence on Osprey habitat selection have focused on migratory populations and report selection of inaccessible sites, isolated from human activity (Löhmus 2001, Toschik *et al.* 2006, Bai *et al.* 2008, but see Shoji *et al.* 2011). In North America, however, many Ospreys nest successfully in close proximity to human activity (Poole 1989a). Quantitative information describing habitat preferences and the influence of humans on cliff-nesting Osprey populations remains scarce (Thibault *et al.* 2001, Shoji *et al.* 2011).

The Osprey breeding population on the Canaries has remained stable in the last three decades, with birds nesting on large, remote sea cliffs, but the species is believed to have been more abundant in the early 20th century, occupying more accessible nest-sites (Siverio & Rodríguez 2007). The main threats are from human disturbance, habitat degradation (coastal urban development) and illegal shooting (Triay & Siverio 2008, Rodríguez *et al.* 2010) in the context of a growing human population. In this study, we (1) identify potential factors affecting density at the island scale, (2) quantify nesting habitat selection by comparing recently active nests, historical nest-sites and randomly selected potential cliff nest-sites, and (3) use our results to predict the availability of optimal habitat and its implications for population recovery.

METHODS

The Canary Islands (27°37'–29°25'N, 13°20'–18°19'W) comprise seven major islands and some smaller islets and marine stacks (Fig. 1, Table S1). In the central-western island group (from Gran Canaria to the most westerly island), the coast is characterized by high basaltic cliffs with scattered boulder rock beaches, whereas in the eastern group large beaches and small cliffs dominate the shores. The human population has increased in recent years (1.7% annual increase) and today around 2.1 million people (280/km²) live on the archipelago (ISTAC 2012), the majority of them concentrated in

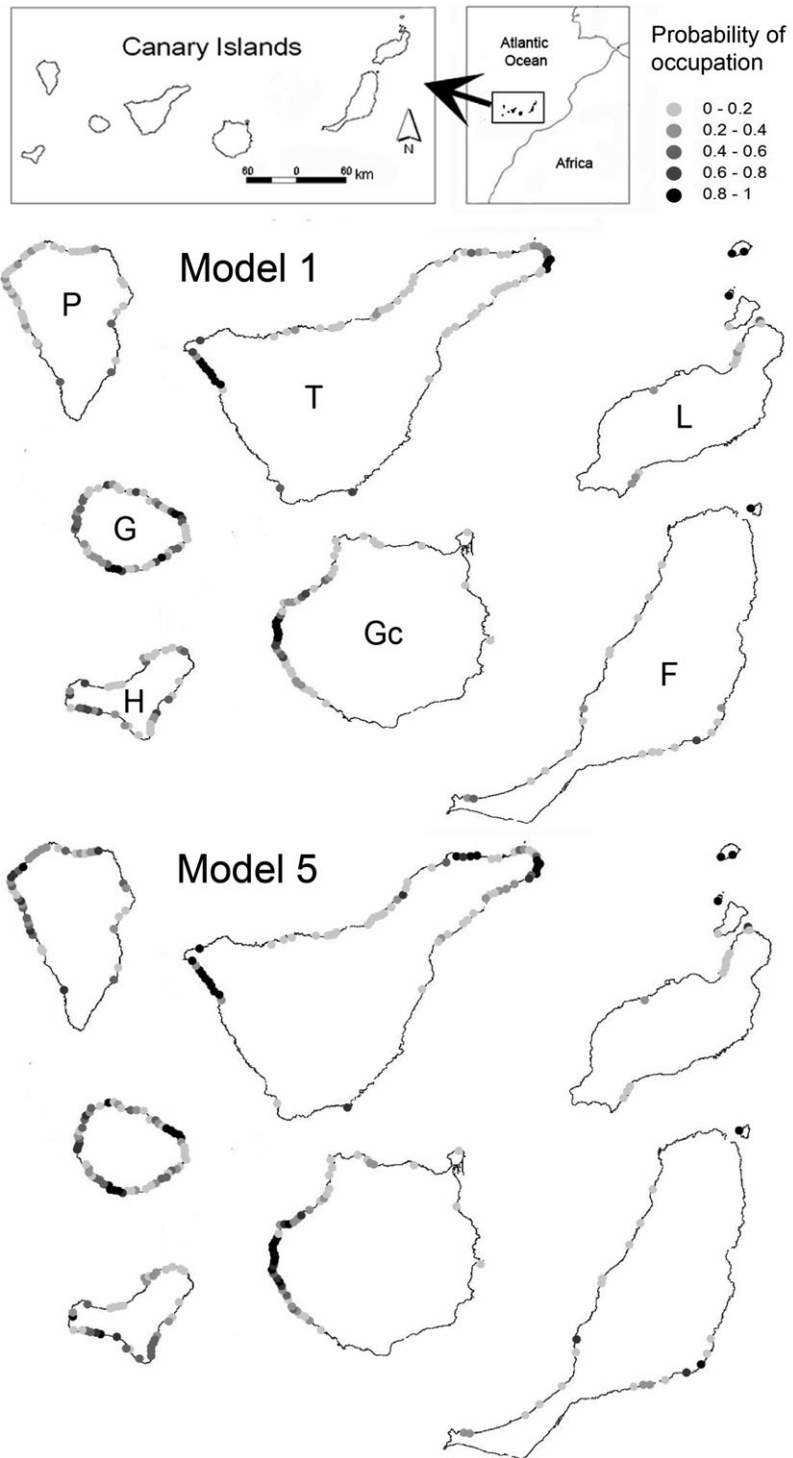


Figure 1. Maps of predicted cliff suitability for breeding Osprey in the Canary Islands. Probability of occupation was predicted by models 1 and 5 in Table 2 (L = Lanzarote, F = Fuerteventura, Gc = Gran Canaria, T = Tenerife, G = La Gomera, P = La Palma, H = El Hierro).

the coastal zones of Tenerife and Gran Canaria, where the landscape has been heavily altered. In addition, more than 500 000 tourists visit the islands monthly (ISTAC 2012).

During February–May 2008, a census of the Osprey population was conducted. Coastal boat transects and observations from vantage points were used to visit all known territories and recognizable nests according to the literature and our own unpublished data (Triay & Siverio 2008 and references therein). An established pair was regarded as present when displaying or perched adults were present at nest-sites, recently used perching sites close to nests were detected or active nests were found (Triay & Siverio 2008).

To examine relationships between island orientation, cliff availability and human occupation and Osprey density, Spearman rank correlations were calculated between the number of nests present in each island and the following variables: (1) the human population in January 2009 (ISTAC 2012), (2) length of southwest-facing coast (greater shelter from the prevailing trade winds ensures better sea conditions here), (3) length of cliff-dominated coast (> 50 m height), (4) length of coast covered by sandy beaches, and (5) length of coast covered by human infrastructures (harbours, coastal cities).

To describe each nest, we used four variables: distance to coast, nest altitude, relative height on the cliff and type of placement on the cliff (Table S2). Seventeen variables were used to characterize nesting cliffs and surrounding areas (both land and sea), and to evaluate the potential interspecific interactions with Barbary Falcons *Falco pelegrinoides* (> 150 breeding pairs in the Canaries) and Yellow-legged Gulls *Larus michahellis* (> 7000 breeding pairs) (Table S2). In the Canaries, both of these species have breeding seasons overlapping that of Ospreys, with laying dates between February and April (Siverio & Rodríguez 2005, Siverio 2006). Behavioural interactions of these species with Ospreys may influence habitat choice or breeding success of Ospreys, so incorporation of measures of these species' presence may be important (Sergio *et al.* 2004).

To test habitat selection by Ospreys, we used 29 recently active nests (i.e. occupied at least once during 2000–2008 according to the literature and our own unpublished data) and 40 randomly selected potential nesting cliffs. We generated random locations, assigning them to the nearest coastal cliff arbitrarily classified as capable of supporting an Osprey nest (> 20 m height and < 100 m from the coast line). To test for changes in nesting habitat selection, we compared the characteristics of the 29 recently active nests with those of 39 historical nest-sites described in the literature and found in 2008 (Siverio & Rodríguez 2007, Triay & Siverio 2008) but unoccupied since 1999 or earlier. For these univariate comparisons, we employed *t*-, *U*- and *G*-tests (Table 1).

We conducted multivariate analyses to evaluate the potential availability of nesting habitat in the archipelago. Specifically, we used generalized linear models (with binomial errors and logit link functions) using only those explanatory variables that showed significant differences in univariate comparisons (Table 1). To avoid multicollinearity, we first constructed a correlation matrix to identify groups of correlated variables (Spearman rank correlation *P*-values < 0.05). Secondly, we ran univariate models to identify those variables with the lowest Akaike information criterion (AICc) values for each group, and then developed multivariate models using only the remaining set of uncorrelated variables. Models with differences in AICc < 2 were considered equally probable. The predictive ability of a model tends to be optimistically biased when evaluated with the same data used to build it. Because of the low number of recently active cliffs, our models were assessed by 'leave one out cross validation'. The fitted probability of a site being occupied was estimated by back-transformation from the final models. We considered cliffs with fitted probabilities of > 0.5 to predict occupation by nesting Ospreys, and values of < 0.5 to predict non-occupancy. We used the best models to calculate the occupation probability of all the 284 potential coastal cliffs (> 50 m height and separated by 1 km from each other) across the whole of the Canary Islands. Models were implemented in R (version 2.15.2, R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

The 2008 survey detected 29 recently active nests and 39 historical nests (Table S1). At least nine additional nests described in the literature had disappeared and were not considered in the analyses. All nests were on coastal cliffs, 69.1% being on ledges. Nests were close to the sea (< 200 m from the coast) and their mean altitude was 55.9 ± 41.4 m, ranging from 10 to 220 m above sea level (Table 1). The majority of nesting sites (79.4%) were within the Canarian Network of Protected Natural Areas (Table 1).

On average, we found 0.53 Osprey nests/10 km of coast. If we only consider coastline with cliffs > 50 m in height, this frequency reaches 3.38 nests/10 km of coast. When only recently active nests were considered, the corresponding figures were 0.22 and 1.44 nests/10 km of coast, respectively. The overall number of identifiable nests and recently active nests per island was positively correlated with the length of coastal cliffs ($r_s = 0.687$, $n = 14$, $P = 0.007$ and $r_s = 0.573$, $n = 14$, $P = 0.032$, respectively).

Univariate comparisons between recently active and randomly selected cliffs showed differences for 10 of the 17 variables considered (Table 1). Compared with random sites, Osprey nests were closer to each other, with

Table 1. Mean values and ranges of variables used in the description of nesting territories of the Osprey on the Canary Islands (see Table S2 for further details). *P*-values correspond to the univariate tests between the two samples (recently active cliffs vs. historical cliffs or recently active cliffs vs. randomly selected cliffs). *P*-values lower than 0.05 are in bold.

Variables	Recently active (<i>n</i> = 29)			Historical (<i>n</i> = 39)			Randomly selected (<i>n</i> = 40)		
	Mean ± sd	Range	<i>P</i> -value	Mean ± sd	Range	<i>P</i> -value	Mean ± sd	Range	<i>P</i> -value
Cliffs									
Nearest neighbour distance ^a	1.1 ± 1.4	0.1–5.9		5.1 ± 14.3	0.0–77.4	0.714	12.3 ± 7.4	1.2–29.5	< 0.001
Orientation ^a	4.1 ± 1.0	2–5		3.8 ± 1.3	1–5	0.561	3.2 ± 1.3	1–5	0.003
Height ^b	118.3 ± 71.2	45–295		96.2 ± 68.4	10–275	0.068	65.8 ± 45.9	20–220	< 0.001
Distance to:									
Depth 50 m ^b	2.8 ± 2.7	0.5–14.5		5.5 ± 4.9	0.2–21.7	0.035	5.7 ± 5.4	0.7–22.3	0.01
Depth 100 m ^b	9.3 ± 6.4	1.3–34.8		11.3 ± 8.2	0.9–34.8	0.767	10.7 ± 9.0	1.6–34.8	0.88
Depth 200 m ^a	14.2 ± 12.6	2.4–74.6		19.9 ± 15.6	1.7–74.6	0.063	15.8 ± 14.3	2.1–74.6	0.72
Beach ^b	1.1 ± 0.8	0.0–3.1		1.8 ± 2.2	0.1–13.6	0.096	2.8 ± 4.3	0.1–18.9	0.17
Road ^a	6.1 ± 7.5	0.2–21.3		4.5 ± 5.5	0.1–19.4	0.343	2.7 ± 5.0	0.1–21.4	< 0.001
Unpaved road ^b	4.1 ± 4.5	0.2–13.3		2.7 ± 3.5	0.1–13.4	0.049	1.2 ± 2.7	0.0–13.1	< 0.001
Path ^b	0.6 ± 0.6	0.1–2.7		1.1 ± 2.1	0.1–12.4	0.507	0.4 ± 0.6	0.0–2.8	< 0.001
Town ^a	5.3 ± 5.3	0.4–16.2		4.4 ± 4.7	0.6–23.9	0.585	3.0 ± 4.1	0.1–16.5	0.002
Harbour ^b	8.1 ± 6.5	1.6–19.5		7.5 ± 5.4	0.6–19.7	0.667	9.6 ± 17.7	0.1–111.1	0.31
Fish farm ^a	41.8 ± 40.4	0.4–140.0		49.2 ± 39.9	2.3–139.9	0.507	45.3 ± 35.1	0.6–127.6	0.88
Freshwater pond ^a	4.1 ± 4.3	0.4–18.9		13.4 ± 38.8	0.4–244.5	0.187	5.5 ± 7.6	0.1–32.6	0.43
Falcon breeding pair ^a	0.8 ± 0.7	0.1–2.5		0.8 ± 0.7	0.1–2.3	0.62	2.5 ± 2.5	0.1–13.1	< 0.001
Gull colony ^b	1.5 ± 1.8	0.1–6.3		1.6 ± 2.1	0.0–10.4	0.902	8.8 ± 8.2	0.1–26.7	< 0.001
Protected area (%) ^c	21 (72.4)			33 (84.6)		0.221	22 (55.0)		0.137
Nests									
Distance to coast ^a	30.9 ± 35.5	4–174		36.5 ± 41.5	0–177	0.453			
Altitude ^a	65.7 ± 37.4	20–200		48.6 ± 43.1	10–220	0.003			
Relative nest position ^a	63.1 ± 24.6	22.9–100		62.4 ± 31.8	6.9–100	0.906			
Nest type									
Cavity (%)	5 (17.2)	–		13 (33.3)	–	–			
Cliff ledge (%)	22 (75.9)	–		25 (64.1)	–	–			
Pinnacle (%)	2 (6.9)	–		1 (2.6)	–	–			

^aU-test. ^b*t*-test carried out on the log-transformed variable. ^c% of sites inside natural protected areas, tested by means of a G-test on the count data.

sunnier and drier orientations, on taller cliffs, close to deeper waters, further away from paths, towns and roads, and closer to Barbary Falcon territories and gull colonies (Table 1). Compared with historical nests, recently active nests were located at higher elevations, closer to deep waters and further from unpaved roads, and were less frequently in cliff cavities (Table 1). Proximity to unpaved roads, sea depths of 50 m and Barbary Falcon breeding pairs entered the model with the lowest AICc value and the highest percentage of correctly classified cliffs (Table 2). The probability of cliff occupation increased with distance to unpaved roads and with sea depth, and declined with distance from Barbary Falcon breeding pairs. Using the five most plausible models, on average 76 of 284 potential cliffs reached occupation probabilities > 0.5, ranging from a minimum of 65 in model 4 to a maximum of 96 in model 3 (Fig. S1). According to competing models (Table 2), cliffs with higher occupation probabilities were located mainly on the west coast of the western islands (Fig. 1).

DISCUSSION

Despite the availability of apparently suitable nesting sites (especially in the western islands: Fig. 1), Osprey density was low compared with other insular populations, such as Corsica or Cape Verde (Thibault *et al.* 2001, Palma *et al.* 2004). Considering our predictive models, nest-site suitability does not appear to limit population expansion. Population size has remained stable since the 1980s, and many sites where old nests are still recognizable have remained unoccupied for decades (Triay & Siverio 2008). The philopatric and semi-colonial behaviour of the species (Poole 1989a,b), together with low breeding success (Siverio & Rodríguez 2005, Siverio 2006), and non-natural sources of mortality (Rodríguez *et al.* 2010) may be limiting population

increase (Poole 1989b, Palma *et al.* 2004). In Corsica, breeding pairs located in coastal sectors with low human pressure and favourable habitats avoided local extinction during an overall population decline, and then provided the nucleus for a subsequent recovery (Thibault *et al.* 2001, Bretagnolle *et al.* 2008). In Cape Verde, the population has increased since nest poaching decreased (Palma *et al.* 2004). Based on the above, the Canarian population could spread to other islands or other potential breeding localities within currently occupied islands.

Contrary to other regions, where Ospreys may nest close to town suburbs or roads (Poole 1989a, Shoji *et al.* 2011), in the Canary Islands this species avoids human pressures, occupying high coastal cliffs, far from human access and settlement. Most nests are on southwest-facing cliffs, near sea areas sheltered against dominant northeasterly winds (blowing 63–90% of days across all seasons). These preferences may be related to foraging, because fishing is easier in calm waters (Grubb 1977). Differences in the extent of shallow platforms in front of recently active and randomly selected cliffs could also be related to human presence because, at a small scale (just in front of the nest), sea characteristics may affect the likelihood of human activities such as anchoring, scuba diving or spear-fishing. On the other hand, the likely higher availability of pelagic fishes (Exocoetidae and Belonidae) in such sites, which constitute the main Osprey prey in the Canary Islands (Siverio *et al.* 2011a), could be also influencing habitat choice. No local studies of the population dynamics of these pelagic fishes are available, but benthic species are much influenced by habitat degradation and over-fishing (Tuya *et al.* 2004).

Osprey nests were located close to Yellow-legged Gull colonies and Barbary Falcon breeding territories. This association could be caused by the occupation of

Table 2. Most plausible models used for the evaluation of the probability of occupation by breeding Ospreys in the Canary Islands. For each model, the AICc, the difference between the current model and the best model (Δ AICc), the Akaike weights (w), Nagelkerke's R^2 and the percentage of correctly classified cliffs assessed by leave one out cross validation (LOOCV) are given.

Model	Linear predictor	AICc	Δ AICc	w	Nagelkerke R^2	LOOCV accuracy (%)
1	$-0.55566579 + 0.00186033 \cdot \text{DNPR} - 0.00121162 \cdot \text{DF} - 0.00012886 \cdot \text{D50}$	49.57	0.00	0.32	0.72	87.0
2	$-1.28672803 + 0.00209017 \cdot \text{DNPR} - 0.00130681 \cdot \text{DF}$	49.84	0.27	0.28	0.70	85.5
3	$-4.24217344 + 0.00188396 \cdot \text{DNPR} + 0.01882968 \cdot \text{H}$	51.03	1.46	0.15	0.69	84.1
4	$-0.17414220 + 0.00123909 \cdot \text{DNPR} - 0.00019511 \cdot \text{D50} - 0.00024349 \cdot \text{DG}$	51.30	1.73	0.13	0.71	81.2
5	$-3.37470542 + 0.00174019 \cdot \text{DNPR} - 0.00012640 \cdot \text{D50} + 0.01645853 \cdot \text{H}$	51.62	2.06	0.11	0.70	85.5
Null model	-0.32158362	95.95	46.38	–	0	58.0

DNPR, distance to unpaved road; D50, distance to sea depth of 50 m; DF, distance to Falcon breeding pair; DG, distance to Gull colony; H, height of cliff.

similar cliffs by the three species after recent expansion of Gull and Falcon populations, aided by higher food availability from a growing human population (refuge for Gulls and Domestic Pigeons *Columba livia* for Falcons) (Barone & Lorenzo 2007, Rodríguez *et al.* 2007, Siverio *et al.* 2011b). Ospreys may also benefit from a behavioural association if the nest defence behaviour of aggressive species acts as an alert (Sergio *et al.* 2004, Quinn & Ueta 2008), or if the presence of Gulls or Falcons indicate higher quality habitat (Parejo *et al.* 2005). Certainly, some Osprey pairs have built new nests close to Gull colonies even when empty cliffs were available (M. Siverio pers. obs.).

Currently, Ospreys prefer nests situated higher above sea level and further away from unpaved roads than in the past, suggesting avoidance of human presence. Some old nests located low on cliffs and close to beaches have been unoccupied for many years (Triay & Siverio 2008), and others have been abandoned recently, probably because of excessive disturbance (Siverio & Rodríguez 2005). Recently used nests situated in caves have been less numerous than historical examples (17.2 vs. 33.3% of sites) perhaps because Ospreys select nests with good visibility in response to increased human activity. Northern populations of Ospreys are also reported to select dominantly located and higher nesting sites, possibly for the same purpose (Van Daele & Van Daele 1982, Poole 1989a, Shoji *et al.* 2011).

Our models have identified the availability of potentially suitable but unoccupied habitat (Fig. 1). Although included in the Canarian Network of Natural Protected Areas, many of these coastal sectors have become unsuitable for nesting due to human disturbances, such as the presence of boats or of people practising sport fishing, diving, camping, kayaking, rappelling or trekking (Fernández-Palacios *et al.* 2004, Siverio & Rodríguez 2005). It is well known that human activity close to breeding areas can negatively affect Osprey demography by reducing breeding success or producing behavioural anomalies (Van Daele & Van Daele 1982, Palma 2001, Thibault *et al.* 2001, Siverio & Rodríguez 2005). The increase of human density in the Canaries has also enhanced other direct anthropogenic threats for the Osprey and other raptor species, such as shooting or collisions with infrastructures (Triay & Siverio 2008, Rodríguez *et al.* 2010).

Direct protection and human guarding of nests have contributed to recovery of the Corsican and Balearic Osprey populations (Triay 1994, Thibault *et al.* 2001). Thus, we suggest avoiding disturbance at breeding eyries and surrounding areas through establishment of buffer zones of reduced human activity (Richardson & Miller 1997). According to our predictive models, nest protection should be targeted to coastal cliffs more than 50 m high and orientated to the south or southwest, even on islands that currently do not hold breeding pairs (e.g. La

Palma or Gran Canaria), because this could lead to the settlement of new pairs in the future. In addition, continued monitoring of the whole Canarian population, complemented by estimation of non-natural mortality and foraging requirements, is urgently needed to develop more efficient conservation measures for this fragile population.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table S1. Number of Osprey *Pandion haliaetus* nests per island or islet of the Canary Islands. Total includes recently active plus historical nests.

Table S2. Variables used for description of nests and breeding cliffs of the Ospreys in the Canary Islands.

Figure S1. Histograms of predicted probabilities of Osprey occupation of all potentially available cliffs in the Canary Islands (i.e. cliffs > 50 m height and separated at least 1 km from each other) and of the 69 cliffs used for model-building.