Diversity **2015**, *7*, 60-73; doi:10.3390/d7010060

OPEN ACCESS
diversity
ISSN 1424-2818
www.mdpi.com/journal/diversity

Article

The Impact of Nesting Socotra Cormorants on Soil Chemistry and Vegetation in a Large Colony in the United Arab Emirates

Taoufik Saleh Ksiksi [1,*], Sabir Bin Muzaffar [1], Robert Gubiani [1] and Rashid Mohamed Alshihi [2]

[1] Department of Biology, UAE University, Al-Ain, UAE; E-Mails: s_muzaffar@uaeu.ac.ae (S.B.M.); robgubiani@gmail.com (R.G.)

[2] Ministry of Environment and Water, Umm Al Quwain, UAE; E-Mail: rmalshihi@moew.gov.ae

* Author to whom correspondence should be addressed; E-Mail: tksiksi@uaeu.ac.ae; Tel.: +971-3-7136548.

Academic Editor: Michael Wink

Received: 31 December 2014 / Accepted: 4 February 2015 / Published: 6 March 2015

Abstract: Socotra Cormorants (*Phalacrocorax nigrogularis*) are regionally endemic seabirds with restricted distribution. To better understand their nest selection, we assessed vegetation and soil elements in their nesting areas at Siniya Island of United Arab Emirates. Field sampling was done from three areas (2011 nesting area, 2012 nesting area and control area) in February and March in 2013. Sampling consisted of vegetation assessment in the field and close-range photography. Ground cover within quadrats was classified into the percent of (1) living cover, (2) dead cover, (3) droppings, (4) bare ground and (5) other. Soil samples were analyzed for thirteen elements. Multivariate stepwise discriminant analysis was performed to determine the importance of the attributes on nest sites. The contribution of Function 1 to the discriminant model was estimated to be 77.4%, whereas Function 2 contributed 22.6% to the discriminant model ($P \leq 0.05$). Sites could not be classified adequately using ground cover alone; however, discriminant analysis using soil attributes could better distinguish sites. We noted that Fe and Mn had high discriminant ability in Function 1, whereas Al and Cr showed high discriminant roles for Function 2. The contribution of Function 1 to the model, using soil attributes, was estimated to be 90.7% ($P \leq 0.05$). The combination of ground cover and soil attributes did not improve discrimination of nest sites. Furthermore, some soil variables (Ca, Na, Cd and Cr) were much higher than normal levels in soil, indicating high transport of marine nutrients to nesting sites, which could detrimentally affect surrounding vegetation.

Keywords: habitat selection; Socotra; seabirds; trophic ecology; nutrient deposition; ecosystem health

1. Introduction

Seabirds transport substantial quantities of nutrients from marine to terrestrial ecosystems through their seasonal breeding activities [1–3]. The impact of this transport is highly variable, ranging from positive (enriched soil, improved vegetation), neutral (soil nutrients are enhanced, but not available to vegetation), to negative (soil nutrients are highly concentrated leading to vegetation loss or reduction in habitat quality) [1,4,5]. Since habitat characteristics are important determinants of nest site selection and ultimately breeding success [2,4,6], understanding long-term effects of allochthonous nutrient transport into seabird breeding islands is an important step towards understanding seabird biology. Additionally, since the breeding habitats of many seabirds are currently threatened by human activities, better understanding habitat characteristics of seabird breeding colonies constitutes an important first step toward conservation [2,6]. Complex interactions among species in ecosystems and how these interactions are shaped by abiotic conditions have largely remained unstudied [2,4,7].

Seabirds in breeding colonies introduce nutrients through the deposition of guano, feathers, eggs shells and carcasses [3]. Although these deposits vary with species, generally, introduction of nutrients increase with nesting density and size of the species concerned [2,3]. Additionally, nest type and habitat structure (rock crevasses, surface, burrow) may also strongly influence nutrient input and usage by vegetation [3]. Overall quantities of nutrient may be lower for small petrels (Hydrobatidae) whereas larger seabirds such as cormorants (Phalacrocoracidae) deposit substantial amount of nutrients into the nesting habitat. Ellis and colleagues [2] showed that Great Black-backed Gulls (*Larus marinus*) that nest in low densities added smaller quantities of ammonia and nitrates compared with densely nesting Double-crested Cormorants (Phalacrocorax auritus). Although large quantities of ammonia and nitrates may be readily added to soils, they may also be lost easily through leaching or volatilization [4,8,9]. On the other hand, phosphates have a tendency to remain in soil for extended periods [8] and may be reflective of the long-term history of a seabird colony [4,10]. In addition to major plant-limiting nutrients, trace elements of various kinds may be greatly altered by seabirds and sodium (Na), Potassium (K), Calcium (Ca), Iron (Fe) and Manganese (Mn) can be significantly different from areas that are not used by seabirds [11]. These differences are often reflected in the vegetation cover, with some species significantly altering vegetation composition [3,5,11,12]. Moreover, nutrient input may alter soil seed banks resulting in long-term change in the species composition of plants in these habitats [2,13].

The Socotra Cormorant is a species that has attracted limited scientific investigation [14,15]. Socotra Cormorants are endemic to the Arabian Gulf and Gulf of Oman regions [16]. Known populations worldwide are retracting [16], with 34% of the global total population occurring within the United Arab Emirates. Current population estimates suggest that the global total is 110,000 breeding pairs and most sub-populations are undergoing declines as a result of oil exploitation, fishing line entrapment and disturbance [14,16,17]. Socotra Cormorants are ground nesters that may nest on both vegetated areas [14] and bare ground [16], and nest location is an important determinant of breeding success in the species [14,18]. Since cormorants in general may have large effects with respect to nutrient input and habitat disturbance [2], they may significantly alter both the biotic and the abiotic conditions of their nesting habitat. Unfortunately, little is known about the requirements in nest site selection for Socotra Cormorants [14,18]. Additionally, precise knowledge about the influence of cormorants on soil nutrient cycling is limited [19] and it is possible that their nesting activities gradually lead to a loss or alteration of vegetation through altered nutrient cycling, as seen in some cormorant species [2]. Thus, better knowledge of habitat characteristics, nest site selection and the influence of allochthonous nutrient input is necessary for the conservation of the species.

To this end, we modeled soil elements and vegetation variables in relation to nest areas using discriminant analysis to determine which factors best discriminate nesting areas for Socotra Cormorants in Siniya Island, Umm al-Quwain, United Arab Emirates. We hypothesized that (1) Socotra Cormorants are indifferent to the edaphic and vegetation features of their nesting areas, (2) vegetation characteristics are more important in nest site selection, and (3) environmental conditions are not important in nest site selection.

2. Experimental Section

2.1. Study Area

The Siniya Island (N25°36'–E55°36') hosts the largest breeding population of Socotra Cormorants in the United Arab Emirates [14]. A detailed description of the island could be found in the article published in 2012 by Muzaffar and colleagues [14]. Briefly, Siniya Island is about 12 km long and about 3.5 km wide at its widest point. It consists of sandy and course gravel substrate with scattered *Haloxylon*/*Arthrocnemum* scrub complex. Trees planted in the 1980s occur in the southwestern part of the island. Natural mangrove trees (*Avicennia marina*) occur along selected areas of Siniya Island. Mudflats occur along the southeastern shoreline of the island, with several lagoons with seagrass beds on the northern shoreline of the island. Socotra Cormorants nest between August and March on bare ground in between areas with scrub vegetation [14]. Native Red Foxes (*Vulpes vulpes*) and feral cats (*Felis catus*) are present on the island and serve as the major predators of breeding Socotra Cormorants.

We were allowed to conduct the study in Siniya Island, as it was part of the funding proposal that the study was requested to be done at the island by the UAE Ministry of Environment and Water. The field studies conducted in this work involved working on the breeding habitat of Socotra Cormorants after the end of breeding activities when birds were no longer present on the island. Permission to work on Siniya Island was provided by the UAE Ministry of Environment and Water.

2.2. Approach

Field sampling procedure involved using four 100-meter transects at the center of each study site. Three sites were identified: 2011 nesting area (where birds nested during 2011), 2012 nesting area (where birds nested during 2012) and a third control area (where there was no nesting in either 2011 or 2012). The latter site was selected through a satellite photo classification process. Each transect was sampled every 10 meters, with a total of 41 sampling points (10 sampling locations within each transect plus one central quadrat) for each site. It is important to note that all sampling was conducted when birds had completed breeding activities and were no longer present on the island.

2.3. Procedure

Field sampling was done on the three different nesting sites during February and March 2013. Sampling consisted of vegetation assessment within a 1-meter quadrat. Field vegetation assessment consisted of cover by species and percent bare ground. Close range photography was also used, taking a picture of each plot from breast height of about 1.5 meters above ground using a Canon Power Shot camera with a 5-megapixel resolution. Images were within the center of the sampled area. Images taken at close range were pixel-analyzed using Multispec [20]. A supervised classification approach was used for each image. Five different classes were identified: Bare ground, Droppings, Dead cover, Living cover and Other. A summary table was developed for each image with percent pixel distribution within each of the five classes identified.

Soil elemental analyses were performed at the Geology Department (UAE University) using Inductively Coupled Plasma Atomic Emission Spectroscopy. The method used was similar to that reported by Bettinelli and colleagues [21]. Thirteen elements were assessed for each soil sample, including Al, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, P and V.

2.4. Statistical Analyses

A discriminant analysis using SPSS [22] was performed. The stepwise multivariate discriminant analysis was performed to assess the significance of contributions from each parameter measured for the three nesting sites (*i.e.*, Control, 2011 site and 2012 site).

Three separate discriminant analyses were performed. First, the analysis included all vegetation-related variables. This included the field assessment of ground cover (referred to as cover, throughout the document) in addition to the five attributes estimated through the image classification (*i.e.*, Bare ground, Droppings, Dead cover, Living cover and Other). All soil elements were then assessed and lastly we performed the same analysis for all the variables together (vegetation and soil related). The aim of this last approach was to see if the model could be improved through a combination of variables from both soil and vegetation components.

ANOVA analyses were also performed for each significant vegetation and soil variable, using SPSS [22]. The aim was to provide an indication on how each variable varies between the three different nesting sites. Significance levels for pairwise comparisons will be indicated where appropriate.

3. Results

3.1. Vegetation Attributes to Discriminate Nesting Areas

The significant vegetation attributes to discriminate between Socotra Cormorants nests were percent "droppings" and "other" ($P \leq 0.001$). The remaining variables (*i.e.*, percent cover, bare ground, dead cover and living cover) were removed as their addition did not improve the significance of the model to discriminate between the three nesting sites. Wilk's lambda was highly significant for both variables in the model ($P \leq 0.001$). The pairwise group comparisons revealed highly significant differences for both discriminant steps (Table 1).

Table 1. Significance levels of the pairwise group comparisons between the three sites (2011 Nest, 2012 Nest and Control Site) used by Socotra Cormorants in the UAE for both discriminant steps: step 1 (percent droppings included) and step 2 (percent droppings and other).

Steps	Variables	2011 *vs.* 2012	2011 *vs.* Control	2012 *vs.* Control
1	Percent Droppings	0.09	0.001	0.004
2	Percent Droppings and Other	0.001	0.001	0.008

The classification function coefficients are as follows:

- 2011 Nesting Area: 0.070 % $\times$ Droppings + 1.040 $\times$ Other $-$ 4.676
- 2012 Nesting Area: 0.054 % $\times$ Droppings + 1.57 $\times$ Other $-$ 5.668
- Control Area: 0.032 % $\times$ Droppings + 1.388 $\times$ Other $-$ 4.084

The contribution of Function 1 to the model was estimated to be 77.4%, while Function 2 contributed 22.6% to the discriminant model ($P \leq 0.05$). The standardized canonical discriminant function coefficients were 0.88 and 0.49 for percent droppings and -0.57 and 0.83 for percent other, relative to functions 1 and 2; respectively.

Figure 1 visually summarizes the contributions of Functions 1 and 2 to the model. Function 1 was slightly better in differentiating between the three nesting areas. The majority of the 2011 nesting area data is concentrated in the positive side of Function 1. From the perspective of Function 2, the segregation was not adequately clear. This supports the higher contribution of Function 1 to the model when compared with Function 2 (77.4% *vs.* 22.6%).

The classification results from discriminant analysis revealed that for the 2011 nesting area, 73.2% of the samples were correctly classified while the remaining 12.2% and 14.6% were classified as 2012 nesting area and control area; respectively (Table 2). For the 2012 nesting area, the discriminant model properly classified only 14.6% of the sampling points. The rest were incorrectly classified as 2011 nesting area (46.3%) and as control area (39%; Table 2). For the control samples, the model was successful in classifying 56%. The model was incorrect in classifying 22% for each as 2011 nesting area and as 2012 nesting area. Overall, the model was successful in classifying 48% of the original grouped cases.

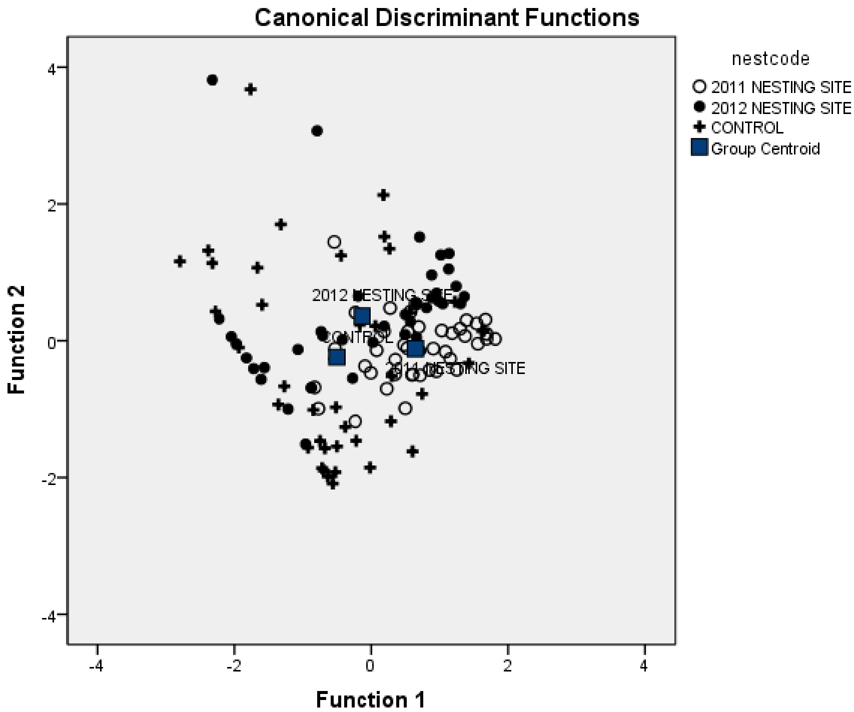

Figure 1. Canonical discriminant functions and their success in separating the three nesting sites (2011 nest, 2012 nest and control) for the significant vegetation variables used by Socotra Cormorants in the UAE.

Table 2. Classification results of the discriminant model for the three sites (2011 Nest, 2012 Nest and Control Site) used by Socotra Cormorants in the UAE.

Sampled Sites	2011 Nesting Site	2012 Nesting Site	Control Site
2011 Nesting Site	73.2	12.2	14.6
2012 Nesting Site	46.3	14.6	39.0
Control Site	22.0	22.0	56.0

3.2. Soil Attributes to Discriminate Nesting Areas

The significant soil attributes that discriminated between nests were Al, Mg, Mn, Cu, P, Ca, Na, Cr, V and Fe. The stepwise methods used in this discriminant analysis assessed these variables using 10 steps, adding one variable at each step ($P \leq 0.001$). The remaining variables (*i.e.*, Cd, Co and K) were removed as their addition did not improve the significance of the model to discriminate between the three nesting areas. Wilk's lambda was highly significant for all ten variables in the model ($P \leq 0.001$). The pairwise group comparisons revealed highly significant differences for all discriminant steps.

Standardized Canonical Discriminant Function Coefficients shown in Table 3. Coefficients with large absolute values correspond to variables with greater discriminating ability. Fe and Mn had high discriminant ability in Function 1; while Al and Cr show high discriminant ability for Function 2. The specific coefficients for each variable, relative to each site, are summarized in Table 4. Ca, Mg, Na and P were not included as the coefficients were very negligible.

Table 3. Standardized Canonical Discriminant Function Coefficients for all ten soil elements used to assess the three sites (2011 Nest, 2012 Nest and Control Site) used by Socotra Cormorants in the UAE.

Soil Elements	Function 1	Function 2
Al (ppm)	1.115	1.066
Ca (ppm)	0.688	0.108
Cr (ppm)	−0.861	1.084
Cu (ppm)	0.494	−0.689
Fe (ppm)	1.906	−0.248
Mg (ppm)	−1.157	0.532
Mn (ppm)	−1.723	−0.852
Na (ppm)	0.475	0.129
P (ppm)	0.058	0.470
V (ppm)	−0.103	−0.596

Table 4. Classification Function Coefficients (using Fisher's linear function) for the Discriminant analysis for all significant soil elements used to assess the three sites (2011 Nest, 2012 Nest and control Site) used by Socotra Cormorants in the UAE.

Soil Elements	2011 Nesting Site	2012 Nesting Site	Control Site
Al (ppm)	0.039	0.022	0.013
Cr (ppm)	−0.048	0.077	0.037
Cu (ppm)	1.903	−0.937	0.060
Fe (ppm)	0.017	−0.012	−0.013
Mn (ppm)	−0.709	−0.110	0.072
V (ppm)	−0.193	−0.291	0.618
(Constant)	−76.434	−52.684	−44.764

The contribution of Function 1 to the model was estimated to be 90.7%, while Function 2 contributed a mere 9.3% to the discriminant analysis ($P \leq 0.05$).

The contributions of Functions 1 and 2 to the model are represented in Figure 2. Function 1 was highly effective in differentiating between the 2011 nesting area on one hand and the 2012 and control areas on the other. All of the 2011 nesting area data points are to the far left of Function 1 axis. From the perspective of Function 2, however, the story is not clear. The differentiation between the 2012 nesting area and the control area could not be detected as most of the former data points are aggregated toward the positive side of the Function 2 axis.

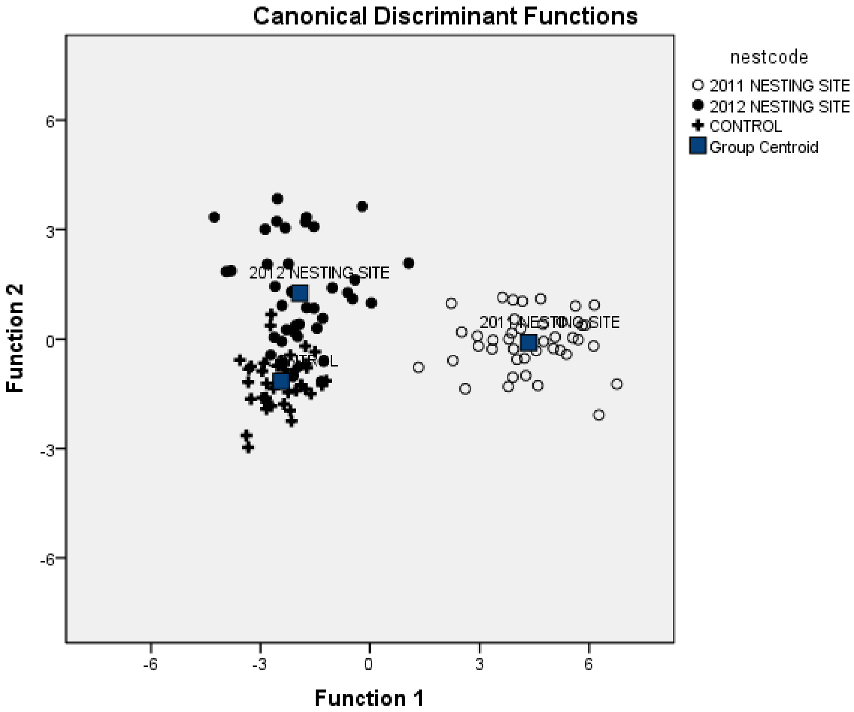

Figure 2. Canonical discriminant functions and their success in separating the three nesting sites (2011 nest, 2012 nest and control) for the significant soil variables used by Socotra Cormorants in the UAE.

The classification results from discriminant analysis revealed that for the 2011 nest area, 100% of the samples were correctly classified (Table 5). For the 2012 nest, the discriminant model properly classified 80.5% of the sampling points. The rest were incorrectly classified as control (19.5%). For the control samples, the model has been successful in classifying 95.1%. The model was incorrect in classifying 4.9% as 2012 nest. Overall, the model was successful in classifying 91.9% of the original grouped cases.

Table 5. Classification results of the discriminant model for the three sites (2011 Nest, 2012 Nest and Control Site) used by Socotra Cormorants in the UAE.

Sampled Sites	2011 Nesting Site	2012 Nesting Site	Control Site
2011 Nesting Site	100	0	0
2012 Nesting Site	0	80.5	19.5
Control Site	0	4.9	95.1

3.3. Combining Vegetation and Soil Attributes to Discriminate Nest Areas

Overall, the attributes that were important in classifying nest areas are summarized in Table 6. Percent dead cover and the elements Al, Mg, Mn, Cu, P, Ca, Na, Cr and V were included in the model. Wilk's lambda was highly significant for all ten variables in the model ($P \leq 0.001$). Moreover, the pairwise group comparisons revealed highly significant differences for all discriminant steps ($P \leq 0.001$).

The Standardized Canonical Discriminant Function Coefficients are shown in Table 6. Al and Mn have high discriminant ability in Function 1; while Cr and Al showed high discriminant roles for Function 2.

Table 6. Standardized Canonical Discriminant Function Coefficients for significant soil and vegetation variables used to assess the three sites (2011 Nest, 2012 Nest and control Site) used by Socotra Cormorants in the UAE.

Soil Elements	Function 1	Function 2
Al (ppm)	2.402	.809
Ca (ppm)	0.636	0.040
Cr (ppm)	−0.101	1.003
Cu (ppm)	0.621	−0.796
Mg (ppm)	−1.116	0.645
Mn (ppm)	−1.454	−0.834
Na (ppm)	0.514	0.088
P (ppm)	0.025	0.437
V (ppm)	−0.057	−0.551
Dead cover %	−0.234	−0.276

The contribution of Function 1 to the model was estimated to be 89.8%, while Function 2 contributed a mere 10.2% to the discriminant analysis ($P \leq 0.05$).

The contributions of Functions 1 and 2 to the model are represented in Figure 2, which are very similar to the extent of discrimination discussed above, using soil variables only. Function 1 was very effective in differentiating between the 2011 nest site versus the 2012 and control areas. All of the 2011 nesting area data points are to the far left of Function 1 axis. Function 2, however, poorly differentiated between the 2012 nesting area and the control area.

The classification results from discriminant analysis revealed values identical to the soils variables alone. This highlights the necessity for using soil variables to only discriminate between nesting sites for Socotra Cormorants.

3.4. Importance of Vegetation and Soil Attributes

For percent droppings, the 2011 and 2012 nests had a higher average than control site at $P \leq 0.05$ (59.2% and 48.8% *vs.* 30.7%). Percent dead cover was highest for the control site when compared with both 2011 area and 2012 area ($P \leq 0.01$). Percent living cover was also highest for the control area (6.5%) compared with 2011 nest area at $P \leq 0.05$. The 2012 nest area had a higher percent living cover than the 2011 area (5.6%) at $P = 0.05$.

Regarding the soils attributes, except for Cr, all other variables had significant differences at $P \leq 0.05$. Only significant pairwise comparisons are discussed hereafter. The 2011 nest site had the highest Al content and the control site had the lowest Al levels (2551.3 ppm, 1563.7 ppm and 1407.5 ppm; respectively) at $P \leq 0.05$. For Ca and Cd, the 2011 nesting area showed the highest average in comparison with the other two nest areas ($P \leq 0.05$). For the average K, the 2012 nesting site had a higher average than the 2011 nest area ($P \leq 0.05$) and the control area ($P \leq 0.01$). The control area had the lowest average Mg (*i.e.*, 6705.5 ppm) when compared with the other two areas ($P \leq 0.01$). The average Mn level was highest for the 2011 area (95.4 ppm) at $P \leq 0.01$. The 2012 nest area, however, had the highest average Na levels (6142.5 ppm) at $P \leq 0.01$, while the 2011 nest area and the control area had similar averages (2592.3 ppm and 2547.6 ppm; respectively) at $P \geq 0.05$. A similar pattern was observed in P for the 2012 area (7124.2 ppm), the 2011 nesting area (1035.0 ppm) and the control area (1794.8 ppm).

Functions 1 and 2 contributions to the model are shown in Figure 3. Function 1 was very effective in discriminating between the 2011 nesting area and the 2012 and control areas.

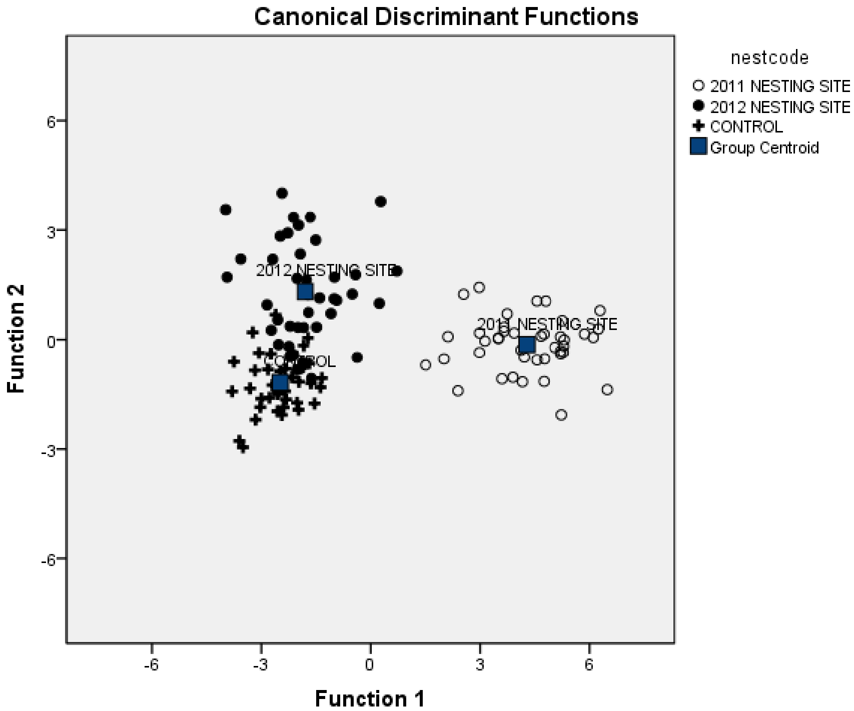

Figure 3. Canonical discriminant functions and their success in separating the 3 nesting sites (2011 nest, 2012 nest and control) for the significant vegetation and soil variables used by Socotra Cormorants in the UAE.

4. Discussion

Nest site fidelity in Socotra Cormorants has not been studied [16]. Although the documented colonies throughout its range are used repeatedly [16], it has also been observed that Socotra Cormorants may use completely different areas within the same colony in subsequent years [14,16]. For example, in 2011, Muzaffar and colleagues [14] reported nesting of Socotra Cormorants in areas with plantations on Siniya Island. This area had never been used in the past and was putatively being used by the birds in response to disturbance. In 2012, the Socotra Cormorants returned to nesting in areas on Siniya Island that had been historically used by the species for nesting [14]. In this study, we found that Socotra Cormorant nesting areas (2011 nest site, 2012 nest site, and control site) could be discriminated based on percent cover, droppings and other ($P \leq 0.001$). Furthermore, ten out of the thirteen elements in soil could be used either independently or in combination with cover variables to distinguish these nest sites and the control site. The control site also had greater overlap with the 2012 nest site, suggesting overall similarity between sites. Thus, vegetation and soil characteristics were collectively important in distinguishing areas selected for nesting. Notably limited amount of vegetation (percent cover ranged between 7.8% and 20% in all three sites) had strong discriminating ability whereas other attributes of vegetation did not show clear patterns (data not shown). This is consistent with breeding site selection in many seabird species [6]. Depending on species, percent cover tends to have positive and negative effects on nesting seabirds [6]. Kelp Gulls (*Larus dominicanus*) may preferentially select nesting areas with bare ground to allow them a clear view of approaching aerial predators [23]. In contrast, Common Terns (*Sterna hirundo*) may select areas with greater cover to allow protection from predators or weather [24]. In our study, the contribution of Function 1 to the model from the discriminant analysis was estimated to be 91.1%, while Function 2 contributed only 8.9% to the discriminant model ($P \leq 0.05$). Muzaffar and colleagues [14,18] reported higher egg volumes and hatching success under shaded areas, suggesting that plant cover benefited Socotra Cormorants on Siniya Island. Thus, our finding suggests that percent cover is an important discriminant of nest location and could indicate better microhabitat quality.

Microhabitat quality may be strongly influenced by the topography, nutrient input, wind action and nesting density in seabird colonies, along with the underlying geology of the area [3–6,11,25,26]. In this study, the elements Al, Mg, Mn, Cu, P, Ca, Na, Cr, V and Fe had strong loadings with Functions 1 and 2 and were significant in discriminating areas based on soil variables alone. Furthermore, Fe, K, Mg, P and Ca all occurred at much higher concentrations in all three areas compared with areas without seabirds. This suggested stronger input of these elements associated with breeding Socotra Cormorants. However, natural loading of certain cations and heavy metals may be high and variable in the soils of the UAE. For example, in the coastal areas of the UAE the first 10 m of soil in dominated by CaCO_3, along with high levels of Cr and Fe arising from naturally occurring mixed metal oxides of Fe and Cr [25,26]. Few studies have examined nutrients (including trace elements) in relation to seabird nesting activities [1,2,5,11]. Rajakaruna and colleagues [11] showed that enhanced Ca, Mg, Zn, and Pb in the soil resulting from seabird breeding activities could be traced in the leaves although patterns of uptake by *Xanthoria parietina* varied. Higher Ca concentration is expected since seabird guano typically has high Ca [3]. However, this variation could lead to altered species composition of plants although the extent of such variation is unclear from the current study. Phosphorus and nitrogen, important limiting factors for plants, were much higher in the 2012 nesting area compared with either the 2011 nesting area or the control sites. Phosphorous has longer residence time in soils [8,9,27]. Historical data extrapolated from nutrient content in sediment cores illustrate that P can be used as markers of long-term population change of seabirds. For example, abundance of P in soil has been attributed to changes in penguin population size over a 3000-year time frame [10]. It has been showed in [27] that contributions of phosphorus from guano from Westland Petrels (*Procellaria westlandica*) on mainland New Zealand had residence times ranging in 11–41 years for total P, which could be directly associated with nesting activities. Thus we suggest that significantly higher P in the 2012 nesting areas indicates that these areas have been in longer use by Socotra Cormorants compared with the 2011 areas. This is consistent with anecdotal information on the species nesting pattern on Siniya Island that suggests that the 2011 nesting areas were never used in the past (Ministry of Environment and Water, personal communication). We did not measure nitrogen but studies comparing desert islands in Gulf of California showed that islands used by seabirds had higher NO_3^-, NH_4^+ and total N derived from seabird guano [5]. Furthermore, these differences also resulted in lower diversity but higher productivity of vegetation on the islands used by nesting birds. We recognize that measurement of nitrogen could be key to further evaluating the impact of seabird guano on soil chemistry and vegetation of Siniya Island and we intend to include this in future work. Although Cd, Cr and K were removed from some of the analyses due to low influence on the overall models, the concentration of Cd and Cr was much higher than baseline levels [11]. This could indicate enhanced levels of Cd and Cr in the marine environment of the Arabian Gulf and their subsequent transport through the feces of cormorants into their terrestrial breeding habitat. Alyazouri and colleagues [26] conducted a study of soils ranging from coastal to inland areas of some of the northern Emirates. They found consistently high levels of Cr, Fe and other metals in all their study sites, with significantly higher values in areas near the Ajman Industrial Zone. This area is located close to the UAE coastline and is about 20 km from Siniya Island. Although both Cr and Fe occur naturally in high levels in UAE soils [25,26], these metals may be mobilized further near contaminated areas [26], which may then leach into the coastal marine environment. Ecological concern associated with increased mobilization of pollutants of human origin needs to be further studied in relation to seabird islands.

Physical disturbance by nesting activities is also a leading cause of breeding habitat degradation documented in many species of cormorants [3]. All published records of Socotra Cormorants suggest that they breed in open, non-vegetated or poorly vegetated areas [16]. Siniya Island seems to be the exception and they have been observed to nest in between scrub vegetation and under the shade of planted trees [14]. Although disturbance caused by breeding activities seems to be important in Socotra Cormorants, the extent to which physical disturbance contributes towards degradation of the habitat remains unclear.

In summary, overall allochthonous input of elements from the marine environment seems to be high in areas used by nesting Socotra Cormorants. Further studies are required to examine how these inputs translate into changes in vegetation cover, alteration or degradation of nesting areas and ultimately, reproductive success of breeding Socotra Cormorants. Future works will focus on examining nutrients, soil pH and other measures regarding impacts of disturbance to better understand linkages between nutrient input and their impact on habitat quality considering both flora and fauna.

Acknowledgments

The investigators would like to express their sincere appreciation to the United Arab Emirates Ministry of Environment and Water for the financial support of this project through a grant to Sabir Bin Muzaffar and Taoufik Saleh Ksiksi (Grant No. 21S056). The authors would also like to express their gratitude to the UAEU, the College of Science and the Biology Department for their support. Extended thanks are to all colleagues who helped and encouraged the research team during the execution of this project.

Author Contributions

Taoufik Saleh Ksiksi designed the trial and collected and analyzed the data and led the writing of the manuscript. Sabir Bin Muzaffar assisted in the trial design and interpreted the data and substantially contributed to the writing of the manuscript. Robert Gubiani collected the data and analyzed photos. Rashid Mohamed Alshihi collected the data and assisted in data management and commented on manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Ellis, J.C. Marine birds on land: A review of plant biomass, species richness, and community composition in seabird colonies. *Plant Ecol.* **2005**, *181*, 227–241.
2. Ellis, J.C.; Fariña, J.M.; Witman, J.D. Nutrient transfer from sea to land: The case of gulls and cormorants in the Gulf of Maine. *J. Anim. Ecol.* **2006**, *75*, 565–574.
3. Smith, J.; Mulder, C.; Ellis, J., Eds. Seabirds as ecosystem engineers: Nutrient inputs and physical disturbance. In *Seabird Islands: Ecology, Invasion and Restoration*; Oxford University Press: Oxford, UK, 2011; pp. 27–55.
4. Mulder, C.; Jones, H.; Kameda, K.; Palmborg, C.; Schmidt, S.; Ellis, J.; Orrock, J.; Wait, A.; Wardle, D.; Yang, L.; *et al.*, Eds. Impacts of seabirds on plant and soil properties. In *Seabird Islands: Ecology, Invasion and Restoration*; Oxford University Press: Oxford, UK, 2011.
5. Wait, D.; Aubrey, D.; Anderson, W. Seabird guano influences on desert islands: soil chemistry and herbaceous species richness and productivity. *J. Arid Environ.* **2005**, *60*, 681–695.
6. Schreiber, E.A.; Burger, J. *Biology of Marine Birds*; CRC Press: Boca Raton, FL, USA, 2002.
7. Steele, J.H. *The Structure of Marine Ecosystems*; Harvard University Press: Cambridge, MA, USA, 1974.
8. Sharpley, A.N.; Smith, S.; Bain, W. Nitrogen and phosphorus fate from long-term poultry litter applications to Oklahoma soils. *Soil Sci. Soc. Am. J.* **1993**, *57*, 1131–1137.
9. Blackall, T.D.; Wilson, L.J.; Theobald, M.R.; Milford, C.; Nemitz, E.; Bull, J.; Bacon, P.J.; Hamer, K.C.; Wanless, S.; Sutton, M.A. Ammonia emissions from seabird colonies. *Geophys. Res. Lett.* **2007**, *34*, doi:10.1029/2006GL028928.
10. Sun, L.; Xie, Z.; Zhao, J. Palaeoecology: A 3,000-year record of penguin populations. *Nature* **2000**, *407*, 858–858.
11. Rajakaruna, N.; Pope, N.; Perez-Orozco, J.; Harris, T.B. Ornithocoprophilous plants of Mount Desert Rock, a remote bird-nesting island in the Gulf of Maine, USA. *Rhodora* **2009**, *111*, 417–447.
12. Garcia, L.V.; Maranón, T.; Ojeda, F.; Clemente, L.; Redondo, R. Seagull influence on soil properties, chenopod shrub distribution, and leaf nutrient status in semi-arid Mediterranean islands. *Oikos* **2002**, *98*, 75–86.
13. Szpak, P.; Longstaffe, F.J.; Millaire, J.F.; White, C.D. Stable Isotope Biogeochemistry of Seabird Guano Fertilization: Results from Growth Chamber Studies with Maize (*Zea mays*). *PLoS One* **2012**, *7*, e33741.

14. Muzaffar, S.B.; Gubiani, R.; Benjamin, S. Reproductive Performance of the Socotra Cormorant Phalacrocorax nigrogularis on Siniya Island, United Arab Emirates: Planted Trees Increase Hatching Success. *Waterbirds* **2012**, *35*, 626–630.
15. Gubiani, R.; Benjamin, S.; Muzaffar, S.B. First Record of Cannibalism in Socotra Cormorants (*Phalacrocorax nigrogularis*): Large, Immature Birds Opportunistically Feed on Younger Conspecifics. *Waterbirds* **2012**, *35*, 338–341.
16. Jennings, M.C.; Krupp, F.; others. *Fauna of Arabia. Atlas of the Breeding Birds of Arabia*; King Abdulaziz City for Science and Technology: Ryadh, KSA, 2010; Volume 25.
17. Symens, P.; Kinzelbach, R.; Suhaibani, A.; Werner, M. A review of the status, distribution and conservation of the Socotra Cormorant, *Phalacrocorax nigrogularis*. *Zool. Middle East* **1993**, *8*, 17–30.
18. Muzaffar, S.B.; Gubiani, R.; Benjamin, S. Nest location influences hatching success in the Socotra Cormorant (*Phalacrocorax nigrogularis*) on Siniya Island, United Arab Emirates. *Wildl. Res.* **2014**, in press.
19. Breuning-Madsen, H.; Ehlers, C.B.; Borggaard, O.K. The impact of perennial cormorant colonies on soil phosphorus status. *Geoderma* **2008**, *148*, 51–54.
20. Landgrebe, D.; Biehl, L. *An introduction to MultiSpec*; School of Electrical Engineering, Purdue University: West Lafayette, IN, USA, 1994.
21. Bettinelli, M.; Beone, G.; Spezia, S.; Baffi, C. Determination of heavy metals in soils and sediments by microwave-assisted digestion and inductively coupled plasma optical emission spectrometry analysis. *Anal. Chim. Acta* **2000**, *424*, 289–296.
22. Arbuckle, J.L. *IBM SPSS ® Amos 19 User's Guide*; Amos Development Corporation: Crawfordville, FL, USA, 2010.
23. Burger, J.; Gochfeld, M. Colony and habitat selection of six Kelp Gull *Larus dominicanus* colonies in South Africa. *Ibis* **1981**, *123*, 298–310.
24. Storey, A.E.; Montevecchi, W.A.; Andrews, H.F.; Sims, N.; others. Constraints on nest site selection: A comparison of predator and flood avoidance in four species of marsh-nesting birds (genera: *Catoptrophorus*, *Larus*, *Rallus*, and *Sterna*). *J. Comp. Psychol. (Washington, DC: 1983)* **1988**, *102*, 14.
25. Willis, H.H.; MacDonald Gibson, J.; Shih, R.A.; Geschwind, S.; Olmstead, S.; Hu, J.; Curtright, A.E.; Cecchine, G.; Moore, M. Prioritizing environmental health risks in the UAE. *Risk Anal.* **2010**, *30*, 1842–1856.
26. Alyazouri, A.; Jewsbury, R.; Tayim, H.; Humphreys, P.; Al-Sayah, M.H. Applicability of heavy-metal phytoextraction in United Arab Emirates: an investigation of candidate species. *Soil Sediment Contamin.* **2014**, *23*, 557–570.
27. Hawke, D.J. Soil P in a forested seabird colony: Inventories, parent material contributions, and N:P stoichiometry. *Soil Res.* **2006**, *43*, 957–962.