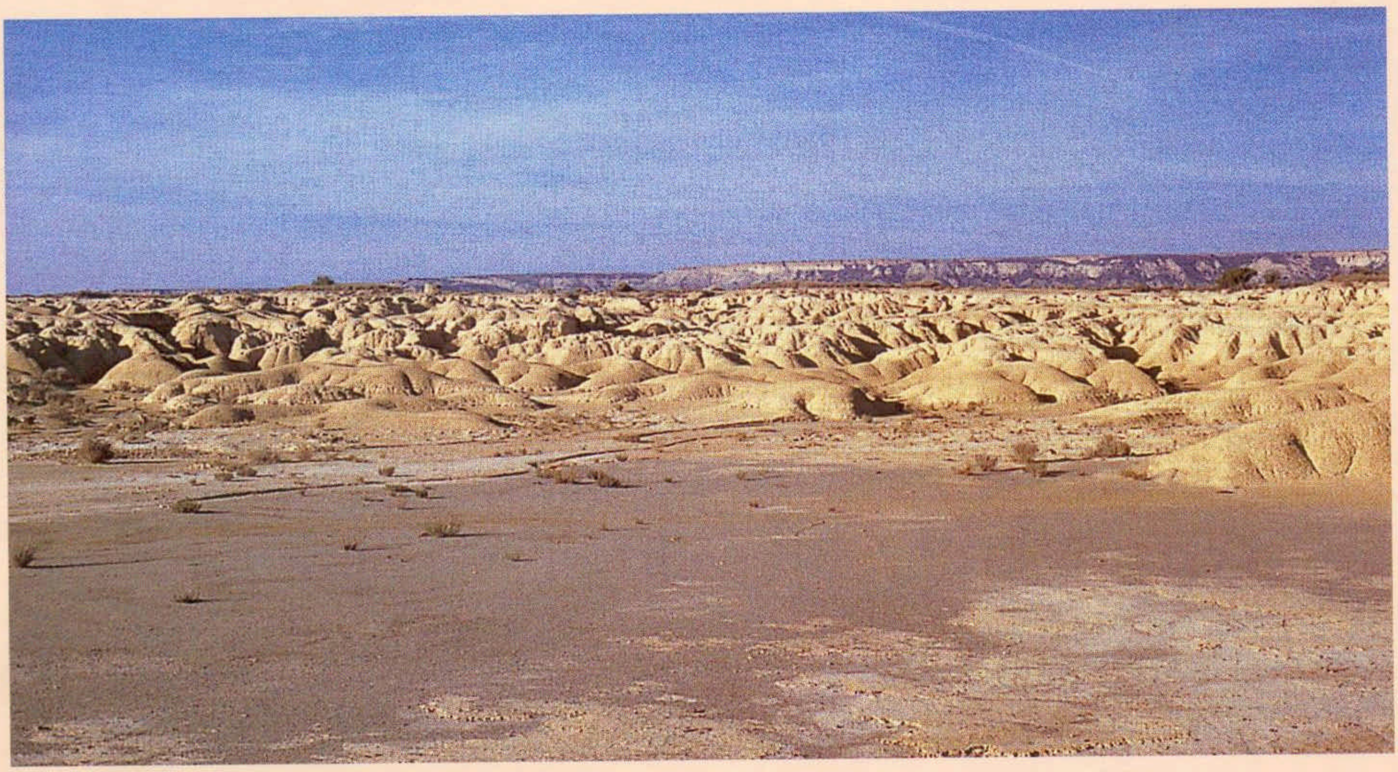
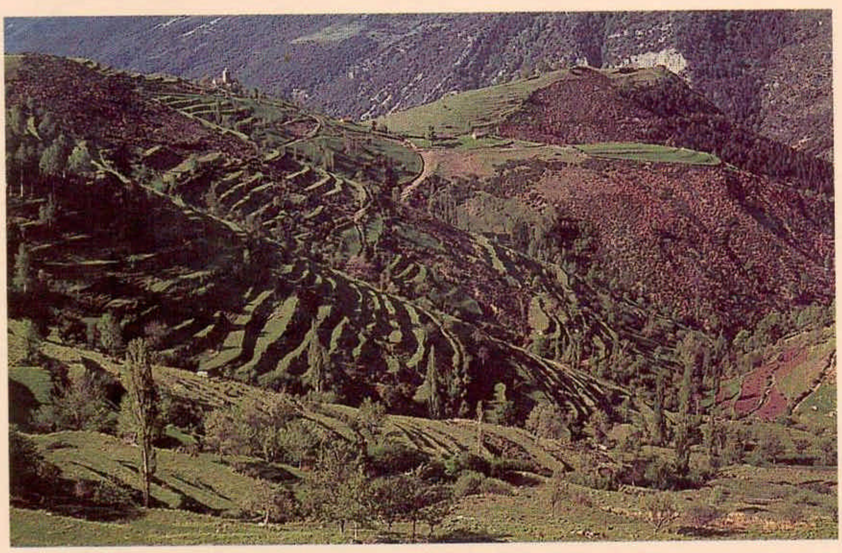
MAN AND SOIL AT THE THIRD MILLENNIUM

VOLUME I





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THIRD INTERNATIONAL CONGRESS OF THE
EUROPEAN SOCIETY FOR SOIL CONSERVATION

Proceedings of the third International Congress Man and Soil at the Third Millennium
J.L. Rubio, R.P.C. Morgan, S. Asins & V. Andreu, eds.
Geoforma Ediciones
Logroño, 2002

Animal influences on soil properties and plant cover in the Chafarinas Islands (NW Africa)

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ABSTRACT

Seagull and rabbit proliferation in the Chafarinas Islands (three small semiarid islets in NW Africa) has produced significant changes in physical and chemical properties of the soil, as well as in plant cover. Analysis of preliminary data has shown that soils in areas with a strong seabird influence were significantly higher in soluble salts (electrical conductivity), macronutrients (total N, nitrate, phosphorous, potassium and magnesium), and organic carbon, than soils located in areas with low seabird influence. Water and nutrient retention capacity (related to saturation percentage) and bioavailability of some heavy metal (Zn, Fe, Cd) were increased significantly in seabird-affected soils. No significant differences in other soil properties (such as soil texture or carbonate contents) were found between seabird-affected and -unaffected areas. On the other hand, percent of bare soil was significantly higher in seabird-affected areas, whereas shrub cover was significantly decreased in those areas. Rabbit grazing (but not seabird presence) strongly reduced above-ground biomass of herbaceous species and soil seed bank density. As long as high seabird density and rabbit pressure significantly reduce plant cover and/or biomass and increase percentage of bare soil, they are relevant factors in conservation strategies of semiarid protected areas. Management practices should be implemented to protect these arid, steep and shallow soils against water erosion.

Key Words: seabirds, rabbits, soil salinity, soil fertilization, bare soil, standing crop, soil erosion

INTRODUCTION

Seabirds tend to nest and rest on small islands where they transport great quantities of nutrients from sea to land, mainly in the form of droppings (guano), rich in nitrogen and phosphorus. Guano accumulation strongly affects chemical composition of soils – especially in arid and semiarid regions – and island vegetation, favouring nutrient-demander species (Gillham 1956, Sobey and Kenworthy 1979, Smith 1978, Vidal et al. 1998, Anderson and Polis 1999, Vidal et al. 2000). Significant physical alteration of soil and vegetation by seabird activities (trampling, sitting, digging and pulling-up) has also been reported (Gillham 1956, Sobey and Kenworthy 1979). Seabird activities, together with grazing by rabbits (a domestic animal frequently introduced in islands), can degrade plant cover and increase bare soil areas, favouring soil erosion, particularly in arid or semiarid areas (Gillham 1963, Hall et al. 1981, Hutchinson 1950, Sobey and Kenworthy 1979).

In this paper, we present preliminary results of soil composition in seabird-affected and -unaffected areas in the Chafarinas Islands, near the Moroccan coast. We analyze the relationships between seagull and rabbit activities with some parameters of plant communities –plant cover, standing crop, and soil seed bank density-. The combined effects of both animals (seagulls and rabbits) seem to affect strongly the plant cover and significantly increase the proportion of bare soil, and consequent soil erosion processes; such soil degradation has become more evident in the biggest (and steepest) island – Congreso.

METHODS

Study area

The Chafarinas islands are located at the western end of the Mediterranean Sea (35º 11' N, 2º 26' W), close (3.5 km) to the Moroccan coast (Fig. 1). They have a volcanic origin (andesite and basalt are dominant parent rocks) and are partly covered by an eroded calcareous crust. The steep slopes and the dry climate (about 250 mm mean annual rainfall) are responsible for a dominance of shallow (<50 cm) soils, and for the arid soil moisture regime (*Lithic Torriorthents* soils are dominant). Soils are poorly developed, have a sandy loam texture, a neutral-to-alkaline pH, and a slight-to-high salinity (Clemente et al. 1999). The vegetation is sparse, and dominated by the chenopod shrubs – *Salsola oppositifolia*, *Suaeda vera* and *Atriplex halimus* – mixed with the solanaceae *Lycium intricatum* (Marañón et al. 1999). More than 100 herbaceous species have been reported in the islands, most of them terophytes (Blanco 1988, Mateos et al. 1999). Iceplant (*Mesembryanthemum cristallinum)* is a widespread annual species in the islands, dominating in disturbed areas.

The Chafarinas Islands support one of the most important nesting colonies (about 4,000 pairs) of the rare Mediterranean seabird, Audouin's seagull (*Larus audouinii*). The breeding sites have been legally protected since 1982, to prevent the gathering of eggs and other human interference menacing the gull populations. The protection of the area has favoured the expansion of the very common yellow-legged seagull *(Larus cachinnans).*

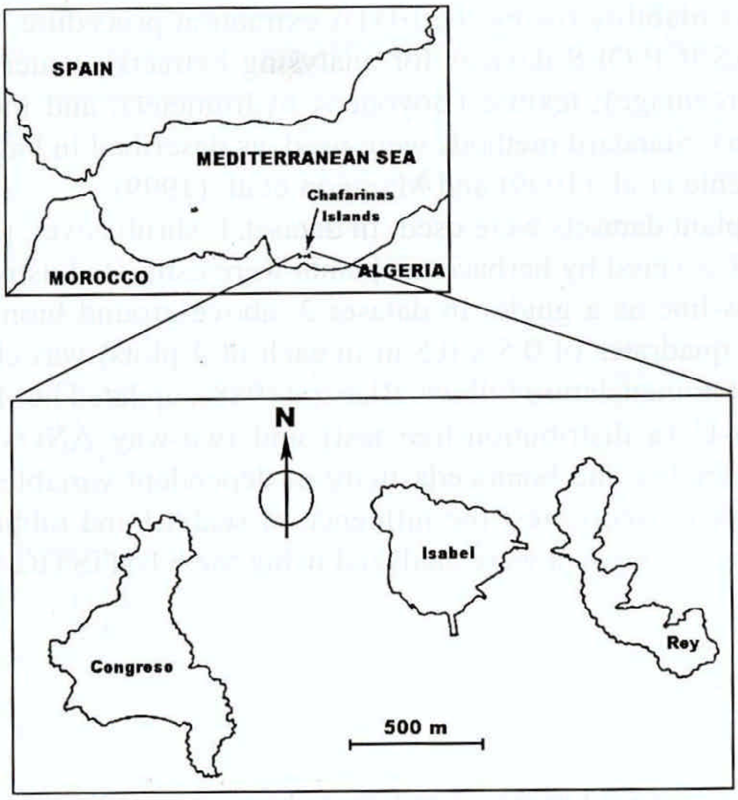

Fig. 1. Location of the Chafarinas Islands in NW Africa

The effects of such a high density of seabirds on soil chemical and physical properties have become significant. Furthermore, the proliferation of rabbits introduced into the biggest island (Congreso, 22.5 ha) has had considerable negative effects on herbaceous communities and shrub seedlings (Marañón et al. 1999).

Sampling

Sampling was carried out in October 1997-March 1998, in 88 plots of 10 m^2 (dataset 1) randomly distributed over the three islands. Additionally, a block-design random sampling was carried out in 4 plots (50 x 20 m), where 10 quadrates (0.5 x 0.5 m) were studied for soil and plant features (dataset 2). Factors were guano-fertilized versus non-fertilized sites, and two different islands with and without rabbit influence.

In each plot, the topsoil (upper 10 cm) was sampled and analyzed for the following parameters: pH (measured electrometrically, in 1:1 soil pastes); macronutrient content/availability (total N, using a Kjeldahl method; P availability, by Olsen's method; K, Ca and Mg, extracted with ammonium acetate – K and Ca were determined by flame photometry and Mg by Atomic Absorption Spectroscopy (AAS)); organic carbon (using a modified Walkley & Black method); electrical conductivity (EC, measured electrometrically in saturation extracts); nitrate (in saturation extracts, using a colorimetric method);

heavy metal bio-availability (using the EDTA extraction procedure described in Ure et al., 1993, and AAS/ICP-OES devices for analysing extracts); water retention capacity (SP, saturation percentage); texture (Boyoucos hydrometer); and inorganic carbonates (using a calcimeter). Standard methods were used, as described in Page et al. (1982) and specified in Clemente et al. (1999) and Marañón et al. (1999).

Two different plant datasets were used. In dataset 1, shrub cover, percent of bare soil, and percent of soil covered by herbaceous plants were estimated using intersection with a 4.5 x 4.5m cross-line as a guide. In dataset 2, above-ground biomass of herbaceous species (inside 10 quadrates of 0.5 x 0.5 m in each of 4 plots) was clipped, oven-dried, and weighed. Plant nomenclature follows Blanco (1988), updated in Mateos et al. (1999).

Mann-Whitney-U (a distribution-free test) and two-way ANOVA (after checking assumptions of normality and homocedasticity of dependent variable, and transforming when necessary) were used to test the influence of seabird and rabbit in measured soil and plant variables. All the data were analyzed using the STATISTICA package (Statsoft 1997).

RESULTS

Seabird activities induced highly significant changes in soil properties. Salinity level and macronutrient (total N, nitrate, phosphorous, potassium and magnesium) concentration were two- to five-fold higher in seagull-affected soils (Table 1). Water retention capacity (SP) and bio-availability of heavy metals (either essential – Fe and Zn – or potentially toxic – Cd) were also significantly higher in seagull-affected areas. On the other hand, no significant differences were found in soil texture, calcium availability, and carbonate contents (Table 1).

Seabird activities significantly increased the proportion of bare soil (40 %), reduced shrub cover (25 %), and changed shrub and herbaceous species composition (Table 2). *Suaeda vera* and *Lavatera mauritanica* had significantly higher abundance in 'fouled' sites, while *Salsola oppossitifolia* and *Pancratium foetidum* were significantly more frequent in areas with no (or low) seabird influence (Table 2).

Rabbit grazing seemed to reduce significantly above-ground biomass of herbaceous cover and seed density in the topsoil (Table 3). No interaction between the two factors (seagull and rabbit activities) was detected by two-way ANOVA.

DISCUSSION

Seabird activities increased macronutrient availability and organic matter in soils of the Chafarinas Islands, as found in other studies of seabird colonies (Gillham 1956, Sobey and Kenworthy 1979, Anderson and Polis 1999). Moreover, they also originated soil salinization (Marañón et al. 1999) and heavy metal accumulation (Otero 1998) which could cause toxicity in non-tolerant plants, although seagull-induced soil changes could

Table 1. Comparison of soil properties in seabird affected (n=80) and non- (or slightly) affected sites (n=48) in Chafarinas Islands. Differences were tested using Mann-Whitney U-test

		Seabird influence						
		High			Low			
		Mean	±	S.E.	Mean	±	S.E.	p-level
Soil fertility & salinity								
Total N	(%)	0.34	±	0.03	0.18	±	0.01	****
Available P	mg Kg^{-1}	281	±	20	96	±	6	****
Available K	mg Kg^{-1}	1059	±	59	785	±	37	***
Organic C	(%)	3.1	±	0.2	2.1	±	0.2	***
NO_3-	meq l^{-1}	61.4	±	13.2	15.0	±	2.7	****
EC_{se}	dS m^{-1}	15.6	±	2.4	3.5	±	0.6	**
Heavy metals	*(EDTA extracted)*							
Cd	mg Kg^{-1}	0.2	±	0.02	0.1	±	0.03	**
Fe	mg Kg^{-1}	59.5	±	7.6	32.0	±	4.0	*
Zn	mg Kg^{-1}	38.3	±	4.7	16.9	±	1.9	***
Water retention								
SP	(%)	50.1	±	1.9	41.3	±	1.0	***
Other soil properties								
Sand	(%)	50.4	±	1.9	52.6	±	2.1	n.s.
Clay	(%)	26.2	±	1.7	25.1	±	1.8	n.s.
Carbonates	(%)	9.0	±	0.9	7.2	±	1.0	n.s.

p-values: n.s.=non-significant, * p<0.05, ** p<0.01, **** p<0.0001.

Table 2. Plant cover, percent of bare soil, and abundance of some relevant shrub and herbaceous species of Chafarinas Islands in seabird affected and non- (or slightly) sites

		Seabird influence						
		High			Low			
		Mean	±	S.E.	Mean	±	S.E.	p-level
Plant cover								
Herbaceous cover	(%)	19.0	±	2.1	26.0	±	3.3	m.s.
Shrub cover	(%)	28.3	±	2.2	36.7	±	2.4	**
Bare soil	(%)	52.9	±	3.2	37.5	±	3.1	**
Abundant of selected species								
Lavatera mauritanica	(%)	1.1	±	0.4	0.0	±	0.0	*
Suaeda vera	(%)	15.7	±	2.1	9.4	±	2.6	*
Salsola oppositifolia	(%)	2.9	±	1.2	15.5	±	2.9	****
Pancratium foetidum	(%)	2.6	±	1.0	10.7	±	3.0	**

-values: n.s=non-signif., m.s.=marginally signif. (p<0.06), *p<0.05, **p<0.01, ****p<0.0001

Table 3. Seabird and rabbit effects in the above-ground biomass and in the seed density and species richness of soil seed banks (Dataset 2). Mean ± Std. Dev., F and p-values are showed

				ANOVA results (n=40)		
					F	*p-level*
Standing crop		Seabird	No seabird	Rabbit	18.64	0.0001
(g/0.25m^2, dry wt.)	Rabbit	35.2 ± 29.1	35.8 ± 18.8	Seabird	3.04	0.0900
No rabbit	115.7 ± 50.7	65.8 ± 31.3	Seab x Rab	1.60	0.2145	
Soil Seed Bank						
Seed Density		Seabird	No seabird	Rabbit	5.10	0.038
(#seed/50cm^2)	Rabbit	26.4 ± 14.60	26.8 ± 11.7	Seabird	0.05	0.821
No rabbit	138.4 ± 181.3	76.6 ± 50.9	Sea x Rab	0.16	0.694	

also counteract the shortage of essential micronutrient (Zn, Fe) availability typically of calcareous soils. Increased water and nutrient retention capacity in 'fouled' areas could enhance the fertilization effect in plant communities, and the significantly higher SAR in these areas (Marañón et al. 1999, would increase soil erodibility (Singer et al. 1982).

Vidal et al. (1998, 2000) have recently pointed out the significant impact of the superabundant yellow-legged seagull in soils and plant communities of the Marseille islands, concluding that their strong demographic explosion in the last few decades has caused the most drastic change in the environmental conditions of those Mediterranean islands.

Guano accumulation produces a (marginally significant) decrease of herbaceous cover and a highly significant decrease of shrub cover that is paralleled with a significant increase of bare areas (Table 2). It is well known that degradation of plant cover by animals increases bare soil areas and favours soil erosion, particularly in arid or semiarid areas with highly seasonal and intense rainfall (Hall et al. 1981).

In the Columbretes Islands (another group of West-Mediterranean islets), the effects of seabirds and rabbits on similar plant communities and soils have been documented by Laguna and Jiménez-Pérez (1995). Populations of rabbits (introduced in the middle of the XIXth century) have produced dramatic changes in plant cover and soil degradation (erosion rates over 300 Tm/ha/yr). Increased seabird populations have also had a noticeable effect on plant communities, favouring ruderal/halo-nitrophilous species and reducing the abundance of native taxa. Rabbit elimination (in 1987) produced a significant recover of plant cover/biomass of all species, while the effects of seabirds on plants originated some conflicts in the conservation policy of plant/soil versus seagull.

A similar, but more extreme, example of the animal-induced detrimental evolution of soil-plant cover in a xeric island environment have been described in Santa Barbara Island, California (Halvorson et al. 1988, D'Antonio et al. 1992). The introduction of rabbits (in the 1940s) was associated with serious damage to and reduction of the original plant cover. Those vegetation changes were, at the beginning, causes of a severe soil erosion process that ultimately produced sheet and gully erosion in the highly saline, fine-textured, steep soils of the area. Unfortunately, no specific studies of seagull (*Larus occi-*

dentalis) influence on soil and plant conditions were made, although damage to herbaceous vegetation was documented in the seagull nesting and roosting areas (D'Antonio et al. 1992, p. 40).

In the Chafarinas Islands, the effects of rabbits on plant communities seem to be specially deleterious: shrub seedlings have been almost completely eliminated (thus impeding regeneration of perennials, Marañón et al. 1999), soil seed banks exhausted, and herbaceous biomass and cover significantly reduced (Table 3). Therefore, we strongly recommend rabbit control measures on Congreso to maintain and restore plant cover and soil integrity.

As long as high seabird densities and strong rabbit pressure significantly reduce plant cover and increase the proportion of bare soil, management practices should be implemented to prevent erosion of the steep and shallow soils in the Chafarinas Islands.

ACKNOWLEDGEMENTS

We thank Georgina Álvarez for the organization support, Tomás Gómez, Manolo Igual, Jesús Charco, and Paco Robles for field assistance, José Mª Alegre for processing plant samples, Rafael López and the IRNAS Analysis Lab staff for chemical analyses, and J. Cara for his help with data and manuscript processing. The Spanish Ministry of Environment supported this research.

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Detected erratum: page 706 (Study site) is "about 325 mm" *instead* "about 250 mm"