FACTORS AFFECTING BREEDING DISTRIBUTION AND SEABIRD RICHNESS WITHIN THE AZORES ARCHIPELAGO

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De León, A., Mínguez, E. & Neves, V.R. 2005. Factors affecting breeding distribution and seabird richness within the Azores archipelago. Atlantic Seabirds 7(1): 15-22. *Seabird populations in the Azores archipelago are currently much smaller and more restricted in distribution than in the past. Important factors in this decline include predation by alien mammals, human exploitation, and habitat loss. We investigated the extent to which the presence of human and introduced predators, and some geographical features of the islands affect distribution and richness of seabirds breeding on this archipelago. Richness of seabird species (five* Procellariiformes*, one gull and two tern species) was higher on the main islands, which possess cliffs. As a result, shearwaters and gulls were more likely to be found on the larger islands that also tended to have rats and cats present. However, Madeiran Storm-petrel* Oceanodroma castro *and Bulwer's Petrel* Bulweria bulwerii *only breed in numbers on a very few rat-free islets. Continued management is needed to avoid human disturbance and alien invasion onto islets with small petrels. We recommend study of the effects of mammals on Little Shearwaters* Puffinus assimilis baroli *and Manx Shearwaters* P. puffinus *in the Azores, as the overlap between the distributions of these two species and rats is surprising.*

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INTRODUCTION

Historical chronicles from the 16th and 17th centuries indicate that the seabird populations of the Azores archipelago suffered remarkable declines following human colonisation of the islands, mainly due to introduction of predators, habitat destruction and direct human exploitation (Monteiro *et al.* 1996). The introduction of predators by itself has been the key factor in the reduction or extinction of more seabird populations in historic times around the world than any other factor (Moors & Atkinson 1984). In the Azores, where a large number of non-native animals have been introduced (Mathias *et al.* 1998), many colonies are now confined to precipitous cliffs and islets, as a result of predation

threats by introduced mammals (Monteiro *et al.* 1999). In the case of this archipelago, a factor that may have been crucial in this decline was direct human exploitation of seabirds (Monteiro *et al.* 1996), which still happens occasionally now despite increased legal protection of seabirds.

We investigated the influence of introduced predators, human presence, and geographical features of the islands on the distribution and richness of seabird species breeding on the Azores archipelago.

METHODS

The study included all nine of the main inhabited islands, and 19 of the 26 islets of the Azores archipelago (five in Flores, three in Terceira, three in Santa Maria, three in São Miguel, two in Graciosa, two in Pico and one in São Jorge). The Azores seabird assemblage comprises eight colonial nesting seabird species: five *Procellariiformes*, one gull and two terns. Our analysis included all the breeding seabirds: Madeiran Storm-petrel *Oceanodroma castro,* Bulwer's Petrel *Bulweria bulwerii,* Cory's Shearwater *Calonectris diomedea borealis,* Manx Shearwater *Puffinus puffinus,* Little Shearwater *P. assimilis baroli,* Yellow-legged Gull *Larus (cachinnans) atlantis,* Roseate Tern *Sterna dougallii*, and Common Tern *S. hirundo.* All these regular breeders, except the Yellow-legged Gull and the Common Tern, are Species of European Conservation Concern with a "Vulnerable" or "Endangered" Conservation Status (Tucker & Heath 1994). Breeding sites were considered as such only if breeding was confirmed. The introduced mammals studied were cats *Felis catus,* rats (Norway Rat *Rattus norvegicus* and Black Rat *R. rattus*), and mustelids (Weasel *Mustela nivalis* and Ferret *M. furo*). Information on the presence or absence of predator and prey species on the islands was extracted from the literature (Mathias *et al.* 1998; Monteiro *et al.* 1996, 1999; Meirinho *et al.* 2003), and interviews with local naturalists, researchers and nature wardens. To complement insufficient information on some islets, fieldwork to record presence or absence of mammals was carried out during August 2003, and consisted of sightings records, collection of excrement, and deployment of "rat sticks". This last technique has been shown to be effective in estimating relative rat abundance (Zonfrillo & Monaghan 1995). It involves the placing along transects of pieces of wood (15 cm x 2 cm), which have been soaked in liquid margarine or butter; the presence of rats is easily detected because they chew the sticks.

For each island, we also recorded the following geographical features that are likely to influence the presence of predator and/or seabird species: number of human inhabitants, the area, maximum altitude (since some seabirds are able to breed at high altitude in Atlantic islands), presence of cliffs, and distance to nearest inhabited island (islands with long distances to the nearest

island with human habitation may be less accessible for rats and other alien species associated with humans). All these variables (except the number of inhabitants) were extracted from large scale maps (1:25,000, Instituto Geográfico do Exército, 2002 edition). Number of inhabitants was obtained from the 2001 population census (http://www.ine.pt/). A binary variable named "islet", distinguished between the nine main islands and the 19 offshore islets.

Statistical analysis Relationships between seabirds, geographical features and presence of predators were modelled through generalized linear models (GLM, Crawley, 2002). Programs for model fitting were written in the statistical language S and implemented in R v. 2.0.1. For seabird richness, GLMs were fitted by specifying a Poisson distribution and a logarithmic link function. To explore a simple presence-absence model of each species, GLMs were fitted by specifying binomial distribution and logistic link. Univariate GLMs were first run to assess the importance of each explanatory variable. The main explanatory variable was then selected by an Akaike information criterion (AIC)-based stepwise procedure. This process allowed objective selection between highly correlated explanatory variables.

Table 1. Details of presence of all species on the nine main islands and the 19 islets studied in the Azores archipelago.

Tabel 1. Aanwezigheid van alle soorten op de negen hoofdeilanden en de 19 eilandjes die op de Azoren onderzocht zijn.

	Islands (n=9)		Islets (n=19)	
	Number	%	Number	%
Cory's Shearwater	9	100	17	89
Manx Shearwater	2	22	0	0
Little Shearwater	8	89	5	26
Madeiran Storm-petrel	1	11	5	26
Bulwer's Petrel	0	0	3	16
Yellow-legged Gull	9	100	8	42
Roseate Tern	7	78	9	47
Common Tern	9	100	12	63
Cat	9	100	1	5
Rat	9	100	4	21
Ferret	5	56	0	0
Weasel	3	33	0	0

*Table 2. Influence of the 10 island descriptors on seabird species composition determined by GLM; NS >0.05, *≤0.05, ** ≤0.01. Trend: '+' positive relationship, '−' negative relationship.*

*Tabel 2. Invloed van de tien eilandvariabelen op de soortensamenstelling, volgens GLM; NS >0.05, *≤0.05, ** ≤0.01. Trend: '+' = positief, '−' = negatief.*

Variable	% deviance explained	*P*	Trend
Cliffs	28.72	**	+
Islet	22.22	*	-
Distance^2	19.89	*	+ -
Area^2	18.45	*	+ -
Altitude	12.66	*	+
Inhabitants	0.01	NS	+
Inhabitants^2	20.63	NS	+ -
Distance	8.62	NS	+
Altitude^2	17.74	NS	+ -
Area	5.02	NS	+
Cats	12.61	NS	+
Rats	2.10	NS	+
Ferrets	7.13	NS	+
Weasel	1.30	NS	+

RESULTS

Cory's Shearwater was present on all the islands and all but two of the islets, while there were no more than two breeding colonies of Manx Shearwater in the archipelago (Table 1). Madeiran Storm-petrel was present only on six islets, breeding in significant numbers in three small rat-free islets (Vila, Baixo and Praia). Bulwer's Petrel certainly breeds on Vila, and probably also on Baixo and Praia (Table 1). Ferrets and Weasels were found only on some of the nine main islands, but all main islands had cats and rats (Table 1). Rats were especially widespread on main islands, and we also found evidence of the presence of rats in three of the islets (Ilhéus S. Lourenço, da Mina and Vila Franca). Additionally, we observed a cat prospecting at Rosto do Cão islet during low tide, and it is very likely that rats also reach that islet.

Presence of cliffs, type of island (main island or islet), distance to the nearest inhabited island, area and altitude appeared to affect seabird richness (Table 2). The influence of the presence of cliffs seemed relatively strong, as it explained up to 28.7% of the deviance in seabird richness (Table 2). Furthermore, the presence of cliffs was the variable with lower AIC value. Possible models containing the remaining explanatory variables were not adequate, since none of the remaining of the variables reduced the AIC.

Table 3. GLM models of seabird species and influence of the 10 island descriptors on Procellariiformes *species composition. P: NS >0.05, *≤0.05, ** ≤0.01, ***≤0.001. Trend: '+' positive relationship, '−' negative relationship.*

Tabel 3. GLM-modellen van zeevogelsoorten en invloed van de tien eiland-variabelen op Procellariiformes*-soortensamenstelling. P: NS >0.05, *≤0.05, ** ≤0.01, ***≤0.001. Trend: '+' = positief, '−' = negatief.*

Model	Variable	% deviance explained	*P*	Trend
Little Shearwater	Cliff	40.67	***	+
	Islet	27.13	**	-
	Altitude	23.10	*	+
Yellow-legged gull	Distance	50.63	*	+
	Cliff	30.31	**	+
Procellariiformes	Cliffs	23.17	*	+
	Islet	6.47	NS	-
	Area	0.38	NS	+
	Area2	5.39	NS	+ -
	Inhabitants	0.004	NS	+
	Inhabitants2	6.39	NS	+ -
	Distance	3.70	NS	+
	Distance2	11.13	NS	+ -
	Altitude	2.83	NS	+
	Altitude2	5.66	NS	+ -
	Gulls	18.57	NS	+
	Cats	1.87	NS	+
	Rats	0.02	NS	-
	Ferrets	0.72	NS	+
	Weasel	0.13	NS	-

Geographical features used in the models seemed to affect the overall seabird community but not each species' distribution; the distributions of only two species (Little Shearwater and Yellow-legged Gull) were explained by significant GLM univariate models (Table 3). Little Shearwater distribution seemed to be related to the presence of cliffs and Yellow-legged Gull colonies appeared to be relatively far from the main islands. The presence of cliffs appeared to affect the numbers of *Procellariformes*. However, the other geographic and anthropogenic features were poor predictors of procellariid distribution in the Azores Archipelago (Table 3).

DISCUSSION

The most distinctive features of the seabird assemblage in the Azores are the very large Cory's Shearwater populations, important tern populations, and the small populations of other *Procellariiformes*. Cory's Shearwaters breed in 26 of the 28 sites studied, including all nine main islands. Apart from Cory's and Little Shearwater, *Procellariiformes* breed only in a handful of islands and in relatively small numbers (at present), even though there are many islets apparently free of potential threats. This suggests that other important ecological constraints may exist that limit the distribution and abundance of small petrels in this archipelago. Intra- and inter-specific competition for nest sites is notable among burrowing *Procellariiformes*, and lack of optimal breeding habitat seems important in limiting their populations (Monteiro *et al.* 1996; Bolton *et al.* 2004). In addition, the Azores are the northern limit of the distribution of Bulwer's Petrel and Madeiran Storm-petrel, which might also explain their small populations and small number of colonies.

Seabirds with a widespread distribution in the Azores (Cory's Shearwater, Common Tern and Yellow-legged Gull) are able to breed on the main islands, apparently in coexistence with introduced predators. Furness *et al.* (2000) previously suggested that the strong negative impact of rats at some Cory's Shearwater colonies in the Mediterranean might not occur in the Azores. However, Little Shearwater and Manx Shearwater, species presumably more vulnerable to rats, are also present in islands containing mammalian predators. The latter have been found coexisting with rats and feral cats in some other North Atlantic colonies (Heaney *et al.* 2002). In the Azores, this might occur because of their habit of nesting along inaccessible sea cliffs (Monteiro *et al.* 1999), where they may suffer less severe predation. Nevertheless, we analysed only their presence and coexistence with introduced predators, which does not mean that birds are unaffected, as their breeding success might be severely reduced by predation (Thibault 1995). Indeed, the Manx Shearwater faces extinction in the Azores with an estimated population of just 100 pairs breeding in the islands of Flores and Corvo (Monteiro *et al.* 1999).

Geographical variables such as presence of cliffs, island area and altitude have proven to be very important for seabird diversity, being the key factors influencing species richness on these islands. Collinearity among these variables, however, probably precluded a multivariable GLM model. The distribution of Cory's Shearwater in the Azores archipelago has already been studied in detail by Furness *et al.* (2000), who concluded that the most important habitat for this species was inaccessible cliffs on the large islands. Most seabird colonies were located on large and high islands, and far from human

settlements. In the Azores, many colonies are now confined to precipitous cliffs, which form an important part of the archipelago's 790 km of coastline. Most of this coastline consists of inaccessible cliffs, although there are not many islets.

It was not possible to analyse the effects of alien predation on Madeiran Storm-petrel and Bulwer's Petrel distribution because of the small number of islets occupied by these species. Nevertheless, Madeiran Storm-petrel and Bulwer's Petrel breed in significant numbers only on a few small rat-free islets (Vila, Praia and Baixo), and their conservation on this archipelago is dependent on preventing rats from colonising those colonies. The elegant demonstration by Bolton *et al.* (2004) that Madeiran Storm-petrel numbers and breeding success on these islets can be considerably enhanced by provision of nest boxes, suggests that breeding habitat is limiting for this species. Installation of nest boxes has also proved to be an efficient conservation measure for related species (De León & Mínguez 2003). Local investigations of nest-site limitation would be very useful in order to determine conservation strategies. Eradication of rats from islets might also help to increase the amount of natural habitat for small petrel nesting in the Azores. Monitoring the continued absence of introduced predators at these islets is essential to prevent potentially large declines or extinction of these populations in Azores. Given that the small populations of Little and Manx Shearwater occur on islands in the Azores archipelago with rats and cats, a study of the impact of mammals on these shearwaters should be given high priority.

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FACTOREN DIE DE BROEDVOGELVERSPREIDING EN ZEEVOGELRIJKDOM OP DE AZOREN BEPALEN

In vergelijking met vroeger zijn zeevogelpopulaties op de Azoren tegenwoordig veel kleiner en kennen ze een beperktere verspreiding. Belangrijke factoren bij deze achteruitgang zijn ondermeer predatie door ingevoerde zoogdieren, exploitatie door mensen en verlies van habitat. Wij onderzochten in welke mate de aanwezigheid van mensen en geïntroduceerde predatoren, en enkele

geografische eigenschappen van de eilanden invloed hebben op de verspreiding van en de rijkdom aan broedende zeevogels. Soortenrijkdom (vijf *Procellariiformes*, een meeuw en twee soorten sterns) was hoger op de grote eilanden die kliffen hebben. Dientengevolge was de kans om pijlstormvogels en meeuwen te vinden groter op de grotere eilanden die er ook toe neigden dat er katten en ratten aanwezig waren. Grotere aantallen Madeira Stormvogeltje *Oceanodroma castro* en Bulwers Stormvogel *Bulweria bulwerii* broeden echter alleen op een klein aantal ratvrije eilandjes. Voortdurend beheer is noodzakelijk om verstoring door mensen en introductie van predatoren op eilandjes waar stormvogeltjes broeden, te voorkomen. Wij doen een aanbeveling om een studie te verrichten naar de effecten van zoogdiern op Kleine Pijlstormvogel *Puffinus assimilis baroli* en Noordse Pijlstormvogel *P. puffinus*, omdat de overlap in verspreiding van beide soorten en ratten verrassend is.

REFERENCES

Bolton M., Medeiros R., Hothersall B. & Campos A. 2004. The use of artificial breeding chambers as a conservation measure for cavity-nesting procellariiform seabirds: a case study of the Madeiran storm petrel (*Oceanodroma castro*). Biological Conservation 116: 73-80.

Crawley M.J. 2002. Statistical computing. An introduction to data analysis using S-Plus. Wiley, New York.

De León A. & Mínguez E. 2003. Occupancy rates and nesting success of European storm-petrels breeding inside artificial nest-boxes. Scientia Marina 67 (2): 109-112

Furness R.W., Hilton G. & Monteiro L.R. 2000. Influences of coastal habitat characteristics on the distribution of Cory's Shearwaters *Calonectris diomedea* in the Azores archipelago. Bird Study 47: 257-65.

Heaney V., Ratcliffe N., Brown A., Robinson P.J. & Lock L. 2002. The status and distribution of European Storm-petrel *Hydrobates pelagicus* and Manx Shearwaters *Puffinus puffinus* on the isles of Scilly. Atlantic Seabirds 4(1): 1-16.

Mathias M.L., Ramalhinho M.G., Santos-Reis M., Petrucci-Fonseca F., Libois R., Fons R., Ferraz de Carvalho G., Oom M.M. & Collares-Pereira M. 1998. Mammals from the Azores islands (Portugal): an updated overview. Mammalia 62 (3): 397-407.

Meirinho A., Pitta Groz M., Silva A.G. & Bolton M. 2003. Propostas de Planos de Gestão para Zonas de Protecção Especial dos Açores. Departamento de Oceanografia e Pescas da Universidade dos Açores, Horta.

Monteiro L.R., Ramos J.A. & Furness R.W. 1996. Past and present status and conservation of the seabirds breeding in the Azores archipelago. Biological Conservation 78: 319-28.

Monteiro L.R., Ramos J.A., Pereira J.C., Monteiro P.R., Feio R.S., Thompson D.R., Bearhop S., Furness R.W., Laranjo M., Hilton G., Neves V.C., Groz M.P. & Thompson K.R. 1999. Status and distribution of Fea's Petrel, Bulwer's Petrel, Manx Shearwater, Little Shearwater and Band-Rumped Storm petrel in the Azores Archipelago. Waterbirds 22(3): 358-366.

Moors P.J. & Atkinson I.A.E. 1984. Predation on seabirds by introduced animals, and factors affecting its severity. In: Croxall, J.P, P.G.H. Evans & R.W. Schreiber (eds) Status and Conservation of the World's Seabirds. pp 667-690. ICBP Technical Publication No. 2, Cambridge, UK.

Thibault J-C. 1995. Effect of predation by the black rat *Rattus rattus* on the breeding success of Cory's shearwater *Calonectris diomedea* in Corsica. Marine Ornithology 23: 1-10.

Tucker G.M. & Heath M.F. 1994. Birds in Europe. Their conservation status. BirdLife Conservation Series No. 3, Cambridge, UK.

Zonfrillo B. & Monaghan P. 1995. Rat eradication on Ailsa Craig. 5th International Seabird Group Conference, Glasgow.