

# Rat control and breeding performance in Cory's shearwater (*Calonectris diomedea*): effects of poisoning effort and habitat features

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## Abstract

Introduced predators are one of the main threats to island avifaunas. However, the magnitude of their impact in the Mediterranean has not often been studied. This is the case for the introduced alien black rats *Rattus rattus*, the most destructive predator of seabirds in the Mediterranean. Here, we analyse the impact of black rats on the breeding performance of Cory's shearwater *Calonectris diomedea* breeding at the Chafarinas Islands, an archipelago with a very high density of rats. An intensive rat control campaign (through anticoagulant poison) was carried out during 1999–2004 at two shearwater sub-colonies with contrasting habitat features (vegetated vs. rocky). Breeding success of Cory's shearwaters increased in proportion to the effort of rat control. Such increase was mainly due to a decline in black rat predation on chicks, while egg losses remained constant throughout the period. We found a differential effectiveness of rat control in each sub-colony. The increase in breeding success after rat control was higher in the sub-colony with lower breeding success (the vegetated habitat), but this parameter never reached the values shown by the other sub-colony (the rocky habitat). Our results suggest that habitat characteristics of each case of study must be taken into account when designing and evaluating specific rat control programs.

## Introduction

Human persecution and introduced alien predators are considered the greatest threats to slow-breeding and long-lived birds such as the petrels and shearwaters (Owens & Bennett, 2000). Island avifaunas are particularly vulnerable to predation by introduced species due to the absence of native mammalian bird-predators on most oceanic and oceanic-like archipelagos (Alcover, Sans & Palmer, 1998). Invasive human-assisted aliens have been the primary source for the extinction of bird species during the last five centuries and are the main threat to island birds at present, with predators affecting 95% of bird species (BirdLife International, 2004; Blackburn *et al.*, 2004). Among predators, the black rat *Rattus rattus* is the leading agent of bird extinction on islands, and is perhaps the world's commonest mammal (BirdLife International, 2004). Seabirds in particular are often social creatures that have evolved to breed on islands where terrestrial predators do not exist. Introduced black rats severely impact on seabirds, reducing their populations and in many cases triggering their extinction (Atkinson, 1985; Moors, Atkinson & Sherley, 1992; Martin, Thibault & Bretagnolle, 2000). Modern techniques such as stable isotope analyses (e.g. Hobson, Drever & Kaiser, 1999;

Stapp, 2002) have not only confirmed that rats do actually feed on seabirds, but have also suggested that the traditional studies of rat stomach contents were underestimating the importance of seabirds in the diet of rats.

Seabirds breeding on islands in the Mediterranean region have been affected by introduced black rats, and only a few species of seabirds have been able to coexist in their presence (Martin *et al.*, 2000). Black rat predation is a relatively recent phenomenon and an evolution in the sense to generate behaviours against terrestrial predators has not been possible. Nevertheless, it is not well known to what extent black rats affect seabird populations in this area. Cheylan (1985) suggested that seabirds are impacted only when rat density is very high and the main food supply (rats are primarily herbivorous) is low. On the other hand, Martin *et al.* (2000) and Thibault (1995) found that the impact was more severe on small than large islands. Rat numbers normally increase or decrease according to the amount of available food. In the Mediterranean, rats have been responsible for the disappearance of colonies of small-sized species such as the storm petrel *Hydrobates pelagicus* and pallid swift *Apus pallidus* and have lowered numbers of larger species such as Cory's shearwater *Calonectris diomedea*.

Similarly, as with other Procellariiformes, shearwaters are highly vulnerable due to their delayed maturity, low productivity (only one egg per year), long reproductive cycle and the lack of any effective anti-predator behaviour. Most nocturnal burrow-nesting species will leave their offspring unattended to forage when the chick is only a few days old (Warham, 1990). Rats are also active mainly during the dark. Although it is known that rat predation reduces the breeding success of Cory's shearwaters (Thibault, 1995), this reduction still remains to be quantified (other seabird species cf. Moors & Atkinson, 1984; Imber, Harrison & Harrison, 2000; Jouventin, Bried & Micol, 2003). Little is also quantified about which breeding stage of Cory's shearwaters (egg incubation and/or chick rearing) is most affected.

The Spanish Chafarinas Islands ( $35^{\circ}20'N$ ,  $2^{\circ}25'W$ ) are 4.5 km off the Mediterranean coast of Morocco. The archipelago consists of three islands (Congreso, Isabel II and Rey Francisco, 53 ha in total), there is no fresh water and vegetation cover is formed by dry scrubs (such as *Salsola*, *Lycium* and *Atriplex* spp.). Historically the three islands have been inhabited since 1848, but there has been human presence since Neolithic times (Bellver & Bravo, 2003). Actually, only Isabel II is currently inhabited, where at the present there are a military base and a biological station. Rat presence at Chafarinas Islands has been recorded at least since the end of the 19th century (Calderón, 1894), being present nowadays on all three islands. The breeding colony of Cory's shearwater (*c.* 800–1000 breeding pairs, see Igual & Gómez, 2000) is located on Congreso, the largest and most rugged island (24 ha, 137 m height above sea level) and the westernmost known colony of the species in the Mediterranean. Here, we analyse the impact of the black rat on Cory's shearwaters breeding on Congreso Island. Two facts suggest that rats have severely impacted this seabird colony: first, a high density of rats exist on this island requiring food (between 30 and  $>60$  rats  $ha^{-1}$ , Aranda *et al.*, 1997); and second, and probably resulting from the former, the breeding success of shearwaters here has been very low in relation to that reported for a number of Mediterranean island colonies (>60%, Gaultier, 1981; Fernandez, 1985; Zammit & Borg, 1987; Ristow *et al.*, 1990; Lopez-Jurado *et al.*, 1992; Sanchez & de Castilla, 1997) and as low as colonies in the absence of control campaigns (<20%, Thibault, 1995). Shearwaters stay in the colony from early February to late October. Individuals breed in two distinct substrates, prompting us to define *a priori* two sub-colonies: sub-colony 1 (SC1 hereafter, or vegetated habitat) located on the vegetated slopes of the island (9 ha), where the substrate allows shearwaters to burrow, and sub-colony 2 (SC2 hereafter, or rocky habitat) on steep rocky cliffs (3.5 ha) where vegetation is absent and shearwaters nest under rocks. Nest density was higher at SC2 (*c.* 80 nests  $ha^{-1}$ ) than at SC1 (about eight nests  $ha^{-1}$ ). Following these facts, an intensive rat control campaign was carried out during 1999–2004 in the two sub-colonies differentiated by habitat features (vegetated vs. rocky habitat). Our objectives were to compare the breeding performance of Cory's shearwaters during 1997–2004 at each sub-

colony before and after the launch of the rat campaign to assess the effects of annual variations in rat predation pressure and in turn to test the effectiveness of the control method.

## Materials and methods

### Breeding performance monitoring

From the end of May to the beginning of June of 1997–2004 (except in 1998) we examined all the accessible areas of the two sub-colonies to find active burrows when most breeders had already laid eggs. All adults found incubating were tagged and their burrows monitored again in late September and early October to record breeding success (as the percentage of successful fledglings relative to the number of nests where laying was confirmed). During 1999–2001 we also recorded the hatching success (as the percentage of hatched eggs relative to the number of laid eggs) for a sub-sample of nests. We considered the hatching success recorded in this sub-sample of nests to be representative of the total population monitored because breeding success calculated from the sub-sample did not differ from that of the whole monitored population in any of the 3 years ( $\chi^2$ -tests, all  $P>0.54$ ).

When breeding failed, the causes were classified as egg predation (egg shell remnants found inside or near the burrows) or chick predation (absence of chick together with soft shell, down and internal membrane remnants; empty nests with a hatchling recorded previously; or half-devoured chicks found outside the burrow). Although other fauna present on Congreso Island, such as gulls and rabbits, have been considered as potential threats for the breeding success of Procellariiformes (as predators and competitors for burrows respectively, see Zino *et al.*, 1987; Imber *et al.*, 2000; but see Fernandez, 1982), such interactions were rarely recorded in our study, and rats can be considered the principal predators of shearwaters.

### Rat control campaign

Prior to the rat control campaign, we performed a palatability test on the rats for different sorts of baits. These tests suggested the use of 16 g briquettes made with a mixture of cereals, wax and the anticoagulant 'Flocoumafen' (a second generation poison) (see details in Orueta *et al.*, 2005). Once the raw materials to be used were decided, the same methodology was applied during the whole study. Rat control campaigns were performed during the non-breeding season (from October, once the breeding season is finished, to March, prior to the start of the next breeding season). The first campaign was performed during winter 1999–2000 (before reproduction of 2000), repeated every year with different efforts with the last in 2003–2004. Bait stations were installed, covering all accessible areas of the island (22.5 ha). Distance between stations varied *c.* between 25 m in 2000 (highest effort) and 50 m in 2001 (lowest effort). Bait stations were loaded up to nine times every 6 or 7 days with three poison baits and then checked and replenished. This

replenishment provided a constant source of poison available to new individuals while minimizing overdose, thus reducing the amount of poison in the environment. On cliffs that were difficult to access (2 ha), stations were loaded with five poison baits and were checked and replenished up to four times.

### Estimation of annual relative rat abundance

The relative abundance of rats was measured during 1999, 2000 and 2001 in October, once the shearwaters left the colony and previous to the next rat control campaign. The use of snap-trap lines made it possible to estimate an abundance index and to compare results among years. Snap trapping is commonly used as a tool for estimating rodent density (Hooker & Innes, 1995; Shanker, 2000; Micol & Jouventin, 2002; Orueta *et al.*, 2005). We placed 30 snap-trap stations baited with wick soaked in fish oil, separated by 15 m intervals. Before setting the traps, we pre-baited stations for 2 days with bread soaked in fish oil. After that, for 5 consecutive days, snap traps were primed in the evening and checked at dawn before being closed until the next evening. Total number of rats captured was used as rat abundance index to compare between years. This variable may depend on rat abundance and also on food detection and availability (Meehan, 1984), but the estimate can also reflect the frequency of burrow intrusion and predation. Rat abundance is thus related first to the effort of the preceding rat control campaign and secondly to the breeding success of Cory's shearwater during the same breeding season when rat abundance was estimated.

### Analyses and statistical procedures

Besides assessing the impact of nest predation on the breeding success of the population, we also estimated the relationship between the annual rat control effort (measured as number of baiting stations  $\text{ha}^{-1}$ ) before the reproduction period and the breeding success between the sub-colonies. This potential differential effect of annual variation in rat control on the breeding success at each sub-colony was performed by applying a general linear mixed model (GLMMIX, see Littlell *et al.*, 1996). We fitted control effort and sub-colony identity to the observed breeding success by using binomial error and the logit link function of the PROC MIXED in SAS (SAS, 1997). Both explanatory variables and their interaction were fitted to the observed data. As the same burrows were sampled repeatedly each year of the study, this variable was treated as a random term in the model. We could not discard the possibility of a year effect on breeding success, which could be independent of annual variation in rat control effort. However, the covariation of both variables (year and rat control effort) along the study period precluded the inclusion of the first factor in the analyses. The final selected model was built following a forward stepwise procedure, which yields the best model (i.e. with lowest final deviance) for explaining variations in the response variable (e.g. Forero *et al.*, 2002).

## Results

Monitoring showed that breeding success increased significantly from 1999 to 2000 after the initiation of the rat control campaign (in late 1999) (Table 1), and was also significantly different among the years of study ( $\chi^2_6 = 141.5$ ,  $P < 0.0001$ ). The largest differences were found between the breeding season of 1999 and the following years with rat control (except in 2001 when rat numbers recovered, see below). Mortality rate at the egg stage did not vary among years ( $\chi^2_2 = 2.6$ ,  $P = 0.28$ ) (Fig. 1a). However, the egg fate varied among years: after the first rat control, the number of missing eggs in 2000 decreased, but the number of abandoned and broken eggs increased. On the contrary, chick mortality was significantly different among years ( $\chi^2_2 = 40.0$ ,  $P < 0.001$ ): very high before rat control in 1999 (52%), and low and medium in 2000 and 2001 after the first rat campaigns (11 and 23%, respectively) (Fig. 1a). The highest rat abundance occurred in 1999, while in 2000 no rats were detected (due to a very low abundance rather than a total eradication) and by 2001 numbers had recovered sharply (Fig. 1b). When the density of poison stations increased, rat abundance decreased and breeding success increased. So, a lower effort in autumn 2000 resulted in a recovery of rat numbers and a higher predation rate in the following breeding season of 2001.

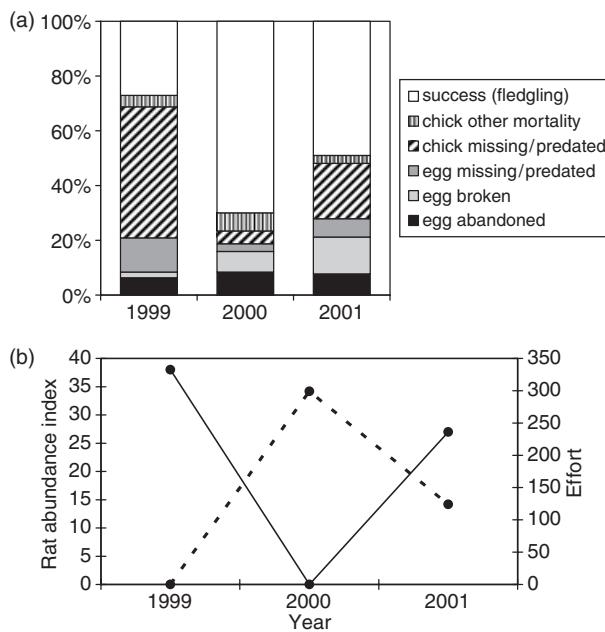
When analysing the effect of rat control effort on breeding success of each sub-colony, and after controlling by the random effect of the burrow identity ( $Z = 2.80$ ,  $P = 0.003$ ), we obtained a model that included the significant effect of the interaction between sub-colony and rat control effort ( $F_{1,403} = 5.29$ ,  $P = 0.022$ ). This model explained up to 31.42% of the original deviance on breeding success and also included the main effect of sub-colony ( $F_{1,403} = 14.14$ ,  $P < 0.001$ ) and rat control effort ( $F_{1,403} = 22.03$ ,  $P < 0.0001$ ). The selected model indicated that breeding success at SC2, the rocky cliff habitat, was significantly higher than at SC1, the habitat with vegetated slopes and excavated nests (Table 2). Although both sub-colonies increased their breeding success with increased rat control effort, the response of

**Table 1** Breeding success of Cory's shearwaters *Calonectris diomedea* (expressed as percentage of nests with a fledgling relative to the number of nests with laying, %) at Congreso Island

Year	n	%	SR
1997	100	44	-3.4
1999	180	27	-9.7
2000	225	70	3.4
2001	210	51	-2.9
2002	220	71	3.6
2003	208	71	3.5
2004	222	71	3.7

Rat control campaign started in October 1999.

n, number of nests monitored with laid egg; SR, standardized residuals of the contingency table: values  $<2$  indicated breeding success significantly lower than expected, whereas values  $>2$  indicated the contrary.



**Figure 1** (a) Fate of eggs of Cory's shearwaters *Calonectris diomedea* (as percentage of total eggs monitored: 48 in 1999, 106 in 2000 and 108 in 2001 by periodic visits every 1–4 days, depending on weather conditions) breeding at Congreso Island during 1999–2001; (b) Relative abundance of rats during 1999–2001 (expressed as number of rats captured/30 traps in 5 nights, solid line) and rat control effort precedent (dashed line).

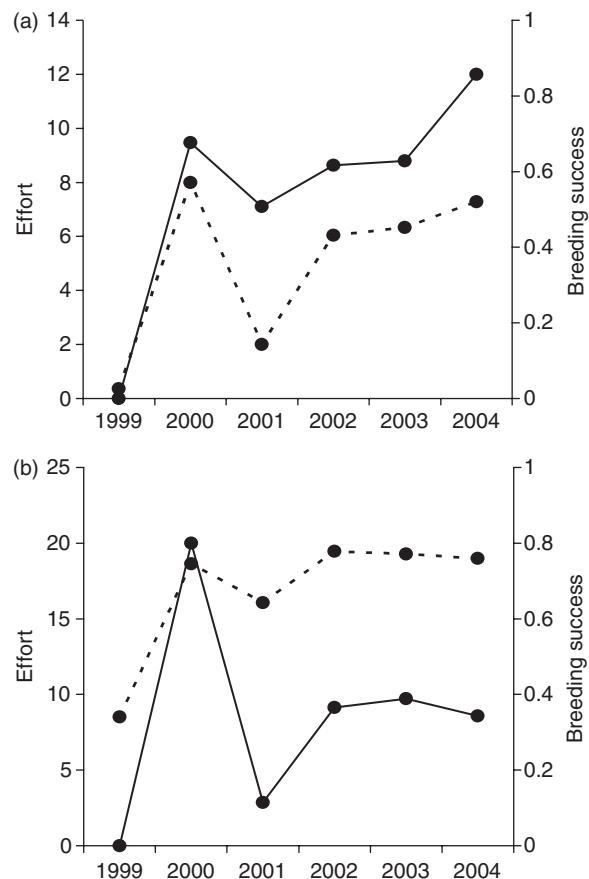
**Table 2** Breeding success of Cory's shearwaters *Calonectris diomedea* at each study sub-colony at Congreso Island

Year	Sub-colony	% breeding success	n
1999	SC1	2.4	41
	SC2	34.5	139
2000	SC1	57.1	56
	SC2	74.6	169
2001	SC1	14.3	56
	SC2	64.3	154
2002	SC1	43.2	44
	SC2	77.8	176
2003	SC1	45.2	42
	SC2	77.7	166
2004	SC1	52.1	48
	SC2	75.9	174

breeding success was higher in SC1 (the sub-colony with lower breeding success) (Fig. 2a) than in SC2 (Fig. 2b).

## Discussion

Our results demonstrate and confirm that rat predation was the main cause of breeding failure of Cory's shearwaters at Congreso Island. In the study colony, breeding success oscillated in parallel to rat control effort. Breeding success values after the initiation of rat control eventually reached those reported for other Mediterranean colonies, where rats



**Figure 2** Annual variation in the effort of rat eradication (expressed as number of baiting stations  $\text{ha}^{-1}$ , solid lines) and breeding success of Cory's shearwaters *Calonectris diomedea* (dashed lines) at each sub-colony (a for SC1, and b for SC2).

were absent or their numbers were controlled or eradicated (Sánchez & de Castilla, 1997). As previously reported for several Procellariidae, we also recorded a relationship between the reproductive success of shearwaters and the probability of rat predation (Cruz & Cruz, 1987; Thibault, 1995; Imber *et al.*, 2000; Jouventin *et al.*, 2003). Furthermore, our results suggest that rats mainly prey upon small chicks rather than on eggs as previously found in related species (Grant, Pettit & Whittow, 1981; Seto & Conant, 1996; Imber *et al.*, 2000). The large size of Cory's shearwaters probably allows them to defend eggs in the burrows against rat intrusions. In our study, egg mortality did not vary but egg fate was different: after rat control, broken and abandoned increased eggs and missing eggs decreased, which indicates that predation only occurred on broken or abandoned eggs. Conversely, smaller sized species are likely to be more vulnerable to egg predation (Imber, 1978; Moors & Atkinson, 1984; Penloup *et al.*, 1997; Martin *et al.*, 2000). Another non-exclusive factor could explain the low predation on eggs: rats in Chafarinas Islands seem to be even unable to feed on many neglected eggs unless they were previously broken (see experimental results in Prieto *et al.*, 2003).

Similar to other Cory's shearwater colonies in the Mediterranean (Thibault, 1995), the main cause of breeding failure in our study was chick mortality caused by rat predation. Most predation events occurred immediately after the brooding stage (between 2 and 7 days after hatching), when both adults left the colony to forage. Chicks older than 3 weeks (when body mass reaches 2/3 of adult weight) were never killed, suggesting that younger chicks were probably too weak to defend themselves against rat attacks. Moreover, the period of chick predation occurred in early July during summer dryness, when vegetation productivity was low (see Moors *et al.*, 1992; Thibault, 1995).

Intriguingly, breeding success of Cory's shearwaters was consistently different between sub-colonies. Several facts suggest that this difference can be mainly attributed to different levels of rat predation at each sub-colony (higher at vegetated habitat than rocky habitat). First, differential availability and/or use of food resources by birds in different sub-colonies are unlikely to explain the differences in breeding success in a colony occupying only 20 ha and where all individuals probably forage in the same marine grounds. Second, in other colonies of the species selection of the habitat type has been demonstrated similar to that of SC1 (Borg, 2000) while individuals of better quality in our study population were spatially segregated preferentially at SC1 (J. M. Igual, unpubl. data).

From our results, we conclude that birds breeding in excavated burrows of the vegetated slopes seem more vulnerable to rat predation than birds breeding in the hollows of the rocky habitat. Three factors (probably inter-related) could explain this difference: (1) a higher rat density in the vegetated habitat (Cheylan, 1988), (2) a higher rat intrusion probability in wider, less intricate nests in the vegetated habitat (Martin & Roper, 1988) and (3) a higher effect of predation due to lower nest density in this sub-colony, as opposed to a greater dilution effect of predation in the rocky habitat (Wilkinson & English-Loeb, 1982; Jones, 2003). Adult birds on the ground arriving at night in SC2 could also reduce the capacity of foraging movements of rats. Thus, both the effectiveness of rat control and the increase of breeding success were more evident in the rocky habitat, this trend being consistent with whatever effort was made on rat control. However, the vegetated habitat was more sensitive to variations in rat control effort, but requiring greater control effort to obtain values of breeding success always lower than those at the rocky habitat.

This study highlighted the positive and strong association between rat control effort and shearwater breeding success as a reliable indicator for the effectiveness of rat control campaigns. It also shows how control rather than eradication is very short term. From a conservation point of view, rat control in our population of Cory's shearwater can be considered temporarily satisfactory, although complete eradication was not possible. The campaigns of rat eradication carried out to diminish secondary poisoning indicated that a part of the rat population could not have access to the

poison. There are areas on the island, such as little accessible cliffs, where it was not possible to put bait stations. Although the population was decimated, some rats survived and have a high capacity of recovery.

The results also suggest that habitat features should be taken into account when planning and/or implementing a rat control programme. Other factors shaping the abundance and the cycle of predators should also be considered in control programmes: availability of plant food, physical characteristics of the colony, such as burrow accessibility or rat detection ability, and even the possibility that some rats become specialized in chick predation (Cheylan, 1988; Moors *et al.*, 1992; Imber *et al.*, 2000). In our case, habitat heterogeneity and a differential response to rat control between sub-colonies probably requires the modification of standard control procedures, such as the maintenance of poison stations at the vegetated habitat during the first weeks after hatching. An important factor determining the success of a control programme is the capacity of rats to recover after the control campaign (see Thibault, 1995; Jouventin *et al.*, 2003). Under this potential scenario, recommendations about any control program and seabird population management must be planned on a case-by-case basis taking into account local ecological conditions and species characteristics.

An alternative and more aggressive strategy aimed at the complete eradication of rats in Congreso Island (as has been achieved in other and even larger islands, see Thibault, 1992; Taylor & Thomas, 1993; Thorsen *et al.*, 2000) is the release of limited quantities of poison in all areas, including cliffs. Knowledge of all fauna and flora on the island is also required, particularly endemic species, to avoid secondary poisoning when targeting rats. In our case, complete eradication should be the main outcome of this pilot study. Control merely represents a constant annual expense and effort while complete eradication safeguards the colony for posterity (with monitoring for potential re-invasion of ship-borne rats).

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