Towards a Conservation Strategy of the Roseate Tern *Sterna dougallii* in the Azores Archipelago

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Candidates Declaration

I declare that the work described in this thesis has been carried out by myself unless otherwise cited or acknowledged. Part of the material included in this thesis is being prepared for submission and part has been submitted and published in co-authorship with others:

Chapter 5. *Published as:* Neves V. C., Murdoch N. & Furness R. W. Population Status and Diet of Yellow-Legged Gull in the Azores. *Arquipelago, Life and Marine Sciences* (*in press*). Arquipelago, Life and Marine Sciences.

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Appendix 6. Neves V. C., Bremer E. & Hays H. 2002. Recovery in Punta Rasa, Argentina of Common Terns banded in the Azores Archipelago, North Atlantic. *Waterbirds,* **25**: 459-461.

I further declare this thesis is entirely of my own composition and has not, in whole or in part, been submitted for any other degree.

Verónica Neves
November 2005

Dedicated to the memory of Luís R. Monteiro (1962-1999)

ABSTRACT

The Roseate Tern, *Sterna dougallii,* is currently regarded as one of the most endangered seabirds in Europe. The mid-Atlantic Azores islands, Portugal, are an important breeding ground for this species, holding more than 50% of the European population. EU directives are aimed at maintaining and enhancing the current range and breeding numbers of Roseate Tern in the Azores and elsewhere and it is thus a priority species on the Conservation Agenda. However, few studies have examined the Roseate Tern in this geographical area of the Atlantic, and this thesis aims to address this need. The thesis investigates and examines several potential factors affecting breeding numbers of these birds in the archipelago, giving particular attention to predation and potential predators. Data were mainly obtained through fieldwork conducted in the period 2002-2004, but investigation of recent historical records of breeding numbers is utilized to assess trends. These historical data were collected between 1989 and 2005, and show that the breeding population has fluctuated widely over the last 16 years. Taking the Roseate Tern demographic parameters into account, this variation can only be explained by means of intermittent breeding. Many more years of research and monitoring will be needed before we can fully understand the factors underlying the decision of Roseate Terns to breed or not in a given year in the archipelago. Nevertheless this lack of a complete understanding of a perhaps natural variation does not prevent implementation of immediate conservation action. This thesis examines the impact of avian predators, such as gulls and starlings, on breeding success. Although terns and starlings can nest in close proximity in the Azores, egg predation by starlings has rarely been reported. In the Azores, this behaviour has only been detected in one colony, Vila islet that holds about 20% of the Azorean Roseate Tern population, but it is the main cause of egg losses in the tern colony. A census conducted to estimate the size of the Yellow-legged Gull population yielded an estimate of 4249 breeding pairs, representing an increase of almost 60% from the previous survey conducted in 1984. A control taste aversion (CTA) experiment was conducted to explore the possibility of using this technique as a way to reduce starling and gull predation. Our results indicate that CTA has potential to work with gulls but it will be much more difficult to use it successfully on starlings. Using an integrated habitat management strategy at Praia Islet, Graciosa, I demonstrate that it is possible to enhance the habitat of the terns and increase their breeding numbers if efforts are global and broad. Future conservation action might need to implement lethal control of starlings in very specific situations. Lethal control should only be undertaken in conjunction with other measures, such as provision of Roseate Tern artificial nests and close monitoring to assess its effect on productivity. The thesis concludes by summarizing the management and conservation implications of the results and placing these ornithological findings in a wider conservation perspective. By rapidly implementing the actions here described, the populations of Roseate Terns should increase in future to the point where it is no longer critically endangered.

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Chapter I

General Introduction

The work in this thesis was carried out in the Azores archipelago, Portugal, with the Roseate Tern *Sterna dougallii*, an endangered seabird in Europe for which the European Union (EU) member states have a legal requirement to take conservation action.

The Roseate Tern (see fig. 1) is an handsome and elegant bird that was first described by Montagu in 1813 from specimens collected on the Eileans, Cumbrae Islands, Scotland (AOU 1983) by Dr. MacDougall.

> "Beautiful, indeed, are Terns of every kind, but the Roseate excels the rest, if not in form, yet in the lovely hue of its breast. I had never seen a bird of this species before, and as the unscathed hundreds arose and danced as it were in the air, I thought them the Humming-birds of the sea, so light and graceful were their movements"
>
> *J. J. Audubon*
>
> *In: Birds of America - Ornithological Biographies 1839*

The Roseate Tern has since then been extensively studied in a few parts of its distribution, specially in North America where some research teams have concentrated several decades of research into the study of this remarkable bird. Examples are the Great Gull Island Project, coordinated by Helen Hays from the American Museum of Natural History since 1969, and the Falkner Island Tern Project, initiated in 1978; and coordinated by Jeffrey Spendelow. Ian Nisbet and associate researchers have also been studying the Roseate Tern at Bird island, Massachusetts since 1970. In 1989 the Tern Conservation project on Rockabill, Ireland, was initiated under the auspices of the Royal Society for the Protection of Birds, National Parks and Wildlife and BirdWatch Ireland. By then only about 200 pairs were breeding on Rockabill but over the years and thanks to an intense and successful conservation programme (for a general description of annual conservation action measures see, for example, Barker *et al.* 2004) numbers have recovered to over 700 pairs in 2004 (Newton 2004). Both in North America and in Europe the conservation efforts to protect the Roseate Tern have been based on a "hands-on" approach to maintain and enhance the range of the roseate tern (e.g. Newbery 2002), and include strict regulation and law enforcement to protect the main colonies, predators control, vegetation management and provision of artificial nests, among other measures (e.g. Newbery 2002 and Barker *et al.* 2004).

In the Azores, despite the fact that this archipelago constitutes its European stronghold, the Roseate Tern has been little studied; this thesis aims to address this need. All the experiments conducted comply with the Portuguese law and were conducted under permits nos. 1/CN/2002, 3/CN/2003 and 6/CN/2004, issued by "Direcção de Serviços de Conservação da Natureza", Secretaria Regional do Ambiente e do Mar, Açores.

This chapter provides a general account of factors that affect seabird populations and conservation (**section 1.1 and 1.2**.) and a description of the Roseate Tern (**section 1.3**), as well as its present status and the international context of conservation of the species (**section 1.4**). It also gives a general description of the study area (**section 1.5**), providing an overview of the Azores seabird assemblage (**section 1.6**), and more specifically a brief overview of previous studies focusing specifically in the Azorean Roseate Tern (**section 1.7**). Finally, the global context and content of this thesis are outlined in summary (**section 1.8**).

28 April 1832 - Indian Key, Florida

Figure 1.1: John James Audubon's depiction of a Roseate Tern defending its territory was published in *Birds of America Ornithological Biographies* (1839) and captures particularly well the character of this species.

1.1 SEABIRD POPULATIONS AND CONSERVATION

Seabirds are exposed to a variety of detrimental factors that have the potential to decrease their survival or reproductive success, such as food shortage, habitat loss, predators, competitors, parasites, disease, human disturbance and adverse weather conditions. Studying changes in seabird numbers is vital for implementation of management plans and conservation action in case of declining species, advocated by EU directives and National Law. Changes in a population size can be detected by monitoring that population on a regular basis. Long-term census records can help to distinguish long-term population trends of decrease or increase, possibly caused by human disturbance, from short-term fluctuations caused by variations in weather, marine conditions or stochastic natural events (Pechmann *et al.* 1991).

Bird populations are regulated by external environmental factors that affect intrinsic demographic features (Newton 1998). External environmental factors include resources such as habitat and food availability, competing species and natural enemies in the form of predators and parasites. The intrinsic factors include the rates of reproduction and mortality, immigration and emigration. The trends of seabird breeding populations are determined by the balance between losses due to adult mortality and emigration and gains from recruitment and immigration. Where the mortality is equal to recruitment the population will remain stable, but self evidently declines will occur where mortality exceeds recruitment and growth (Newton 1998). Recruitment is the rate at which immatures join the breeding population for the first time, and is determined by productivity, the age at which birds breed for the first time and the likelihood of a bird surviving to this age (Newton 1998).

It is often difficult to clearly assess the factors that limit seabird populations because reproduction and survival are seldom influenced by one factor alone but by several, which may act independently, or in combination so that one can enhance or reduce the effects of another on population levels (Newton 1998). The primary limiting factor can be considered as the one that, once removed, will permit the biggest rise in numbers (Newton 1998).

Climatic and oceanographic events can have huge impacts on seabird populations by affecting their food supplies and will be discussed in more detail at sections 2.1.1 and 2.1.2. Aebisher *et al.* (1990), found a correlation between the breeding performance of Black-legged Kittiwakes *Rissa tridactyla*, the abundance of Herring *Clupeus harengus*, and the frequency of westerly winds. All declined at a similar rate from the 1950s to reach a trough around 1979-80, and then recovered somewhat (Aebisher *et al.* 1990). Similarly, changes in the numbers of Adelie Penguins *Pygoscelis adeliae* in the Ross Sea over a ten-year period were correlated with climatic changes (Taylor & Wilson 1990). Year-to-year fluctuations in the breeding of some seabirds have been linked with sea temperatures (Boersma 1978) but could also be due to intermittent breeding, which is described in the next section.

1.2 INTERMITTENT BREEDING

Year-to-year variations in seabird population may in some instances reflect fluctuations in the proportion of the adult population attempting to breed. Movements of breeding birds to or from unmonitored colonies may also contribute to apparent changes. During their breeding life, individuals of many avian species miss one or more breeding seasons, either consecutive or otherwise (Mougin *et al.* 1997) and this can play a crucial part in population demography. Intermittent breeding has been reported for several seabird groups but has not been thoroughly studied. The factors affecting whether or not an individual breeds in any particular year include age and breeding experience (Wooller & Coulson 1977, Wooller *et al.* 1990), the prevailing food availability (Monaghan *et al.* 1992), breeding performance in the previous season (van Heezik *et al.* 1993) and other social factors (Harris & Wanless 1995). Reduced food availability was implicated in an increase in non-breeding by adult Arctic Terns *Sterna paradisaea* (Monaghan *et al.* 1992). Prey limitation has also been show to limit reproduction in the Roseate Tern (Safina *et al.* 1988); however nothing is known regarding the possible occurrence of intermittent breeding in the Roseate Tern. In the next section we give a general description of the Roseate Tern.

1.3 THE ROSEATE TERN

The Roseate Tern belongs to the order Charadriiformes, family Sternidae that includes 43 species in seven genera, from which 16 breed in the western Palearctic (Snow & Perrins 1998). The Roseate Tern is a medium-sized, colonial-nesting seabird with a wingspan of about 60 cm and weighing approximately 120g. Compared with other Sternidae, the Roseate Tern has specialised requirements for breeding and foraging (Gochfeld *et al.* 1998), resulting in a relatively restricted breeding distribution. In the British Islands, for example, this species has one of the most restricted ranges of any seabird, with most of the population breeding in just three colonies (Newton 2004).

The species does, however, have a very widespread breeding distribution when considered on a global scale. There are five recognized subspecies of Roseate Tern occurring on six continents, with the nominate *dougallii* breeding in Britain, Ireland, France, the Azores, the eastern coast of the USA, the Caribbean and Africa (Gochfeld 1983). The race *bangsi* breeds from the Malayan Peninsula eastward into China, Japan, the Philippines, New Guinea and New Caledonia; *korustes* is found breeding in Sri Lanka, and Myanmar, *arideensis* in the Seychelles and Madagascar, and *gracilis* in Australia (Gochfeld 1983). However, recent mitochondrial DNA and microsatellite studies identified only two genetically distinct lineages, *dougallii* in the Atlantic and *gracilis* in the Indo-Pacific (Lashko 2004).

Despite their widespread distribution, Roseate Terns are nowhere abundant and have suffered major declines in all parts of the world. In north-west Europe it was driven to the brink of extinction during the 19th century owing to persecution for the millinery trade but recovered between 1920s and 1960s in response to protective legislation (Cabot 1996). It declined again during 1970s and mid-1980s probably owing to reduced immature winter survival rates (Cabot 1996) and then stabilized in late 1980s and recovered between early 1990s and 2004 (Newton 2004).

In Northern Europe, the Roseate Tern is one of the rarest breeding seabirds (Cabot 1996). For example, it was identified as “near-threatened” in the ICBP World Checklist of threatened Birds (Collar & Andrew 1988). It is classified as a “Species of European Conservation Concern” category 3 (SPEC 3) and “Endangered in Europe” because of its large decline in numbers (Tucker & Heath 1994). Although its main population is not concentrated in

Europe, it does have an unfavourable conservation status there (Tucker & Heath 1994). It is also listed on Appendix II of the Bern and Bonn Conventions, in Annex 1 of the EU Birds Directive, and is a species for which member states must take special conservation actions and notify suitable sites as Special Protection Areas (SPAs).

1.4 STATUS AND INTERNATIONAL CONTEXT OF THE ROSEATE TERN

Gochfeld (1983) estimated the world population of the Roseate Tern to be of the order of 55,500 pairs, but recent data suggest the figure is more than double this at 120,000-130,000 pairs (Newton 2004). The European population of the Roseate Tern is 1,900-2,400 pairs, of which 53-63% are in the Azores, 31-39% are in Ireland and 2-3% are in Britain (Newton 2004).

Population trends in Europe and North America are well documented, but in the Azores annual monitoring only started in 1989; the population in the archipelago has fluctuated since then between 400 and 1,200 pairs. Numbers in Britain and Ireland have also fluctuated widely; they peaked at 3,812 pairs in 1968, but declined rapidly to just 521 pairs in 1985 (Cabot 1996). The decline was probably due to predation and nesting habitat loss (due to erosion, competition with gulls and/or human disturbance), and to poor immature survival rates caused by deliberate trapping in the Ghanaian wintering grounds (Cabot 1996). The population stabilised at around 500 pairs until 1992 when it staged a slow recovery up to 790 pairs estimated during Seabird 2000 (Newton 2004). The population in France declined from 500-600 pairs in the 1950s-1970s to just 70-100 pairs during the 1980s and 1990s (Cabot 1996). The decline during the 1970s may have been due to trapping in the wintering grounds, competition from gulls, human disturbance and predation by mustelids (Cabot 1996).

The population in North America declined from 8,500 pairs in 1930 to 4,000 pairs in the 1950s and to 2,500 in 1979, and fluctuated between 2,500 and 3,300 during the 1970s and 1980s (Gochfeld *et al.* 1998). Causes that might have contributed to this decline include habitat loss due to competition with gulls, predation, pollution and winter trapping mortality (Gochfeld *et al.* 1998). The population has since staged a recovery to 4,000 pairs, although the long-term increase was punctuated by a decline in 1991-92 that was probably due to elevated mortality during a hurricane

(Gochfeld *et al.* 1998). In Europe one of the strongholds of the Roseate Tern is in the Azores, the archipelago where the work described in this thesis has been carried and for which a brief description follows below.

1.5 THE AZORES ARCHIPELAGO

The Azores archipelago is located on the Mid-Atlantic Ridge (36°-39ºN', 25°-31ºW) and lies c. 1500 km from the Portuguese mainland and c. 1900 km from the most westward point of Newfoundland, Canada. The climate is subtropical and oceanic (Monteiro 2000).

It comprises nine volcanic islands (see fig. 1.2) forming three groups: “western” (Corvo and Flores), “central” (Faial, Pico, São Jorge, Graciosa and Terceira) and “eastern” (São Miguel and Santa Maria). Over 600 km separates the most easterly and westerly of the island chain. All the islands are of volcanic origin, dating from the Miocene to the present. The islands are mountainous (maximum height of 2351 m on Pico), bounded by precipitous, often deeply dissected cliffs, with several caves, stacks, and islets. Within one kilometer of the main islands lie ca. 26 small islets (0.1-10 ha) and stacks. The archipelago has a land surface of 2335 km^2 and covers 755 km long coastline that is rocky with boulder shores, and with cliffs frequently reaching 100 to 300 m in height.

The oceanographic conditions in the Azores are strongly influenced by the Gulf Stream, which in the central North Atlantic has a southern multi-branched current system with many unstable meanders and eddies at the Azores front (Haney 1986). Oceanographic features of the area show steep submarine walls, ridges and escarpments and a very narrow continental shelf. Due to the complex circulation patterns and upwelling of nutrient-rich deepwater currents against the steep walls of the islands, the area constitutes a relatively food-rich area in the nutrient-poor central North Atlantic. Therefore many species of marine mammals, sharks and seabirds use the area to breed and reproduce. Average winter sea surface temperatures (SST) are typically 15-16ºC and average summer temperatures 22-24ºC (Santos *et al.* 1995). Tides in the Azores are small and semi-diurnal, averaging 1.32-1.54m.

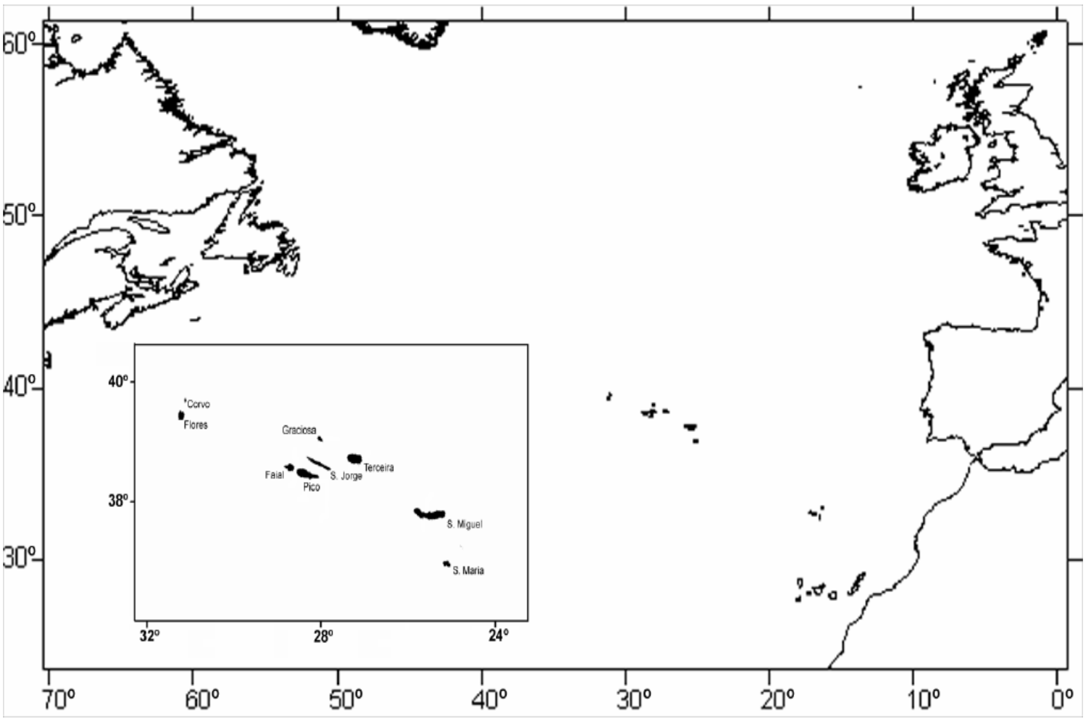


Figure 1.2: Location of the Azores archipelago within the North Eastern Atlantic

1.6 THE AZORES SEABIRD COMMUNITY

The Azores seabird community includes nine breeding species, five procellariiforms and four charadriiforms, and is of international conservation importance (Monteiro *et al.* 1999). The archipelago maintains the Western Palearctic stronghold of the endangered fast-declining Roseate Tern holding between 53% and 63% of the European population (Monteiro 2000). The islands also hold the world's largest concentration of Cory's Shearwater *Calonectris diomedea* and two temporally distinct (hot- and cool-season) and genetically divergent breeding populations of Madeiran Storm-petrel *Oceanodroma castro* that are in the process of being classified as taxonomically distinct (Smith *et al.* in prep.). The Azores seabird assemblage is therefore important in the European context.

Manx Shearwater *Puffinus puffinus* also occur in small numbers in the Azores and the archipelago constitutes the southern limit for this species. Islets off the coast of Graciosa have the highest numbers of breeding Madeiran storm-petrel in the archipelago. This island has also hosted attempted breeding of Red-billed Tropicbird *Phaeton aethereus*, the only known European site where this has occurred (Furness & Monteiro 1995).

Graciosa is also the only island in the archipelago where Fea's Petrel *Pterodroma feae* has ever been captured (Monteiro & Furness 1995, Neves 1999 unpublished data), but breeding has never been confirmed (Neves *et al.* 2003). The Azores is also the only place where the Cahow Petrel *P. cahow* has been found ashore outside of Bermuda (Bried 2003a). The Azores is also the only known breeding locality of Sooty Tern *Sterna fuscata* in Europe; these birds have breed in Vila islet, Santa Maria island, for many decades and have recently bred in Praia islet, Graciosa island (Monteiro 2000; Neves personal observation).

Some species, such as Bulwer's Petrel *Bulweria bulwerii,* Little Shearwater *Puffinus assimilis* and Madeiran Storm-petrel have small breeding populations in the Azores, and their totals are close to the thresholds of effective population size estimated for similar species (Friesen 1997, as cited in Monteiro *et al.* 1999).

Despite its geographical isolation, the environment has been affected by increasing human activity and, as a consequence of the ecological deterioration, during the last two decades various isolated legislative measures have been taken for the conservation of marine species and habitats. After the introduction of the EU "Birds" and "Habitats" Directives in the Archipelago, conservation benefited greatly when 18 Sites of Community Interest (SCIs) and 13 Special Protection Areas (SPAs) on coastal and marine habitats (that include in their range the main Roseate Tern colonies) were designated. Recent projects, including LIFE-EU, have developed management plans for the protected areas but legislation enforcement remains problematic.

Harvesting of adult and young Cory's Shearwater is still a practice (illegal) in several colonies of Santa Maria. Vigilance of the main colonies is still an issue and vandalism and recreation remain occasional causes of major disturbance at protected tern colonies.

1.7 STUDIES ON ROSEATE TERN IN THE AZORES

Godman (1870) was the first to ever refer to the presence of Roseate Terns in the Azores but it wasn't until 60 years later that Chavigny and Mayaud

(1932) provided confirmation of breeding in the archipelago. Some decades later, Bannerman and Bannerman (1966) provided the first indication of population size, reporting a colony of "some hundreds of pairs" on Praia Islet off Graciosa, and they also saw large numbers (possibly hundreds) carrying food off Santa Crus (Flores). In 1984 Gerald Le Grand and the Royal Society for the Protection of Birds organized the first systematic and comprehensive survey in the archipelago estimating a total of 647 pairs (Dunn 1989); however the authors noted that the timings of visiting some colonies were later than desirable and provided underestimates. In 1989 and based in the knowledge of Roseate Tern distribution built-up from the 1984 survey the census was repeated taking the timing of breeding into consideration and a total of 992 pairs were counted (del Nevo *et al.* 1993). From then onwards Roseate Tern numbers have been annually monitored in the archipelago by the University of the Azores. Ramos and del Nevo (1995) provided the first detailed study on nest site preferences in the archipelago and diets have also received reasonable study (Ramos & del Nevo 1995, Pereira 1997, Ramos *et al.* 1998 and 1998a; and finally Meirinho 2000). Recently a paper modelling energetics and food availability looked at the effects of different quality fish species and reductions in their abundance in the growth of Roseate Tern chicks in the Azores (Martins *et al.* 2004).

1.8 OUTLINE OF THE THESIS

Considering the European significance of the Azores islands as a breeding area for Roseate Tern it is essential to enlarge our knowledge of this seabird in the archipelago in order to ensure its successful protection and conservation. Therefore, the main thrust of this thesis is to yield knowledge that can be used to design effective management plans for the Roseate Tern in the Azores.

In **chapter II** data on Roseate Tern breeding numbers for the period between 1989 and 2005 are analysed to assess population trends and identify priority sites for conservation. The Azorean breeding population shows an intriguing cycle that has not been detected before in other parts of the geographical range of this species. With the current knowledge of the Azores ecosystem we can hardly do more than speculate regarding the factors that might be regulating this pattern; more inter-disciplinary-studies looking at climatic and oceanographic features as well as the dynamics of other links of the Azores trophic web are needed.

Chapter III looks at the important issue of predation on a particular islet in the Azores and investigates the impact of egg-predation by the European Starling *Sturnus vulgaris*. Starlings can cause big losses of Roseate Tern eggs and lethal control of starlings might prove necessary. The Azores starlings have been described as an endemic subspecies and in **chapter IV** mtDNA is used to investigate this hypothesis by sequencing the ND2 gene of Azorean, Spanish and British populations. Gulls have no direct competitors in the Azores and their numbers are thought to be increasing in the archipelago raising conservation concerns such as possible displacement of Roseate Tern colonies and depredation of tern eggs, chicks and even adults. Therefore **chapter V** looks at population changes of Yellow-legged Gull *Larus michahellis atlantis* in the last two decades and investigates their diet, predicting that gulls breeding in islands with larger human populations will consume larger amounts of refuse. A control taste aversion experiment was conducted to investigate whether predation by starlings and gulls could be reduced (**chapter VI**).

Chapter VII evaluates the results of a habitat restoration plan implemented on Praia islet in 1995 under the framework of EU Life project and its benefits for the terns. Finally, **chapter VIII** presents a brief synthesis of the findings of the previous chapters and outlines questions arising from the thesis, identifying areas where more research is needed.

Chapter II

Description of the main colonies and analysis of breeding numbers over the period 1989-2005

This chapter starts by reviewing the causes and consequences of seabird population fluctuations that were briefly presented in section 1.1. It goes on to give a general characterisation of the main Roseate Tern colonies in the Azores and analyse the data obtained through annual census of breeding numbers over a 17-year period (1989-2005). Possible explanations for the fluctuation in breeding numbers observed are briefly discussed.

2.1 INTRODUCTION

2.1.1 The importance of measuring changes in seabird populations

As mentioned in section 1.1, studying changes in seabird numbers is vital for implementation of management plans and conservation action in the case of declining species. Seabirds are long-lived organisms with delayed reproductive strategies; they show high adult survival, which is reflected in their life span and they also present delayed age of first reproduction and low fecundity (Gaston 2004). However, these shared attributes and others such as breeding numbers and breeding success can vary widely between species. The variability is partially due to inherent characteristics and partially due to their sensitivity to respond to fluctuations in environmental factors (Furness & Tasker 2000). Different seabird breeding strategies reflect phylogenetic affinities, which in turn reflect the result of the evolutionary process. For example, species with smaller clutches have longer breeding season lengths and higher survival; this partly reflects the trade-off between fecundity and longevity (Roff 2002). Although this does not explain why breeding productivity varies within a species, it provides useful information on the reason for inter-specific variation. Sensitive species normally have a more constrained ecology and provide better bioindicators of marine-ecosystems productivity.

A comprehensive understanding of the way environmental factors affect species is crucial to understand and predict changes in seabirds' populations. Some species, such as terns and kittiwakes, respond more to environmental fluctuations, and additionally they can also show higher spatial variability (see for example Diaz 2005). Species showing higher variability, both temporally and spatially, can be said to be more sensitive to changes in environmental factors than to intrinsic species features. Analysing the relationships between breeding numbers, breeding productivity and survival (of both adults and juveniles) can give us hints as to how the environment is affecting seabirds. Important environmental factors to analyse include sea surface temperature (SST), chlorophyll *a*, food availability and atmospheric variability at larger scale. Additionally, as a result of seabirds' large foraging areas, fluctuations in breeding biology may reflect oceanographic conditions over much larger areas than the immediate foraging grounds around the colony (Schreiber & Schreiber 1984, Schneider *et al.* 1987, Croxall *et al.* 1988, Kitaysky & Golubova 2000). Therefore, it is important to understand the responses of seabirds to environmental change over different spatial and temporal scales to allow their use as environmental indicators and predict future trends (LeMaho *et al.* 1993, Durant *et al.* 2003).

Species that are more sensitive to changes in environmental factors provide more useful bio-indicators to monitor productivity or lower trophic level interactions (e.g. Croxall *et al.* 1988, Barrett & Krasnov 1996, Gjerdrum *et al.* 2003) or high oceanographic impacts (Schreiber & Schreiber 1984).

Environmental factors can affect individuals at different stages of their life and individuals' behaviour can change according to weather conditions, e.g. breeding phenology, incubation shifts and food foraging time (Salamolard & Weimerskirch 1993, Yorio & Boersma 1994, Waugh & Weimerskirch 2003, Frederiksen *et al.* 2004). Many studies have linked seabirds' life history parameters with environmental conditions. These effects have been studied specially during the breeding period but they are also important during the non-breeding phase, when birds face the challenges of migration and have to cope with major changes in a very short time. During migration and wintering phases, juvenile survival represents one of the most sensitive parameters to environmental factors (Potts 1969), and, not surprisingly, also one of the most difficult to study.

Studies of the reactions of birds to climate change are in the increase in recent years (Durant *et al.* 2003), especially regarding the effects of rising temperatures across the world (see McCarty 2001 for review). In this context, species' responses to environmental fluctuations are an important way of predicting population changes and addressing conservation issues. But before we can go on to make predictions on population numbers and changes it is important to fully understand the plasticity of each species/group of species to environmental fluctuations (Furness & Tasker 2000). Many studies have found significant effects of large climatic events on seabirds' performance (e.g. Ainley & Boekelheide 1977, Ainley 1987, Croxall 1992, Orzack & Tuljapurkar 2001, Croxall *et al.* 2002, Barbraud & Weimerskirch 2001, Jenouvrier *et al.* 2003). Oceanographic factors have also been related to breeding performance, and there is very good evidence that food availability affects seabird productivity (e.g. Monaghan 1992, Caldow & Furness 2000, Kalmbach *et al.* 2004, Davis *et al.* 2005).

Sensitive species can provide good bioindicators of oceanographic conditions (LeMaho *et al.* 1993, Furness & Greenwood 1993); different seabird species forage over different spatial scales, some using foraging areas around the colony, e.g. terns, and some others foraging over much larger areas, e.g. shearwaters, (Schreiber & Schreiber 1984, Hunt *et al.* 1986, Croxall *et al.* 1988, Kitaysky & Golubova 2000). Long-term studies have provided integrated information on breeding productivity and changes in marine ecosystems at different time-scales (e.g. Black-legged Kittiwake *Rissa tridactyla,* Aebischer *et al.* 1990; Northern Fulmar *Fulmarus glacialis*, Thompson & Ollason 2001), but few studies have integrated relationships at different spatial regions and the sensitivity of the model species (Diaz 2005). A better understanding of species sensitivity is crucial for conservation management.

2.1.2 Immigration and emigration

Immigration and emigration of birds may occur among a group of colonies collectively termed as a metapopulation (Spendelow *et al.* 1995). In the case of the Roseate Tern, the limits of the metapopulation can expand to US and Canada, such that emigration and immigration can affect national trends.

It is difficult to assess clearly the factors that limit seabird populations because reproduction and survival are seldom influenced by one factor alone, but by several, which may act independently, or in combination so that one can enhance or reduce the effects of another on population levels (Newton 1998). The primary limiting factor can be considered as the one that, once removed, will permit the biggest rise in numbers (Newton 1998).

For endangered species, one important factor to investigate is the number of individuals necessary to ensure the long-term survival of the population, defined by Shaffer (1981) as the minimum viable population (MVP). To plan for the long-term protection of endangered species, we not only have to provide for their survival in average years, but also in exceptionally harsh years. However, accurate estimates of the MVP size for a particular species require a detailed demographic study of the population and an analysis of its environment (Primack 1998), which can be expensive and require years of research (Thomas 1990). For vertebrates, it has been suggested that protecting at least 500 to 5000 individuals would adequately preserve genetic variability and allow a minimum number of individuals to survive in catastrophic years and return to former levels (Lande 1988 & 1995). Roseate Terns have relatively low adult survival rates for seabirds, and therefore need high productivity levels (1.2 fledglings per pair) in order to maintain a stable population (Ratcliffe *et al.* 1998). Productivity at Rockabill is very high, averaging 1.5 chicks per pair, and this has been a major factor in the recent increase in the north-west European population as a whole (Ratcliffe *et al.* 1998; Newton 2004).

2.1.3 Roseate Tern

In western North Atlantic colonies, mean clutch sizes usually range from 1.6-1.9 eggs per nest (Gochfeld *et al.* 1998) whereas means typically range from 1.1-1.8 eggs in Caribbean colonies (Shealer 1995). A very important cause of mortality is human persecution; boys in West Africa trap large numbers of immature Roseate Terns for sport, food and sale (Dunn & Mead 1982, Ntiamoa-Baidu *et al.* 1992, Stienen *et al.* 1998). Protective legislation and education in Ghana caused a cessation of tern trapping along the coast by 1994, but subsequent research has demonstrated a resurgence of this activity in recent years (Ratcliffe 2004).

Tern monitoring in the Azores made a start in the 1960's when Bannerman visited the islands. During their visit 1963, the Bannermans discovered a breeding colony of several hundred pairs on Praia islet off Graciosa and they also saw large numbers carrying food off Santa Cruz (Flores). The first survey was conducted in 1980 by Le Grand yielding an estimate of 300 breeding pairs; he conducted another survey in 1981, counting 500 pairs. These estimates did not cover the complete archipelago and represent an underestimate. In 1984 an expedition organized by the RSPB conducted the first thorough census of Roseate Tern in the Azores, estimating a total of 645 pairs distributed over 24 colonies (Dunn 1989). Del Nevo *et al.* (1993) found 107 colonies of terns in the Azores, of which 20 were mixed Roseate and Common Terns and 87 contained only Common Terns.

2.2 METHODS

When undertaking a census, factors such as census unit, timing, frequency and accuracy of counts need to be considered. Roseate Terns may move among colonies between years in response to food availability, predation, human disturbance, habitat change or other factors, and so a census of the population should ideally survey all colonies within a single year to avoid missing pairs or making duplicate counts if there is intercolony movement between years. Colonies were located and surveyed using a mixture of land-based and sea-based transport.

Roseate Terns were counted in units of apparently occupied nests (AON). Counts were made either by direct ground search of clutches and broods (colony visit) or by flushing terns sounding a horn close to the colony (flush count) (see del Nevo *et al.* 1993 for more details). Counts of individuals using binoculars (at sea) and telescope (on land) were undertaken when the former methods proved impracticable. When flush counts were used, the population was estimated using a correction factor of three flying (or sighted) birds to two breeding pairs; this correction factor was established by del Nevo *et al.* (1993) based on an assessment of the relationship between colony attendance and several factors including stage of breeding and time of day. On the Azores there are nine colonies where direct counts of the Roseate Tern nests are possible, two in Santa Maria (Vila islet and Lagoinhas), one in São Miguel (Caloura islet), two in Terceira (Contendas and Cabras islets), one in Faial (Capelinhos), one in Pico (St António islet) and two in Flores (Alagoa complex and Baixa do Moinho islet).

Adult Roseate Terns are fairly easily distinguished from Common Terns at close range by their unique combination of pale plumage, elongate outer tail feathers, dark bill and, during courtship and incubation, a rosy flush on the breast (Olsen & Larsson 1995). Their calls are very distinctive and distinguish them from Common Terns in flocks of flushed birds. They normally nest in denser cover than Common Terns and their eggs are more elongate and finely speckled (Cramp 1985). The timing is also a very important aspect to consider and can also vary widely (up to two weeks) from year to year. For example, counts conducted too early in the breeding season will omit pairs that have not yet laid and those conducted later will miss AONs as chicks disperse from the nest and hide just a few days after hatching (Newton 2004).

Recent Roseate Tern surveys were conducted under the framework of EU LIFE contracts, run by the University of the Azores, the University of Glasgow and the RSPB. Details of the original counts made are held by Dept. of Oceanography and Fisheries - University of the Azores (unpublished data). Regular annual censuses of Roseate Tern were initiated in 1989. The precise timings of some of the censuses are unknown, but they all took place between late April and early July. Roseate Tern colonies in the Azores islands are difficult to census due to the inaccessible nature of some of the breeding terrain. Additionally the extent of the coastline makes it very time consuming and costly to monitor entirely. Therefore, the annual censuses were only conducted on colonies that traditionally held more than five pairs. For the years of 1989, 1996, 2001 and 2004 a more thorough census was conducted covering the whole archipelago.

2.3 RESULTS

Roseate Terns breed in a large variety of habitats in the archipelago, mostly in association with Common Tern. As a matter of fact, there is only one Roseate Tern colony (Baixa do Moinho, Flores island) where Common Terns do not breed. The number of breeding Roseate Terns within the Azores islands has varied widely over the study period, with an average of 826±249 breeding pairs (Table 2.1). The number of breeding pairs has varied by more than 40% on either side of the mean level. The mean numbers percentage of breeding pairs in each of the nine islands of the archipelago over the period 1989-2005 is presented in Table 2.1.

Table 2.1: Total of Roseate Tern breeding pairs in the nine islands of the archipelago over the period 1989-2005. CVU=Corvo, FLW=Flores, FAI=Faial, PIX=Pico, SJZ= São Jorge, GRW=Gaciosa, SMI=São Miguel, SMA=Santa Maria.

	CVU	FLW	FAI	PIX	SJZ	TER	GRW	SMI	SMA	Total
1989	0	480	0	23	5	93	275	0	116	992
1990	19	455	60	50	2	95	150	0	220	1051
1991	**	694	90	21	135	5	74	0	102	1121
1992	**	316	20	6	10	**	119	**	279	750
1993	**	122	0	0	0	21	13	**	223	379
1994	**	249	0	3	0	11	24	**	241	528
1995	**	599	70	32	0	114	13	**	200	1028
1996	83	419	138	17	37	84	30	**	389	1197
1997	0	489	0	28	0	120	27	**	315	979
1998	**	432	0	22	**	188	34	**	198	874
1999	0	215	0	8	0	125	1	**	167	516
2000	0	262	0	15	5	351	31	**	114	778
2001	0	315	0	7	30	342	25	0	95	814
2002	8	372	0	0	2	269	133	6	201*	991
2003	0	185	19	0	0	58	231	125	134	752
2004	0	391	17	0	17	32	402	33	**	892
2005	0	141	1	9	0	0	130	16	92	389
Mean	10	361	25	14	15	119	101	23	192	826
StDv	25	158	41	14	34	113	112	43	88	249

* This value is probably an over estimate. There was much egg predation by Starlings and some nests counted later in the breeding season were probably second attempts.
** No data available

The western group is composed by only two islands, Flores and Corvo, and has systematically held a large proportion of the Azores breeding population (see Fig. 2.1). Numbers have been mainly concentrated in Flores since Corvo has only erratically been used as a nesting ground for Roseate Tern, and always in very low numbers. Therefore, Flores island alone really constitutes the Azorean hotspot of the Roseate Tern in the Azores, as illustrated by Figure 2.1 and Table 2.2 (please note the difference in the number of islands and amount of coastline between different groups).

Table 2.2: Analysis of Roseate Tern breeding numbers over the period 1989-2005 split into the three groups of islands of the archipelago, western, central and eastern.

	% of the yearly total of Roseate Tern breeding pairs		
Parameter	Western (%)	Central (%)	Eastern (%)
Mean	42.1	31.9	24.2
Max.	58.3	61.4	58.8
Min.	18.9	7.2	4.4
St. Dv.	10.1	14.9	14.3

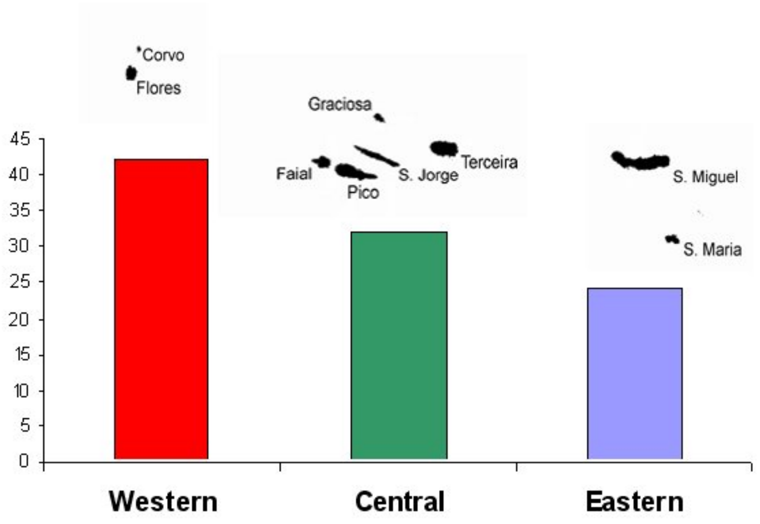


Figure 2.1: Mean values of breeding pairs on the western, central and eastern group of islands over the period 1989-2003 (values given in percentage). Please note the islands silhouette above indicating the variation in the extension of coastline.

Figures 2.2 to 2.19 indicate the location of Roseate and Common Tern in the nine islands of the archipelago; sizes of colonies given are for the maximum numbers ever detected in the study period. The colony name, geographic coordinates and respective breeding numbers are presented in Appendix 1.

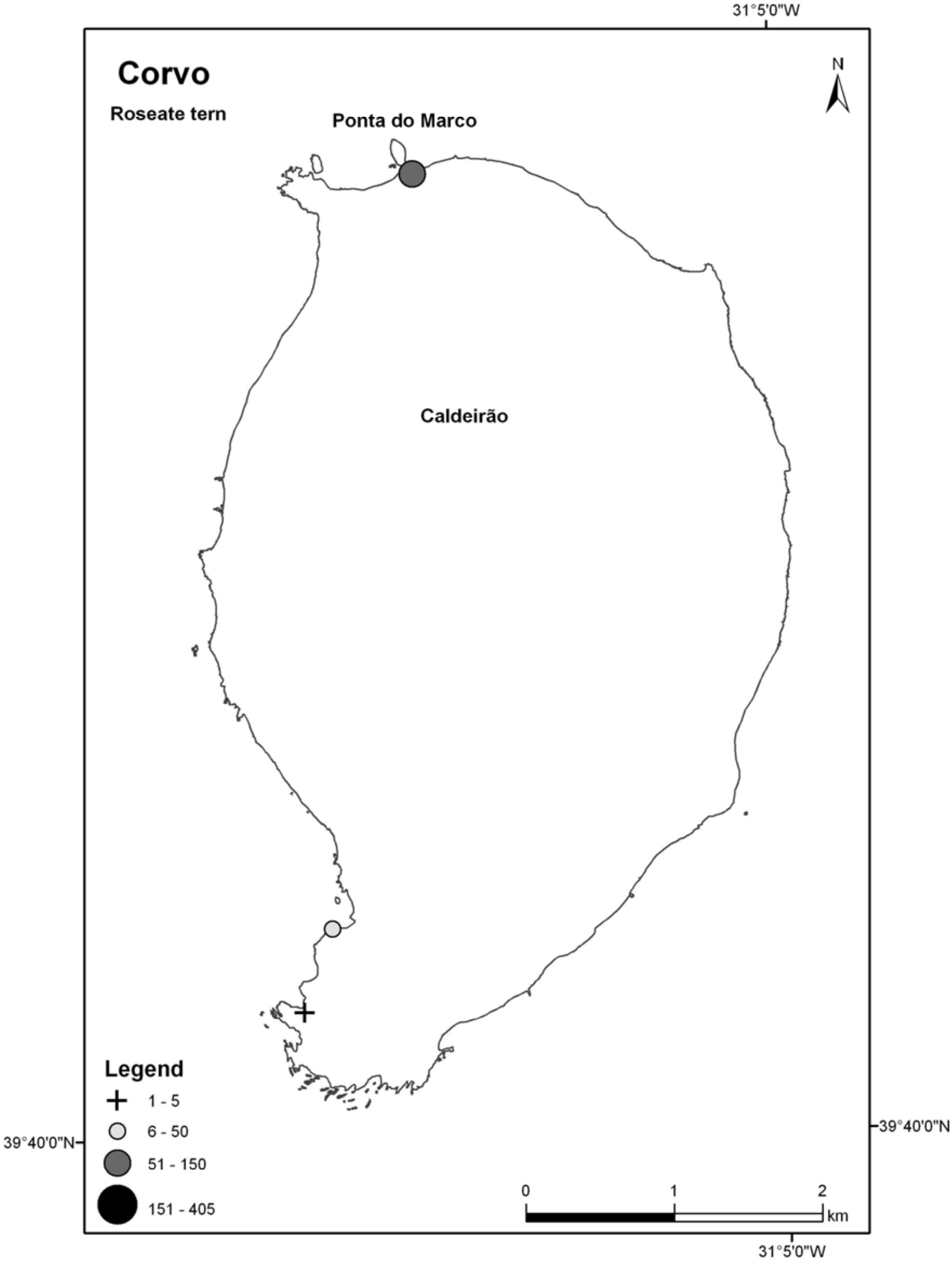


Figure 2.2: Location and peak count of Roseate Tern colonies on Corvo island, 1989-2005.

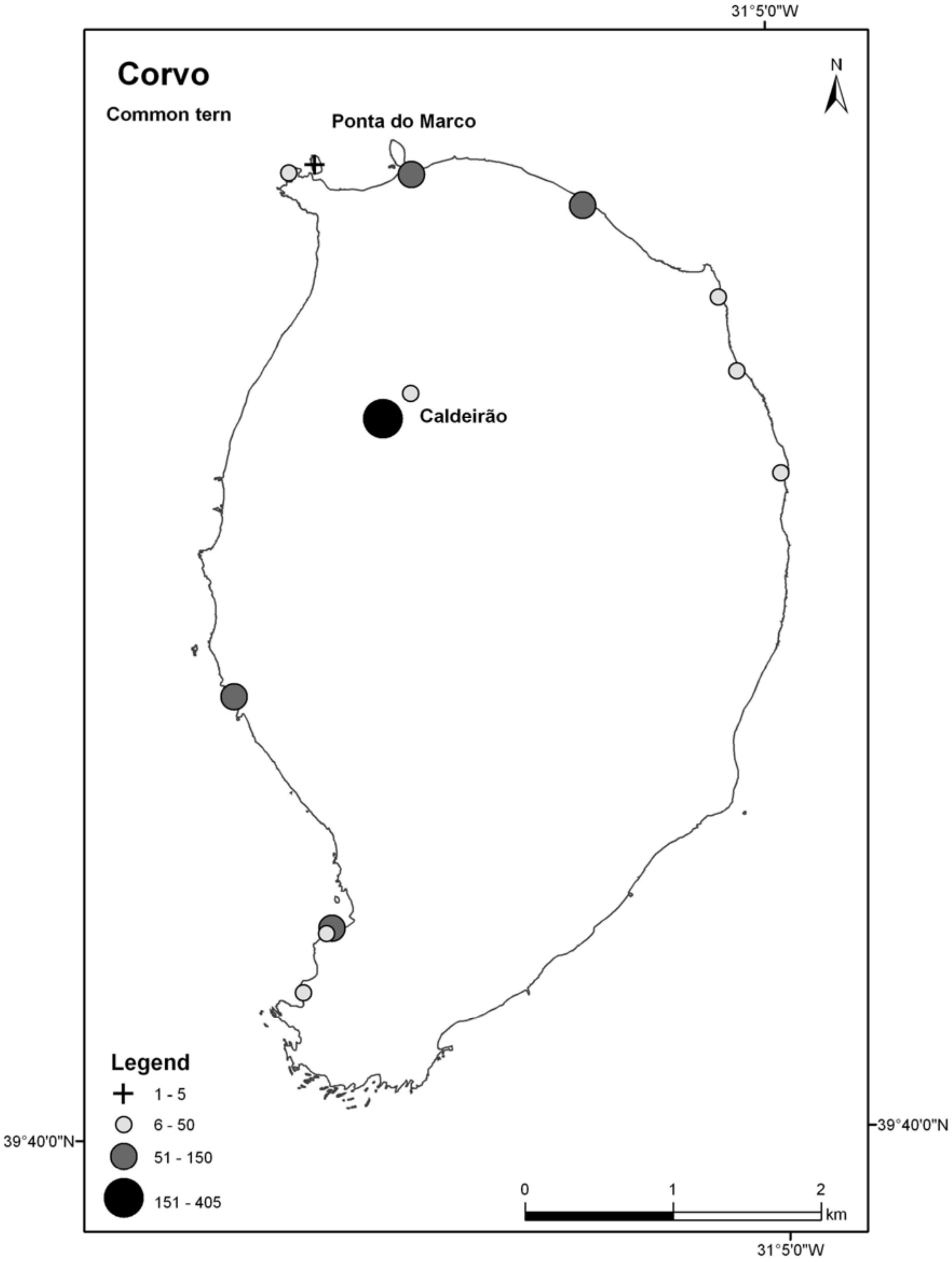


Figure 2.3: Location and peak count of Common Terns at colonies on Corvo island, 1989-2005.

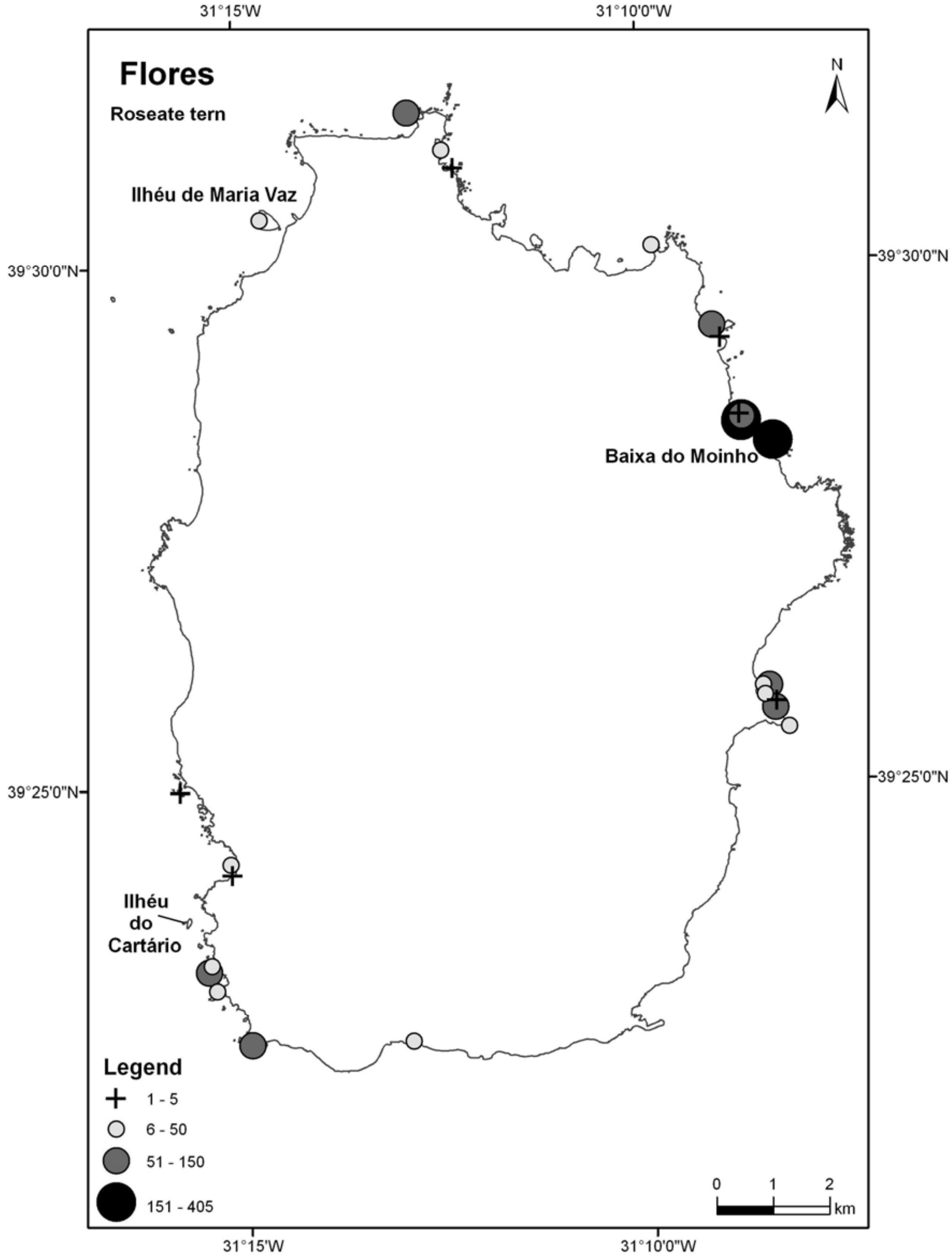


Figure 2.4: Location and peak count of and Roseate Terns at colonies on Flores island, 1989-2005.

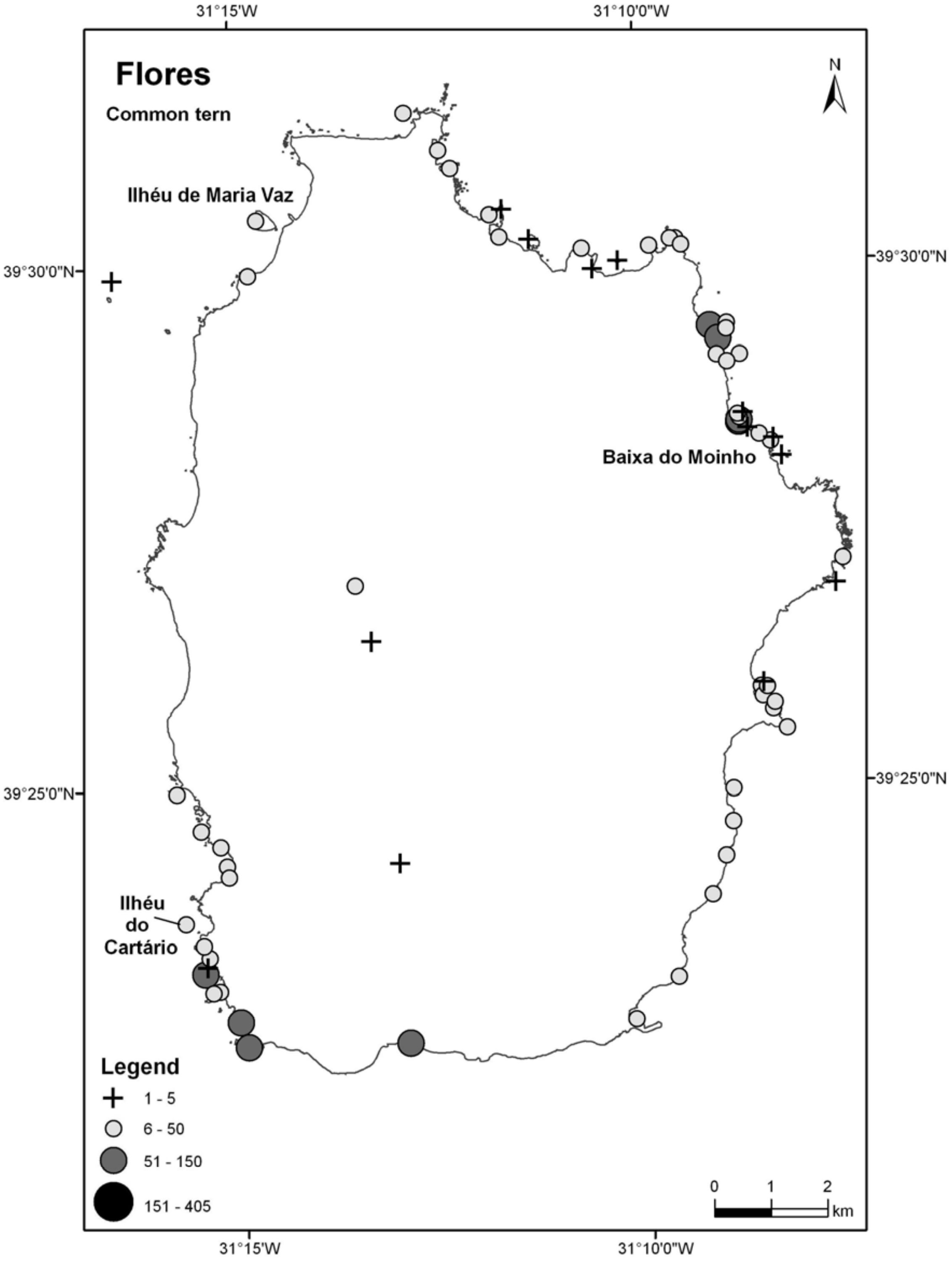


Figure 2.5: Location and peak count of Common Terns at colonies on Flores island, 1989-2005.

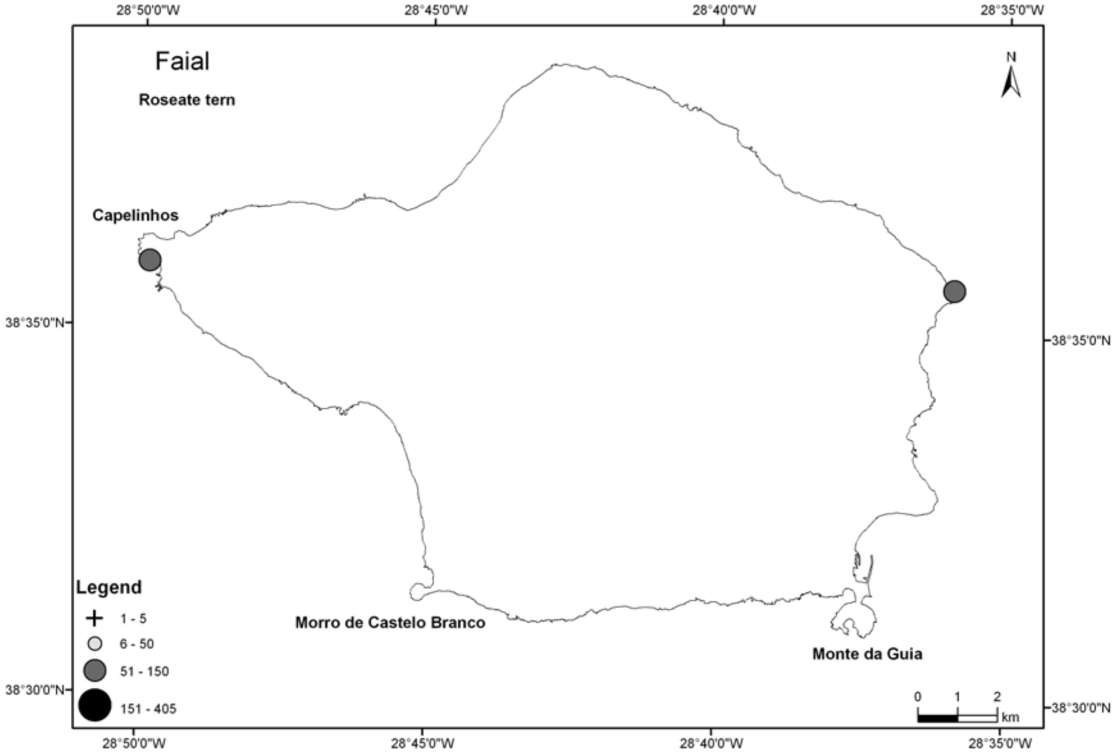


Figure 2.6: Location and peak count of Roseate Terns at colonies on Faial island, 1989-2005.

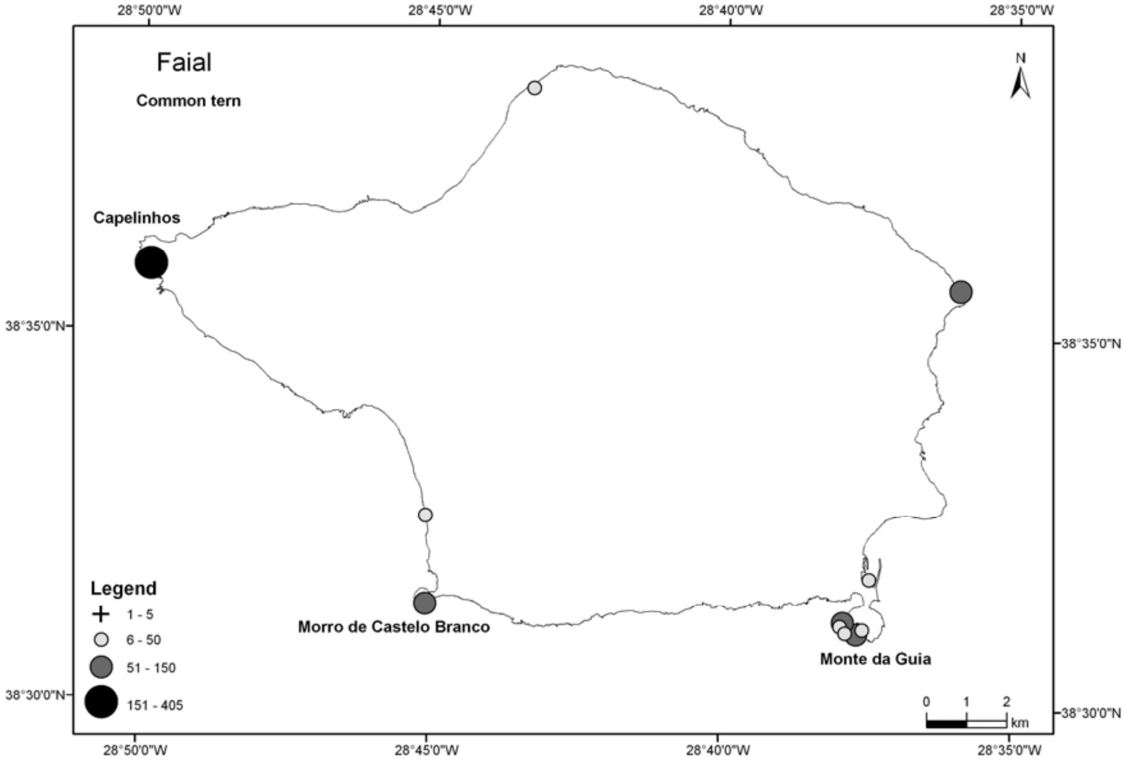


Figure 2.7: Location and peak count of Common Terns at colonies on Faial island, 1989-2005.

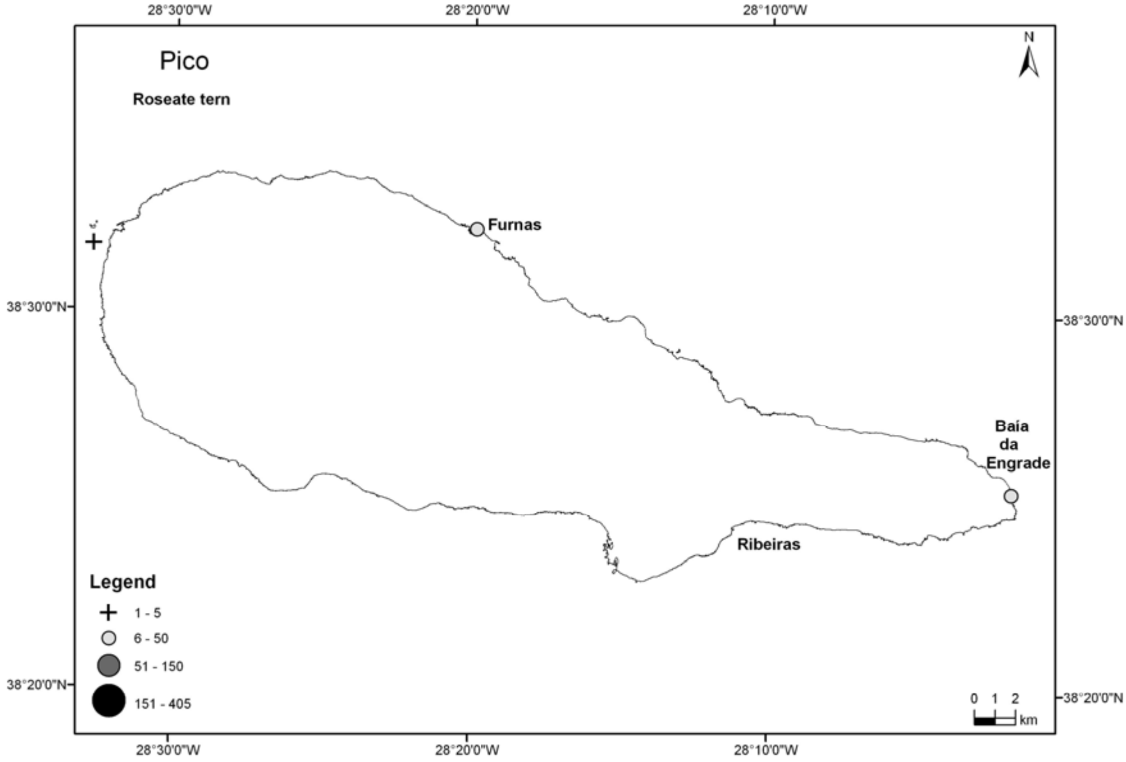


Figure 2.8: Location and peak count of Roseate Terns at colonies on Pico island, 1989-2005.

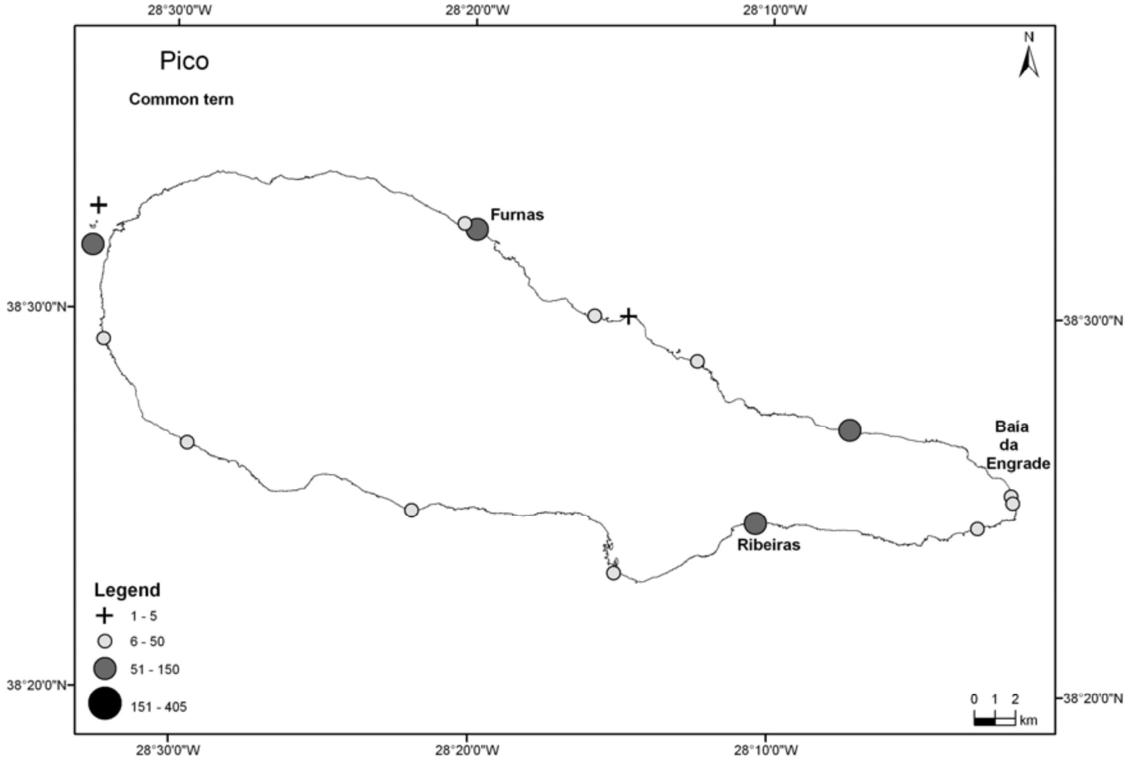


Figure 2.9: Location and peak count of Common Terns at colonies on Pico island, 1989-2005.

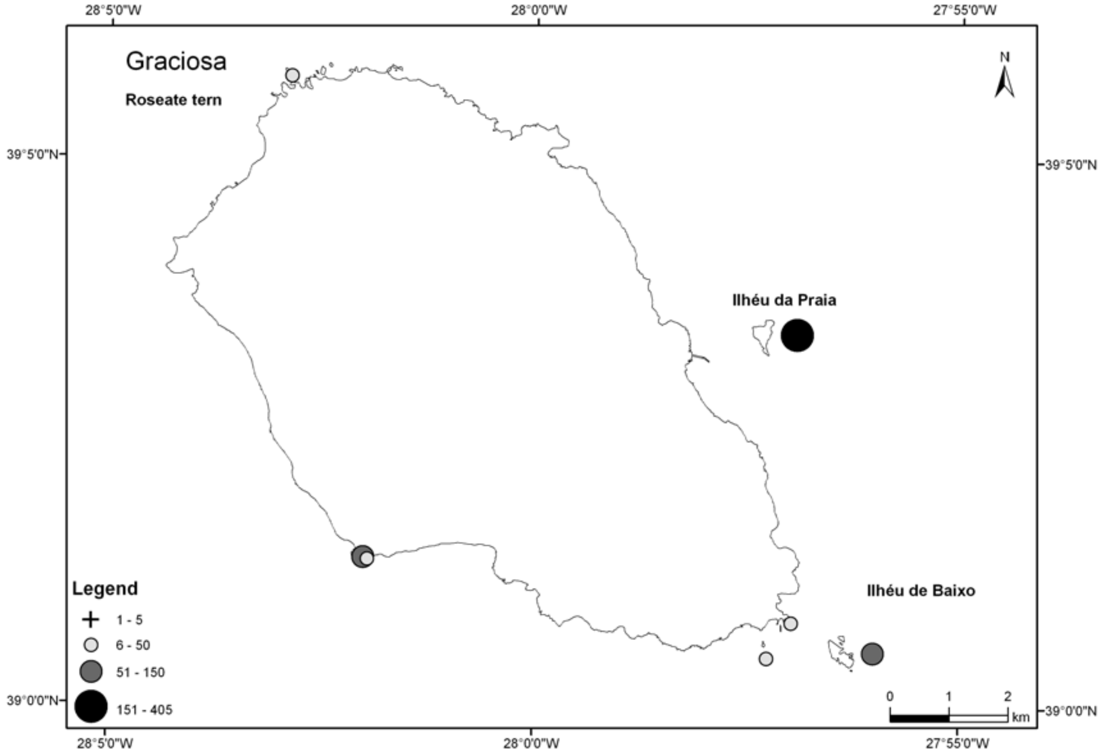


Figure 2.10: Location and peak count of Roseate Terns at colonies on Graciosa island, 1989-2005.

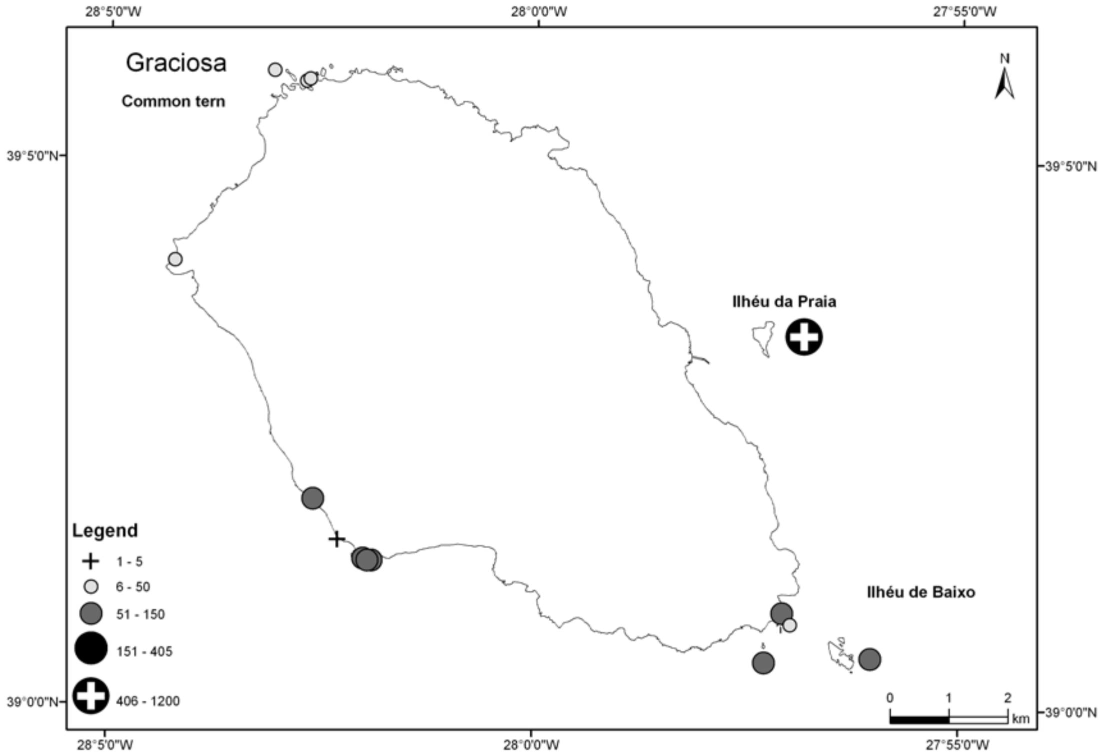


Figure 2.11: Location and peak count of Common Terns at colonies on Graciosa island, 1989-2005.

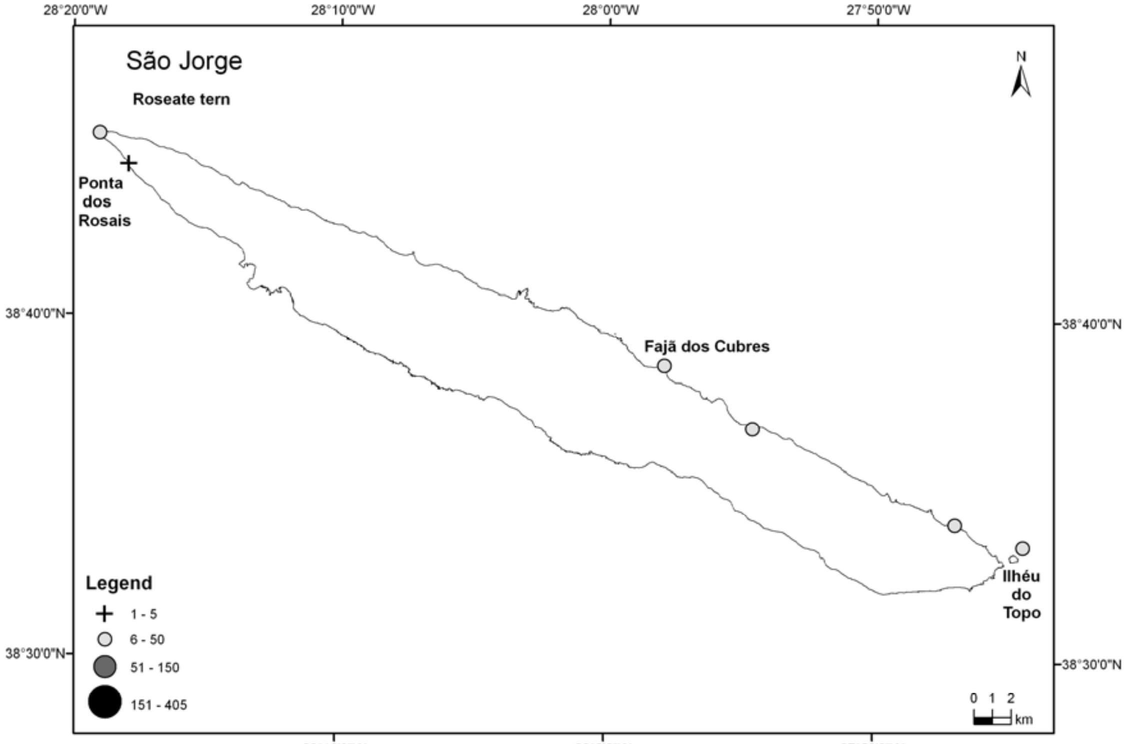


Figure 2.12: Location and peak count of Roseate Terns at colonies on São Jorge island, 1989-2005.

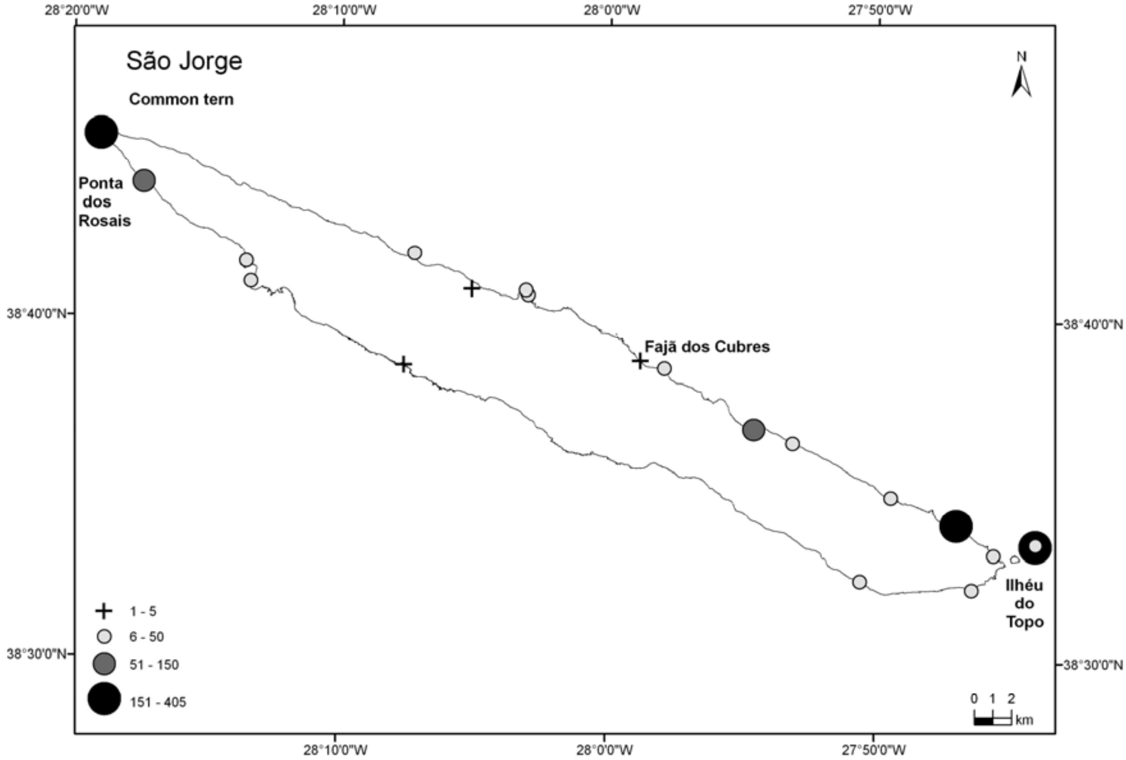


Figure 2.13: Location and peak count of Common Terns at colonies on São Jorge island, 1989-2005.

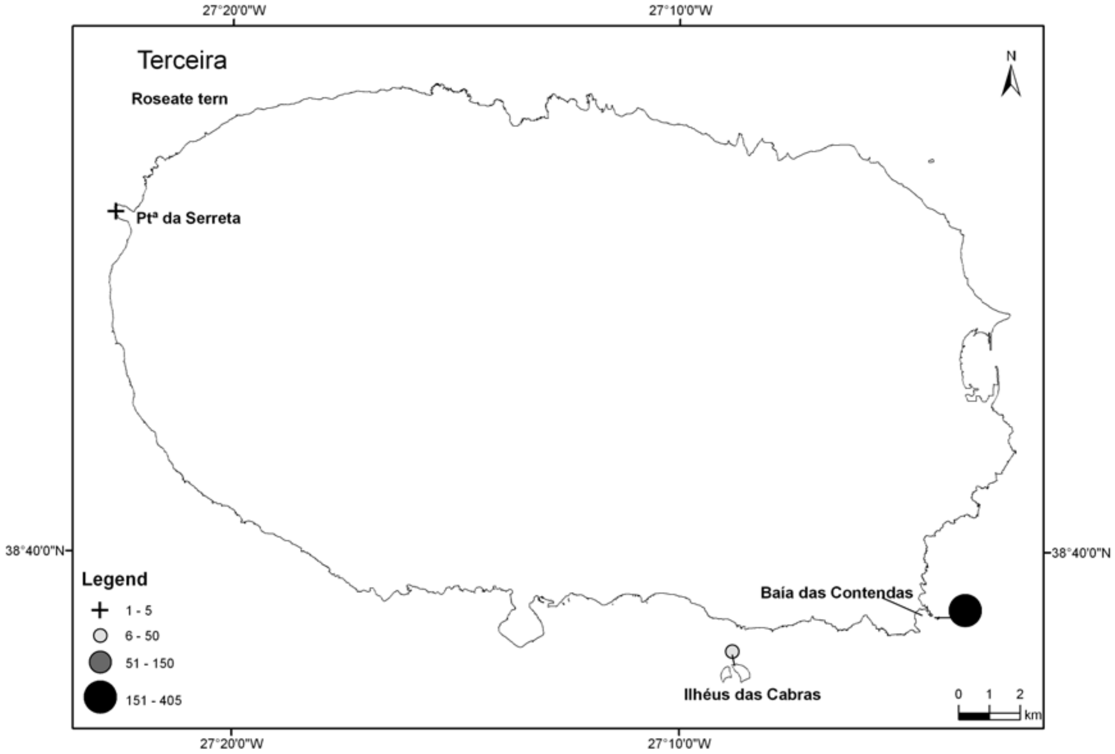


Figure 2.14: Location and peak count of Roseate Terns at colonies on Terceira island, 1989-2005.

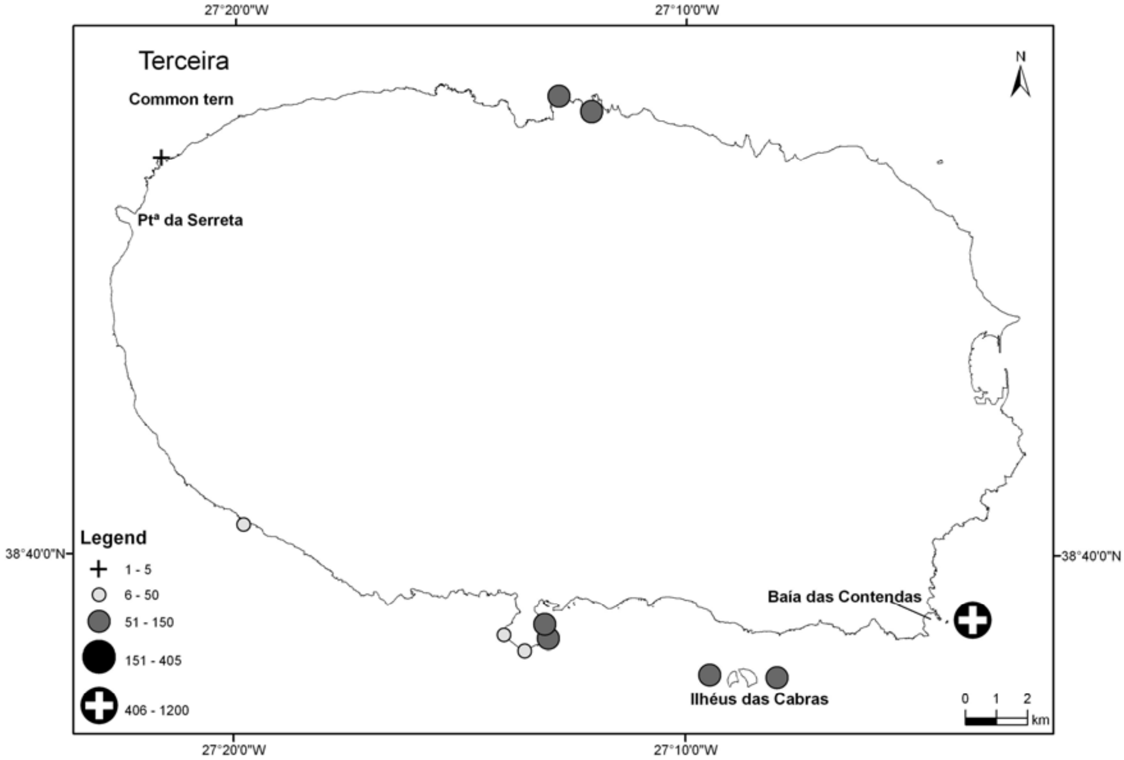


Figure 2.15: Location and peak count of Common Terns at colonies on Terceira island, 1989-2005.

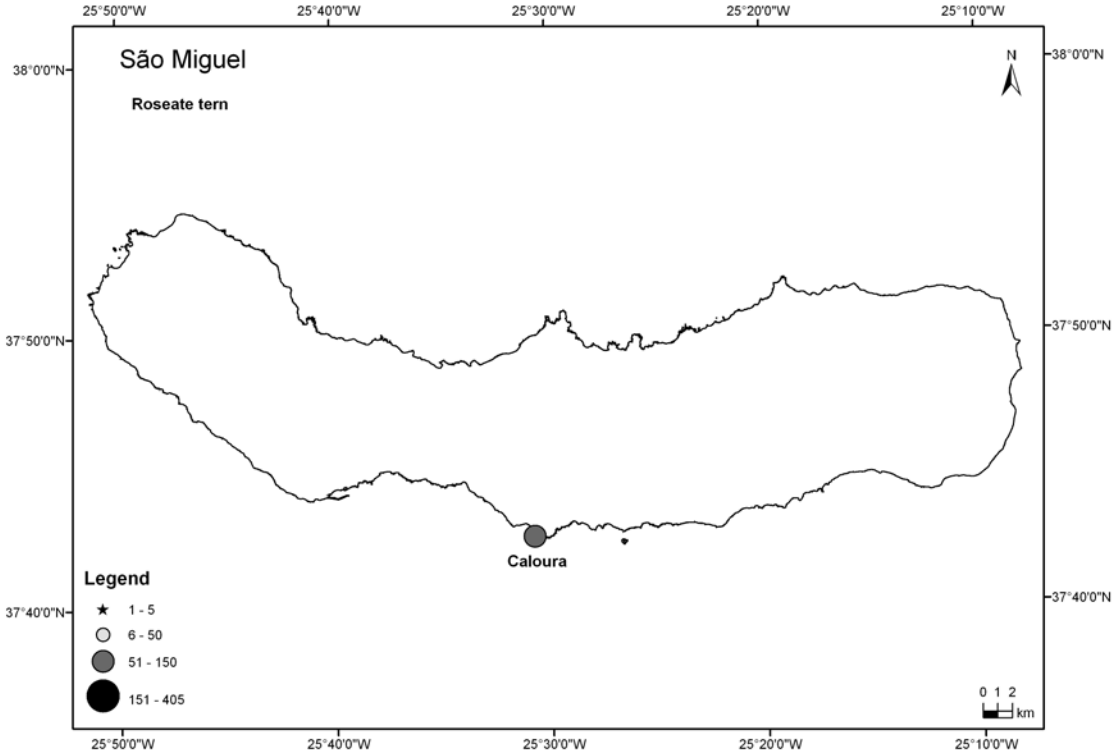


Figure 2.16: Location and peak count of Roseate Terns at colonies on São Miguel island, 1989-2005.

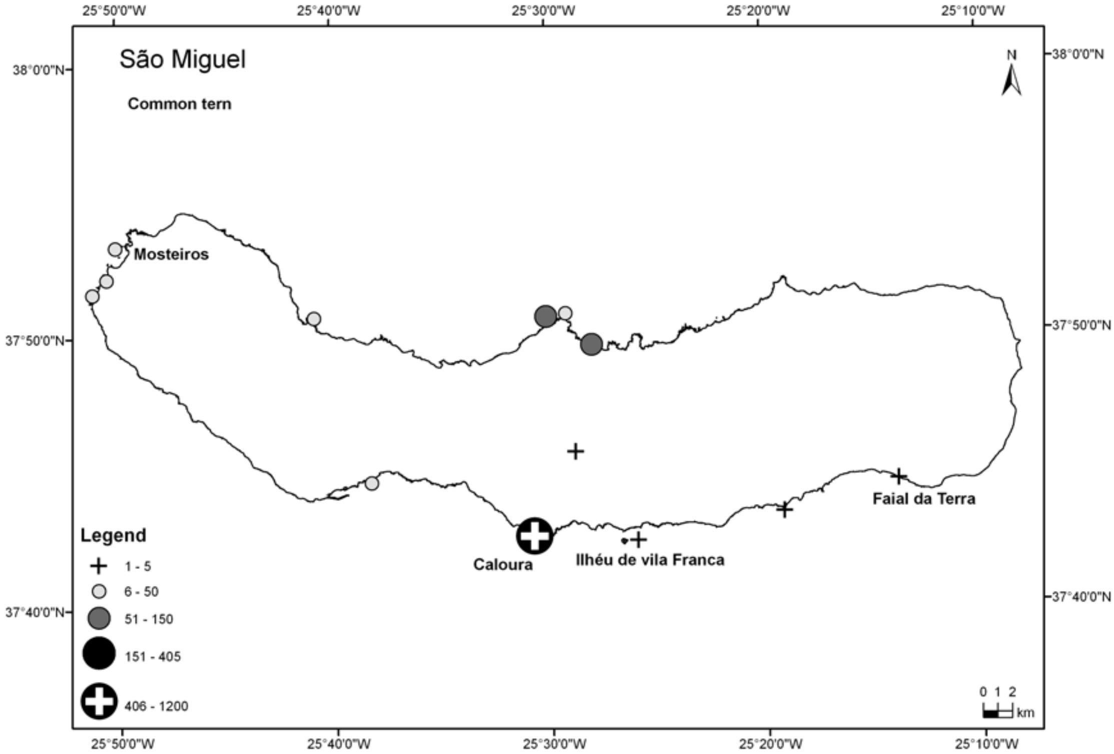


Figure 2.17: Location and peak count of Common Terns at colonies on São Miguel island, 1989-2005.

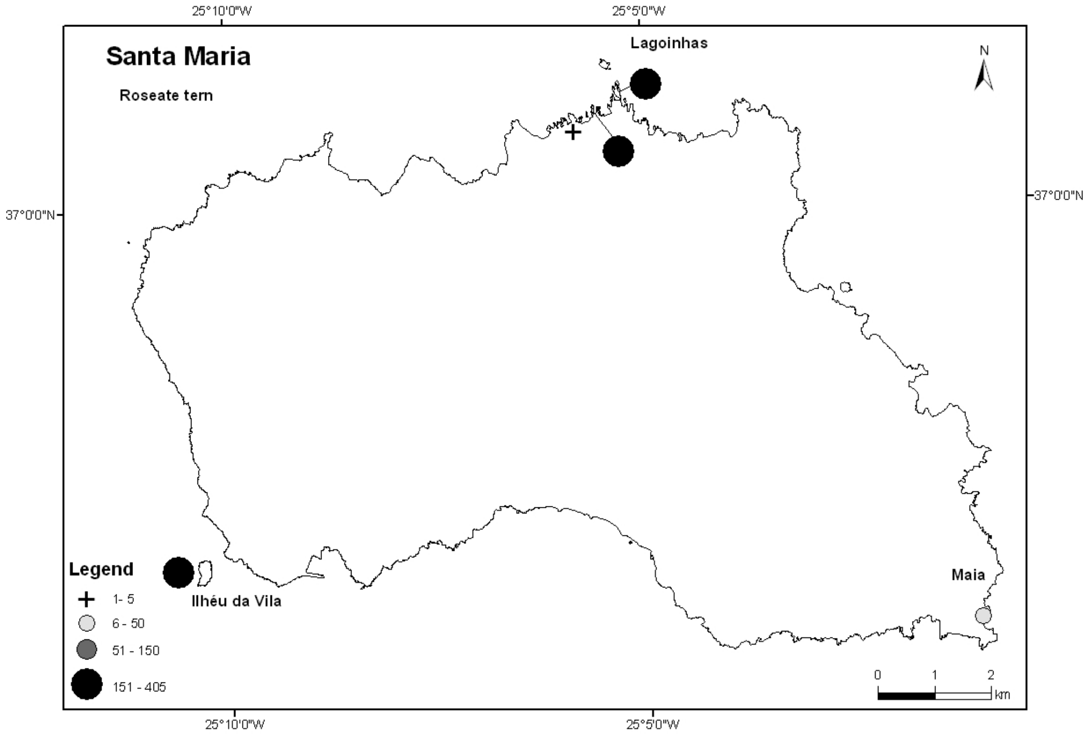


Figure 2.18: Location and peak count of Roseate Terns at colonies on Santa Maria island, 1989-2005.

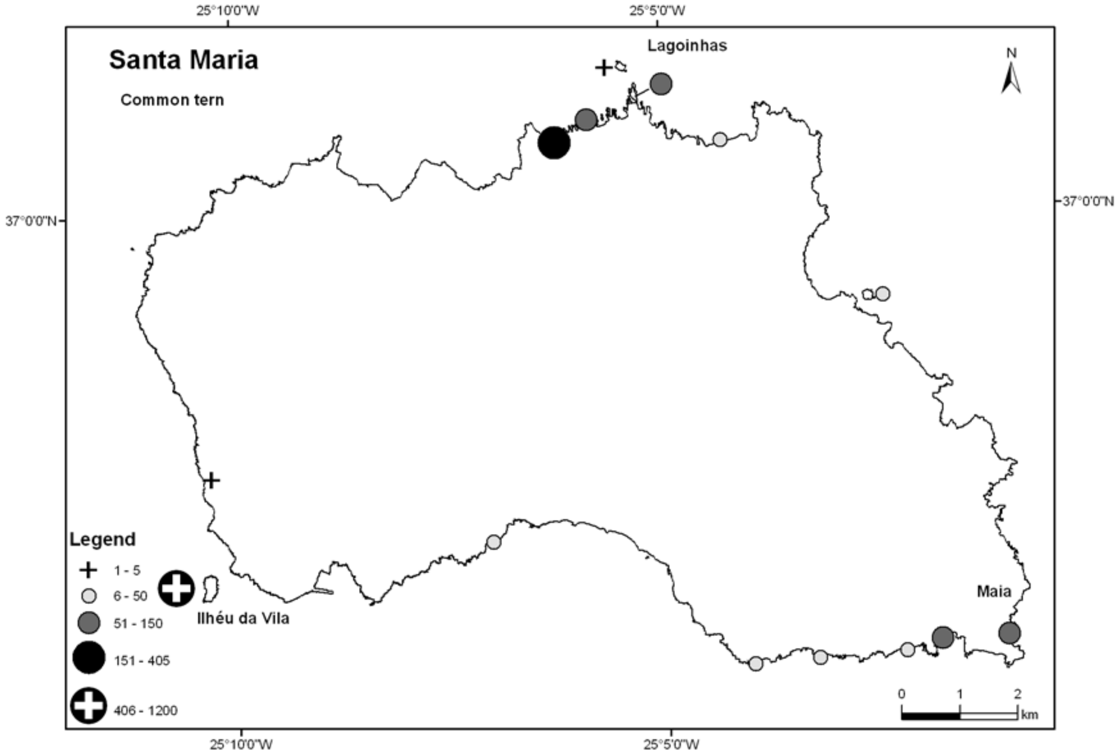


Figure 2.19: Location and peak count of Common Terns at colonies on Santa Maria island, 1989-2005.

Over the period 1989-2005 Roseate Terns have been observed breeding in 49 different locations (see Table 2.3). Roseate Tern colonies in the Azores archipelago are largely confined to islets, sea stacks and precipitous mainland cliffs and are normally inaccessible from land. Some colonies on islets and sea stacks can be observed and monitored from land but the vast majority can only be surveyed by sea; islets normally allow landing but cliff colonies, especially in Flores, are totally inaccessible.

Tabela 2.3: Number of Roseate Tern colonies according to habitat type in each island of the archipelago.

Island	Cliff	Islet	Rocky beach	Lagoon	Total
Corvo	3	0	0	0	3
Flores	10	16	0	0	26
Faial	0	0	1	0	1
Graciosa	2	3	0	0	5
Pico	1	2	0	0	3
São Jorge	2	1	0	1	4
Terceira	0	2	0	0	2
Santa Maria	2	2	0	0	4
São Miguel	1	0	0	0	1
Total	21	26	1	1	49

Some colonies have retained important numbers over the entire period of study but others have only occasionally been used. The most important Roseate Tern breeding sites in the archipelago are: 1) Baixa do Moinho and Alagoa Complex (Flores island), 2) Vila islet (Santa Maria island), 3) Praia islet (Graciosa island) and 4) Contendas Bay islets (Terceira island). These five colonies have consistently held a large percentage of the Azores population over the last decade (see Table 2.4). The island containing the largest number of colonies was Flores, but Graciosa, Terceira and Santa Maria also contained a reasonable number of breeding birds. All the other islands supported relatively low numbers of colonies and birds.

Table 2.4: Total of Roseate Tern breeding pairs in the five main colonies and the respective percentage of the Azores population over the period 1989-2005.

	Alagoa	Baixa do Moinho	Praia	Contendas	Vila	% Azores Total
1989	127	160	0	90	116	49,7
1990	**	260	136	95	126	**
1991	**	**	**	**	**	**
1992	**	**	**	**	**	**
1993	13	5	10	31	193	66,5
1994	95	89	0	30	241	86,2
1995	321	265	0	114	236	91,1
1996	147	163	0	84	141	44,7
1997	198	232	0	120	135	70,0
1998	135	135	0	188	198	75,1
1999	83	119	0	125	167	95,7
2000	136	125	31	351	90	94,2
2001	110	113	25	342	95	84,2
2002	172	179	133	269	201	96,3
2003	68	105	231	58	134	79,3
2004	176	151	402	32	0	85,3
2005	23	66	128	0	92	79,4

** No data available

There have also been colonies that have inconsistently held large numbers in some years. Colonies that have at some point in time held more than 5% of the breeding population are:

Caloura islet (São Miguel)
125 pairs in 2002 (representing 16,6% of the population breeding that year)

Ponta do Burquilhão (Flores)
75 pairs in 2001 (representing 9,2% of the population breeding that year)

Lagoinhas (Santa Maria)
180 pairs in 1997 and 248 pairs in 1996 (representing 18,4 and 20,7% of the population breeding that year)

Capelinhos (Faial)
70 pairs in 1995 and 38 in 1996 (representing 6,8 and 11,5% of the population breeding that year)

Ponta Fernão Jorge (Flores)
77 pairs in 1993 (representing 20,3% of the population breeding that year)

Rabo de Peixe (Flores)
27 pairs in 1991 and 64 in 1994 (representing 7,1 and 12,1% of the population breeding that year)

Baixo islet (Graciosa)
133 pairs in 1989 (representing 13,4 and 11,5% of the population breeding that year)

Ponta Branca (Graciosa)
113 pairs in 1989 (representing 11,4% of the population breeding that year)

Ponta dos ilhéus (Flores)
150 pairs in 1989 (representing 15,1% of the population breeding that year)

Baixa do Moinho and Alagoa islets (off Flores) have systematically held a large proportion of the breeding population of Roseate Tern in the Azores. The islets are small and rocky, but hold a community of native and endemic plants where Roseate Tern chicks can hide for protection. The major problem with these islets is its close proximity to the mainland (see Fig. 2.20), becoming an easy target for human disturbance. Young boys sometimes swim from the mainland to the Alagoa islets. Additionally, fishermen have a tradition of using Baixa do Moinho islet as a fishing spot.

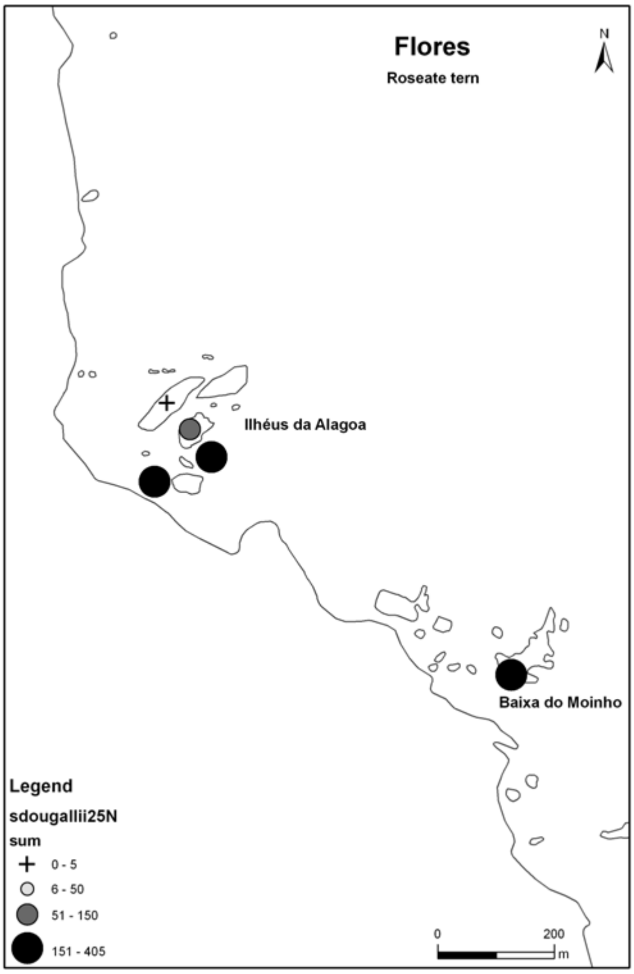


Figure 2.20: Aspect of Baixa do Moinho & Alagoa complex colonies. Please note the proximity of the islets to the island coastline. Alagoa complex encompasses five islets but Roseate Terns have only bred on the southernmost three.

Vila islet (off Santa Maria) is a rocky islet of basalt, with steep slopes and cliffs (Fig. 2.21), the islet is 8 ha in size and is the second largest islet where terns breed. On top of the islet and on steep slopes the rock is overlain with soil, which supports annual plants. Vila islet was used to raise livestock until 1993, when the last 18 goats were removed (Monteiro 2000). After that the vegetation recovered substantially, specially the main species *Spergularia azorica* and *Tolpis succulenta*. At the moment the plant community of the islet is still changing. Vila is also a breeding site for Common Terns *Sterna hirundo* and is the only known breeding site of Sooty Tern *Sterna fuscata* in the western Palearctic. This islet is also an important ground for other Azorean breeding seabirds, such as Cory´s Shearwaters *Calonectris diomedea*, Little Shearwater *Puffinus assimilis*, Bulwer´s Petrel *Bulweria bulwerii*, and Madeiran Storm-petrel *Oceanodroma castro*.

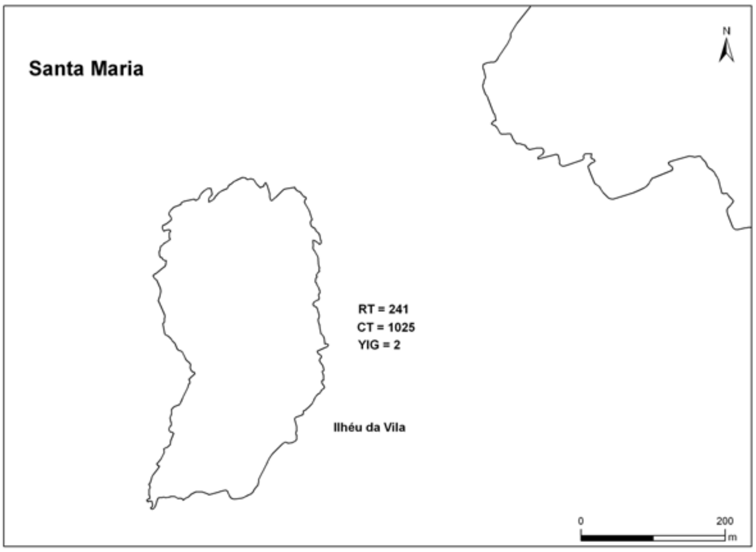


Figure 2.21: Aspect of Vila islet with the peak count of breeding pairs detected for Roseate Tern (RT), Common Tern (CT) and Yellow-legged Gull (YlG).

Lagoinhas islet is another colony in Santa Maria island that held considerable numbers of Roseate Terns in 1996 and 1997 (see Fig. 2.22 and 2.23). However, since 1998 terns did not breed on the islet. 200m to the north of the islet where tern breeds there is another islet with a colony of Yellow-legged Gulls (*Larus michahellis)* and this close proximity might have discouraged terns.

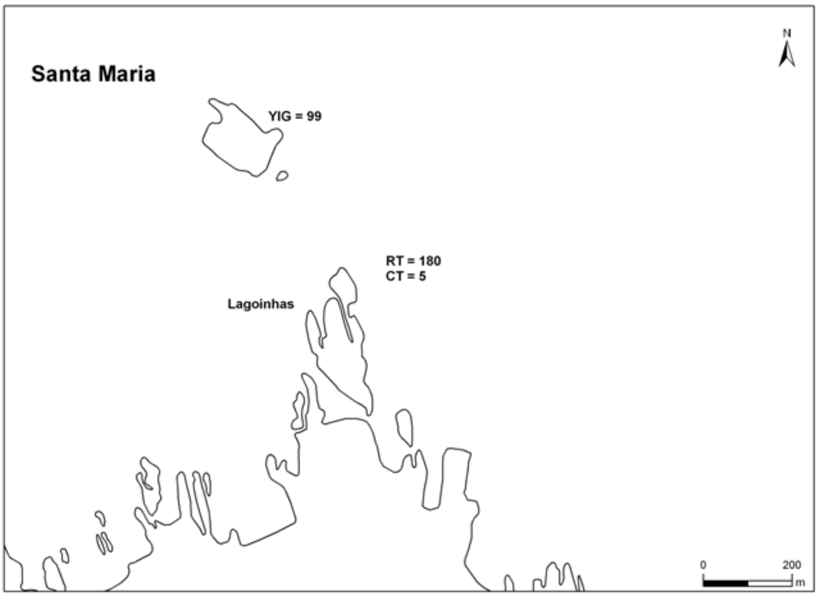


Figure 2.22: Aspect of Lagoinhas with the maximum number of breeding pairs detected for (RT) Roseate Tern, (CT) Common Tern, and (YIG) Yellow-legged Gull (breeding in the northern islet).

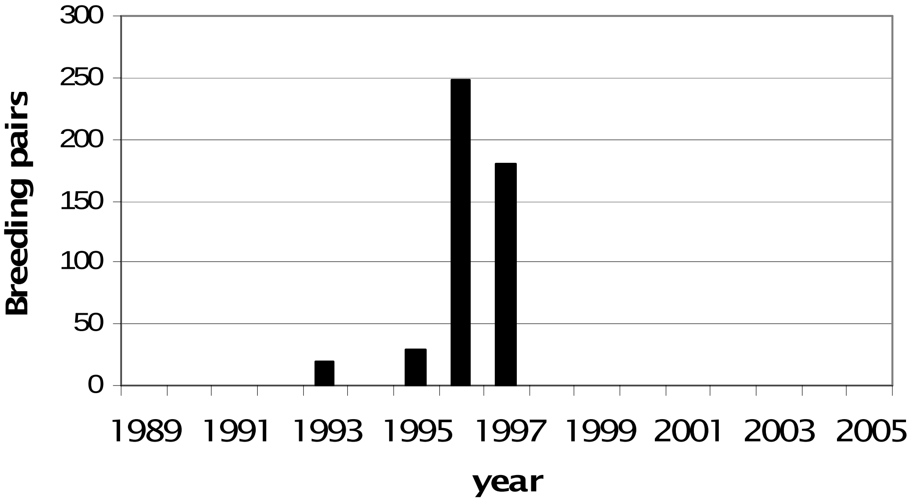


Figure 2.23: Variation in Roseate Tern breeding pairs at Lagoinhas islet, Santa Maria island.

Praia islet (see location off Graciosa island on Fig. 2.10) has an area of 12 ha and it is the largest islet where the Roseate Tern breeds in the Azores. The islet supports several major habitats, some of which are well suited for the Roseate Terns nesting requirements. The islet holds important populations of many other seabird species and is one of only two locations in the Azores where several individuals of the globally threatened Fea´s Petrel *Pterodroma feae* have been caught.

The islet has a gentle slope and has been extensively used by humans since the Azores were inhabited in the 15th century. Rabbits have been introduced to the islet on two occasions (please see chapter VII) and recreational hunting weekends were popular for many decades. It is the only islet in the Azores where a little house was built. The contents of this house are well illustrative of the uses man has chosen to give it. There are several wood benches and long tables to lay outside when the feasts were held. There are large metal grills too. The islet has been “chewed to the bone” with respect to a wide variety of marine life from surrounding waters, from limpets to crabfish, from Fork Beard (*Phycis phycis*) to Ornate Wrasse (*Thalassoma pavo*), regardless of size. Some of these activities are technically illegal, but in many ways Praia islet has been a land of no-man rule. During 1993 Praia islet was disturbed by overnight rabbit hunting during the breeding season (at least twice). Additional disturbance was caused by a helicopter landing late in the breeding season to leave hunters and sport fisherman. General and persistent disturbance by fishermen and local visitors to collect limpets also occurred. Rabbit hunting was stopped in 1994 and rabbits were eradicated in 1997 (see chapter VII).

There is a single warden working on the island that alone must control all types of activity in any part of the island and in the islets and to perform his duties he has an old boat, prone to breakdown. On some nights local people have deliberately vandalized the boat. However, in recent years the situation described here has changed as will be described in chapter VII. The positive results were rapid and very encouraging but it is important to continue the efforts, otherwise the past situation will easily re-emerge, human nature can prove harder to change than Roseate Terns breeding numbers.

The Praia islet colony has shown dramatic fluctuations in the numbers of breeding pairs see Fig. 2.24), but in recent years numbers have increased due to conservation and habitat management efforts (see chapter VII).

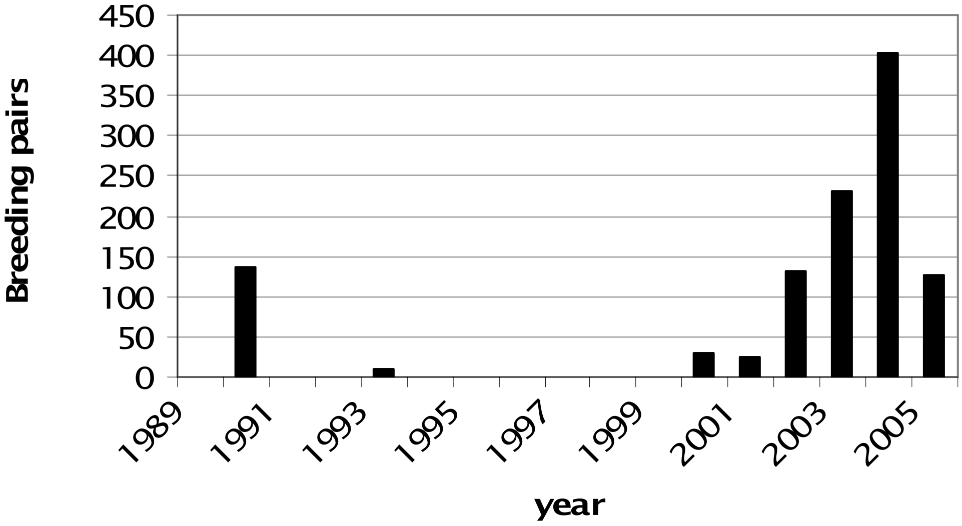


Figure 2.24: Variation in Roseate Tern breeding pairs at Praia islet, Graciosa island. No terns bred on Praia in 198.9 and 1995-1999 and for 1992 and 1993 no data is available.

Contendas islets off Terceira are another important Roseate Tern colony (see Fig. 2.25). These islets are so close to the main island that with low tide it is possible to cross over, managing to get wet only waist down. The islets were formed by erosion and are actually just the continuation of the mainland landscape. They include rocky areas and a sedimentary plateau (about 20m high), where vegetation grows. This plateau is the favoured breeding habitat of the Roseate Tern in this colony. To the south of this there is also a small rocky islet rising 2.5 m above the sea level. It has hardly any vegetation but on some occasions it has been used by a considerable number of both Roseate and Common Terns (up to a few hundreds of each). The islet provides a very poor habitat with few opportunities for successful breeding. Nevertheless, the terns still use them, probably because the availability of food in Contendas Bay provides a stronger stimulus than the negative effect of a poor nesting habitat. The islet has small rocky depressions caused by wave-spray erosion that are used as nests. However, these depressions are extremely impermeable and when the weather is inclement and the rain strong (as is common in the Azores), eggs are lost and chicks drown/are chilled. A way to help prevent flooding would be to fill hollows with rubble and coarse soil. There is hardly any vegetation in the islet and the other only breeding bird present is the Rock Pigeon (*Columba* *livia*). I once found a dead rat in this islet but it was not clear to me if it had arrived alive or had been brought to the islet dead by gulls or fishermen. However, in 2003 I found several predated eggs that had all the signs of having been predated by rats. Both the rocky islet and the erosion-formed islet are frequently visited by fishermen and snorkellers during the terns breeding season. They cross the small gap and walk on to areas where they can sit and fish or swim in the case of the snorkellers. In the late eighties, local fishermen built a bridge between the mainland and the islet, which made access very easy. With time the bridge eroded and finally collapsed in 1995, considerably reducing the disturbance to the terns and over the following years there was a marked increase in breeding numbers. Numbers in this colony have also fluctuated dramatically (see Fig. 2.26).

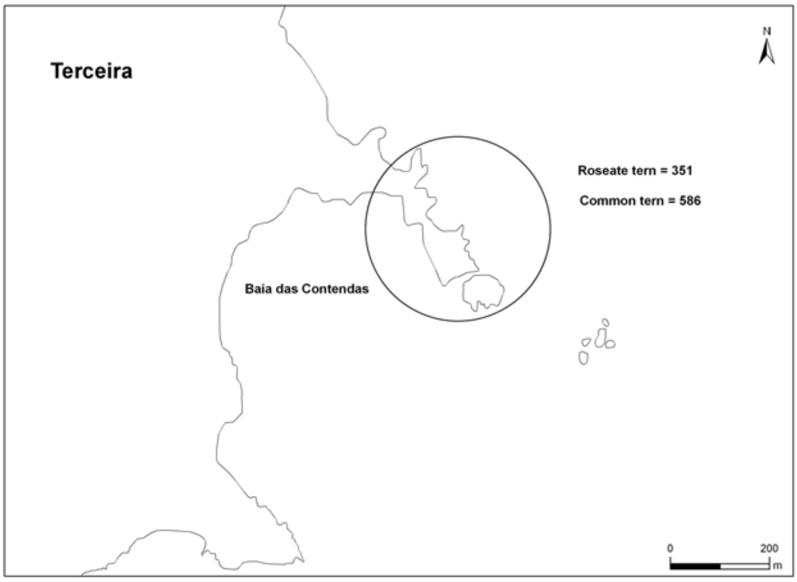


Figure 2.25: Aspect of Contendas colony. Contrary to what the map indicates, the area within the circle is separated from the mainland.

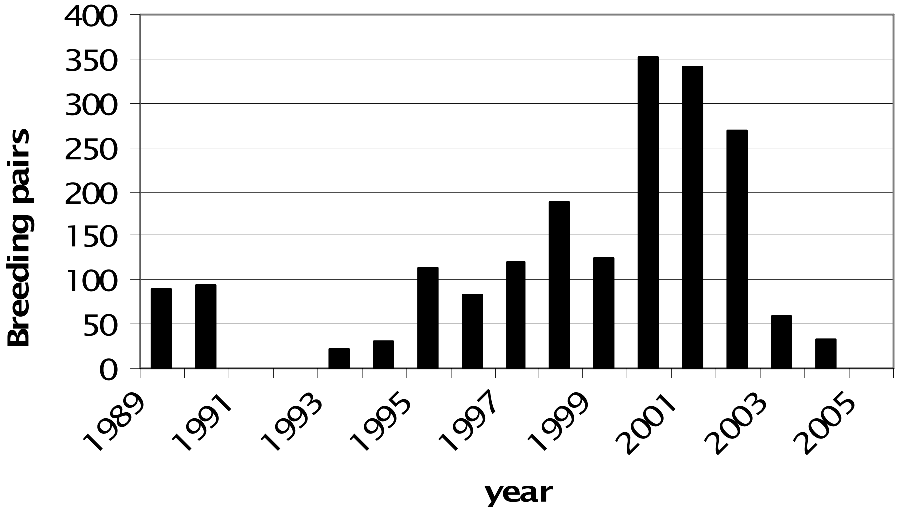


Figure 2.26: Variation in Roseate Tern breeding pairs at Contendas colony, Terceira island. In 1992 and 2005 no terns bred in Contendas and for 1993 no data is available.

All the five main colonies have showed dramatic fluctuation in breeding numbers over the period 1989-2005 (please see table 2.5), but the degree of variation was highest at Praia and Contendas islet.

Table 2.5: Mean values and Standard Deviation (SD) of the number of breeding pairs in the five main colonies of the archipelago over the period 1989-2005.

	Alagoa	Baixa do Moinho	Praia	Contendas	Vila
Mean	129	136	69	130	144
SD	78	65	119	116	63

2.4 DISCUSSION

From the analysis presented in this chapter it seems probable that Roseate Tern distribution in the Azores is in some way limited by predation. All the main colonies are located on islets where mammalian predators are in most of the cases absent. One of the main colonies where numbers have showed a higher degree of variation is Contendas, an islet very close to the mainland where rats have been detected. The situation at this colony is dramatic and in 2005 no pairs were found breeding there; management action is vital because this is one of only 5 colonies that has consistently been important for Roseate Terns in the Azores.

The use of remote islets by nesting terns is a response to predation and disturbance pressures. In the case of Praia islet, the large fluctuation within years is probably due to the intense human use of the islet and the disturbance associated. However in any given year in the Azores there are suitable colonies available that are not utilized by the terns, even if they had been used in the past. This indicates that apart from predation there might be other factors affecting breeding numbers. So far there are insufficient data available regarding breeding success, but it is important to collect these data on breeding success in different colonies in the near future. The comparison of colonies with different densities will help to understand if fluctuations are in some way related to density-dependent factors.

Food availability may also affect Roseate Tern breeding numbers in the archipelago. However, there is no data to consubstantiate this possibility and more research is needed on tern diets, chick feeding frequency and oceanographic conditions that might be affecting food availability to the terns.

The fluctuations in the Azores breeding numbers of Roseate Tern cannot be explained by adult mortality alone, otherwise they would not allow such spectacular recoveries in successive years. However, fluctuations are more likely to be due to intermittent breeding; birds with previous breeding experience refraining from breeding for one or more years. If intermittent breeding is occurring in the Azores then there is an appreciably greater population of breeding birds associated with the archipelago then indicated by counting nests every year. The analysis of the annual percentage of change in breeding numbers show that sudden declines are normally followed by an immediate recovery, indicating that these changes are probably due to deferred breeding as suggested above rather than adult mortality (Nur & Sydeman 1999). Breeding numbers of Roseate Tern at Lady’s Island Lake (Wexford, Ireland) have tended to be very variable and between the mid-1990s and 2003 fluctuated between 50 and 120 pairs (Mavor *et al.* 2004). Intermittent breeding has been suggested to this colony, since there is no evidence of birds moving to breed at other colonies during years when breeding numbers were low at Lady’s Island (Newton 2004).

During the censuses most of the main islets were surveyed; therefore it is difficult to believe that large colonies might have been overlooked in a given year. Census methodology was the same for the period of study but varied between colonies using a combination of flush counts and direct nest count methods. Census timing can affect the results. Previously it was thought that birds breeding in Flores and Corvo laid earlier than terns on the central group and markedly earlier that those breeding on Santa Maria but over the course of this study I have come to realize that this is not the norm. Actually, there does not seem to be a consistent trend across time. The yearly censuses were conducted at different dates and in some cases colonies might have been monitored too early or too late in the breeding season. There are marked annual differences in the breeding chronology of Azorean Roseate Terns, making it difficult to decide when best to do the census. Apparently, the time of breeding of Roseate Terns in the Azores during 1993 differed considerably from the normal pattern of c. 4 weeks of delayed laying from west to east. On the 24 May birds were not yet present in Alagoa (17 June, 13 pairs), while in previous years they had well incubated eggs at this stage. Conversely, in Vila Roseate Terns were advanced compared with previous years (108 chicks, 20 June).

Despite Roseate Tern fluctuation in numbers in the Azores (see Fig 2.27), the overall trend for the species in north-west Europe is upward. Over the recent years, the Britain & Ireland total has been increasing thanks to an integrated effort that includes active habitat restoration and occasional control of predators (please see Fig. 2.28). However, it is becoming clear that conservation efforts directed toward this endangered species only during the breeding season may be insufficient to aid its recovery (Shealer *et al.* 2005).

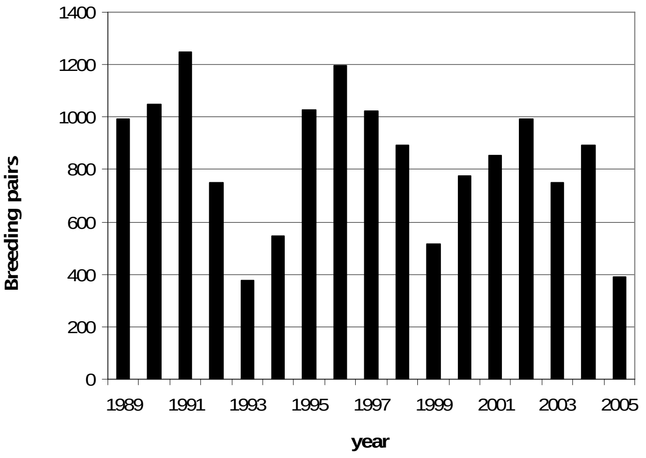


Figure 2.27: Breeding numbers of Roseate Tern in the Azores over the period 1989-2005

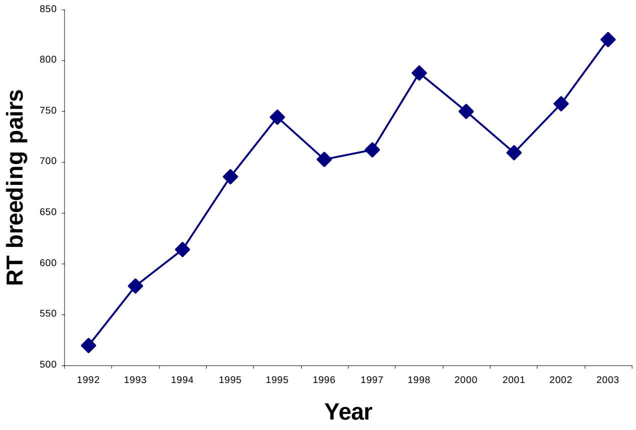


Figure 2.28: Number of Roseate Tern breeding pairs in Britain & Ireland over the period 1992-2003.

(Source: Newton 2004)

There are no studies on Roseate Tern numbers in the Azores archipelago before 1981 that could enable us to clearly assess long-term changes in numbers. There is also no indication that birds breeding in the Azores can also breed in other geographical areas, despite the number of birds that have been ringed. Movement among colonies may account for increases and decreases on specific colonies, but it cannot account for the large fluctuations in total numbers across years.

Food supplies can affect birds breeding numbers by influencing the survival of full-grown birds or their production of young, or through influencing immigration/emigration (Newton 1998). However, its precise effects are difficult to quantify. Food shortage has been linked to dramatic decreases in the breeding success of the Arctic Tern (Monaghan *et al.* 1989). In the specific case of the Roseate Tern in the Azores, more data is necessary to identify the main factors associated with the hypothesis of intermittent breeding.

Large-scale climatic oceanographic variation can dramatically affect seabird population dynamics (Grosbois & Thompson 2005). Aebisher *et al.* (1990) has reported significant effects of climatic variation on reproductive success in seabirds. However, the population dynamics of these long-lived species are more sensitive to variation in adult survival rates than to variation in breeding parameters (Croxal & Rothery 1991). For example, Grosbois and Thompson (2005) have found a negative correlation between Northern Fulmars adult survival and the winter North Atlantic Oscillation (WNAO). The index of the NAO is based on the difference of normalized sea level pressure (SLP) between Lisbon, Portugal and Reykjavik, Iceland; the WNAO is based on values from December through March (Hurrell 1995). It is important to remember that the patterns that emerge from studies of bird populations depend partly on the timescale over which the studies are made (Newton 1998).

Concluding, the breeding population of the Roseate Tern in the Azores has fluctuated dramatically since monitoring began, showing an apparent 6-year cyclicity that has not been detected for other North Atlantic populations (Fig. 2.27). Before we can be sure that this cycle is real or just an artificiality the relative small period of data collection many more years of monitoring will be needed. Marine food-web are complex systems and our present knowledge is very limited. But meanwhile it is important to have a hands-on approach to conservation of terns in the Azores and undertake direct management action in the colonies. At present, the main colonies of Roseate Tern in the Azores cannot be left alone to manage themselves. Man has already caused much damage in recent times, through introduction of mammal predators, grazing of sheep, cows and goats and direct disturbance in the colonies. These factors associated with a potential limitation due to food shortage in some years could put the Azores population at serious risk.

Chapter III

Predation on Roseate Tern *Sterna dougallii* Eggs by European Starlings *Sturnus vulgaris*

3.1 INTRODUCTION

This study looks at the important issue of predation among Roseate Terns *Sterna dougallii* on a particular islet in the Azores. Vila islet is of European importance in that the Roseate Tern is an endangered species and this is one of the few remaining European colonies (around 10% of the European population).

Over the last decade or so studies have indicated that the colony was vulnerable to egg predation but the predators have never been identified. It was therefore decided to do a thorough analysis of the predation levels and the types of predators of the tern nests. Part of the study was also to investigate whether some sort of management of the predation problem was needed. Predation can have a profound impact on seabirds' breeding success and may reduce survival rates or productivity to levels below those required to maintain viable populations (Lauro & Tancredi 2002; Thomas 1972; Whittam & Leonard 1999). Predation can affect productivity directly through losses of eggs, chicks and adults, and indirectly by causing the adults to desert the nests leaving them susceptible to chilling and other predators that would not normally be able to scare the terns away from their nests (Nisbet & Welton 1984). Special concern has been expressed regarding predatory species whose numbers have increased because they benefit direct or indirectly from human activity (e.g. gulls, crows, rats and starlings; Lauro & Tancredi 2002). As a colonial ground-nesting species, the Roseate Tern is very vulnerable to predation, and its current distribution is very much restricted to small islands free from native or introduced ground predators (Newbery 2002). Predation affects Roseate Tern distribution by preventing them from establishing colonies on the mainland and making them shift periodically from one island site to another, with first time breeders being especially susceptible to emigration and colony abandonment following predation losses (Spendelow 2003). Nevertheless, predation and human disturbance still occur at many colonies and are generally important factors limiting breeding success in Roseate Terns throughout the species' range (Nisbet 1981).

Predation at tern colonies has been widely reported (Craik 1995, Guillemette & Brousseau 2001 and references below) and in the specific case of the endangered Roseate Tern losses of up to 77% of chicks have been found as a result of avian predator activities (Whittam & Leonard 1999). At Rockabill, Ireland, one of the main European colonies, impacts have been more severe in some years than others, with occasional predation of incubating adults but the greatest impact is on eggs and chicks (Newton & Crowe 2000; Newbery 2002).

Predators of Roseate Terns include birds such as falcons (*Falco peregrinus, F. tinnunculus* and *F. sparverius*; Nisbet 1992; Shealer & Burger 1992; Newton & Crowe 2000), great-horned owl (*Bubo virginianus*, Nisbet & Welton 1984), Black-crowned Night Heron (*Nycticorax nycticorax;* Spendelow 2003), Herring, Great black-backed and Laughing Gull (*Larus argentatus, L. marinus* and *L atricilla*; Nisbet 1981; Shealer & Burger 1992; Whittam & Leonard 1999), Oystercatcher (*Haematopus palliatus*; USFWS 1999), Sparrowhawk *(Accipiter nisus*; Newton & Crowe 2000), and corvids (*Corvus corax* and *C. brachyrhynchos*; Whittam & Leonard 1999, *C. corone* and *C. monedula*; Newton & Crowe 2000).

Mammal predators include: Brown Rat (*Rattus norvegicus*, Gochfeld 1976), American Mink (*Mustela vison*, Shealer & Burger 1992), Fox (*Vulpes vulpes*) and Badger (*Meles meles*) (Newbery 2002). Additionally, some species of ants (e.g. *Lasius neoniger* and *Solenopsis invicta*) may kill young terns when eggs are pipping or soon after hatching. Nisbet & Welton (1984) reported that losses were more substantial in colonies subject to predation by owls that kept terns away from the nests overnight, allowing the ants access to the eggs and chicks for long enough to kill them. In some years ant predation accounted for as much as 33% of Roseate Tern chick mortality

(Spendelow 1982). Hatchling mortality due to ant predation has also been observed in the Azores but its impact seems to be negligible (VC Neves pers. obs.).

Predation can also affect Roseate Tern population dynamics by reducing adult survival, productivity and consequently future adult and natal recruitment (see for example Spendelow 2003). Roseate Terns are especially sensitive to predation because they have relatively low adult survival rates for seabirds, and therefore need high productivity levels (1.2 fledglings per pair) in order to maintain a stable population (Ratcliffe *et al.* 1998). This value of productivity is much higher than for other tern species such as the Caspian Tern, which only requires an annual production of 0.32-0.74 fledglings per pair in order to maintain a stable population (Suryan *et al.* 2004). Roseate Tern adult survival rates range between 0.81-0.85 at European colonies (Green 1995; Ratcliffe 1997), 0.74-0.85 at north-eastern American colonies (Spendelow & Nichols 1989; Lebreton *et al.* 2003), and 0.71-0.80 at Caribbean colonies (Spendelow *et al.* 2005), while values are much higher for other terns: 0.89–0.93 for Common Tern *S. hirundo,* (Nisbet 2002), 0.87-0.88 for Arctic Tern *S. paradisaea* (Coulson & Horobin 1976) and 0.85 for Least Tern *S. antillarum* (Renken & Smith 1995).

During the last few years, the mixed Common Tern and Roseate Tern colony at Vila islet (Santa Maria island, Azores archipelago) has been affected by increasing rates of egg predation (V.C. Neves pers. obs.). Predation was noted in the islet when annual monitoring was initiated in 1989, by then Adrian del Nevo counted 154 Roseate Tern nests and found “several eggs predated” (IMAR-Açores unpublished data). Monteiro *et al.* (1996b) mention ‘minor episodes of presumed hedgehog (*Erinaccus europaeus*) predation on tern eggs at Vila islet’. But hedgehogs have never been found at Vila islet and it is possible that the European Starling *Sturnus vulgaris* was already causing the predation events mentioned in that study. In 1999, 167 nests of Roseate Tern and 181 nests of Common Tern were counted at Vila islet and 112 eggs (of both species) were found depredated (VC Neves pers. obs.). Hays *et al.* (2002) reported pecked and partially eaten eggs on Vila islet in 1999 and 2000. These two studies mention the fact that a pair of Eurasian Buzzards (*Buteo buteo rothschildi*) was also nesting on the islet and these birds have regularly taken large chicks and adult terns, but it is not suggested that the buzzard ate the eggs. On another island of the archipelago, Flores, Ramos and del Nevo (1995) observed a Grey Heron (*Ardea cinerea*) depredating eggs and chicks. Additional potential tern predators in the Azores include Little Egret (*Egretta garzetta*), Cattle Egret (*Bubulcus ibis*), Yellow-legged Gull (*L. michahellis atlantis*), Ruddy Turnstone (*Arenaria interpres*), Short-eared Owl (*Asio otus*), European Starling, Black Rat (*R. rattus*), cats (*Felis catus*) and mustelids (Weasel *Mustela nivali*s and Ferret *M. furo*).

Estimating productivity of the endangered Roseate Tern is of particular importance to conservation and establishment of management plans. The seemingly increasing rates of predation observed at Vila islet in recent years are presumed to have serious adverse effects on the Azores population, since Vila islet is one of the most important tern colonies in the archipelago. Therefore, during 2002 and 2003 we estimated nesting success and conducted regular observations in the colony to identify the main predators of Roseate Tern eggs at Vila islet.

3.2 METHODS

3.2.1 Study Area

Vila islet is a rocky islet of basalt, with steep slopes and cliffs, located about 300 m southwest of Santa Maria Island (36°55'N, 25°10'W), in the Azores archipelago in the middle of the North Atlantic. It has an area of 10 ha and a maximum altitude of 60 m (Monteiro 2000). On the top of the islet and on some of the steep slopes the rock is overlaid with soil, which supports annual plants. Vila islet has been declared an Important Bird Area (IBA 014) and holds a mixed colony of Common and Roseate Terns that also include the only known breeding pair of Sooty Tern *S. fuscata* in Europe (Monteiro 2000). A pair of Eurasian buzzards breeds regularly on a cliff in the east side of the islet (Monteiro 1996). Vila Islet has no mammalian predators and holds about 20% of the Azores Roseate Tern population (201 pairs in 2002 when the total breeding population in the archipelago was 991 pairs). Egg laying in the Azores normally occurs between early May and late June (Hays *et al.* 2002; Ramos & del Nevo 1995).

3.2.2 Direct observation of predation events

To identify the main predators during the egg-laying and incubation stages we conducted observations from hides overlooking the colony, during 2002 and 2003. We used a portable hide that enabled the observer to sit in different areas adjacent to the colony to a minimum distance of 4 m from the nests. Apart from the hides we also conducted observations from the highest point of the islet, which provides a view over some parts of the colony. Observations were made by naked eye and with binoculars (Swarovski, 7x50). In 2002 we conducted observations in three periods 1-18 May, 28 May-2 June and 15-30 June, totalling 86 hours of observation and covering different times of the day. In 2003 we conducted observations for 12 days between 14 and 26 May, totalling 37 hours of observation and covering different times of the day. During the observations we noted the presence and abundance of predators in the colony and terns' reaction to their presence.

3.2.3 Daily nest survival rate

Both Common and Roseate Terns breed on the islet, but only nests of Roseate Tern were monitored. In 2002, nests were detected by searching the islet systematically at 3-day intervals from 25 April onwards. The first egg was recorded on 4 May. Nests were marked with tongue depressors and the number of eggs in each clutch was recorded; nest fates were then determined by visits every 1-5 day. To minimize disturbance during 2003 only a small part of the colony was studied and the fate of 45 nests monitored.

We estimated the survival of Roseate Tern clutches assuming a constant daily survival rate and using the Mayfield (1961) approach. Nests that were already depredated when first discovered were not included in the analysis. Exposure days were calculated using the last observed active date for nests with uncertain fate and using the mid-point between the last observed active and the first observed inactive dates for nests of known fate (Manolis *et al.* 2000).

The daily nest survival rate was estimated using a general linear model (GLM) with nest fate as the response variable and the number of exposure days as the binomial denominator. The effects of site (NW and SW sub-colonies) on nest survival rates were tested and the minimal adequate model was selected. The model was fitted with a logit link function and a binomial error distribution. Year was defined as factor with two levels. A forward stepwise model selection procedure was adopted, with explanatory variables being retained if they produced a significant reduction in the residual deviance. Significance of terms was tested using the Chi-square statistic. If the errors of the model were overdispersed, the model was rescaled by the residual Chi-square divided by the residual degrees of freedom. The model was then refitted and F ratio tests were used to test the significance of the terms (Crawley 1993).

3.2.4 GLM model for hatching success (integrating renesting)

Replacement clutches might play an important role in the productivity of some species. By replacing clutches birds increase their probability of breeding success. The probability of renesting is higher when failure occurs early in the breeding season, decreasing to zero later in the season. Estimates of productivity based on fate of individual nesting attempts will therefore be underestimates. To estimate hatching success I used a simulation model allowing for renesting, based on the structure of those used by Beintema and Müskens (1987), Green (1988) and Green *et al.* (1997). The parameters used in the model were obtained from this study and those extracted from the literature.

Females were randomly allocated a start date (the date on which incubation of the first clutch started) and a stop date (the date after which further clutches were not laid) from a frequency distribution calculated from the parameter mean and standard deviation. No empirical data on nesting phenology were available, so nest period durations were simulated over the range of plausible values. The longest possible laying season was assumed to last for 56 and was then shortened by one-day increments until it was only one day in duration. The actual laying season duration would be sure to lie between these values (that on Rockabill is normally 29 days).

Clutch size was assumed two unless a randomly generated probability exceeded the estimated proportion of two-egg clutches (0.40), in which case the clutch size was one egg. During each day of the laying and incubation period (23 days, SD 0.5: Cramp 1985), the clutch was subjected to a year-specific likelihood of failure by testing whether a random probability exceeded the daily nest survival rate until it failed or hatched.

Addling or infertility on Rockabill was 8% (S Newton pers. comm.) and this value was used for Azorean Roseate Terns. A random likelihood was generated for each egg in the clutch and the egg was classed as being infertile or addled if this was below 0.08. If the nest survived the incubation period and at least one of the eggs was not addled or infertile, the nest was classed as hatching a chick. In this event, one was added to the number of pairs experiencing hatching success.

Pairs that did not hatch a chick from their first nesting attempt owing to predation, or abandonment were assumed by the model to relay if the date of failure plus the replacement period (10 days, SD = 2, J Spendelow pers. comm.) was earlier than their allocated stop date. Pairs with a nest that survived the incubation period that lost the whole clutch to addling or infertility were assumed to continue incubating for a further 10 days before abandoning it, with the nest being subjected to the same daily nest survival rate as viable eggs through this period.

This procedure was repeated for each pair in each year, and hatching success was calculated by dividing the number of pairs that hatched at least one chick by the total number of pairs. Hatching success of the population was estimated 999 times, and the mean and SD of these bootstrapped replicates were calculated as the estimate of hatching success with SE. A program written in Microsoft Visual Basic 6.0 was used to perform the simulations.

3.3 RESULTS

3.3.1 Direct observation of predation events

Starlings were observed in the colony every day we conducted observations. In both years of this study only starlings were observed eating tern eggs, both Common and Roseate. However gulls and turnstones were also observed in the islet and could have been undetected as predators.

Observations of predation events showed that single starlings or small groups of up to six individuals were responsible for egg predation. Starlings were wandering and foraging in the colony for seeds and insects without being mobbed by terns. When walking among the nesting terns, starlings would sometimes detect an egg and very quickly start eating it, normally leaving it broke in two halves. On other occasions, starlings would approach the area of a nest even when a bird was incubating; the incubating bird would fly up to mob one of the starlings at which point the other individuals moved quickly towards the nest and broke the eggs. On two occasions starlings were also seen returning to the exact places where predation had occurred, and sometimes even removing egg remains away from the nest and eating those. In one predation event the egg contained a large embryo, and was left by the starling without being eaten.

During 2002 we observed 42 instances of a Roseate Tern mobbing starlings, and seven complete sequences of egg-predation by starlings, the earliest occurring at 08:52 and the latest at 18:55 local time. Where one egg was depredated out of two, the remaining egg would continue to be incubated, but would normally be depredated later. From 30 two-egg clutches predated, the second egg survived in only four cases. The two eggs would either be depredated simultaneously (starlings sometimes broke the second egg without finishing eating the first one) or some hours later (up to one day maximum).

During 2003 we observed 15 instances of a Roseate Tern mobbing starlings and two complete sequences of egg-predation by starlings. During 2003 we worked in an area where we could also observe Common Terns and we observed 20 mobbing events and 5 complete sequences of egg-predation by starlings. For both species the earliest mobbing event was observed at 07:30 and the latest at 19:54.

On one occasion a group of three starlings was seen distressing a Kentish Plover (*Charadrius alexandrinus*), which performed the broken wing behaviour but depredation of the eggs was not confirmed.

A pair of Yellow-legged Gulls was breeding on a cliff on the west coast of the islet; this is the first breeding record of Yellow-legged Gull for Vila islet. On a few occasions, we observed gulls being mobbed by groups of up to 30 terns but we never had any evidence that they were preying on tern eggs. Gulls were never observed landing near to tern nests but they were observed trying to steal fish from flying terns on several occasions (never successfully). Even if gulls are not successful depredating tern eggs they certainly cause some disturbance, keeping terns away from incubation and providing additional chances for starlings to take eggs. The same is true of buzzards that were mobbed by terns on several occasions, even when they did not approach the colony but were just passing by.

3.3.2 Daily Nest survival rate and hatching success

In 2002, the fates of 165 clutches were recorded (43 in the SW sub-colony) and in 2003 we monitored the fates of 45 clutches. Daily nest survival rates did not vary between the two sub-colonies but differed significantly among years when rescaling the deviance for overdispersion ($F_{1, 236} = 5.79$, $P < 0.05$, Scale parameter = 2.79). The daily nest survival rate in 2002 was 94.2% (LCI = 93.1, UCI = 95.0) while that in 2003 was lower at 90.0% (LCI = 85.0, UCI = 92.0). Over the 23-day average incubation period, the predation rate was 73.1% in 2002 and 90.2% in 2003.

The hatching success of Roseate Terns in 2002 and 2003, based on the model, is presented in Fig. 3.1. The nesting season on Rockabill is 29 days, and if that on the Azores is similar the model predicts that the nesting success in 2002 would be 0.42 and that in 2003 would be 0.17.

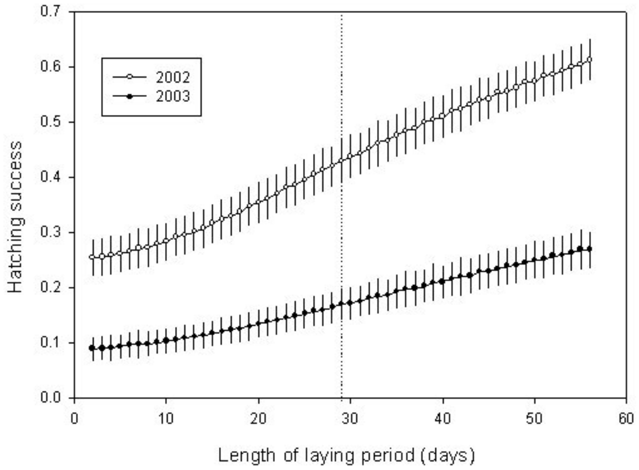


Figure 3.1. Relationship between the length of the laying period and nesting success of Roseate Terns on the Azores, as predicted by the model. The dotted line is the average length of the nesting season on Rockabill (Ireland).

3.4 DISCUSSION

The values of hatching success estimated in this study, 0.42 in 2002 and 0.17 in 2003, are considerably lower than the 0.97 hatching success on Rockabill over the period 2001-2003. Hatching success in Vila during 2002 and 2003 was remarkably low compared with other European colonies. In Rockabill during 2003 and 2004 no predation on viable eggs was observed and the percentage of failed eggs was only 8.5% during 2003 and 11.6% during 2004 (Patrick *et al.* 2003, Barker *et al.* 2004). A study conducted by Nisbet and Drury (1972) found values of hatching success between 88% and 100% in three colonies studied. However other studies have also demonstrated a strong impact of an aerial predator on Roseate Tern breeding success. At one colony in Connecticut, Black-crowned Night Herons reduced fledging success of Roseate Terns by about 90% (Spendelow 2003). According to Nisbet (1981) predation lowers regional production of terns in northeastern America by no more than 20-25%, which is a much lower value than the one found in this study. The predation rates found in this study are also considerably higher than the 24% of tern eggs eaten, presumably by corvids, reported by Whittam and Leonard (1999).

The rates of predation we found are so high that even if chick survival was 100% (which is unlikely), productivity would not reach the 1.2 fledglings per pair required to maintain a stable population and the colony at Vila would be expected to decline even if birds don’t emigrate in response to repeated failure. Vila colony has been monitored annually since 1989 and the average number of breeding pairs for the period 1989-2003 is 163.5±55.8 (minimum of 62 pairs in 1991 and maximum of 241 pairs in 1994). Average number of breeding pairs at Vila decreased from 179.9±67.1 for the period 1989-1995 to 149.1±43.2 for the period 1996-2003. Overall average in the whole archipelago for the same intervals increased from 815.3±269.8 to 866.5±203.5 breeding pairs. It is possible that immigration from other colonies has compensated predation losses and prevented so far a major decline in Vila that would be expected to result from the high predation rates we found. Egg predation is known to occur in Vila since the colony started being monitored and starlings were most probably already causing it. But it is possible that predation rates were higher in 2002 and 2003 than in previous years and we can not exclude the possibility that this was partly due to our presence in the colony during the pre-laying and incubation phases (but see below).

3.4.1 Researcher disturbance

Nisbet (2000) states that there is little scientifically acceptable evidence that human disturbance cause substantial harm to terns. Shealer and Haverland (2000) showed that intensive study of Black Terns (*Chlidonias niger*), involving trapping, banding and repeated nest visits did not have detrimental impacts on reproductive success. However when predators are present this situation may change dramatically. The presence of a human intruder could be a behavioural key, which triggers the flocking, and foraging response in individual birds (Reichel & Glass 1990). These authors considered that starling predation, in conjunction with human disturbance, could be a substantial factor reducing black noddy (*Anous minutus*) breeding success. During this study we were always very aware of our potential impact on the terns. Since we suspected that starling predation might be enhanced by our presence we reduced presence in the colony to a minimum and took care to avoid flushing terns from their nests. Nevertheless there is no easy way of studying predation and simultaneously evaluating the observers’ impact on it.

3.4.2 Factors contributing to the emergence of the predatory behaviour

European Starlings were first reported breeding at Vila islet in 1903 when Ogilvie-Grant visited the islet and “found many nests placed on the ground under heaps of loose stones, and containing fresh eggs or young birds” (Hartert & Ogilvie-Grant 1905). During 2003 we estimated that Vila islet held about 50 breeding pairs of starlings, with nests distributed over the whole area of the islet. In some cases starlings were observed breeding in cavities that have on other occasions been used by Bulwer´s Petrel (*Bulweria bulwerii*) and Madeiran Storm-Petrel (*Oceanodroma castro*). Starlings also roost on the islet in a cavity located in a western cliff that can hold as many as 500 individuals (VC Neves pers. obs.).

Starlings tend to roost up to 200 m above sea level (Feare 1984); in the Azores they roost abundantly on remote sea cliffs and on islets (VC Neves pers. obs.) and their roosting areas overlap with tern breeding areas. So far starling predation on tern eggs has not been detected at other colonies in the Azores. No predation has been recorded at the tern colony on Caloura islet off São Miguel despite the fact a few hundred starlings roost in the islet and adjacent coast. However, breeding of European starlings at Caloura islet has never been confirmed and this, together with the fact that Caloura is much rockier and has little vegetation to provide alternative prey for starlings may contribute to the absence of starling predation.

The reasons for the emergence of this predatory behaviour are not fully understood but the following factors might be involved: 1) Overlap of tern and starling breeding seasons; 2) Starling foraging range when breeding: adults rarely forage more than 500 m from the nest and spend most of the time within 200 m of the nest (Feare 1984). Vila islet colony is located approximately 300 m from the mainland; 3) Past history of disturbance to the colony, Vila islet was used for grazing livestock until 1993 (Monteiro 2000) and 4) Breeding starling’s energy requirements. When breeding, starlings consume large quantities of invertebrates, presumably because of their high protein content (Feare 1984). The estimated calorific content of a Roseate Tern egg is 36.9 kcal (egg size from Nisbet & Cohen, 1975). Assuming a Field Metabolic Rate of 56.5 kcal/day for starlings (from equation in Nagy 1987) and an assimilation efficiency of 73% (Taitt 1973) a Roseate Tern egg would represent an estimated 48% of a starling's daily energy requirements. However during the predation events we observed starlings were usually displaced by parent terns before eating the whole egg. As such, each egg is shared between several starlings and some of the contents lost onto the ground.

3.4.3 Starlings as predators of seabird eggs

Predation by the European Starling on eggs of Arctic Terns breeding in the Farne Islands, Northumberland, has been reported by several authors (Cullen 1956, Gill 1968, Horobin 1971). Cullen (1956) first reported starlings "breaking, opening and drinking" the contents of Arctic Tern eggs on the Inner Farne. Gill (1968) found that starlings predated 42% of the eggs, a rate of predation that compares well with the values found in this study. Later, Horobin (1971) also reports low values of hatching success in the Inner Farne due mainly to starlings' egg predation (1966=44.4%, 1967=47%; 1968=15.6%). In recent years there has been a decline in numbers of Arctic Terns at Farne Islands, but this has been attributed to declining food availability (Ratcliffe 2004a).

In the Pacific Ocean, Micronesian Starlings (*Aplonis opaca*) were observed eating Black Noddy and Red-footed Booby (*Sula sula)* eggs (Reichel & Glass 1990). The attacks we observed, mostly by small groups of birds, were very similar to the ones described by Reichel and Glass (1990) who report that groups of 2-5 Micronesian starlings were present at the nest during predation events.

On Ascension Island, Indian Mynahs *Acridotheres tristis* (closely related to starlings) are known to eat abandoned eggs of Sooty Tern and they have also been observed disturbing incubating birds and predating on viable eggs (Hughes *et al.* 1994). However the percentage of eggs taken by mynahs is relatively small. This form of predation could become serious if ever there was a big increase in the mynah population (Hughes 1997). On St. Helena Island, the Indian Mynah will also take eggs and chicks of the St. Helena Plover *Charadrius sanctahelenae* (Hayman *et al.* 1986).

3.4.4 Terns' defence behaviour

In the Vila colony, buzzards and gulls are mobbed by groups of up to 40 terns but starlings are never mobbed by more than a single bird. Terns do not seem to sense starlings as a real threat and show no reaction to starlings wandering amongst nests, unless they come very close or approach nests temporarily unattended. In another study incubating terns failed to recognize the turnstone as a predator, no matter how closely these approached (Farraway *et al.* 1986). Some studies have looked at individual variation in tern reaction to predators (Meehan & Nisbet 2002) but fewer studies have looked at the predator morphological and behavioural features that trigger nest defence.

Gill (1968) found a trend towards less predation at higher densities. He also remarks that the “passive” behaviour of terns sitting tight during incubation was an effective counter to the starling. However in two occasions Gill (1968) observed starlings driving incubating terns off their eggs. Hughes *et al.* (1994) also observed mynahs disturbing incubating birds and in the Azores we recorded four episodes of predation when terns were induced to leave the nest by a group of 2-3 starlings. While the tern mobbed one of the starlings the others ate the eggs.

3.4.5 Predator control and other forms of management

Vila islet colony has been classified as a Special Protected Area (SPA) and as an Important Bird Area (IBA PT068) and holds a Roseate Tern breeding population of European importance; for the period 1989-2003 Vila islet held on average 22% of the Azorean breeding population. Vila islet is one of the less disturbed Azorean colonies regarding human interference. However, despite its isolation and apparent undisturbed status, Vila colony has a natural predation factor that induces high clutch losses and requires conservation management. Predator control has long been considered necessary for the survival of the north eastern American population of Roseate Terns (Nisbet 1981) and many studies have reported on management strategies in tern colonies and the results of their implementation. When avian predators were involved, mostly gulls and crows, management strategies have included culling, deterring birds from nesting and destruction of their nests until the terns reach an advanced stage of incubation after which point the terns can drive away any gulls that attempt to nest near them (Morris *et al.* 1992; Whittam & Leonard 1999; Guillemete & Brousseau 2001; Finney *et al.* 2003). Although not all of these management efforts have been successful, strategies against gulls seem to have a significant effect on tern productivity. However, as these studies point out, conservation of tern colonies requires regular management efforts.

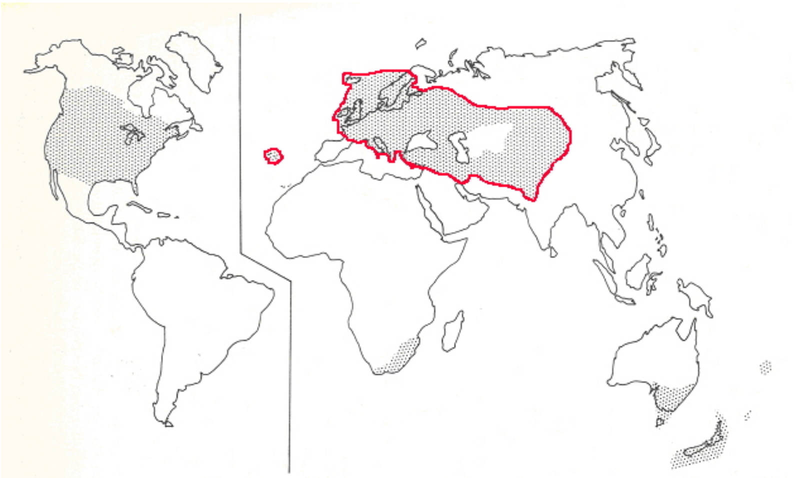
The perceived link between predation and threats to bird populations has led to predator removal being instigated in conservation contexts but recently more emphasis has been put into non-lethal control. Avery *et al.* (1995) suggested that non-lethal control might be an effective method for managing egg predators at tern colonies and conducted a successful taste-aversion experiment on Common Ravens *Corvus corax* eating California Least Tern eggs, using Quail *Coturnix coturnix* eggs injected with methiocarb. In the Azores, some form of controlling the impact of starlings on Roseate Terns seems necessary if the Azores population of Roseate Terns is to be maintained. Lethal control of starlings would be difficult to implement in Vila and offers few chances of success since the islet is located less than 300 m from the mainland and could be easily re-colonized. Therefore the possibility of controlling starling predation using control taste aversion should be investigated.

Chapter IV

ARE EUROPEAN STARLINGS BREEDING IN THE AZORES GENETICALLY DISTINCT FROM BIRDS BREEDING IN THE MAINLAND? INSIGHTS FROM mtDNA STUDIES

4.1 INTRODUCTION

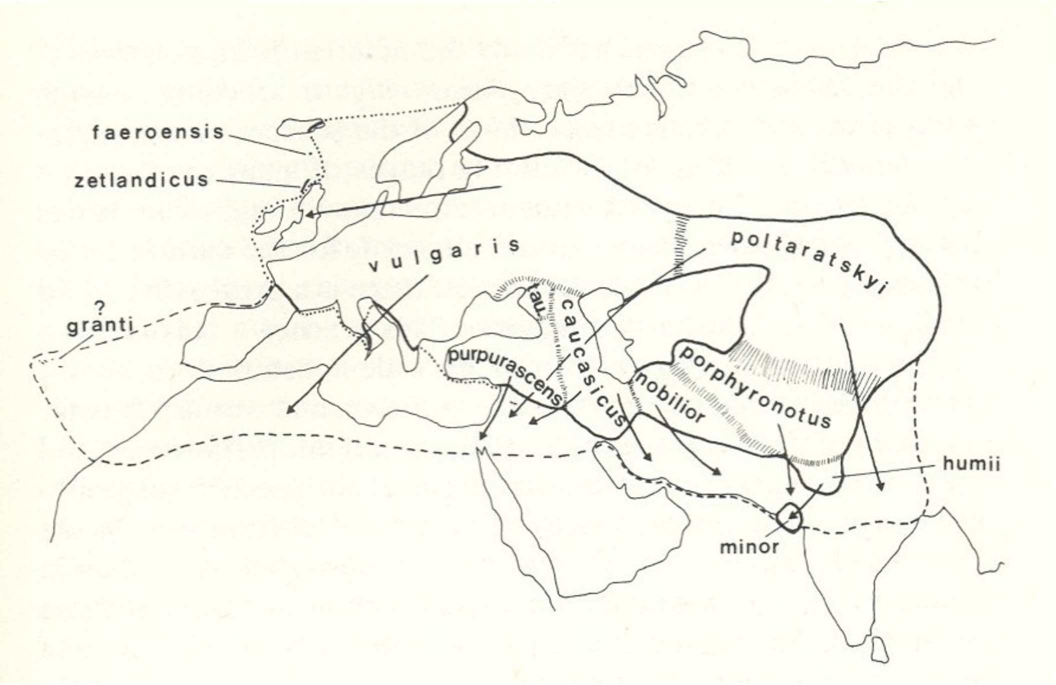
The European Starling *Sturnus vulgaris* is native to Europe and western Asia (see Fig. 4.1) but, following introductions by Man, has successfully colonized North America, New Zealand, the south tip of Australia and parts of southern Africa (Feare 1984).



From: Feare 1984

Figure 4.1: Present world distribution of the European Starling, including in red the natural range in the western Palaearctic and dotted the areas successfully colonized following introduction by man.

The European Starling has the largest geographical range of any *Sturnus* species, crossing various natural barriers that are considered to have led to the evolution of several subspecies (Feare 1984). The main differences between subspecies are the colours of the glossy iridescent sheens on different parts of the plumage of adults (Feare 1984). However, these differences are subtle and there is considerable overlap between subspecies. Birds in most subspecies are migratory but the breeding and wintering ranges of many overlap to a certain extent (see Fig. 4.2).



From: Feare 1984

Figure 4.2: Distribution of the different subspecies of the European Starling and their approximate direction of autumn migration.

Overall, the European Starling increased in most of its European range up to the early eighties (Feare 1984), but populations started to decline throughout Europe over the last two decades (Robinson *et al.* 2002). From the middle of the 20th century there has been a south-westernly range extension and they have been breeding in the Iberian Peninsula. The Spanish breeding population is currently estimated to be between 400,000 to 1,200,000 pairs and still increasing (Estrada *et al.* 2004).

According to Berthold (1968, as cited in Feare 1984) this increase in Europe can possibly be attributed to climatic change, with milder winters reducing the distances that starlings have to migrate to avoid inhospitable conditions. Having reduced migration journeys, birds would then be able to arrive earlier to breeding grounds and increase their chances of producing a second brood. This increase in the reproductive output could then promote the current observable expansion.

Feare (1984) suggests that in the past starlings have occupied a range as extensive as the present one, which seems to be corroborated by the existence of three possible subspecies breeding at the extreme western limits of the geographical distribution (Fig. 4.2). Feare also suggests that the contraction of the previous range of distribution was probably due to climatic reasons. If this was the case, then, later, the population would have expanded southwards again from the few isolated populations that remained. This expansion began in the British Isles somewhere around 1830 (Parslow 1968, as cited in Feare 1984) and appears to be still continuing (Estrada *et al.* 2004).

The closely related Spotless Starling *Sturnus unicolor* is very similar to the European Starling, but adult birds in spring lack spots and also have longer body feathers than their more widespread relative (Feare 1984). Hybridisation between *unicolor* and *vulgaris* has been detected in northern Spain populations but it is now known to what extent it occurs (de la Cruz-Cardiel *et al.* 1997). It is generally believed that the Spotless Starling has evolved from a *vulgaris*-like ancestor and is presumably a relic of a former invasion of Europe by *Sturnus* starlings: if this occurred before the last glaciation, the present geographical distribution of this species may represent the ice free refuge in which it was able to survive (Feare 1984).

Due to their isolation from the mainland, island populations frequently diverge over time (genetically and morphologically) from populations of respective mainland species due to genetic drift, changed selection pressures, or both. Given enough time, isolation on islands can lead to speciation between the island and mainland (Adler 1992), speciation between islands in an archipelago (Cox 1990), or even speciation between habitats within an island (MacArthur & Wilson 1963 e.g., Hawaiian *Drosophila*).

The presence of the European Starling in the Azores archipelago constitutes an intriguing geographic occurrence. The species does not breed in mainland Portugal or in the other Macaronesian archipelagos, such as Madeira and the Canaries. As mentioned above, until recently it did not even breed in Spain. If the European Starling colonized the Azores islands naturally, then these islands would constitute the western natural limit of the Palearctic distribution of this species. Simultaneously, the Azores is also close to the southern limit of the species. The question then is did starlings arrive to the Azores naturally, or were they brought in by people? And if they arrived naturally how much genetic divergence has accumulated between the Azores and other European populations? It is also intriguing that they are not breeding, for example, in Madeira (located around 900 km southeast of the Azores). Starlings have been observed in Madeira during wintertime but do not breed in the archipelago (Bannerman & Bannerman 1966).

There are not many studies on Azorean starlings but they have been described as a relic population (Feare 1984). The Azorean starlings have been described by Ernst Hartert (1903) as a sub-species, *Sturnus vulgaris granti*. This separation was based on colouration and a shorter outer (tenth) primary (Feare 1984). However, Vaurie (1959) questioned the validity of this difference since there is considerable overlap with the nominate *S.v.vulgaris*. Bannerman (1966, as cited in Feare 1984) notes that the Azorean starling has pronounced purple reflection on the back, and more purple in the flank than *vulgaris*. Bannerman also refers to behavioural differences, particularly voice and nest site. More recently, Feare (1984) argues that these slight differences are noteworthy, but even more important is the geographical position of the Azores resident population. Feare (1984) believes that the Azores starling may be a remnant of a former wide distribution of starlings that subsequently contracted to the north and east. Furthermore he argues "if *granti* were a remnant of a former more south westerly distribution, this would place this race on an equal footing, in terms of recent historical developments, with *zetlandicus* (from the Shetland and Outer Hebrides islands) and possibly *faroensis* (from the Faeroe islands)".

At this point it is important to mention that the Azores population is resident as opposed to the mainland Europe populations that generally migrate southwards as indicated by the arrows on Fig. 4.2. The endemic *zelandicus* and *faroensis* populations from the Shetlands and the Faeroe islands are also considered to be resident but receive migrants during winter (C. Feare pers. communication). As illustrated in chapter III, European Starlings have recently been found to predate on Roseate Tern *Sterna dougallii* eggs and as will be discussed in chapter VI, control taste aversion does not seem to be effective in minimizing its impacts. Stronger control measures might prove necessary in the short term and it is therefore important to clarify its taxonomic status before lethal control measures are planned and undertaken.

This chapter addresses the phylogenetics of the European Starling in the Azores by sequencing the mitochondrial DNA (mtDNA) gene ND2 of four populations: *granti* from the Azores (samples from Terceira and Santa Maria islands), *vulgaris* from Spain, *zetlandicus* from Fair isle and *vulgaris* from south west England (Bristol). The main aim of this preliminary study was to investigate historical relationships and assess genetic diversity within and among populations.

4.2 METHODS

4.2.1 DNA sampling

We sampled blood from live individuals in the wild from four populations of three named subspecies: Azores archipelago - *granti*, Spain - *vulgaris* and the UK (mainland Bristol - *vulgaris* and Fair Isle – *zetlandicus*). Sample collection details are listed in Table 4.1. All samples were collected from breeding birds.

Table 4.1: Collection locality, date and approximate distance between sampling areas.

Code	Ring	Date	Locality	Others	Approximate distance in km (from Terceira island)
Az C	F016701	8.5.03	Terceira Mist net	Male	-
Az 2	F016702	8.5.03	‘’ ‘’	Male	-
Az 3	F016703	10.5.03	‘’ ‘’	-	-
Az 6	F016706	1.6.03	Terceira	Chick	-

			nest		
Az 7	F016707	1.6.03	‘’ ‘’	Chick	-
Az 4	F016704	14.5.03	Santa Maria *nest*	Female	260
Az 5	F016705	25.5.03	‘’ ‘’	Female	260
Spain 10	3218703	2003	Spain Aiguamolls de l'Empordà[*]	Female	1200
Spain 9	3242591	2003	Spain - Garrotxa		2400
Spain 11	3242723	2003	‘’ ‘’		1200
Spain 12	3242590	2003	‘’ ‘’		1200
Spain 13	3242722	2003	‘’ ‘’		1200
Fair 14	F5134	-	UK, Fair Isle		2925
Fair 15	F5137	-	‘’ ‘’		2925
Fair 16	F5049	-	‘’ ‘’		2925
Fair 17	F5010	-	‘’ ‘’		2925
Bristol 19	F4985	-	UK, Bristol		2380
Bristol C		-	‘’ ‘’		2380
Bristol 20	46	-	‘’ ‘’		2380
Bristol 21	73	-	‘’ ‘’		2380
Bristol 22	100	-	‘’ ‘’		2380
AF407048[**]	Data from Sorenson & Payne 2001	-	USA, Michigan		4790

[*] Aiguamolls de l'Empordà and Garrotxa are located in Catalonia, about 45 km from eachother.

[**] Accession number at the GenBank on National Centre for Biotechnology Information NCBI http://www.ncbi.nlm.nih.gov/

Note: There are no familiar relationships amongst sampled individuals.

Amongst the Muscicapoidea superfamily, *Creatophora* with only one species *C. cinerea* (Wattled Starling) and *Sturnus* genus are the most closely related phylogenetically (Cibois & Cracraft 2004) and the Wattled Starling was therefore chosen as an outgroup.

4.2.2 Laboratory Authenticity Criteria

Cooper and Poinar (2000) have called attention to the paramount need of using authenticity criteria when conducting DNA studies. And Gilbert *et al.* (2005) have recently reinforced this message to the science community. In this thesis we followed their advice regarding: 1) isolation of working areas; DEEB Molecular Lab. has two different rooms to separate samples and DNA extraction procedures from PCR amplified products and avoid contamination, 2) Negative control extractions and amplifications, to screen for contaminants entering the process at any stage. We also took a cautionary approach when later examining the sequences in the computer and did not include in the analysis variable regions, where variance was not clear enough and could be due to other factors that were not real haplotypes pair base differences.

4.2.3 Preliminary PCR's and Gene chosen

Given that relationships between a single species were being analysed, mitochondrial DNA was chosen because it evolves monophyly 4× faster than the average nuclear gene (Palumbi *et al.* 1991, Hudson & Turelli 2003) and can therefore better detect species-level phylogenies for taxa that have recently diverged (Moore 1995). We conducted trial PCR's and sequenced two mitochondrial protein-coding genes, cyt b and ND2, in a few European Starling blood samples. The mitochondrial cytochrome-b (cyt b) gene has been more widely used to study species-level phylogenies in bird groups than has ND2 (Moore & DeFilippis 1997) and its rate of sequence divergence has also been well characterized (Fleischer *et al.* 1998). However, in this study it was found that ND2 was more variable than cyt b. Despite the more generalized use of cyt *b*, ND2 is in fact one of the most variable genes (in terms of amino acid sequence) after ATPase 8 and ND6, which are relatively small and thus provide less information than ND2 (Sorenson *et al.* 1999). Therefore, we chose ND2 (second subunit of mitochondrial nicotinamide adenine dinucleotide dehydrogenase) to try to clarify our question regarding the origin of Azorean starlings. We conducted additional trial PCR's for ND2 (see Table 4.2), but PCRs for the fragments did not work well. Most of the ND2 gene was amplified and sequenced successfully and therefore elected to address our hypothesis and test if Azorean starlings are genetically distinct from the mainland birds. Primers used are detailed in Table 4.2.

Table 4.2: Primer pairs used to amplify and sequence each gene region.

Region	Primer[a]	Sequence[b]	Portion (bp)	Source[c]
Cyt b	H15916	5'ATGAAGGGATGTTCTACTGGTTG-3'	912	1
	L14990	5'CATCCAACATCTCTGCTTGATGAAA-3'		2
	H15916	5'ATGAAGGGATGTTCTACTGGTTG-3'	484	1
	L15383	5'GGACAAACACTAGTAGAATG-3		3
ND2	H5766	5'GGATGAGAAGGCTAGGATTTTKCG-3'		4

L5216	5’GGCCCATACCCCGRAAATG-3’	550	4
H6313	5’CTCTTATTTAAGGCTTTGAAGGC-3’		4
L5758	5’GGNGGNTGAATRGGNYTNAAYCARAC-3’	555	4
H6313			4
L5216	5’CTCTTATTTAAGGCTTTGAAGGC-3’	1026	4
	5’GGCCCATACCCCGRAAATG-3’		

[a] The letters L and H refer, respectively, to the light and heavy strands, and the numbers refer to the base position at the 3’ end of the primer in the complete chicken mt-DNA sequence (Desjardins & Morais 1990). [b] degenerate primer positions area: K=G or T; M=A or C; N=A, C, G or T; R=A or G; Y=T or C. [c] (1) Edwards *et al.* 1991; (2) Kocher *et al.* 1989 ; (3) Cibois *et al.* 1999; (4) Sorenson *et al.* 1999.

4.2.4 DNA extraction

Total genomic DNA was extracted from alcohol–preserved (Azores and Spain) and BLB buffer preserved (Bristol and Fair Isle) blood samples using proteinase K digestion following the manufacturer’s protocol (DNeasy® tissue kit by Qiagen).

4.2.5 PCR amplification and sequencing

Following DNA extraction, we used a polymerase chain reaction (PCR)-based approach to complete mitochondrial genome sequencing of the ND2. PCR’s were performed in a 25 µl volume/sample containing 9.6 µl of the mastermix (1 µl of buffer, 0.6 µl of $MgCl_2$, 1 µl of each dNTP (10 µM), 5.95 µl of water, 0.05 µl of *Taq* DNA Polymerase_Q-Biogene) and 0.4 µl of DNA template. Amplifications were carried out for 40 cycles under the following profile: an initial 94°C hot start for 180s, 94°C denaturing for 30-45s, 45-56°C annealing for 60s, extension at 72°C for 60s, and terminal extension at 56°C for 60s and 72°C for 5m. Negative controls (no DNA added to the mastermix) were included with each PCR reaction to monitor the possibility of DNA contamination.

The PCR products were purified by excising bands from agarose gels and purifying using the QIAquick Gel Extraction Kit (Qiagen) and then sequenced by an automated sequencer. Amplified products were purified on 2% agarose gels and electrophoresed for 30 minutes at 100 volts; bands containing target products were excised from the gel under UV light, and DNA recovered using QIAquick spin columns (Qiagen). Finally, purified gel bands from PCR products were sent to the University of Dundee for cycle sequencing (in both directions) on an ABI 3730 automated sequencer.

4.2.6 Phylogenetic and statistical analysis

Chromatographs were visualized, aligned and corrected using Sequencher, version 4.1 (Gene Codes Corporation, Ann Arbor, Michigan). Corrected sequences were pasted into Word and saved as text files in FASTA format (>sequence name <paragraph return> sequence). Sequences were then imported into MacClade version 4.0 (Sinauer Assoc., Massachussetts) to visualize differences between sequences. The "match first" option was used to highlight differences. Files were saved as NEXUS files (without the match first feature) for use in tree-building programs. The program TCS (version 1.18) was used to construct a haplotype network (see Fig. 4.3) and estimate gene genealogies (Clement et al. 2000). The program PAUP* (Phylogenetic Analysis using Parsimony, version b10) was used to build an evolutionary tree (see Fig. 4.4), using Distance as the optimality criterion and simple pair wise differences model of evolution.

4.3 RESULTS

Partitioning the 1026 pair bases sequenced by coding position revealed that 16 (1.5%) were variable and there was a total of 9 different haplotypes (see Table 4.3). All individuals from the Azores had identical sequences. In our analysis we also included a sequence of a European Starling collected in Michigan, USA, obtained through GenBank (accession number: AF407048). There was one shared haplotype between Spain and Fair Isle and another between Bristol and the Fair Isle. However, there were no shared haplotypes between the Azores and any of the other populations. There was more variation within than among populations (see Table 4.4). It is apparent from the F_{ST} analysis (see Table 4.5) that there is considerable gene flow between the populations. Table 4.6 includes details on the mean nucleotide composition of the various populations, as well as number of haplotypes and gene diversity.

The outgroup chosen, *C. cinerea*, proved to be too different from *S. vulgaris* (see Appendix 4) and could not therefore be used in the construction of tree phylogenies. For subsequent studies we suggest using *S. unicolor* as an outgroup because this species is thought to have originated from *S. vulgaris* during the last glaciation (Feare 1984).

Table 4.3: Variable sites over 1026 bp of ND2

	Position (bp)															
Sample	**15**	**108**	**184**	**243**	**262**	**448**	**539**	**556**	**654**	**675**	**741**	**742**	**771**	**849**	**952**	**980**
AZSTC	T	G	A	**C**	T	G	C	A	G	A	T	T	A	T	T	T
AZ2	T	G	A	**C**	T	G	C	A	G	A	T	T	A	T	T	T
AZ3	T	G	A	**C**	T	G	C	A	G	A	T	T	A	T	T	T
AZ4	T	G	A	**C**	T	G	C	A	G	A	T	T	A	T	T	T
AZ5	T	G	A	**C**	T	G	C	A	G	A	T	T	A	T	T	T
AZ6	T	G	A	**C**	T	G	C	A	G	A	T	T	A	T	T	T
AZ7	T	G	A	**C**	T	G	C	A	G	A	T	T	A	T	T	T
SPAIN9	T	**A**	A	T	T	G	C	A	**A**	**G**	**C**	T	A	**C**	T	**C**
SPAIN10	**C**	**A**	A	T	T	G	C	A	**A**	**G**	**C**	**C**	A	**C**	T	T
SPAIN11	T	G	A	T	T	G	C	A	G	A	T	T	A	T	T	T
SPAIN13	T	G	A	T	T	G	C	A	G	A	T	T	A	T	T	T
SPAIN12	T	G	**G**	T	T	G	C	A	G	A	T	T	**G**	T	T	T
FAIR14	**C**	G	A	T	**G**	G	C	**G**	G	A	**C**	T	A	T	T	T
FAIR15	T	G	A	T	T	G	C	A	G	A	T	T	A	T	T	T
FAIR16	**C**	G	A	T	T	**A**	C	A	G	A	**C**	T	A	T	**C**	T
FAIR17	**C**	G	A	T	T	**A**	C	A	G	A	**C**	T	A	T	**C**	T
BRISTC	**C**	G	A	T	T	**A**	C	A	G	A	**C**	T	A	T	**C**	T
BRIS19	**C**	G	A	T	T	**A**	C	A	G	A	**C**	T	A	T	**C**	T
BRIS20	T	G	**G**	T	T	G	C	A	G	A	T	T	A	?	?	?
BRIS21	**C**	G	A	T	T	G	C	A	G	A	**C**	T	A	T	T	T
BRIS22	**C**	G	A	T	T	**A**	C	A	G	A	**C**	T	A	T	**C**	T
MICH	T	G	A	T	T	G	C	A	G	**G**	**C**	T	A	**C**	T	T

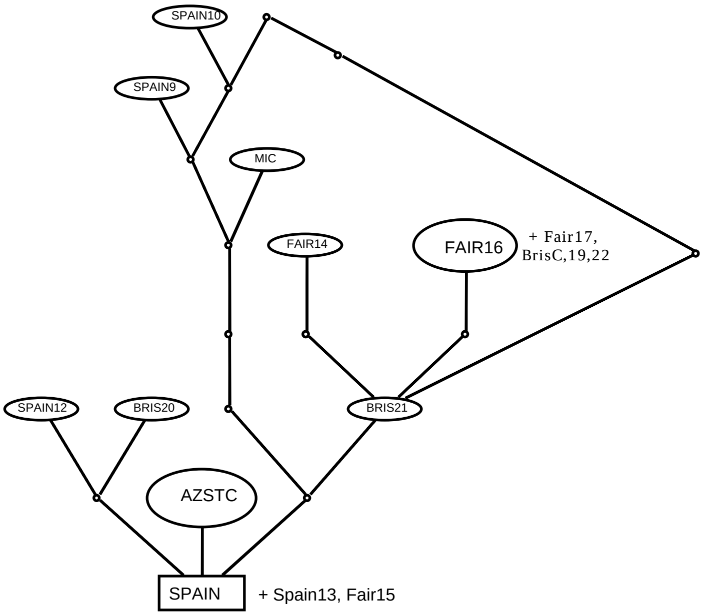


Figure 4.3: TCS Network; Phylogenetic network for the populations of *Sturnus vulgaris* studied based on ND2 sequences. Single base pair changes are joined by single lines; small open circles indicate missing mutations. Circle sizes are proportional to number of individuals with a particular haplotype. Boxed sequence is inferred to be ancestral.

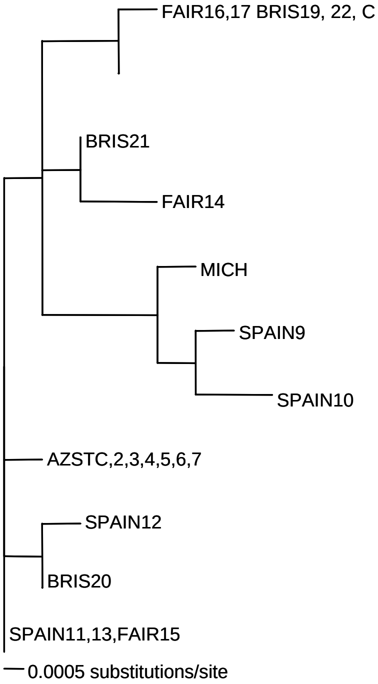


Figure 4.4: Evolutionary tree rooted according to TCS, using distance as the optimality criterion and simple pair wise differences model of evolution.

Table 4.4. Analysis of Molecular Variance (AMOVA) results indicating percentage of variation among and within populations

Source of variation	d.f.	Sum of squares	Variance components	Percentage of variation
Among populations	4	21.282	0.99939 Va	46.69
Within populations	17	19.400	1.14118 Vb	53.31
Total	21	40.682	2.14057	
Fixation Index FST :		0.46688		

Table 4.5. Pairwise F_{ST} between the different populations studied based on haplotypes frequency data; Michigan was not included in the analysis because we only had one sample. (+) indicates significance for P<0.05. All the populations are significantly different from each other, except for Fair Isle/Spain and Fair Isle/Bristol.

	Azores	Spain	Fair Isle	Bristol
Azores	---			
Spain	0.45312 (+)	---		
Fair Isle	0.69499 (+)	0.17127	---	
Bristol	0.78267 (+)	0.30233 (+)	-0.14216	---

Table 4.6. Nucleotide composition, number of haplotypes and gene diversity for the different populations studied.

Population	Nucleotide composition (%) C	T	A	G	No. haplotypes	Gene diversity
Azores	34.11	23.78	29.63	12.48	1	0
Spain	34.15	23.74	29.63	12.48	4	0.90±0.16
Fair Isle	34.25	23.65	29.67	12.44	3	0.83±0.22
Bristol	34.21	23.66	29.65	12.48	3	0.70±0.22

4.4 DISCUSSION

ND2 seems to offer potential for resolving relationships among different subspecies of European Starling. We found no genetic variation between the Azores individuals even though we had samples from two different islands (Santa Maria and Terceira) that are approximately 300km from each other. The European Starling is widely distributed and abundant in all the nine islands of the Azores archipelago but no data is available regarding population size. This genetic homogeneity of birds from different islands might indicate a recent common ancestry. The lack of genetic variability in Azores individuals could indicate a bottleneck and it is possible that the Azores population all originated from a single female. The samples collected in two sites in Spain (45 km apart) showed one of the highest degrees of variation but the Bristol and Fair Isle also had some degree of variation. The fact that the Azorean population shows less variation than the other populations studied might be due to the small size of the founder population and/or a bottleneck effect. Indeed, the results would be consistent with the Azores starling population being derived from a single female. However, the sample size is very small and interpretation must be cautious.

The TCS analysis suggested that the haplotype “Spain11” (and other samples with the same haplotype) was the ancestral type. The fact that we found one common haplotype for the Spanish and the Fair Isle populations can seem surprising if we remember that the Fair Isle birds are considered a subspecies (*zetlandicus*). However, it is less surprising if we consider previous studies looking at starling ringing recoveries in Europe, which have shown that a concentration of starlings from several countries occurs in Spain (Fliege 1984, as cited in Peris 1991).

The occurrence of Fair Isles haplotypes both in Bristol and in Spain can have two possible explanations. Either the Fair Isle has never been an isolated population or Fair Isle birds have at some point in history increased their natal dispersal with some individuals colonising new areas. Natal dispersal is well known to affect the genetic structure of populations (see for example Cabe 1999). Supposing that an increase in natal dispersal had in fact happened with the Fair Isle population, it could be due either to a decrease in food availability or to an increase in population size and, therefore, inter-specific competition. However at the moment we do not have enough information on the Fair Isle population to enable us to go farther with these speculative possibilities.

The European Starling in North America is a good case study; all starlings in North America are thought to be derived from introductions made in 1890 and 1891 to Central Park, New York (see Cabe 1994). Although there is some disagreement on the precise number, it is believed that about 60 were released in 1890, and 40 more in 1891 (see Cabe 1993). Although the source of the founders is no longer known, it was likely to have been Great Britain; Eugene Schiefflin, who arranged the release, was attempting to import and establish all of the birds mentioned in Shakespeare's writings. According to Evans's (1980), 'continental Western Europe may be regarded effectively as a single panmictic population'. Starlings have now colonized the country from one coast to the other but the population remains nearly single panmictic (Cabe 1999). According to Cabe (1999) this is due to the high density of local populations and the extreme vagility of juvenile dispersers producing a population that is genetically homogenous across its range. In section 4.3 we included the haplotype of a Michigan bird (obtained through genBank) in the construction of a phylogenetic tree.

A preliminary analysis shows that the Azorean birds are genetically distinct from all the other populations and only have one mutation compared to the common sequence inferred to be ancestral from the TCS analysis. If indeed starlings did reach the Azores by their own means (millions of years ago) they would represent, due to a continuous isolation of the archipelago, unusual in most of its European range, one of the oldest lineages in Europe. Future analysis of the Faroe Islands subspecies *faroensis,* might help to clarify the origin of the Azores population, if they too show a small degree of haplotypes and genetic variation. Maybe the Faeroe Islands are, as opposed to the Fair Isle, isolated enough to prevent birds from other populations coming in to mix their genes and promote mutations

The *zetlandicus* subspecies breeding in the Shetland and west Hebrides has been considered a remnant of a former widespread distributed species (Evans 1980, as cited in Feare 1984). However, as seen above, this study indicates that birds from Fair Isle share haplotypes found in populations from other nominate subspecies, such as Spain and Bristol.
Our study shows that the phylogeny of the European Starling is complex. Analysis/sampling of a broader European area including other populations might indicate which populations are closer to the Azorean birds and whether the *zetlandicus* subspecies is supported by mtDNA data, or, as it appears to be, is largely the same as the nominate *vulgaris* subspecies.

4.5 FURTHER WORK

More work is needed to identify the source population from which the Azores one might have originated or be closely related. The oldest populations are thought to be the ones breeding in the Faeroe and Scottish islands (Feare 1984). We could not obtain samples from the *faroensis* subspecies (Faeroe islands), but future studies should include these populations as well as sample more intensively the *zetlandicus* subspecies from the Scottish isles populations (Shetlands and the Outer Hebrides). We only had samples from the Fair Isle and recently some authors have cited sources that indicate that Fair Isle birds are intermediate between *zetlandicus* and nominate (McGowan *et al.* 2003); therefore, it is important to sample additional areas of the *zetlandicus* distribution. A broader study on the phylogenetics of this species should also include additional populations from other parts of Europe closer to the eastern limit such as Russia, and populations that may migrate through Shetland (e.g. Norwegian starlings) that may recruit into the Shetland population.

Chapter V

Population Status and Diet of Yellow-Legged Gull in the Azores

5.1 INTRODUCTION

The Yellow-legged Gull (*Larus michahellis atlantis*) seems to be increasing in the Azores archipelago and has recently been found breeding at colonies traditionally occupied by terns. This study looks at changes in distribution and numbers of Yellow-legged Gull over the last 20 years in the Azores archipelago. Additionally diets were also studied in some of the main colonies.

Gulls act both as competitors and predators and are generally considered to significantly reduce the attractiveness of potential breeding sites for other birds (Finney *et al.* 2003). For example, Finney *et al.* (2003) showed that puffins *Fratercula arctica* recruiting to the Isle of May avoided nesting in close proximity to gulls. And the abandonment, by terns, of traditional nesting areas in response to the encroachment of breeding gulls has also been demonstrated in a number of studies (Wanless 1988; Morris *et al.* 1992; Howes & Montevecchi 1993). Gulls are notorious predators of tern eggs, chicks, and sometimes adults (Shealer & Burger 1992; Yorio & Quintana 1997; Whittam & Leonard 1999; Guillemete & Brousseau 2001; Finney *et al.* 2003; O'Connel & Beck 2003), and tern colonies at the leading edge of gull breeding range expansions may experience rapid increases in predation as gulls expand into new areas (Burger & Lesser 1978; Kirkham & Nettleship 1987; Burger & Gochfeld 1990). Gulls can also negatively impact on terns through kleptoparasitism (Oro 1996; Ratcliffe *et al.* 1997; Arnold *et al.* 2004).

Another severe impact of gulls on other seabirds is that of predation and the Yellow-legged Gull has been the subject of several predation studies and accounts. For example, Yellow-legged Gull has been shown to prey on eggs and chicks of Greater Flamingo (*Phoenicopterus ruber,* Salathé 1983), eggs, chicks and adults of Audouin's Gull (*Larus audouini,* Oro & Martinez-Vilalta 1994; González-Solís *et al.* 1997) and chicks and adults of Storm Petrel (*Hydrobates pelagicus,* Borg *et al.* 1995; Oro *et al.* 2005), threatening some colonies with extinction (Borg *et al.* 1995). In the salines of the Rhône delta, Yellow-legged Gulls take over the best nesting sites to the detriment of terns and other charadriiforms (Sadoul *et al.* 1996) that are then forced to nest in poorer quality areas where their breeding success is insufficient for population maintenance (Sadoul *et al.* 1996).

During the last decades the Yellow-legged Gull has increased in numbers throughout the western range of its distribution (Snow & Perrins 1998). In the Mediterranean the increase has also been noticeable over the past few decades (Vidal *et al.* 1998), mostly owing to the availability of abundant and predictable food sources from rubbish dumps and from commercial fisheries discards (Arcos *et al.* 2001; Oro *et al.* 1995).

In the Azores, Yellow-legged Gulls have no direct competitors and, following the same trends as observed in other areas, their numbers are also thought to be increasing in the archipelago (mainly due to refuse availability), raising conservation concerns such as possible displacement of Roseate Tern *Sterna dougallii* colonies and depredation of tern chicks as well as other seabird chicks and adults. Available data on gull numbers in the Azores are restricted to a census carried out in 1984, when 2705 breeding pairs were counted at 27 colonies (Dunn 1989). Recently gulls have been observed establishing at two of the main Roseate Tern colonies in the Azores: Ilhéu das Contendas, Terceira island and Ilhéu da Vila, Santa Maria island (V Neves, personal observation), and in Ilhéu da Vila gulls have been observed taking tern chicks (J. M. Soares, personal communication). Two previous studies have described the diet of Yellow-legged Gull in the Azores, reporting the presence of mesopelagic fish in their pellets (Hamer *et al.* 1994) and variations in the proportions of prey types between colonies (Ramos *et al.* 1998).

The main aim of this study was to document current population size of the Yellow-legged Gull in the Azores to assess if expected population increases have occurred. In order to investigate the extent to which gulls may be affecting terns, both as competitors and predators, data were also collected on the diet of Yellow-legged gull at six different islands of the archipelago. We examine the relationship between number of human inhabitants and percentage of refuse in the gull pellets, predicting that gulls breeding on islands with larger human populations should consume larger amounts of refuse. We also examine the relationship between island area and the area/coastline ratio and the percentages of marine and terrestrial items in the pellets. At one of the colonies, Capelinhos – Faial Island, pellets were collected throughout the breeding cycle to evaluate if there are seasonal changes.

5.2 METHODS

5.2.1 Population survey

Gulls were surveyed in summer 2004 using two methods: 1) transects with direct counts of nests and 2) counts of incubating birds from vantage points, as described by Walsh *et al.* (1995). Gull breeding sites are mostly located in inaccessible cliffs and sea stacks and therefore we could only do transect counts on nine out of the 32 colonies monitored, i.e. Lagoa do Fogo - São Miguel island, Ilhéu de Baixo - Graciosa island, Ilhéu do Topo - São Jorge island, Mistério da Prainha - Pico island, Capelinhos & Costa da Nau - Faial island and Ilhéu Maria Vaz, Ilhéu do Cartário & Ilhéu Álvaro Rodrigues - all in Flores island. Only the colonies in São Jorge and Flores could be monitored by transect counts alone.

We attempted to survey all the colonies discovered during the 1984 census (Dunn 1989). Additionally, boats were used to monitor colonies that could not be seen from land and to detect new colonies formed since 1984. For Santa Maria, Terceira, Faial, and Flores the whole perimeter of the coastline was covered but for the remaining islands only smaller sections were covered. Fieldwork was conducted between 23 April and 6 June. The census unit was Apparently Occupied Nest (AON), i.e. a well-constructed nest, attended by an adult and capable of holding eggs (Walsh *et al.* 1995). Due to weather constraints we could not monitor three small colonies detected in 1984 (Fajã do Nortezinho & Fajã do Cardoso in São Jorge Island and Ponta do Marco in Corvo Island).

5.2.2 Diet studies

Diet was studied using pellets collected on six different colonies: Capelinhos (Faial), Mistério da Prainha (Pico), Ilhéu do Topo (São Jorge), Lagoa do Fogo (São Miguel), Ilhéu de Baixo (Graciosa), and Ilhéu das Cabras (Terceira). Pellets were collected during the incubation and early hatching stages, while conducting the census. Faial colony was monitored over a longer period, and sampling included incubation and chick rearing periods. Diet in Faial was also studied through samples obtained from adults and chicks that regurgitated when handled and measured. Pellets were collected in individual plastic bags, labelled with the date of collection and colony and identified later in the laboratory.

Food items were classified into the following categories: vegetable matter (grass and other), refuse (paper, glass, plastic, aluminium foil, poultry remains and others), goose barnacle (*Lepas anatifera*), gastropod molluscs (mainly *Janthina janthina*), fish, squid, bird, insect, mammal, and unidentified. Sagittal otoliths were identified using the reference collections of the Dept. of Oceanography and Fisheries (University of the Azores) and of the Belgian Royal Museum of Natural History (with the help of Dr. Dirk Nolf) and reference books (Nolf 1985; Cohen *et al.* 1990; Smale *et al.* 1995; Queró *et al.* 2003; Veen & Hoedmakers 2005).

Other prey items such as fur, bones, fish vertebrae, scales and bird feathers were identified with the help of reference material, literature (Zariquiey 1968, Whitehead *et al.* 1986), museum collections, and specialists (birds by R. W. Furness and insects by Geoff Hancock).

Frequencies of occurrence were calculated as the number of samples with a given prey type (e.g. fish, refuse, etc.) expressed as a percentage of the total number of pellets. Differences in the proportion of prey types between colonies and between the incubation and chick-rearing periods were tested following Zar (1996) using Chi-square analysis.

5.3 RESULTS

5.3.1 Population survey

The census yielded an estimate of 4249 pairs of Yellow-legged Gull (see Table 5.1) distributed over 32 colonies (locations given on Figs. 5.1-5.3). During both surveys, a total of 37 colonies were detected from which 24 were no more than one km from a tern colony (see Table 5.2).

Table 5.1: Number of breeding pairs in 1984 and in 2004 and percentage of change between the two surveys. Number of colonies shown in brackets.

Island	1984[a]	2004	Percentage increase
Santa Maria	90 (1)	96 (2)	7
São Miguel	650 (6)	820 (7)	26*
Terceira	430 (3)	904 (7)	110*
Graciosa	260 (1)	320 (1)	23
São Jorge	560 (5)	980 (2)	75
Pico	250 (3)	483 (3)	93
Faial	270 (3)	480 (5)	78*
Flores	105 (4)	166 (5)	58
Corvo	90 (1)	-	-
TOTAL	**2705 (27)**	**4249 (32)**	**57**

[a] from Dunn 1989

*** indicates islands where the percentage of refuse in the pellets was higher than 35%**

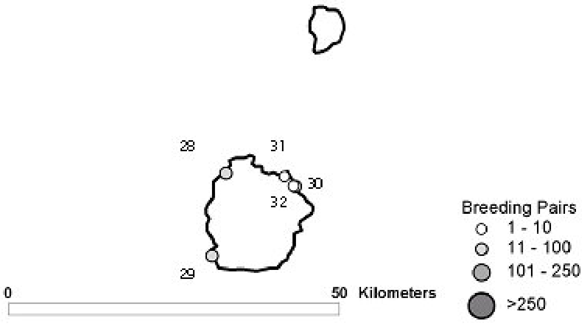


Figure 5.1: Distribution and estimated colony sizes of Yellow-legged Gull in the western group. Colony numbers as in Table 5.2.

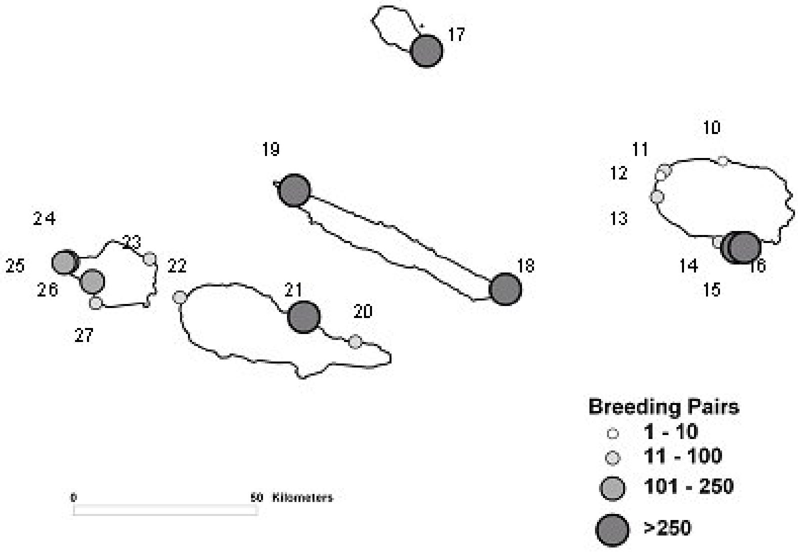


Figure 5.2: Distribution and estimated colony sizes of Yellow-legged Gull in the central group. Colony numbers as in Table 5.2.

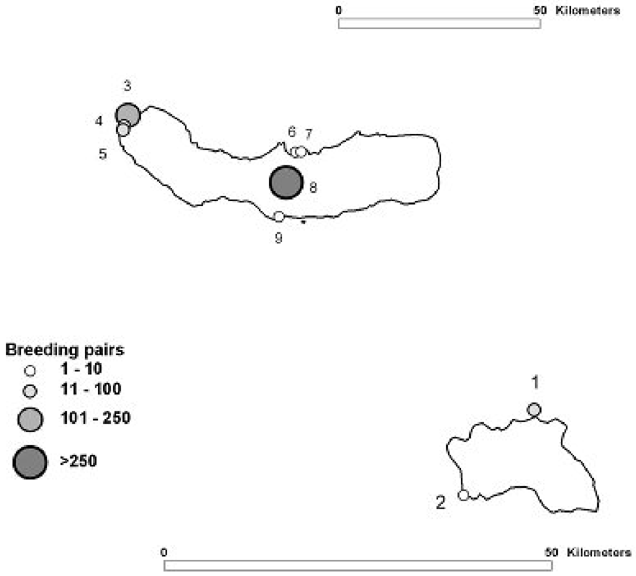


Figure 5.3: Distribution and estimated colony sizes of Yellow-legged Gull in the eastern group. Colony numbers as in Table 5.2.

Table 5.2: Details of surveys in 1984 and in 2004.

Colony	Island	Site	Habitat description	Estimated pairs 1984	2004	On or whithin 1km of tern colonies
1	Santa Maria	Lagoinhas	Sea stack	90	95	√
2		Vila°	Islet	0	1	√
3	São Miguel⊗	Mosteiros*	Islet & sea stacks	-	115	√
4		Ponta do Escalvado	Cliff	-	40	√
5		North of Ponta da Ferraria	Cliff	-	60	√
6		Ladeira da Velha (Miradouro de Santa Iria)	Cliff	-	1	
7		Praia dos Moinhos	Cliff & sea stack	-	2	
8		Lagoa do Fogo•	Inland lake	-	600	
9		Porto da Caloura	Cliff	-	2	
10	Terceira	Quatro Ribeiras	Cliff	0	10	√
11		Ponta do Raminho	Cliff	30	36	
12		Ponta da Serreta	Cliff	0	3	√
13		Ponta Rubra (south Serreta)	Cliff and cliff base	0	65	
14		Monte Brasil	Cliff	0	50	√
15		Ilhéu das Cabras W	Islet	150	350	√
16		Ilhéu das Cabras E	Islet	250	390	√
17	Graciosa	Ilhéu de Baixo•	Islet	260	320	√
18	São Jorge	Ilhéu do Topo°	Islet	300	730	√
19		Ponta dos Rosais**	Cliff & sea stacks	150	250	√
		Morro do Lemos	Cliff	45	0	
		Fajã do Cardoso	Cliff base	35	n.s.	√
		Fajã do Nortezinho	Cliff base	30	n.s.	
20	Pico	Ponta do Espigão	Cliff	100	50	
21		Mistério da Prainha•	Lava edge	100	380	
22		Ilhéus da Madalena***	Sea stacks	50	53	√
23	Faial	Costa dos Espalhafatos	Cliff base	0	25	
24		Costa da Nau (N Capelinhos)•	Cliff	0	125	√
25		Vulcão dos Capelinhos•	Cliff and volcano slopes	100	160	√
26		Baía do Varadouro	Cliff	150+	150	
27		Morro de Castelo Branco	Cliff	20	20	√
		Mte. da Guia	Cliff	▿	0	√
28	Flores	Ilhéu Maria Vaz°	Islet	40	86	√
29		Ilhéu do Cartário°	Islet	10	32	√
30		Ilhéu Álvaro Rodrigues°	Islet	50	42	√
31		Ilhéu da Muda°	Islet	5	5	√
32		Ponta Furada°	Cliff	0	1	√
	Corvo	Ponta do Marco	Cliff	90	n.s.	

n.s. not surveyed

Only the colonies where gulls were found breeding in 2004 are numbered

° Transect count

• Transect count plus vantage point

⊗ Dunn (1989) refer to six colonies totalling 650 pairs but numbers for individual colonies are not given.

* The islet had 105 breeding pairs. Additionally there are three sea stacks. The two furthest north had one and nine breeding pairs, respectively.

** This colony is scattered along the north coast from Ponta dos Rosais to Fajã Fernando Afonso. The colony also includes two sea stacks (Torrão de Açúcar and Caralhete) with two and one breeding pairs respectively.

*** This colony includes two sea stacks; the smaller one (Ilhéu em Pé) had only 3 pairs.

▿ small colony, not counted

Direct nest counts accounted for 42% of the total number of breeding pairs counted and the rest were derived from counts of birds and apparently occupied nests. During the 1984 census all the colonies were monitored using only counts from vantage points. For the colonies where transect counts were made in 2004 there was an increase of 104% (897 pairs) from 1984 and on the remaining colonies there was an increase of 35% (647 pairs).

Anecdotal observations were carried out at six rubbish dumps, Faial, São Miguel, Terceira, Graciosa, São Jorge and Flores. While in the former three islands hundreds of gulls were present, in the others only a few dozens were observed.

The refuse dump that serves the main city of the archipelago, Ponta Delgada (65.854 inhabitants in 2001) is located less than 15 km from the main gull colony in São Miguel, Lagoa do Fogo with 605 pairs. We visited the refuse dump on 24 April and observed an estimated 600 gulls foraging in the area. On Faial, Dunn (1989) mention the existence of a small gull colony at Porto Pim, Monte da Guia in 2004 only terns were found breeding at this site. A new colony (25 pairs) was found at Costa dos Espalhafatos on a landfall formed after the 1998 earthquake. The main gull colony, Capelinhos, is located less than 5 km from the refuse dump where we observed 400-450 individuals foraging.

On Santa Maria, only one colony was found in 2004, at Ilhéu das Lagoinhas (95 pairs) on the northern coast. Additionally a single nest (3 eggs) was detected at Ilhéu da Vila, a Special Protected Area that holds important populations of Roseate Tern and other seabirds. Gulls have been observed breeding at Ilhéu da Vila since 2002. In 2003 a gull nest had also been found on a sea stack where Roseate Terns have bred, Ilhéu das Lagoinhas but this site was not used by the gulls in 2004.

On Pico, the colony at Mistério da Prainha (Pico) spreads over a large area from the geodesic mark up to the west extreme of the lava flow and is located at an altitude of 18m. Overall the colony is very accessible but some areas have large stones and a dense cover of scrub vegetation, mainly *Erica azorica* that make it very difficult to survey. On the accessible area we counted 327 nests and we estimated an additional 60 nests on the remaining area. The colony at Ponta do Espigão (Pico) was one of the few that showed a decrease in numbers from 1984. Sea conditions prevented us from surveying the colony by boat so numbers were estimated by land from Baía do Canto, and are probably an underestimate.

On São Jorge, Dunn (1989) mention the existence of a small gull colony at Morro Grande (São Jorge), but during 2004 no gulls were found breeding at this site. Ilhéu do Topo (São Jorge) is used to raise cattle and in 2004 it had six cows and more than 50 sheep. Nevertheless gull nests were found everywhere in the islet. Both Roseate and Common Terns *S. hirundo* have bred in this islet in the past but in 2004 only 37 pairs of Common Tern were breeding. There are two refuse dumps on the island; one located 11 km from Ponta dos Rosais colony and other located 23 km from Ilhéu do Topo colony. The refuse is regularly covered in both places and gulls are present in smaller numbers; we counted 75 individuals in the dump near Rosais and 70 individuals in the dump near Topo.

On Terceira, a gull nest was detected at Ilhéu das Contendas in 2003, an important colony for both Common and Roseate Terns, but in 2004 no gulls were breeding there. Terceira has a large refuse dump that receives refuse from the whole island; during our visit (8 June, 12:00-12:30), we counted 950-1000 individuals foraging in the area.

On Flores, access to the islets proved to be extremely difficult due to the high and almost vertical cliffs. At the time of our visit most eggs had hatched but the nests were still recent and easy to count. We counted a total of 165 nests on the islets and a total of 350-380 individuals. Additionally a nest with 2 chicks was detected at Ponta Furada when monitoring tern colonies on 28 May. This site held a colony of 91 pairs of Common Tern and three pairs of Roseate Terns and we found the remains of at least 10 predated eggs. When we approached the colony six gulls were flying over the colony but only one nest was found.

We visited Corvo Island between 28 May and 1 June but due to weather constraints it was completely impossible to survey the island by boat as planned. On 1 June we did attempt to survey the island by boat; we counted 30 individuals at Pão de Açúcar, but we could not reach Ponta do Marco, where a colony of 90 pairs was found in 1984. The individuals observed at Pão de Açúcar were not breeding.

5.3.2 Diet

Pellets

A total of 1950 pellets were collected in six colonies of the Azores (see Table 5.3). A single pellet contained up to 5 types of prey, with only a few pellets being a discrete prey type (mostly fish, goose barnacle or bird). Fish was not very abundant in the samples and contributed to a maximum frequency of occurrence of 37.1% (during chick-rearing at Graciosa); nevertheless the fish prey was highly diverse with a total of 35 different species identified through otoliths and vertebrae (see Table 5.4).

In the Faial colony, the proportion of prey types during the incubation period was significantly different from the proportion of prey types during the chick-rearing period ($\chi^2=92.5$, d.f.=8, $p<0.0001$). The proportion of fish in the pellets during chick rearing was significantly higher than during the incubation period ($\chi^2=19.0$, d.f.=1, with Yates correction, $p<0.000$) as were the proportions of goose barnacle and mollusc ($\chi^2=19.4$ and $\chi^2=17.1$, d.f.=1 with Yates correction both $p<0.0001$) whereas the proportion of insect, mammal and refuse were lower during the chick rearing period ($\chi^2=4.3$, $\chi^2=4.3$, $\chi^2=11.0$, d.f.=1 with Yates correction all $p<0.05$).

Table 5.3: Frequency of occurrence (%) of different prey types in pellets of Yellow-legged Gull. SMG=São Miguel, TER-Terceira, GRW=Graciosa, FAI=Faial, PIX=Pico & SJZ=São Jorge.

	INCUBATION				**CHICK-REARING**		**Includes late incubation and early chick-rearing**	
Prey type	Lagoa do Fogo (SMG) 25 April N=86	Cabras Islet (TER) 9 May N=34	Baixo Islet (GRW) 10 May N=34	Capelinhos (FAI) 3-13 May N=576	Baixo Islet (GRW) 29 June N=62	Capelinhos (FAI) 16 May–8 June N=402	Mistério Prainha (PIX) 17 & 24 May N=587	Topo Islet (SJZ) 18 May N=169
Fish (Otoliths)	8.1 (1.2)	0	20.6 (2.9)	13.7 (5.7)	37.1(17.7)	24.9 (9.5)	28.3 (12.4)	3.6 (0)
Gastropod molluscs[1]	0	0	17.7	3.7	3.2	10.5	10.1	23.7
Goose barnacle	5.8	3.2	32.4	22.7	46.8	35.8	16.2	32.5
Squid	0	0	2.9	0.2	0	0	0	0
Vegetable matter	1.2	3.2	14.7	63.2	22.6	39.8	70.00	61.0
Refuse[2]	91.9	96.8	20.6	46.2	21.0	35.3	30.2	13.1
Bird[3]	0	3.2	23.5	0.5	14.5	1.7	6.0	5.9
Eggshells	0	0	8.8	5.4	0	3.2	5.1	3.0
Insect[4]	0	9.7	11.8	3.9	11.3	1.5	6.3	31.4
Mammal[5]	2.3	6.5	26.5	18.1	14.5	12.9	22.0	10.1
Unidentified	0	3.2	0	3.7	4.8	2.7	5.8	0

[1] Mainly *Janthina janthina*

[2] Plastic, glass, paper, aluminium foil, cigarette filters, kitchen scraps, strings. Pellets from SMG and TER contained large percentages of bones and feathers of chicken, 91.4% and 76.7%, respectively.

[3] Cory's Shearwater *Calonectris diomedea*, Madeiran Storm-Petrel *Oceanodroma castro*, Buzzard *Buteo buteo*, Canary *Serinus canaria*, European Starling *Sturnus vulgaris* and other passerines

[4] Scarabaeid beetles subfamily Coprinae: *Onthopagus sp.*; Cicindelidae: *Cicindela sp.*; Curculionidae: *Otiorhyncus sp.*; Elateridae and unidentified.

[5] Mainly rats *Rattus norvegicus*, *R. rattus* and rabbits *Oryctolagus cuniculus*

Table 5.4: List of identified fish prey species, percentage of occurrence of otoliths (number of otoliths in brackets) and respectively habitat and depth ranges.

Order	**Family**		**Species**	**% of occurrence of otoliths (n=203)**	**Habitat and depth*****
Anguiliformes	Congridae			**2.0 (4)**	
			*Conger conger**	-	Demersal; 0-500m
			Gnatophis mystax	1.5 (3)	Demersal; 80-800m
			Paraconger macrops	0.5 (1)	Demersal; 30-100m
Myctophiformes	Myctophidae			**38.9 (79)**	
			Unidentified	1.5 (3)	
			Ceratoscopelus warmingii	0.5 (1)	Bathypelagic; 25-1500m
			Diaphus effulgens	0.5 (1)	Bathypelagic; 40-700m
			D. rafinesquii	1.5 (3)	Bathypelagic; 40-1080m
			Electrona rissoi	29.6 (60)	Bathypelagic; 90-820m
			Hygophum hygomii	0.5 (1)	Bathypelagic; 0-800m
			Lampanyctus crocodilus	0.5 (1)	Bathypelagic; 45-1000m
			L. photonotus	0.5 (1)	Bathypelagic; 40-1100m
			Lobianchia dofleini	0.5 (1)	Bathypelagic; 20-750m
			L. gemellarii	3.0 (6)	Bathypelagic; 25-800m
			Myctophum punctatum	0.5 (1)	Bathypelagic; 0-1000m
Gadiformes				**12.3 (25)**	
	Macrouridae			10.3 (21)	
			Unidentified	0.5 (1)	
			Caelorinchus caelorinchus	4.9 (10)	Benthopelagic; 140-2000m
			C. labiatus	0.5 (1)	Bathydemersal; 460-2220m
			Gadomus longifilis	1.0 (2)	Bathypelagic; 630-2165m
			Malacocephalus laevis	0.5 (1)	Bathydemersal; 200-1000m
			Odontomacrurus murrayi	3.0 (6)	Bathypelagic; 0-2500m
	Phycidae	£	*Phycis phycis*	1.5 (3)	Benthopelagic; 13-614m
	Gadidae		*Gadiculus argenteus*	0.5 (1)	Pelagic; 100-1000m
Beloniformes	Belonidae		*Belone belone**	-	Epipelagic; 2-4m
Beryciformes				**13.8 (28)**	
	Diretmidae			10.3 (21)	Mesopelagic; 500-700m
			Diretmus argenteus		
	Trachichthyidae		*Hoplostethus mediterraneus*	1.5 (3)	Benthopelagic; 100-1175
	Berycidae			2.0 (4)	
		£	*Beryx.sp.*	1.5 (3)	
		£	*B. splendens*	0.5 (1)	Benthopelagic; 25-1300
Scorpaeniformes	Scorpaenidae			**1.5 (3)**	
		£	*Pontinus kuhlii*	1.0 (2)	Bathydemersal; 100-600m
			Scorpaenodes arenai	0.5 (1)	Demersal
Perciformes				**20.2 (41)**	
	Serranidae		*Anthias anthias*	3.5 (7)	Epipelagic; 0-300m
	Apogonidae		*Apogon imberbis*	3.5 (7)	Epipelagic; 10-200m
	Epigonidae		*Epigonus constantiae*	1.5 (3)	Bathydemersal; 200-600m
	Carangidae	£	*Trachurus picturatus*	4.5 (9)	Benthopelagic; 0-370m
	Sparidae			6.9 (14)	
			Unidentified	2.5 (5)	
		£	*Boops boops*	1.5 (3)	Demersal; 0-350m
		£	*Diplodus cervinus*	0.5 (1)	Demersal; 30-300m
		£	*Diplodus sargus*	0.5 (1)	Demersal; 0-50m
		£	*Pagellus bogaraveo*	2.0 (4)	Demersal; 0-700m
	Sphyraenidae	£	*Sphyraena sphyraena*	0.5 (1)	Pelagic; 0-100m
Unidentified**				**11.3 (23)**	

£ species with commercial interest
* identified through vertebras
** otoliths too broken or eroded to be identified
*** from Whitehead *et al.* (1984)

For Graciosa colony, the difference in the proportion of prey types during the incubation and the chick rearing periods was not so marked but it was still statistically significant ($\chi^2=17.1$, d.f.=8, $p<0.05$). The proportion of mollusc prey was higher during the incubation period ($\chi^2=4.2$, d.f.=1 with Yates correction, $p<0.05$) there were no differences for all the other prey types. We found differences in the proportion of different prey items between Faial and Graciosa colonies, both for the incubation and chick-rearing periods ($\chi^2=134.9$ and $\chi^2=59.7$ respectively, both d.f.=8 and $p<0.0001$). The refuse at Graciosa landfill is regularly covered and only one individual gull was observed in the area during our visit. Nevertheless, refuse was found in more than 20% the pellets; in addition to the landfill there are some small illegal dumps in the island and the gulls are probably also using them.

The percentage of pellets containing refuse in islands with less than 20000 inhabitants was less than half that on islands with more than 55000 inhabitants (see Fig. 5.4).

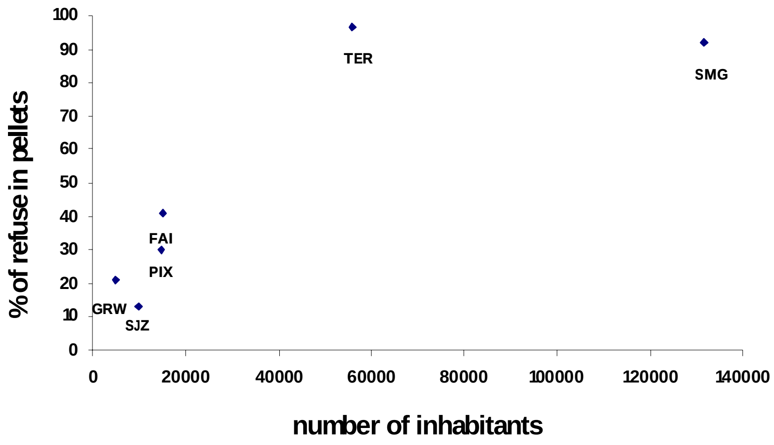


Figure 5.4: Relationship between number of inhabitants and the percentage of refuse in the pellets for the different islands. SJZ=São Jorge, GRW=Graciosa, PIX=Pico, FAI=Faial, TER=Terceira and SMG=São Miguel.

The proportions of prey types in the pellets collected during the incubation period for São Miguel, Terceira, Graciosa and Faial colonies were significantly different ($\chi^2=337.9$, d.f.=24, $p<0.0001$). Refuse accounted for 46.2% in Faial, which is significantly less than on São Miguel and Terceira ($\chi^2=60.8$ and $\chi^2=28.2$, d.f.=1, Yates correction, both $p<0.0001$), but significantly higher than on Graciosa ($\chi^2=7.5$, d.f.=1, Yates correction, both $p<0.001$, Table 5.3). The proportion of bird remains in Graciosa Island was higher and significantly different from Faial, São Miguel and Terceira colonies ($\chi^2=83.4$ $\chi^2=18.064$ and $\chi^2=4.0$, respectively all with d.f.=1 and $p<0.05$ and Yates correction).

Pellets collected in Pico and São Jorge include both incubation and early chick rearing period due to the dates of collection. We found significant differences in the proportion of prey types between these two colonies ($\chi^2=165.262$, d.f.=8, $p<0.0001$).

The only inland colony, Lagoa do Fogo, had the smallest percentage of marine items (see Table 5.3), but we found no relationship between the ratio area/coastline for each island and the abundance of marine and terrestrial items in the pellets (see Fig. 5.5).

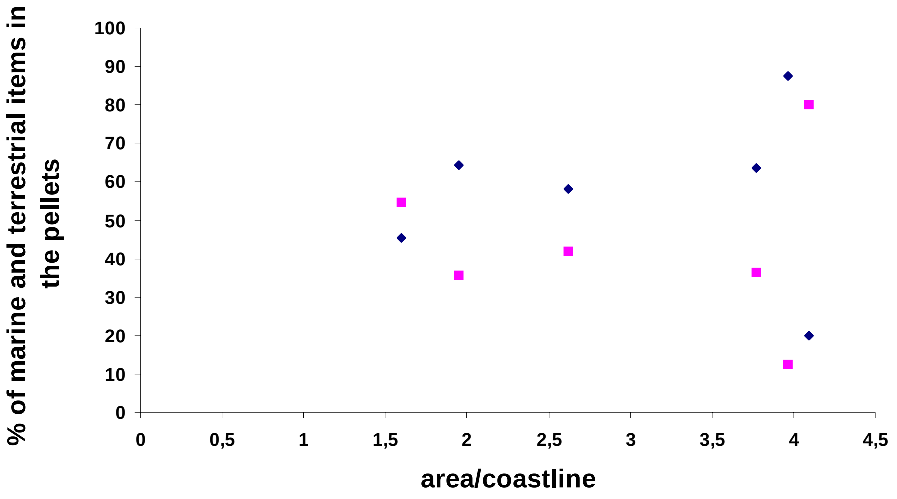


Figure 5.5: Relationship between area/coastline ratio for each island and the percentage of marine (diamonds) and terrestrial (quadrates) items in the pellets.

Regurgitates from adults and chicks

A total of 46 regurgitates were collected at Faial colony, 7 from adults and 39 from chicks. The food regurgitated by adults included rice, mushroom, corn, meat and bones (possibly chicken) and earthworms. Chick regurgitates include mainly fish (43.8%), meat (25.6%) and earthworms (10.3%); the remaining 20% included molluscs, goose barnacle, vegetable matter and unidentified.

5.4 DISCUSSION

The census yielded an estimate of 4249 pairs of Yellow-legged Gull, distributed over 32 colonies, which represents an increase of almost 60% from the previous survey conducted in 1984. The rate of increase in the archipelago seems to be lower that at other localities. The western Mediterranean population of Yellow-legged Gull is currently estimated to be increasing at a rate of between 7 and 10% per year (Thibault *et al.* 1996) while the Azorean population is increasing at an average annual rate of only 2.3%, as deduced from the 1984 and 2004 estimates. On the French Mediterranean coast there was an average annual increase of 6.9-7.8% for the period 1966-76 (Snow & Perrins 1998). And in the Balearic Islands, Spain, there was an annual increase of 3% for the period 1983-1987 (Rodriguez 1999). Recently in La Palma, Canary Islands, Ramos (2003) found an annual increase of 8.3% for the period 1987-2002.

Gulls are also spreading their distribution in the archipelago; eight new breeding sites were discovered but in total they comprised less than 4% of the population. All the colonies monitored but one (Lagoa do Fogo inland crater) were coastal. The main concentrations of gulls were found on São Jorge (980 pairs), Terceira (904 pairs), and São Miguel (820 pairs). The growth of the breeding population resulted mainly from the increase in established colonies, especially at Ilhéu do Topo (increased from 300 to 730 pairs), Mistério da Prainha (increased from 100 to 380 pairs) and Ilhéu das Cabras (increased from 400 to 740 pairs).

Isolated breeding pairs were located in Flores, Santa Maria and São Miguel islands and it is possible that our survey overlooked other cases due to the difficulty in detecting isolated pairs. We found considerable differences in the percentage increase amongst the different islands, with Santa Maria, São Miguel and Graciosa showing increases much smaller than the other islands. Only one colony was detected in Graciosa, Ilhéu de Baixo, which compared with other colonies of the archipelago registered only a small increase in numbers (23%). Terceira Island registered the largest increase, regarding both breeding pairs and number of colonies. Five new colonies comprising 128 pairs were found in the island.

Gulls were detected in a total of 14 islets and sea stacks (see Table 5.2), which accounted for more than 55% of the breeding population. The presence of gulls on these islets is probably limiting the distribution of terns in the archipelago and, excluding Ilhéu da Vila, which has been a traditional large colony for Roseate and Common Terns, most of these islets occupied by gulls had none or only small numbers of breeding terns; this was the case of Ilhéu das Cabras W (50 pairs of Common Tern), Ilhéu do Topo (37 pairs of Common Tern) and Ilhéu de Baixo (3 pairs of Common Tern).

The increase in numbers from 1984 to 2004 could be partly attributed to the fact that during 1984 no nest counts were attempted, causing the estimates to be less reliable in some colonies. This is particularly relevant for Flores Island where in 2004 all the colonies were surveyed by transect counts. However, the biases due to method are probably small (Walsh *et al.* 1995). Furthermore, our results are probably slightly underestimated because Corvo Island was not surveyed and because due to intermittent breeding (non breeding in individuals that have previously bred) some birds will not be included in the nest counts. Several studies have documented intermittent breeding in seabirds (e.g. Kadlec & Drury 1968; Bradley *et al.* 2000), and Calladine & Harris (1997) report that between 33-40% of previously breeding adults of Herring Gull *Larus argentatus* and Lesser Black-backed Gull *Larus fuscus* failed to breed in two successive years.

There have been many studies linking the population increase of gulls to the availability of food from refuse dumps (Mudge & Ferns 1982, Blockpoel & Spaans 1990) and from fisheries offal and discards (Furness *et al.* 1992). Gulls have no direct competitors in the Azores and probably benefit from recent development of fisheries and increases in rubbish dumps. The foraging range of the Herring Gull, similar in size and feeding habits to the Yellow-legged Gull, has been estimated to be 40 km (Witt *et al.* 1981). Most of the largest gull colonies in the Azores have refuse sites well within this distance and it is therefore not surprising that pellets collected on several colonies indicate that in some colonies the birds are largely dependant on rubbish dumps to feed. This conclusion is supported by the large numbers of individuals, both adults and juveniles, observed feeding at the rubbish dumps of the main islands, Terceira and São Miguel. Garbage production in the archipelago has only been monitored for a very short period and it is not know how much it has changed over the last decades. But even if the human population in the Azores has increased by less than 2% in the period 1991-2001 (http://www.ine.pt/), we can assume that the garbage production has increased due to changes in consumption habits and a massive increase of tourism in the archipelago over the last decade. In 1998, 88% of the rubbish produced in the archipelago was disposed on rubbish dumps and only 12% was going to controlled landfills (INE 2005). The situation has considerably changed since then, and, according to governmental, during 2003 80% of the total solid waste production (118,650 tonnes) was disposed in landfills. However, this value only includes the officially declared rubbish production and it is not know how much rubbish is produced and disposed without being declared. We visited rubbish dumps and landfills at São Miguel, Terceira, Faial, Graciosa and Flores and found considerable numbers of gulls feeding on all of them except in Graciosa, where the rubbish is regularly covered and only one gull was observed.

Being highly opportunistic birds, Yellow-legged Gulls make extensive use of available food and feed on a large variety of prey in the Azores. The differences in the frequency of occurrence of different prey across colonies suggest major spatial variation in the availability of prey. Despite the bias inherent to using pellets, this method it is still one of the most frequently used when studying seabird diets (Duffy & Jackson 1986; Zijlstra & Van Eerden 1995; Votier *et al.* 2001) because it allows an assessment of important dietary components through the collection of large samples that can be easily obtained causing minimum levels of disturbance to the colony. Analysis of pellets will underestimate the importance of items that produce little indigestible remains (Johnstone *et al.* 1990), like earthworms that were found in regurgitates of both adults and chicks. Similarly to our results, studies on Herring Gull have also found high frequencies of vegetable matter in pellets (e.g. Davis 1956; Morton & Hogg 1989; Noordhuis & Spaans 1992; Nogales *et al.* 1995). The vegetable matter could be ingested incidentally when gulls feed on earthworms and other invertebrates, however the fact that it appears in such large proportions might indicate that it has been consumed deliberately.

Bosch *et al.* (1994) reported that more than 60% of food ingested by Yellow-legged Gull in the Medes Islands was garbage. In the Azores, these values varied significantly among islands and were only surpassed in São Miguel and Terceira islands, with 91.9% and 96.8% respectively, containing essentially chicken (91.4% and 76.7% for São Miguel and Terceira respectively). Similar results have been reported by Annett and Pierotti (1999) who found that the major food types of Western Gulls *Larus occidentalis* were garbage from which > 90% was chicken. On a study with Yellow-legged Gulls breeding in the French Mediterranean, Duhem *et al.* (2003) showed that landfills were the preferred food source, even when gulls were breeding on islands far from landfills. It has also been found that in some colonies, proximity of refuse dumps increases hatching success (Duhem *et al.* 2002). However it has also been demonstrated that gulls using the scavenging mode of foraging and taking high-refuse diets are much less successful at reproduction, having smaller clutches, reduced hatching success, and shortened reproductive life-spans (Annett & Pierotti 1999). Previous diet studies of the Yellow-legged Gull in the Azores (Hamer *et al.* 1994; Ramos *et al.* 1998) did not find refuse in the pellets in Mistério da Prainha (Pico) and Ilhéu do Topo (São Jorge); however in the present study these values were 30.25 and 13.1% respectively.

Previous studies on gull diets in the Azores have found much higher occurrences of fish (Ramos *et al.* 1998) in the pellets than this study; nevertheless species diversity was small and consisted predominantly of boar fish (*Capros aper*). In a study conducted by Ramos *et al.* (1998) this species was present in up to 98.6 of the fish pellets. Boar fish has been detected in the diet of several other predators in the Azores (Morato *et al.* 2003) and probably exhibits strong variation in abundance among years. It seemed to have reached a peak of abundance in 1995 and 1996 but has not been as abundant since and was not detected in our study. Ilhéu do Topo (São Jorge) had the lowest proportion of fish in the pellets with only 3.6% of the total, however it had the highest proportions of molluscs, goose barnacles and insects. This is in contrast with the findings of Hamer *et al.* (1994) who reported fish in 89.4% of total pellets, vs. 8.2% for goose barnacles and 0.6% for molluscs. This might indicate a decrease in fish stocks surrounding that colony or might be due to differences in sampling dates; our samples were collected in May and those of Hamer *et al.* (1994) in August.

The presence of meso and benthopelagic fish species in Yellow-legged Gull pellets has been reported in previous studies conducted in the archipelago (Hamer *et al.* 1994; Ramos *et al.* 1998). Hudson & Furness (1988) postulated that these species may be made available to surface predators as discards from fisheries. The present study has once more found the presence of deep-water fish species. Even if some species might become available through fisheries activity the presence of several species from the Myctophidae family is harder to explain. This family was represented by 79 otoliths of 10 different species, but was mainly *Electrona rissoi*, a species that also occurs in other seabird species diets in the Azores (terns - Meirinho 2000; Cory's shearwater *Calonectris diomedea*, Bulwer's petrel *Bulweria bulwerii* and Madeiran storm petrel O*ceanodroma castro* - Neves unpublished data). 31% of the 35 different fish species present in the gull pellets have commercial interest (see Table 5.4). Fishery waste is a large food supply for gulls of the British Isles (Furness *et al.* 1992), but in the Azores discards and offal are rare. However sometimes fishermen will carve some of the fish caught and use it as bait. In this way some fishes might become available to the birds, as in the case of the Berycidae family. The low frequency of occurrence of this species corroborates the possibility that they are consumed by gulls only when made available by fishermen.

The differences in the diet found between incubation and chick rearing at the Faial colony suggest that adults shift their diet to more nutritious prey types when they are rearing their chicks. Prey items such as fish and to some extent goose barnacle and mollusc increased, and food with low nutritious value such as insects decreased. This shift in diet between incubation and chick rearing has been detected before in other gull studies. On a study conducted with Western Gulls Annett & Pierotti (1989) showed that chick hatching triggers dietary switches.

Pellets from Graciosa colony had larger percentages of birds than any other colony, probably because the site where gulls breed also holds colonies of several small petrel species (Monteiro *et al.* 1996a).

The presence of the mollusc *Janthina janthina* in the pellets probably reflects seasonal food availability. During the months of April and May *J.*

janthina can occasionally be very abundant at sea nearby Faial and Pico islands and large strandings have also been recorded during these months at Porto Pim beach (Faial) (L Barcelos, personal communication).

Gulls are expanding in the archipelago and it is important to monitor numbers and distribution over the forthcoming years. The progressive replacement of rubbish dumps by landfills following new environmental policies will reduce an important source of food for the gulls and might result in a larger predatory pressure on other seabirds, such as the Roseate Tern. Priority sites to monitor include Ilhéu da Vila and Ilhéu das Contendas; both are of major importance to Roseate Tern and have had isolated breeding pairs of Yellow-legged Gull breeding over the past few years. In 2005 two gull pairs bred at Ilhéu da Vila (J Bried personal communication). It is important to act in this early stage of colonization when control measures are not so onerous and ensure higher probabilities of success.

Chapter VI

A control taste aversion experiment on predators of Roseate Tern (*Sterna dougallii*) eggs

6.1 INTRODUCTION

The Azores archipelago (Portugal) holds the largest European breeding population of the endangered Roseate Tern *Sterna dougallii* (778 pairs in the year 2000), representing 51% of the European population (Ratcliffe 2000). Management of endangered species requires accurate knowledge of the main factors that affect survival and breeding success, and recently the international East Atlantic action plan for Roseate Tern (Newbery 2002) identified predation as one of the main factors threatening and limiting breeding numbers.

During the last few years, the mixed Common (*S. hirundo*) and Roseate Tern colony at Vila Islet (Santa Maria island) has been suffering from increasingly high rates of egg predation by the European Starlings *Sturnus vulgaris* (see chapter III) (Neves unpublished data). Gulls are also well known predators of tern eggs and chicks at a wide variety of sites (Burger & Gochfeld 1994, Becker 1995, Yorio & Quintana 1997, Whittam & Leonard 1999, Guillemette & Brousseau 2001, Hernández-Matías & Ruiz 2003, O'Connell & Beck 2003). The gulls detrimental effects on Roseate Terns have been detected in Ireland (Merne 1997), Brittany (Monnat & Cadiou in press), and the USA (Nisbet 1992). In the Azores there are several tern colonies in close proximity to gull colonies but the impact of gulls as predators has not been assessed.

The perceived link between predation and threats to bird populations has led to predator removal being instigated in conservation contexts but recently more emphasis has been put into non-lethal control. Aversive behaviour in general might be exploited to modify the feeding behaviour of species to meet wildlife management objectives (Avery *et al.* 1995). The use of non-lethal methods to reduce egg predation is preferred for a number of reasons: 1) the amount of toxin introduced in the environment is reduced, 2) the risk of affecting non-target organisms is also reduced, 3) secondary poisoning of scavengers is eliminated, and 4) in the case of territorial predators, conditioned animals act as deterrents for other potential predators (Avery *et al.* 1995).

Bird repellent products containing methiocarb (3,5-dimethyl-4-(methylthio)-phenyl methylcarbamate; Mesurol®), have been widely used in the USA and Europe (Crocker & Perry, 1990) and have shown to be highly efficient as feeding deterrents (Avery & Mason 1997, Clark & Mason 1993, Kononen *et al.* 1986, Rogers 1974). Methiocarb's effectiveness is due to its ability to produce severe, reversible illness after ingestion, which causes birds to learn and avoid ancillary sensory cues –e.g., colour, patterns, odours, and tastes- that are paired with the illness (Conover 1984, Mason & Reidinger 1983; Tobin 1985).

Avery *et al.* (1995) conducted a successful taste-aversion experiment on Common Ravens *Corvus corax* eating California Least Tern *Sterna antillarum browni* eggs, using Quail *Coturnix coturnix* eggs injected with methiocarb. Success of such experiments depends on several factors, such as the location of the treated eggs (Nicolaus *et al.* 1983), the availability of untreated eggs, and the number of times individuals encounter untreated eggs. Avery *et al.* (1995) suggest that conditioning of birds will be effective if repellent eggs are deployed 2-3 weeks prior to egg laying by terns, so that birds frequently encounter treated eggs. This is explained by the fact that ravens tend to explore, meaning that if untreated eggs are available the birds will find them and will be encouraged to keep searching (Avery & Decker 1994).

The persistence of the aversions varied from 14 days (Nicolaus & Nellis 1987) to a year (Dimmick & Nicolaus 1990). In some cases the aversion was generalized toward eggs that did not look like treated eggs (Nicolaus *et al.* 1989) while in others this did not occur (Nicolaus *et al.* 1983). Such differences perhaps reflect the complexities of working with a diversity of free-living species, but understanding their causes will be important in developing an effective management technique (Cowan *et al.* 2000). Key questions about predator behaviour and field logistics, which may ultimately limit or prevent the efficient exploitation of CTA (Control Taste Aversion) in wildlife management, can only be answered in the field (Cowan *et al.* 2000).

6.2 METHODS

6.2.1 Study area

We conducted our experiment in Vila Islet, off Santa Maria island (36°55'N, 25°10'W), a rocky islet of basalt, with steep slopes and cliffs. It has an area of 10 ha and a maximum altitude of 60 m (Monteiro 2000). There are no mammalian predators on the island.

Vila Islet has been declared an Important Bird Area whithin Portugal (IBA 014) and holds a mixed colony of Common and Roseate Terns. It also includes the only known breeding pair of Sooty Tern (*S. fuscata*) in Europe (Monteiro 2000). Vila Islet holds about 20% of the Azores population of Roseate Terns (201 pairs in 2002 when the total breeding population was 991). Tern egg laying in the Azores occurs between late April and late July (Hays *et al.* 2002, Ramos & del Nevo 1995).

6.2.2 Experimental design

Fieldwork was conducted between 17 April and 26 May 2003. We chose quail eggs because of their resemblance in size and general pattern to tern eggs, and because they could be obtained locally in large quantities. We prepared methiocarb-treated eggs according to the method described in Avery et al. (1995) using Mesurol® 75% wettable powder, Bayer. We replaced the methiocarb-treated eggs every three days to make sure that the chemical retained its potency (Avery et al. 1995). Since it was not possible to have a control group we decided to deploy untreated quail eggs for the first three days and only then to deploy treated eggs. The difference in predation rates on treated and untreated eggs was used to indicate modification of the bird predatory behaviour. Artificial nests had one egg per nest, which compares well with a typical Roseate Tern clutch (for example, during 2002 the mean clutch size for Vila islet was 1.4, n=193) (Neves, unpublished data). All nests were checked daily by walking up to the nest. Additionally, we conducted observations, from the top of the islet or from a hide situated 10m away from the nests, three times daily (morning, mid day and late afternoon), in order to identify predators and record their behaviour and abundance.

Experiment 1 - Egg deployment before terns laid

Eggs were deployed targeting starlings but at this time starling activity was low in the islet and starlings took no eggs. However gulls took the eggs. We initially deployed twenty-four untreated quail eggs on 19 April (four groups: A, B, C and D, of six eggs each), in artificial shallow scrapes created to resemble tern nests. Artificial nests were deployed in areas of the islet where terns were observed breeding during previous years. Treated eggs were not later deployed in area D because no predation was recorded on the untreated eggs, and no activity was noted in that area.

We checked the nests five times daily at specified hours (07:00, 10:00, 13:00, 16:00, 18:00) except for two days when they were checked four times instead of five, due to very bad weather conditions. We recorded predation and eggs that were missing or broken were replaced. Three days later the untreated eggs were replaced with methiocarb-treated eggs. The LD_{50} of methiocarb for starlings is 13 mg kg^{-1} bodyweight (Crocker & Perry 1990). However, starlings are not capable of swallowing quail eggs, and it is not likely that a bird will receive a lethal dose before it acquires a repellent dose. In addition, a relatively high dose of chemical should be used, so that the effects are emetic, since the magnitude of the conditional avoidance response is generally positively related to the magnitude of the illness (Sayre & Clark 2001). In consideration of these facts, the experiment was originally designed so that a higher dose of chemical would be added in each egg (30 mg). However, our observations showed that gulls were taking the eggs whole. At one occasion we observed that 5 eggs were taken in only two approaches by gulls, so it was highly probable that a gull would consume a high dose of chemical, before there was any chance of it suffering from any adverse effects. Therefore it was decided that a lower dose of chemical (11.25 mg per egg) should be used to avoid gulls receiving a lethal dose of methiocarb.

We made a total of 24.5 h of observation effort during the 9 days of the experiment. It was originally planned that at least six hours of observations would be conducted daily, but very poor visibility (up to a few meters), made observations almost impossible on several days.

Deployment of quail eggs was continued for a total of nine days, and during that time starling activity in the islet remained negligible, while clear effects on gull activity were seen. Therefore the first deployment was ended and a second deployment started some days later when terns were incubating and starling activity had increased.

Experiment 2 - Egg deployment during tern incubation

An area of the Roseate Tern colony containing 45 nests was specified and monitored daily for predation events so that they could be used as a control for comparisons with methiocarb-treated eggs. No untreated eggs were used as a control this time because terns were already incubating and it was important that starlings would encounter treated eggs in order to try to modify their feeding behaviour. We deployed eighteen treated quail eggs on 14 May in three groups of six eggs, corresponding to the location and arrangement similar to groups A-C from Experiment 1. In order to minimize disturbance to the terns we deployed the treated eggs slightly away from terns' main breeding areas. However after two days, when no predation occurred on the treated eggs but tern eggs were being predated, we moved the treated eggs closer to Roseate Terns nests and deployed the artificial nests 2-3 m apart from eachother. We checked the nests twice daily by walking up to the nests, once in the morning (10:00) and once in the evening (18:00), except in one case, when we checked them only in the morning. We reduced the number of nest checks from five to two in order to minimize disturbance to terns that were now incubating. We recorded predation and eggs that were missing or broken were replaced immediately, except in one case when they were replaced during the following check.

The experiment was conducted for a total of thirteen days (14/05 – 26/05) and a total of 37 hours of observations on starling predatory behaviour were made. The first two batches of eggs contained 11.25 mg of methiocarb per egg as used in the first experiment, while the following two batches contained 22.5 mg per egg. We increased the chemical dose because rates of recorded egg predation of methiocarb-treated eggs were gradually increasing, which indicated that the chemical dose initially used was not sufficient to deliver the desired effect. The number of starlings observed foraging in the colony remained fairly constant during the experiment so we assumed that the increase in predation was not due to starlings' density.

6.3 RESULTS

6.3.1 Experiment 1

In the first experiment, eggs started to disappear from the first day of deployment and only gulls were seen taking quail eggs from the artificial nests. Gulls took 32 untreated eggs during days 1-3, compared to 15 methiocarb-treated eggs during days 4-9. Therefore, the rate of egg predation decreased from 10.6 eggs/day to 2.5 eggs/day when methiocarb was used. Fig. 6.1 shows that the rate of egg predation increased every day when untreated eggs were deployed. When an egg from one nest had been taken, the following day the rate of predation recorded from that nest was as high or higher, indicating that gulls were being trained to location. When more than one gull was seen taking quail eggs, one of them would eventually be chased away by the other individual. On presentation of eggs treated with methiocarb, the rate of predation fell rapidly to 0-1 eggs per day (Fig. 6.1).

Predation was recorded at all time-intervals, but gulls seemed to take eggs especially from 13:00-16:00 (11 eggs depredated). Another 15 eggs were taken after 18:00 but before 10:00 the next morning so the rate of predation per hour of sunlight is not as high. There were six hours of sunlight from 18:00-10:00 the following morning, so the rate of predation would be 0.83 eggs/hour compared to 1.22 eggs/hour from 13:00 to 16:00.

These rates refer to the total number of untreated eggs predated during the first three days of the experiment (19/04-22/04).

When methiocarb-treated eggs were deployed, 11 eggs were taken between 13:00 and 16:00. Eight of these eggs were predated a few hours after the first batch of treated eggs were deployed and predation rates showed a steep decrease after that time, which did not allow for clear patterns in timing of predation to show.

We calculated the average number of eggs taken per hour for each of the five check periods and tested for differences between untreated and treated eggs using the independent-samples T-test. The T-test, when equal variances are not assumed, showed that the average number of eggs eaten per hour for each period is different between groups (t=2.566, p=0.02) and higher for untreated eggs than for methiocarb treated eggs. Mean predation rates are 0.69±0.69(SD) eggs/hour for untreated quail eggs and 0.19±0.45(SD) eggs/hour for methiocarb treated quail eggs.

Starling activity remained very low during the time we conducted the experiment. They were usually seen in small numbers in the morning, after which time they dispersed, mostly towards Santa Maria island. During the day almost no starling activity was observed on the islet. Activity was evident again in the evening, before they returned to the roost. During these days starlings were rarely seen feeding on the islet, except for occasional groups of 2-3 birds. Activity was concentrated mostly around potential starling nest sites, where males were displaying.

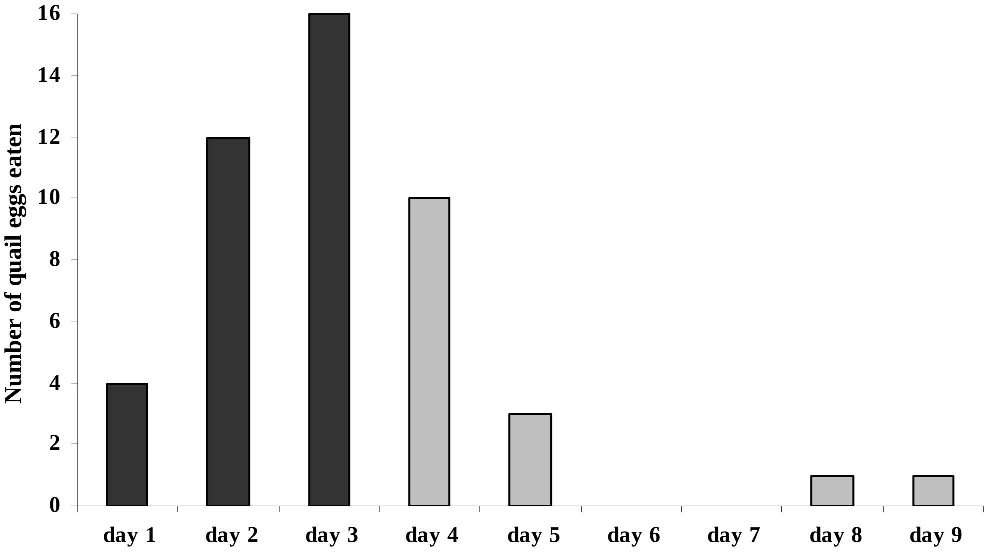


Figure 6.1 Experiment 1- Gull daily predation rate. Black: untreated eggs; grey: methiocarb-treated eggs.

6.3.2 Experiment 2

While the second experiment was being conducted (May), terns nesting in the colony on Vila Islet had already started laying. Although gulls were present in the islet, they were not seen taking eggs during experiment 2, but starlings were observed on a daily basis taking eggs or attempting to do so. Starlings were seen feeding alone or in several small groups (up to a total of 16 birds) scattered on top of the islet. At this time starlings were also incubating and the first chicks had hatched. During April, before starlings started to breed, a total of 392 birds was counted entering the roost on Vila Islet. Only 180 birds were counted in May, after starlings had started breeding in the islet.

The total number of nests and eggs of Roseate Tern available changed daily and therefore we calculated daily predation rate percentages to allow comparisons to be made between days (see Fig. 6.2). Predation rate percentages in both cases increased during the first days and decreased later. In the last days of the experiment, predation increased again, but only in the case of untreated tern eggs. From day 1-6 the mean daily predation rate percentage was 12.98 for tern eggs and 9.34 for treated eggs. When the concentration of the treated eggs increased to 22.50 mg per egg, the mean daily predation on treated eggs dropped to 5.57% but the predation on tern eggs remained high at 12.34%.

Predation on tern eggs and the eggs treated with two different concentrations of methiocarb (11.25mg and 22.50mg) was significantly different (X^2_1=11.04, p<0.01, and X^2_1=4.91, p<0.05 respectively, both with Yates correction).

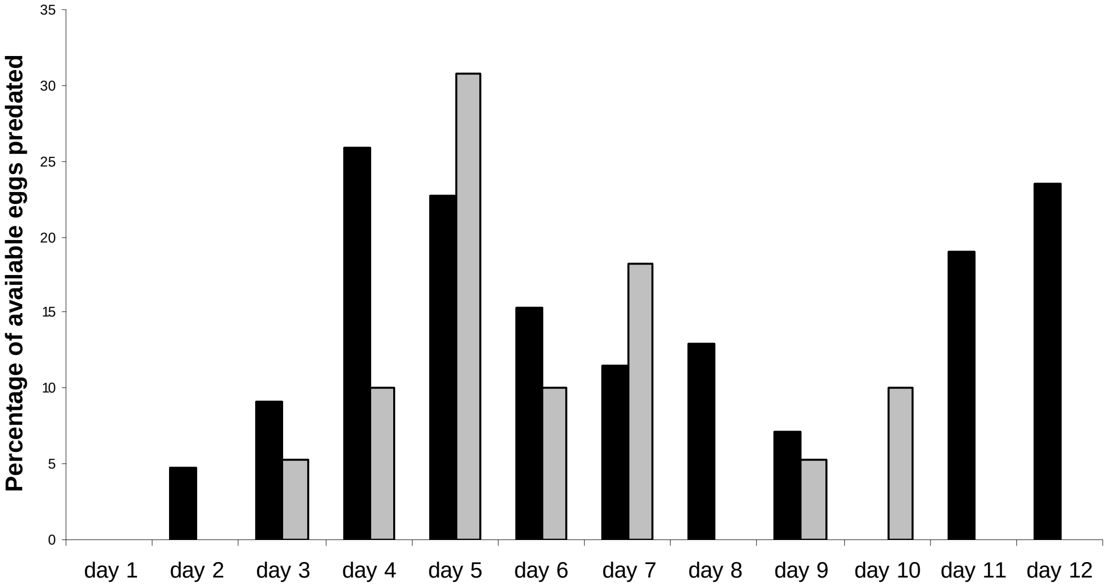


Figure 6.2 Experiment 2 - Starling daily predation rate percentages. Black: Roseate Tern eggs; grey: methiocarb-treated quail eggs (day 1-6: 11.25 mg methiocarb/egg and day 7-12: 22.50 mg methiocarb/egg).

6.4 DISCUSSION

Consumption of quail eggs by gulls decreased dramatically when eggs treated with methiocarb were deployed, but gulls still took one egg each day during the last two days of the experiment. This can be explained by the birds' exploratory behaviour, as has been shown for other species (Avery 1985). At the time this experiment was conducted terns had not started to lay eggs, meaning that nest defence behaviour would be at its minimum, in accordance with the observations. Therefore, tern activity levels cannot explain the sudden decrease in egg predation by gulls when methiocarb was deployed, as tern activity remained the same during the whole period. Deployment of methiocarb-treated eggs appears to be a promising management strategy to reduce egg predation by gulls and additional taste aversion experiments are worthwhile. This is reinforced by the fact that no gulls were observed predating on either tern or treated eggs during the second experiment, despite their presence in the islet at that time. A concentration of 11.25 mg of methiocarb per egg was sufficient to induce taste aversion behaviour, but additional toxicity laboratory tests would help to elucidate safe dosages causing sublethal but emetic responses by gulls.

Starlings were observed feeding on Vila Islet all day throughout May as opposed to April when the first experiment was conducted. The fact that starlings were not feeding in the islet during April seems to indicate that only breeding birds feed in the islet, as starlings started breeding early in May. Additionally, the fact that we never observed large numbers of starlings feeding simultaneously in the islet might indicate that the predatory behaviour is restricted to a small number of specialist birds. Observations indicate that starlings concentrated their activity around tern nests in particular, even when a bird was incubating, suggesting that tern activity may have acted as an attraction for starlings. This is also corroborated by the fact that no predation on the treated eggs occurred during the first two days of the experiment when eggs were deployed with some distance to the Roseate Tern nests in order to minimize disturbance. It was only when the treated eggs were moved very close to tern nests that starlings started predating on them. Although quail eggs have a similar pattern to tern eggs, they may differ enough, especially in size, for starlings to distinguish between them. It is possible therefore, that after suffering noxious effects, starlings learned not to feed on quail eggs, but continued to eat tern eggs. Our results suggest that the deployment of methiocarb-treated eggs did not have a significant effect on starling predatory behaviour, and birds did not show any conditioned aversion learning.

Treated eggs should preferably be deployed well in advance of the availability of the eggs to be protected (Dimmick & Nicolaus 1990), allowing predators to feed repeatedly on treated eggs at a given site, for conditioned avoidance to take place. However, in our second experiment, starlings did not encounter only treated eggs, and did not encounter treated eggs for prolonged time periods. Because starlings start nesting at almost the same time that terns start laying, at which time they also seem to concentrate their feeding activity on top of the islet and close to tern nests, it will be very difficult to control starling predation through CTA. However, before we can rule out the use of CTA, it would be worthwhile doing further experiments in which tern decoys are deployed close to the quail eggs as a way to attract the starlings. If the decoys are successful attracting the starlings, there would be a possibility of conditioning starlings before terns start to lay.

The attractiveness of Vila as a nesting habitat for starlings may be difficult to overcome. Vila is an islet isolated from, but close to Santa Maria island, with several completely inaccessible crevices that seem ideal for these birds (Feare 1984). This coupled with the fact that Vila does not seem to be a habitat large enough to provide food for a great number of birds that have to feed nestlings as well, may be another indication that it would be very difficult to deter starlings from taking tern eggs. Location has been shown to be a good visual cue (Sayre & Clarke 2001), suggesting that starlings may learn to avoid the artificial nests that contain the treated eggs. Changing locations of treated eggs regularly to avoid this effect would require relatively large amounts of time to be spent in the colony, probably causing serious disturbance to the terns and possibly increasing possibilities for egg predation.

It may be assumed that deployment of methiocarb treated eggs for a longer period prior to initiation of laying from terns may have a more significant effect on starling predatory behaviour. However, this will only be possible if the use of tern decoys is useful attracting starlings to the quail eggs, because as seen above starlings did not take quail eggs when they were deployed before terns started breeding.

6.4.1 Management recommendations for Vila islet

Vila Islet is one of the major Roseate Tern colonies in the Azores, and maintenance of population numbers is of primary conservation importance. Low productivity at Vila Islet is expected to persist, in the absence of predator control, because the availability of alternative high-quality breeding sites is limited. The other site on the island where terns have bred is Lagoinhas Islet, but terns have not been observed breeding there since 1997. Lagoinhas Islet is very close to another islet with a gull colony and recently a pair of gulls was observed breeding in the islet where terns used to breed (Neves, pers. obs.). Since available breeding habitat for the Roseate Tern in the Azores is apparently limited, management efforts should focus on maintaining already established tern colonies. The present study suggests that measures other that control taste aversion have to be taken to stop predation of eggs by starlings. Lethal control of starlings nesting on Vila seems likely to be the most successful measure. This measure should be adopted as part of an integrated management strategy that should also include other measures, such as preventing gulls from breeding at tern colonies, providing artificial nests boxes for the terns, control of vegetation cover and stricter law enforcement with regards to human disturbance at the colonies.

Chapter VII

Seabird habitat restoration on Praia islet, Graciosa (Azores): a success story

7.1 INTRODUCTION

Most anthropogenic species introductions have proven catastrophic (reviews in Atkinson 1985; Veitch 1985; Boersma *et al.* 2002). They represent the second main cause of biodiversity loss in the world after habitat transformations (Vitousek *et al.* 1997), but might already have become the main cause of extinctions on islands (Clout & Veitch 2003). Because most seabird species have evolved in areas to which mammals had limited or no access, (i.e., oceanic islands and inaccessible cliffs on mainland), seabirds lack adaptations to cope successfully with alien predators or disturbance of their nesting habitat, making them especially vulnerable to mammalian introductions (Lack 1968). Among the *ca* 330 extant seabird species, 32 are classified as “Near Threatened”, 54 as “Vulnerable” and 44 as “Endangered” or “Critical” according to the IUCN Red List criteria (BirdLife International 2004a).

The seabird assemblage from the Azores archipelago, subtropical northern Atlantic, comprises eight species. Two of these, Cory’s Shearwater (*Calonectris diomedea borealis*) and Yellow-legged Gull (*Larus michahellis atlantis*) belong to a subspecies endemic to the subtropical north-eastern Atlantic (Monteiro *et al.* 1996b; Liebers *et al.* 2001; BirdLife International 2004b). Two other species, Manx Shearwater (*Puffinus puffinus*) and Common Tern (*Sterna hirundo*) breed essentially in temperate areas; the Manx Shearwater reaches the southern limit of its distribution in Macaronesia (i.e., the Azores, Madeira and the Canary islands), where it occurs in low numbers. Three species, namely the Little Shearwater (*Puffinus* *assimilis baroli*), Bulwer's Petrel (*Bulweria bulwerii*) and the Madeiran Storm-petrel (*Oceanodroma castro*), breed in tropical and subtropical areas, with the former two species reaching the northern limit of their Atlantic distribution in the Azores. The eighth species is the Roseate Tern (*Sterna dougallii*), which breeds at tropical as well as at temperate latitudes (Monteiro *et al.* 1996b; BirdLife International 2004a,b) and is one of the rarest breeding seabirds in northern Europe (Cabot 1996). Although its global population is not concentrated in Europe, it does have an unfavourable conservation status there (Tucker & Heath 1994). It is also listed on Appendix II of the Bern and Bonn Conventions, in Annex 1 of the EC Birds Directive, and is a species for which member states must take special conservation action.

The Azores seabird assemblage is intermediate between tropical and temperate avifaunas and four species have important (at an European scale) breeding numbers in the Azores (Table 7.1). However, the introduction of alien mammals by the Portuguese during the 15th century resulted in many seabird species becoming extirpated from the main islands and being now restricted to a few islets and remote coastal strips. As a consequence, the percentage of nesting areas shared between species probably increased, with negative effects on survival and breeding success through increased inter-specific and intra-specific competition for nest sites (Monteiro *et al.* 1996b; Ramos *et al.* 1997).

All the seabird species from the Azores are included in Annex 2 of the Bern Convention, and six of them (all but the Manx Shearwater and the Yellow-legged Gull) are included in Annex I of the EU Birds Directive and currently considered "of Conservation Concern" in Europe (BirdLife International 2004b). In addition, the importance of the Azores as a breeding area at the European level is notable for four of these six species (Table 7.1).

Table 7.1. Conservation status in Europe of the seabirds that breed in the Azores (data drawn from BirdLife International 2004b).

Species	*Species of Conservation Concern*	*Conservation status*	*% of European population breeding in the Azores*
Calonectris diomedea [a]	Yes (category 2)	Vulnerable	65-70%
Bulweria bulwerii	Yes (category 3)	Rare	0.5-0.6%
Puffinus puffinus	Yes (category 2)	Vulnerable	< 0.1%
Puffinus assimilis [a]	Yes (category 3)	Rare	13-25%
Oceanodroma castro [a]	Yes (category 3)	Rare	20-31%
Larus michahellis	No	Secure	0.8-1.5%
Sterna dougallii [a]	Yes (category 3)	Rare	53-56%
Sterna hirundo [a]	No	Secure	0.3-0.9%

[a] Breeds on Praia islet.

For all the above reasons, the Azores have an international importance for seabird conservation and study (Santos *et al.* 1995; Monteiro *et al.* 1996b), and one of the priorities should be to eradicate introduced mammals and to restore habitat wherever possible in the archipelago. Whereas the area and topography of the nine main islands of the Azores presently preclude mammal eradication, such operations are possible on the smaller islets.

Praia islet is an Important Bird Area in Europe (site code 007) and holds breeding populations of at least five of the eight extant Azorean seabird species (Monteiro 2000). However, rabbits (*Oryctolagus cuniculus*) have been present in the site for *ca* 50 years (Bell *et al.* 1997). Like most of the *ca* 800 islands where they have been introduced (see review in Courchamp *et al.* 2003), rabbits depleted the native vegetation and intensified soil erosion, but they were also competing for burrows with petrels, including Cory’s Shearwaters, the largest species (840 g, see Monteiro *et al.* 1996a). Robinson and Hamer (1998) were the first to document the killing of seabirds by rabbits. This behaviour is understandably difficult to observe and might be going on undercover at other sites and colonies. To our best knowledge it was not happening at Praia Islet before the eradication but he could have developed if the rabbits had remained in the colony. Therefore, this islet was chosen to conduct what is to our knowledge the first habitat restoration campaign involving reintroduction of endemic plant species and reduction of soil erosion after rabbit eradication in the western Palearctic. In this study, we describe the restoration measures implemented on Praia islet and discuss their results and consequences.

7.2 METHODS

7.2.1 Situation of Praia islet

Praia islet (39°03'N, 27°57'W) has an area of 0.12 km^2 and is situated 1 km off Graciosa island (Fig. 7.1). It is an Important Bird Area (site 007, Monteiro 2000) and the only locality in the Azores where the globally threatened Fea's petrels (*Pterodroma feae*) has been recorded (Monteiro & Furness 1995). Praia islet colony holds the largest concentration of Madeiran Storm-petrel in the Archipelago (more than 40% of the Azores breeding population), from both hot and cool season populations (Monteiro 2000). Other breeding seabirds are Cory's Shearwater, Little Shearwater, Roseate Tern and Common Tern (Monteiro *et al.* 1996b), all included in Annex I of the EU Birds Directive and Annex 2 of Bern Convention. With the exception of Common Tern all breeding seabirds are considered "Species of Conservation Concern" (SPEC) (Table 7.1). Bulwer's Petrel is present in the islet but breeding has never been confirmed.

The coast of Praia islet is rocky with volcanic boulders and, in the eastern and northern parts, cliffs falling to the sea. Before habitat restoration measures were implemented, the islet was very barren, with little native vegetation; the only trees were introduced tamarisks (*Tamarix africana*), which served as shelter for local people visiting the islet. In addition, extensive erosion was occurring at the southern and western extremities of the islet, where several areas had already lost the topsoil layer. There were no other mammals than rabbits. Like all the other major seabird sites from the archipelago, Praia islet was given the status of Special Protection Area under the EU Birds Directive in 1990 (Anonymous 1991).

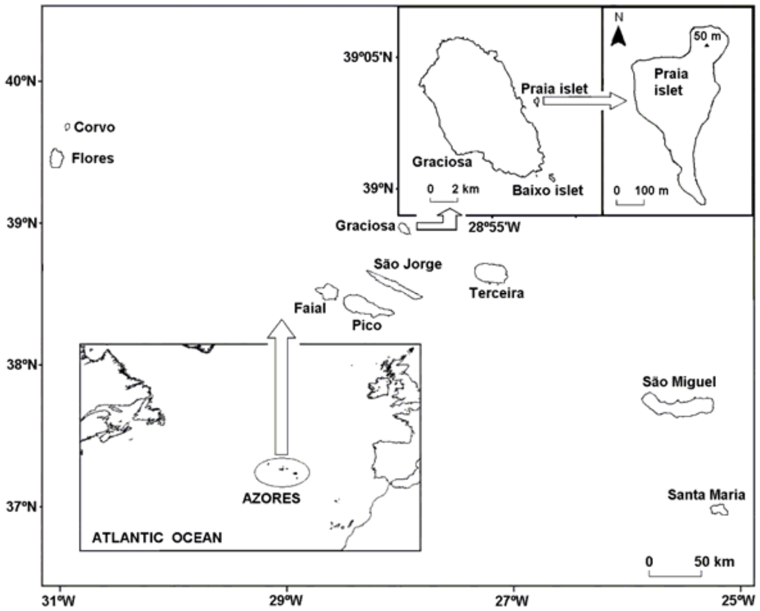


Figure 7.1. Situation of Praia islet in the Azores archipelago.

7.2.2 Measures to restore and improve the habitat

Rabbit eradication

After a poisoning attempt using racoumen (an anticoagulant rodenticide usually used to kill mice) failed in 1995, the Azores Government (Environmental Department) approached Elizabeth Bell from the Wildlife Management International Limited, for assistance in conducting an eradication programme. A visit to the islet on 12 September 1997 enabled us to determine the areas where rabbit concentrations were highest. Although rabbits were observed everywhere on the islet, they tended to concentrate near the tamarisks. The herbaceous cover of the islet was very dry and/or dead and we found several dead rabbits, facts that associated with observations of rabbits browsing on the lowest tamarisk branches, strongly suggested us that rabbits were facing high nutritional stress. Therefore, it was decided to take advantage of this situation by beginning the poisoning phase as soon as possible. Brodifacoum, which had already proven its efficiency during previous rabbit eradication campaigns (e.g., Merton 1987), was used. Brodifacoum is a second-generation anticoagulant with delayed effects, but due to its high toxicity it can kill after a single feeding (Torr 2003). It prevents the formation of blood clotting proteins by blocking the vitamin K1 oxidation-reduction cycle in the liver, and death results from internal haemorrhages (Smith & Greaves 1987).

Poisoned bait (cereal-based pellets containing 20 ppm brodifacoum; manufacturer: Animal Control Products, Wanganui, New Zealand) was deployed near the tamarisk trees on the 12 September to test its attractiveness and palatability. Because of the sudden occurrence of a hurricane (Cyclone Erica) in the Azores archipelago, large-scale poisoning started, later than planned, on 20 September. Our aim was to get poisoned bait within the home range of each rabbit, and to achieve it, we placed 150-200 g bait per station on a 20-meter grid. Closer spacing was used when high rabbit activity (large number of burrows, scratching or faeces) was noted, and we put extra bait around the tree thickets, underneath the trees, and whenever we found an area with signs of high rabbit activity. Finally, we deployed bait in all the cliff faces. Overall a total of 90 kg of poisoned bait was deployed in the islet, averaging 7.5 kg/ha. A visit conducted one day after this deployment revealed that baits had been consumed, partially or totally, at most stations. Therefore, a second poisoning session was carried out on 24 September accordingly to the same protocol as above, but using only 100 g of bait per station, so that a total of 70 kg of bait was used this time (5.8 kg/ha). To maximise our chances of success, additional poisoning sessions occurred on 30 September and 2 October, using 30 kg of bait (2.5 kg/ha). Ten kilograms of bait were left on the islet in the case where further rabbit activity would be detected during the forthcoming follow-up sessions, or in the event of a subsequent introduction.

From the second poisoning session onwards, a follow-up was conducted daily, by walking systematically throughout the entire islet looking for active burrows, fresh scratching, faeces and tracks. Whenever signs of recent rabbit activity were found, bait was placed out near the location. In addition, searching sessions were conducted at dawn and at dusk, and we performed spotlighting at night with a shotgun. We also set leg hold traps at the entrance of the burrows that still seemed to be active. To avoid contamination of predatory and scavenging birds (Common Buzzards [*Buteo buteo rothschildi*] and Yellow-legged Gulls), rabbit corpses were removed upon discovery.

Control of soil erosion

Due to rabbit presence and to the friable nature of the islet substrate, erosion was very important in some areas. Although vegetation recovery following rabbit eradication was expected to reduce soil loss, some additional practical management was needed to stop and revert the high levels of erosion. For this purpose, two techniques adapted from those described by Gray & Leiser (1982) were used. They consisted in laying branches cut down from the tamarisks into erosion ridges and building debris dams made of wooden planks or rock piles in erosion ridges. These measures were carried out in 1995 and 1997.

Reintroduction of native and endemic plants

Because there was no data concerning the vegetation of Praia islet before rabbit introduction, we determined the species that should be re-introduced based on the results of a preliminary survey conducted on the neighbouring Baixo islet (ca 2 km south of Praia) in 1996. Small plants of Azorina vidalii, Erica scoparia azorica, Myosotis maritima, Festuca petraea, Solidago sempervirens, Spergularia azorica, Tolpis azorica, Myrica faya, Carex hochstetteriana collected on Baixo islet and on Graciosa island were planted on Praia islet from May 1998 onwards, according to their habitat preferences.

Artificial nests

Common and Roseate Tern breeding numbers on Praia islet have been annually determined since 1988. The census occurred three to five weeks after the first incubating individual was observed, which corresponds to the period when the number of active nests (that is, with eggs or chicks) observable in the colony is maximal (Bibby *et al.* 1992). Counts were made by direct ground search of clutches and broods. Because Roseate Terns tend to use more sheltered sites for nesting than Common Terns in the Azores (Ramos & del Nevo 1995), 50 wooden nest boxes (internal dimensions: 0.28 × 0.26 × 0.14 m) have been installed in some open areas of the islet each year since 1996, in order to increase the availability of suitable nesting sites for Roseate Terns; suitability criteria were established based on the study of

Ramos & del Nevo (1995). Nest boxes are installed at the onset of the breeding season in early April, and removed in September, after all the chicks have fledged.

To increase the size of the breeding population of Madeiran Storm-petrels, 150 PVC or plastic nest boxes were installed in 2000-2001 (see details in Bolton *et al.* 2004). Since then, the maintenance and the monitoring of the storm petrel artificial nests have been annually conducted for each seasonal population. Annual monitoring sessions of the Madeiran Storm-petrel population enable us to determine occupancy rates, number of breeding pairs, and productivity. Adults are identified from their rings or newly ringed, and chicks are ringed before fledging.

7.3 RESULTS

7.3.1 Rabbit eradication

Overall at least 82 rabbits were killed during the eradication campaign. When we returned on 20 September 1997, the bait left around the house on 12 September 1997 had been totally consumed, and we found ten dead rabbits. On 21 September, 24 hours after the first whole islet poisoning session, many bait stations had been visited and bait had been totally consumed at some of them. Between 22 and 25 September, we found another 12 dead rabbits, and we also noticed the abnormal behaviour of some individuals that were for instance unable to flee rapidly when we approached them or were sitting motionless for a long time. Between 25 and 29 September, we found 57 new rabbit corpses. Three live individuals were still observed on 29 September; during the subsequent night, however, two of them were recovered dead and the third one was shot. During the monitoring and spotlight sessions conducted throughout the two subsequent days and nights, we observed neither live rabbits nor signs of recent rabbit activity. Since then, no sign of the presence of rabbits has been observed.

No adverse effects of poisoning on the avifauna of the islet were detected, except for two Blackbirds (*Turdus merula*) found dead between 25 September and 2 October. Insects were also observed consuming the bait, but they are very unlikely to be affected by brodifacoum (Shirer 1992), especially at the concentration used in our eradication campaign (Booth *et al.* 2003).

7.3.2 Control of soil erosion and reintroduction of native and endemic plants

Putting tree branches into erosion ridges and constructing debris dams proved very efficient in terms of soil retention, and was followed by colonisation of herbaceous plants the following year. By 2004, the vegetal cover had noticeably increased (Fig. 7.2), and all the ridges were partially filled up and contained vegetation.

The success of the operations of vegetation restoration was dependent on plant species. The only plant for which introduction resulted in total failure was *Myosotis maritima*. The programme is still ongoing due to some difficulties experienced with *Erica scoparia azorica* and *Solidago sempervirens* which have very low growth rates (in addition, only two plants of the former species have survived), and *Carex hochstetteriana* which needs specific habitat conditions. *Azorina vidalii* also grows slowly and, in addition, it is the unique representative of a genus endemic to the Azores (Schäfer 1999). Three plants of this species were introduced in 1998, but one of them died a few weeks later. However, the two surviving plants are thriving and already produced seeds that have germinated. On 3 August 2005, we censused 125 young plants of *A. vidalii* on Praia islet. All of them but one were growing within a 30 m radius around one of the introduced plants. *Festuca petraea* and *Tolpis azorica* are spreading on a larger scale, and several tens of plants of each species are now present on the islet.

The few exotic plants that attempt to colonise the islet (essentially *Carpobrotus edulis* and *Lantana camara*) are removed. Plant introductions and removal of exotic species are currently conducted by one of the authors (LA).

Figure 7.2. Vegetation recovery at Praia islet. Top: in September 2004, just before rabbit eradication (photos EB). Bottom: the same areas on 10 September 2004 (photos JB; bottom right: the wooden boxes for terns have not yet been removed).

7.3.3 Artificial nests

Terns

Tern breeding numbers increased significantly once rabbits were eradicated and nest boxes were installed (even if we considered our minimal estimate for Common Terns in 2004, see below; Spearman rank correlation, both species pooled: $r = 0.833$, $n = 8$, $p < 0.025$), although the increase did not occur immediately (Fig. 7.3). Roseate Terns had been almost totally absent from Praia islet since 1991. Two individuals were observed in 1998, the year following eradication; however, no colony settled until 2000. Overall, the breeding numbers of this species on Praia islet have increased significantly since rabbit eradication (Spearman rank correlation, $r = 0.881$, $n = 8$, $p = 0.01$), experiencing a 13-fold increase between 2000 and 2004 (Fig. 7.3); the steep decrease that occurred in 2005 was also observed in most of the other Roseate Tern colonies from the Azores (MCM unpublished data). Because most pairs breed in a rocky area which provides chicks with a sufficient number of shelters from sun and intense rain and the few remaining pairs nest in a zone where the vegetation cover also provides sufficient protection, Roseate Terns never used the nest boxes.

When considering Common Terns, a few tens of pairs have always been breeding on Praia since 1988, except in 1995 and 1996. This species bred again on Praia islet in 1997, before rabbits were eradicated. Since then, breeding numbers have kept increasing (Fig. 7.3), and Praia islet now holds the largest Common Tern colony of the Azores. In 2004, however, many chicks had already hatched when we visited the islet. For this reason, and because large chicks can wander far from their nests, the results of our census could not be as accurate as for previous years, and we obtained an estimate ranging from 689 to 1196 breeding pairs. The dramatic increase in Common Tern breeding numbers after rabbit eradication was significant if we considered the higher value for 2004, but failed to reach significance if we considered the lower estimate (Spearman rank correlation, $r = 0.833$, $p < 0.025$ and $r = 0.667$, $0.05 < p < 0.1$, respectively; both $n = 8$).

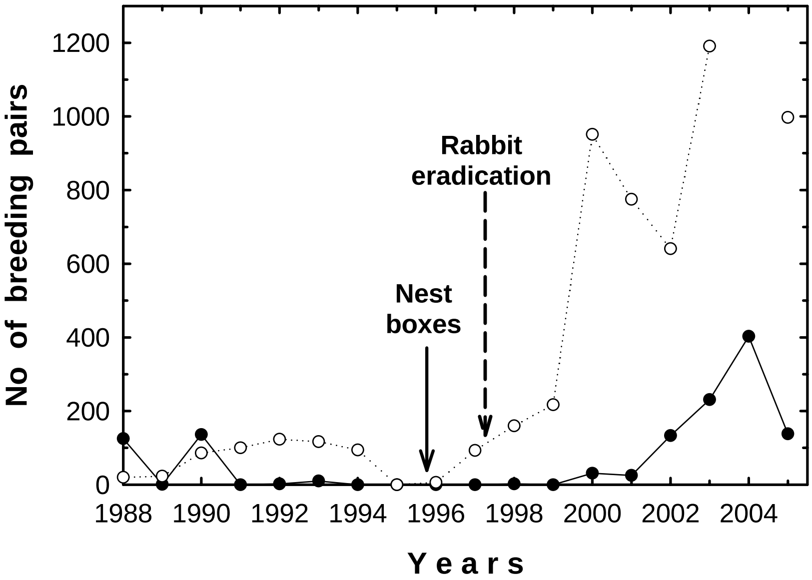


Figure 7.3. Breeding numbers of Roseate (dots) and Common Terns (open circles; breeding numbers in 2004 were not represented, see text) on Praia islet between 1988 and 2005.

Because the Common Tern colony from Praia islet is situated in a much more open habitat than that of Roseate Terns, natural shelters are in low supply. However, adult Common Terns do not use nest boxes, but chicks use them as shelters from both predators and weather. Finally, a Sooty Tern (*Sterna fuscata*) was found incubating an egg on Praia islet in June 2004.

Madeiran Storm-petrels

Monitoring results show a continuous increase in the number of birds (breeders and prospecting non-breeders) occupying the artificial nests during the breeding season for both seasonal populations. Between 2000 and 2005, the number of Madeiran Storm-petrel pairs breeding in the artificial nests showed a 3.5-fold increase in the hot season morph and an almost 3-fold increase in the cool season morph (Table 7.2).

Table 7.2. Occupancy rate and breeding parameters of the artificial colony of Madeiran Storm-petrels from Praia islet (number of artificial nests in brackets).

Season and year	*No of occupied nest boxes*	*No of breeding attempts*	*Chicks hatched/fledged*	Source
Hot 2000	47 (115)	13 15	6/5 (15/5)	Bolton *et al.* 2004
Hot 2001	49 (147)	28 18	22/18 (18/3)	Bolton *et al.* 2004
Hot 2002	32 (147)	22 _	16/13 --	This thesis
Hot 2003	49 (150)	44 8	29/21 (5/4)	This thesis
Hot 2004	50 (150)	46 15	34/27 (8/7)	This thesis
Cool 2000/01	40 (147)	22 21	16/14 (21/6)	Bolton *et al.* 2004
Cool 2001/02 [b]	-	-	-	This thesis
Cool 2002/03	53 (150)	47 or 48 10	33/31[c] (10/8)	This thesis
Cool 2003/04 [d]	50 (150)	46 12	37/34 (?/11)	This thesis
Cool 2004/05	67 (150)	64 22	59/44[c] (12/12)	This thesis

[a] Probably underestimated since only one visit to the colony was carried out.

[b] Harsh meteorological conditions prevented the access to the islet throughout the breeding season.

[c] Minimal figure since the fate of one chick was unknown.

[d] Minimal numbers since bad weather prevented the access to the islet during the incubation period, so that some pairs that failed during the early stages of this period may have been missed.

In red: values for natural nests.

Breeding success in nest boxes tended to be higher than in natural nests; mean fledgling success for the period 2000-2004 was 60.1% in the artificial nests and 50.2% in natural sites (Bolton *et al.* 2004; authors' unpublished data). A long-term demographic survey is being conducted to estimate other demographic parameters such as adult survival rate, age at first breeding and breeding frequency, which will make it possible to assess the dynamics of each seasonal population.

7.4 DISCUSSION

7.4.1 Rabbit eradication

Our rabbit eradication was very successful and all the rabbits were killed after the first campaign. Additionally it had a negligible impact on the native avifauna. Our results contrast with the results from other localities, where additional campaigns often remain necessary during subsequent years because there was always a small proportion of individuals that did not consume baits (e.g., Merton 1987; Chapuis *et al.* 2001; Micol & Jouventin 2003). The efficacy of our eradication campaign may be explained by the high poisoning intensity since we used 1583 kg of poisoned bait per km^2, which was similar to the concentration of 1687.5 kg/km^2 on Saint-Paul island (calculated from Micol & Jouventin 2003), but higher than the 500 to 1000 kg per km^2 on Enderby and Rose islands (Torr 2003). However, it was necessary to shoot and/or to trap rabbits during several weeks or even years after poisoning at the last three localities whereas the last rabbit observation on Praia islet occurred only five days after the second poisoning session. This difference may be due to the small area and the accessibility of Praia islet which both facilitated poisoning, the short time interval between two successive poisoning sessions, and also by the fact that rabbits were experiencing a severe food shortage when we started poisoning. Our rabbit eradication campaign is the second out of the only four so far conducted in Europe (Genovesi 2005), and, at least in Europe, the first to be associated with habitat restoration measures.

Two other introduced species might pose problems in the long term. The first species, the feral pigeon (*Columba livia domestica*), nests in rock cavities in the cliffs of the islet, and might prevent small petrel species, like the Madeiran Storm-petrel but also Bulwer's Petrel, from nesting. With only a few tens of breeding pairs (Monteiro *et al.* 1999), the Azorean population of the latter species is a relict one (Monteiro *et al.* 1996b); breeding on Praia has never been confirmed although a few individuals are present each summer (Monteiro *et al.* 1999; data from this study). The second introduced species remaining on Praia is the Madeira lizard (*Lacerta dugesii*), which is regularly observed in the Madeiran Storm-petrel nest boxes. Although lizards do not seem to break storm petrel eggs (MB & JB unpublished data), they might cause some disturbance to incubating birds, inducing nest switches and divorces (see Bried & Jouventin 1999). When changing nest and/or mate, seabirds can lose up to several breeding years (Bried & Jouventin 2002), which leads to a decrease in reproductive lifespan. Therefore, it is desirable to assess the impact of lizards on Madeiran Storm-petrels.

7.4.2 Control of soil erosion and reintroduction of native and endemic plants

The climate of the Azores is very humid, so that the scarcity of herbaceous plants on the islet at the time the eradication campaign started (Fig. 7.2, top), compared to the much thicker vegetal cover observed in 2004 (Fig. 7.2, bottom) should not be due to a drought. Supporting this, summer rainfall (i.e., between 1 June and 31 August) on Graciosa island was 27% heavier in 1997 than in 2004, and August and September were drier in 2004 than during the previous seven years (Azorean Meteorological Institute, pers. comm.). Therefore, we are confident that vegetation recovery on Praia islet is due to our rehabilitation measures, and not to better meteorological conditions for plant growth after 1997.

Although our results are encouraging, monitoring needs to be continued for several more years to determine the patterns of re-colonisation accurately. In the long term, the colonisation of the islet by *Festuca petrae* might lead to decreased availability of nesting habitat for terns, and this needs to be followed up. In addition, the removal of exotic plants needs to be repeated every year to be efficient.

7.4.3 Artificial nests

Praia islet was an important breeding site for terns in the 1960s and although Bannerman & Bannerman (1966) could not land on the islet, they observed a mixed colony of Common and Roseate Terns (they counted at least 200 to 300 individuals, the majority being Roseate Terns). Tern populations on Praia islet were very reduced in the early 90s but have been dramatically increasing since rabbit eradication (Fig. 7.3). In 2003, the islet held 25 and 34% of the breeding population of Roseate and Common Terns from the Azores, respectively, whereas the breeding numbers of the former species in the archipelago have remained stable since 1989 (del Nevo *et al.* 1993; authors' unpublished data).

The presence of researchers on the islet was virtually continuous from March 2000 to September 2001, due to the installation and monitoring of the storm petrel artificial nests. This presence discouraged people to visit the islet, which might also have played an important part in the steep increase in tern numbers between 1999 and 2001. Nevertheless, tern numbers (and especially those of Roseate Terns, see Fig. 7.3) continued increasing during the subsequent years, when scientists were present only intermittently on the islet, making us confident that the efficacy of the restoration programme was not confounded by an effect due to the presence of researchers. Similarly, the decrease observed in 2005 for both tern species on Praia islet (Fig. 7.3) also occurred at most of the archipelago, and in some colonies was even more prominent (MCM unpublished data). The presence of the incubating Sooty Tern in 2004 is of some interest since it is the first known breeding attempt of this species on Praia islet. The Azores represent the northern limit of the breeding range of the Sooty Tern in the Atlantic, but until now, the only known breeding locality of this species in the Palearctic was Vila islet (*ca* 350 km south-east of Praia), where one or two pairs have been annually breeding since at least 1990 (Monteiro *et al.* 1996*b*; authors' unpublished data).

Madeiran Storm-petrels also benefited from the measures implemented, and the speed at which they colonized the artificial nests supports the hypothesis of a previous shortage of suitable breeding sites for this species (Bolton *et al.* 2004). Because storm petrel nest boxes were installed almost three years after rabbit eradication, the nest shortage experienced by Madeiran Storm-petrels on Praia islet was probably not due to the presence of rabbits. The most likely factor is the presence of introduced mammals and human settlements on the main islands of the Azores archipelago, which has led to the species now being restricted essentially, if not exclusively, to offshore islets (see Introduction and Monteiro *et al.* 1999). Currently, Praia islet holds about one third of the cool season and half of the hot season breeding population of Madeiran Storm-petrels in the Azores (Monteiro *et al.* 1999; authors' unpublished data). The consequences of habitat restoration are less clear for the other petrel species, even though Little Shearwaters sometimes breed in storm petrel nest boxes and Cory's Shearwaters may use rabbit burrows for nesting. Concerning Fea's petrel, historical evidence suggests that it was common in the Azores in the 15th century (Fructuoso 1561; Monteiro *et al.* 1996*b*). Since then, and even though a few individuals have been observed in the archipelago since 1990 (review in Monteiro *et al.* 1999), no breeding attempt has ever been recorded.

7.5 CONCLUSION: FUTURE WORK AND PROSPECTS

Overall the habitat restoration measures implemented have reinforced Praia islet as a site of major importance for the conservation of Azorean seabirds. However, and despite the success of the measures implemented, Praia islet remains a vulnerable area. Visits to the islet are still allowed, and people continue coming with boats, mainly between May and August, i.e. during the most sensitive stage of the breeding period of most seabird species. Information panels explaining the impact of human disturbance on seabirds have been installed regularly since 1995, to discourage the access by visitors to the tern colony, and overnight stays are only permitted to researchers. In addition, a permanent year-round position of nature warden on Graciosa island was created in 1998, and the nature warden is present during most diurnal visits to Praia islet (although he has no obligation to do so). Nonetheless, people may also visit the islet outside the working hours of the nature warden, including at night, and cause disturbance inadvertently and/or perform illegal fishing. This does represent a problem since in the Azores severe disturbance has been proved to cause terns to abandon the site on the following year (Monteiro *et al.* 1996*b*).

Another problem is the potential introduction of rats (*Rattus* spp.) following ship wrecks, such as that of the cargo ship *Corvo* which broke up on a small reef barrier situated a few tens of meters south of Praia islet in December

2000; fortunately, no signs of rat presence on the islet and no impact on the fauna and the flora were subsequently detected. Therefore, it is desirable to continue informing the public of the effects of human disturbance on breeding seabirds and the catastrophic impact of introductions on insular ecosystems. Simultaneously, it should be worth circulating information on the dramatic effects of the introduction of alien species, including providing identification keys for the main invasive species.

Control and/or removal of exotic plants remain necessary, and so do the monitoring of the potential excessive growth of *Festuca petraea*, the maintenance of the tern nesting habitat (installation and removal of the wooden nest boxes) and that of the storm petrel artificial nests (removing the vegetation at the entrance of the nest boxes, checking that nest box ceilings remain waterproof). In addition, the remoteness of the Azores makes the smallest populations of this archipelago very vulnerable to exogenous predators arriving on their own, even in small numbers. These vagrants settle on the first available land mass and, because their usual prey species are absent, exploit the local food resources opportunistically and can have a strong impact in a short time lag (Bried 2003b; MB unpublished data).

Nevertheless, several lessons can be drawn from this eradication campaign and the ensuing follow-up. First, our study highlights the advantages of conducting eradication campaigns during the period of lowest food availability for the target species, so that (1) eradication can be achieved more rapidly without using higher poison concentrations, and (2) financial costs (logistic, and travel expenses) are reduced compared to situations where several visits to the sites are needed before introduced mammals are totally eradicated (e.g., Chapuis *et al.* 2001; Micol & Jouventin 2003). Second, installing artificial nest boxes for seabirds permits an increase not only in breeding numbers, but also in the lifetime reproductive success of the individuals. Third, and because of the long-term context (especially human pressure), the diversity of the measures that were implemented here, and the failure of a previous eradication attempt, this study highlights the potential complexity of restoration operations, even on very small land masses, and confirms the need to consider each situation independently when conducting such operations (see review in Courchamp *et al.* 2003).

Chapter VIII

General Discussion

This chapter reviews and synthesises the key findings of the work presented in this thesis. It also discusses management considerations that emerged from the main results and from the logistical experience gained during the study, and suggests approaches for further research. In Appendix 2 I include an Action Plan for the Roseate Tern in the Azores prepared for use by local conservation and policy making authorities.

8.1 KEY FINDINGS

The key findings can be summarised as follows.

1. Breeding numbers of Roseate Tern in the Azores archipelago have fluctuated dramatically. This fluctuation has not been observed in other north Atlantic populations, where Roseate Tern numbers have been generally increasing, and deserves further study. The causes for intermittent breeding are complex and might be associated with large-scale phenomena, such as climatic and oceanographic features that affect marine food webs and consequently abundance of top predators such as Roseate Tern. Amongst the Azores seabird community, the Roseate Tern constitutes an environmentally sensitive species that might prove very useful to monitor marine food-webs functioning around the archipelago. Because the Roseate Tern has a short-distance foraging range around the breeding colony it provides a far more useful species to monitor the Azores region than, for example, the very abundant Cory's Shearwater that has a foraging range of hundreds of kilometres.

2. It was finally proved that the European Starling has been the predator consuming tern eggs since long-term monitoring started back in 1989 (chapter III). This behaviour seems to be restricted to Vila islet colony but

monitoring elsewhere is crucial to detect eventual expansion of this predatory behaviour at an early stage.

3. The increase of the population of Yellow-legged Gull (chapter IV) is a cause for concern and should be tackled at this point in time when gulls are just starting to breed closer to tern colonies. Control Taste Aversion might be a useful tool dealing with gull predation but it does not seem to offer many prospects of success to control starling´s predation (chapter VI). However it might be useful if used in combination with other measures, such as provision of artificial nests for terns and provision of sources of water for starlings.

4. Azorean starlings have a very distinctive haplotype from the three continental populations studied; in addition, all the Azores haplotypes were the same (chapter V). This result indicates that there is starling mobility between the different islands of the Azores, but none with mainland Europe.

5. An integrated approach to habitat restoration in Praia Islet proved very successful increasing breeding numbers of both Roseate and Common Tern (chapter VII) and this approach should be extended to other Roseate Tern colonies of the archipelago and perhaps elsewhere.

8.2 MANAGEMENT CONSIDERATIONS AND PRIORITIES

In order to effectively protect the Roseate Tern in the Azores, it is of paramount importance to identify its optimal habitat requirements and understand the functioning of the ecosystems and food webs on which they are dependent, as well as the ecology of other species, which can act as predators and competitors.

It seems clear from the experience gained here, and on other geographic areas, that it will be difficult to conserve this remarkable bird without actively managing and protecting the whole habitat. At least some degree of a “hands-on conservation approach” seems desirable if the protection of the Roseate Tern is to be pursued and hopefully achieved. At the present, the Roseate Tern is facing too many pressures and threats in Azorean archipelago to allow for a neutral and/or passive approach. Over the last decades and probably over the next few years, the potential negative factors will continue to intensify in the archipelago. These factors include: a) competition with fisheries; b) expansion of gulls numbers and c) intensified disturbance and use of the coast by man at the expense of compromising tern habitat quality. Worryingly, the basic and effective protection of the colonies, which should have been implemented by European law, and should have been achieved during the last EU-funded LIFE projects, has not yet become a reality in the archipelago.

The dispersion of the colonies in nine islands and several islets, stretching over 600km, undoubtfully make it difficult to achieve a successful and integrated protection policy. It is therefore important to involve and employ the local people as protectors/guardians of tern colonies. I have personally experienced (e.g. Caloura, São Miguel island) how willing local people can be when it comes to protecting terns from disturbance. However, most of the time, local people lack appropriate knowledge on how to act and, therefore, the local government conservation agency needs to provide adequate support and disseminate the legal and ornithological information in more creative and effective ways. It is vital to find more proficient ways of disseminating the message and earning the support of the population regarding the protection of the Roseate Tern. A considerable effort has been made over the last decade and in some cases, the results of these efforts have been successful. Nevertheless, much remains to be done.

It is important to extend the areas where integrated conservation action is implemented and make sure the projects already implemented are followed up. Regular monitoring of colonies where success as been temporarily achieved, such as Praia islet - Graciosa, is necessary to ensure that the ideal breeding requirements are maintained and to monitor at the earliest opportunity any potential changes that might quickly impact on terns and be difficult to control. Continuous monitoring programmes are fundamental, but many colonies are remote and difficult to access (e.g. Vila) and there is a long tradition of disturbance and harvesting of protected Cory's Shearwater for food. Creative solutions are needed. It is also very important to collect and archive information in a systematic way. Well-trained and equipped rangers could easily collect basic, but very important information. For example, the dates of arrival of terns in the different islands and colonies, the presence or not of predators in the colonies, amongst others. At the moment the large majority of the rangers from the Azores islands lack knowledge and skills in how to protect and monitor the Roseate Tern.

It can not be stressed enough that without knowledgeable human resources operating simultaneously in the different islands, something that has proved difficult to deliver in the past, effective conservation of the Roseate Tern in the Azores will not be achieved. More cooperation amongst the different entities and interested parts is not only desirable but crucial: politicians, researchers, rangers, technical staff, local people, all need to come together to address the problem, formulate solutions and activate a conservation plan.

Below I list some issues that are necessary to achieve success:

1) To continue, and extend to other islands/locations, campaigns to raise awareness of seabird biology & conservation;
2) Build local capacity and participation in wildlife management - engage the local population and train residents in selected areas for leadership roles in conservation;
3) To combine education and training with employment opportunities. Education campaigns should also include results from research and population increases (e.g., the good example of Praia Islet should be promoted). Education campaigns should reinforce existing cultural norms/traditions that favour conservation, rather than introducing new norms from the outside;
4) To improve habitat protection and conduct additional research;
5) To be aware that this is a long-term process and results are not always immediate.

8.3 FUTURE RESEARCH

8.3.1 Migrations

Migration is the regular seasonal movement of animals from one place to another, often from a breeding site to a non-breeding site and back (Webster *et al.* 2002) and represents a fundamental aspect of the ecology of populations and individuals (Hobson 1999). The study and understanding of the ecology and evolution of migrating birds implies following individuals and populations all year round, which can be a very hard task. Nowadays the use of devices such as Platform Transmitter Terminal (PTT's) and geolocators has become widespread due to the advances in technology, but nevertheless, the use of these methods in small and endangered birds, such as the Roseate Tern, is perhaps ill-advised. Future studies may benefit from making use of a stable isotope approach; this useful tool has recently received great scientific attention on the study of birds migrations (in passerines Bearhop *et al.* 2005) and has been used on the study of terns´diets (Nisbet *et al.* 2002).

However, this technique requires further development before a basic calibration study is undertaken that will identify the potential, and limitations, of using this technique on terns in the Azores. It is important to gather data of the carbon and nitrogen signatures of organisms living in the Azores and to investigate whether Roseate Terns shown systematic differences in the C and N signatures between breeding and wintering grounds. If differences are found it is then important to investigate if the specific signatures can be undoubtfully linked to reliable geographic areas. The use of stable isotopes in this particular case may not be worthwhile before other fundamental knowledge becomes available. Regarding migrations, one important issue to address is to know whether the individuals that comprise a single breeding population all migrate to the same non-breeding location, or if they spread out over the entire non-breeding range of the species. Ringing recoveries of Roseate Terns have suggested that West Africa, particularly Ghana, is the regular wintering area of European terns. Azorean Roseate Terns have been recovered (see table 8.1) in West Africa (Ghana and Ivory Coast) and in South America, Brazil (Hays *et al.* 2002), and Common Terns have been recovered in Brazil (Hays *et al.* 1999) and Argentina (Neves *et al.* 2001).

Table 8.1: Recoveries of Roseate Terns ringed in the Azores.

Code	Ring*	Age when ringed	Ringing date	Ringing location	Age when recovered (years)	Recovery date	Recovery location	Reference
1		1	1984	Azores	?	Sept-Dec 1988	Ghana	1
2		1	1984	Azores	?	Sept-Dec 1988	Ghana	1
3		?	1989	Azores	?	Sept-Dec 1989	Ghana	1
4		?	1989	Azores	?	Sept-Dec 1989	Ghana	1
5		?	1989	Azores	?	Sept-Dec 1989	Ghana	1
6		?	1989	Azores	?	Sept-Dec 1989	Ghana	1
7	G5212	1	18.6.95	Santa Maria-Vila Islet	1	16.11.95	Abidjan (Ivory Coast)	2
8	G5323	1	22.6.95	Santa Maria-Vila Islet	1	16.11.95	Abidjan (Ivory Coast)	2
9	G5234	1	18.6.95	Santa Maria-Vila Islet	2	10.1.97	Accra (Ghana)	2
11	G11514	4	29.5.00	Terceira-Contendas islet	>= 5	19.6.02	Malama (Liberia)	2
12	G9569	4	1.6.01	Terceira-Contendas islet	5	19.4.03	Huelva (Spain)	2
13	G9741	4	23.5.02	Terceira-Contendas islet	4	21.4.03	Tenerife (Spain)	2
14	99X1919	4	24.4.03	Senegal (La Somone)	>=5	20.8.03	Praia, GRW (Azores)	3
15	G10530	1	16.6.02	Santa Maria-Vila Islet	472 days	01.10.03	Praia S. Pedro (Ivory Coast)	2
16	CO4286	?	20.10.99	Songor Ramsa Ghana	?	25.5.00	Baixa Moinho, Flores (Azores)	4
17	1172-38015	4	3.2.00	Mangue Seco Bahia	?	03.6.00	Mos, Terceira (Azores)	4
18	G1303	1	26.5.91	Flores	11	01.3.02	Mangue Seco (Brazil)	2

* rings of birds 1 to 5 are not specified on Dunn´s report
1=Dunn 1989; 2=unpublished; 3=Neves *et al.* 2003; 4=Hays *et al.* 2002

At the moment, the number of ringing recoveries are too few and not enough ringed Roseate Terns are picked up dead or retrapped away from the Azores to clearly understand their migration patterns once they leave the archipelago. Two hypotheses are possible: 1) some Azores birds go to West Africa and some to South America; 2) birds from the Azores may first move to the African coast where they have been seen with birds from Britain and Ireland, and after December move offshore, some making a trans-Atlantic flight to South America.

As seen by the locations and dates of recovery, Roseate Terns can be found in both sides of the Atlantic at all dates. For example, the bird captured at Praia islet in August 2003 had been ringed in Senegal in 24 April 2003 (Neves *et al.* 2003) and it is very likely that this bird would have flown directly from Senegal. Similarly, it is probable that birds ringed in Brazil in March would have returned directly to the Azores to breed. Therefore, with the present knowledge it seems likely that hypothesis 1) applies and that part of the population winters in the east Atlantic and part in the west Atlantic, as opposed to the possibility of the same individuals visiting both areas before returning to the Azores to breed.

8.3.2. Limiting the negative potential of starling predation

As seen in chapter VI, control taste aversion (CTA) is not *per se* an efficient way of reducing starling predation. However the possibility of using this technique in association with other measures should be investigated. A integrated approach, as shown in chapter VII, has more chances of success. CTA could be undertaken simultaneously with deployment of tern artificial nests and provision of sources of water for the starlings. Vila islet, the colony where starling predation constitutes a problem has no sources of water and it might be that starlings are predating on the eggs as a mean of obtaining water.

As in other parts of its breeding range, the European Starling is extremely successful in the Azores and its breeding and roosting areas overlap widely with those of terns. No easy solution to tackle this problem is currently available; monitoring and further taste aversion experiments combined with an inter-disciplinary approach are needed.

Our mtDNA results for the European Starling are promising and further research might come to identify the founder population from which the Azores population originated and reveal the history of this bird in the archipelago.

8.3.3 Limiting Factors

In order to preserve the Roseate Tern in the Azores archipelago, it is important to identify and understand the factors responsible for the annual fluctuations in breeding numbers. It is possible that food availability is one of the important factors currently limiting Roseate Tern breeding numbers in the Azores archipelago. To test this hypothesis, a regular monitoring programme will be needed to understand how breeding pairs in the archipelago vary in relation to other biotic and abiotic factors, and how these factors interact with each other.

In 2005 breeding numbers of Roseate Tern reached the second lowest minimum in the archipelago since monitoring started, and 2006 therefore represents an excellent opportunity to start an annual monitoring program. Data on breeding numbers for the whole archipelago, and breeding success on selected colonies, chosen according to accessibility and importance as a breeding ground, should be collected annually for both Common and Roseate Tern. Breeding numbers are regularly monitored since 1989 but several different researchers and volunteers have collected the data over the years. It is absolutely crucial that an explicit template for data collection is created to ensure clarity is retained between the years and simplifies the future process of analysing the data. It is important to create good GPS maps with the location of the colonies and ensure that from year to year the same colony is designated and monitored the same way.

This procedure will be especially relevant for Flores Island, where several coastal colonies are located close to each other and can vary considerably in numbers from year to year. The best timing to collect the data will also vary widely by up to two weeks, from year to year according to factors not yet fully understood. It is therefore important to establish a volunteer network of local observers who will collect information, such as date of first tern returning every year and date of egg laying. The data on first initiation dates might also prove useful to understand how variations on dates, caused perhaps by changes in food availability, might be affecting terns breeding success, such as it has been demonstrated for other studies. For example, Burger *et al.* (1996) found that early nesting roseate terns have higher productivity than birds laying at the peak, suggesting strong selection for earlier breeding. If this selection is also acting on Azorean terns than we could predict that the changes in breeding initiation dates observed are probably reflecting food availability.

Collecting data on tern diets on a regular basis will also provide a better understanding of the reasons why breeding numbers vary so dramatically from year to year. By knowing what terns are eating, at times when they are breeding in different proportions of total numbers, will enable us to explore how diet and food availability might affect breeding numbers. The use of pellets to collect diet data is recommended because it is a fast, cheap and non-intrusive approach. Despite the bias associated with this method when conducting short-term studies, it can be a useful tool if one is establishing longer-term monitoring programmes. In fact, the use of pellets enables comparisons across years and across different colonies, for the species from which otoliths can be detected, despite the lack of detailed and accurate information on all the different fish prey items consumed each single year (Ramos *et al.* 1998a, Granadeiro *et al.* 2002).

It is also important to measure food availability and the use of passive special designed methods is recommended. The majority of the fishing methods currently used in the archipelago involve active pursuit of prey and (e.g. tuna fisheries) and, therefore, total captures reflect effort more than real prey availability.

Simultaneously, it would also be important to estimate adult Roseate Tern survival as a part of research on the population dynamics of Roseate Terns. As seen in chapter II, adult mortality alone will not explain the wide variations in breeding numbers observed because the high rates of mortality would not enable the population to stage spectacular year-to-year recoveries (see Fig. 2.26). As with many long-lived seabird species, the life history strategy of terns is to have a long lifespan and a relatively low breeding output. Declines in survival are of more concern than short-term fluctuations in productivity and there is evidence that this has occurred for Roseate Terns in the Atlantic region (Ratcliffe & del Nevo 1995).

In conclusion, the postulated highly responsive behaviour of the Roseate Tern to the environment fluctuations might offer some advantages but it also places this species in a delicate situation regarding long-term persistence. The Azores presents an ideal location to further study and understand the environmental and oceanographic processes underpinning Roseate Tern breeding behaviour, because they offer such a challenging and variable habitat in which to breed; especially if compared to the more stable British Isles and North America habitats. If action is not taken, it is inevitable that the Roseate Tern will face serious risk of extinction in the

Azores, due to the present North Atlantic fast changing food-web arena. Further research should pursue an inter-disciplinary understanding of the factors that support Roseate Terns' "decision" to make a breeding attempt, as well as the factors and variables that favour their success. Ultimately it is hoped that the measures suggested in this thesis will be used as a stepping-stone to an effective wide-scale protection management strategy for the Roseate Tern in the Azores.

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Numbers of breeding pairs of Roseate Terns at different colonies of Corvo (COR) and Flores (FLW) islands. FC=flush count; CC=clutch count; SS=sitting count.

Island (habitat)	Method	Lat.	Long.	Colony name	1989	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
COR (cliff)	FC	39,725137	-31,111415	Ponta do Marco	0	0	0	0	83	0	0	0	0	0	0	0	0	0
COR (cliff	FC	39,679299	-31,118925	Pão de Açúcar N	0	0	0	0	0	0	0	0	0	0	7	0	0	0
COR (cliff	FC	39,674237	-31,121225	Pingas	0	0	0	0	0	0	0	0	0	0	1	0	0	0
FLW (islet)	FC	39,507486	-31,244671	Ilhéu Maria Vaz	0	0	0	0	0	20	0	0	0	0	0	0	0	0
FLW (islet)	FC	39,524210	-31,213888	Ilhéu João Martins	0	0	0	0	80	6	2	0	0	0	0	0	0	0
FLW (islet)	FC	39,518178	-31,206938	Ponta Delgada N	0	0	0	0	7	0	25	0	0	17	28	20	15	15
FLW (islet)	FC	39,515235	-31,204535	Ilhéu Ponta Delgada	0	0	0	2	0	0	0	2	0	0	0	0	0	0
FLW (islet)	FC	39,502452	-31,163912	Ilhéu da Muda	0	0	0	0	16	3	21	0	0	0	0	0	0	3
FLW (cliff)	FC	39,489499	-31,151741	Ponta do Burquilhão	0	0	0	0	0	0	0	0	0	111	0	6	0	0
FLW (cliff)	FC+CC	39,487455	-31,150084	Baía do Burquilhão	0	0	0	0	0	0	0	0	0	0	0	0	3	3
FLW (islet)	FC+SC	39,473973	-31,146152	Alagoa 1	60	13	95	266	2	4	3	0	3	2	162	80	9	16
FLW (islet)	FC	39,474263	-31,146068	Alagoa 2	62	0	0	50	128	142	107	79	111	95	10	2	163	1
FLW (islet)	FC	39,475267	-31,146366	Alagoa 3	1	0	0	5	17	52	25	7	22	13	0	0	4	6
FLW (islet)	FC	39,474752	-31,146008	Alagoa 4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
FLW (islet)	FC+CC	39,470887	-31,139653	Baixa do Moinho	160	5	89	265	163	232	135	119	125	113	179	105	151	66
FLW (cliff)	FC	39,431852	-31,142572	Pta Fernão Jorge N	0	0	0	4	7	4	16	2	0	0	1	0	0	1
FLW (cliff)	FC	39,431759	-31,141307	Pta Fernão Jorge (península)	1	77	1	7	0	0	0	0	0	0	0	1	0	0
FLW (cliff)	FC	39,430278	-31,142227	Furna Jorge	2	0	0	0	7	4	7	5	0	0	0	0	0	0
FLW (cliff)	FC	39,429230	-31,139847	Pé do Alho	0	0	0	0	0	0	0	5	0	0	0	0	0	0
FLW (cliff)	FC	39,428160	-31,140121	Furna dos Encharéus	4	0	0	0	2	20	56	1	0	0	0	0	7	5
FLW (cliff)	FC	39,425043	-31,137357	Ponta da Caveira	0	0	0	0	0	0	0	0	0	0	4	0	7	0
FLW (islet)	FC	39,416063	-31,263166	Mosteiro série de Ilhéus	0	0	0	0	0	2	0	0	0	0	2	4	0	1
FLW (islet)	FC	39,404503	-31,253042	Baía do Mosteiro-Ilhéu	0	0	0	0	1	0	0	0	0	0	0	0	15	0
FLW (cliff)	FC	39,402694	-31,252718	Baía Sul do Mosteiro	1	0	0	0	0	0	0	0	0	0	0	0	0	0
FLW (cliff)	FC	39,384305	-31,256327	Rocha do Pico- Falésia	43	0	0	0	0	0	0	0	0	0	3	0	0	0
FLW (islet)	FC	39,387330	-31,257888	Rabo de Peixe Ilhéu 1	20	27	64	0	0	0	0	0	0	0	0	0	0	0
FLW (islet)	FC	39,388374	-31,257371	Rabo de Peixe Ilhéu 2	10	0	0	0	0	0	0	0	0	0	0	0	0	0
FLW (cliff)	FC	39,375800	-31,216019	Fajã de Lopo Vaz	0	0	0	0	3	0	0	0	1	0	0	10	10	8
FLW (islet)	FC	39,375541	-31,249276	Ponta dos Ilhéus	150	0	0	0	2	0	0	0	0	0	0	0	7	16

Numbers of breeding pairs of Roseate Terns at different colonies of Faial (FAI), Graciosa (GRW), Pico (PIX), São Jorge (SJZ), Terceira (TER), São Miguel (SMI) and Santa Maria (SMA). FC=flush count; CC=clutch count; SS=sitting count.

Island habitat)	**Method**	**Lat.**	**Long.**	**Colony name**	**1989**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
GRW (islet)	FC+SC	39,095742	-28,048142	Ponta da Barca	0	0	0	0	0	12	2	0	0	0	0	0	0	0
GRW (islet)	FC	39,056812	-27,955665	Ilhéu da Praia	1	10	0	0	0	0	0	0	31	25	133	231	402	138
GRW (cliff)	FC	39,022461	-28,033301	Ponta Branca-Calhaus	113	0	0	0	0	0	31	0	0	0	0	0	0	0
GRW (cliff)	FC	39,022175	-28,032482	Ponta Branca 2	4	0	10	2	0	0	0	0	0	0	0	0	0	0
GRW (islet)	FC	39,009626	-27,954778	Ilhéu do Carapacho	29	2	6	5	30	15	3	1	0	0	0	0	0	2
GRW (islet)	FC+SC	39,008002	-27,938382	Ilhéu de Baixo	133	1	8	6	0	0	0	0	0	0	0	0	0	0
FAI (cliff)	FC	38,597835	-28,831344	Capelinhos	0	0	0	70	138	0	0	0	0	0	0	19	17	1
PIX (islet)	FC	38,536829	-28,331690	Nariz de Ferro	21	0	3	31	7	28	22	8	15	7	0	0	0	9
PIX (islet)	FC	38,535193	-28,546545	Ilhéu Deitado	1	0	0	0	0	0	0	0	0	0	0	0	0	0
PIX (cliff)	FC	38,421988	-28,031264	Baia da Engrade	1	0	0	0	11	0	0	0	0	0	0	0	0	0
SJZ (cliff)	FC	38,755283	-28,316872	Pta dos Rosais	3	0	0	0	0	0	0	0	0	30	0	0	0	0
SJZ (lagoon)	FC	38,613545	-27,909295	Fajã Sto Cristo F Redon	0	0	0	0	16	0	0	0	0	0	0	0	0	0
SJZ (cliff)	FC	38,567075	-27,783078	Ponta das Vinhas (Leste)	0	0	0	0	21	0	0	0	0	0	0	0	0	0
SJZ (islet)	FC	38,550121	-27,746212	Ilhéu do Topo	0	0	0	0	0	0	0	0	5	0	2	0	17	0
TER (islet)	FC	38,648382	-27,072826	Contendas	90	21	30	114	84	120	188	130	351	342	269	65	32	0
TER (islet)	FC	38,631816	-27,149822	Ilhéu das Cabras E	3	0	0	0	0	0	0	0	0	0	0	0	0	0
SMI (islet)	FC	37,709492	-25,512767	Caloura	0	0	0	0	0	0	0	0	0	0	6	125	33	16
SMA (islet)	FC	37,022095	-25,090449	Ilhéu das Lagoinhas	0	0	0	0	0	180	0	0	24	0	0	0	0	0
SMA (islet)	FC+SC	37,017980	-25,088206	Lagoinhas	3	19	0	30	248	0	0	0	0	0	0	0	0	0
SMA (cliff)	FC	37,014123	-25,097525	Vaca	1	0	0	0	0	0	0	0	0	0	0	0	0	0
SMA (islet)	FC	36,942309	-25,171964	Ilhéu da Vila	116	204	241	236	141	176	198	167	90	95	200	134	0	92
SMA (cliff)	FC	36,932423	-25,030226	Ponta do Castelo NW	7	0	0	0	0	0	0	0	0	0	0	0	0	0

Numbers of breeding pairs of Common Terns at different colonies of Corvo (COR) and Flores (FLW) islands. FC=flush count; CC=clutch count; SS=sitting count.

Island (habitat)	Method	Lat.	Long	Colony name	1989	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
COR (islet)	FC	39,725859	-31,118987	Ilhéu Ponta do Marco	5	0	0	0	0	1	0	0	0	0	0	0	0	0
COR (cliff)	FC	39,725407	-31,121081	Ponta dos Torrais	11	0	0	0	0	0	0	0	0	0	0	0	0	0
COR (cliff)	FC	39,725137	-31,111415	Ponta do Marco	40	0	0	0	83	43	0	0	0	27	0	0	0	0
COR (cliff)	FC	39,721034	-31,099435	Falésia Verga do Norte	0	0	0	0	0	0	0	0	0	0	0	0	33	73
COR (cliff)	FC	39,717107	-31,089139	Canto da Carneira	0	0	0	0	0	0	0	0	0	0	21	0	0	0
COR (cliff)	FC	39,712057	-31,087804	Cancela do Pico	10	0	0	0	7	0	0	0	0	0	0	0	0	9
COR (lagoon)	FC	39,711821	-31,111854	Caldeirão E	23	0	0	0	40	23	0	0	0	28	42	29	30	37
COR (lagoon)	FC+SC	39,710315	-31,114061	Caldeirão W	120	0	0	0	100	183	0	0	0	0	0	0	0	7
COR cliff)	FC	39,705768	-31,085357	Pico João de Moura	0	0	0	0	0	0	0	0	0	45	0	0	0	0
COR (cliff)	FC	39,694684	-31,122136	Pingas	0	0	0	0	0	0	0	0	0	0	7	0	56	0
COR (cliff)	FC	39,679299	-31,118925	Pão de Açúcar N	23	0	0	0	0	80	0	0	0	45	60	11	4	0
COR (cliff)	FC	39,678977	-31,119370	Pão de Açúcar E	6	0	0	0	13	17	0	0	0	0	0	11	0	0
COR (cliff)	FC	39,675419	-31,121271	Portinho da Areia	15	0	0	0	0	0	0	0	0	0	0	0	0	0
FLW (islet)	FC	39,524210	-31,213888	Ilhéu João Martins	27	0	0	0	50	6	10	5	0	0	7	11	0	11
FLW (islet)	FC	39,518178	-31,206938	Ponta Delgada N	4	0	0	0	5	0	7	0	0	0	0	0	0	0
FLW (islet)	FC	39,515235	-31,204535	Ilhéu Ponta Delgada	6	0	0	0	1	0	0	5	0	5	0	0	15	14
FLW (cliff)	FC	39,508624	-31,194037	Ponta do Ilhéu E	1	0	0	0	0	0	0	0	0	0	0	0	0	0
FLW (cliff)	FC	39,507835	-31,196691	Ponta do Ilhéu N	9	0	0	0	3	0	0	0	0	0	50	0	0	0
FLW (islet)	FC	39,507486	-31,244671	Ilhéu Maria Vaz	7	0	0	0	3	3	0	0	0	0	0	0	0	0
FLW (cliff)	FC	39,504211	-31,194716	Baia do Cabouco	5	0	0	0	4	0	0	0	0	0	0	1	0	17
FLW (islet)	FC	39,503782	-31,188529	Ilhéu dos Abrões	2	0	0	0	2	0	0	0	0	0	0	0	0	0
FLW (cliff)	FC	39,503572	-31,159619	Ponta Ruiva-Falésia	3	0	0	0	0	0	11	0	0	0	0	0	0	0
FLW (islet)	FC	39,503503	-31,158539	Ponta Ruiva-E-Ilhéu	5	0	0	0	9	5	10	5	0	17	28	0	0	0
FLW (islet)	FC	39,502553	-31,157362	Ponta Ruiva-SE-Ilhéu	0	0	0	0	0	0	0	0	0	0	0	0	0	10
FLW (islet)	FC	39,502452	-31,163912	Ilhéu da Muda	13	0	0	0	19	33	9	30	0	6	0	13	10	6
FLW (cliff)	FC	39,502162	-31,177779	Pta Barrosas N	0	0	0	0	3	8	0	0	0	0	0	0	0	0
FLW (islet)	FC	39,500086	-31,170364	Ilhéu Pão de Açúcar	3	0	0	0	0	0	0	0	0	0	0	0	0	0
FLW (cliff)	FC	39,498806	-31,175585	Barrosas derrocada	0	0	0	0	1	0	0	0	0	0	0	0	0	0

(cont.) Numbers of breeding pairs of Common Terns at different colonies of Flores (FLW) islands. FC=flush count; CC=clutch count; SS=sitting count.

Island (habitat)	**Method**	**Lat.**	**Long**	**Colony name**	**1989**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
FLW (cliff)	FC	39,498653	-31,246568	Quebrada Nova	0	0	0	0	10	0	0	0	0	48	15	0	0	0
FLW (islet)	FC	39,495329	-31,275325	Ilhéu Monchique	1	0	0	0	0	0	0	0	0	0	0	0	0	0
FLW (islet)	FC	39,489858	-31,148274	Ilhéu Álvaro Rodrigues N	5	0	0	0	9	0	0	0	29	0	0	0	0	0
FLW (cliff)	FC	39,489499	-31,151741	Ponta do Burquilhão	11	0	0	0	1	37	0	0	0	0	0	0	91	79
FLW (islet)	FC	39,488961	-31,148345	Ilhéu Álvaro Rodrigues S	17	0	0	0	0	0	0	0	0	0	0	0	0	0
FLW (cliff)	CC+FC	39,487455	-31,150084	Baía do Burquilhão	57	0	0	0	3	0	0	0	0	0	0	23	0	0
FLW (islet)	FC	39,484875	-31,145671	Ilhéu Garajau	1	0	0	0	0	0	0	0	0	11	0	0	0	0
FLW (cliff)	FC	39,484835	-31,150414	Baía dos Cedros	7	0	0	0	0	0	0	0	0	0	0	0	0	0
FLW (islet)	FC	39,483713	-31,148381	Ilhéu dos Cedros	4	0	0	0	3	0	0	0	0	7	0	0	5	0
FLW (islet)	FC	39,475508	-31,145190	Alagoa 5	5	0	0	0	2	0	0	0	0	0	0	0	0	0
FLW (islet)	FC	39,475267	-31,146366	Alagoa 4	34	0	0	0	17	0	0	0	0	25	0	0	5	0
FLW (islet)	FC	39,474752	-31,146008	Alagoa 3	31	0	0	0	17	5	26	14	4	16	49	0	6	0
FLW (islet)	FC+SC	39,474267	-31,146067	Alagoa 2	1	0	0	0	20	10	63	69	56	0	5	15	28	39
FLW (islet)	FC	39,473974	-31,146150	Alagoa 1	45	112	55	86	52	5	47	58	44	67	51	20	58	23
FLW (cliff)	FC+SC	39,473037	-31,144309	Ponta Lagoa (Falésia)	1	0	0	0	0	0	0	0	0	0	0	0	0	0
FLW (islet)	SC	39,472012	-31,141995	Ponta Lagoa (Ilhéu)	7	0	0	0	3	0	0	0	0	0	0	0	0	0
FLW (islet)	FC+CC	39,470887	-31,139653	Baixa do Moinho	4	0	0	0	0	0	0	0	23	0	1	0	0	2
FLW (islet)	FC	39,468496	-31,137316	Baixa Vermelha	0	0	0	0	1	0	0	0	0	0	0	0	0	0
FLW (islet)	FC	39,452140	-31,125279	Santa Cruz	5	0	0	0	10	0	0	0	0	0	0	0	0	0
FLW (lagoon)	FC	39,448878	-31,225643	Caldeira Branca	7	0	0	0	5	0	0	0	0	0	22	11	0	19
FLW (islet)	FC	39,448136	-31,126761	Santa Cruz A	0	0	0	0	3	0	0	0	0	0	0	0	0	0
FLW (lagoon)	FC	39,439965	-31,222496	Caldeira Comprida	3	0	0	0	0	0	0	0	0	0	0	0	0	0
FLW (islet)	FC	39,432424	-31,141957	Bugio	0	0	0	0	3	0	0	0	0	0	0	0	0	0

(cont.) Numbers of breeding pairs of Common Terns at different colonies of Flores (FLW) islands. FC=flush count; CC=clutch count; SS=sitting count.

Island (habitat)	**Method**	**Lat.**	**Long**	**Colony name**	**1989**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
FLW (cliff)	FC	39,431852	-31,142572	Pta Fernão Jorge N	2	0	0	0	20	11	16	27	0	14	20	4	8	35
FLW (cliff)	FC	39,431759	-31,141307	Pta Fernão Jorge (Península)	7	0	0	0	0	0	0	0	0	0	0	0	0	0
FLW (cliff)	FC	39,430278	-31,142227	Furna Fernão Jorge	8	0	0	0	23	0	14	21	0	0	0	3	10	6
FLW (cliff)	FC	39,429230	-31,139847	Pé do Alho	0	0	0	0	0	0	0	8	0	0	0	0	0	0
FLW (cliff)	FC	39,428160	-31,140121	Furna dos Encharéus	12	0	0	0	1	0	0	14	0	0	0	15	13	10
FLW (islet)	FC	39,416063	-31,263166	Mosteiro serie de Ilhéus	10	0	0	0	0	0	0	0	0	0	0	0	0	0
FLW (cliff)	FC	39,415541	-31,148648	Ponta de Fora	11	0	0	0	21	0	0	0	0	16	15	19	27	7
FLW (cliff)	FC	39,410345	-31,148890	Rochão da Fajã	0	0	0	0	33	0	0	0	0	0	0	0	0	0
FLW (islet)	FC	39,410146	-31,258271	Mosteiro N (Ilhéus)	3	0	0	0	0	6	0	0	0	42	48	12	0	0
FLW (cliff)	FC	39,407594	-31,254293	Baia Mosteiro Falesia	9	0	0	0	36	6	0	0	0	0	5	0	0	0
FLW (cliff)	FC	39,404872	-31,150409	Ponta de Fora-Cardoso	11	0	0	0	0	0	0	0	0	28	0	0	0	0
FLW (lagoon)	FC	39,404548	-31,217433	Caldeira funda -S	1	0	0	0	0	0	0	0	0	0	0	0	0	0
FLW (islet)	FC	39,404503	-31,253042	Baía do Mosteiro Ilheu	20	0	0	0	6	0	0	0	0	0	0	23	31	25
FLW (cliff)	FC	39,402694	-31,252718	Baía Sul do Mosteiro	10	0	0	0	27	0	0	0	0	0	0	4	0	0
FLW (cliff)	FC	39,398644	-31,153362	Lomba de baixo	0	0	0	0	27	0	0	0	0	0	0	0	23	9
FLW (islet)	FC	39,395351	-31,261747	Ilheu do Cartário	7	0	0	0	6	0	0	0	0	34	10	3	0	0
FLW (cliff)	FC	39,391831	-31,258110	Rabo de Peixe Falésia2	18	0	0	0	23	0	0	0	0	0	0	0	0	0
FLW (cliff)	FC	39,389898	-31,256958	Rabo de Peixe Falésia1	50	0	0	0	0	0	0	0	0	0	0	0	0	0
FLW (islet)	FC	39,388374	-31,257371	Rabo de Peixe Ilhéu 2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
FLW (islet)	FC	39,387330	-31,257888	Rabo de Peixe Ilhéu 1	10	0	0	0	0	0	0	0	0	0	0	14	57	30
FLW (cliff)	FC	39,385669	-31,160631	Pta Capitão-Pta Lajes	4	0	0	0	0	0	0	0	0	0	0	0	20	24
FLW (cliff)	FC	39,384545	-31,254949	Rocha do Pico-Falésia	17	0	0	0	13	0	0	7	0	0	14	0	0	0
FLW (islet)	FC	39,384314	-31,256317	Rocha do Pico	0	0	0	0	7	0	0	0	0	0	0	0	0	0
FLW (islet)	FC	39,379547	-31,250838	Falso Ilhéu	84	0	0	0	0	0	0	35	0	0	0	0	0	0
FLW (cliff)	FC	39,378997	-31,169540	Porto das Lajes	0	0	0	0	10	0	0	0	0	0	0	0	0	0
FLW (cliff)	FC	39,375800	-31,216019	Fajã de Lopo Vaz	9	0	0	0	63	0	0	0	13	0	60	21	18	35
FLW (islet)	FC	39,375541	-31,249276	Ponta dos Ilhéus	55	0	0	0	27	5	4	14	10	0	20	14	19	49

Numbers of breeding pairs of Common Terns at different colonies of Faial (FAI), Graciosa (GRW) and Pico (PIX), FC=flush count; CC=clutch count; SS=sitting count.

Island (habitat)	**Method**	**Colony name**	**Lat.**	**Long.**	**1989**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
FAI (cliff)	FC	Cedros	38,638772	-28,722523	0	0	0	0	28	0	0	0	0	0	0	0	0	0
FAI (cliff)	FC	Monte da Guia-Baia 2	38,516677	-28,627812	80	0	0	0	0	0	0	0	0	90	0	0	0	0
FAI (cliff)	FC	Monte da Guia 3	38,516986	-28,631026	17	0	0	0	3	0	0	0	0	0	5	0	0	0
FAI (cliff)	FC	Monte da Guia-Baia 1	38,517721	-28,626114	27	0	0	0	0	0	0	0	0	0	0	0	0	0
FAI (cliff)	FC	Monte da Guia 4	38,518466	-28,632487	11	0	0	0	30	0	0	0	0	0	0	0	0	0
FAI (cliff)	FC	Monte da Guia 5	38,519373	-28,631715	28	0	0	0	0	0	0	0	60	0	40	30	0	0
FAI (cliff)	FC	Morro de Castelo Branco	38,522195	-28,751288	80	0	0	0	73	0	0	0	0	0	0	0	0	0
FAI (cliff)	FC	Baía do Varadouro	38,542023	-28,751542	30	0	0	0	0	0	0	0	0	0	0	0	0	0
FAI (cliff)	FC	Capelinhos	38,597835	-28,831344	300	0	0	0	263	0	124	5	0	133	108	136	190	0
FAI (harbour)	FC	Porto da Horta	38,529214	-28,624354	0	0	0	0	3	0	0	0	20	0	0	0	0	0
GRW (islet)	FC+SC	Ilhéu de Baixo	39,008002	-27,938382	73	75	0	27	25	0	3	0	0	0	0	0	0	0
GRW (islet)	FC	Ilhéu do Carapacho	39,009626	-27,954778	33	0	0	0	34	41	50	20	0	61	0	0	0	6
GRW (cliff)	FC	Ponta da Restinga	39,012943	-27,949700	39	0	0	0	15	30	0	0	0	0	0	0	0	5
GRW (cliff)	FC+SC	Ponta Portela	39,014667	-27,951269	53	0	0	0	57	40	0	0	0	0	0	0	0	0
GRW (cliff)	FC	Ponta Branca 2	39,022175	-28,032482	28	0	0	0	0	54	78	0	0	0	0	0	0	0
GRW (cliff)	FC+SC	Ponta Branca 1	39,022182	-28,031667	43	0	0	0	86	3	40	0	0	104	0	0	0	0
GRW (cliff)	FC	Ponta Branca-Calhaus	39,022461	-28,033301	113	0	0	0	0	0	3	0	0	0	0	0	0	0
GRW (islet)	FC+SC	Serra Branca-Ilhéu	39,025305	-28,038312	5	0	0	0	0	1	0	0	0	0	0	0	0	0
GRW (cliff)	FC+SC	Serra Branca-Derrocada	39,031536	-28,043254	3	0	0	0	0	0	0	0	0	0	0	0	0	53
GRW (islet)	FC	Ilhéu da Praia	39,056812	-27,955665	23	117	91	0	6	140	160	217	951	775	641	1191	1094	997
GRW (islet)	FC	Porto Afonso	39,067669	-28,070666	25	0	0	0	13	0	0	0	0	7	5	0	0	7
GRW (islet)	FC	Ponta Negra	39,095172	-28,045254	20	0	0	0	0	0	0	0	0	18	0	0	0	0
GRW (cliff)	FC	Ponta Negra	39,095557	-28,044530	1	0	0	0	7	0	0	0	0	0	0	0	0	0
GRW (islet)	FC+SC	Ponta da Barca	39,095742	-28,048142	3	0	0	0	10	17	3	0	0	0	0	0	0	8
PIX (cliff)	FC	Pta do Castelete	38,386208	-28,252808	0	0	0	0	0	0	0	0	0	0	0	31	27	35
PIX (cliff)	FC	Baía Domingos Pereira	38,407413	-28,049990	5	0	0	0	1	0	0	0	0	0	21	45	37	21
PIX (cliff)	FC	Ponta de São João	38,412594	-28,365968	13	0	0	0	0	0	0	0	0	0	0	0	0	0

(cont.) Numbers of breeding pairs of Common Terns at different colonies of Pico (PIX) and São Jorge (SJZ). FC=flush count; CC=clutch count; SS=sitting count.

Island (habitat)	**Method**	**Colony name**	**Lat.**	**Long.**	**1989**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
PIX (cliff)	FC	Baía do Céu de Abraão	38,418838	-28,030441	19	0	0	0	0	0	0	0	0	7	14	25	27	32
PIX (cliff)	FC	Baía da Engrade	38,421988	-28,031264	0	0	0	0	33	0	0	0	0	0	0	0	0	0
PIX (cliff)	FC	Candelária-São Mateus	38,440832	-28,491963	5	0	0	0	9	0	0	0	0	0	0	0	0	0
PIX (cliff)	FC	Pt Espigão (Terra Alta)	38,450198	-28,121881	0	0	0	0	13	0	0	0	0	0	27	93	0	47
PIX (cliff)	FC	Rocha do Galo	38,479734	-28,207438	4	0	0	0	8	0	0	0	0	0	0	0	0	0
PIX (cliff)	FC	Calhau N	38,486168	-28,539550	4	0	0	0	0	0	0	0	0	9	0	27	0	0
PIX (cliff)	FC	Ponta do Mistério	38,499370	-28,245997	0	0	0	0	2	0	0	0	0	0	5	0	0	0
PIX (cliff)	FC	Cedros	38,499433	-28,265259	5	0	0	0	0	0	0	0	0	0	9	0	0	0
PIX (islet)	FC	Ilhéu dos Forges	38,408683	-28,174022	63	0	0	0	50	0	0	0	0	17	0	47	38	41
PIX (islet)	FC	Ilhéu Deitado	38,535193	-28,546545	53	0	0	0	4	0	0	0	0	0	17	0	0	0
PIX (islet)	FC	Nariz de Ferro	38,536829	-28,331690	69	0	0	37	40	57	79	51	73	35	41	33	20	62
PIX (islet)	FC	Ilhéu em Pé	38,537686	-28,544535	4	0	0	0	0	0	0	0	0	0	0	0	0	0
PIX (islet)	FC	Calhau	38,539248	-28,338607	5	0	0	0	8	0	0	0	0	0	0	0	0	0
SJZ (lagoon)	FC	Fajã dos Cúberes-Este	38,643027	-27,965111	10	0	0	0	0	0	0	0	15	0	30	11	0	18
SJZ (cliff)	FC	Cais da Urzelina	38,643553	-28,126866	3	0	0	0	0	0	0	0	0	0	0	0	0	0
SJZ (lagoon)	FC	Fajã dos Cúberes-Oeste	38,646571	-27,979860	1	0	0	0	0	0	0	0	0	0	0	0	0	0
SJZ (islet)	FC	Fajã do Ouvidor	38,678357	-28,050127	5	0	0	0	0	0	0	0	0	14	32	45	35	19
SJZ (islet)	FC	Ponta do Norte Grande	38,680665	-28,051596	4	0	0	0	0	0	0	0	0	0	0	0	0	41
SJZ (cliff)	FC	Fajã Ponta Nova	38,681085	-28,084976	0	0	0	0	3	0	0	0	0	0	0	0	0	0
SJZ (cliff)	FC	Pta Morro Grande	38,683824	-28,222723	0	0	0	0	0	15	0	0	0	0	0	0	0	0
SJZ (cliff)	FC	Morro de Lemos	38,693641	-28,225743	47	0	0	0	20	0	0	0	0	47	33	27	12	33
SJZ (cliff)	FC	Ponta Furada	38,698212	-28,121141	0	0	0	0	0	0	0	0	0	0	0	0	0	25
SJZ (rocky beach)	FC	Baía Grande - Praia de Calhaus	38,731857	-28,289854	0	0	0	0	0	30	0	0	26	0	84	90	24	0
SJZ (cliff)	FC	Pta dos Rosais	38,755283	-28,316872	40	0	0	0	33	8	0	0	0	159	0	0	7	79
SJZ (cliff)	FC	Morro	38,535563	-27,773452	0	0	0	0	15	0	0	0	0	0	0	18	0	26
SJZ (cliff)	FC	Fajã do Cardoso	38,539589	-27,842785	17	0	0	0	0	0	0	0	0	0	0	0	0	14

(cont.) Numbers of breeding pairs of Common Terns at different colonies of São Jorge (SJZ), Santa Maria (SMA) and São Miguel (SMI). FC=flush count; CC=clutch count; SS=sitting count.

Island (habitat)	**Method**	**Colony name**	**Lat.**	**Long.**	**1989**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
SJZ (cliff)	FC	Fajãzinha	38,552438	-27,759908	30	0	0	0	0	0	0	0	0	0	0	0	42	12
SJZ (cliff)	FC	Fajã do Nortezinho	38,580569	-27,823968	50	0	0	0	31	0	0	0	0	0	0	25	5	29
SJZ (cliff)	FC	Fajã do Sanguinhal	38,606754	-27,885143	0	0	0	0	10	0	0	0	0	0	0	0	0	7
SJZ (islet)	FC	Ilhéu do Topo	38,550121	-27,746212	0	0	0	0	59	83	0	24	240	122	13	67	38	38
SJZ (islet)	FC	Ilhéu do Topo W	38,551480	-27,748222	0	0	0	0	0	0	0	0	0	0	0	0	50	0
SJZ (lagoon)	FC	Fajã S. Cristo-F. Redo	38,613545	-27,909295	0	0	0	0	64	0	0	0	0	22	20	17	27	14
SJZ (rocky beach)	FC	Ponta das Vinhas(Leste)	38,567075	-27,783078	3	0	0	0	65	153	0	0	0	0	0	36	11	13
SMA (cliff)	FC	Pta da Malbusca	36,928954	-25,066612	0	0	0	0	0	0	0	0	0	0	15	0	0	0
SMA (cliff)	FC	Malbusca Sul	36,929768	-25,054103	0	0	0	0	0	0	0	0	0	0	7	0	0	0
SMA (cliff)	FC	East of Sul	36,930642	-25,037183	1	0	0	0	0	0	0	0	0	0	27	16	0	16
SMA (cliff)	FC	Ponta do Castelo - Baía	36,932423	-25,030226	67	0	0	0	0	0	0	0	0	0	0	0	0	0
SMA (cliff)	FC	Maia	36,932968	-25,017297	80	0	0	0	0	0	0	0	0	0	9	18	0	31
SMA (cliff)	FC	Touril	36,948733	-25,116976	10	0	0	0	0	0	0	0	0	0	0	17	0	0
SMA (cliff)	FC	Campo Pequeno N	36,959344	-25,172979	1	0	0	0	0	0	0	0	0	0	0	0	0	0
SMA (cliff)	FC	Baía Salto dos Cães	37,010719	-25,103788	0	0	0	0	0	0	0	0	191	0	0	0	0	70
SMA (cliff)	FC	Vaca	37,014123	-25,097525	33	0	0	0	105	0	68	67	0	0	0	0	0	0
SMA (islet)	FC	Ilhéu da Vila	36,942309	-25,171964	486	586	0	0	769	1025	847	181	207	0	144	159	0	576
SMA (islet)	FC	Ilhéu de São Lourenço	36,985951	-25,043572	7	0	0	0	0	0	0	0	0	0	21	33	0	15
SMA (islet)	FC+SC	Lagoinhas	37,017980	-25,088206	78	0	0	0	113	40	40	55	140	0	0	11	0	46
SMA (islet)	FC	Ilhéu das Lagoinhas	37,022095	-25,090449	5	0	0	0	0	0	0	0	0	0	0	0	0	0
SMA (islet)	FC	Ilhéu de V.Franca do Campo	37,707036	-25,443810	0	0	0	0	1	0	0	0	0	0	0	0	0	3
SMA (islet)	FC	Ponta da Caloura	37,709492	-25,512767	37	0	0	0	286	0	0	0	0	0	81	560	490	141
SMA (rocky beach)	FC	Baía do Tagarete	37,010668	-25,071561	43	0	0	0	17	0	0	35	0	0	0	20	0	5
SMI (cliff)	FC	Faial da Terra E	37,742222	-25,230273	2	0	0	0	0	0	0	0	0	0	0	0	0	0
SMI (cliff)	FC	Ponta do Cintrão	37,845936	-25,486517	47	0	0	0	40	0	0	0	0	0	0	4	15	27
SMI (cliff)	FC	Pta da Ferraria	37,860300	-25,852601	0	0	0	0	0	0	0	0	0	0	40	0	0	0

(cont.) Numbers of breeding pairs of Common Terns at different colonies of São Miguel (SMI) and Terceira (TER), FC=flush count; CC=clutch count; SS=sitting count.

Island (habitat)	**Method**	**Colony name**	**Lat.**	**Long.**	**1989**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
SMI (cliff)	FC	Ponta do Escalvado	37,869297	-25,841628	0	0	0	0	0	0	0	0	0	0	0	0	0	19
SMI (islet)	FC	Rosto de Cão	37,743254	-25,638268	8	0	0	0	15	0	0	0	0	0	3	40	0	12
SMI (islet)	FC	Baia de Sta Iria	37,826422	-25,466547	0	0	0	0	0	0	0	0	0	0	0	60	25	0
SMI (islet)	FC	Ponta do Ermo	37,844169	-25,501670	87	0	0	0	80	0	0	0	0	0	0	37	120	0
SMI (islet)	FC	Morro das Capelas	37,844551	-25,681195	37	0	0	0	33	0	0	0	0	0	0	35	0	0
SMI (islet)	FC	Ilhéu dos Mosteiros	37,888951	-25,834446	0	0	0	0	9	0	0	0	0	0	0	0	0	0
TER (cliff)	FC	Monte Brasil B	38,642545	-27,217389	87	0	0	0	3	0	0	0	0	0	0	40	0	0
TER (cliff)	FC	Monte Brasil D	38,643512	-27,233717	7	0	0	0	30	0	0	0	0	0	0	0	0	0
TER (cliff)	FC	Monte Brasil A	38,646659	-27,218641	67	0	0	0	40	0	0	0	0	0	0	38	0	0
TER (islet)	FC	Contendas	38,648382	-27,072826	60	107	91	0	41	70	166	586	392	229	143	60	42	0
TER (cliff)	FC	Ponta do Queimado	38,675306	-27,329951	3	0	0	0	25	0	0	0	0	0	0	0	0	0
TER (cliff)	FC	Ponta do Raminho	38,781796	-27,360651	0	0	0	0	0	0	0	0	0	5	0	0	0	0
TER (cliff)	FC	Ponta do Mistério Baia	38,795583	-27,201765	73	0	0	0	0	0	0	0	0	0	0	0	0	0
TER (cliff)	FC	Quatro Ribeiras	38,799944	-27,213922	0	0	0	0	78	0	0	0	0	17	20	5	0	35
TER (cliff)	FC	Monte Brasil C	38,638999	-27,226113	27	0	0	0	23	0	0	0	0	0	0	0	0	0
TER (islet)	FC	Ilhéu das Cabras W	38,631116	-27,143011	0	0	0	0	100	0	0	0	0	0	0	0	0	0
TER (islet)	FC	Ilhéu das Cabras E	38,631816	-27,149822	93	0	0	0	0	0	0	0	0	0	0	6	0	0

Roseate Tern Action Plan for the Azores Archipelago

Foreword

This document was written by Verónica Neves within her doctoral studies at the University of Glasgow. It is being presented to the local conservation agency *Secretaria Regional do Ambiente e do Mar* as a draft Action Plan proposal for the conservation and protection of Roseate Tern *Sterna dougallii* in the Azores. It should be discussed and reviewed by all the stakeholders involved in the conservation and protection of the species in the Azores: government, university, local NGO´s and other interested citizens.

Geographical Scope

This plan describes actions to be implemented on the Azorean colonies, specially the five larger ones that will be briefly described below.

Summary

Herewith I review what has been achieved so far with Roseate Tern conservation in the Azores and systematize current problems and limitations. Priority conservation actions are given.

Conservation Priorities

- To ensure the protection and appropriate management of Roseate Tern breeding colonies throughout the nine main islands of the archipelago, but especially on the five colonies that have held on average 80% of the Azores population. Maintain favourable conditions at Praia islet colony and extend habitat amelioration action to other major colonies such as: Contendas islet (Terceira), Vila islet (Santa Maria), Baixa do Moinho and Alagoa Complex (both in Flores).

- To continue regular monitoring of breeding numbers to assess population trends. Extend monitoring programme to include other parameters such as breeding success and diet.
- To support further research to determine the major factors limiting Roseate Tern number in the Azores, especially food availability.

Conservation Status

The Roseate Tern is listed on Annex I of the EC Birds Directive and Appendix II of the Bern Convention and is classified as a SPEC 3 Species because of large declines in Europe (Tucker & Heath 1994). It has a very restricted distribution in Europe, breeding only in a few coastal localities in northwestern Europe (UK, Ireland and France) and in the Azores islands; Roseate Terns have bred on other Atlantic islands such as Madeira and Canaries but only in negligible numbers. In recent years the population has recovered at Rockabill (Ireland); this colony has high levels of productivity and has been a major factor in the recent increase in the northwestern European population as a whole. In the Azores the population has not shown any clear trend, but has fluctuated dramatically over the period 1989-2005.

The Present State of the Roseate Tern in the Azores

Studies of Roseate Tern in the Azores were initiated by Gerald de Grand in the early 1980s and in 1984 the first census of the species was conducted with the support of RSPB (Dunn 1989). The census was repeated in 1989 and from then onwards the population size has been monitored every year under the supervision of the University of the Azores with the collaboration of RSPB, University of Glasgow and the Great Gull Island Project from the American Museum of Natural History. In the1990s, studies on the ecology of the species in the archipelago provided some insight into nest-site selection (Ramos &

del Nevo 1995) and diets (Pereira 1997, Ramos *et al.* 1998 and 1998a, Meirinho 2003). Recently Martins *et al.* (2004) assessed the effects of different quality fish species and reductions in their abundance in the growth of Roseate Tern chicks in the Azores. The European Starling *Sturnus vulgaris* has been identified as an important predator of tern eggs at Vila islet, one of the main Azorean colonies and control taste aversion has been found to be ineffective reducing this predation (Neves 2005). Adults and chicks have been ringed since 1984, and in the period 1999-2003 the number of birds ringed increased through the collaborative effort of members of the Great Gull Island Group and the University of the Azores. Azorean Roseate Terns have been recovered in West Africa (regular wintering ground for northwest European birds) and off the South American coast (regular wintering ground for North American birds) (Hays *et al.* 2002).

Population size

When studies with Roseate Tern began in the Azores it was thought that the population was decreasing, numbers decreased from 1000 pairs in 1991 to 750 in 1992, and down to 380 breeding pairs in 1993. But in following years it was observed that numbers fluctuated in the archipelago, sometimes very dramatically, so that no clear trend could be identified. After some cyclical fluctuations, the numbers were down again in 2005, when only 389 pairs were counted.

Figure 1: Roseate Tern nest.

Main breeding sites

Roseate Tern have nested at 49 different sites spread across the nine islands of the archipelago. Of these, 23 are located on the mainland (mainly cliffs, rocky beaches and lagoons) and 26 on islets. However most colonies have had small breeding numbers and have only rarely been used. The bulk of the population has consistently bred in five colonies that over the period 1995-2005 held on average about 80% of the breeding population (see Table 1).

Table 1: Number of breeding pairs at the main Azorean colonies over the last decade.

	Alagoa	**Baixa do Moinho**	**Praia**	**Contendas**	**Vila**	**% Azores Total**
1995	321	265	0	114	236	91,1
1996	147	163	0	84	141	44,7
1997	198	232	0	120	135	70,0
1998	135	135	0	188	198	75,1
1999	83	119	0	125	167	95,7
2000	136	125	31	351	90	94,2
2001	110	113	25	342	95	84,2
2002	172	179	133	269	201	96,3
2003	68	105	231	58	134	79,3
2004	176	151	402	32	0	85,3
2005	23	66	128	0	92	79,4

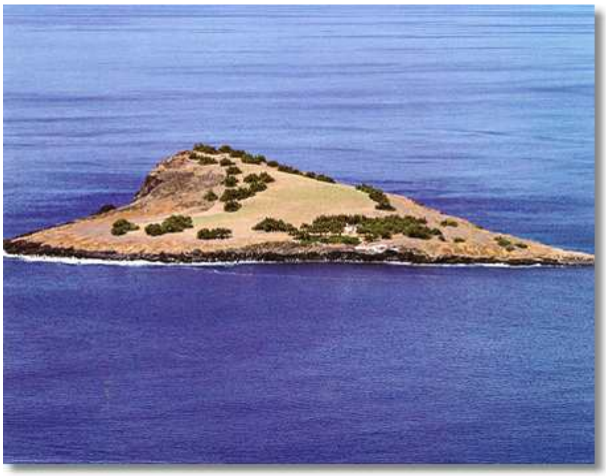
All of the five main colonies are located on islets at variable distances from the mainland: 1) Vila islet (see Fig. 2) is located around 300 m off Santa Maria island; 2) Contendas islet (see Figs. 3 and 4) is located less that 10 m off Terceira island; 3) Praia islet (see Fig. 5) is located around 800 m off Graciosa island; 4) Alagoa complex (see Fig. 6 & 7; Roseate terns breed in three out of five islets) located between 30 and 100 m off Flores and 5) Baixa do Moinho islet (see Fig. 8, photo unavailable) located around 50m off Flores island.

Figure 2: Vila islet off Santa Maria island.

Gerbrand Michielsen

Figure 3: Contendas colony off Terceira island.

Figure 4: Another view of Contendas colony (Terceira).



Pierre Sousa Lima

Figure 5: Praia islet off Graciosa island.

Luís Monteiro

Figure 6: Alagoa Complex off Flores island. Terns breed on the 3 most distant islets.

Luís Monteiro

Figure 7: One of the Alagoa islets showing the area where terns tend to concentrate.

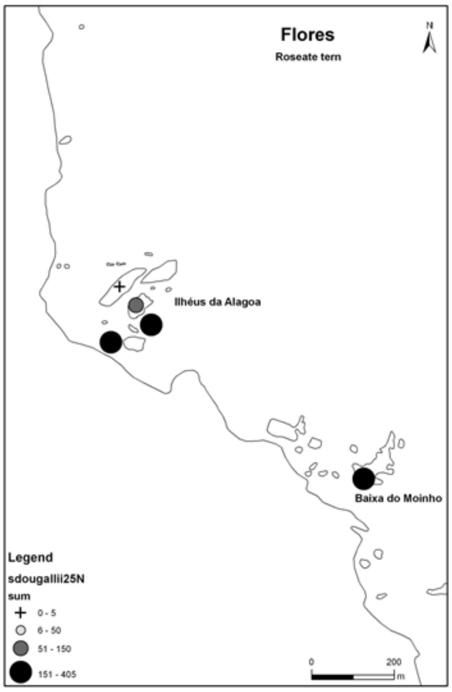


Figure 8: Alagoa Complex and Baixa do Moinho islet off Flores island.

Other colonies that have occasionally held important colonies of Roseate Terns are: 1-Ponta dos ilhéus, 2_4-Ponta Fernão Jorge, Ponta do Burquilhão, Rabo de Peixe (all in Flores), 5-Capelinhos (Faial), 6 & 7-Baixo islet and Ponta Branca (Graciosa), 8-Lagoinhas (Santa Maria) 9-Caloura islet (São Miguel).

Current Problems and Limitations

The main problems at Roseate Tern colonies in the Azores are human disturbance, predation and in some cases changes in vegetation.

Despite adequate legal protection, official vigilance of the main colonies by wardens has not yet been achieved in the Azores. This is mainly due to personnel limitations; the wardens (employed by the *Secretaria Regional do Ambiente e do Mar*) in the archipelago are responsible for the monitoring of a large geographical area and their tasks include many other activities beside vigilance of tern colonies.

Therefore several colonies are prone to human disturbance, especially from fishermen. Due to its proximity to land, Contendas islet is under strong pressure from human disturbance. For example, fisherman sometimes use Contendas islet for fishing (see Fig. 9), and during 2003 some pigeon hunters were seen landing at the Contendas colony and collecting chicks of the Rock Pigeon (*Columba livia*). Scuba divers also hunt in the bay adjacent to the colony. At Vila islet, chicks of Cory´s Shearwater have been harvested as a regular practice in the past. Although it had stopped for a while, it has resumed in recent years (see Fig. 10). Amongst the five main Roseate Tern colonies in the Azores only Praia islet has received regular vigilance, but even in this case the island sometimes goes without vigilance for several consecutive days during the breeding season of the terns. This is because the only warden of the island has to do several tasks in other parts of Graciosa apart from Praia islet.

Figure 9: Fishermen at Contendas colony (Terceira) during terns' breeding season.

Terns have several predators in the Azores. Yellow-legged Gulls have increased at a rate of 2.3% over the last 20 years and have begun to breed in colonies that were traditionally used exclusively by terns. Starlings have been causing high rates of egg predation at Vila islet (see Fig. 11). Starlings have also been observed breeding in Contendas colony and roosting in large numbers at Caloura colony but predation on tern eggs has not been observed so far. Nevertheless it is very important to monitor the situation. Predated eggs have been found in Contendas in 2003, probably by rats (see Fig. 12). A Buzzard has regularly bred at Vila colony and has been found to prey on several seabird species, including tern chicks.

Figure 10: Cory´s Shearwater chicks harvested at Vila islet.

Figure 11: European Starling (left) and Roseate Tern nest with egg predated by starlings (right).

Figure 12: Roseate Tern eggs predated at Contendas Colony (Terceira) in 2003.

Summary of Conservation Action taken to date

The most important Roseate Tern colonies in the Azores are currently within nature reserves and the majority have been designated as Special Protected Areas (SPAs). Breeding numbers have been monitored annually since 1989 and in the case of the Praia islet colony habitat restoration has been undertaken. Chicks and adults have been ringed with national and field readable rings and in 2002 and 2003 adults were also marked with colour rings.

Figure 13: Ringed Roseate Tern chick.

Paulo Faria

Figure 14: Roseate Tern marked with colour rings at Baixa do Moinho (Flores).

Actions Proposed

The dispersion of the colonies over several islands makes the logistics of effectively protecting Roseate Terns expensive and difficult to coordinate. It is therefore important to focus efforts where beneficial results can be maximised. In this case it means giving special attention to the main colonies described above. If these five colonies are optimally managed, Roseate Tern numbers are likely to increase in the archipelago. It is also important to ensure some degree of protection and management to other colonies that can occasionally hold a considerable number of breeding pairs.

a) **Prevention of disturbance at breeding colonies**: Of highest priority is constant vigilance of the main colonies, namely: Vila islet (Santa Maria), Caloura islet (São Miguel), Contendas islet (Terceira), Praia islet (Graciosa) and Baixa do Moinho & Alagoa Complex (Flores). Praia islet is subject to a reasonable amount of vigilance but it is important to intensify the protection in the colony by ensuring that a warden is present in the colony on a daily basis during the breeding season. Other colonies such as Capelinhos (Faial) and Contendas (São Miguel) should also be visited regularly during the breeding cycle but do not require constant wardening. The presence of wardens will prevent human disturbance and they can also monitor for the presence of predators. Timing: late April-early August.

b) **Control of ground predators at breeding sites**: Adequate control measures should be taken at Contendas islet where the presence of rats has been confirmed. The other colonies should be regularly monitored using chew sticks and upon discovery of predators control measures should be immediately implemented Timing: late February-early April.

c) **Gull control at breeding sites**: It is important to prevent gulls from breeding at tern colonies. In the specific case of Vila islet, where two pairs of gulls have recently been breeding, it is important that their eggs are destroyed early in the breeding season and that birds be discouraged to remain on the islet. A gull has also been found breeding in Contendas islet during 2003 breeding season; the eggs were destroyed by vigorous agitation but left in the nest; the gulls later abandoned the colony and were not seen in 2004 and 2005. Nevertheless, it is important to monitor the situation every year. The main colonies should be visited prior to tern arrival and any gulls located should be deterred from breeding and remaining on the tern colonies. Timing: late March-late June.

d) **Starling control and monitoring at breeding sites**: Starlings have been found to prey on tern eggs at Vila islet and it is therefore important to monitor their presence and their potential for predation in other colonies. In the specific case of Vila islet it is important to monitor the situation and try to minimize the impact of starlings. Artificial nests (boxes) should be deployed to attempt to reduce predation but active ways of reducing the starling population size might also be necessary, including lethal control. Timing: April- late June.

e) **Other aerial predators:** The Buzzard nest at Vila islet should be destroyed by removing the nest material and placing big stones that will make unsuitable the places normally used for breeding. The islet should be visit prior to tern arrival and buzzards found in the islet should be deterred from remaining there. Timing: February and March.

f) **Vegetation management**: It is very important to ensure that the vegetation cover is appropriate for tern breeding. Some colonies such as Praia islet (Graciosa) and Contendas islet (Terceira) have seen an increase in the vegetation over the last few years. This has been due to successful conservation measures aimed at reducing erosion and re-introducing native vegetation. Nevertheless in some cases the vegetation cover can become too dense and high for tern breeding. This vegetation encroachment can degrade habitat for terns and should be prevented. In these cases it is advisable to strategically reduce vegetation density. This action is particularly important at Praia islet (Graciosa) and at Contendas islet (Terceira). Timing: March.

f) **Provision of nest boxes**: An adequate number of nest boxes should be sited at colonies where there are aerial predators and/or where there is little vegetation. Nest boxes have been used successfully for many years in America and Europe and consist of simple wooden boxes with open or half-closed fronts. The boxes are 30 cm square and 15 cm height and the entrance is 10 cm wide. A few dozens of nest boxes have been placed in the Azores at the Praia islet colony but have only been used by Common Terns. It is important to provide a large number of closely spaced nest boxes because the rate of occupation can be low. Nest boxes should be used primarily in Praia, Vila and Contendas islets. These are the islands where predation pressure is stronger and where the surface of the islet is flat enough to install nest boxes. The colonies at Flores are very small and rocky but also have vegetation patches and seem to already provide ideal conditions for tern breeding. Timing: Late March.

Further Research

a) Continue on-going studies on the population dynamics of the Azores population. To achieve this, it is important to continue to monitor annual number of breeding pairs, as well as continue to ring chicks and adults. It is very important to start a regular program of assessing breeding success in the five main colonies.

b) Investigate the main population limiting factors. There are indications that food shortage may be a factor currently limiting numbers of Roseate Terns breeding in the Azores in any one year, and their productivity, and it is therefore important to investigate this hypothesis. To achieve this it is important to study Roseate Tern diets and feeding frequency of chicks on a regular basis. Data from fisheries and from oceanography should also be used.

c) It is also important to investigate ways of reducing starling predation. Experiments using Control Taste Aversion have not proved successful and it is necessary to continue looking for other possible solutions.

Public Awareness and Training

It is important to maintain communication and information exchange between workers in the different islands of the archipelago. The Azores are split into nine major islands scattered over several hundred kilometres making communication difficult. Making use of the internet and establishing a mailing list would help bring together technicians, researchers, and wardens from the different islands. Additionally, a regional newsletter exchanging information on Azores Roseate Terns colonies would be beneficial for all involved parties.

Network of Volunteer Support Groups for Portuguese IBAs

The Portuguese Society for the Study of Birds (SPEA) runs a volunteer programme to monitor and protect Important Bird Areas (IBAs) in Portugal. The successful implementation of this programme in the Azores would give an important contribute to the conservation of the main Roseate Tern colonies. This would provide a way to overcome the resource limitations that have so far constrained and limited efficient protection by the governmental conservation agency. In Caloura islet (São Miguel) local people living close to the colony have actively protected the colony from intruders. It is important to provide such dedicated volunteers with information, training, equipment, and funds so that they can continue to help protect the terns.

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Factors Affecting Breeding Distribution and Seabird Richness within the Azores Archipelago

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ABSTRACT

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.

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 michahellis,* 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.

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 variables reduced the AIC.

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 procellariidae 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.

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

	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. P: NS >0.05, *≤0.05, ** ≤0.01. Trend: '+' positive relationship,'–' negative relationship.

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	+

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.

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	**	+
Procellariiforme*s*	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	-

COMPLETE ND2 SEQUENCES

Please note: Numbers 1 to 22 include sequences of *Sturnus vulgaris* used in the study described in chapter IV. Numbers 23 to 26 include sequences from other Sturnidae obtained from GenBank that we tried to use as an outgroup. However, they were too different from *Sturnus vulgaris* to be helpful in the construction of phylogenetic trees.

1) AZSTC

CTAGTCTTTACCCTTAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCGCTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
CTCCACCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
CACCCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
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CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCGCCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
ACTTAGGCTGAATAGCAATTGTCATCGCCTACAGCCCCAAACTAGCCCTACTCAACTTCT
ATTTATACGTAATAATAACCGCCGCCGTATTCCTCACCCTAAACACAATTAAAACGCTAA
AACTGTCCACACTAATAACCACATGAGCAAAAACCCCAGCTCTGAGCGCGATACTAATA
CTGACTTTACTCTCCCTAGCAGGTTTACCCCCTCTGACCGGCTTCCTTCCTAAATGACTG
ATTATTCAAGAACTGGTCAATCAAGAAATAGCCCCAACAGCAACAATCATCGCCCTACTG
TCCTTATTAGGTCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCTTAGTC
GCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTATG
TCTAAGAAA

2) AZ2

CTAGTCTTTACCCTTAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCGCTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
CTCCACCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
CACCCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
AGGACTTGCTCCGTTCCACTTCTGATTCCCCGAAGTACTACAAGGCTGCCACCTCACCAC
CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCGCCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
ACTTAGGCTGAATAGCAATTGTCATCGCCTACAGCCCCAAACTAGCCCTACTCAACTTCT
ATTTATACGTAATAATAACCGCCGCCGTATTCCTCACCCTAAACACAATTAAAACGCTAA
AACTGTCCACACTAATAACCACATGAGCAAAAACCCCAGCTCTGAGCGCGATACTAATA
CTGACTTTACTCTCCCTAGCAGGTTTACCCCCTCTGACCGGCTTCCTTCCTAAATGACTG
ATTATTCAAGAACTGGTCAATCAAGAAATAGCCCCAACAGCAACAATCATCGCCCTACTG
TCCTTATTAGGTCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCTTAGTC
GCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTATG
TCTAAGAAA

3) AZ3

CTAGTCTTTACCCTTAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCGCTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
CTCCACCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
CACCCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
AGGACTTGCTCCGTTCCACTTCTGATTCCCCGAAGTACTACAAGGCTGCCACCTCACCAC
CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCGCCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
ACTTAGGCTGAATAGCAATTGTCATCGCCTACAGCCCCAAACTAGCCCTACTCAACTTCT
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AACTGTCCACACTAATAACCACATGAGCAAAAACCCCAGCTCTGAGCGCGATACTAATA
CTGACTTTACTCTCCCTAGCAGGTTTACCCCCTCTGACCGGCTTCCTTCCTAAATGACTG
ATTATTCAAGAACTGGTCAATCAAGAAATAGCCCCAACAGCAACAATCATCGCCCTACTG
TCCTTATTAGGTCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCTTAGTC
GCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTATG
TCTAAGAAA

4) AZ4

CTAGTCTTTACCCTTAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCGCTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
CTCCACCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
CACCCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
AGGACTTGCTCCGTTCCACTTCTGATTCCCCGAAGTACTACAAGGCTGCCACCTCACCAC
CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCGCCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
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TCCTTATTAGGTCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCTTAGTC
GCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTATG
TCTAAGAAA

5) AZ5

CTAGTCTTTACCCTTAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCGCTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
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CACCCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
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CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCGCCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
ACTTAGGCTGAATAGCAATTGTCATCGCCTACAGCCCCAAACTAGCCCTACTCAACTTCT
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CTGACTTTACTCTCCCTAGCAGGTTTACCCCCTCTGACCGGCTTCCTTCCTAAATGACTG
ATTATTCAAGAACTGGTCAATCAAGAAATAGCCCCAACAGCAACAATCATCGCCCTACTG
TCCTTATTAGGTCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCTTAGTC
GCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTATG
TCTAAGAAA

6) AZ6

CTAGTCTTTACCCTTAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCGCTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
CTCCACCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
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AGGACTTGCTCCGTTCCACTTCTGATTCCCCGAAGTACTACAAGGCTGCCACCTCACCAC
CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCGCCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
ACTTAGGCTGAATAGCAATTGTCATCGCCTACAGCCCCAAACTAGCCCTACTCAACTTCT
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AACTGTCCACACTAATAACCACATGAGCAAAAACCCCAGCTCTGAGCGCGATACTAATA
CTGACTTTACTCTCCCTAGCAGGTTTACCCCCTCTGACCGGCTTCCTTCCTAAATGACTG
ATTATTCAAGAACTGGTCAATCAAGAAATAGCCCCAACAGCAACAATCATCGCCCTACTG
TCCTTATTAGGTCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCTTAGTC
GCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTATG
TCTAAGAAA

7) AZ7

CTAGTCTTTACCCTTAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCGCTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
CTCCACCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
CACCCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
AGGACTTGCTCCGTTCCACTTCTGATTCCCCGAAGTACTACAAGGCTGCCACCTCACCAC
CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCGCCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
ACTTAGGCTGAATAGCAATTGTCATCGCCTACAGCCCCAAACTAGCCCTACTCAACTTCT
ATTTATACGTAATAATAACCGCCGCCGTATTCCTCACCCTAAACACAATTAAAACGCTAA
AACTGTCCACACTAATAACCACATGAGCAAAAACCCCAGCTCTGAGCGCGATACTAATA
CTGACTTTACTCTCCCTAGCAGGTTTACCCCCTCTGACCGGCTTCCTTCCTAAATGACTG
ATTATTCAAGAACTGGTCAATCAAGAAATAGCCCCAACAGCAACAATCATCGCCCTACTG
TCCTTATTAGGTCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCTTAGTC
GCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTATG
TCTAAGAAA

8) SPAIN9

CTAGTCTTTACCCTTAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCACTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
CTCCACCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
CACTCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
AGGACTTGCTCCGTTCCACTTCTGATTCCCCGAAGTACTACAAGGCTGCCACCTCACCAC
CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCGCCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
ACTTAGGCTGAATAGCAATTGTCATCGCCTACAGCCCCAAACTAGCCCTACTCAACTTCT
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AACTGTCCACACTAATGACCACATGAGCAAAAACCCCAGCTCTGAGCGCGATACTAATA
CTGACTTTACTCTCCCTAGCAGGCTTACCCCCTCTGACCGGCTTCCTTCCTAAATGACTG
ATTATTCAAGAACTGGTCAATCAAGAAATAGCCCCAACAGCAACAATCATCGCCCTACTG
TCCTTATTAGGCCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCTTAGTC
GCCATTCTAGTCACAATATCCACCATCCTCCTACCCATCTCCCCTATACTCCTCACTATG
TCTAAGAAA

9) SPAIN10

CTAGTCTTTACCCTCAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCACTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
CTCCACCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
CACTCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
AGGACTTGCTCCGTTCCACTTCTGATTCCCCGAAGTACTACAAGGCTGCCACCTCACCAC
CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCGCCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
ACTTAGGCTGAATAGCAATTGTCATCGCCTACAGCCCCAAACTAGCCCTACTCAACTTCT
ATTTATACGTAATAATAACCGCCGCCGTATTCCTCACCCTAAACACAATTAAAACACTAA
AACTGTCCACACTAATGACCACATGAGCAAAAACCCCAGCTCTGAGCGCGATACTAATA
CTGACTTTACTCTCCCTAGCAGGCCTACCCCCTCTGACCGGCTTCCTTCCTAAATGACTG
ATTATTCAAGAACTGGTCAATCAAGAAATAGCCCCAACAGCAACAATCATCGCCCTACTG
TCCTTATTAGGCCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCTTAGTC
GCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTATG
TCTAAGAAA

10) SPAIN11

CTAGTCTTTACCCTTAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCGCTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
CTCCACCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
CACTCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
AGGACTTGCTCCGTTCCACTTCTGATTCCCCGAAGTACTACAAGGCTGCCACCTCACCAC
CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCGCCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
ACTTAGGCTGAATAGCAATTGTCATCGCCTACAGCCCCAAACTAGCCCTACTCAACTTCT
ATTTATACGTAATAATAACCGCCGCCGTATTCCTCACCCTAAACACAATTAAAACGCTAA
AACTGTCCACACTAATAACCACATGAGCAAAAACCCCAGCTCTGAGCGCGATACTAATA
CTGACTTTACTCTCCCTAGCAGGTTTACCCCCTCTGACCGGCTTCCTTCCTAAATGACTG
ATTATTCAAGAACTGGTCAATCAAGAAATAGCCCCAACAGCAACAATCATCGCCCTACTG
TCCTTATTAGGTCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCTTAGTC
GCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTATG
TCTAAGAAA

11) SPAIN12

CTAGTCTTTACCCTTAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCGCTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
CTCCGCCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
CACTCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
AGGACTTGCTCCGTTCCACTTCTGATTCCCCGAAGTACTACAAGGCTGCCACCTCACCAC
CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCGCCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
ACTTAGGCTGAATAGCAATTGTCATCGCCTACAGCCCCAAACTAGCCCTACTCAACTTCT
ATTTATACGTAATAATAACCGCCGCCGTATTCCTCACCCTAAACACAATTAAAACGCTAA
AACTGTCCACACTAATAACCACATGAGCAAAAACCCCAGCTCTGAGCGCGATACTAATA
CTGACTTTACTCTCCCTAGCAGGTTTACCCCCTCTGACCGGCTTCCTTCCTAAGTGACTG
ATTATTCAAGAACTGGTCAATCAAGAAATAGCCCCAACAGCAACAATCATCGCCCTACTG
TCCTTATTAGGTCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCTTAGTC
GCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTATG
TCTAAGAAA

12) SPAIN13

CTAGTCTTTACCCTTAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCGCTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
CTCCACCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
CACTCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
AGGACTTGCTCCGTTCCACTTCTGATTCCCCGAAGTACTACAAGGCTGCCACCTCACCAC
CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCGCCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
ACTTAGGCTGAATAGCAATTGTCATCGCCTACAGCCCCAAACTAGCCCTACTCAACTTCT
ATTTATACGTAATAATAACCGCCGCCGTATTCCTCACCCTAAACACAATTAAAACGCTAA
AACTGTCCACACTAATAACCACATGAGCAAAAACCCCAGCTCTGAGCGCGATACTAATA
CTGACTTTACTCTCCCTAGCAGGTTTACCCCCTCTGACCGGCTTCCTTCCTAAATGACTG
ATTATTCAAGAACTGGTCAATCAAGAAATAGCCCCAACAGCAACAATCATCGCCCTACTG
TCCTTATTAGGTCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCTTAGTC
GCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTATG
TCTAAGAAA

13) FAIR14

CTAGTCTTTACCCTCAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCGCTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
CTCCACCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
CACTCAACTAACCTGCCCAGTAGCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
AGGACTTGCTCCGTTCCACTTCTGATTCCCCGAAGTACTACAAGGCTGCCACCTCACCAC
CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCGCCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
ACTTAGGCTGAATAGCAGTTGTCATCGCCTACAGCCCCAAACTAGCCCTACTCAACTTCT
ATTTATACGTAATAATAACCGCCGCCGTATTCCTCACCCTAAACACAATTAAAACGCTAA
AACTGTCCACACTAATAACCACATGAGCAAAAACCCCAGCTCTGAGCGCGATACTAATA
CTGACTTTACTCTCCCTAGCAGGCTTACCCCCTCTGACCGGCTTCCTTCCTAAATGACTG
ATTATTCAAGAACTGGTCAATCAAGAAATAGCCCCAACAGCAACAATCATCGCCCTACTG
TCCTTATTAGGTCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCTTAGTC
GCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTATG
TCTAAGAAA

14) FAIR15

CTAGTCTTTACCCTTAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCGCTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
CTCCACCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
CACTCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
AGGACTTGCTCCGTTCCACTTCTGATTCCCCGAAGTACTACAAGGCTGCCACCTCACCAC
CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCGCCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
ACTTAGGCTGAATAGCAATTGTCATCGCCTACAGCCCCAAACTAGCCCTACTCAACTTCT
ATTTATACGTAATAATAACCGCCGCCGTATTCCTCACCCTAAACACAATTAAAACGCTAA
AACTGTCCACACTAATAACCACATGAGCAAAAACCCCAGCTCTGAGCGCGATACTAATA
CTGACTTTACTCTCCCTAGCAGGTTTACCCCCTCTGACCGGCTTCCTTCCTAAATGACTG
ATTATTCAAGAACTGGTCAATCAAGAAATAGCCCCAACAGCAACAATCATCGCCCTACTG
TCCTTATTAGGTCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCTTAGTC
GCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTATG
TCTAAGAAA

15) FAIR16

CTAGTCTTTACCCTCAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCGCTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
CTCCACCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
CACTCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
AGGACTTGCTCCGTTCCACTTCTGATTCCCCGAAGTACTACAAGGCTGCCACCTCACCAC
CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCACCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
ACTTAGGCTGAATAGCAATTGTCATCGCCTACAGCCCCAAACTAGCCCTACTCAACTTCT
ATTTATACGTAATAATAACCGCCGCCGTATTCCTCACCCTAAACACAATTAAAACGCTAA
AACTGTCCACACTAATAACCACATGAGCAAAAACCCCAGCTCTGAGCGCGATACTAATA
CTGACTTTACTCTCCCTAGCAGGCTTACCCCCTCTGACCGGCTTCCTTCCTAAATGACTG
ATTATTCAAGAACTGGTCAATCAAGAAATAGCCCCAACAGCAACAATCATCGCCCTACTG
TCCTTATTAGGTCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCCTAGT
CGCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTAT
GTCTAAGAAA

16) FAIR17

CTAGTCTTTACCCTCAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
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CTCCACCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
CACTCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
AGGACTTGCTCCGTTCCACTTCTGATTCCCCGAAGTACTACAAGGCTGCCACCTCACCAC
CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCACCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
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ATTTATACGTAATAATAACCGCCGCCGTATTCCTCACCCTAAACACAATTAAAACGCTAA
AACTGTCCACACTAATAACCACATGAGCAAAAACCCCAGCTCTGAGCGCGATACTAATA
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CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCCTAGT
CGCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTAT
GTCTAAGAAA

17) BRSTC

CTAGTCTTTACCCTTAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCGCTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
CTCCACCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
CACTCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
AGGACTTGCTCCGTTCCACTTCTGATTCCCCGAAGTACTACAAGGCTGCCACCTCACCAC
CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCACCATAGCCCTCCTATCCGCAGCTGTGGGAG
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GTCTAAGAAA

18) BRIS19

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ATTATTCAAGAACTGGTCAATCAAGAAATAGCCCCAACAGCAACAATCATCGCCCTACTG
TCCTTATTAGGTCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCCTAGT
CGCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTAT
GTCTAAGAAA

19) BRIS20

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ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCGCTAATCTCAAAA
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CTCCGCCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
CACTCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
AGGACTTGCTCCGTTCCACTTCTGATTCCCCGAAGTACTACAAGGCTGCCACCTCACCAC
CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCGCCATAGCCCTCCTATCCGCAGCTGTGGGAG
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TCCTTATTAGGTCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
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GCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTATG
TCTAAGAAA

20) BRIS21

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CACTCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
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CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCGCCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
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AACTGTCCACACTAATAACCACATGAGCAAAAACCCCAGCTCTGAGCGCGATACTAATA
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TCCTTATTAGGTCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCTTAGTC
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TCTAAGAAA

21) BRIS22

CTAGTCTTTACCCTCAGCCTACTTCTAGGATCAACTATCACAATCTCGAGTAACCACTGA
ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCGCTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
CTCCACCCTACTCCTATTCTCCAGCATGACTAACGCATGACACACTGGACAATGAGACAT
CACTCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
AGGACTTGCTCCGTTCCACTTCTGATTCCCCGAAGTACTACAAGGCTGCCACCTCACCAC
CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCACCATAGCCCTCCTATCCGCAGCTGTGGGAG
GATGAATGGGACTCAACCAAACGCAAACCCGAAAAATCCTTGCCTTCTCATCTATCTCCC
ACTTAGGCTGAATAGCAATTGTCATCGCCTACAGCCCCAAACTAGCCCTACTCAACTTCT
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AACTGTCCACACTAATAACCACATGAGCAAAAACCCCAGCTCTGAGCGCGATACTAATA
CTGACTTTACTCTCCCTAGCAGGCTTACCCCCTCTGACCGGCTTCCTTCCTAAATGACTG
ATTATTCAAGAACTGGTCAATCAAGAAATAGCCCCAACAGCAACAATCATCGCCCTACTG
TCCTTATTAGGTCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCCTAGT
CGCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTAT
GTCTAAGAAA

22) MICH

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ATTATAGCCTGGACTGGACTTGAAATCAATACCCTAGCGATCCTACCGCTAATCTCAAAA
TCGCACCACCCCCGAGCCATTGAAGCTGCAACCAAGTACTTTCTAGTACAAGCAGCCGC
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CACTCAACTAACCTGCCCAGTATCCTGCGTAATCCTTACTGCAGCCATTGCAATAAAATT
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CGGCCTACTCCTGTCCACAGTCATGAAATTCCCACCAATCACACTCCTCTATATGACCTC
CCAATCACTAAACCCCTCCCTACTAACCGCCATAGCCCTCCTATCCGCAGCTGTGGGAG
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AACTGTCCACACTAATGACCACATGAGCAAAAACCCCAGCTCTGAGCGCGATACTAATA
CTGACTTTACTCTCCCTAGCAGGCTTACCCCCTCTGACCGGCTTCCTTCCTAAATGACTG
ATTATTCAAGAACTGGTCAATCAAGAAATAGCCCCAACAGCAACAATCATCGCCCTACTG
TCCTTATTAGGCCTATTCTTCTACCTCCGACTCGCATACTGTGCAACAATCACACTTCCC
CCACATACGACAAACCACATAAAACAGTGGTATACCAACAAACCTACCAACACCTTAGTC
GCCATTCTAGTCACAATATCCATCATCCTCCTACCCATCTCCCCTATACTCCTCACTATG
TCTAAGAAA

23) *Lamprotornis nitens* (red-shouldered glossy starling)

atgaaccccc aagcaaatct agtcttcgtc ctgagcctaa ttctaggatc aactatcgca

61 atctcaagca accactgaat tacagcctga gctggacttg aaatcaacac cctggcggtc
121 ctccctttaa tctcaaaatc ccaccacccc cgagccatcg aagctgcaac caagtacttt
181 ctagtacaag cagctgcctc cgccctaatt ttattctcca gcataaccaa cgcatgatac
241 atcgggcaat gggatatcac cctactgacc tgcccagtat catgcgcgat cttaacctcg
301 gccgtcgcaa taaaactagg actagcccca tttcactttt gattccccga ggtactccaa
361 ggctgctccc tcaccaccgg cctcctccta tccacagcca tgaagttccc accaatcaca
421 ctcctgtaca taacctctca atcactaaac ccctccctac tgatcgccat ggccatccta
481 tccacagcct taggagggtg aataggacta aatcaaaccc agactcgaaa aatcctcgcc
541 ttctcatcca tctctcacct aggatgaata gccatcatca tggtctacag ccccaaacta
601 gccctaatta acttctacct atatacaaca ctaactgcaa ccgtattcct catcctggac
661 tcaaccaaga ctctgaaact aactacactg ataaccgcat gaacaaaagc cccctcccta
721 agcgcaatac tgatactagc cctactctcc ctagcaggcc ttccccctct cactggcttc
781 ctccccaaat gactgatcat ccaagaacta gtcaaccaag agatagcccc aacggcaaca
841 gctatcgccc tcctctccct actaagcctt ttcttctacc tccgccttgc atattgcgcg
901 acaatcacgc ttcccccaca tactacaaac catataaaac agtggtatat ccacaagcca
961 atcaacgtct caattgctag cctaacctca gcatcactct tcctcttacc catctcaccc
1021 ctcatcctca ccactgtgta a

24) *Creatophora cinerea* (wattled starling)

atgaaccccc aagcaaaact aatctttgcc tccagcttac tcctaggatc aactatcaca

61 atctcgagca accactgaat cacagcctgg actggactcg agatcaacac cctagcaatc
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181 ctagtccaag cagctgcctc cgccctgctg ctattctcca gcataactaa cgcatgacat
241 acagggcagt gagatatcac ccaactaaca tgcccaacat cctgcgtaat cctaactgca
301 gccattgcaa taaaactagg actagcccca ttccacttct gattcccaga agtgctacaa
361 ggctgctcca ttactaccgg actcctccta tctacagcca taaaatttcc accaatcacc
421 ctcctctaca taacctctca atcactaaac ccttctatac taaccaccat agcgctcctt
481 tccgcagccc taggaggatg aatggggctt aaccaaaccc aaacccgaaa aatcctcgcc
541 ttctcatcta tctcccacct aggatgaata gccgtagtca tcgcctacaa ccccaaacta
601 gccctattta acttctacct gtacgtagta ataaccgcag ccgtattcct taccctaaac
661 acaattaaaa ccctaaatct atctacacta ataactacat gggcaaaaac cccagctttg
721 agcgcaatac ttatactaac cctactctcc ctagcaggac tgccccctct aacaggcttc
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901 acaatcacgc ttccccctca tacgacaaac cacatgaaac agtgacacat tcacaaacca
961 accaacacct caatcgccat tctggtcaca ctatccatca tcctactacc catcttccca
1021 atactactca ccattggcta a

25) ***Orescoptes montanus***

atgaaccccc aagcaaaact agtctttacc accagtttac ttctaggatc aacaatcaca

61 atctcaagca accactgaat cacggcctgg gccggtcttg aaatcaacac cctagcaatt
121 ctaccactaa tctcaaaatc ccaccacccc cgagccattg aagccgcaac taaatacttc
181 ctagtgcaag cagccgcctc cgccctagtc ctattctcta gcataaccaa tgcatgaaac
241 accggacaat gggacatcac ccaactaacc tgcccaacat catgcacaat tctaaccgca
301 gccattgcca tgaaactagg actagccccc ttccactttt gattcccaga agtacttcaa
361 ggctgctccc ttattacagg gctcctccta tctacggcca tgaaattccc ccctatcgtc
421 ctcctgttta tgacctccca atcactaaac cccaccctac taacctccat ggccatccta
481 tccgtagccc tagggggatg aaccggacta aaccaaaccc aaacccgaaa aatcctagcc
541 ttctcatcca tctcccacct aggctgaata gccgccatca tcacctacta ccccaaacta
601 gccctactaa acttctacct atacgtcata atgaccgcag ccgtattcct cgccctaaac
661 tcaatcaaaa ccctaaaact atccacacta ataaccacat gaaccaaaac cccagcacta
721 agcgcaatac taatactaac cctactgtct ctagcaggac ttccccctct aacaggcttc
781 ctccctaaat gacttatcat ccaagaacta actaaacaag aaataatccc aaccgcagta
841 atcatcgccc tcctctccct actaagcctc ttcttctacc tccgactcgc atactgcgca
901 acaattactc tcccccccaca caccacaaac cacatgaaac agtgacatac aaacaaaccc
961 accaacttca tggttgccac cctaatcacc atgtccatcg tcctcctacc catatcccca
1021 ataatcctca ccctagttta a

26) ***Orescoptes montanus*** **(2nd sequence)**

atgaaccccc aagcaaaact agtctttacc accagtttac ttctaggatc aacaatcaca

61 atctcaagca accactgaat cacggcctgg gccggtcttg aaatcaacac cctagcaatt
121 ctaccactaa tctcaaaatc ccaccacccc cgagccattg aagccgcaac taaatacttc
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241 accggacaat gggacatcac ccaactaacc tgcccaacat catgcacaat tctaaccgca
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361 ggctgctccc ttattacagg gctcctccta tctacggcca tgaaattccc ccctatcgtc
421 ctcctgttta tgacctccca atcactaaac cccaccctac taacctccat ggccatccta
481 tccgtagccc tagggggatg aaccggacta aaccaaaccc aaacccgaaa aatcctagcc
541 ttctcatcca tctcccacct aggctgaata gccgccatca tcacctacta ccccaaacta
601 gccctactaa acttctacct atacgtcata atgaccgcag ccgtattcct cgccctaaac
661 tcaatcaaaa ccctaaaact atccacacta ataaccacat gaaccaaaac cccagcacta
721 agcgcaatac taatactaac cctactatct ctagcaggac ttccccctct aacaggcttc
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841 atcatcgccc tcctctccct actaagcctc ttcttctacc tccgactcgc atactgcgca
901 acaattactc tcccccccaca caccacaaac cacatgaaac agtgacatac aaacaaaccc
961 accaacttca tggttgccac cctaatcacc atgtccatcg tcctcctacc catatcccca
1021 ataatcctca ccctagttta a

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Banded Roseate Terns from different continents trapped in the Azores

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ABSTRACT. Banded Roseate Terns (*Sterna dougallii*) trapped on nests in the Azores illustrate that, during the nonbreeding season, birds from the Azores are found on the coast of Africa in groups of Roseate Terns from northern Europe and on the coast of South America with birds from the northeastern U.S. and the Caribbean. One Roseate Tern, probably originally banded on a nest in a western Atlantic colony, suggests the possibility of gene flow between these colonies and the Azores.

SINOPSIS. **Individuos de *Sterna dougallii*, anillados en diferentes continentes atrapados en las Azores**

Individuos anillados de *Sterna dougallii*, atrapados en las Azores, demuestran que durante la época no reproductiva, estas aves se encuentran en la costa de África con otros miembros de su especie que se originan de Europa y otros se encuentran en las costas de Sur América con individuos del noreste de los E.U.A. y el Caribe. Un individuo, aparentemente anillado en una colonia de la parte oeste del Atlántico, sugiere la posibilidad de flujo genético entre esas colonias y las de las Azores.

Key words: Brazil, Ghana, migration, movement, recoveries, *Sterna dougallii*

In the western hemisphere, Roseate Terns (*Sterna dougallii*) breed on both sides of the north Atlantic. In the 20th century their populations underwent substantial reductions in numbers (Gochfeld 1983; Everett et al. 1987; Cabot 1996). Analyses of band recoveries from the U.S. population (Hamilton 1981; Nisbet 1984) and the British Isles (Langham 1971) give us an idea of the timing and routes Roseate Terns take when they migrate south. Most recoveries of Roseate Terns are of young birds on their first fall migration (Mead 1978; Dunn 1981; Hamilton 1981; Cabot 1996). There are relatively few recoveries for the period January–March on either side of the Atlantic; however, Hays et al. (1997, 1999) report large roosting concentrations of Roseate Terns during these months on the coast of Bahia, Brazil, between 11°27′S and 17°33′S.

Recoveries and resightings of color-banded Roseate Terns from Britain, Ireland, and the Azores have been made on the coast of Ghana through December (Everett et al. 1987; del Nevo et al. 1990, 1993; del Nevo 1993; Cabot 1996). There are three recoveries of Azores Roseate Terns on the African coast (L. Monteiro, pers. comm.). These birds were banded as chicks in June 1995 at Santa Maria, Azores: G5212 and G5323 were found dead at Abidjan, Ivory Coast, on 16 November 1995, and G5234 was found dead in Ghana on 10 January 1997. Only a few observations of Roseate Terns have been made after December in Ghana. A. Smith counted 700–1000 Roseate Terns on the Tema breakwater in January and February 1970 (Dunn 1981), and Everett et al. (1987) counted 70 on the same breakwater in January–February 1986. There is no information in the literature as to where Azores Roseate Terns can be found after December.

Recovery data from both sides of the Atlantic are for the most part based on bands from birds found dead, but also include some data from banded birds that were netted and released. For the remainder of this paper, a recovery will refer to a dead banded bird.

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Relatively few Roseate and Common Terns (*Sterna hirundo*) have been banded in the Azores (L. Monteiro, pers. comm.). Banding of these species started in 1984, when five young Roseate and 29 young Common Terns were banded. No terns were banded from 1985–1988, with the exception of one adult Roseate Tern in 1986. From 1989–1997, 37 adult Roseate, 101 adult Common, 1282 young Roseate, and 1549 young Common Terns were banded. No terns were banded in 1998.

In February and December 1996, Pedro Lima, working at Mangue Seco, Bahia, Brazil (11°27′S, 37°21′W; Fig. 1), netted three and recovered one Common Tern banded as young in the Azores archipelago (Hays et al. 1999). In 1997, a Common Tern banded at Mangue Seco in 1996 was trapped on a nest at Vila Islet, Azores (Hays et al. 1999). Lima's data provided the first indication that there might be a regular transatlantic movement of Common Terns between the Azores and the South American coast. In contrast, four earlier transatlantic recoveries of this species (Nisbet and Safina 1996) were widely spaced in different years with no apparent pattern. Lima's data led us to ask whether Roseate Terns from the Azores also spend time on the South American coast during the nonbreeding period.

STUDY AREA AND METHODS

Egg laying by Roseate and Common terns in the Azores occurs from late April to mid-July. From mid-May through early June in 1999 and 2000, a team from the Great Gull Island Project and the Azores trapped and banded adult Roseate Terns nesting on three islets in the archipelago (Fig. 1): Baixa do Moinho (39°29′N, 31°7′W), Mós (38°41′N, 27°3′W), and Vila (36°56′N, 25°9′W). Trapping on successive days whenever possible, the team set treadle traps over nests containing newly hatched Roseate Tern chicks and those that contained eggs incubated at least 18 d. The eggs were floated to determine stage of incubation (Hays and LeCroy 1971). The team banded adult and young Roseate Terns with a numbered metal band issued by the Instituto de Conservação da Natrureza in Portugal on one leg and a field-readable band (FR) on the other. FR bands are metal bands with a letter and three numbers imprinted twice on opposite sides of the band in a square pattern (Casey et al. 1995), making them easier to read in the field than bands with more digits.

In 1999 the team trapped at Mós on 29–30 May and 6–7 June, at Vila on 3–4 June, and at Baixa do Moinho on 9 June. They visited Mós in May and again in June because it was the only islet with large concentrations of terns and no signs of predation. In 2000 the team trapped at Baixa do Moinho on 21–23 May and 25 May and at Mós on 27–30 May and 2–3 June.

RESULTS

In 1999, 161 pairs of Roseate and 606 pairs of Common Terns nested at Mós. A dense concentration of Common Terns and a few Roseate Terns nested on top of the plateau at the center of the island. Seventy Roseate Terns were trapped around the base of the plateau. At Vila, 167 pairs of Roseate Terns and 181 pairs of Common terns nested. The team found pecked and partially eaten eggs at Vila and trapped three Roseate Terns there. At Baixa do Moinho, 119 pairs of Roseate Terns nested. Two pairs of Common Terns were observed on the island, but nesting was not confirmed. A delayed nesting followed by abandonment of many of the eggs at Baixa do Moinho meant that only 10 adult Roseate Terns were trapped.

In 2000, 351 pairs of Roseate Terns and 312 pairs of Common Terns nested at Mós. Roseate Terns were the predominant species nesting on top of the plateau where Common Terns nested in numbers in 1999. Roseate Tern nests around the base of the plateau had been destroyed. The team trapped 144 adult Roseate Terns at Mós. At Vila, 90 pairs of Roseate Terns and 207 pairs of Common Terns attempted to nest. Broken eggs and deserted nests were found as in 1999. A Eurasian Buzzard (*Buteo buteo rothschildi*) nested on a rocky ledge out of sight of the tern colony, and there were carcasses of adult terns near the nest. The team banded five Roseate Tern chicks, but left the islet shortly after arriving to avoid causing more disturbance. At Baixa do Moinho, 126 pairs of Roseate Terns nested, and we trapped 67 adult Roseate Terns. No Common Terns nested, and there were no abandoned nests.

Of the 83 Roseate Terns trapped in 1999, two (2.4%) were previously banded in the

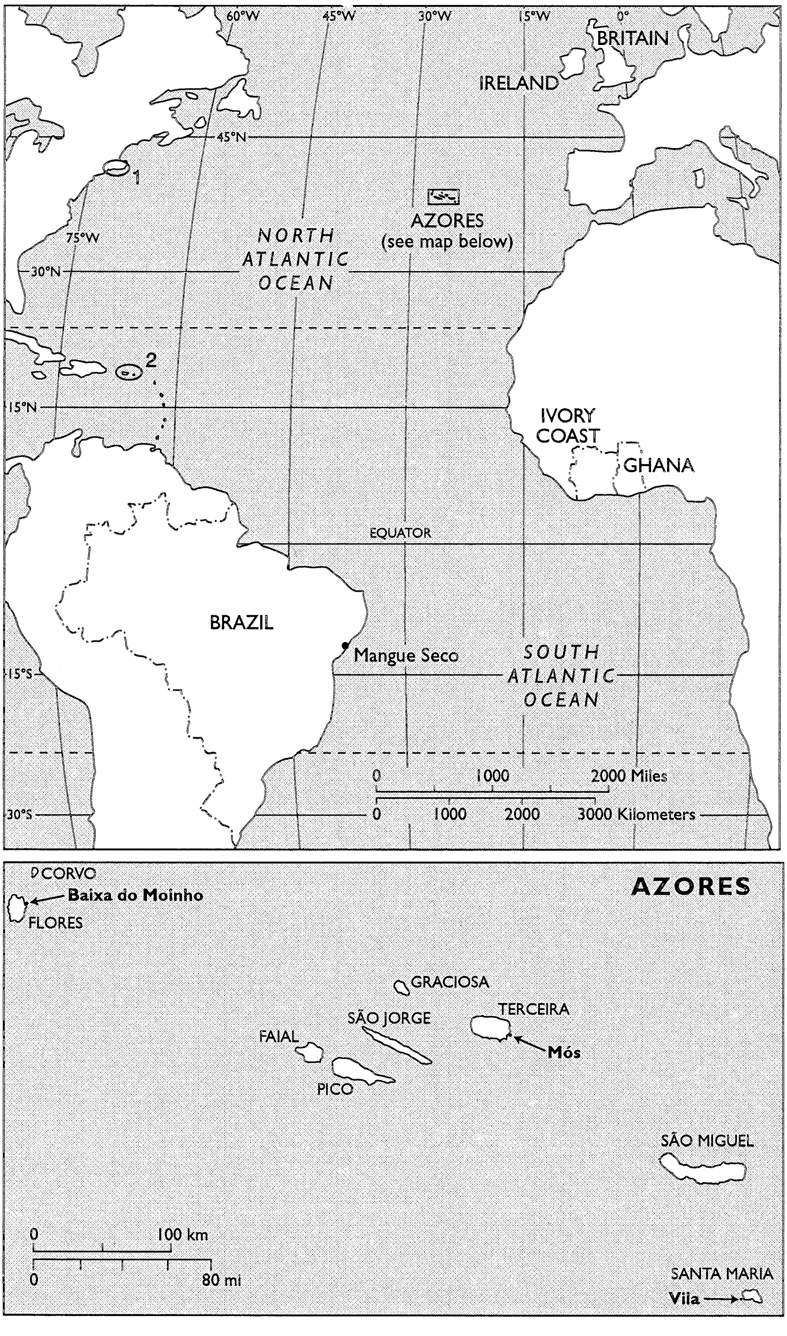

Fig. 1. Banding and recovery areas for Roseate Terns. Upper: (1) study colonies in the northeastern U.S.; (2) study colonies in the Caribbean. Lower: Islets in the Azores (bold face) where Roseate Terns were trapped.

Azores. Of the 211 Roseate Terns trapped in 2000, 20 (9%) were previously banded birds. Seventeen (85%) of these were birds banded in the Azores. The remaining three (15%) were banded outside the Azores and are of particular interest.

One bird, C04286, trapped on 25 May 2000 at Baixa do Moinho, was banded on 20 October 1999 at the Songor Ramsar Site, Ghana, by Jan Veen and Yaa Ntiamoa-Baidu. A second bird, 1172-38015, trapped at Mós on 3 June 2000, had been banded on 3 February 2000 on a sandbar off Mangue Seco, Bahia, Brazil, by Pedro Lima and a Great Gull Island team. The third bird was trapped on 25 May 2000 at Baixa do Moinho. It wore two plastic bands, a yellow on the right leg and a white on the left. The bands appeared to be Darvic bands, a particular type of butt-end plastic band, and the ends of the bands had been heat-sealed (Nisbet 1991; Spendelow et al. 1994). The bird had no numbered metal band.

DISCUSSION

The adult Roseate Tern banded in Ghana and trapped on a nest in the Azores is consistent with Azores birds moving to the coast of Ghana during the post-breeding period (del Nevo et al. 1993). This is the first report of an adult Roseate Tern captured during the post-breeding period on the coast of Ghana and later trapped on a nest in the Azores.

The Roseate Tern banded in Brazil in February 2000, then trapped on a nest in the Azores in May, suggests that at least some Roseate Terns nesting in the Azores spend time during the nonbreeding season on the coast of South America. Nisbet and Cabot (1995) reported the first record of transatlantic movement by a Roseate Tern, a bird in a Massachusetts colony that had been banded in Ireland. This bird could have crossed the Atlantic directly from Ireland or taken a more southern route via Brazil and moved north from there.

As yet there are not enough recoveries or resightings of Roseate Terns from the Azores to say much about their migration patterns once they leave the archipelago. However, some Azores birds may go to Africa and some to South America. It is also possible that birds from the Azores first move to the African coast, where they have been seen with birds from the United Kingdom and Ireland, and after December move offshore, some making the transatlantic flight to South America. Hays et al. (1997) described a difference in the nonbreeding distributions for first-year and adult Common Terns along the South American coast. This may also be characteristic of Roseate Terns during the nonbreeding period in the eastern Atlantic.

The Roseate Tern trapped at Baixa do Moinho wearing only Darvic bands is clearly distinguishable from Roseate Terns color-banded in the Azores, France, Ireland, and the United Kingdom where wrap-around plastic bands are used (A. del Nevo, pers. comm.; N. Ratcliffe, pers. comm.). Its heat-sealed plastics match those used on Roseate Terns in the northeastern U.S. (Spendelow et al. 1995; Nisbet and Spendelow 1999) and in the Virgin Islands; banders in these locations began heat-sealing the ends of the plastic bands in 1989 (Nisbet 1991; Spendelow et al. 1994; J. Pierce, pers. comm.). Nearly all Roseate Terns marked in the metapopulation study and in the Caribbean were trapped on nests; thus, it is likely the bird at Baixa do Moinho was originally banded on a nest in a western Atlantic colony. This recovery suggests the possibility of gene exchange between the two areas.

The banded Roseate Terns from different continents trapped in the Azores and reports of Azores birds in other European colonies (del Nevo et al. 1993; Newton and Crowe 2000) underline the importance of banding and observing this species on both sides of the Atlantic. Is there gene exchange between eastern and western Atlantic populations and between these populations and the Azores? To answer these questions it is critical to define further the movements of Atlantic Roseate Terns by continuing to trap and band birds in their breeding colonies and also at roosting sites in the southern hemisphere.

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Recovery in Punta Rasa, Argentina of Common Terns Banded in the Azores Archipelago, North Atlantic

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Abstract.—We report the southernmost recoveries of Common Terns (*Sterna hirundo*) banded in the Azores archipelago, North Atlantic. Two birds banded as chicks and one bird banded as an adult were recovered at Punta Rasa, Argentina, adding support to the hypothesis of a regular movement of Common Terns between the Azores and the South American coast rather than to the African coast. *Received* 14 November 2001, accepted 25 April 2002.

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There have been four trans-Atlantic recoveries of Common Terns (*Sterna hirundo*) banded in North America (Nisbet and Safina 1996). These birds were recovered over a long period of time and may not indicate a regular pattern of movement by this species across the Atlantic. In contrast, recoveries on the coast of Brazil of Azores Common Terns, as well as recoveries in the Azores (birds trapped on nests) of birds originally banded on the coast of Brazil (Hays *et al.* 1999) indicate movement of the species between the Azores and the coast of Brazil, a distance of about 4800 km. Since then, the number of Common Terns banded in the Azores and later recovered on the South American coast has quadrupled (H. Hays, pers. comm.), supporting the suggestion that there is regular movement by this species between the two areas (Hays *et al.* 1999).

Here we report the first recoveries of Azores Common Terns from the coast of Argentina. From 1999 to 2002, R. E. B. recaptured three Common Terns that had been originally banded in the Azores: G003966, recovered on 14 February 1999, G002698, recovered on 11 November 2001 and G011704, recovered on 16 January 2002. The late Dr. Luís Monteiro banded the first two birds as chicks in 1993 on Vila islet, Santa Maria Island, Azores (36°55'N, 25°10'W). The third bird was banded as an adult on Mós islet, Terceira Island (38°41'N, 27°03'W), in 2000 by Great Gull Island Project researchers.

In the Azores, banding of Common Terns began in 1984 but relatively few birds have been banded in the last 18 years: 1,777 young and 225 adults. In Argentina, R. E. B. began netting annually at Punta Rasa, Buenos Aires Province, Argentina (36°18'N, 56°46'W) in 1996 (Hays *et al.* 1997). He has netted on a few nights each month from November through April, giving a total of 20-25 nights for the six-month period each year. Between 1996 and 2002, he netted 3,590 Common Terns, of which 590 were recoveries.

R. E. B.'s second recovery of an Azores Common Tern at Punta Rasa on 11 November constitutes an early recovery date. Although some recoveries of Common Terns have been made in November between latitudes 30°-40°S, the majority have been recovered after November (Hays *et al.* 1997). If this Common Tern came from the Azores in 2001, the date suggests the possibility of a direct flight from the Azores archipelago to the South American coast.

Many Britain Common Terns have been recovered wintering all along the West African coast (Langham 1971; Cramp 1985); however, no Azores Common Tern has been recovered there. It is probably too early to rule out the African coast as a stopover point or wintering area for some Azores Common Terns because the current sample of recoveries is still small and relatively few Common Terns have been banded in the Azores. In addition, recoveries on the west coast of Africa of European banded Common Terns and Common Tern recoveries on the east coast of South America have been collected differently. In Africa, most recoveries have been made by youths in Ghana and Senegal using baited hooks or nooses to catch terns for sport, food or income (Dunn and Mead 1982; Stienten *et al.* 1998). In South America, netting programs like R. E. B.'s continuing program in Argentina as well as netting programs in Brazil at Lagoa do Peixe, Rio Grande do Sul in the 1980's (Harrington *et al.* 1986) and Lima's program at Mangue Seco, Bahia (Hays *et al.* 1999) have sampled large roosting concentrations for a number of consecutive years. Although all recoveries to date of Common Terns banded in the Azores have been from the east coast of South America, further work may show that some of the Azores Common Terns move to the west coast of Africa, as do Azores Roseate Terns *Sterna dougallii* (Hays *et al.* 2002).

Azores Roseate Terns have been recovered both on the West African coast (Ghana and Abidjan) and in South America (Brazil) (Hays *et al.* 2002). However it is not known if some of these birds fly to Africa and some to South America, or if they first move to the African coast and then make the trans-Atlantic flight to South America (Hays *et al.* 2002). A recovery of a Roseate Tern originally banded in Ireland on the coast of Bahia, Brazil (Hays *et al.* 2000) raises the question as to whether some of the birds banded in the British Isles may also regularly move to the South American coast during the nonbreeding season. Trans-Atlantic recoveries of Roseate Terns from the wintering season are extremely rare and only one transatlantic recovery has been reported during the breeding season (Nisbet and Cabot, 1995).

Given that up to four Azores Common Terns have been recovered in each year since 1996 on the coast of Brazil (H. Hays, pers. comm.), and now three from Argentina, it is possible that a majority of Azores Common Terns move to the South American coast for the period November to March. Hays *et al.* (1997) described Punta Rasa as the most significant wintering area in Argentina and perhaps anywhere in South America for Common Terns from North America. Interestingly, Hays *et al.* (1997) also noted that all Common Terns recovered at Punta Rasa were over one year old, suggesting that older birds may occupy the more southern parts of the wintering range. The Azores birds recovered in Argentina were 5.5, 7.5 and >3 years old. It is possible that older birds from the Azores also move further south than the younger birds during the nonbreeding period, but more recoveries are needed to test this hypothesis.

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