Predation on roseate tern eggs by European starlings in the Azores

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Predation by the European starling (*Sturnus vulgaris*) was the main reason for roseate tern (*Sterna dougallii*) hatching failure on Vila islet, Azores, one of the species' largest colonies in Europe. Observations showed that single or small groups of starlings were responsible for predation events and that tern nest defence against starlings was generally ineffective. Daily nest survival rate was 94.2% in 2002 and 90.0% in 2003. Nesting success was estimated using a simulation model that allowed for renesting following failure and was 0.42 in 2002 and 0.17 in 2003. These values are considerably lower than the 0.97 nesting success at Rockabill, Ireland, one of the main European colonies, for the period 2000-2003. The sensitivity and importance of the roseate tern population in the Azores are discussed in relation to predation. Management strategies to reduce predation could include non-lethal control of starlings, destruction of starling nests and prevention from nesting in the vicinity of tern colonies.

Key words: *Sterna dougalli*, egg-predation, Mayfield method, nest survival rate, Santa Maria

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INTRODUCTION

Predation can have a profound impact on seabird breeding success and may reduce survival rates or productivity to levels below those required to maintain viable populations (Whittam & Leonard 1999). Special concern has been expressed regarding predatory species whose numbers have increased because they benefit from human activity (e.g. gulls, crows, rats and starlings). Predation at tern colonies has been widely reported (Craik 1995; Guillemette & Brousseau 2001; references below).

In the case of the endangered roseate tern (*Sterna dougallii*) losses of up to 77% of chicks have been reported as a result of avian predator activities (Whittam & Leonard 1999). At Rock-abill, Ireland, one of the main roseate tern European colonies, impact severity varies among years, with occasional predation on incubating adults but the greatest impact is on eggs and chicks (Newton & Crowe 2000; Newbery 199). Predation and human disturbance are generally the most important factors limiting breeding success in roseate terns throughout the range of this species (Nisbet 1981).

Predators of roseate terns include birds such as black-crowned night heron (*Nycticorax nycticorax* (Spendelow 2003), falcons (*Falco peregrinus, F. tinnunculus* and *F. sparverius*) (Nisbet 1992; Newton & Crowe 2000; Shealer & Burger 1992), sparrowhawk *(Accipiter nisus)* (Newton & Crowe 2000), great-horned owl (*Bubo virginianus*), American oystercatcher (*Haematopus*

palliates) (Saliva 1995 in MSRP 1999), herring, great black-backed and laughing gull (*Larus argentatus, L. marinus* and *L atricilla*) (Nisbet 1981; Whittam & Leonard 1999; Shealer & Burger 1992), 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), red fox (*Vulpes vulpes*), and badger (*Meles meles*) (Newberry 2002). Additionally, some species of ants (e.g. *Solenopsis invicta*) may kill young terns when eggs are pipping or soon after hatching (MSRP 1999). In some years ant predation accounted for as much as 33% of roseate tern chick mortality (Spendelow 1982) in the North-eastern United States. Hatchling mortality due to ant predation has also been observed in the Azores but its importance is negligible (V.C. Neves, pers. obs.).

During the last few years, the mixed common tern (*Sterna hirundo*) and roseate tern colony on Vila islet (Santa Maria Island, Azores archipelago, North-eastern Atlantic) has been affected by increasing rates of egg predation (V.C. Neves, pers. obs.). Predation was noted on the islet when annual monitoring was initiated in 1989, and Adrian del Nevo counted 154 roseate tern nests and found "several eggs predated" (IMAR-Açores unpublished data). Monteiro et al. (1996) mention "minor episodes of presumed European hedgehog (*Erinaceus europaeus*) predation on tern eggs on Vila islet". However, hedgehogs were never found at Vila and it is possible that European starlings (*Sturnus vulgaris*) were 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 (V.C. 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 common buzzards (*Buteo buteo rothschildi*) was also nesting on the islet and regularly took large chicks and adult terns, but it was not suggested that buzzards ate eggs. On another island of the archipelago (Flores), Ramos & del Nevo (1995) observed a grey heron (*Ardea cinerea*) depredating eggs and chicks. Recently, Amaral et al. (2010) found that black rat (*Rattus rattus*) predation lead to colony desertion on Feno islet (Terceira).

Additional potential tern predators in the Azores include little egret (*Egretta garzetta*), cattle egret (*Bubulcus ibis*), yellow-legged gull (*L. michahellis atlantis*), turnstone (*Arenaria interpres*), short-eared owl (*Asio otus*), cats (*Felis catus*) and mustelids (weasel *Mustela nivali*s and ferret *M. furo*).

Ramos & del Nevo (1995) concluded that in the early 1990s the role of predation on tern colonies was insignificant as a factor affecting nest-site selection by terns. However, the seemingly increasing rates of predation observed on Vila islet in recent years are presumed to have serious adverse effects on the tern population from the Azores, since Vila islet holds one of the most important tern colonies in the archipelago (20% of the roseate tern population in 2002) (Neves 2006).

Estimating productivity of roseate terns in the Azores and assessing the impact of nest predation is of particular importance to conservation and management plans. 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 on Vila islet.

MATERIAL AND METHODS

STUDY AREA

Vila islet is a rocky islet of basalt, with steep slopes and cliffs, located about 300 m southwest of Santa Maria Island (36º55'N, 25º10'W). 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 is a Special Protected Area (SPA) and holds a mixed colony of common and roseate terns (Monteiro 2000). A pair of common buzzards regularly breeds on a cliff on the east side of the islet (Monteiro 1996) and there are no mammalian predators. Egg laying of roseate terns in the Azores normally occurs between early May and late June (Ramos & del Nevo 1995; Hays et al. 2002).

To identify the main predators during egg-laying and incubation, 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 of the colony up 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 parts of the colony. Observations were made with naked eye and with binoculars (Swarovski, 7×50). 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 13 days between 14 and 26 May, totalling 37 hours of observation. During the observations we noted the presence and abundance of predators in the colony and the reaction of terns to their presence.

DAILY NEST SURVIVAL RATE

Both common and roseate terns breed on the islet, but only roseate tern nests 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 clutch size was recorded in each nest; nest fates were then determined by visits every 1-5 days. In 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 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).

NESTING SUCCESS

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. Later in the season the probability of renesting decreases to zero. Estimates of productivity based on the fate of individual nesting attempts will therefore be underestimates. We used a simulation model allowing for renesting to calculate nesting success, based on the structure of those used by Beintema & Muskens (1987), Green (1988) and Green et al. (1997). Nesting success is the probability of a pair of birds hatching at least one chick in a breeding season. This differs from hatching success, which is generally regarded as the probability of a nesting attempt hatching at least one chick and ignores renesting. The model was parameterised with estimates obtained from this study, from studies at Rockabill (S.F. Newton pers. comm.) and those extracted from the literature.

Females were randomly allocated a start date (the date on which incubation of the first clutch starts) and a stop date (the date after which further clutches are not laid) from a frequency distribution calculated from the parameter's 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 start on 4 May (SD 6 days) and end on 29 June (SD 7 days): a duration of 56 days.

The nesting season was then shortened by one-day increments until its duration was only one day. The actual nesting season duration would be sure to lie between these values (that on Rockabill was 29 days), which enabled us to determine the range of values in nesting success.

Clutch size was assumed to be two eggs 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 (26 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% (Ratcliffe et al. 2004) 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 considered as hatching a chick. In this event, one was added to the number of pairs experiencing nesting success.

Pairs that did not hatch a chick from their nesting attempt owing to predation, or abandonment were allowed 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 lost the whole clutch to addling or infertility were assumed to continue incubating for another 10 days before abandoning it, with the nest being subjected to the same daily nest survival rate as nests containing viable eggs through this period.

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

RESULTS

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 on the islet and could have been undetected as predators.

Observations of predation events showed that single starlings or small groups of up to 6 individuals were responsible for egg predation. Starlings wandered and foraged 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 eat it. 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 a few 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 them. In a few predation events the egg contained a large embryo, and was left by the starling without being eaten.

Terns did not fear starlings and did not take any defensive action to deter them, even when starlings were standing at distances as small as 30 cm from an incubating bird. Individual terns would sometimes mob starlings but normally only when the latter were approaching their nests at a time no bird was incubating. However, starlings seemed quite persistent even when they were mobbed, and many returned to exactly the same place they were foraging seconds before.

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. When one egg was depredated out of two, the tern would continue to incubate the second, but the latter would usually be depredated later. From 30 two-egg clutches that were predated, the second egg survived in only four cases. The two eggs would either be depredated simultaneously (starlings sometimes broke the second egg without

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finishing eating the first one) or within a few-hour interval (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 actively distressing a Kentish plover (*Charadrius alexandrinus*), which performed the broken wing behaviour but predation of the eggs was not confirmed.

A pair of yellow-legged gulls was breeding on a cliff on the west coast of the islet in 2002 and 2003; 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 found no evidence that they were predating tern eggs. Gulls were never observed landing near tern nests but they were observed trying to steal fish from flying terns on several occasions (never successfully). Gulls are also causing additional disturbance by 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.

DAILY NEST SURVIVAL RATE

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 re-scaling the deviance for overdispersion ($F_{1, 236}$ = 5.79, P < 0.03, Scale parameter = 2.79). The daily 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 24-day average incubation period, the predation rate in 2002 was 76.2% and in 2003 was 92.1%.

NESTING SUCCESS

The nesting success of roseate terns in 2002 and 2003 is presented in Fig 1. The nesting season on Rockabill lasts 29 days, and if in the Azores the duration is similar the nesting success in 2002 would be 0.42 and that in 2003 would be 0.17. That means that in 2002 a pair of birds had 42% chances of hatching at least one chick and in 2003 that was only 17%.
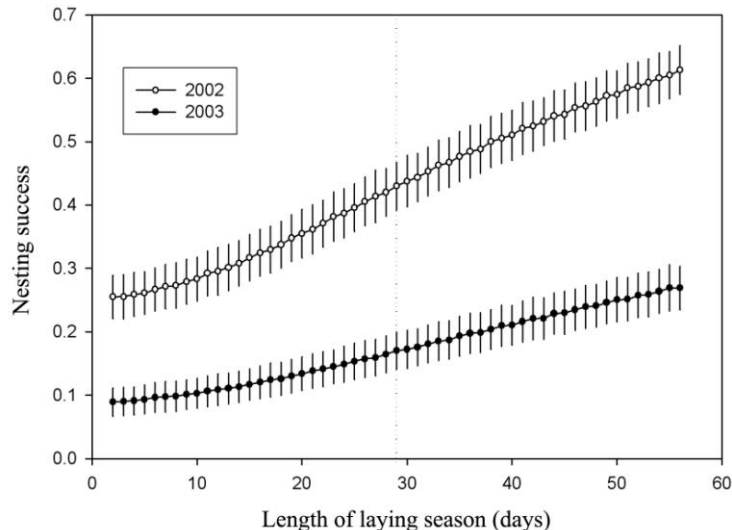

Fig 1. Relationship between the length of the nesting season and nesting success of roseate terns in the Azores. Nesting success is the probability of a pair of birds hatching at least one chick in a breeding season. The dotted line is the average length of the nesting season on Rockabill, Ireland.

DISCUSSION

FACTORS CONTRIBUTING TO THE EMERGENCE OF THE PREDATORY BEHAVIOUR

European starlings were first reported breeding on 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, four to five in number" (Hartert & Ogilvie-Grant 1905). They are also known to roost on the islet (V.C. Neves pers. obs.). During 2003 we estimated that Vila islet holds about 50 breeding pairs and can hold as many as 500 roosting individuals.

Starlings tend to roost up to 200 m above sea level (Feare 1984); in the Azores they commonly roost on remote sea cliffs and on islets (V.C. Neves pers. obs.) and their roosting areas overlap with tern breeding areas. However, 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 that several hundreds of starlings roost on the islet and the adjacent coast. However, breeding of European starlings on 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. In recent years, egg predation was also detected on Praia islet (off Graciosa) but it is unclear if it was caused by starlings, turnstones or any other undetected predator.

STARLINGS AS PREDATORS OF SEABIRD EGGS

Predation by the European starling on eggs of Arctic terns (*Sterna paradisaea*) breeding on the Farne Islands, Northumberland, UK has been reported by several authors (Cullen1956; Gill 1968; Horobin 1971). Cullen (1956) first reported starlings "breaking, opening and drinking" the contents of Arctic tern eggs on Inner Farne. Gill (1968) found that starlings predated 42% of the eggs, a rate of predation, which compares well with the values found in this study. We assume that most egg predation at Vila islet has been caused by starlings because of the way the eggs were broken and also because we have not ob-

served any other predators in the islet apart from gulls. Gulls do not break the eggs like starlings but eat the whole egg. Later, Horobin (1971) also reports low values of hatching success on Inner Farne due mainly to egg predation by starlings (1966=44.4%, 1967=47%; 1968=15.6%). In recent years there has been a decline in Arctic tern numbers on the Farne Islands, but this has been attributed to declining food availability (Mitchell et al. 2004).

In the Pacific Ocean, Micronesian starlings (*Aplonis opaca*) were observed eating black noddy (*Anous minutus*) 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 observed by Reichel & Glass (1990) who report that groups of 2-5 Micronesian starlings were present at the nest during predation events.

On Ascension Island, common mynahs (*Acridotheres tristis*, closely related to starlings) are known to eat abandoned sooty tern eggs and they have also been observed disturbing incubating birds and predating 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, common mynahs will also take eggs and chicks of the St Helena plover (*Charadrius sanctahelenae*) (Hayman et al. 1986).

DEFENCE BEHAVIOUR OF TERNS

At the Vila colony, groups of up to 40 terns mob buzzards and gulls but starlings are never mobbed by more than a single bird. Terns do not seem to consider starlings as a real threat and show no reaction to starlings wandering amongst nests, unless they come very close or approach temporarily unattended nests. In another study, incubating terns failed to recognise the turnstone as a predator, no matter how closely turnstones 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's morphological and behavioural features that trigger nest defence.

Gill (1968) found a trend towards less predation at higher densities. He also noticed that the "passive" behaviour of Arctic terns sitting tight during incubation was an effective counter to starlings. In two occasions, however, he 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.

RESEARCHER DISTURBANCE

The presence of a human intruder could be a behavioural key, which triggers the flocking, and foraging response in individual birds (Reichel & Glass 1989). These authors considered that starling predation, in conjunction with human disturbance, could be a substantial factor reducing black noddy 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 the nest. Nevertheless there is no easy way of studying predation and simultaneously evaluating the impact made by the presence of observers.

PREDATOR CONTROL AND OTHER FORMS OF MANAGEMENT

Vila islet is one of the least disturbed Azorean colonies regarding human disturbance. Even when the islet is visited by fishermen they normally stay on the lower rocky coast and do not climb to the plateau where the terns breed. However despite its isolation and apparent undisturbed state, Vila colony has a natural predation factor, which induces high clutch losses and requires conservation management. The values of nesting success estimated in this study, 0.42 in 2002 and 0.17 in 2003, are considerably lower than the 0.97 nesting success on Rockabill over the period 2001-2003. Predator control has long been considered necessary for the survival of the Northeastern American population of roseate terns

(Nisbet 1981) and many studies have reported on the implementation and /or the results of management strategies in tern colonies. 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 they can drive away any gulls that attempt to nest near them (Morris et al. 1992; Whittam & Leonard 1999; Guillemette & 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.

According to Nisbet (1981) predation lowers regional production of terns in north-eastern America by no more than 20-25%. The predation rates found in this study are also considerably higher than the 24% of tern eggs eaten, presumably by corvids, reported by Whittam & Leonard (1999). 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. Avery et al. (1995) suggested that non-lethal control using taste aversion might be an effective method for managing egg predators at tern colonies. This technique was tried at Vila islet but proved unsuccessful to deter starlings from eating tern eggs (Neves et al. 2006). Therefore, lethal control should be used carefully and directed exclusively at individuals predating the eggs.

ACKNOWLEDGEMENTS

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