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V. C. Neves · S. Panagiotakopoulos · R. W. Furness

A control taste aversion experiment on predators of roseate tern (*Sterna dougallii*) eggs

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Abstract European starlings (*Sturnus vulgaris*) are responsible for high rates of egg predation at one of the main colonies of the endangered roseate tern (*Sterna dougallii*) in the Azores archipelago. Control taste aversion has been effective in controlling raven predation in a colony of California least tern (*Sterna antillarum browni*), but there is little quantitative information about its efficacy on other species of predators taking eggs. We conducted a control taste aversion experiment on yellow-legged gulls (*Larus michahellis*) and European starlings eating eggs of terns in a mixed colony of common (*Sterna hirundo*) and roseate terns in the Azores. We treated quail (*Coturnix coturnix*) eggs with methiocarb and deployed them in artificial nests in the tern colony. On the first experiment, conducted before the terns laid eggs, predation rates on quail eggs by yellow-legged gulls showed significant and rapid decrease after deployment of treated eggs. During the second experiment, after the terns had started laying, results were mixed. Although predation rates by European starlings on treated quail eggs decreased, predation rates on tern eggs did not. We conclude that control taste aversion using methiocarb-treated eggs is likely to reduce depredation by gulls but not starlings because of the need to pre-train the birds and the tendency of starlings to be attracted by the movement of adults, not the presence of nests.

Keywords Azores · Egg predation · European starling (*Sturnus vulgaris*) · Control taste aversion · Methiocarb · Yellow-legged gull *Larus michahellis*

V. C. Neves · S. Panagiotakopoulos · R. W. Furness (✉)
Institute of Biomedical, and Life Sciences,
Graham Kerr Building, University of Glasgow,
Glasgow, G12 8QQ, UK
e-mail: r.furness@bio.gla.ac.uk
e-mail: neves_veronica@yahoo.com
e-mail: sotpan@hotmail.com

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 (*Sterna 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* (predation rates were 73.1 and 90.2% in 2002 and 2003, respectively; from Neves, unpublished data). Gulls are also well-known predators of tern eggs and chicks at a wide variety of sites (Burger and Gochfeld 1994; Becker 1995; Yorio and Quintana 1997; Whittam and Leonard 1999; Guillemette and Brousseau 2001; Hernández-Matías and Ruiz 2003; O'Connell and Beck 2003). In the Azores, there are several tern colonies in close proximity to gull colonies, but the impact of gulls as predators was not 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 toxicant 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) conditioned animals act as deterrents for other potential predators in the case of territorial predators (Avery et al. 1995).

Bird repellent products containing methiocarb [3,5-dimethyl-4-(methylthio)-phenyl methylcarbamate; Mesurol] were widely used in the USA and Europe (Crocker and Perry 1990) and were shown to be highly efficient as feeding deterrents (Avery and Mason 1997; Clark and 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 and 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. The 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 before 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 and Decker 1994).

The persistence of the aversions varied from 14 days (Nicolaus and Nellis 1987) to a year (Dimmick and Nicolaus 1990). In some cases, the aversion was generalised toward eggs that did not look like treated eggs (Nicolaus et al. 1989), whilst 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 control taste aversion (CTA) in wildlife management, can only be answered in the field (Cowan et al. 2000).

Materials and methods

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 within Portugal (IBA 014) and holds a mixed colony of common and roseate terns. It also includes the only known breeding pair of sooty tern (*Sterna 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 and del Nevo 1995).

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 3 days to make sure that the chemical retained its potency (Avery et al. 1995). Because it was not possible to have a control group, we decided to deploy untreated quail eggs for the first 3 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. In addition, we conducted observations from the top of the islet or from a hide situated 10 m away from the nests three times daily (morning, mid day and late afternoon), 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 24 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 2 days when they were checked four times instead of five due to very bad weather conditions. At the time the experiment was being conducted, terns were not yet breeding; therefore, the fact that we were checking nests so frequently did not constitute a source of disturbance. 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 and 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 because the magnitude of the conditional avoidance response is generally positively related to the magnitude of the illness (Sayre and 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, and we assumed that all eggs taken were being consumed. At one occasion, we observed that five 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/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 6 h of observations would be conducted daily, but very poor visibility (up to a few meters) made the conduction of observations almost impossible on several days.

Deployment of quail eggs was continued for a total of 9 days, and during that time starling activity in the islet remained negligible, whilst 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 to try to modify their feeding behaviour. We deployed 18 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. To minimise disturbance to the terns, we deployed the treated eggs slightly away from terns' main breeding areas. However after 2 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 each other. We checked the nests twice daily by walking up to the nests, once in the morning (at 10:00 hours) and once in the evening (at 18:00 hours), except in one case, when we checked them only in the morning. We reduced the number of nest checks from five to two to minimise 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 13 days (14/05–26/05) and a total of 37 h 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, whilst the following two batches contained 22.5 mg/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.

Results

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 to 2.5 eggs/day when methiocarb was used. Figure 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

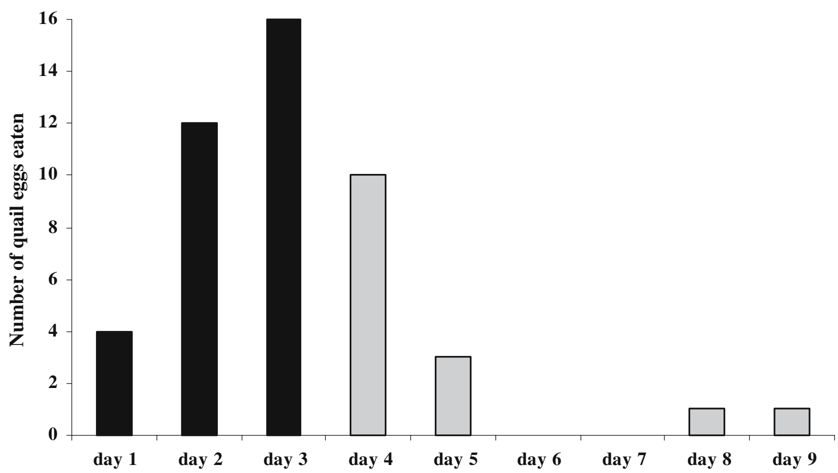

Fig. 1 Experiment 1. Gull daily predation rate. *Black* untreated eggs, *grey* methiocarb-treated eggs

methiocarb, the rate of predation fell rapidly to 0–1 egg/day (Fig. 1).

Predation was recorded at all time intervals, but gulls seemed to take eggs especially from 13:00 to 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 6 h of sunlight from 18:00 to 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 3 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.

Experiment 2

Whilst 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 weren't 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 were 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; therefore, we calculated daily predation rate percentages to allow comparisons to be made between days (see Fig. 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 days 1 to 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/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 (11.25 and 22.50 mg)

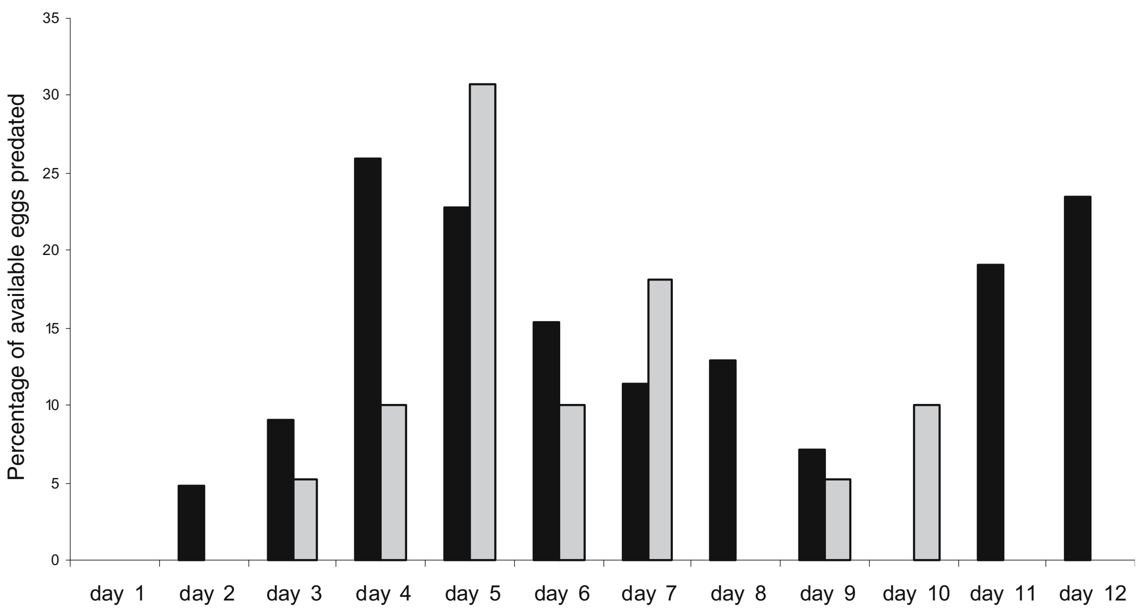

Fig. 2 Experiment 2. Starling daily predation rate percentages. *Black* roseate tern eggs, *grey* methiocarb-treated quail eggs (days 1–6, 11.25 mg methiocarb/egg; days 7–12, 22.50 mg methiocarb/egg)

was significantly different ($X_1^2 = 11.04$, $p<0.01$ and $X_1^2 = 4.91$, $p<0.05$, respectively, both with Yates correction).

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 2 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, which means 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 sub-lethal 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. In addition, 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 2 days of the experiment when eggs were deployed with some distance to the roseate tern nests to minimise 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 and 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 were 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 and Clark 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 before 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 in attracting starlings to the quail eggs because, as seen above, starlings did not take quail eggs when they were deployed before terns started breeding.

Researcher disturbance

Nisbet (2000) states that there is little scientifically acceptable evidence that human disturbance causes substantial harm to terns. 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 predators (Reichel and Glass 1990). 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. Because 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 observers' impact on it.

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, personal observation). Because available breeding habitat for the roseate tern in the Azores is apparently limited, management efforts should focus on maintaining already established tern colonies. Vila islet is one of the main colonies and it is crucial to ensure its suitability for the terns. The problem of starling predation might be better dealt with if several measures are used together. The present study suggests that measures other than 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 nest boxes for the terns, control of vegetation cover and stricter law enforcement with regard to human disturbance at the colonies.

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