

Rapid shift in clutch size distribution of white-cheeked terns *Sterna repressa* following feral cat removal on Shidvar Island, Persian Gulf

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SUMMARY

Mammalian predators present a threat to ground-nesting seabirds. In 2021, 17 feral cats were unintentionally introduced to Shidvar Island, a protected seabird breeding island in the Persian Gulf. Fourteen individuals were removed through live-trapping in 2021, and the remaining three were captured using foot snares in autumn 2022. Follow-up monitoring over eight months detected no further evidence of cats on the island. We compared clutch size distribution of white-cheeked terns (*Sterna repressa*) across three conditions: prior to cat introduction (2014), during residual predator presence (2022), and following complete removal (2023). Clutch size frequencies differed significantly among years (χ^2 test, d.f. = 6, $p < 0.001$). In 2022, when three cats remained present, one-egg clutches comprised 74.7% of nests ($n = 1,052$). In 2023, the first breeding season after complete removal, two-egg clutches comprised 77.7% of nests ($n = 1,254$), closely resembling the 2014 distribution. The rapid redistribution of clutch sizes following removal suggests that even a small number of introduced predators may influence reproductive patterns in ground-nesting seabirds. Continued monitoring will help determine whether this pattern persists under predator-free conditions.

BACKGROUND

Invasive mammalian predators are among the leading drivers of biodiversity loss on islands worldwide, where native species often evolved in the absence of terrestrial predators and therefore exhibit limited defensive adaptations. Feral cats *Felis catus* are particularly widespread and have been implicated in population declines and local extinctions of island vertebrates, especially birds (Medina *et al.* 2011, Nogales *et al.* 2013). Ground-nesting seabirds are particularly vulnerable because their nests are exposed and typically located on open substrates, making eggs and chicks easily accessible to introduced predators (Spatz *et al.* 2014, Greenwell *et al.* 2019). As a result, predator eradication has become a widely implemented conservation strategy on seabird breeding islands globally.

Seabird breeding islands in the Persian Gulf and wider Middle East support regionally important colonies of terns and other coastal species, many of which nest at high densities on small, low-lying islands. These systems are ecologically sensitive and can be strongly influenced by even small changes in predator presence. Despite the global documentation of invasive mammal impacts on island biodiversity (Spatz *et al.* 2014), relatively few

published case studies describe predator introduction and subsequent removal in seabird colonies within the Persian Gulf region. Where eradication has been implemented elsewhere, substantial conservation gains have frequently been reported (Jones *et al.* 2016).

Most studies evaluating the effects of mammalian predator control on seabirds, including those synthesised in the Conservation Evidence database (Williams *et al.* 2019), report improvements in reproductive success, survival, or population recovery following predator removal (Cooper & Fourie 1991, Keitt & Tershy 2003, Ratcliffe *et al.* 2010). Although breeding success provides a more direct measure of reproductive outcome, clutch-size distribution can also provide a useful early indicator of changes in nesting conditions, especially on remote seabird islands where repeated nest monitoring may be logistically difficult or may increase disturbance. In predator-sensitive colonies, recorded clutch contents may reflect both reproductive investment and egg loss before survey, making this measure relevant but requiring cautious interpretation. Less attention has been given to potential shifts in clutch-size distribution under changing predator presence

conditions. Published information on clutch-size distribution in white-cheeked terns remain limited, particularly for breeding colonies in the Persian Gulf. However, available data from the Egyptian Red Sea suggest that two-egg nests can be common in this species, although comparisons among regions should be interpreted cautiously because colony conditions, survey timing, and field methods may differ (Habib 2022).

Furthermore, few systems provide clearly documented timing of predator introduction and complete removal alongside pre-introduction baseline data. The unintentional arrival of feral cats on Shidvar Island in 2021, followed by documented complete removal in 2022, provided an opportunity to examine clutch size distribution across distinct predator states. This study therefore evaluates changes in clutch size of white-cheeked terns before, during, and after feral cat presence on a protected seabird breeding island in the Persian Gulf.

ACTION

Site context and unintended predator introduction

Shidvar Island (also known as Maru) (Figure 1) is a 98-ha uninhabited island in the Persian Gulf, Hormozgan Province, Iran (26°47'N, 53°25'E). The island is designated as an internationally important wetland under the Ramsar Convention and is legally protected during the seabird breeding season, when public access is restricted by the Iranian Department of Environment. Shidvar supports a large breeding colony of white-cheeked terns which nest directly on open sandy substrates across the island.

In 2021, seventeen feral cats were unintentionally transported to Shidvar Island from a nearby inhabited island during a separate animal control operation. Because the island lacks permanent human settlement and had no established terrestrial predator population prior to this event, the sudden presence of feral cats raised immediate concern for the conservation of the ground-nesting seabirds. In coordination with the Hormozgan Department of Environment, a removal operation was initiated to eliminate the introduced cats and reduce potential predation pressure on nesting white-cheeked terns.



Figure 1. Location of Shidvar Island in the Persian Gulf, southern Iran. Panel A shows the regional context within the Middle East. Panel B shows the location of the island within the Persian Gulf.

Initial live-trapping removal (2021)

Following confirmation of the cats' presence, a rapid response removal operation was initiated. The objective was to remove the introduced individuals as quickly as possible while minimising additional disturbance to nesting seabirds.

Twelve baited live cage traps were deployed across areas where cat activity had been observed. Trap locations were selected based on signs of movement and accessibility and were distributed to maximise island-wide coverage. All traps were checked at least once every 24 hours to ensure animal welfare and to reduce stress in captured

individuals. Captured cats were removed from the island immediately after detection.

Through this operation, 14 of the 17 introduced cats were successfully captured and removed in 2021. Despite sustained trapping effort, three individuals consistently avoided capture, suggesting trap avoidance behaviour or limited interaction with baited cages. Because three individuals remained after sustained trapping effort, a second, more targeted operation was planned for the following year.

Targeted foot-snare operation (November 2022)

Because three cats remained on the island after the initial live-trapping effort, a second, more targeted removal operation was conducted in autumn 2022. The timing of this intervention was selected to avoid the peak breeding season of white-cheeked terns, thereby minimising disturbance to nesting seabirds while addressing the remaining predation risk.

A team of three to five trained personnel conducted the operation over a one-week period. Three anchored cable foot snares were deployed in areas showing repeated signs of cat movement. Placement focused on likely travel routes and areas of concentrated terrestrial activity. The snares were fitted with swivels to reduce cable twisting and were secured to minimise the risk of escape or prolonged restraint. All devices were checked at least once every 24 hours to ensure humane treatment and rapid response following capture.

During this one-week operation, the remaining three cats were successfully captured. No non-target species were captured during the intervention. Following capture, individuals were safely restrained and transported by boat to Lavan Island, where they were transferred to the responsible contractor under the oversight of the Hormozgan Department of Environment. Removal procedures were conducted in accordance with local wildlife management guidelines.

To confirm the effectiveness of the intervention, follow-up monitoring was conducted over the subsequent eight months. Four field visits were carried out to assess the presence of any remaining cats on the island. Surveys focused on detecting footprints, scat, direct sightings, or other signs of terrestrial predator activity across accessible areas. No evidence of feral cats was

detected during these follow-up assessments, and the absence of further signs of cat activity was taken as confirmation that all introduced individuals had been successfully removed.

Nest survey and clutch-size recording

Nest surveys were conducted during the peak breeding period of white-cheeked terns in early July. In 2022 and 2023, field surveys were carried out over two days each year (9–11 July 2022 and 10–12 July 2023) by a five-person trained field team. Two members of this team had also participated in the 2014 census, helping to maintain consistency in field procedures across survey years. The sandy nesting areas were divided into survey zones using GPS, and observers systematically walked parallel transects approximately 20–30 m apart to provide comprehensive coverage of the nesting habitat. For each nest containing eggs, observers recorded the number of eggs (1–4) present at the time of survey. Observers also recorded empty nests and any visible signs of predation or disturbance, including eggshell remains, broken eggs, or disturbed nest contents.

Statistical analysis

Differences in clutch size distribution among years were assessed using a chi-square (χ^2) test of independence, based on frequency data for clutch size categories across survey years (2014, 2022 and 2023). The test evaluated whether the distribution of clutch sizes was independent of year. Statistical significance was assessed at $\alpha = 0.05$. All analyses were conducted using SPSS Version 27.0.

CONSEQUENCES

Clutch size distribution of white-cheeked terns differed markedly among survey years (Table 1). A chi-square test indicated a significant difference in clutch size frequencies among 2014, 2022 and 2023 ($\chi^2 = 880.53$, d.f. = 6, $p < 0.001$).

In 2014, prior to the confirmed presence of feral cats on Shidvar Island, two-egg clutches were most frequent, representing 67.2% of nests ($n = 3,068$). One-egg clutches comprised 29.4%, while three-egg and four-egg clutches together accounted for 3.2%.

In 2022, when three feral cats remained present on the island, one-egg clutches comprised 74.7% of nests ($n = 1,052$), while two-egg clutches declined

to 24.6%. Three-egg and four-egg clutches together accounted for less than 1% of nests.

In 2023, the first breeding season following complete removal of feral cats in October 2022, two-egg clutches comprised 77.7% of nests ($n = 1,254$), while one-egg clutches declined to 20.7%. Three-egg and four-egg clutches remained rare (1.6% combined).

Total nest numbers differed among years (3,068 in 2014; 1,052 in 2022; 1,254 in 2023). Despite these differences in overall nesting abundance, the proportional distribution of clutch sizes in 2022 differed substantially from both 2014 and 2023. The most pronounced proportional change occurred between 2022 and 2023, with a reversal in dominance from one-egg clutches to two-egg clutches.

Table 1. Clutch size distribution of white-cheeked terns *Sterna repressa* on Shidvar Island in 2014, 2022 and 2023. Values show the number of nests (n) and percentage (%) of total nests per year.

Clutch size	2014 n (%)	2022 n (%)	2023 n (%)
1 egg	902 (29.4%)	786 (74.7%)	260 (20.7%)
2 eggs	2,062 (67.2%)	259 (24.6%)	974 (77.7%)
3 eggs	89 (2.9%)	6 (0.6%)	17 (1.4%)
4 eggs	9 (0.3%)	1 (0.1%)	3 (0.2%)
Total nests	3,068	1,052	1,254

COSTS

The direct financial cost of the predator removal operation was approximately 900 USD. Equipment costs included 12 live cage traps and three foot-snares, each costing approximately 30 USD, giving a total equipment cost of around 450 USD. Labour costs were based on payments of approximately 10 USD per person per day. The targeted removal operation in 2022 involved three to five personnel over one week, resulting in an estimated labour cost of approximately 280 USD. Transport costs consisted of boat access to the island, at

approximately 30 USD per return trip, with multiple trips required for removal operations and follow-up monitoring, giving an estimated total of around 180 USD. Accommodation costs were covered by the Department of Environment and are therefore not included in the financial estimate. These relatively low costs reflect Iran local economic conditions and may not be directly transferable to other regions.

DISCUSSION

The clutch size distribution of white-cheeked terns on Shidvar Island changed markedly across the three survey years, with a clear reversal in dominant clutch type between 2022 and 2023. In 2022, when three feral cats remained present on the island, one-egg clutches comprised nearly three-quarters of all nests. In contrast, in 2023, the first breeding season following complete removal of feral cats carried out in October 2022, two-egg clutches became dominant and closely resembled the distribution recorded in 2014, prior to the introduction of cats. This shift was proportional rather than solely driven by changes in total nest numbers, but the mechanism underlying the pattern cannot be determined with certainty from the available data. Because nests were not followed continuously from laying onward, the predominance of one-egg nests in 2022 may reflect altered reproductive investment, partial egg loss before survey, or a combination of both.

The pattern observed is consistent with studies showing that predator presence can influence reproductive parameters in birds, including clutch size and breeding output (Martin 1995, Dillon & Conway 2018).

The proportional shift in clutch size observed between 2022 and 2023 is consistent with reduced predation pressure following the complete removal of feral cats from the island. Ground-nesting seabirds are particularly vulnerable to terrestrial predators because nests are exposed and eggs are laid directly on open substrates (Spatz *et al.* 2014). Even low numbers of invasive mammalian predators can influence breeding outcomes in island systems (Medina *et al.* 2011). In 2022, despite most introduced cats having already been removed, the continued presence of three individuals coincided with a predominance of one-egg clutches. Following full removal, the rapid

return to a two-egg-dominated distribution in 2023 suggests that reproductive output responded within a single breeding cycle. Similar patterns of improved reproductive parameters after invasive predator control have been documented on other islands (Jones *et al.* 2016, Campolina *et al.* 2024). Although direct predation rates were not quantified, observers did not commonly detect clear signs of egg predation, such as eggshell remains or disturbed nest contents, during nest surveys. Nevertheless, partial egg loss before survey cannot be fully excluded. The temporal association between predator removal and the rapid shift in recorded clutch-size distribution therefore suggests that predator presence may have affected observed nest contents through direct or indirect pathways.

An important strength of this study is the clearly defined timing of predator introduction and complete removal. Shidvar Island previously lacked an established terrestrial predator population, and the arrival of feral cats in 2021 was both recent and documented. Likewise, the final removal of the remaining three individuals in October 2022 provides a clear temporal boundary between predator presence and absence. This sequence allowed comparison of clutch size distribution across three distinct conditions: pre-introduction (2014), residual predator presence (2022), and post-eradication (2023). Such defined transitions are rarely available in island systems, where predator presence is often long-standing or removal occurs without pre-disturbance baseline data (Nogales *et al.* 2013, Jones *et al.* 2016). The rapid redistribution of clutch sizes following complete removal therefore offers a structured before–during–after comparison, strengthening inference that predator presence was associated with altered reproductive patterns.

Several limitations should be considered when interpreting these results. First, total nest numbers differed substantially among years, with lower nesting abundance recorded in 2022 and 2023 compared to 2014. Although the primary analysis focused on proportional clutch size distribution rather than absolute nest counts, variation in colony size may reflect broader population dynamics not fully captured in this study. Second, direct predation rates were not quantified during

the survey years, and no behavioural observations were conducted to assess changes in adult vigilance or nest attendance. Consequently, the mechanisms underlying the observed redistribution of clutch sizes cannot be directly confirmed. Finally, although basic meteorological conditions were broadly similar between 2022 and 2023, additional environmental variables were not formally modelled, and comparable clutch-size data were available for only three years. We therefore could not fully separate predator-associated effects from natural interannual variation in clutch-size distribution. Continued multi-year monitoring would help determine whether the two-egg-dominated pattern observed in 2023 is sustained under predator-free conditions.

The rapid shift in clutch size distribution following complete feral cat removal suggests that even a small number of introduced predators may influence reproductive patterns in ground-nesting seabirds. The return to a two-egg-dominated distribution within one breeding season indicates a prompt response under predator-free conditions. These findings support the value of rapid detection and removal of invasive predators on seabird breeding islands, particularly in systems where terrestrial predators were previously absent (Nogales *et al.* 2013, Jones *et al.* 2016). Continued monitoring of white-cheeked terns on Shidvar Island will be important to determine whether this reproductive pattern remains stable over time and to further inform predator management strategies in similar island environments.

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