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Article

Update on the conservation status of Townsend's Shearwater (*Puffinus auricularis*): distribution of breeding colonies, reproductive success and population trends under various conservation scenarios

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Abstract Townsend's Shearwater (*Puffinus auricularis*) is a critically endangered seabird. Its distribution is restricted to the Pacific Ocean and ranges from Mexico to Central America. Nearly 20 years ago, the breeding population of Townsend's Shearwater, which is endemic to the Revillagigedo Archipelago in Mexico, was estimated to consist of fewer than 100 breeding pairs. Since then, conservation initiatives, including eradicating invasive mammals, have been implemented in the archipelago. We assessed the current status of Townsend's Shearwater by mapping the distribution of breeding colonies, estimating breeding population size, evaluating reproductive success, describing ongoing threats and modelling population trends under different conservation scenarios. From 2016 to 2024, we conducted field surveys on the islands of Socorro and Clarión using acoustic monitoring techniques in historical nesting areas. We estimated that the breeding population of Townsend's Shearwater on Socorro consists of fewer than 200 pairs and documented the return of a small breeding population to Clarión after a 30-year absence. However, notable reproductive failure persists due to native predators such as land crabs, snakes and ravens. Indeed, the population has exhibited a slow decline driven by interactions between native and invasive species. Without ongoing restoration efforts, including the removal of feral sheep and cats, the population will likely face extinction. To ensure the survival of Townsend's Shearwater, it is crucial to implement innovative management actions to improve reproductive success.

Keywords bird conservation, breeding biology, invasive species, Mexico, Revillagigedo Archipelago, species management, threatened species, Townsend's Shearwater

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Introduction

Seabirds are the most threatened bird group worldwide due to human-induced threats, including invasive species at nesting sites, fisheries bycatch, climate change impacts and infectious diseases (Dias et al., 2019; FAO, 2024). Indeed, 56% of seabird species are experiencing population declines, with 43% listed as Threatened and 5% listed as Critically Endangered on the Red List of the International Union for Conservation of Nature (IUCN) (Phillips et al., 2022). In Mexico, 25% of the seabird species found within the country are listed on the IUCN Red List (IUCN, 2024). This is particularly concerning, as Mexico currently ranks third globally in terms of seabird diversity and second in terms of the number of endemic seabird species that breed within its territory (Croxall et al., 2012). At present, 21% of seabird species are protected under Mexican law, including Townsend's Shearwater (*Puffinus auricularis*) (Berlanga et al. 2008).

Townsend's Shearwater is listed as Critically Endangered on the IUCN Red List (BirdLife International, 2018). Although Townsend's Shearwater is an endemic breeder of the Revillagigedo Archipelago in Mexico (BirdLife International, 2018), its distribution, which is restricted to the Pacific Ocean, ranges from Mexico to Central America (Ainley et al., 2020). In Mexico, Townsend's Shearwater has historically used the islands of Socorro, San Benedicto and Clarión as breeding sites (Anthony, 1898; Hanna, 1926). Like other seabird species, Townsend's Shearwater is subject to several anthropogenic and natural threats that have decimated its breeding sites and resulted in population declines and the extirpation of multiple seabird colonies in the region (Wolf et al., 2006; Bedolla-Guzmán et al., 2019).

The introduction of sheep (*Ovis aries*) in 1869 (Brattstrom, 2015) to Socorro resulted in a loss of breeding habitat that persisted for over 100 years (Ortiz-Alcaraz et al., 2016). In addition, human settlements on Socorro, which were first established in 1957, have resulted in the introduction of invasive predators such as cats (*Felis catus*) and house mice (*Mus musculus*; Jehl & Parkes, 1982). In San Benedicto, volcanic eruptions that occurred in 1952 and 1953 extirpated the breeding population (Brattstrom & Howell, 1956). In recent decades, individuals have occasionally been reported near San Benedicto (Pitman & Ballance 2002), but the reestablishment of a Townsend's Shearwater colony on the island has not been confirmed. In Clarión, introduced species, such as sheep (*Ovis aries*), pigs (*Sus scrofa*), rabbits (*Oryctolagus cuniculus*) and chickens (*Gallus gallus*), have deleteriously affected the ecosystem, with feral pigs causing the extirpation of Townsend's Shearwater by the 1980s (Santaella & Sada, 1991).

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Accurately estimating the breeding population size of Townsend's Shearwater is challenging due to the inaccessibility of nesting colonies and the lack of systematic surveys, resulting in variable estimates over the years, ranging from tens to thousands of pairs. Using 15 years of pelagic survey data (1980–1994), the average global breeding population was estimated to consist of 10,600 pairs (Spear et al., 1995). In 1981, the first quantitative estimate conducted on Socorro suggested that the breeding population consisted of 1,000 pairs (Jehl, 1982). Later on, Martínez-Gómez & Jacobsen (2004) added the maximum counts of 1993 and 1997 and estimated the breeding population on Socorro to consist of 550 pairs. These authors also predicted a rapid decline in the breeding population due to the presence of feral cats while reporting no evidence of nesting activity on Clarión (Martínez-Gómez & Jacobsen, 2004). Notably, the recent estimates of a global population of 200–999 individuals (Birdlife International, 2018) and 75 breeding pairs on Socorro indicate a severe decline in abundance (Martínez-Gómez et al., 2015). The status of Townsend's Shearwater on San Benedicto remains unknown due to the complexity to access the island to conduct surveys.

In response to the threats posed by invasive species, invasive mammals have been removed from numerous seabird-islands over the past 25 years (Aguirre-Muñoz et al., 2018), allowing some seabird populations to recover (Méndez Sánchez et al., 2022). *Grupo de Ecología y Conservación de Islas* (GECI), in coordination with the Mexican federal government, eradicated pigs from Clarión in 2002 (Aguirre-Muñoz et al., 2018) and sheep from Socorro in 2012 (Ortíz-Alcaraz et al., 2016). In 2014, GECI began to eradicate cats on Socorro (Ortíz-Alcaraz et al., 2017). These actions have allowed the recovery of vegetation (Ortíz-Alcaraz et al., 2016) and increased the abundance of landbirds and reptiles on the island (Ortíz-Alcaraz et al. 2017). While some populations of flora and fauna have recovered, the status of the Townsend's Shearwater population has not been assessed.

To update the current status of Townsend's Shearwater on Socorro and Clarión, we conducted the first systematic monitoring (2016–2024) of its remaining breeding populations. In particular, this study aimed to 1) map the current distribution of breeding colonies, 2) estimate breeding population size, 3) evaluate reproductive success, 4) model population trends under different conservation scenarios, 5) identify current threats at breeding sites and 6) propose novel conservation and restoration actions. The results of this study will be essential for guiding future conservation actions for this critically endangered species.

[Study area]

Fieldwork was conducted on the islands of Socorro and Clarión during the breeding season (November to June, occasionally extending to mid-July) from 2016 to 2024. These islands are located

over 300 km from mainland Mexico in the Eastern Tropical Pacific and form part of the Revillagigedo Archipelago National Park (Fig. 1; SEMARNAT–CONANP, 2019), also a World Heritage Site. The California Current and North Equatorial Current systems converge in the region, creating conditions that support high biodiversity (SEMARNAT–CONANP, 2019). At present, 12 pelagic seabird species breed in the region, including Townsend's Shearwater (SEMARNAT et al., 2015).

Socorro (13,039 ha) is the largest island in the Revillagigedo Archipelago and has an elevation of 1,050 m.a.s.l. at its highest point (SEMARNAT–CONANP, 2019). Two climate zones are present on Socorro, namely a semiarid zone (0–400 m.a.s.l.) and a subtropical zone (400–1050 m.a.s.l.), and the average temperature of the island ranges from 19.7–11.2 °C (SEMARNAT–CONANP, 2019). Potential native predators for Townsend's Shearwater adults and chicks on Socorro include the Red-tailed Hawk (*Buteo jamaicensis socorroensis*) and the land crab (*Johngarthia oceanica*) (Whetje et al. 1993, GECI unpublished data).

Clarión is the second largest island (1,925 ha) in the Revillagigedo Archipelago and has an elevation of 320 m.a.s.l. (CONANP, 2017). The island hosts grasslands, scrublands and coastal vegetation, including 58 species of xerophilous plants (CONANP, 2017). A large fire in 1984 and the introduction of mammals have severely modified the vegetation of the island (Everett, 1988). Potential native predators for Townsend's Shearwater on Clarión include the endemic Clarión raven (*Corvus corax clarionensis*) and the Clarión snake (*Masticophis anthonyi*) (McLelland, 1926, CONANP, 2017).

Methods

Distribution of breeding colonies

To determine the current distribution of Townsend's Shearwater colonies on Socorro and Clarión, we conducted auditory surveys, acoustic surveys, and burrow searches. Auditory surveys were performed from November to April (2016–2023) on new moon days at dusk (19:00 to 21:00 h) and, occasionally, at dawn (03:30 to 05:30 h). At each site, we recorded the number of calls, call direction, and approximate distance and whether the birds emitted calls in flight or from the ground (Raine et al., 2017). Survey sites were selected based on historical records (Martínez-Gómez & Jacobsen, 2004), mapped, and analysed to identify potential nest areas for subsequent burrow searches.

Acoustic surveys were conducted from November to April (2019–2023). All call counts were recorded with Song Meter (SM2, SM3 and SM4) Acoustic Recorders (Wildlife Acoustics Inc., Maynard, USA). On Socorro, acoustic recorders were deployed over a historical nesting area of

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1,819.43 ha (600 m.a.s.l.) (Jehl, 1982). The acoustic recorders were deployed every 300 m to avoid double counting (Raine et al., 2017) with two recording schedules: 1) 10 min on and 20 min off (2019-2022) and 2) 1 min on and 5 min off (2022-2023). Recorders operated from 19:00 to 05:30 h, independent of the moon phase. The recording mode was mono, with a sampling rate of 24-92 KHz, gain of 16.0 dB and Preamp of 26 dB. On Clarión, the acoustic recorders (SM4) were deployed every 500 m using the same recording program and specifications as those deployed on Socorro.

Burrow searches were conducted from November to February and from June to July (2016–2023) in sites with historic records of burrows, high nocturnal activity, circling birds or ground calls. Field personnel conducted exhaustive searches and were sometimes accompanied by wildlife detection dogs (pointers and shepherds) (Grymm-Seyfarth et al., 2021). The dogs were trained to passively detect targets by remaining static to avoid damaging burrows or birds. Search tracks were recorded using handheld GPS or GPS mounted on dog collars.

Reproductive success

We used infrared Trophy Cam HD trail cameras (Bushnell Corporation, Overland Park, USA) to record data on burrow status (active or inactive), activity, predation events and fledgling success. The cameras operated in night mode and were checked every 15 days, and additional cameras were installed in nest colonies to identify cat presence. We checked for predation signs between camera checks.

We visually assessed burrow occupancy (Eq. 1) by the presence of feathers, guano, and cleanliness and by confirm burrow visits in photographs:

$$Occupancy = \frac{Number\ of\ active\ burrows}{Total\ number\ of\ burrows} \quad . \qquad \text{Eq. (1)}$$

Nest content was examined with a borescope (NTS 300 [8-mm lens, Teslong Technology, New York, USA) to confirm the presence of adults, eggs, or chicks. The burrows were checked once a week, and the reproductive metrics of clutch size, hatching success (proportion of eggs that hatch), fledgling success (proportion of chicks that fledge), reproductive success (proportion of eggs that result in fledglings) and reproductive rate (proportion of pairs breeding) were calculated. The seasons of 2016 and 2017 were omitted from the analysis due to the lack of borescope data. In 2019 and 2020, the borescope failed, and breeding signs (e.g., eggshells, down remains and chick carcasses) were used to determine the number of breeders. Reproductive success was estimated considering only confirmed breeders. We included the breeding success results of one occupied artificial burrow from 2019 to 2023 and two of these burrows in 2024.

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Population size and dynamic model

We used call rates as a proxy of burrow density (Oppel et al., 2014; Hart et al., 2021). Four fixed recorders were deployed at sites with known burrow abundance from November to May (2017–2024). Recorders operated under the first schedule and specifications previously described. Population size was projected with a Leslie matrix (Leslie, 1945; Martínez-Gómez & Jacobsen, 2004) using three scenarios: 1) current (chick predation by land crabs and no cat predation), 2) worst-case (no management interventions and high predation by cats) and 3) optimal management (reduced chick predation and a moderate increase in reproductive success). Population and reproductive parameters were estimated from monitoring data (2018–2023) (Table 1); survival probability (for each age class [1–6 years]) and the cat predation rate were taken from Martínez-Gómez & Jacobsen (2004).

Data analysis

We manually reviewed recordings (Hart et al., 2021) using Raven Pro v. 1.5 (Cornell Lab of Ornithology) and counted all Townsend's Shearwater calls that were visible in spectrograms. Calls that were obscured or overlapped were counted by listening to the recording. Recordings that contained calls that were highly obscured by heavy rains or strong winds were excluded. Townsend's Shearwater calls were classified as broad-band information with low fundamentals (<1.4 kHz) and harmonics reaching 4 kHz (Baptista & Martínez-Gómez, 2002). The duration of each call was ~5 s; spectrograms longer than 5 s were considered more than one call (e.g., 10 s = 2 calls). Townsend's Shearwater presence or absence and the number of calls per site were plotted and classified by natural breaks in QGIS. Pictures and videos from camera traps were reviewed manually to confirm the presence or absence of birds, fledglings or predators.

We estimated breeding population size from the call rates in a sample consisting of the three darkest days of each month in each nesting area with a known number of burrows. An average call rate from all recorders was calculated for each year (2019–2021). The density of burrows and call rates from the known nesting areas on Socorro were used to estimate the number of burrows in the area (including sites without calls) (Fig. 2). Through a linear equation, we estimated the total number of breeding pairs ($N_{breeding}$).

The total population size (N_{total}; number of pairs) was calculated from the number of breeding pairs ($N_{breeding}$) and the breeding proportion ($r_{breeding}$) of the population with Eq. (2):

$$N_{total} = \frac{N_{breeding}}{r_{breeding}} \quad . \qquad \text{Eq. (2)}$$

The proportion of breeding pairs was calculated with Eq. (3):

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$$r_{breeding} = r_{mature} \times \rho_{breeding} \,, \quad \text{Eq. (3)}$$

where r_{mature} is the proportion of sexually mature individuals in the population and $\rho_{breeding}$ is the breeding probability of a mature individual (i.e., 0.55), which was calculated with data from 2016–2023. The number of non-breeding pairs ($N_{non-breeding}$) was calculated from the total population size and the proportion of non-breeding pairs according to Eq. (4):

$$N_{non-breeding} = N_{total} \times r_{non-breeding} \,. \quad \text{Eq. (4)}$$

The proportion of non-breeding pairs ($r_{non-breeding}$) was calculated with Eq. (5):

$$r_{non-breeding} = r_{mature} \times \rho_{non-breeding} \,, \quad \text{Eq. (5)}$$

where $\rho_{non-breeding} = 1 - \rho_{breeding}$ is the non-breeding probability of a mature individual. Lastly, the number of sexually immature pairs ($N_{immature}$) was calculated from the total population size and the number of mature non-breeding and breeding pairs with Eq. (6):

$$N_{immature} = N_{total} - \left(N_{breeding} + N_{non-breeding}\right). \quad \text{Eq. (6)}$$

Results

Distribution of breeding colonies

On Socorro Island, we recorded Townsend's Shearwater calls in 87 (47%) of the 183 surveyed sites (Fig. 2). Of these, 29 (16%) high-potential nesting sites within ~400 ha (22%) of the surveyed area and 3% of the surface area of the island were identified. The other sites were considered to be flyway paths for shearwaters entering or exiting the island. Through burrow searches, we covered ~145 ha (36%) of the potential nesting area and identified 27 active burrows above 800 m.a.s.l. that were distributed in small colonies consisting of 2–9 burrows. Some isolated burrows were found at sites without calls or with few recorded calls. Eight burrows were occupied by new pairs (i.e., pairs that were not identified in previous surveys or pairs occupying newly dug burrows). In 2023, a potential colony was identified through acoustic recordings in the north-eastern area of the island at an altitude of 600 m.a.s.l., although no active burrows were recorded.

On Clarión, we identified a breeding pair at the *Cerro Gallego* site in 2016. Four new burrows were found from 2017 to 2019. By 2020, we had surveyed 95% of the island with acoustic recorders and identified nine sites with calls and two sites with active burrows (Fig. 3). Calls were located in the eastern portion of the island in the *La Mujer Dormida* site and in the northern portion of the island in

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the *Cerro Gallego* site. Active burrows (n = 5) were found only on rocky substrates with sparse or no vegetation.

Reproductive success

Reproductive success on Socorro varied among years (average of 43% [0–63%]). No fledglings were detected in 2018, and only one fledgling from an artificial burrow was detected in 2019 (Table 1). The average burrow occupancy was 92% (76–100%), and the average reproductive rate was 59% (31–82%). All except two pairs were confirmed to be breeders at least once. Most breeding pairs (79%) produced a fledgling at least once, whereas only 28% succeeded in producing fledglings more than once in consecutive years; 21% never produced fledglings. Breeding success in artificial burrows (100% hatching success, 66.6% fledgling success) was higher than in natural burrows over six consecutive years. However, in 2024, a new nesting pair in an artificial burrow failed to hatch a chick.

Failures in reproductive success occurred due to different factors. Land crabs predated 24.3% of chicks, which was visually confirmed by direct observations or chick remains in nests (Plate 1). Although crab attacks on fledglings and adults were recorded, crab predation occurred only with chicks aged 20 days or younger. In addition, 16.2% of chicks disappeared without evidence, although these disappearances coincided with increased crab activity. In 2020 and 2024, the failure of two chicks to fledge in an artificial burrow coincided with the presence of land crabs inside the nest chamber. In 2022, we found evidence of land crabs consuming a broken egg. Notably, we did not find any evidence of cat predation. Egg failures were due to disappearances (21.6%) and hatching failure (2.7%), as well as broken (2.7%), non-viable (2.7%) or abandoned eggs (2.7%). In addition, 27% of egg or chick losses could not be explained because the failure occurred between the incubation and hatching stages.

On Clarión, average burrow occupancy was 81%. Reproductive success was not estimated due to the depth and complexity of the burrows. However, egg laying at the entrance of a burrow was recorded on video in 2019. Auditory surveys and camera traps confirmed breeding attempts in three burrows, but no fledglings were recorded. Photographic evidence showed frequent visits by Clarión snakes (Plate 2) and land crabs, which are potential predators of eggs and chicks. Raven visits were less frequent.

Population size and dynamic model

The Townsend's Shearwater breeding population on Socorro Island was estimated to be 175 pairs (90%, CI = 94–386 pairs). Considering all other non-breeders and young birds at sea, the global

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population was estimated to be 481 pairs (962 individuals). The breeding population on Clarión was not estimated due to insufficient data. However, with the available data from field observations and surveys, we conservatively estimated that no more than 10 breeding pairs inhabit the island.

The total population of Socorro, including breeders, non-breeders and young birds, was modelled according to the current scenario, which indicated that the population will continue to decline at a rate of 1% over the next 15 years. The worst-case scenario model, which included high predation by cats, indicated that without management actions, the breeding population would decrease by 63% over the next 15 years. The optimal management model predicted a 30% increase in population size over the next 15 years (Fig. 4), considering a conservative increase of 0.14 in breeding success (60%) by reducing chick predation.

Discussion

Distribution of breeding colonies

We confirmed the presence of Townsend's Shearwater breeding colonies at high elevations (800 m.a.s.l.) on Socorro. However, no evidence of colonies was found in the southern portion of the island, although a few scattered burrows were present to the north-west of Mount Evermann, which differs from previous records (Martínez-Gómez & Jacobsen, 2004). The calling activity and presence of feather and faeces indicated that the Townsend's Shearwater has recovered some of its historical nesting areas (Wehtje et al., 1993) on Socorro.

In Clarión, we confirmed active burrows in the two highest points of the island known as *Cerro el Gallego* and *La Mujer Dormida* in the western and eastern areas of the island, respectively. However, we found no evidence of colonies in sandy soil under grasslands, as reported by Anthony (1900) and Hanna (1926). Instead, Townsend's Shearwater burrows were confined to rocky areas above 200 m.a.s.l. The absence of colonies under grasslands may have been due to ravens, which dig into sandy burrows to access chicks and eggs (Hayward et al. 2015). In addition, competition with invasive rabbits for habitat (Ávila-Guerrero et al., 2016) may have also resulted in the notable absence of colonies. Lastly, habitat destruction and predation by invasive pigs (Howell & Webb 1989), as well as a fire in 1984 (Everett 1988), may have also negatively affected Townsend's Shearwater nesting habitat.

Reproductive success

Reproductive success in Socorro was highly variable between years and lower (59%) than that of similar species like Newell's Shearwater (*Puffinus newelli*) (66%, Ainley et al., 2001), Manx

Shearwater (*Puffinus puffinus*) (62–75%, Lee et al., 2023) and Wedge-Tailed Shearwater (*Ardenna pacifica*) (68.5%, Hyrenbach & Hester, 2022), but similar to that of the Black-Vented Shearwater (*Puffinus opisthomelas*) (36%) during El Niño conditions and subject to predation (Keitt, et al., 2003). The reproductive failures of Townsend's Shearwater in 2018, 2019, 2021 and 2024 coincided with the transitions from La Niña to neutral and neutral to El Niño conditions (National Weather Service NOAA). Under neutral and El Niño conditions, sea surface temperatures, the frequency of tropical storms (CONANP 2017), humidity and, consequently, land crab activity increase (Pérez-Chi, 2005), which may have been responsible for high chick predation. In Clarión, no Townsend's Shearwater fledglings were recorded during the study period. Based on video data, the main predators of chicks are likely snakes, which have been documented predating Laysan Albatross (*Phoebastria immutabilis*) chicks on the island (Wanless et al., 2009).

Population size and dynamic model

Our population estimate for Socorro (175 pairs) is more optimistic than the previous estimate of ~75 pairs of Martínez-Gómez et al. (2015). However, the current scenario model predicted a sustained population decline despite managing invasive mammals and increasing the availability of breeding habitat on Socorro. This suggests that native predators, particularly land crabs, hinder population recovery. Notably, the impacts of land crabs on seabirds have been documented in other regions, such as Cayo Ratón in Puerto Rico, where loss of Roseate Terns (*Sterna dougallii*) chicks was likely due to predation by a land crab (*Gecarcinus ruricola*; Shealer & Burger, 1992). Similarly, on Malpelo Island in Colombia, another land crab (*Johngarthia malpilensis*) was found to predate Nazca Booby (*Sula granti*) eggs and chicks (López-Victoria & Werding, 2008).

Indeed, Kaeding (1905) suggested that crabs may have prevented nesting on Socorro by predating on birds. In contrast, thousands of shearwaters were found nesting on San Benedicto where very few crabs were observed (Anthony, 1900). Hanna (1926) did not suggest any relation, but noted low land crab abundance and bigger shearwater nesting colonies on Clarión. Thus, Townsend's Shearwater breeding populations on Clarión and San Benedicto may have been historically larger (Anthony, 1989) than on Socorro due to predation and the poor suitability of available habitat. Importantly, the estimates of breeding population size reported for Socorro by previous authors (Jehl, 1982; Whetje et al., 1993; Martínez-Gómez & Jacobsen, 2004) may have been overestimated due to the inclusion of immigrants from remnant populations on San Benedicto and Clarión, where nesting habitats were lost (Santaella & Sada, 1991), or due to shearwater behaviour that led to double counting (e.g., flying in circles while arriving to colonies (Griesemer and Holmes 2011).

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On Clarión, human activities and invasive rabbits have increased food availability for native ravens and snakes (Ávila-Guerrero et al., 2016). Rabbits, which serve as prey for snakes, inhibit the recovery of vegetation, including cactus (*Opuntia* sp.; Brattstrom, 2015), a food item for ravens. Thus, the reduction in the availability of *Opuntia* sp. has been found to indirectly probably increase seabird predation by ravens (Ávila-Guerrero et al., 2016). Indeed, the decline of the Townsend's Shearwater population is likely the result of synergistic effects due to habitat loss and hyperpredation (Spatz et al., 2023a).

Conservation implications and future research needs

All management actions for Townsend's Shearwater must be accompanied by monitoring programs (Raine et al. 2020), with particular attention paid to the behaviours and responses of predators to management actions. Importantly, while cat eradication is concluded, cat incursions can be managed by a permanent field team and by controlling invasive mammals throughout the breeding season. While progress in cat removal has reduced the extinction risk of Townsend's Shearwater (Croll et al. 2021), breeding success remains low due to predation by native predators, necessitating further action.

Increasing breeding success by mitigating chick predation is critical to preventing extinction. The optimal management model highlighted the importance of increasing fledgling and breeding success to boost the population size of Townsend's Shearwater. To this end, social attraction techniques have proven to be an effective tool. Indeed, these techniques have resulted in a positive response (79%) when implemented with 49 procellariids species (Schreiber and Burger, 2002).

On Clarión, key future restoration actions should include establishing artificial colonies within a predator-proof fence to protect chicks from rabbits, snakes, and land crabs. Additional actions should include eradicating rabbits, appropriately managing human garbage which provides food for ravens, and restoring grasslands where shearwaters historically nested. On Socorro, fully eradicating cats from the island and preventing chick predation by land crabs are critical to improving breeding success.

Although nest boxes limit the risk of predation by land crabs, their designs must be improved to fully exclude these predators. In addition, translocating chicks to safer breeding areas may improve breeding success. In the Hawaiian Islands, this action has successfully improved the breeding success of Newell's Shearwater (Young & VanderWerf, 2024). Thus, this action, which would result in establishing new colonies in protected areas, could produce the same outcomes on Socorro and Clarión.

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If chicks are translocated on Socorro, then the Barn Owl (*Tyto alba*) must also be managed to ensure the safety of Townsend's Shearwater fledglings (Raine et al., 2022). To this end, the ecology of the Barn Owl must be understood to successfully implement management actions during key periods of the Townsend's Shearwater breeding season (Raine et al., 2022). The Barn Owl has been recorded on Socorro since the 1960s (Jehl & Parkes, 1982), but its potential impact on Townsend's Shearwater has likely been underestimated, especially considering that Barn Owls can catch birds in mid-air away from their burrows (Raine et al. 2020).

Lastly, further research on Townsend's Shearwater vocal behaviours is needed to improve estimates of population size and dynamics (Arneill et al., 2019). In addition, post-breeding studies are needed to identify potential threats at sea such as bycatch and the effects of climate change (Días et al., 2019, Rodríguez et al., 2019). It must also be determined if the Townsend's Shearwater has returned to breed on San Benedicto, with future studies on this island evaluating potential predation by land crabs, potential competition with Wedge-Tailed Shearwater for nesting habitat (Villard et al., 2006), and erosion (Brattstrom, 2015).

Author contributions

Study design: AOA, FSC; funding acquisition: FMS, AAM, AOA; fieldwork: FSC, IML, EPV, YBG, AFB, AAO, JGS, NCH, BRM; data analysis: BRM, FSC; writing: FSC, YBG, AFB; revision: all authors.

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Conflicts of interest None.

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Ethical standards This research did not involve human subjects, experimentation with animals, or specimen collection.

Data availability The raw data supporting the findings of this study are available from the corresponding author upon reasonable request.

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573 TABLE 1 Reproductive performance of Townsend's Shearwater (*Puffinus auricularis*) on the Socorro
574 Island, Revillagigedo Archipelago, Colima, Mexico, during the breeding season (2016–2024).
575 Numbers in parenthesis are breeders in artificial burrows.

Parameter	2016 n = 4	2017 n = 12	2018 n = 17	2019[bc] n = 20	2020[c] n = 21	2021 n = 21	2022 n = 24	2023 n = 28	2024 n = 29
Occupancy (%)	100	100	94	95	95	95	87	89	76
Breeding pairs	2[a]	7[a]	5	1(1)	9(1)	12(1)	17(1)	15(1)	11(2)
Reproductive rate (%)	ND	ND	31	ND	50	65	82	64	62
Hatching success (%)	ND	ND	ND	50	70	92	72	75	69
Fledging success (%)	100	100	0	100	86	42	69	83	55
Overall success (%)	ND	ND	0	50	60	38	50	63	38

576 [a] based on number of fledglings
577 [b] No content checks. Egg shell remains were used to estimate breeding pairs.
578

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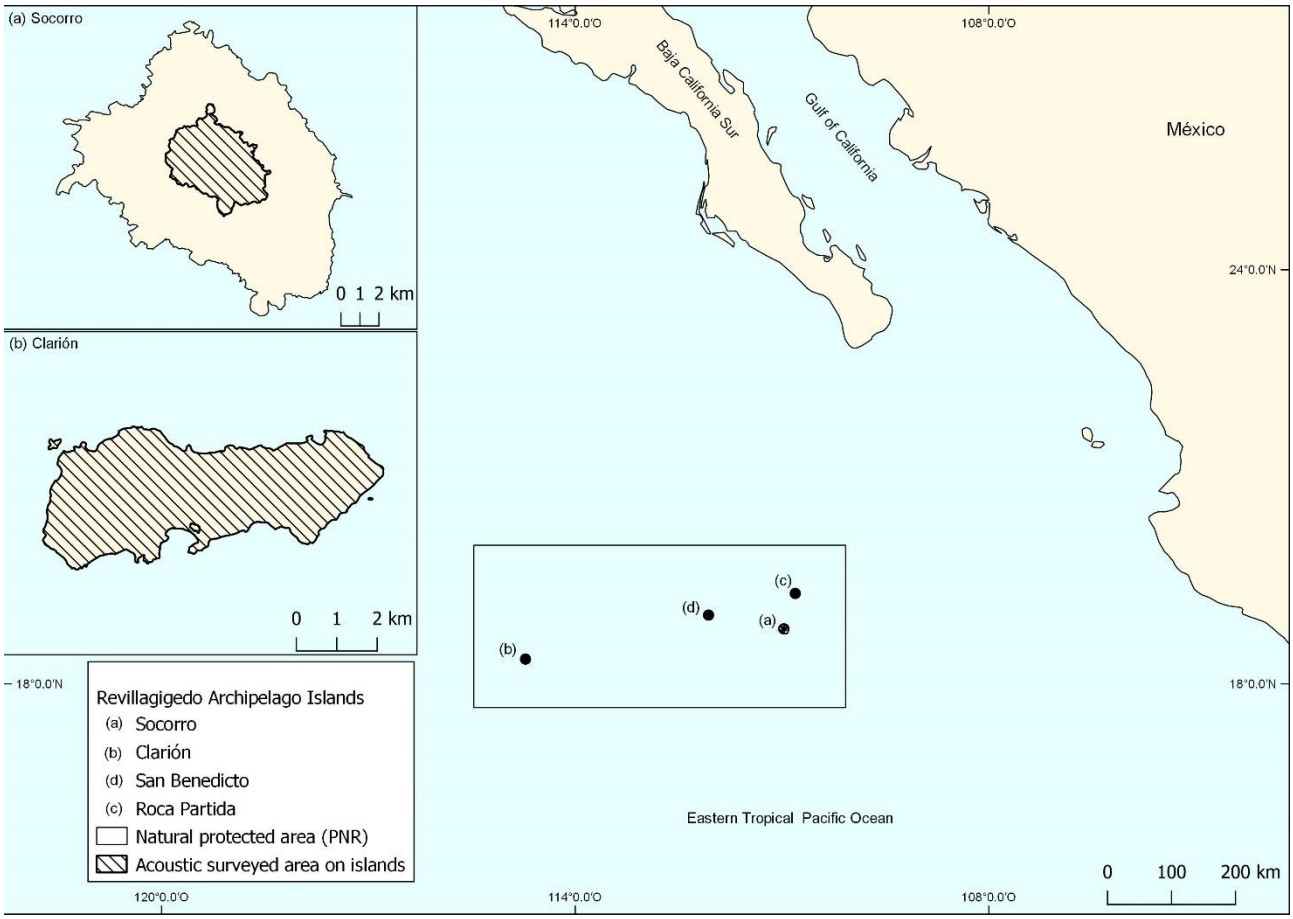

FIG. 1 Location map of the Revillagigedo Archipelago, Colima, Mexico. Acoustic surveyed areas on Socorro Island (a) and Clarión Island (b) are shaded with lines.

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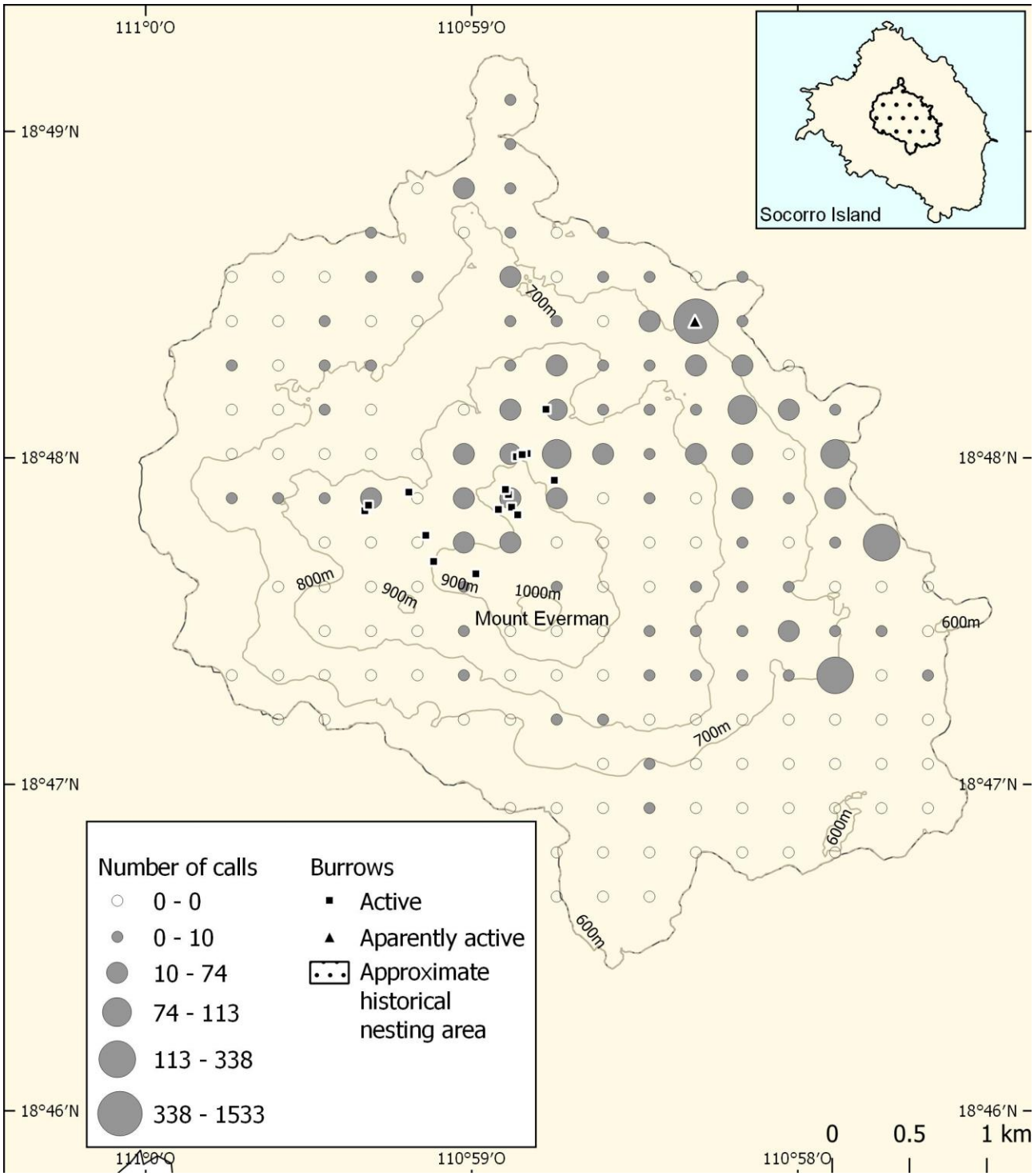

584

585 FIG. 2 Map of acoustic recording sites on Socorro Island, Revillagigedo Archipelago, Colima,
586 Mexico. Number of calls per site and Townsend's Shearwater (*Puffinus auricularis*) burrow locations
587 are shown in circles and squares respectively.

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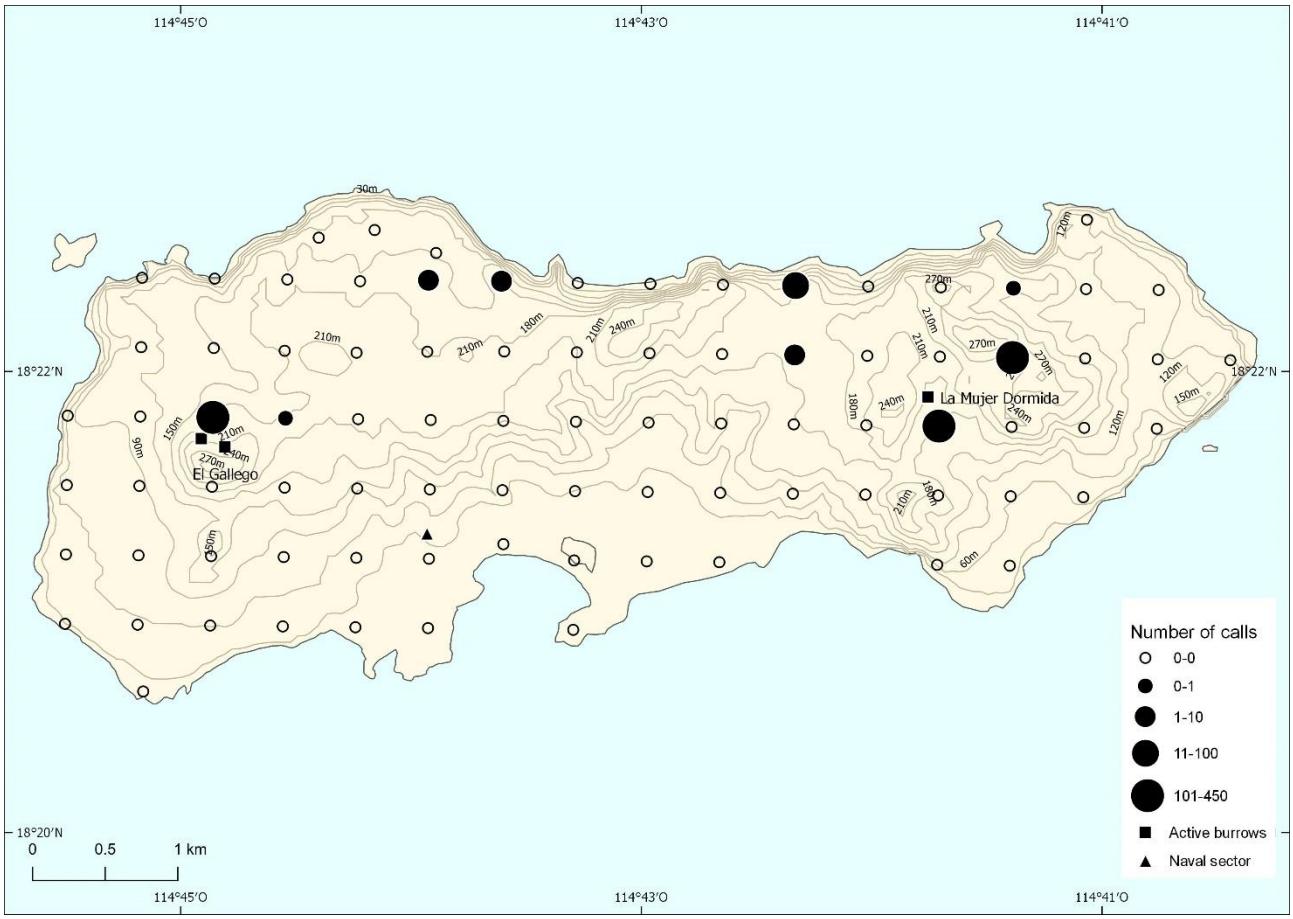

FIG. 3 Map of recording sites on the Clarión Island, Revillagigedo Archipelago, Colima, Mexico. Number of calls per site and Townsend's Shearwater (*Puffinus auricularis*) burrows locations are shown in circles and squares respectively.

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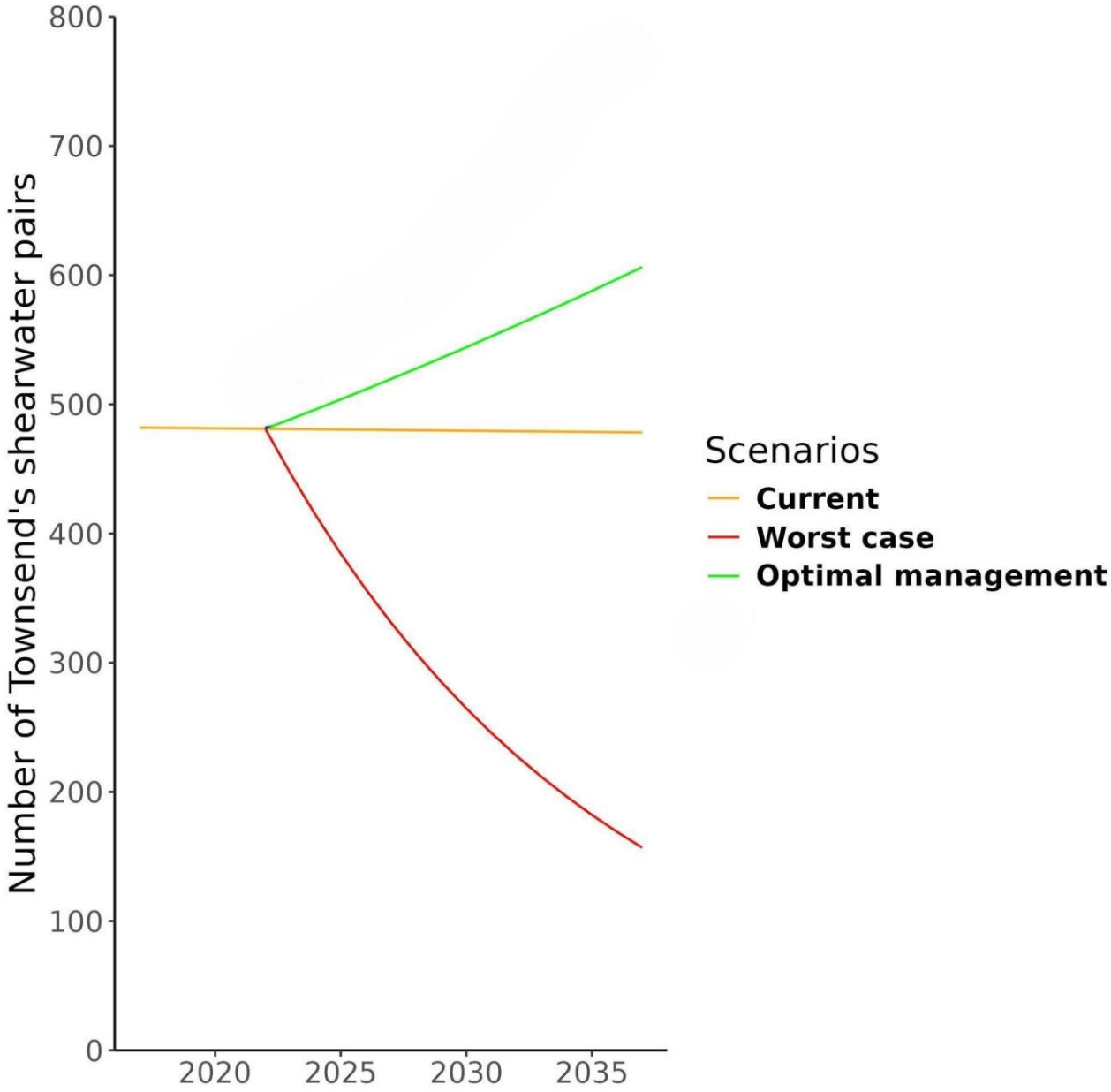

592

593 FIG. 4 Population trends of the Townsend's Shearwater in the Revillagigedo Archipelago, Mexico,

594 under different conservation scenarios.

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PLATE 1 Land crab (*Jhongarthia oceanica*) predating Townsend's Shearwater chick in 2021 on Socorro Island, Revillagigedo Archipelago, Colima, Mexico (Photo Credit: GECI).

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PLATE 2 Clarión snake (*Masticophis anthonyi*) visiting an active burrow of the Townsend's Shearwater (*Puffinus auricularis*) on Clarion Island, Revillagigedo, Mexico (Photo Credit: GECI).