

Return of endemic plant populations on Trindade Island, Brazil, with comments on the fauna

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Abstract Trindade (20° 30' S, 29° 20' W, 10 km²) is an oceanic archipelago of volcanic origin, 1200km east of Vitória, the coastal capital of the State of Espírito Santo, South-eastern Brazil. The main island has lush terrestrial vegetation, with c. 130 species of vascular plants (10 of them endemics) and many endemic seabird species. Since the early 1700s, the forests which historically covered 85% of Trindade gradually dwindled to less than 5%, due to devastation by feral goats (*Capra hircus*), pigs (*Sus scrofa*), sheep (*Ovis aries*), and mice (*Mus musculus*). This change greatly reduced nesting opportunities for seabirds, especially the two endemic frigate birds. From 1965 to 1995, approximately 800 goats and thousands of mice remained, hindering the regeneration of vegetation. The eradication of goats, concluded in 2004, led to rapid revegetation of barren areas and the expansion of populations of endemic plant species *Psilotum triquetrum* Sw. f. *insularis*, *Achyrocline disjuncta*., *Peperomia beckeri*, and *Plantago trinitatis*, which were considered extinct or endangered in prior decades. The number of nesting *Sula leucogaster* nearly quadrupled following elimination of the goats and cats (*Felis catus*).

Keywords: Oceanic island, endemic species, invasive herbivorous vertebrates, eradication, vegetation recovery, *Bulbostylis*, *Colubrina*, *Cyperus*

INTRODUCTION

Trindade (20° 30' S, 29° 20' W, 10 km²) is an oceanic archipelago of volcanic origin, 1200km east of Vitória, the coastal capital of the State of Espírito Santo, south-eastern Brazil (Fig. 1). The nearest islands to Trindade are Martin Vaz (50 km E), Ascensão (2130 km NE) and Saint Helena (2550 km ENE). Only the main island, Trindade, harbours significant terrestrial vegetation with more than 130 species of vascular plants. Many seabird species occur; some of them believed to be endemic. Among the 100 plus species of arthropods, the most conspicuous is the land crab, *Gecarcinus lagostoma*, which is also common on Ascensão (Pain *et al.* 2000). Scanty surveys of marine habitats have revealed relatively rich faunas, with several endemic species of fish and molluscs (Murphy 1915; Miranda-Ribeiro 1919; Carvalho 1950; Breure and Coelho 1976; Leal and Bouchet 1991).

The last volcanic activity on Trindade occurred in the Holocene (Almeida 2006), when eruptions around 30,000 years b.p. buried the forests in volcanic ash. These forests are now seen as recently exposed fossilised and preserved

wood (Alves *et al.* 2003). In the late 17th Century, ship captains reported that Trindade was almost entirely covered with forest. Our mapping of fallen and buried tree trunks indicated that *Colubrina glandulosa* was the predominant species in these forests (Alves 1998).

Recorded invasions by vertebrates (Table 1) began in 1700, when Sir Edmund Halley introduced the first goats (*Capra hircus*), pigs (*Sus scrofa*) and guinea fowl (*Numida meleagris*) to the island (Copeland 1882; Thrower 1981). Between 1781 and 1782, the island was colonised for a year and two months by a 150-man English garrison under the command of commodore George Johnstone (Ribeiro 1951). Between 1785 and 1797 a new occupation by 200 Portuguese took place (Brito 1877; Azevedo 1898; Ribeiro 1951). During these occupations, the forests were overexploited, and the remaining trees were reported as dead, yet standing (Knight 1892).

All through the 19th and most of the 20th Century, introduced and invasive animals such as goats, pigs, sheep, cats (*Felis catus*), guinea fowl, and mice (*Mus musculus*) left on the island by fishermen and shipwrecks, prevented vegetation from recovering and exerted continued pressure on the terrestrial ecosystem. Populations of feral herbivorous, domestic mammals have now affected the terrestrial biota for more than three centuries.

In 1916, a research expedition to Trindade from the National Museum, Brazil, concluded that the introduced mammals were causing erosion and damage to the flora and fauna. Since 1957, the Brazilian Navy has had a permanent Oceanographic Post on Trindade, usually manned by 35 personnel. The Navy promoted sporadic efforts to eradicate introduced mammals throughout this period, but ironically introduced donkeys (*Equus asinus*) in order to pull cargo rafts from ships (Ribeiro 1951; Mayer 1981). Feral sheep, pigs, and donkeys, which were regularly hunted for food by the garrison, were eliminated by 1965 (Alves 1998).

Our field survey in 1994 (Alves 1998) revealed several hundred feral goats and the Navy ordered staff to eradicate them. The rugged mountainous terrain of Trindade posed many difficulties and about 200 goats were dispatched by 2002 by traditional ground hunting and, on one occasion, by helicopter. The Navy intensified the effort by sending

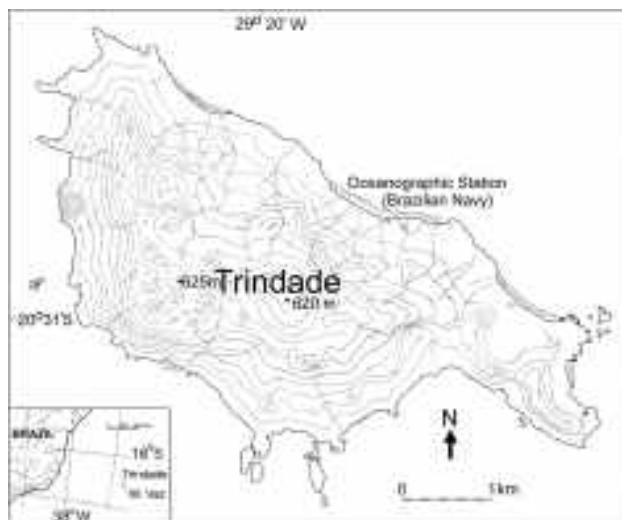


Fig. 1 Trindade Island, also showing the location of Martin Vaz Island.

Table 1 Recorded vertebrate invasions on Trindade island.

Species	Period	References	Observation
Goat <i>Capra hircus</i>	1700–2005	Copeland 1882; Thrower 1981	Introduced by Edmund Halley, eradicated by Navy.
Pig <i>Sus scrofa</i>	1700–1965	Copeland 1882; Thrower 1981	Introduced by Edmund Halley, eradicated by Navy.
Guinea fowl <i>Numida meleagris</i>	1700– late 1980s	Copeland 1882; Thrower 1981	Feral population possibly reintroduced several times, eradicated by Navy
Sheep <i>Ovis aries</i>	1781–1965	Bücherl 1959	300 up to 1950s, eradicated by Navy
Domestic cat <i>Felis catus</i>	1783–1989	Delano 1817; Copeland 1882	Eradicated by Navy
Donkey <i>Equus asinus</i>	1916–1965	Ribeiro 1951	Introduced and eradicated by Navy
Cattle <i>Bos taurus</i>	1916	Ribeiro 1951	One pair, did not survive.
Canary <i>Serinus canaria</i>	?– 1985	Neves 1986	Small population, self-extinguished
Tropical house gecko <i>Hemidactylus mabouia</i>	2006– 2007–?	Bugoni & Welff-Neto 2008	15 individuals recorded.

Marine sniper hunters on several four month hunting missions, and thus the last 251 goats were shot by 2004 (Alves 2006). As the military personnel were on the island as a regular crew of the Oceanographic Post, the additional cost of this eradication effort was only that of the ammunition. In parallel, several thousand saplings, mainly of *Colubrina glandulosa*, were experimentally planted between 2000 and 2004. The feral cats, present at least since Amaro Delano's visit in 1803 (Knight 1892) decimated seabird populations, and were only eradicated by traditional ground hunting methods by the military in 1998 (Alves 1998).

TERRESTRIAL FLORA

Among the endemic vascular plants, *Bulbostylis nesiotis* and *Cyperus atlanticus* are common to the Trindade and Martin Vaz Archipelagos, while the remaining species (Table 2) grow, or grew, exclusively on Trindade.

Conservation results

Positive results of the goat eradication include the recovery of endemic plant populations. *Plantago trinitatis* was considered extinct until 1998, and began a slow recovery from the seed bank in the soil when the goat population began to decline. *Peperomia beckeri*, another endemic species known only from the type collection, was rediscovered in December 2009 and is now present as a few individuals. In 1994, the documented surviving population of *Achyrocline disjuncta* was of 13 individuals, with fewer than 50 individuals estimated for the entire island.

Areas kept barren by feral goats up to the 1990s are currently being colonised by herbaceous vegetation (Fig. 2). The chief pioneer species in this process are the endemic sedges *Cyperus atlanticus* and *Bulbostylis nesiotis*, followed by the fern *Pityrogramma calomelanos* (Alves and Martins 2004; Martins and Alves 2007).



Fig. 2 A ridge on Trindade Island in 1995, when hundreds of feral goats degraded the vegetation and impeded recovery (left) and the same area in 2009, five years after feral goat eradication. The herbaceous layer is composed mainly of the two endemic sedges *Cyperus atlanticus* and *Bulbostylis nesiotis*, and the widespread fern *Pityrogramma calomelanos*.

Table 2 Conservation status of plant taxa endemic to Trindade Archipelago.

Taxon	Discovered / described	Status
<i>Asplenium beckeri</i>	1965/1969	Extinct?
<i>Doryopteris campos-portoi</i>	1965/1969	Relatively common in shaded places.
<i>Thelypteris</i> sp. (= <i>Dryopteris novaeana</i>)	1965/1969	Relatively common associated to <i>Cyathea copelandii</i> forest.
<i>Elaphoglossum beckeri</i>	1965/1969	Extinct?
<i>Cyathea copelandii</i>	1874/1882	Relatively common above 400 m a.s.l.
<i>Polypodium trinidadense</i>	1965/1969	Relatively common on exposed hilltops.
<i>Psilotum triquetrum</i> Sw. f. <i>insularis</i>	1965/1969	Considered extinct until 2000, currently expanding rapidly (ca 100 individuals).
<i>Achyrocline disjuncta</i>	1876/1885	Fewer than 20 individuals in 1990s, expanding rapidly (>100 individuals).
<i>Peperomia beckeri</i>	1965/1998	Considered extinct until 2009, recently recollected and in cultivation. Field survey in progress.
<i>Plantago trinitatis</i>	1965/1974	Twelve when discovered in 1965, after goat-eradication. expanding rapidly (ca 800 individuals on the tallest peaks).
<i>Bulbostylis nesiotis</i>	1876/1885	Common on Trindade and Martin Vaz; on Trindade now spreading to all barren land with fine soil.
<i>Cyperus atlanticus</i>	1876/1885	Common on Trindade and Martin Vaz; on Trindade now spreading to all barren land with fine soil.

Since 2004, the freshwater streams on Trindade have increased in volume and number; we found four new streams on the eastern flanks alone and observed that the total volume of water is about twice that of the late 1990s.

Several hundred saplings of about 60 non-native tree species were sent to Trindade and planted there without our knowledge, although luckily most of them were planted close to the barracks. Some of these saplings displayed a strange form of allelopathy, killing the native endemic *Cyperus atlanticus* within the reach of their root systems, and left a barren halo around their trunks. This is especially true for *Syzygium cumini* (Fig. 3), the halos of which are perceptible even on Google Earth satellite imagery. We recommend the substitution of the non-native allelopathic trees by native species.

EXTANT TERRESTRIAL FAUNA

Insects

The beetle, *Liagonum beckeri*, is almost certainly the world's most extreme example of narrow endemism. The population is restricted to a wet rock of <1 m², inside a deep ravine. About 20 individuals of this beetle are visible



Fig. 3 Allelopathic halos of dead *Cyperus atlanticus* within the reach of root systems of the mistakenly introduced tree *Syzygium cumini*.

at any time. In 1959, it was discovered there by the late Professor Johann Becker, entomologist of the National Museum in Rio de Janeiro, and was described by Jeannel (1961). In 1994-95, we spent two months searching the entire Island, but only found the population on the very same spot as the Becker population. The beetles run around only on those parts of the rock that are covered with a green algal biofilm. The population was last revisited in 2002 and many individuals were observed.

Birds

The Trindade petrel (*Pterodroma arminjoniana*) is known to breed on Trindade, Round Island (Mauritius), and North Keeling Island (Australia, Cocos Archipelago) in the Indian Ocean. Luigi (1995) found no breeding pairs on Martin Vaz. It may also have nested on a coastal island in Espírito Santo, Brazil (Neves *et al.* 2006). There is no evidence to suggest that there is genetic exchange between the Australian and extralimital populations (Anonymous 2010). Unlike the frigates, this species nests and breeds on cliff ledges and in fissures, and does not depend on tree nesting. The petrel was listed as critically endangered (Neves *et al.* 2006, Silveira and Straube 2008) for Brazil, and the IUCN (2004) listed it as Vulnerable (D2). We have observed a gradual increase in the Trindade population coincident with the cat and goat eradication effort.

The boobies, *Sula sula* and *S. leucogaster*, have undergone a gradual global decline although both species are listed as "Least Concern" (Birdlife International 2009a, 2009b). They are not considered threatened in Brazil (not listed by Silveira and Straube 2008). Both are ground-nesting, and their populations on Trindade were under constant pressure from feral goats, which not only trampled their nests, but were recorded eating the eggs (Sergeant Ruy Barreto pers. comm.). Colonies of *S. sula* were recorded on Trindade up to the late 1960s, became very rare on the island by the 1990s, and no nests have been recorded since. On the other hand, the number of nesting *S. leucogaster* multiplied exponentially following cat and goat eradication, and currently covers four times the original territory.

Two critically endangered frigate bird subspecies *Fregata ariel trinitatis* and *F. minor nicolli* are endemic to Trindade and Martin Vaz Archipelagos (Silveira and Straube 2008). Even though frigate birds are believed to nest exclusively on trees, Martin Vaz has only herbaceous vegetation. On Trindade, no nest has been recorded since 1975 (Silveira and Straube 2008). During a visit in June 2009, we photographed a single pair of frigate birds soaring over the island (species not determined).

Reptiles

Between 2006 and 2007, a small and geographically restricted population of the tropical house gecko (*Hemidactylus mabouia*) was recorded on Trindade, feeding mainly on exotic insects (Bugoni and Welff-Neto 2008). Whether the gecko is still present is uncertain, due to its nocturnal habits, but it has not been recorded since 2007.

Mammals

The only invasive vertebrate species now present on Trindade is the house mouse. The population is estimated to be in the order of hundreds of thousands of individuals. An assessment of their spatial distribution and seasonality on the island is being conducted. A detailed analysis of the house mouse's role in the Trindade food web is also pending. Preliminary observations indicate that mice consume most of the seeds produced on land, thus retarding vegetation recovery. They have been observed picking seeds of the endemic sedges *Cyperus atlanticus*, *Bulbostylis nesiotis*, and those of *Colubrina glandulosa*. The mice have also been seen foraging on eggs from seabird nests on the ground. Since the goat eradication was confirmed in 2004, and the island's vegetation shows clear signs of recovery, the invasive mice are the only significant setback to vegetation regeneration. Invasive rodents can also

significantly change marine rocky intertidal communities (Kurie *et al.* 2008) and suppress terrestrial invertebrates (Van Aarde *et al.* 1996). A year-long rodent population survey has been started in February 2010, to help plan an eradication using methods proven effective on other islands (*viz.* Samaniego-Herrera *et al.* 2009a, 2009b). As proven by preliminary field trapping, land crabs are likely to pose a major difficulty by consuming large quantities of the bait (Fig. 4).

DISCUSSION

The order of eradication of invasive mammals was not considered during the goat hunting campaign. The feral sheep, pigs and donkeys had already been eradicated decades prior to our intervention, during which the goats were perceived as the largest threat. It could well be that the presence of goats, which kept the vegetation from recovering, may have facilitated the eradication of feral cats by ground hunting. It is also probable that by eliminating the goats first, we have helped the mouse population to increase. However, no hard data are available on these matters.

Due to its remote location, efficient management, and especially to the lack of economic exploitation, the recovery of terrestrial ecosystems on Trindade Island has begun with astonishing speed. The eradication of feral goats took a decade, but it was achieved without allocation of substantial resources – the salaries of the military personnel would be paid anyway and, considering the environmental benefits, the cost of ammunition was insignificant. Furthermore, the eradication represented an excellent training opportunity for the snipers.

Future introductions of any non-native species to Trindade should be subjected to prior evaluations by several specialists of different areas, in order to minimize potential impacts on the natural ecosystems. In the case of non-native fruit trees, for example, the benefits of their introduction must be weighed against the potential risks of their becoming new invasive species. The adoption of simple and preliminary biosecurity measures by the Navy would greatly benefit the Trindade Island biota, especially considering that without effective biosecurity measures, the upcoming eradication of house mice could easily be followed by a new invasion.

Provided with the right information, the Brazilian Navy has proven to be very efficient and conservation-minded, and we recommend that it should remain the sole administrator of Trindade Island. We consider that the adoption of simple biosecurity measures can benefit the environmental recovery of Trindade more effectively than the bureaucratic inclusion of the Island in the Brazilian National System of Protected Areas (SNUC).

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Fig. 4 The land crabs (*Gecarcinus lagostoma*) consumed most of the bait during preliminary field trapping in February 2010.

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