

Earth, fire and water: applying novel techniques to eradicate the invasive plant, procumbent pearlwort *Sagina procumbens*, on Gough Island, a World Heritage Site in the South Atlantic

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Abstract The Eurasian plant procumbent pearlwort (*Sagina procumbens*) was first reported in 1998 on Gough Island, a cool-temperate island and World Heritage Site in the central South Atlantic. The first population was discovered adjacent to a meteorological station, which is its assumed point of arrival. Despite numerous eradication attempts, the species has spread along a few hundred metres of coastal cliff, but has not as yet been found in the island's sub-Antarctic-like mountainous interior. At South Africa's sub-Antarctic Prince Edward Islands *Sagina* is spreading rapidly in vegetated and unvegetated habitats, and is considered beyond control. A similar situation could eventuate on Gough Island if the plant spreads inland, with deleterious effects on the island's ecosystems. Eradication methods progressively used on Gough Island included mechanical removal and dumping of plants and seed-infested soil at sea well away from the island, application of herbicides to kill both growing plants and germinating seeds, gas flames to kill seeds and seedlings in rock cracks, near-boiling water to kill seeds in soil, high-pressure water jets to strip infested areas of soil and peat down to bedrock, and spraying with salt water. Germination trials have shown that spraying with sea water inhibits seedling production and a steady decline in seed load in infested areas over almost a decade. However, eradication has been hampered by the plant's inconspicuous nature, fast growth rate, large seed production leading to an equally large seed bank, long-lived seeds, difficult terrain that requires qualified rope-access technicians to work in safety, and the island's remote location. Although eradication has not yet been achieved, *S. procumbens* remains confined to its current restricted distribution on the island.

Keywords: Inconspicuous, long-lived, seed bank, mechanical removal, herbicide, salt water, pressure spray

INTRODUCTION

Gough Island, a cool-temperate oceanic island in the mid South Atlantic, has often been described as one of the most important seabird islands in the world (Ryan 2007). The island is part of the United Kingdom Overseas Territory of St Helena, Ascension and Tristan da Cunha. The 6400-ha island and its surrounding 12 nautical mile territorial waters have been designated a nature reserve under the Conservation of Native Organisms and Natural Habitats (Tristan da Cunha) Ordinance of 2006, as a World Heritage Natural Site since 1995 (expanded to include Inaccessible Island in the Tristan Group in 2004), and as a Ramsar

Wetland of International Importance since 2008. The island has also been listed as an Important Bird Area and an Endemic Bird Area (Ryan 2008). Gough supports over 70 species of indigenous vascular plants (Ryan 2007), four of which are endemic to the island and a further 25 endemic to the Tristan da Cunha Group (Jones *et al.* 2003). Activities on the island are controlled through a management plan adopted in 1993 (Cooper and Ryan 1994).

Gough Island has never been permanently inhabited. A meteorological station on the coastal cliffs above Transvaal Bay has operated since 1963 under lease by South Africa from Tristan da Cunha. The station has a year-round staff of six to eight with an annual relief from Cape Town, South Africa, in September/October when the number of people ashore increases to 30-40 for three weeks.

Despite their remoteness, biological importance, and restrictions on access, some invasive species continue to reach these islands. In this paper, we describe the arrival on Gough Island and subsequent attempts to eradicate a localised population of the Eurasian plant, procumbent pearlwort (*Sagina procumbens*: Caryophyllaceae), a small, prostrate mat-forming herb.

SAGINA PROCUMBENS ON GOUGH

Discovery and likely source

Sagina procumbens (hereafter referred to as *Sagina*) has become invasive on at least 14 islands in the Southern Ocean, probably aided by its creeping habit, high seed production and capacity for vegetative propagation (Shaw *et al.* 2010; Fig. 1). The species was first reported from Gough Island at the meteorological station during the annual relief on 11 September 1998 (Hänel 1998). Numerous well-developed plants were then found on and around the concrete platform adjacent to the cliff crane, on concrete sections of the walkway to the main base buildings, and on the cliff near the diesel-pumping point (Hänel 1998).

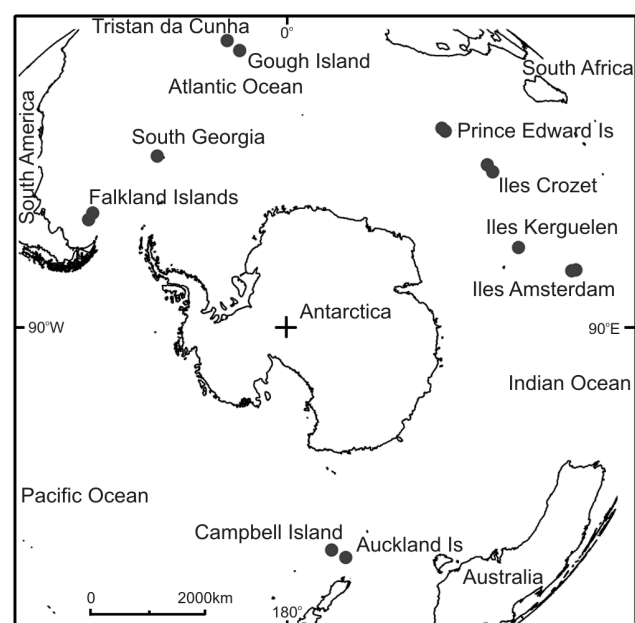


Fig. 1 Distribution of procumbent pearlwort *Sagina procumbens* on islands in the Southern Ocean.

Sagina was not at that time found at localities searched farther afield along the coastline or inland.

Given the presence of a mature, post-flowering plant collected in 1998, *Sagina* had been on the island for some time before the 1997/98 summer growing season. However, annual environmental inspection reports from 1991 (when they commenced) to 1997 make no mention of any new alien plants around the station that could have been *Sagina*, despite directed checks. Plants may have been overlooked by non-botanical inspectors but the 1996 environmental inspection was undertaken by a botanist, who reported that no new introduced plants were observed around the station's buildings despite a directed search (Roux 1996). It is most unlikely that *Sagina* was present in October 1984, when Nigel Wace, a botanist with previous experience of Gough, conducted a survey of alien plants on the island (Wace 1986).

In addition to Gough Island, South Africa operates a meteorological station on sub-Antarctic Marion Island, Prince Edward Islands, in the southern Indian Ocean. Both stations are supplied through the Directorate: Antarctica and Islands, Department of Environmental Affairs (DA&I: DEA). In the 1990s, the same shipping containers were used for supplies to both islands. These containers were not always adequately cleaned before being loaded onto the supply vessel (JC pers. obs.). At Marion Island, containers unloaded from the ship by helicopter were then landed on sites inhabited by *Sagina* (Ryan 2000; JC pers. obs.), which was first reported on the island in 1965 (Gremmen and Smith 1999). Some of these containers were subsequently used annually to supply Gough Island, suggesting one potential source of infestation. However, *Sagina* also occurs in the Cape Town docks area (NJMG pers. obs.), where the island cargo is loaded, so mainland Africa is also a potential source.

Sagina procumbens was first recorded on the main island of Tristan da Cunha, 380 nautical miles NNW of Gough, in 1999 on the Settlement Plain in the village of Edinburgh of the Seven Seas and within the boundary of Calshot Harbour. Subsequently, the species has been found up to 10 km from the village (Gremmen and Halbertsma 2009; JC pers. obs.). Its spread on Tristan is thought to be facilitated by human pedestrians, domestic stock and vehicular traffic. Eradication on Tristan is not considered feasible, but control was initiated in the village and Calshot Harbour in 2009 as a biosecurity measure, to reduce the risks of the plant reaching the other islands in the group (A. Rosler *in litt.* to JC 2009).

Current distribution on Gough

Since discovery in 1998, *Sagina* on Gough has spread along coastal cliffs in Transvaal Bay to its current patchy distribution over c. 400 m. Annual searches away from the coast, concentrating on foot paths and the less-vegetated areas in the interior, have revealed no additional plants over 10 years of effort. The very rugged nature of the island makes adequate surveys of all cliffs impossible since they reach heights of 50-300 m along most of the 42 km of coastline. However, no plants have been discovered along the island's east coast as far as 9 km from the meteorological station in Transvaal Bay. In 1999, a single *Sagina* seedling was found growing among lichens and bryophytes on a dead island tree (*Phyllica arborea*) some 200 m south of the meteorological buildings. The plant may have been spread by Gough buntings (*Rowettia goughensis*) regularly seen in the vicinity (Gremmen 1999). Since then, there have been no further records of *Sagina* growing epiphytically at Gough, or outside the area described above.

The results of these surveys lead us to believe that *Sagina* is currently restricted to its known range and thus its eradication from the island should be feasible.

Prognosis of spread

On Marion Island (Prince Edward Islands), *Sagina* is spreading at a rate of 100-300 m per year (Gremmen and Smith 1999; JDS pers. obs. 2009). In May 1997, *Sagina* was found on nearby Prince Edward Island at a few sites but in subsequent years it has spread significantly (Ryan *et al.* 2003; PGR and JC pers. obs. 2008 and 2010). The plant is now considered naturalised on Prince Edward Island. Given this, and the likelihood that indigenous animals may now be facilitating its dispersal, it is considered beyond control by known methods on both Marion and Prince Edward Island.

The global distribution of *Sagina* suggests wide ecological amplitude. Although Gough is generally classified as cool temperate, its mountainous interior predominantly has herbfield and feldmark vegetation (Wace 1961) broadly similar to that of the lowlands of the sub-Antarctic Prince Edward Islands (Gremmen 1981). The precautionary view assumes that if *Sagina* becomes established in the sub-Antarctic-like uplands of Gough it will become as invasive as on the Prince Edward Islands and will then be impossible to eradicate or control.

Biosecurity procedures

Since the discovery of *Sagina* on Gough, and as part of a general improvement of biosecurity procedures within the South African National Antarctic Programme (SANAP), containers dedicated to specific islands are now used to avoid interchange between Gough and Marion. Containers are also cleaned using water under pressure inside and out before packing and loading onto the supply ship at the DA&I: DEA stores in the Cape Town docks. Once containers are loaded, the ship's holds are fumigated against invertebrates, usually the day before sailing, but this is unlikely to kill dormant seeds. The outsides of containers are also inspected visually on arrival ashore on Gough before they are opened, and their insides inspected when opened and unloaded.

ERADICATION EFFORTS ON GOUGH

On and shortly after discovery

In the year of discovery, mechanical control of *Sagina* was attempted. Plants were scraped out of cracks or removed from rock and soil surfaces, placed in strong plastic bags by volunteer members of the meteorological station and later removed from the island. Despite these measures, by the annual relief a year later (1999) the infested area had increased to about one hectare around the buildings (Gremmen 1999; Gremmen *et al.* 2001). Based on this inspection by NJMG, an eradication programme was designed and implemented in May 2000, with funding from the United Kingdom Government (Gremmen 2000).

The 2000-2004 eradication programme

A four-person team, led by NJMG, arrived on the island in May 2000 for two months (Barendse 2000; Ryan 2000). All visible plants with surrounding soil to a depth of c. 15 cm were removed from around the meteorological station in an attempt to remove buried seeds (Gremmen *et al.* 2001). After tests of efficacy on germination, sites where the plants had been found were treated with hot (>80°C) water from a specially designed diesel-fuelled boiler in an attempt to kill any remaining seed banks. Broad-spectrum and pre-emergent herbicides (*Glyphosate 360/Glyphogen*, 'Round-up' and *Outpace Flowable*) were also used where it was difficult to remove plants. Lastly, hand-held blow torches were used to kill seeds in rock cracks. The use of rope-access techniques was necessary to access many of the infested sites in safety.

By the end of the 2000 visit, no plants were to be seen. Regular monitoring and herbicide spraying by volunteer

team members and inspections during the annual reliefs were then viewed as the only measures required for the eventual eradication of *Sagina* from the island. A detailed manual was prepared to guide this work (Gremmen 2000). An inspection during the annual relief in September 2001 indicated that *Sagina* was under control. However, this proved to be mistaken. When JC visited the island on the 2003 relief, large coalescing clumps of *Sagina* were found at several cliff sites. The team volunteer who had been treating *Sagina* with herbicide at intervals during 2002/03 reported to JC that for safety reasons he had not ventured into all the areas where the plant was known, especially on steep and slippery cliff sections with drop-offs directly into the sea.

During the 2003 relief, another attempt was made to remove all plants for dumping at sea but there were insufficient personnel for this to be achieved. Many plants had to be left to continue growing and to flower and set seed through the 2003/04 summer, despite the efforts of the voluntary conservation officer on the meteorological team who continued to remove plants, spray herbicides and use a blow torch at intervals in infested areas throughout the year (Leveridge 2004).

Most seriously, in September 2004 wider searches for *Sagina* revealed that plants had spread northwards along the coastal cliff to a popular fishing spot known as Snoekgat, most likely through adhering to footwear (Cuthbert and Glass 2004).

Restarting and expanding the eradication programme 2005-2010

During late 2004, new funding obtained from the United Kingdom's Overseas Territories Environment Programme (OTEP) by the Tristan da Cunha Government, enabled a sustained eradication programme to be recommenced in September 2005 (Gremmen 2005; Cooper *et al.* 2006; Gremmen 2006). Because *Sagina* on Gough Island is able to set seed within three months or less from germination, it was desired to place eradication teams (with rope-access qualifications and skills) on the island for several months during each summer-growing season and at roughly quarterly intervals for long enough to remove all plants within the known distribution. In practice, such a programme was not fully achievable, primarily due to a shortage of available berths on the few vessels travelling between South Africa and the Tristan Group.

Over approximately four years, all plants found were removed and the sites treated with herbicides and/or heat during each visit. However, a few plants continued to escape detection and as a consequence flowered and set seed, thereby adding to the seed bank. This led to the prevailing situation, which since September 2008 has involved two field assistants qualified in rope access on the island for a full year. Their duties have included careful checks of the area known to be infested with *Sagina* at no more than monthly intervals, when all plants found are removed. Funding for this latest stage has again been received from OTEP, with administration of the project switching from a South African environmental consultancy (CORE Initiatives) contracted by Tristan da Cunha to the Royal Society for the Protection of Birds (RSPB), a UK-based NGO that is part of the BirdLife International partnership. The second (2009/10) team was replaced by a further two, rope access-qualified, field assistants in September 2010. Two field assistants will be appointed for 2011/12 for a fourth consecutive year. This extends the period of active eradication efforts against *Sagina* until at least October 2012. As a result of the latest protocol, very few plants have escaped notice until after they have set seed. Semi-quantitative germination trials (Visser *et al.* 2010) confirm that this has rapidly reduced the seed bank.

Expanding the 'tools in the box': new eradication techniques adopted

By 2008, despite seven years of effort, the eradication of *Sagina* on Gough had not been achieved. However, plants were being confined to a coastal distributional range, which reduced the risk of spread to the mountainous interior. Further progress required new techniques to be tested and added to those available. One new method used during the September 2008 relief was a high-pressure jet of water used to blast the peat and soil into the sea from selected infested areas, exposing bed rock. Trials in 2009 showed that salt water inhibits the germination of *Sagina* seeds (Visser *et al.* 2010). At vegetated sites, tussock grass, forbs and mosses were first removed with spades and mattocks. The vegetation and peat were then thrown or washed over the cliff edge onto the rocks below or into the sea. Subsequent checks of the newly exposed rock showed that whereas *Sagina* seedlings did continue to emerge from rock cracks they were relatively few in number, and were then easily spotted and removed. In addition, an enhanced spraying regime was commenced from October 2008 with broad-spectrum and pre-emergent herbicides applied in selected areas each month.

The soil-blasting system was not sufficiently portable for use over the full distribution of *Sagina*. In September 2009, a portable fire-fighting pump (*Davey Fire Chief*), along with a 1200-l water tank was lifted by helicopter to the northern edge of the plant's distribution at Snoekgat. A start was then made to strip the area using high-pressure hoses with a range of up to c. 100 m. This stripping technique is slow, labour-intensive, and may take several years to remove cover from all areas on the coastal cliffs within the range of *Sagina* down to bed rock. From September 2010, thick stands of indigenous vegetation (mainly *Spartina arundinacea* tussocks) were trimmed prior to soil blasting with a petrol-powered brush cutter. Once stripping to bed rock is completed, regular monitoring to remove seedlings soon after they germinate from rock crevices and from any small pockets of remaining soil should deplete the seed bank to zero and lead to the plant's eventual eradication from the island.

Following successful suppression of germination using salt water elsewhere (Visser *et al.* 2010), the portable pump has also been used to spray salt water (mixed in the large water tank using commercial salt brought to the island in 25 kg bags) onto the stripped rock at Snoekgat.

In addition to the new eradication attempts since September 2009, quarantine/biosecurity procedures have been strengthened in order to reduce the risks of inadvertently spreading *Sagina* inland and along the coastline. Procedures include a permanent boot wash basin at the meteorological station to ensure that footwear is cleaned of adhering soil and plant propagules plus the cleaning and inspection of containers and materials flown to food caches and camp sites in the island's interior (Gibbs 2009). These procedures are additional to the hosing down of protective clothing and footwear when leaving infested areas that has been a normal practice of the eradication campaign since its inception.

'Upping the ante': possible new techniques to test and adopt

In September 2009, an independent audit of the eradication campaign was conducted by an expert in managing alien plant eradications in South Africa (Gibbs 2009). Suggested new eradication techniques to test included salt applied in its solid form to sites where plants had been removed and the use of a helicopter-borne monsoon bucket to water-bomb the infested cliffs with salt water. The former suggestion was tested at the time, but

has not proven particularly successful (Visser *et al.* 2010). The latter suggestion may be tested if an opportunity arises during annual relief visits.

Less practical suggestions included: covering the infested cliffs with a sealant material (such as the sprayed cement sometimes used to stabilise road cuttings); explosives to blast the cliff face into the sea; portable flame throwers to incinerate both plants and peat; and, probably more realistically, using some form of hormonal growth agent that would promote synchronised germination of the remaining seed bank. Weeds growing in cracks on hard surfaces can be killed with a foam surfactant created from a biodegradable glucose polymer that retains heat for longer than just water (Quarles 2001; Bridge 2005). However, hot foam would be logistically difficult to apply at any distance from the immediate surrounds of the meteorological station, given that the equipment required is not designed to be carried by hand.

The applied and proposed eradication techniques described here are not thought to place the island's indigenous biota and physical environment at any long-term risk, given that the eradication methods used are restricted to a very small part of the island

CONCLUSIONS

The eradication of *Sagina procumbens* from Gough Island has proved to be a protracted exercise. Eradication will require years of continued and concentrated effort to remove all emerging plants before they set seed, so as eventually to exhaust the existing seed bank. Biosecurity efforts to halt new propagules arriving at Gough (Lee and Chown 2009) from either Cape Town or Tristan da Cunha need to be rigorously applied, along with continued monitoring ashore to reduce the risks of the species spreading away from its current distribution. To help achieve these goals, new eradication methods and technologies should continue to be sought, tested, and adopted.

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