Strategies to eradicate the invasive plant procumbent pearlwort *Sagina procumbens* on Gough Island, Tristan da Cunha

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SUMMARY

In 1998, procumbent pearlwort *Sagina procumbens* a non-native and invasive plant was discovered on Gough Island (Tristan da Cunha). Efforts to eradicate this species have been underway since 2000. To date it has been restricted to a small (400 m length; approximately 1.2-1.6 ha area) but complex stretch of coastal cliffs. Measures of seed density, based on germination trials of soil samples collected from *Sagina* infested areas, indicate that "standard eradication" methods (digging up individual plants, heat-treating soil and spot-treatment with herbicides) in place over the last 10 years have resulted in a three orders of magnitude reduction in the seed load. However, around 200 seedlings per m^2 continue to be recorded due to germination from seeds within the soil. In 2008-09 we investigated the effectiveness of three methods designed to eradicate *Sagina* on Gough: "standard eradication" based on methods used in previous years (n = 5 plots); monthly "herbicide treatment" across the whole plot (n = 4 plots); and "soil stripping" where all plants and soil was removed down to bedrock (n = 2 plots). *Sagina* plants remained present within the standard eradication plots, with an average of 64 ± 79 (range 6 - 200) plants recorded per plot cleared in 8-months of monitoring. No *Sagina* plants were found in herbicide treated plots, although this method is unlikely to tackle the problem of dormant seeds remaining within the soil. Soil stripping was effective at removing the seed bank and only five and 33 plants were found over the 8-months monitoring period. We recommend that a combination of monthly herbicide spraying across the whole infested area (to prevent plants maturing and setting seed) and a programme of soil stripping (working from the outer edge of the plants range) to remove the seed bank, be utilised in order to provide a potential method to eradicate *Sagina* from Gough.

BACKGROUND

Sagina procumbens (commonly known as procumbent pearlwort, birdseye pearlwort or mossy pearlwort and hereafter referred to as *Sagina*) is a small prostrate herb native to Eurasia and North Africa. It is listed as one of the "One Hundred of the World's Worst Invasive Alien Species" due to its spread on cool temperate and sub-Antarctic islands (ISSG 2010). It is known to have invaded islands in at least the following areas: Falkland Islands, South Georgia, South Sandwich Islands and Tristan da Cunha (all islands within the UK Overseas Territories), Prince Edward Island and Marion Island (South Africa), Kerguelen Archipelago, Crozet Archipelago and Amsterdam Island (French Southern Territories) and Navarino Island (Chile), as well as becoming naturalised in parts of Australia, New Zealand, USA and Japan (ISSG 2010). *Sagina* is a small perennial, which once established can in some sub-Antarctic environments form large, dense mats, threatening native vegetation and soil fauna communities (Cooper *et al*. 2010). The plant germinates and reaches maturity within a few months, and produces large numbers of small, easily dispersed seeds which can persist in the soil for a minimum of several years

(Gremmen *et al*. 2001). At both Marion and Prince Edward Islands, *Sagina* is highly invasive, spreading at a rate of 100-300 m a year on Marion Island, where the plant is now considered naturalized and beyond control (Cooper *et al.* 2010).

In 1998, *Sagina* was discovered growing on concrete slabs close to the meteorological station at Gough Island, Tristan da Cunha (Hänel 1998, Gremmen 1999). Due to Gough's conservation importance as a natural World Heritage Site and Nature Reserve, and the fact that the mountainous interior of the island is superficially ecologically similar to the vegetated areas of Marion and Prince Edward Islands where *Sagina* has spread extensively, efforts were initiated in 2000 in order to try and eradicate the species (Gremmen *et al*. 2001). Measures to eradicate *Sagina* from Gough are reviewed by Cooper *et al.* (2010) and include mechanical removal of plants, treatment with hot-water and blow-torches, and application of herbicides. These procedures are complicated by the plant's distribution, as the weather station and area of infestation is located in the southeast of the island adjoining 15-40 m high, steep coastal cliffs (Fig. 1), necessitating specialised rope-access equipment and appropriately trained staff in order to safely tackle the plant which has spread in to these areas. Despite nearly a decade of eradication efforts *Sagina* remains present on Gough, although it has been restricted to a small (around 400 m in length; 1.2-1.6 ha in area) stretch of coastline adjoining the weather station (Cooper *et al.* 2010).

Funding for long-term programmes is difficult to obtain, and in order to determine if there is a realistic chance of eradicating *Sagina*, we set out to measure the effectiveness of different methods at reducing the number of germinating plants and reducing the soil seed bank with a view to devising a rapid eradication protocol.

ACTION

Gough Island: Gough Island, part of the UK Overseas Territory of Tristan da Cunha, is located in the central South Atlantic (40°21' S, 9°53' W) 380 km southeast of Tristan da Cunha. It is a volcanic island, 64 km^2 in area, with steep mountainous terrain. Lowland areas are dominated by a coastal tussock and fernbush vegetation type, characterised by relatively tall (up to 3-4 m), dense vegetation of mostly ferns, sedges, *Phylica arborea* trees and tall tussock grass *Spartina arundinacea* (Wace 1961).

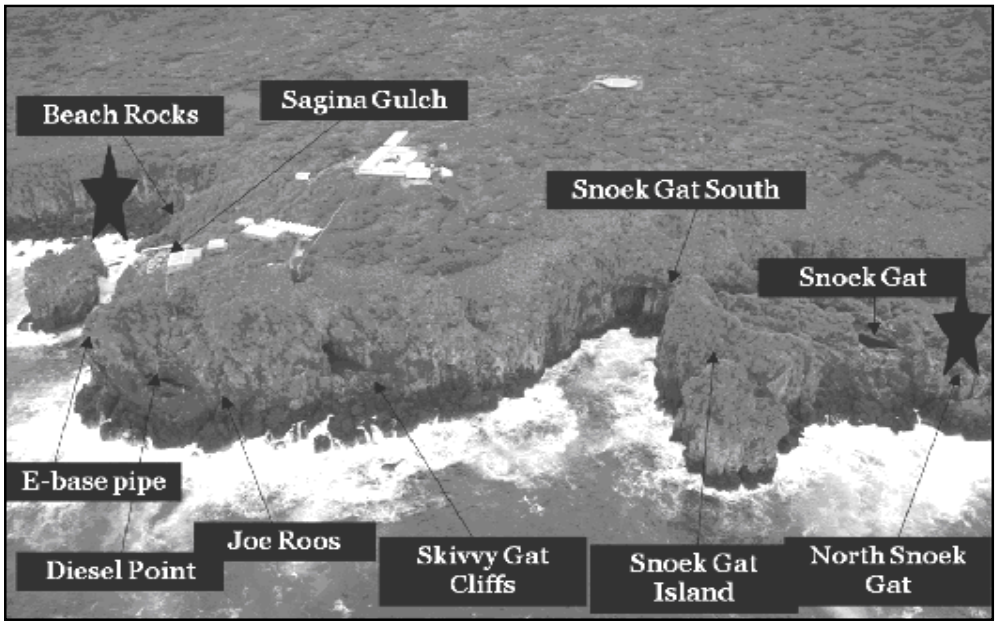

Figure 1. Aerial photograph indicating the areas where abseiling surveys were undertaken and the location of the *Sagina* infestation on Gough Island. The stars (left Beach Rocks, right North Snoek Gat) indicate the extremes of distribution where *Sagina* was found in the 2008-2009 field season.

***Sagina* infested area:** *Sagina* is currently known to occur along an approximate 400 m stretch of coastline adjoining the weather station. The main areas of infestation are along the edge of the coastal cliffs and in areas of bare rock and thin soils, where an absence of other native plants and cover has allowed *Sagina* to colonise. Plants also occur on concrete slabs and areas of bare soil underneath and alongside buildings and other structures at the weather station. In the area of infestation it is likely that *Sagina* has primarily spread via the movement of seeds along watercourses and possibly on boots or clothing of station personnel. From 1998 until 2003, the *Sagina* infested area was restricted to around a length of 200 m of cliffs close to the weather station from Beach Rocks to Skivvy Gat Cliffs (Fig. 1). However, in 2004 a new area of infestation was found at Snoek Gat (Cuthbert & Glass 2004), approximately 250 m from the weather station and where *Sagina* has occupied a further 100 m stretch of coastline from Snoek Gat South to North Snoek Gat (Fig.1).

Eradication methods: Trials to evaluate the efficacy of three different eradication methods were undertaken from September 2008 to September 2009. These were the "standard eradication" i.e. following a combination of techniques used over the previous 10 years (Cooper *et al.* 2010), "herbicide treatment", and "soil stripping" (both introduced in September 2008).

1) The standard eradication method consisted of removing visible plants and small areas of underlying soil by hand, treating local areas of remaining soil (e.g. that remaining in rock crevices) with a single treatment of herbicides and/or heating the soil/cracks in rocks with blow torches to destroy any remaining seeds (Gremmen *et al*. 2001, Cooper *et al.* 2010). Heat treatment of soil (spraying with water heated to 80˚C following plant removal) was applied in areas close to the weather station in an attempt to kill any remaining seeds. Five plots (each approximately 0.15 to 0.25 ha in area) were treated with the standard eradication techniques, with each plot checked at monthly intervals from September 2008 until September 2009.

2) The herbicide treatment method comprised a higher intensity of herbicide application than the standard method. Herbicide spraying was undertaken on a monthly basis across the whole plot area, rather than a single spot treatment at sites where *Sagina* plants had been removed (as with the standard eradication method). Two herbicides were used: a broad-spectrum glyphosphate-based herbicide (Roundup Ultra®, Monsanto, USA) acting upon plants through foliage application; and a pre-emergent hormonal based herbicide (Outpace Super®, Ububele Alfa chemicals, South Africa) that kills germinating seeds. Herbicides were mixed according to the manufacturer's recommendations and applied by spraying either with hand-held sprayers, or with 20-litre Napsack sprayers over larger areas. Whenever possible, spraying was undertaken in dry weather and in low wind conditions. Four plots (each 0.15-0.25 ha) were treated, with monthly spraying throughout the study period.

3) The soil stripping method consisted of removing soil down to bare rock. Soil was grubbed out with spades and mattocks, along with all other (native) vegetation. Removed soil was either bagged up for removal, or else dumped into the sea. The areas were then water blasted through a hose system and high-pressure water pump to attempt to denude areas of all remaining soil and strip the site down to bare bedrock. Soil stripping was combined with regular follow up checks for *Sagina* along with herbicide spraying of any emerging plants in areas of soil that had accumulated after stripping and water blasting. Two plots (each 0.2-0.25 ha) were treated with this method, with soil stripping of both undertaken in September-November 2008.

All other areas where *Sagina* was known to be present were treated with the standard eradication method, including areas accessed by rope-access and abseiling methods. Counts of the approximate number of plants encountered and areas cleared were recorded. This was done for 10 areas of cliffs (each 20-30 m in length, with boundaries of each area demarcated by natural features) where abseiling was required (Fig. 1), and for 10 other areas (as described by Gremmen *et al.* 2006, each covering approximately 0.15-0.30 ha) along the plants total range, in addition to the smaller areas (plots) used for the experimental methods outlined above. These counts were used to identify particular areas where *Sagina* remains a major problem and where future efforts should be best focused.

Measuring eradication efforts: To evaluate the effectiveness of the eradication methods, 11 plots were established in September 2008. Five areas (two close to Crane Point at the weather station and three in Snoek Gat) were treated with the standard eradication methods,

four areas (two near Crane Point and two at Snoek Gat) were treated with the herbicide method, and two areas (near Crane Point) were subjected to soil stripping. All of these areas were known to be heavily infested with *Sagina* based upon surveys in previous years and in September 2008. Consequently any change in the presence or abundance should reasonably reflect the effectiveness of the treatment used. Monitoring entailed counts of *Sagina* plants within each sample plots within each treatment area. Two or three counts were made each month, searching for emerging seedlings and established plants in the 11 plots. The number of plants found over the period November 2008 to May 2009 was recorded for each plot and treatment type. Due to the very small size of some *Sagina* plants (only 2-3 mm across shortly after germinating) and the difficulty and complexity of the terrain where it occurs, the monitoring is unlikely to have recorded every plant within each plot. However, such errors are likely to have occurred at all sites and treatments fairly evenly as the terrain and vegetation cover was similar, thus we do not consider any such effect to bias the overall pattern of the results. The only potential systematic bias might be under-recording of *Sagina* in standard eradication plots, as the presence of other vegetation and soil made checks more difficult.

Germination trials: Germination trials were established to quantify the number of viable *Sagina* seeds within the soil across the whole area of infestation. Topsoil samples were collected using a hand-trowel, with each sample removing an area of around 20-30 cm in diameter and 4-6 cm in depth (ca. 0.8 kg). In 2008 and 2009, each trial consisted of 20 soil samples collected from 20 stratified locations from areas across the known range of the plant around the weather station and Snoek Gat. Each sample was spread on to an individual plastic tray (20.0 x 11.8 cm) in the laboratory and kept under a spot-lamp to provide light and warmth, and regularly watered to maintain soil moisture. Trays were inspected for 14 days and the number of germinating *Sagina* seedlings recorded. These trials broadly follow the methods used in earlier years on Gough (Gremmen *et al*. 2006), allowing a semi-quantitative assessment of the change in seed-bank for the period 2000 to 2008. For comparison between years we only considered soil samples collected in October and November 2008, in order to provide germination data from the same period as sampled in earlier years.

We also investigated if saltwater kills or prevents germination of *Sagina* seeds. Using soil from sites where *Sagina* seed had been found to be present in earlier germination trials, saltwater treatments were set up in 10 trays filled with soil from infested sites, five were soaked with sea water for 24 h and five soaked with fresh water for 24 h. After 24 hours excess water was poured off and germination was monitored for 14 days. Conditions (light, warmth and watering with fresh water) were similar for all trays. Three separate salt water trials, each of 10 trays, were run in total.

CONSEQUENCES

Distribution and eradication effort in 2008-09: On average around 110 plants were cleared each month from all infested areas across the plant's range. This equated to removing roughly 30 kg of infested soil each month. Standard eradication methods across the whole infested area used around 15 l of mixed herbicide each month. In contrast, around 80 l of mixed herbicide was required to treat the four experimental "herbicide treatment" areas. Counts of the number of plants removed from different areas close to the weather station indicated that the original site of infestation still had the highest number of *Sagina* plants, with three sites at Crane Point having the first (338 plants), second (149) and fourth (61) highest number of plants in comparison to other areas. The other site close to the station that retained a high number of plants was at Diesel Point, where 135 plants were removed in the year. Considerable effort was required to check cliff areas where the plant occurred, with each 3-monthly check requiring over 80 separate abseils to survey all ground (Table 1). Major areas of infestation remain near Beach Rocks and the Skivvy Gat Cliffs (Table 1; Fig. 1), and these zones will require intensive treatment in order to clear *Sagina*.

Germination trials 2000-08: Germination trials undertaken pre- and post- treatment in 2000, and post-treatment in 2005, 2006 and 2008 indicate an exponential decline in seedling density in areas of soil infested with *Sagina* (Fig. 2). Numbers have decreased from around 100,000 seedlings per m^2 in 2000 (when eradication efforts were first started) to around 100 per m^2 in the 2008-09 season. In the saltwater treated trays, no *Sagina* seedlings emerged. In contrast, all 15 trials using the same soil soaked in fresh water produced *Sagina* seedlings (mean 12 seedlings/tray).

Table 1. Areas of cliffs searched for *Sagina* on Gough Island using rope-access methods, total number of *Sagina* plants cleared in November 2008, February and May 2009, and an assessment of whether areas are considered a major problem for treatment. Search areas correspond to those as indicated in Figure 1.

Search area	Cliff height (m)	Abseils per area	Number of plants found and removed	Problem areas for treatment
Beach Rocks	20	6	48	Yes
Archway Point	20	6	2	No
E-base pipe	30	8	3	No
Diesel Point*	30	10	6	Yes *
Joe Roos Cliffs	15	5	5	No
Skivvy Gat cliffs	40	10	> 100	Yes (major infestation)
Snoek Gat South**	30	10	17	Yes **
Snoek Gat Island**	20	8	10	Yes **
Snoek Gat Cliffs	30	10	0	No
Snoek Gat North	30	8	3	No

* Whilst the Diesel Point area had a relatively low number of plants it is regularly visited during logistic operations for the weather station, hence highly desirable to clear to reduce the risk of further spreading *Sagina*.
** Snoek Gat South and Snoek Gat Island are rated as high priorities for clearance as thick tussock vegetation in these areas makes checking for *Sagina* very difficult, thus more likely that some reach maturity and set seed.

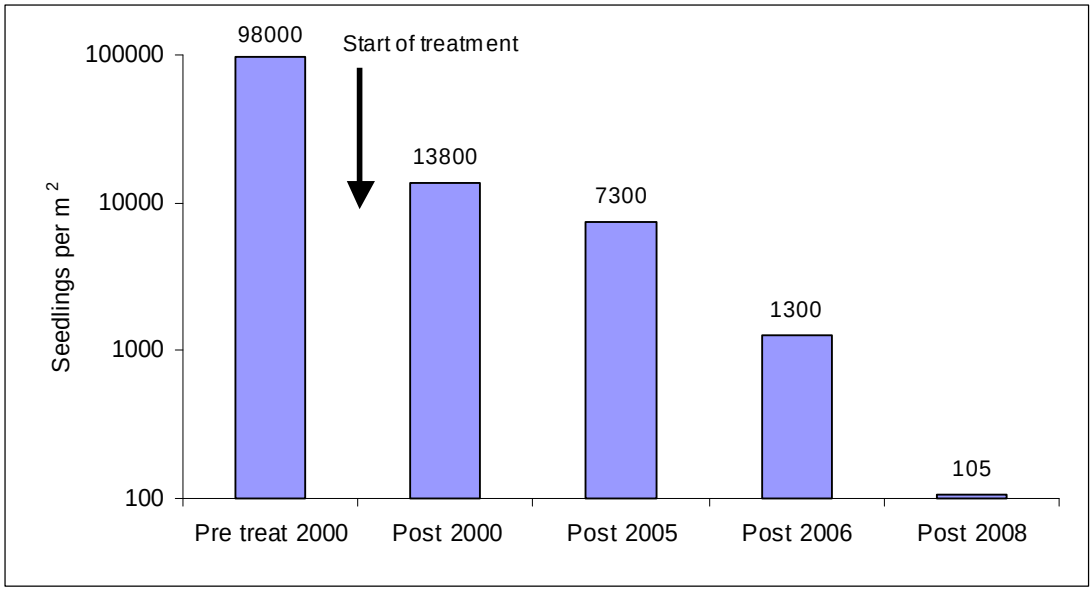

Figure 2. Results of germination trials indicating the number of *Sagina* seedlings per m^2 emerging for topsoil collected from *Sagina* infested areas around the weather station on Gough Island. Data for the period 2000 to 2006 are taken from Gremmen *et al.* (2006) with eradication interventions starting in 2000. (Estimated seedling densities are indicated above each bar).

Experimental trials: The results indicate that monthly spraying of herbicides over a broad area (as indicated by plot monitoring) was the most effective treatment, with no *Sagina* plants found in any of the five plots over 8-months of monitoring. Soil stripping showed good results, with just five and 33 plants found within the two plots. Stripping also made it much easier to locate any emerging seedlings and moreover the majority of plants found at these two sites were in areas where residual soil had gathered following water blasting, and these plants could be easily treated with herbicides. The five areas treated with the standard eradication method showed a continued presence of *Sagina* plants (mean 64 ± 79; range 6 - 200 plants/plot) cleared throughout the 8-months of monitoring. The

time and effort required to search and treat these sites was also considerably greater than those treated by herbicide spraying or by soil stripping, due to the presence of other vegetation making locating germinating *Sagina* plants extremely difficult. The remaining vegetation in these sites also makes it more likely that we under recorded the total number of plants within the standard eradication areas.

Discussion: Attempted *Sagina* eradication on Gough has been ongoing for nearly 10 years and to date appears to have been successful at restricting the plant to a small area of coastal cliffs. These efforts have probably prevented *Sagina* from becoming established in mountainous areas of the island where it is likely it would spread rapidly and cause most ecological damage. Eradication efforts have been successful at reducing the seed load within the soil, further reducing the risk that the plant will spread to new areas. While these results are encouraging, eradication remains problematic as it requires the complete removal of all seeds and plants. The small size of *Sagina* plants, its ability to rapidly mature (and hence set seed), coupled with the difficulty of the terrain where it is established, means that continued concerted effort will be required in order to hold the plant in check and that more aggressive methods are required to achieve eradication.

The standard eradication method of digging up individual plants, heat-treating soil and one off spot-treatment with herbicides (Gremmen *et al*. 2001, Cooper *et al*. 2010) have restricted the range and abundance of *Sagina*, however despite extensive efforts plants are still emerging. In 2008-2009 areas on or adjoining Crane Point, the site where *Sagina* was first recorded and an area intensively treated for nearly a decade, remained one of the major problem areas with the most plants removed from these sites in comparison to all other areas near the weather station. The continued presence of *Sagina* in these and other areas is consequently likely to be due to the remaining seed within the soil (ISSG 2010), which the standard eradication method has failed to eliminate.

The results of the treatments undertaken in this study bear out this assumption, with large number of plants still geminating under the standard eradication approach. No mature plant or seedling was found in any of the five plots treated with monthly spraying with broad-spectrum and emergent herbicides. Due to the area that can be relatively quickly covered with this method (with 2 workers the five plots could be sprayed in around 4-5 h), herbicide spraying could allow the whole infested area to be treated, thus reducing the likelihood of any *Sagina* plants reaching maturing and setting seed. While spraying prevented any plants from germinating in the experimental plots, it is unclear if Outpace Super herbicide application is killing dormant seed within the soil. Given the high rainfall on Gough (mean annual precipitation around 3,000 mm/year) it is likely that herbicide residues will be washed out of the soil, thus rendering herbicide treatment less effective as a sole eradication method. Soil stripping showed encouraging results, with low numbers of plants recorded from these two experimental areas, and with any remaining plants easy to find and "trapped" in areas where stripped soil had collected. While this method is time-consuming (2 workers estimated to take around 3 days to strip a 10 x 10 m area) it effectively removes dormant seed, offering the real possibility that *Sagina* can be eradicated if this method can be undertaken across the plant's range on the island. While concerns have been raised that stripping might inadvertently spread the plant due to infested soil being washed up by the sea on new areas of coastline, the results of the saltwater germination trials suggest that this is unlikely. Suggestions to use saltwater spraying or spreading of salt to treat actual infested areas (Gibbs 2009) were trialled in 2009 but appear to be unsuccessful as the high rainfall quickly washes salt out of the soil, allowing *Sagina* and other plants to germinate and continue growing (RSPB unpublished data).

Recommendations: Based on the last decade of work aimed at *Sagina* eradication on Gough Island and the results of the more recent concerted trials undertaken in this study, we recommend that a combination of monthly herbicide treatment and soil stripping be employed in order to attempt to eradicate *Sagina*. Herbicide treatment should be undertaken in all areas of the plants distribution to prevent germination and further seed set, with particular attention focused on the priority cliff areas (identified in Table 1) and around Crane Point, where most remaining plants have been recorded. Whilst monthly herbicide application prevented all plants from germinating, investigating if a less intensive regime (e.g. spraying every 2 or 3 months) would be desirable to reduce manpower costs and quantity of herbicides used. In conjunction with herbicide treatment, soil stripping should

be undertaken in a systematic fashion to remove seeds. Following the recommendations of Gibbs (2009), stripping (with herbicide application) should be undertaken working from the outer edges of the plants current distribution, aiming to reduce the infested zone to an ever decreasing area. Strict quarantine procedures, as detailed in Gibbs (2009) and Cooper *et al.* (2010) should be undertaken in order to prevent reintroducing the plant in to areas that have been cleared and to further reduce the risk of *Sagina* spreading elsewhere on the island.

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