Persistence, accuracy and timeliness: finding, mapping and managing non-native plant species on the island of South Georgia (South Atlantic)

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Abstract The South Georgia ecosystem-based habitat restoration project is a major project that began with the eradication of invasive rats (*Rattus norvegicus*) and reindeer (*Rangifer tarandus*), 2011–2017. As part of this restoration programme a non-native plant management strategy was developed and implemented. With only 8% of the whole South Georgia landmass suitable for vascular plants (ca. 283 km²) due to permanent ice and bare rock, there have been 25 indigenous vascular plants and 41 non-native plants recorded from earlier surveys. Following removal of grazing pressure from introduced mammals, surveys were conducted to quantify the current status and distribution of non-native plant populations and enable a non-native plant control strategy to be developed for the island. Due to the vast scale of the island, multiple seasons were required to carry out rapid surveys of key indicators such as species, area of plant coverage in square metres and age class (mature or juvenile). Survey and control data were entered into a spatial database to enable analysis, allow data-informed management decisions and be used for long-term control-based monitoring of outcomes. During this series of surveys, 44 naturalised, non-native plant species were identified and mapped. Of these, 34 species are now being managed at zero density with 56,851 m² at 184 sites controlled to date; four are managed at specific sites with 22,443 m² controlled to date, three require confirmation of species and the remaining three species are widely established and receive limited control. Spatially quantifying the distribution and control of non-native plants has enabled the development and implementation of an effective management strategy which contributes to the restoration of South Georgia's native biodiversity.

Keywords: Atlantic Ocean, control-based monitoring, habitat restoration, non-native plants, South Atlantic, South Georgia

INTRODUCTION

South Georgia (3,533 km², 54°21' S, 36°42' W) is located in the South Atlantic Ocean approximately 1,450 km south-east of the Falkland Islands (Fig. 1). South Georgia is a United Kingdom Overseas Territory (UKOT) managed by the Government of South Georgia and the South Sandwich Islands (GSGSSI). The island is mountainous and glaciated, and it is only the coastal fringes that are snow free in the summer months and able to support vegetation. An estimated 8% of the land mass of South Georgia (i.e. 283 km²) provides suitable habitat for vascular plants (GSGSSI GIS, 2007) and, in spite of the sub-Antarctic climate, many non-native species have naturalised or persisted for many years.

The first non-native plant species recorded on South Georgia was *Poa annua* in 1902 (Walton, et al., 1973) and this may have been introduced with early sealing expeditions. Increasing disturbance due to the activity of shore-based whaling operations after their establishment from 1904 (Burton, 2012) likely contributed to many of the later introductions. Greene (1964) classified 51 vascular species for the island with 24 as listed as native and 27 as non-native or introduced. There are now considered to be 25 native vascular species with the addition to Greene's list of the hybrid *Acaena magellanica* × *A. tenera* (Galbraith, 2011; Burton, 2012)

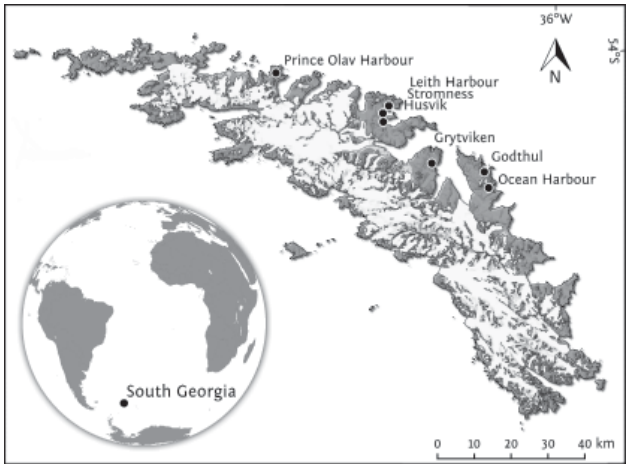

Fig. 1 Location of South Georgia Island and main whaling station locations on the island.

Osborne, et al. (2009) recorded 24 introduced vascular plant species during the survey undertaken in 2009 as part of the Royal Society for the Protection of Birds (RSPB) South Atlantic Invasive Species Project.

Local management of selected non-native plant species on South Georgia has been undertaken since 2004 when efforts to control bittercress (*Cardamine glacialis*) were initiated. In 2010 the efforts to control bittercress were increased and other non-natives were targeted at selected sites (GSGSSI, 2016).

In 2014, GSGSSI obtained funding from the UK Government-funded Darwin Plus initiative (www.darwininitiative.org.uk) for the project 'Strategic Management of Invasive Alien Plants on South Georgia'. This project enabled a more strategic approach to island-wide non-native plant control. As well as on-going control of low incidence species, comprehensive surveys were completed and the distribution and range of non-native plant species on the island were mapped. This paper outlines the processes that were undertaken to determine the extents of non-native plant species to support the development of a non-native plant management strategy for the island.

METHODS

Desktop review

The first step to determine the plant species present was a desktop review of all documents available that had location information for non-native species recorded on

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South Georgia. These included published and unpublished reports, herbarium records, and personal communications with researchers, staff and visitors. Many of these records had limited spatial accuracy and were recorded by general location only, which restricted the ability to map these records. Osborne, et al. (2009) had good spatial data for the sites they visited although they had not been able to access the restricted areas in some of the historic whaling stations. All the records found in the desktop review were compiled into a filterable dataset which generated a species list by locality which was then checked for presence/absence during any visits to that area. This dataset provided the initial non-native plant species list and search targets, with more recent records given a higher search priority. While not many of these records were very accurate spatially they gave a good starting point for surveying.

Field surveys

Using the compiled historical records, surveys were undertaken to obtain accurate information on the current abundance and distribution of non-native plant species in each search area. Priority survey locations were given to those with recent records, areas of human disturbance particularly whaling stations, and where reindeer had been present. All the surveys were conducted on foot with access to some areas, where required, provided by ship or small boat.

A rapid GPS survey technique was used to cover the large areas involved. The resolution for survey points was based on plant population size whereby the larger the population, the further apart points were recorded to reduce the time required for recording. GPS waypoints were taken at the centre of each non-native plant infestation with separate waypoints for each species present. Key indicators for each waypoint were recorded i.e. the plant species, the area of plant coverage in square metres, and age class (mature or juvenile not capable of reproduction). Coverage was estimated from the ground cover of the infestation, and is the ground area covered by the plant if forming a monoculture. In the case of scattered plants the percentage cover is used to estimate the total square meters of the infestation.

From the spatial information collected non-native species were classified into 5 classes depending on population size and distribution (Table 1). Rather than determine whether a non-native species was likely to be invasive, the precautionary principle (Williams, 1997) was adopted and all non-native vascular plants have been classified as part of the strategy.

The main surveys were conducted in February–March 2015 and in February–March 2016, when most non-native plants were in flower; this made it easier to assess distribution, and the flower structures provided the diagnostic characteristics to differentiate non-native species from closely related native plants.

Accurate geographical coordinates were essential for relocating infestations; coordinates were recorded using hand-held global positioning system receivers (Garmin GPS62 & 64). To manage these data a GPS Exchange Format file (gpx) import and export capability was developed in the recording database to facilitate data storage and display. Data were collected continuously during different control and survey visits as weather and logistics allowed more time to check areas more thoroughly. Additional data were collected where necessary during these visits to improve spatial knowledge of the infested areas and outlier plants.

Control based monitoring

Along with surveys, control was undertaken on selected known sites and all control activities were recorded using the same key indicators that had been used during survey data collection (GPS coordinates, coverage in square metres and age class), with the addition of the type of herbicide, the application rate used, and the volume of water used.

Management units

In order to manage the site-led control of Class Two species, South Georgia was divided into 117 management units. The management units were determined by a two-step process; firstly the island was divided into eight eco-geographic zones, defined primarily by climate, vegetation and the historic presence of introduced mammals (Martin, et al., 2009). For the purpose of non-native plant management, these zones were further divided into smaller units based on the level of historic human disturbance, presence of non-native plants, geographical features and ease of logistical access.

RESULTS

South Georgia's vegetation is mostly short grassland or low-growing rush and sedge communities, apart from the tall stands of coastal tussac (*Parodiochloa flabellata*). Many of the non-native plants are also low-growing which makes detection very difficult; persistent surveying is required to locate all individuals. Sometimes a number of visits are needed as many species are not very visible until flowering, and timing is critical to finding and controlling these species before seed becomes viable. New infestations and new non-native species have also continued to be found which highlights the need for persistent surveys. Due to the size of the island, multiple seasons were required to survey the priority areas. Following repeated surveys between

Table 1 Classification of non-native plants on South Georgia and number of non-native plants in each weed strategy class.

Class	Description	Number of species
One	Priority species; require species-led control at the island-wide level, to control all plants before they reach maturity. All sites with these species have a 'Site Tag' in the Weeds Database, for management of follow-up visits.	34
Class Two – Site-Led	Species of moderate distribution, requiring site-led control. Priority populations are those at high-use visitor sites, and sites with small infestations where control will reduce further dispersal.	4
Class Three – Site-Led	Species which are widespread and abundant, and require management at high-use visitor sites and at some remote outlier sites where appropriate.	3
Research	More information required before classification, to confirm status.	3
Historic	Historic species, not seen for at least 10 years. A re-sighting promotes the species to Species-Led – Class One.	35

2014 and 2017, we consider there to be 44 non-native species present on the island or that have recent records from the last 10 years, with a further 35 species recorded historically but no longer present (Appendix 1).

There have now been 4,245 non-native survey locations recorded to date. Following the survey these non-native species have been classified depending on population size and distribution (Table 1).

From the survey results a non-native plant management strategy (GSGSSI, 2016) and an associated environmental impact assessment were developed. In line with GSGSSI requirements, these documents were peer-reviewed to ensure they met best practice standards. After their finalisation, more widespread control of non-native plant species was undertaken across the island.

There are 34 Class One species occurring at 184 control sites; these are managed on a species-led basis by targeting them across their entire known range on South Georgia. Each of the Class One species is managed at zero density whereby all plants are controlled where found.

Fig. 2 shows the small increase in new Class One sites found and treated each season, along with the proportion that were active (some plants found) and not active (no plants seen at that site that season).

Control-based monitoring data show that 49,202 m^2 of Class One species have now been controlled on South Georgia with 850 m^2 of follow-up required in 2016/17 (Fig. 3). The majority of the treated species controlled in 2015/16 were *Rumex acetosella* since this was the most widespread Class One species and control was undertaken only once the full extent of the infested area of this species was known after surveys that season.

There are currently four Class Two species with 221 control locations, these records total 44,903 m^2 of plants treated over the seasons shown in Fig. 3.

DISCUSSION

Spatially quantifying the distribution and control of non-native plants has enabled the development and implementation of the 'South Georgia Non-Native Plant Management Strategy 2016-2020' (GSGSSI, 2016) which contributes to the restoration of South Georgia's native biodiversity.

Control of Class Two species is prioritised according to the potential dispersal risk posed by small populations and the threat they present to surrounding areas. Spatial data from the surveys overlaid with the units was essential in presenting this information to enable decision-making for the strategic management of the surveyed species.

There were 44 non-native plant species detected during the surveys and of these, 34 are currently being controlled using a range of methods with the aim being to eradicate them from South Georgia. Many remote areas have not been able to be visited yet, and although the risk of non–native infestations at these sites is considered to be low, based on historic records, all the vegetated areas of the island will eventually need to be surveyed. This may take many years due to the logistical difficulties of accessing the island's remote areas.

To ensure success of the non-native plant strategy, persistence is required in treating all target plants until their seed bank is fully diminished. Control-based monitoring will assist in determining success by utilising the data recorded on plant coverage, age class, herbicide rates and volumes in order to measure progress season by season.

We are confident that most of the non-native species and infestations have now been located. However, due to the large size of the areas to be searched, new records are not unexpected and the weed strategy has been designed to be adaptive based on the data available.

While all high priority areas for non-native species have now been surveyed, continued checks will be required to ensure all infestations are located around the island. Also, as vegetation communities are likely to recover from grazing following the reindeer eradication, further searches for non-native plants will be required across the estimated 4,500 ha of vegetated landscape on the Barff Peninsula and in the Stromness Bay area (3,250 ha) where the reindeer were present.

Monitoring new incursions and unknown infestations will be ongoing and this persistence can be achieved only if there is a long-term commitment to providing necessary resources, as is currently the case with the present control programme funded by the Government of South Georgia and the South Sandwich Islands.

Timeliness is also vital for ensuring that populations are successfully controlled. All control operations and surveys must take place during the optimum time for locating and treating non-native targets. For South Georgia, this is between December and February.

Accuracy is also essential, all target species need to be spatially documented using GPS waypoint data to aid in re-locating plants. While there are some small differences in estimating plant coverage by observers, regular comparisons between people improve accuracy and consistency of

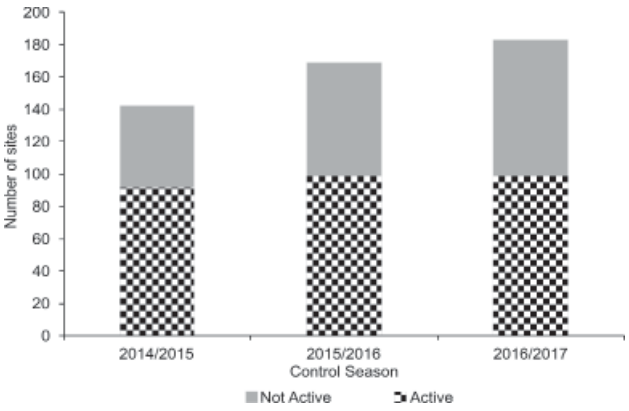

Fig. 2 Number of Class One non-native plant sites on South Georgia 2014–2017.

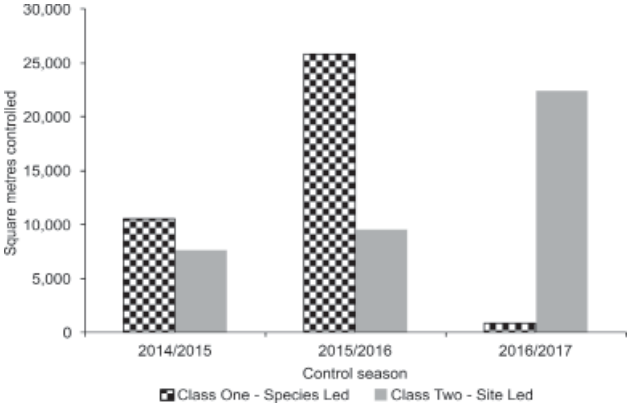

Fig. 3 Area of Class One and Class Two non-native plant sites controlled on South Georgia over the last three seasons (2014/15–2016/17).

measuring. Having data in quantifiable measures allows changes in the size and number of infested areas to be monitored as control efforts are undertaken. Control-based monitoring provides quantitative information for managing the target species and enables the comparison of control and survey data. This information will assist with further refinement of the management strategy and enable data driven decision making.

Finally, as with all eradication projects, strong biosecurity to prevent new introductions to South Georgia and the movement of already established non-native plant species between areas is essential. In South Georgia, there is a wide range of biosecurity measures in place from cargo packing facilities in the UK and mandated equipment cleaning before every landing to a bespoke biosecurity facility on the island itself. Ongoing education and awareness raising is key to ensure that all visitors to the island are aware of their biosecurity obligations and the vital role it plays in protecting native biodiversity.

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Appendix 1 Naturalised non-native vascular plants on South Georgia species list, 2017.

Latin Name	Common Name	Family	Strategy Class
Achillea millefolium	yarrow	Asteraceae	One
Achillea ptarmica	sneezewort	Asteraceae	One
Agrostis vinealis	brown bent	Poaceae	One
Allium schoenoprasum	chives	Amaryllidaceae	One
Anthoxanthum odoratum	sweet vernal grass	Poaceae	One
Anthriscus sylvestris	cow parsley	Apiaceae	One
Capsella bursa-pastoris	shepherd's purse	Brassicaceae	One
Cardamine glacialis	bittercress	Brassicaceae	One
Carex aquatilis	water sedge	Cyperaceae	One
Carex nigra	common sedge	Cyperaceae	One
Carex sp.	sedge unknown (not flowering)	Cyperaceae	One
Carex vallis-pulchrae	marsh sedge	Cyperaceae	One
Dactylis glomerata	cocksfoot	Poaceae	One
Deschampsia cespitosa	tufted hair-grass	Poaceae	One
Deschampsia flexuosa	wavy hair-grass	Poaceae	One
Elytrigia repens	couch grass	Poaceae	One
Empetrum rubrum	diddle dee	Ericaceae	One
Festuca rubra	red fescue	Poaceae	One
Juncus filiformis	thread rush	Juncaceae	One
Leptinella scariosa	feathery buttonweed	Asteraceae	One
Lobelia pratiana	berry lobelia	Campanulaceae	One
Luzula multiflora var congesta	heath wood-rush	Juncaceae	One
Nardus stricta	mat grass	Poaceae	One
Ranunculus acris	meadow buttercup	Ranunculaceae	One
Ranunculus repens	creeping buttercup	Ranunculaceae	One
Rumex acetosella	sheep’s sorrel	Polygonaceae	One
Rumex crispus	curled dock	Polygonaceae	One
Sagina procumbens	pearlwort (procumbent)	Caryophyllaceae	One
Scorzonerioides autumnalis	autumn hawkbit	Asteraceae	One
Stellaria media	common chickweed	Caryophyllaceae	One
Trifolium repens	white clover	Fabaceae	One
Tripleurospermum inodorum	scentless mayweed	Asteraceae	One
Vaccinium vitis-idaea	cowberry	Ericaceae	One
Veronica serpyllifolia	thyme-leaved speedwell	Scrophulariaceae	One
Agrostis capillaris	common bent	Poaceae	Two
Deschampsia parvula	punk grass	Poaceae	Two
Poa pratensis	smooth meadow grass	Poaceae	Two
Trisetum spicatum	spike trisetum	Poaceae	Two
Cerastium fontanum	common mouse-ear	Caryophyllaceae	Three
Poa annua	annual meadow grass	Poaceae	Three
Taraxacum officinale	dandelion	Asteraceae	Three
Agrostis? unknown	unknown grass - TBC	Poaceae	Research
Galium saxatile	heath bedstraw	Rubiaceae	Research
Holcus lanatus	Yorkshire fog	Poaceae	Research
Aegilops sp.	goat grass	Poaceae	Historic
Alchemilla monticola	velvet lady’s mantle	Rosaceae	Historic

Appendix 1 (continued) Naturalised non-native vascular plants on South Georgia species list, 2017.

Latin Name	Common Name	Family	Strategy Class
Alopecurus geniculatus	marsh foxtail	Poaceae	Historic
Artemisia sp.	mugwort	Asteraceae	Historic
Avena fatua	wild-oat	Poaceae	Historic
Brassica cf. *napus*	rape	Brassicaceae	Historic
Carum carvi	caraway	Apiaceae	Historic
Centella sp.	centella	Apiaceae	Historic
Cerastium arvense	field mouse-ear	Caryophyllaceae	Historic
Daucus carota	carrot	Apiaceae	Historic
Festuca ovina	sheep's fescue	Poaceae	Historic
Hypericum tetrapterum	square-stemmed St John's-wort	Clusiaceae	Historic
Lactuca sp.	wild lettuce	Asteraceae	Historic
Lamium purpureum	red dead-nettle	Lamiaceae	Historic
Lolium multiflorum	Italian rye grass	Poaceae	Historic
Lolium temulentum	darnel ryegrass	Poaceae	Historic
Lotus corniculatus	bird's foot trefoil	Fabaceae	Historic
Lupinus sp.	lupin	Fabaceae	Historic
Matricaria discoidea	pineapple weed	Asteraceae	Historic
Phleum pratense	timothy grass	Poaceae	Historic
Pisum sativum	pea	Fabaceae	Historic
Plantago sp.	hoary plantain	Plantaginaceae	Historic
Poa trivialis	rough meadow grass	Poaceae	Historic
Raphanus sp.	radish	Brassicaceae	Historic
Rorippa islandica	northern yellow-cress	Brassicaceae	Historic
Rumex alpinus	alpine dock	Polygonaceae	Historic
Senecio vulgaris	common groundsel	Asteraceae	Historic
Sinapis arvensis	charlock	Brassicaceae	Historic
Solanum tuberosum	potato	Solanaceae	Historic
Sonchus sp.	sow thistle	Asteraceae	Historic
Stellaria graminea	grass leaf starwort	Caryophyllaceae	Historic
Thlaspi arvense	field penny-cress	Brassicaceae	Historic
Trifolium hybridum	alsike clover	Fabaceae	Historic
Urtica dioica	common nettle	Urticaceae	Historic
Urtica urens	annual nettle	Urticaceae	Historic