Darwin Initiative: Final Report

Darwin Project Information

Project reference	DPLUS080
Project title	Securing South Georgia's native habitats following invasive species control
Country(ies)	South Georgia
Lead organisation	Royal Botanic Gardens, Kew (Kew)
Partner institution(s)	Indigena Biosecurity International (Indigena) and Durham University
Darwin grant value	£256,544
Start/end dates of project	01 April 2018 – 30 September 2021
Project leader's name	Rosemary Newton
Project website/blog/social media	Kew project website Twitter: Follow @KewUKOTs; Search #KewSouthGeorgia
Report author(s) and date	Rosemary Newton & Colin Clubbe 31/12/2021

1 Project Summary

The project focussed on securing native habitats and their constituent native species on South Georgia following non-native species control. South Georgia is an isolated UK Overseas Territory in the Southern Atlantic Ocean. The island is 165 km long and 35 km wide and located around 1300 km south-east of the Falkland Islands (Figure 1).

Invasive non-native species are one of the most important drivers of biodiversity loss, and this impact is particularly severe on islands. South Georgia is a wildlife haven which has, until recently, been significantly impacted by introduced reindeer and rodents. Reindeer have been successfully removed and the island was declared rodent free in May 2018 (DPLUS031).

In response to the predicted grazing pressure release following mammal eradication, a Non-Native Plant Management Strategy was developed by the Government of South Georgia & the South Sandwich Islands (GSGSSI; DPLUS015) and implemented to manage to zero density 33 of the 41 non-native plant species on the island and to control the more widespread invasive plant species. Eradication of non-native plant species is exceedingly difficult because of the formation of a persistent soil seed bank from which plants can regenerate, often for many years.

The project was developed in collaboration with Indigena Biosecurity International, the New Zealand based company that is undertaking the non-native plant species control programme under contract to GSGSSI, as well as Durham University with advice from GSGSSI. The project aims were to: 1) safeguard South Georgia's native habitats by monitoring and assessing vegetation changes following invasive non-native species control; 2) estimate from soil seed bank and seed viability studies the risk of non-native plant species persisting beyond 2020 (the end date for the existing Non-Native Plant Management Strategy) to inform future management strategy; 3) quantify the potential for non-native plant species to disperse into new areas following glacial retreat due to climate change; and, 4) secure seed and fern spore collections of native plant species for long-term conservation at Kew's Millennium Seed Bank (MSB) at Wakehurst.

Project outcomes will inform future management strategies by GSGSSI of non-native plant control and of terrestrial communities in the face of predicted climate change.

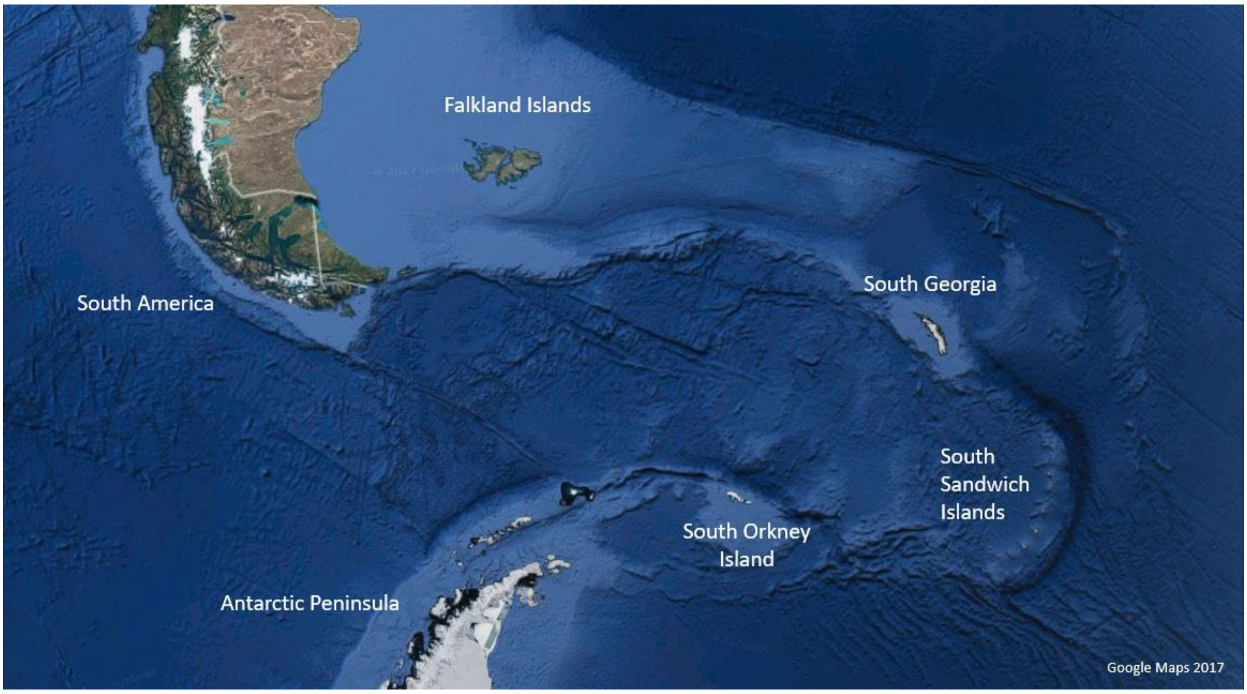

Figure 1: Location of the UK Overseas Territory of South Georgia and the South Sandwich Islands

2 Project Partnerships

The main stakeholder is the Government of South Georgia & the South Sandwich Islands (GSGSSI). We have maintained contact with and provided updates to Helen Havercroft (Chief Executive for most of the project period), Jennifer Black (Environment Officer) and Ross James (Visitor Management and Biosecurity Officer) at GSGSSI throughout the project. The project was designed to provide the scientific evidence underpinning GSGSSI's 5-year Non-Native Plant Management Strategy and to directly feed into the direction of the next 5-year strategy.

A project steering group involving all the partners was established at the start of the project to ensure that all partners were involved in all planning, development and decision making. Six-monthly steering group meetings (Annexes 8-15) and regular email and phone conversations maintained good communications between Kew (Rosemary Newton, Colin Clubbe, Marcella Corcoran) and project partners Indigena (Bradley Myer, Kelvin Floyd, based in New Zealand) and Durham University (Wayne Dawson) to discuss and review project activities. All partners were fully engaged in the project development and writing the original proposal and have been involved in decision-making and reporting throughout the project delivery.

The formal project launch and workshop were held in Stanley in the Falkland Islands 16 – 22 December 2018. During this week meetings were held with project partners (Indigena, Durham University and Kew) and key stakeholders, including GSGSSI and Falklands Conservation (FC), to ensure that they were fully briefed about the project and had an opportunity to contribute early on to project planning (Annexes 16&17).

GSGSSI's advice and recommendations on field sites and activities were invaluable in developing protocols for sample and data collection to minimise the impact of project activities on South Georgian wildlife, enabling permits for field work (Annexes 18&19) to be issued following Regulated Activity Permit (RAP) applications (Annexes 20&21).

A face-to-face meeting with Helen Havercroft and Jennifer Black (at the GSGSSI Science and Stakeholder Event, hosted at Kew in September 2019) enabled useful discussions between Kew and GSGSSI and these helped inform the development of the GSGSSI's new 5-year stewardship framework for SGSSI: Protect, Sustain, Inspire 2021-2025, particularly the Biosecurity section, which was published in January 2021.

A recent half-day online workshop held in October 2021, arranged by Jennifer Black of GSGSSI and in which Rosemary Newton and Wayne Dawson presented key results from the project (Annex 22), provided input into developing a new science strategy and an updated non-native plant management plan to replace the existing one. GSGSSI have remained very engaged and supportive of the project throughout.

This is a strong partnership of people who know each other well and have worked together for some time. The partnership strengthened during the Covid-19 pandemic with support offered and received from and by all partners as needed during the challenging year of 2020. Kew and Durham University's partnership continue with funding received for the DPLUS144 project: "Protecting South Georgia's terrestrial communities from climate change invasion synergies" in collaboration with the British Antarctic Survey (BAS) and the South Atlantic Environmental Research Institute (SAERI). Kew continues to explore project opportunities with Indigena colleagues.

3 Project Achievements

3.1 Outputs

Output 1 activities

The South Georgia DPLUS080 project was formally launched at the workshop held in Stanley in the Falkland Islands in December 2018. This was a unique and valuable opportunity to bring the project team, field team and stakeholders together to meet ahead of the first field season on South Georgia. Although the methodologies and protocols were collaboratively prepared in the months prior to the workshop through online discussions, the meeting enabled final discussions to take place to ensure that everyone was clear on and in agreement about the activities to be completed on South Georgia during the upcoming field seasons and the methods being employed (Annex 23). Despite a day of the workshop being lost due to the unexpected flight cancellation from Punta Arenas to Mt Pleasant because of rotary winds over the Falkland Islands, we were able to fully discuss and clarify all aspects of the project amongst the partners and field team and so the workshop was a great success, achieving all its aims (Figure 2).

Dissemination activities were undertaken whilst in Stanley to ensure maximum exposure to the project scope and activities. The full team undertook a radio interview at the Falkland Islands Radio Station (Annex 24). This was recorded on 18 December 2019 (Annex 16) and broken down into three separate segments which were broadcast on several occasions over the subsequent weeks. The project team was also interviewed by Penguin News, the weekly newspaper of the Falkland Islands. A double-spread feature with colour images was published on 18 January 2019 (Annex 25).

The Memorandum of Collaboration (MoC) was discussed at the meeting held at the offices of GSGSSI and agreed in principle. However, as legal teams from each of the partners needed to review the document, the MoC could not be signed off at this meeting. The MoC was subsequently approved by all legal teams and signed by all parties (Annex 26).

A Regulated Activity Permit (RAP) is required for all field work on South Georgia; these ensure that GSGSSI is aware of and grants approval for all planned activities and that any possible environmental impacts are minimized. A RAP to cover the first field season activities was approved and issued by GSGSSI (Annex 20). Following the first field season, the required RAP feedback form was returned to GSGSSI (Annex 27). In the lead up to the second field season, the RAP renewal application was submitted (Annex 21) and the permit for the second field season approved and issued (Annex 19), enabling the field activities to commence.

Figure 2: Rosemary Newton (Kew, project leader), Wayne Dawson (Durham University), Kelvin Floyd (Indigena, field team leader), Bradley Myer (Indigena, managing director), Pamela Quilodrán, Ken Passfield and Sally Poncet (Indigena, field team members) and Colin Clubbe (Kew) discussing activities of the South Georgia DPLUS080 project.

The field team spent a total of 12 weeks on South Georgia in each of the two field seasons, completing activities related to both the DPLUS080 project (e.g. monitoring non-native plant abundance and distribution; collecting seeds, soil samples and dispersing seeds) as well as the Non-Native Plant Management Strategy (e.g. treating non-native plants with herbicide; surveying new areas for non-native plant occurrence). The field team leader, Kelvin Floyd, kept in email contact with Kew throughout the field season ensuring a dialogue on progress was maintained. Weekly accounts of field activities were kept, including details on the occurrence of non-native plant species at field sites (Annexes 28&29). Regular photographs documenting activities were emailed by the field team to Kew, which were posted on Twitter (Annex 30).

Vegetation data from the different field sites have been analysed and changes in vegetation composition, plant height and cover of target non-native and native plant species in herbicide plots determined (Annex 22, Slides 6-9). These data suggest that native plant species are increasing in cover (particularly *Acaena* spp., *Phleum alpinum*, *Deschampsia antarctica* and *Poa flabellata*) and the non-native *Poa annua* is decreasing. These data have provided evidence that the native vegetation is recovering following reindeer removal and that the control programme for non-native plants on South Georgia is working for most Class 1 species (Annex 22, Slides 6-9; Annex 31). At the most recent steering group meeting we decided to include an additional season of data in the analysis which will be collected in the field season of 2021-2022. This will ensure that longer vegetation change trends will be captured. Once the final analysis is complete a summary report on non-native species distribution will be produced and a paper for submission to a peer-reviewed journal prepared to document the vegetation changes on South Georgia following non-native species removal.

<u>Output 2 activities</u>

The soil sampling protocols were developed following a review of field sampling methods and the methodology was finalised at the Falkland Islands workshop (Annex 23). Five soil samples from 26 sites and five soil samples from 20 sites were collected over the 2018-2019 and 2019-2020 field seasons, respectively (Annexes 32&33). The second field season had to be cut short to ensure the safe return of field team members to their respective countries following the Covid-19 outbreak. These last-minute changes in field work plans did not have a major impact on the project as soil samples had already been collected.

Prior to sending the soil samples to the UK, a Standard Operating Procedure (Annex 34) was written to safely process soil samples from South Georgia at the Millennium Seed Bank (MSB) and to identify and quantify viable seeds in the samples whilst ensuring that risks to the UK environment from organisms in the soil are minimised. This was submitted to the Animal and Plant Health Agency (APHA) and a Licence to import, move and keep prohibited soil was issued by Defra to the MSB in March 2019 (Annex 35). This was updated with an added minor amendment in December 2019 to enable the harvesting of leaf material for DNA analysis from seedlings germinated in South Georgia soil (Annex 36). Transporting living (i.e., non-autoclaved) soil samples from South Georgia via the Falkland Islands to the UK involved significant logistical organisation and authorisation. The Falkland Islands biosecurity officer was key in this and helped ensure that all the correct approvals and paperwork were put in place.

Funds were available from Kew to support a Kew MSc student to work on the South Georgia project in the second year. Kaitalin White selected the South Georgia project and started at the MSB in late March. Following training in seed processing techniques, she researched different seed extraction techniques and tested the feasibility of these methods on UK soil.

Seeds are typically concentrated by washing soil through a series of sieves using water, removing large and small soil particle fractions not containing seed. This method was not, however, possible to use, due to stringent quarantine requirements of the Defra soil licence.

Seed was therefore dry-extracted from twenty South Georgia soil samples of 20 ml each (five replicates from four sites) using sieves. Over 600 seeds or seed fragments were found, including 122 full seeds, with 51 viable. Viable seeds comprised four native species, four non-native species (three Class 3 and one Class 1 species) and some unknown species. Although a very precise and accurate method for obtaining seeds from the soil, it was exceptionally time intensive.

A second method, consisting of spreading a thin layer of a subsample of South Georgia soil on top of sterilized potting soil and then moistening and incubating at temperatures most likely to stimulate seed germination (25°C, 12 hr day / 10°C, 12 hr night, with a corresponding 12 hr / 12 hr photoperiod), was tried for one replicate of soil samples collected from all 26 sites in 2018-2019. These were kept in sealed plastic bags in growth chambers according to agreed quarantine conditions (Figure 3) and monitored for germination for a minimum of 60 days. This was found to be an effective method for obtaining seedlings: from the first replicate of soil samples collected from all 26 sites in 2018-2019, 482 seedlings were obtained.

Identification of species, both from seed and seedlings, was challenging. Seedlings could not be grown on in a glasshouse until flowering, because of quarantine regulations. Seeds of 56 native and non-native species that occur on South Georgia from collections already held at the MSB were therefore photographed to aid identification. Some seeds were straightforward to distinguish; however, seeds, particularly of the Poaceae (grass family), were very similar and difficult to identify to species level with reasonable certainty. Seedlings were therefore grown from germination tests and were photographed; but again, particularly in the Poaceae, seedlings were very similar and difficult to identify to species level.

Young plants were grown on and photographed, and vegetative material then collected to enable the production of a DNA library of all the species likely to occur on South Georgia, with the aim that this DNA library could then be used to identify seedlings to species level using molecular methods, where seed and seedling morphological details had been inadequate to identify specimens beyond family or genus level. Additional funding was obtained from other sources to use DNA barcoding as an alternative way to identify unknown seeds found in and seedlings produced from soil samples and seed traps (Output 3).

Trays containing soil samples were checked on a weekly basis and seedlings identified from morphology (where possible). Vegetative material was then harvested, dried, and stored in silica gel for identification using molecular methods, for processing by intern Rachel Day during 2021. Her original placement of one year was unfortunately reduced to five months by Kew as a direct result of the Covid-19 pandemic restrictions; nevertheless, she was able to process replicates 1, 2 and 3 from all 26 sites sampled in the 2018-2019 field season. Seedlings from the 4th and 5th replicates were identified from morphological differences, with any of uncertain identification collected for confirmation by molecular techniques. A total of 130 soil samples were processed, with 1,423 seedlings emerging from these samples (Annex 22, Slide 11), exceeding our target of assessing the viability of seeds from at least 5 soil samples from 20 invaded sites.

Figure 3: Seedlings germinating from moistened South Georgia soil samples contained in sealed plastic bags in designated growth chambers, as specified by the Defra Soil Quarantine Licence.

Non-native seeds that germinated to emerge from moistened soil samples dominated the soil seed bank, with approximately ten times more emerging from soil than native plant species. Non-native *Cerastium fontanum* and *Poa annua* (both Class 3) were the most abundant species (Annex 22, Slide 12). Five Class 1 species were found in soil samples, but these were all restricted to a single site with only one Class 1 species found at two sites. The number of seedlings that we were unable to identify was less than 12% of the total number of seedlings that emerged, with most of these unknown species being either in the Poaceae or Juncaceae families. These data highlight non-native species likely to persist past 2020. A manuscript on seed persistence in the soil and seed dispersal on South Georgia following non-native plant species control is being prepared for submission to a peer-reviewed journal. Summary reports will be uploaded to suitable websites once these data have been submitted for publication.

<u>Output 3 activities</u>

Following email discussions between project partners, the seed trap design that was selected for use on South Georgia was a modified version of the bucket trap (after Morris et al., 2011, J Veg Sci 22:807-801, Figure 4). Thirty traps in total were installed at six localities on South Georgia during January 2019, five per site, and retrieved prior to the departure of the field team from South Georgia (Annex 37). We had concerns that later maturing seeds of species may not have been represented in the first field season, following observations of the field team that seeds were still dispersing when they left, and so team leader, Kelvin Floyd, planned to stay on a month later in the second field season to enable the seed traps to remain in the field for longer.

Thirty seed traps were again installed during December 2019 and early January 2020, in the same six localities (five per site) as the 2018-2019 field season (Annex 38). Unfortunately, seed traps had to be removed sooner than planned because of the forced early departure of the field team from the island due to the Covid-19 pandemic. The Covid-19 outbreak also affected international flights, including the military flight from the Falklands to RAF Brize Norton in the UK. Sally Poncet ensured that the seed and soil samples were safely stored in cool, dry conditions in the Falkland Islands until it was possible for these to be transported to the United Kingdom.

Figure 4: Pamela Quilodrán installing seed traps at Brown Mountain on South Georgia.

Earlier removal of seed traps may have influenced the diversity of seed collected, as the latter part of the seed dispersal season may have been missed. However, as other methods of monitoring non-native plant species were used (soil samples, monitoring of plants establishing in areas of glacial retreat), the overall understanding of the threat of non-native plant species to native South Georgia plants and habitats should still be able to be adequately determined from the combination of these different monitoring approaches.

In the 2018-2019 field season, the 30 seed traps collected 742 seeds, of which 211 were empty seed husks. The remaining 531 seeds appeared full. Seeds were identified, where possible, from seed morphology: 5% were native, 62% non-native and 33% could not be identified (so unknown). Seeds of *Taraxacum officinale*, *Cerastium fontanum* and Poaceae species, the former two both Class 3 non-native plant species, were most abundant in the traps. There were no non-native Class 1 seeds identified in the traps.

Seeds from the seed traps were sown on agar to assess viability and any unknown seedlings were collected for identification using molecular methods. With the first field season of seed trap contents, we have met the target of processing at least five traps per site for six sites. However, the lost time on the project during 2020-2021 due to Covid-19 meant that we had insufficient time and personnel to process and analyse the contents of the seed traps collected in the second field season. Although this will have some impact on our ability to fully understand the movement of seeds across South Georgia over different field seasons, we have strong results from the first set of seed traps. This has allowed us to identify those species that are most prolifically dispersed by wind on South Georgia and are therefore most likely to spread. This has enabled us to make practical recommendations to GSGSSI for their new non-native plant management strategy.

We will endeavour to find additional funds to complete the analysis for the second field season as part of our exit strategy post-project and the results will be published post-project, and these will be shared with GSGSSI as part of our regular updates.

<u>Output 4 activities</u>

Suitable pairs of congeneric native and non-native plant species were selected to experimentally determine the impact of climate change on seed germination using a thermal gradient plate, which enables the germination characteristics of a species to be precisely determined over a wide range of constant and alternating temperatures. Native *Poa flabellata* was paired with non-native *P. annua* (with *P. pratensis* as a backup if *P. annua* could not be collected in sufficient quantities); native *Festuca contracta* with non-native *F. rubra*; and native *Deschampsia antarctica* with non-native *D. parvula* (with *D. cespitosa* as a backup if *D. parvula* collections were not suitable).

Seeds of these species were targeted for collection by the field team during the first field season specifically for these experiments (Annex 39), which require many seeds (at least 3,380) per species. Germination testing of species pairs on the thermal gradient plate could only proceed once 2018-2019 seed collections had been processed (accessioned, counted, and x-rayed) and initial germination tests to assess seed viability were complete.

Seed collections with initial tests yielding >85% germination should ideally be used for thermal gradient plate experiments, to ensure maximum germination at optimum temperatures. From the first field season, only non-native *P. annua* and native *P. flabellata* initial seed germination tests achieved >85% germination. Although germination in native *F. contracta* and non-native *D. parvula* seed was >75%, and could likely be used, the non-native *F. rubra* seed collection was immature and therefore unusable. Seeds of the native *D. antarctica* achieved <20% seed germination in initial tests. As physiological dormancy is documented in the literature to be present in *D. antarctica*, and as seeds appeared full and viable in x-ray tests, we set up germination tests to confirm whether a period of cold treatment (termed cold stratification) resulted in greater seed germination when moved to warmer temperatures.

Preparations for setting up the *Poa* species pair on the thermal gradient plate included x-raying over 6000 seeds of non-native *P. annua*, to enable individual removal of empty or partially filled seeds prior to starting the experiment, as the initial x-ray and cut-tests had revealed that a substantial number were empty or part-filled. This was completed, and the seeds were ready for sowing in March 2020; however, this was not done due to the sudden closure of the MSB building because of the Covid-19 pandemic. This also resulted in MSc student, Calum Sweeney, having to rescope his project, as his planned work on the thermal gradient plate was not possible with the MSB closed to all but essential staff.

Thermal gradient plate tests on the *Poa* species pair commenced in September 2020 as soon as the MSB reopened. Additional seeds of non-native *F. rubra*, *D. parvula* and *D. cespitosa* were collected in the second field season to complete the remaining species pairs for this work (Annex 40). Despite reduced staff, the MSB seed collections teams prioritised processing and accessioning the South Georgia seeds collected during the second field season to enable these collections to be assessed for suitability for paired *Festuca* and *Deschampsia* thermal gradient plate tests. *Festuca rubra* seed collections from the second field season were again immature (due to early collection; later collection was not possible as the field team had to leave the island early), a U.K. collection banked in the MSB was therefore used instead.

The second and third thermal gradient plate experiments commenced in the first quarter of 2021. Seeds of the *Deschampsia* species pair were initially subjected to a 12-week cold stratification at 0°C prior to sowing on the thermal gradient plate, as tests confirmed that cold stratification improved seed germination in *D. antarctica*.

Germination has finished in all the thermal gradient plate experiments and initial analyses undertaken. Germination in both *Poa* and *Festuca* species pairs was high, with non-native *Poa annua* and *Festuca rubra* seeds germinating more rapidly than native *Poa flabellata* and *Festuca contracta* (Figure 5). In contrast, following a cold stratification period, seeds of native *Deschampsia antarctica* germinated well while *Deschampsia parvula* seed germination was poor. Detailed analyses comparing germination rate, total germination and temperature thresholds are being completed (e.g., see *Poa annua*, Annex 22, Slides 17&18) to enable a better understanding of the differences between species, to be able to predict their behaviour under climate change. Summary reports will be uploaded to suitable websites once these data have been submitted for publication.

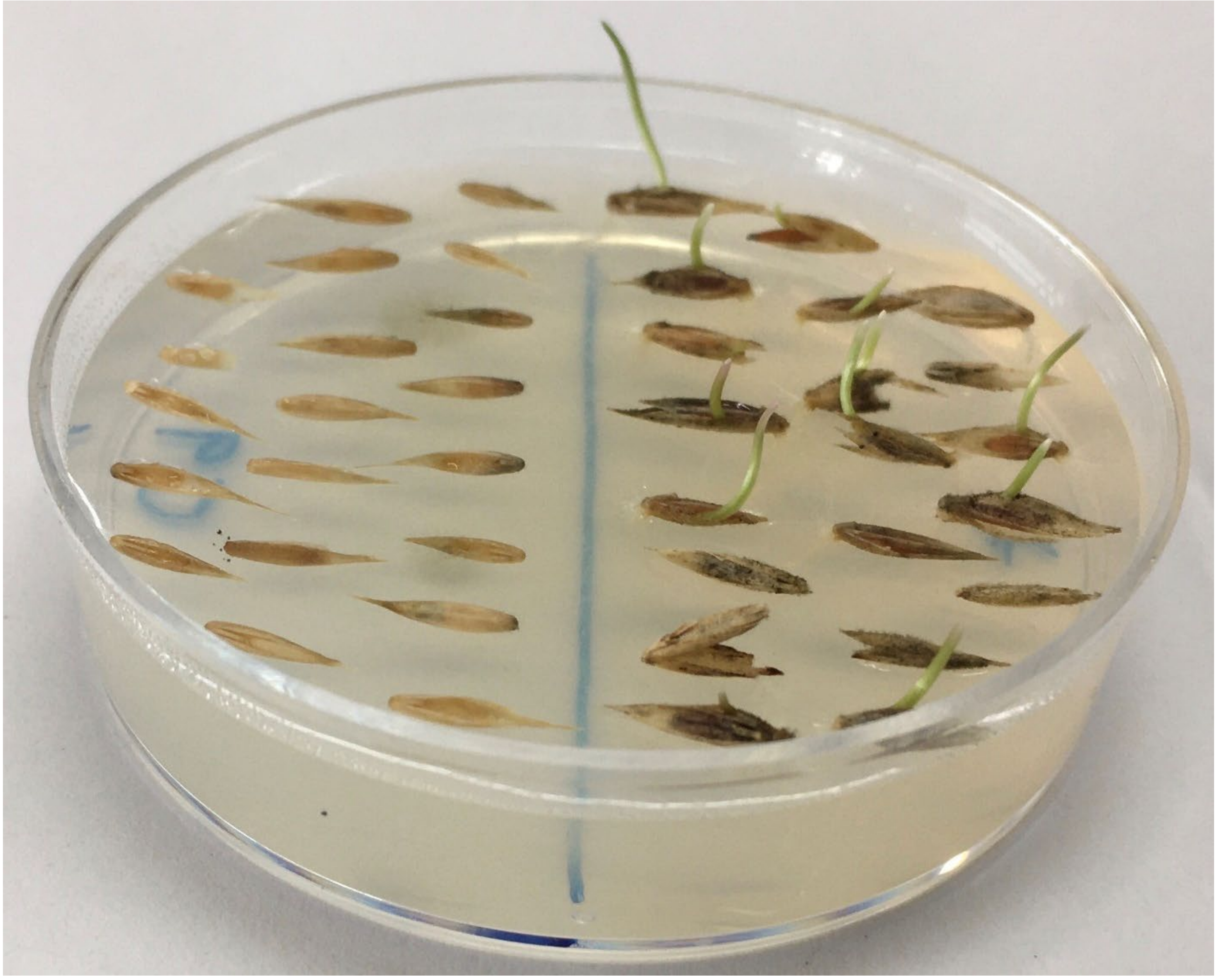

Figure 5: Native Festuca contracta (left) and non-native Festuca rubra (right) following several days on the thermal gradient plate. Germination occurred more rapidly in non-native F. rubra.

<u>Output 5 activities</u>

Over both field seasons, 52 collections comprising 22 taxa (21 species; 1 native seed plant hybrid) were collected. All the required paperwork for importing the seeds (Annexes 41&42) was in place prior to their transport to the MSB. The collections arrived on 3 April 2019 and 10 July 2020, respectively. All native seed-bearing plants and ferns of South Georgia are now held in the MSB, with every species being represented by at least two collections except for *Juncus scheuchzeroides* (Annex 22, Slide 19). This exceeds the target of at least three fern species and all native seed plants of South Georgia securely banked and at least two thirds (i.e., 17 species) with multiple collections for improved genetic diversity.

Using seeds already banked at the MSB, seed germination tests at different conditions were completed for all native plant species on South Georgia and non-native plant species (for which a seed collection is held at the MSB) to determine germination requirements. These results inform our understanding of seed dormancy characteristics and the conditions required to break dormancy. Germinated seeds have been grown on to produce seedlings for imaging, and seed and seedling images at various stages of development (emergence, seedling, and young plant) have been captured for all species in which germination tests were completed. These data are included in the field guide (Annex 43). Output 5 has, through *ex-situ* seed banking activities, improved the conservation status of the native flora of South Georgia.

3.2 Outcome

The project has made good contributions towards achieving the overall project outcome, which is to protect South Georgia's native habitats by identifying the non-native species most likely to persist, by determining potential climate change effects on native and non-native species survival and by banking seeds and spores of native plant and fern species at the MSB.

Of the original 33 Class 1 species that were targeted for management to zero density in the Non-Native Plant Management Strategy 2016-2020, 13 are considered likely eradicated and 14 near eradication (Figure 6, Annex 31). During the management programme, five new species were found on South Georgia, one species was moved from Historic to Class 1, one species was moved from Research to Class 1 and one species was moved from Class 1 to Class 2. The non-native Class 1 plant species predicted to be problematic, requiring eradication efforts post-2020, include the following: 5 'persistent' species that will require sustained effort to eradicate (*Achillea ptarmica*, *Anthoxanthum odoratum*, *Leptinella scariosa*, *Luzula congesta* and *Veronica serpyllifolia*) and 4 species classed as 'difficult' to eradicate (*Agrostis vinealis*, *Cardamine glacialis*, *Rumex acetosella* and *Sagina procumbens*). Three recently discovered/identified new species have also been added to Class 1, which will require control (*Gunnera magellanica*, *Poa trivialis* and *Rumex acetosa*). There are also two new Research species requiring future investigation, which will be undertaken post-project by Kew (Annex 31).

Figure 6: Kelvin Floyd spraying Cardamine glacialis (bittercress) with Grytviken and Mt Hodges in the background.

Soil seed bank results confirm the above-ground observations that *Cardamine glacialis*, *Rumex acetosella* and *Sagina procumbens* have a persistent seed bank, although only the latter species was found at more than one site. *Scozoneroides autumnalis* and *Deschampsia cespitosa* are other Class 1 species (currently near eradication) that may prove more difficult to eradicate due to viable seeds found in the soil seed bank (albeit only at a single site for both species).

It is encouraging that no seeds of non-native Class 1 or 2 species were found in seed traps, suggesting that these Class 1 populations are likely to be eradicated if control treatments continue to be applied early in the season before seed set and dispersal. The main non-native species caught in seed dispersal traps were *Taraxacum officinale* and *Cerastium fontanum* (both Class 3 species).

We have also secured all native plant species (as detailed in "A Field Guide to the Flora of South Georgia" by Deirdre Galbraith, published by the South Georgia Heritage Trust in 2011) as *ex-situ* collections at the MSB, with all but one species having multiple collections, ensuring genetic diversity of these species has been captured.

GSGSSI have committed to continue non-native plant species monitoring and control into the future and their new 5-year stewardship framework for SGSSI, Protect, Sustain, Inspire 2021-2025, includes a strong commitment to biosecurity. Results from our project are being used in discussions (the first of which was held on 28 October 2021) to develop a new science strategy and an updated non-native plant management plan to replace the existing one.

3.3 Monitoring of assumptions

Assumptions were monitored throughout the course of the project.

Weather conditions and transport problems did not significantly hamper project activities in either field season. The field team received full support from BAS and GSGSSI on-island support teams, enabling them to get to all field sites for both year one and year two activities. The second field season was cut short due to having to leave the island early because of the Covid-19 pandemic; however, all planned samples were still collected (Assumptions 0.1, 1.1, 1.2).

Seeds or spores from all target species were collected in the first field season (Annex 39). Six of these collections, following processing, had to be discarded as they did not contain fully developed seeds or few spores, indicating that they had been collected too early in their development (or too late, in the case of fern spores). Missing species were included in the 2019-2020 target list for collection and were recollected (Annex 40). Seven collections of this batch had to be discarded because they were collected too early in the field season (this was unavoidable as the team had to leave the island early due to the Covid-19 pandemic threat). Despite this, additions of seed collections from this project have increased the MSB holdings of South Georgia species to 103 collections, comprising all native species, with at least two collections of each (except one), ensuring a greater representation of genetic diversity of the populations on the island. In addition, there are 22 non-native seed collections from the island (Annex 22, Slide 19). We were also able to obtain adequate seed for thermal gradient plate germination experiments (Assumptions 0.2; 4.1, 4.2, 5.1).

The success of the non-native plant control programme remains at risk from new non-native species being discovered or introduced to South Georgia. Since 2016, the field team have discovered five new Class 1 species on the island, moved one species from Historic to Class 1, one species from Research to Class 1, one species from Class 1 to Class 2 and identified two more species requiring research (Annex 31). Herbarium specimens and DNA material have been collected from research species for investigation at Kew. However, as the biosecurity measures implemented on South Georgia are amongst the most rigorous in the world and are regularly reviewed and strongly enforced (Biosecurity Handbook 2020-2021.pdf),the occasional new discoveries are more likely to represent over-looked species rather than genuine new recent introductions (Assumption 1.3).

Sufficient soil samples from a variety of sites were collected and good germination was obtained from most of the soil samples that were used in experiments (Assumption 2.1).

Seed and seedling imaging of native and non-native plant species that occur on South Georgia has shown that identification of some species with a reasonable level of certainty is impossible. DNA barcoding has been used to identify most unknown species from soil samples and seed traps and this work is being continued outside this project with Kew funding (Assumptions 2.2, 3.3).

Dispersal traps were robust, were not disturbed whilst they were *in-situ* in either field season, and were successfully retrieved (Assumption 3.1), Sufficient seeds were extracted as the number of full seeds removed from seed dispersal traps from the first field season was 530 (Assumption 3.2).

3.4 Impact: achievement of positive impact on biodiversity and poverty alleviation

The impact statement in our application form was: "South Georgia's native habitats and plant species diversity are protected through the eradication of non-native species, conservation of native species, rehabilitation and maintenance of native habitats and improved biosecurity."

As South Georgia does not have a permanent population, our project could not contribute to human development and wellbeing (poverty alleviation) of residents.

Analyses of vegetation data have provided evidence that the native vegetation is recovering following reindeer removal (detailed in Output 1, Section 3.1) and that the control programme for non-native plants on South Georgia is working for most Class 1 species (Annex 22, Slide 9). Eradication activities of Class 1 species on South Georgia by the Indigena field team have resulted in 13 species likely eradicated and 14 near eradication (Annex 31). This outcome directly improves the outlook for the native plant diversity and consequently habitats of South Georgia and, as such, contributes to their long-term protection.

GSGSSI have committed to continue non-native plant species monitoring and control into the future. GSGSSI's new 5-year stewardship framework for SGSSI, published in January 2021, includes a strong commitment to biosecurity, one of the seven pillars of the Framework. Results from our project are being used in discussions (the first of which took place on 28 October 2021) to develop a new science strategy and an updated non-native plant management plan to replace the existing one.

4 Contribution to Darwin Initiative Programme Objectives

4.1 Contribution to Global Goals for Sustainable Development (SDGs)

The project's main contributions are to Target 15: Life on Land: "To protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss". Specifically, the project addresses the key invasives sub-target, Target 15.8: "By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species". The project context and activities have made a significant contribution to the achievement of this target through the provision of robust, quantitative data for GSGSSI to support their biosecurity programme and invasive control programme. It will also inform SGSSI's next 5-year non-native plants management strategy currently in development. Target 15.8 is a major priority for GSGSSI and features strongly in their recently published 5-year stewardship framework strategy: Protect, Sustain, Inspire 2021-2025.

4.2 Project support to the Conventions or Treaties (e.g. CBD, Nagoya Protocol, ITPGRFA, CITES, Ramsar, CMS, UNFCCC)

The UK's signatory to the Convention on Biological Diversity (CBD) was extended to South Georgia in 2014 and implementing the CBD is a key priority for GSGSSI. It is at the heart of SGSSI's approach to conserving the unique biodiversity of South Georgia (www.gov.gs/environment/south-georgia-the-south-sandwich-islands/). The project's main contributions are to Article 8(h): "To prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species". As tackling the threat from invasive plants is the focus of the project, we are also working within the objectives of the Global Strategy for Plant Conservation (GSPC), itself a cross-cutting theme of the CDB. The project outcomes contribute to Target 10 of the GSPC: "Effective management plans in place to prevent new biological invasions and to manage important areas for plant diversity that are invaded".

The whole project design and implementation, and subsequent outputs are supporting SGSSI's implementation of the CBD and GSPC, and specifically the invasives component of these. Other elements of project activity have also contributed to other articles of the CBD. The seed and spore collecting components of the projects are supporting Target 8 of the GSPC: "At least 75 per cent of threatened plant species in *ex-situ* collections, preferably in the country of origin, and at least 20 per cent available for recovery and restoration programmes". *Ex-situ* seed and spore banking facilities do not exist on South Georgia, so under an MoC with GSGSSI we are holding these collections in Kew's Millennium Seed Bank (MSB) at Wakehurst. Project activities are also contributing to several other CBD articles or targets: Article 12 – Research and Training, Article 13 – Public Education and Awareness, Article 17 – Exchange of Information, and Article 18 – Technical and Scientific Cooperation.

4.3 Project support to poverty alleviation

South Georgia has no permanent population and as such poverty alleviation targets cannot be applied to South Georgia.

4.4 Gender equality

South Georgia is uninhabited apart from the research scientists that are based there seasonally, at either King Edward Point or Bird Island. The research teams are recruited via their institutional recruitment schemes which incorporate processes to promote diversity. The collaborating partners for this project have processes in place to promote diversity and inclusion. These partners came together to implement this project, but individuals were already on staff and not recruited specifically for this project. The core Kew Team consisted of three staff members (1 male, 2 female) with 1 female and 1 male MSc student supporting the project in 2019 and 2020, respectively, a female intern working on the project in 2021, and a female volunteer helping with the project one day a week in 2019 and again from the beginning of 2021. The gender-balance of our partners is skewed (6 male : 2 female), but for two seasons a locally-based Chilean female (Pamela Quilodrán) was included in the field team (Annex 22, Slide 2). In 2020-2021 there were 2 females and 1 male in the field team (Annex 44).

4.5 Programme indicators

- **Did the project lead to greater representation of local poor people in management structures of biodiversity?**

N/A.

- **Were any management plans for biodiversity developed and were these formally accepted?**

Yes, this is detailed in Section 3.4.

- **Were they participatory in nature or were they 'top-down'? How well represented are the local poor including women, in any proposed management structures?**

This was led by GSGSSI and has included all relevant South Georgia stakeholders.

- **How did the project positively influence household (HH) income and how many HHs saw an increase?**

N/A.

- **How much did their HH income increase (e.g. x% above baseline, x% above national average)? How was this measured?**

N/A.

4.6 Transfer of knowledge

The project has resulted in formal qualifications for female USA student Kaitalin White (Figure 7) and male Irish student Calum Sweeney, who completed their MSc projects on aspects of the

South Georgia project. They were both awarded the degree of Master of Science in Plant and Fungal Taxonomy, Diversity and Conservation by the Queen Mary University of London, in 2019 and 2020, respectively (with Kaitalin White achieving a distinction). Female UK student, Rachel Day, completed a 5-month internship within her undergraduate degree (at the University of Bath) during 2021. Knowledge transfer has also taken place to enable GSGSSI to make informed decisions about their future strategic plans, contributing to their 5-year stewardship framework: Protect, Sustain, Inspire 2021-2025.

Figure 7: MSc student, Kaitalin White, processing soil samples under a dust hood in quarantine conditions.

4.7 Capacity building

Our project was not dealing with the Global South and so we had no developing country partners who could benefit from this type of capacity building. However, we have developed significant capacity locally, in that one male (Ken Passfield) and one female (Sally Poncet) member of the Indigena field team now have their own invasive species control company based in the Falkland Islands, where they are full-time residents.

5 Sustainability and Legacy

Our planned exit strategy is still valid. The partnership between Kew, Indigena and Durham University with support from GSGSSI worked well and strengthened over the course of the project. This continues and has been consolidated by other project work (e.g., the Indigena field team are continuing non-native plant management on South Georgia in 2021-2022 for GSGSSI, and Kew continues to provide plant identification services and new herbarium specimens collected during the 2021-2022 season will be accessioned into Kew's herbarium. Kew and Durham are collaborating on the new Darwin DPLUS144 project "Protecting South Georgia's terrestrial communities from climate change invasion synergies". We are exploring future opportunities to continue this work together for the long-term protection of this unique wilderness and to utilise knowledge generated and share our experience to benefit other UKOTs.

GSGSSI published their new 5-year stewardship framework Protect, Sustain, Inspire 2021-2025 in January 2021. The Biosecurity section, which our discussions and project results fed into, makes the specific commitment to ‘continue to fund a comprehensive invasive plant management programme to drive down prevalence of key invasive species, building on the success of the previous 5 years’. We are delighted to see this commitment from GSGSSI and are gratified by the role the outputs of this project have played in supporting this. The involvement of all parties in the GSGSSI online workshop held on 28 October 2021, aimed at developing a new science strategy and an updated non-native plant management plan to replace the existing one, indicates the commitment of all parties to maximising the benefit of this project to the protection, rehabilitation and maintenance of native habitats and plant species diversity through the eradication and continued monitoring of non-native species and improved biosecurity.

6 Lessons learned

South Georgia is a harsh environment in which to undertake field work. Having a team that is experienced working in these conditions is key. Despite the challenging environment, both field seasons proceeded well. With the support of BAS and GSGSSI, the field team were able to access all areas necessary to deploy and later retrieve seed traps, collect samples, and monitor non-native plant populations in areas of concern. Seeds and spores from all targeted species were collected, often from more than one population. Soil samples collected and seed traps set and collected also exceeded target numbers.

Unfamiliarity with permit regulations related to soil importation resulted in more time than anticipated ensuring the correct permits were in place to move soil from South Georgia into the UK via the Falkland Islands. It was important to have knowledgeable and experienced local partners to navigate local authorities on behalf of the project to ensure that the samples reached the UK successfully and legally and were not confiscated or destroyed en route or just turned back at a border.

Arranging sample shipment was very time consuming in the first year, and care had to be taken to ensure no documentation or permissions were missing. Keeping detailed records of the process and contacts made the shipment of second year South Georgia field samples much easier, despite Covid-19 pandemic difficulties. The samples were flown directly from Mount Pleasant Airport in the Falkland Islands to RAF Brize Norton in the UK. Mount Pleasant and RAF Brize Norton staff provided helpful advice to ensure smooth passage of the samples and Kuehne and Nagel, the handling agents, cleared the samples through customs.

Stringent procedures required in dealing with soil under quarantine conditions in the UK, led to slower progress than anticipated, and consequently some delays in starting the laboratory work. Alternative processing methods were trialled for extracting and germinating seeds. Seedlings had to be grown on in sealed polyethylene bags in designated quarantine growth chambers for identification, instead of being placed in glasshouse facilities as was originally planned. This highlights the need for flexibility when undertaking this sort of experimental work.

The Covid-19 pandemic overshadowed 2020 and major lessons learnt were around how project management copes in the face of this unprecedented derailment. Good communication and co-operation remained essential, and we maintained good virtual contact (email, MS Teams, Skype, phone) with all partners throughout the period of project pause and as we got the project started again. We held a full Steering Group meeting as soon as possible after the project was fully up and running again (Annexes 12&13). We drafted a new implementation plan and modified some laboratory protocols to account for changed timelines (discussed in more detail in Section 8).

6.1 Monitoring and evaluation

There were no major changes to the project design requiring changes to the logframe. However, changes to methodology were required with the laboratory work for soil processing, and seed and seedling identification, which delayed progress and required additional time input from Kew project staff to enable targets to be met. For example, the original plan of extracting seeds from soil (Output 2, Section 3.1) had to be changed as this process was too time-consuming. The second method of assessing seed viability, by watering soil samples to encourage germination, was then successfully trialled. This methodology was more suited to processing larger quantities of soil. However, identification of some species, especially in the Poaceae (grass family), was difficult because of the lack of characteristic morphological features at the seedling stage, and soil quarantine restrictions have prevented plants being grown on to a reproductive stage at which identification could be confirmed. Vegetative material of seedlings was identified where possible, and then collected for confirmation of identification to species level using molecular methods (enabled by additional funding secured specifically for this work), by comparison against a DNA library of the angiosperm species on South Georgia (Figure 8).

Figure 8: Intern, Rachel Day, extracting DNA for species identification from seedling material.

The project's main monitoring and evaluation was via the steering group and regular communication between all the partners and with GSGSSI and this has proved to be a successful model. The simple design of the project with distinct field components and laboratory components, each with their own dedicated and specialist teams, meant there was a degree of autonomy within the sub elements, especially as the field element was overseen more directly by GSGSSI. The field team produced weekly update reports where progress could be monitored in real time and challenges identified and dealt with immediately. Comments from external reviewers of our annual reports were helpful to confirm that project progress was satisfactory.

6.2 Actions taken in response to annual report reviews

All issues raised in the first and second reviews have been answered in subsequent annual reports. There were two questions in the most recent annual report which we have not yet had a chance to respond to:

Comment 1: Unfortunately, the team feel that they will not be able to complete the full analysis of seed traps collected in the second season, because of time lost due to the pandemic. They anticipate strong results from the first set of seed traps that should be sufficient to make practical recommendations, but the full impact of losing those additional results is not clear – is it possible that the analysis might be completed at a later date, if that would make a significant contribution?

Answer: The situation has not changed. Due to the lost laboratory time and lost intern support, the second set of seed trap contents will be stored for future analysis. We will endeavour to undertake this as soon as is practicable; but given our staff resources and other commitments, this is unlikely until we secure some specific funding to complete this. However, the success of the methodology and the analysis of year one seed trap contents means we are confident that the method works and that it is a valuable way to capture this type of data which can be used to inform management interventions and future planning. We are confident that a single year's data provides us with the evidence needed to address the seed dispersal question.

Comment 2: It appears that the team still do not have a representative sample of seed dispersing over the late summer, but the implications of this to the project outcome is unclear. However, the team indicate that there are other methods of gaining the information it requires, such as field surveys of plants establishing in areas of recent glacial retreat, but it is not evident when this might be undertaken, or how it would be funded.

Answer: This remains the case. Initial surveys of recent glacial retreats were undertaken by the Indigena field team, and a species list of both seed dispersers and colonists is being compiled. This activity will be incorporated into the 2021-2022 field season under the extended GSGSSI contract to continue to implement control of non-native species pending the new 5-year Non-Native Plant Management Strategy which is currently being developed. We are feeding into discussions to ensure that this valuable monitoring will be routinely captured and included in the monitoring programme being developed as part of the implementation of the new strategy.

7 Darwin identity

The Darwin Initiative has been identified as the funder of the project in all communications, including in presentations, on the Kew website, in written or published works and frequently on our Twitter feed. The Darwin Initiative funding has always been recognised as a distinct project with a clear identity. The Darwin Initiative is well known by researchers on South Georgia and has received good exposure in the Falkland Islands, the closest inhabited territory to South Georgia.

Dissemination activities were undertaken with the formal launch of the project at the workshop held in Stanley in December 2018. The whole team participated in a radio interview at the Falkland Islands Radio Station (Annex 24) on 18 December 2019 (Annex 16), This was recorded and broadcast in three separate programmes and on several occasions over the subsequent weeks. Penguin News, the weekly newspaper of the Falkland Islands produced a double-spread feature on the project with colour images, which was published on 18 January 2019 (Annex 25).

Colin Clubbe was invited by the Commissioner of South Georgia & the South Sandwich Islands to join his annual stakeholder trip to South Georgia (24 February – 16 March 2019). This provided an opportunity to publicise the project during discussions on board the Pharos SG and through presentations given on board as well during a 2-day stop at King Edward Point, the British Antarctic Survey research station on South Georgia, and 4-day stop in Stanley, Falkland Islands. Presentations (e.g. Annexes 22, 45-47), in which Darwin has been acknowledged as the funder of the project, include:

- White K. Using Seed Soil Bank Samples to Assess Introduced Species Control on the Island of South Georgia, Masters project presentations to Kew staff. RBG, Kew, Richmond, United Kingdom, 18 June 2019.
- Clubbe C. Conservation Challenges on the Remote Southern Ocean Island of South Georgia. KABaM Science Seminar, RBG, Kew, Richmond, United Kingdom 15 July 2019.
- White K. Using Seed Soil Bank Samples to Assess Introduced Species Control on the Island of South Georgia, Masters project presentations, Linnean Society, London, 6 September 2019.
- Newton RJ. Plant Management on South Georgia. Government of South Georgia & the South Sandwich Islands Stakeholder meeting. RBG, Kew, Richmond, United Kingdom, 12 September 2019.
- Sweeney C. Securing South Georgian Flora. Masters project presentations to Kew staff, online, 23 June 2020.
- Day R. Has South Georgia Won the Battle Against Invasive Flora? Intern presentations to Kew staff, online, 16 July 2021.
- Newton R & Dawson W. DPLUS080: Securing South Georgia's Native Habitats Following Invasive Species Control. South Georgia Weed Management Workshop, online, hosted by the Government of South Georgia & the South Sandwich Islands, 28 October 2021.

Rosemary Newton has been invited to give a talk in 2022 on "Invasive Species and their Effects on Native Plants" in the Ecology and Conservation Studies Society Lecture Series to be held at the Royal Botanic Gardens Kew in 2022, which will include reference to the Darwin project and appropriate funding acknowledgement.

The Darwin Initiative has been identified as the funder in the project page on the Kew website and in blogs, all of which have a large readership:

https://www.kew.org/science/our-science/projects/south-georgias-native-habitats (201 views since posting to 9 December 2021)

https://www.kew.org/read-and-watch/invasive-species-south-georgia (1,031 views since posting to 9 December 2021)

https://www.kew.org/read-and-watch/alien-species-soil-south-georgia (502 views since posting to 9 December 2021)

We were also delighted to have an update on our project included in the Alien Invasions edition of the March 2021 Darwin Newsletter, including the Newsletter lead image (Annex 48). Twitter is an effective way of promoting the project, identified by #KewSouthGeorgia, and @Darwin_Defra is always tagged along with @GovSGSSI, @KewScience and @KewUKOTs, who have many followers, and usually retweet about the project (Annex 30).

We are currently working on the outputs of the research component of the project: at least three peer-reviewed papers are planned and Darwin Initiative will be acknowledged as the source of funding in all:
1) Vegetation change on South Georgia following non-native species removal (based on data from Output 1)
2) Seed persistence in the soil and seed dispersal on South Georgia following non-native plant species control (based on data from Output 2 and 3)
3) Comparison of germination characteristics of native and non-native seed plants on South Georgia (Output 4)
In addition, the Seed and Seedling Field Guide (Annex 43) will document characteristics of seeds and seedlings to enable identification in the field (Output 5). It will also provide information on seed germination and dormancy of native and non-native seed plants on South Georgia. This will provide an excellent complement to the earlier publication produced as an output of DPLUS015 (Upson, R., Myer, B., Floyd, K., Lee, J. & Clubbe, C. 2017. Field Guide to the Introduced Flora of South Georgia. Royal Botanic Gardens Kew, Richmond) and will be a valuable resource for the field teams who will be implementing the new 5-year invasive plant control programme.

8 Impact of COVID-19 on project delivery

The global pandemic and restrictions primarily imposed by the UK government, resulted in Kew not being able to operate as normal, with activities temporarily ceased for a significant period. Laboratory work detailed in Activities 2.5 - 2.8; 3.6 – 3.8; 4.4, and 5.5 – 5.7 could not be completed within the scheduled time, which had the impact of delaying progress on subsequent activities.

Kew project staff were furloughed for varying periods and percentages of time from April 2020 through March 2021 under the UK Government's Job Retention Scheme. Postponement of planned laboratory work between April and August 2020 was necessary as project staff had no access to offices and labs, leading to home working (when not furloughed). During this period, no-cost administrative tasks and email communication about the status of project staff, working arrangements and national restrictions and options for project delivery were discussed (by staff who were not furloughed). Project partner Wayne Dawson took on the role of co-supervising MSc student, Calum Sweeney, as his main supervisor, Rosemary Newton, was furloughed for several months during this period. A formal Steering Group meeting was held in February 2021 when full time laboratory work could resume (Annexes 12&13).

Additional impacts included the loss of laboratory assistance from Kew MSc student Calum Sweeney with thermal plate laboratory work, and the loss of more than 6 months' help from an intern student with the seed trap and soil processing work, as her contract was delayed by more than 6 months and the end date not extended, both of which were due to provide significant data and results for the project. There was additional assistance lost due to volunteer Carey Kelting being unable to return to Kew to assist with laboratory work on the project until May 2021. This work placed additional burden on Kew staff, primarily Marcella Corcoran and project leader, Rosemary Newton. The laboratory team consequently had to work additional hours to try and get the project back to a manageable timetable for completion.

A formal change request was made to Darwin in December 2020 to postpone the funded elements of the project for 6 months with no alteration to the log frame and partial budget transfer to the new financial year with a revised project end date of 30 September 2021, which was approved by Darwin in January 2021 (Annexes 49&50). The 6-month no-cost extension to the project granted by Defra helped to get the project back on track and with the revised implementation plan enabled successful completion of the laboratory work. Of necessity, data analysis and the writing of papers has been delayed and is now underway with the aim of submitting these to peer-reviewed journals for publication in the new year.

Kew made significant investment to ensure that all their staff remained safe and supported during the pandemic. All buildings and workspaces were fully tested and passed as Covid-19 secure for safe working, but with a much lower capacity to ensure safe working and adequate social distancing. All staff had to undertake a full Covid briefing and risk assessment before resuming work and limited access was prioritised for critical activities, such as the laboratory work required to get this project re-started. Kew also invested heavily in virtual platforms to ensure that staff could remain connected whilst working from home and ensured that staff had appropriate computer facilities at home to work effectively. This enabled members of the Steering Group and project partners to keep in touch and work efficiently towards project goals. The success of this has resulted in a hybrid model of working at Kew and will likely influence future decisions about travel and what types of meetings/activities need to happen face to face and what can remain virtual, with potentially positive impacts on travel and carbon emissions. Kew has published its new Sustainability Strategy with the aspiration to be Climate Positive by 2030, and some of the learning from the pandemic around scientific-related travel informed this.

9 Finance and administration

9.1 Project expenditure

Project spend (indicative) since last annual report	2020/21 Grant (£)	2020/21 Total actual Darwin Costs (£)	Variance %	Comments (please explain significant variances)
Staff costs (see below)				
Consultancy costs				
Overhead Costs				
Travel and subsistence				
Operating Costs				
Capital items (see below)				
Others (see below)				
TOTAL				

Staff employed (Name and position)	Cost (£)
Rosemary Newton	
Marcella Corcoran	
TOTAL	

Capital items – description	Capital items – cost (£)
N/A	
TOTAL	

Other items – description	Other items – cost (£)
Molecular costs	
Laboratory costs	

Nursery costs	
TOTAL	

9.2 Additional funds or in-kind contributions secured

Source of funding for project lifetime	Total (£)
GSGSSI logistical support	
% overheads for Colin Clubbe, Marcella Corcoran and Rosemary Newton (Kew budget)	
Molecular work (Juan Viruel: £and Calum Sweeney: £budgets)	
Intern Rachel Day (Kew budget)	
Transport costs for Marcella Corcoran between Kew and Wakehurst sites (Colin Clubbe departmental budget)	
TOTAL	

Source of funding for additional work after project lifetime	Total (£)
Open access publication (Kew budget)	
TOTAL	

9.3 Value for Money

South Georgia is a remote location and challenging to work in. The infrastructure is supported by GSGSSI. This whole project was built around synergising with GSGSSI's contract to Indigena to implement the non-native plant control work under the Non-Native Plant Management Strategy. Consequently, all data and specimen collection for this project were undertaken whilst the Indigena field teams were on South Georgia delivering non-native plant control and thus costs to the Darwin project were heavily subsidised. All the boat logistics were provided by GSGSSI as part of their planned schedule, therefore avoiding any costs to the Darwin project. The activities undertaken by the Darwin team in the Falkland Islands were facilitated by our local collaborator, Falklands Conservation, who provided meeting facilities when we needed them free of charge, as did GSGSSI. They helped us locate reasonably priced local accommodation. They also helped us with local transportation ensuring that we didn't need to hire any vehicles locally, thus keeping overall costs down. This highlights the importance of strong local support and collaboration when implementing these types of projects. At Kew we were able to draw on Kew's established infrastructure and commitment to delivering this project successfully, so we had access to laboratories, core materials and consumables within the laboratories incurring only nominal laboratory costs. The Millennium Seed Bank Partnership is a global network providing secure *ex-situ* storage of seeds and spores for long-term conservation. Consequently, there were reduced charges to the project for laboratory testing (e.g., processing, quality checking and germination of the South Georgia seed and spore collections). The use of video conferencing was maximised throughout the project to reduce the requirements for physical meetings between partners which helped to keep travel and subsistence costs to a minimum. Overall, this project provided excellent value for money because it synergised so well with the non-native plant control work on South Georgia, a key priority for GSGSSI, as well as being a core project for Kew.

10 OPTIONAL: Outstanding achievements of your project during the (300-400 words maximum). This section may be used for publicity purposes

I agree for the Darwin Secretariat to publish the content of this section

Suitable pairs of congeneric native and non-native plant species were selected to experimentally determine the impact of climate change on seed germination using a thermal gradient plate, which enables germination characteristics of a species to be precisely determined. A bidirectional temperature gradient delivers a wide range of constant and alternating temperatures to the surface on which Petri dishes are placed, enabling detailed investigation of seed germination behaviour. A single congeneric species pair comparison experiment (three of which were run in total) comprised 169 Petri dishes with agar containing 40 seeds each (20 per species), with a total of 6,760 seeds being monitored daily for germination until germination rates slowed. Native *Poa flabellata* was paired with non-native *P. annua*; native *Festuca contracta* with non-native *F. rubra*; and native *Deschampsia antarctica* with non-native *D. parvula*.

Seeds of these species were targeted for collection by the field team on South Georgia specifically for these experiments. Seed collections with high viability and known germination requirements must be used to ensure maximum germination at optimum temperatures. Preparations for setting up the *Poa* species pair on the thermal gradient plate included x-raying over 6000 seeds of non-native *P. annua*, to enable individual removal of empty or partially filled seeds prior to starting the experiment, as x-ray and cut-tests had revealed that a substantial number of seeds in this species were empty or part-filled. A period of cold stratification, known from the literature to be required to break dormancy in *D. antarctica* seeds, was confirmed by initial tests, and so seeds of the *Deschampsia* species pair were subjected to a 12-week cold stratification at 0°C prior to sowing on the thermal gradient plate.

Germination in both *Poa* and *Festuca* species pairs was high, with non-native *P. annua* and *F. rubra* seeds germinating more rapidly than native *P. flabellata* and *F. contracta* (Figure 5). In contrast, seeds of native *D. antarctica* germinated well while *D. parvula* seed germination was poor. Detailed analyses comparing germination rate, total germination and temperature thresholds will enable a better understanding of the differences between species and allow us to be able to predict their behaviour under climate change.

Figure 9: Rosemary Newton, Colin Clubbe and Marcella Corcoran examining the thermal gradient plate setup for our DPLUS080 project at Kew's Millennium Seed Bank at Wakehurst in the United Kingdom. Photo credit: Pablo Gomez-Barreiro (Annex 51).

Annex 1 Project's original (or most recently approved) logframe, including indicators, means of verification and assumptions.

Project summary	Measurable Indicators	Means of verification	Important Assumptions
Impact: South Georgia's native habitats and plant species diversity are protected through the eradication of non-native species, conservation of native species, rehabilitation and maintenance of native habitats and improved biosecurity			
Outcome: South Georgia's native habitats protected by identifying non-native species most likely to persist, determining potential climate change effects on native and non-native species survival and banking seeds of native species	0.1 The number of non-native species predicted to persist post-2020 determined 0.2 Native and non-native species likely to colonise new habitats identified 0.3 Spores of at least three fern species and all native seed plants of South Georgia securely banked at the Millennium Seed Bank	0.1 Summary report published on GSGSSI and Kew websites and Research Gate 0.2 Seed Bank Database (SBD) for seed collected and excel database of results	0.1 Weather conditions allow boats to access South Georgia and field work to be completed 0.2 All target species produce sufficient seeds or spores during the lifetime of the project to allow safe collection for storage and not impact the future of native populations
Output 1 Vegetation changes following reindeer removal from established vegetation monitoring plots quantified and success of the control programme of non-native plants on South Georgia evaluated	1.1 Data from 2 established vegetation monitoring plots analysed in year 1 and year 2 and across the monitoring period to demonstrate change in numbers and frequency of native and non-native plant species 1.2 Data from at least 2 invaded sites (4 plots per site) analysed in year 1 and year 2 and across the monitoring period to demonstrate change in numbers and frequency of native and non-native plant species	1.1 Excel database and report on vegetation changes in established monitoring plots and in non-native species distribution in invaded sites where control is taking place 1.2 Summary report published on GSGSSI and Kew websites and Research Gate 1.3 Scientific paper on vegetation changes following non-native species control submitted to open access journal for publication end of year 3	1.1 Team able to visit all sites every year to collect data unhampered by weather conditions 1.2 GSGSSI boat operational and able to transport team from the Falkland Islands to South Georgia and to field sites 1.3 No new non-native species introduced to South Georgia
Output 2	2.1 Viability of seeds from at least 20 invaded sites with a minimum of	2.1 Excel database on seeds found in soil seed bank	2.1 Soil samples contain sufficient seeds

Project summary	Measurable Indicators	Means of verification	Important Assumptions
The risk of non-native plant species persisting past 2020 estimated	5 soil samples of 200 cm^3 per site determined	2.2 Summary report on potential for non-native species to spread into new areas published on GSGSSI and Kew websites and Research Gate	2.2 Reliable identification of species is possible from seeds or young plants
Output 3 The potential for non-native species to spread quantified	3.1 The number of species and number of seeds per species dispersed into at least 5 traps per site each placed in a minimum of 2 invaded sites, 2 native sites and 2 sites recently exposed by retreating glaciers identified 3.2 Likelihood of new areas recently exposed by retreating glaciers being colonised by non-native species, over native species, quantified	3.1 Excel database on seeds caught in dispersal traps 3.2 Summary report on potential for non-native species to spread into new areas published on GSGSSI and Kew websites and Research Gate	3.1 Dispersal traps are robust enough to survive the field season and are not disturbed 3.2 Dispersal traps collect sufficient seeds 3.3 Reliable identification of species is possible from seeds or young plants
Output 4 Impact of climate change on selected native and non-native plant species in South Georgia estimated	4.1 Germination characteristics of 3 native and 3 non-native plant species at current and warmer temperatures of seeds determined (as a proxy of establishment success) 4.2 Likelihood of non-native success over native species under climate change quantified	4.1 Scientific paper on the thermal germination niche of three closely related pairs of native and non-native species and associated predictions of a changing climate on seed germination behaviour submitted to open access journal for publication by the end of year 3	4.1 Adequate seed can be sourced for germination experiments 4.2 Seeds germinate under tested conditions
Output 5 Seeds and fern spores of native plant species of South Georgia collected and stored at the Millennium Seed Bank for *ex-situ* conservation and seed germination protocols determined	5.1 Spores of at least three fern species and all native seed plants of South Georgia securely banked and at least two thirds (i.e. 17 species) with multiple collections for genetic diversity at the Millennium Seed Bank	5.1 Kew's internal Seed Bank Database at the Millennium Seed Bank 5.2 Blog detailing seeds banked at end of year 3 on GSGSSI and Kew websites	5.1 Populations of target native plant species produce seeds which are mature and in sufficient quantities for collection (no more than 20% of available seed to be collected to ensure native

Project summary	Measurable Indicators	Means of verification	Important Assumptions
	5.2 Seed dispersal and dormancy syndromes identified and seed germination protocols determined for all native species 5.3 Seedling images captured for all native plant species	5.3 Germination protocols on Kew's open access Seed Information Database: http://data.kew.org/sid/ 5.4 Seedling images for native plant species to South Georgia available online 5.5 Publish a Guide to Seeds and Seedlings of the Plants of South Georgia	populations are not harmed) at the time the sites are visited

Activities

1.1 Agree a Memorandum of Collaboration with GSGSSI, Indigena, University of Durham and Kew
1.2 Review and finalise current methodology, including sites and plots for sampling, in light of planned South Georgia activities and data analyses
1.3 Project launch and workshop in the Falkland Islands
1.4 Discuss and finalise field data protocols at Falkland Islands workshop
1.5 Collect data on non-native species distribution at field sites visited in year 1 and year 2
1.6 Analyse data to quantify the success of control methods in year 1 and year 2
1.7 Update excel database and produce a summary report on non-native species distribution
1.8 Upload summary report onto GSGSSI and Kew websites and Research Gate
1.9 Prepare scientific paper for open access publication in an international peer-reviewed journal

2.1 Develop soil sampling protocols
2.2 Discuss and finalise field data protocols at Falkland Islands workshop
2.3 Collect soil samples from field sites in South Georgia
2.4 Transport samples to the MSB for analysis
2.5 Process samples in the laboratory by sieving soil and removing seeds
2.6 Identify species where possible from seeds
2.7 Seed germination and tetrazolium tests to quantify seed viability
2.8 Grow on seedlings in a glasshouse at Kew for plant species identification
2.9 Analyse data to estimate the proportion of viable non-native seeds in soil samples
2.10 Update excel database and produce a summary report on soil sample analysis and the risk of non-native plant species persisting past 2020
2.11 Upload summary report onto GSGSSI and Kew websites and Research Gate

3.1 Develop and test seed trap design
3.2 Agree seed trap sites and set-up protocols at Falkland Islands workshop

Project summary	Measurable Indicators	Means of verification	Important Assumptions

3.3 Set seed traps at the beginning of the field season to catch dispersed seeds
3.4 Collect seed from seed traps before the end of the field season
3.5 Transport samples to the Millennium Seed Bank (MSB) for analysis
3.6 Identify species where possible from seeds
3.7 Seed germination and tetrazolium tests to quantify seed viability
3.8 Grow on seedlings in a glasshouse at Kew for plant species identification
3.9 Analyse data to quantify potential native and non-native species spread
3.10 Update excel database and produce a summary report on the potential for non-native species to spread
3.11 Upload summary report onto GSGSSI and Kew websites and Research Gate

4.1 Identify non-native and closely-related native species to research the impact of climate change on seed germination and subsequent recruitment in South Georgia
4.2 Determine germination requirements for paired native and non-native plant species from SBD or the literature
4.3 Collect target non-native seed from populations in South Georgia or the Falklands if not available from MSB collections
4.4 Seed germination tests on a thermal gradient plate at the MSB on three closely related species pairs, where one species is native and the other is non-native
4.5 Analyse data to determine germination characteristics (e.g. temperature thresholds)
4.6 Prepare scientific paper for open access publication in an international peer-reviewed journal

5.1 Identify suitable populations for seed and fern spore collection
5.2 Collect seeds and fern spores of native plant species of South Georgia for *ex-situ* conservation at the MSB
5.3 Transport collections to the MSB for processing and banking
5.4 Produce blog on South Georgia collecting trip for GSGSSI and Kew websites
5.5 Process seed and fern spore collections and produce germination protocols
5.6 Identify seed dispersal and dormancy syndromes
5.7 Photograph seedlings from germination tests and make images available online
5.8 Upload germination protocols onto the Seed Information Database (SID)
5.9 Publish a Guide to Seeds and Seedlings of the Plants of South Georgia

Annex 2 Report of progress and achievements against final project logframe for the life of the project

Project summary	Measurable Indicators	Progress and Achievements
Impact: South Georgia's native habitats and plant species diversity are protected through the eradication of non-native species, conservation of native species, rehabilitation and maintenance of native habitats and improved biosecurity		Analyses of vegetation data have provided evidence that the native vegetation is recovering following reindeer removal (detailed in Output 1, Section 3.1) and that the control programme for non-native plants on South Georgia is working for most Class 1 species (Annex 22, Slide 9). Eradication activities of Class 1 species on South Georgia by Indigena team members have resulted in 13 species likely eradicated, 14 near eradication, with only 5 remaining persistent, 4 difficult to control and 3 newly identified (and so not yet controlled) (Annex 31). This outcome directly improves the outlook for the native plant diversity and consequently habitats of South Georgia and thus contributes to their long-term protection. GSGSSI have committed to continue non-native plant species monitoring and control into the future. GSGSSI's new 5-year stewardship framework for SGSSI, published in January 2021, includes a strong commitment to biosecurity, one of the seven pillars of the Framework. Results from our project are being used in discussions (the first of which took place on 28 October 2021) to develop a new science strategy and an updated non-native plant management plan to replace the existing one.
Outcome South Georgia's native habitats protected by identifying non-native species most likely to persist, determining potential climate change effects on native and non-native species survival and banking seeds of native species	0.1 The number of non-native species predicted to persist post-2020 determined 0.2 Native and non-native species likely to colonise new habitats identified 0.3 Spores of at least three fern species and all native seed plants of South Georgia securely banked at the MSB	The project has made good contributions towards achieving the overall project outcome of protecting South Georgia's native habitats. We have identified 14 non-native plant species that are likely to persist post-2020 from both above ground observations and below ground soil germination results that will require control, and two species requiring further investigation to be undertaken post-project by Kew (details in Output 1 and Output 2, Section 3.1, and Section 3.2). Seed trap results identified that two Class 3 species were the main non-native seeds being dispersed, with seeds of several other native plant species also caught in traps (details in Output 3, Section 3.1, and Section 3.2). All native plant species (as detailed in "A Field Guide to the Flora of South Georgia" by Deirdre Galbraith, published by the South Georgia Heritage Trust in 2011) are secured as *ex-situ* seed or spore collections at the MSB, with all but one species having multiple collections (details in Output 5, Section 3.1, and Annex 22, Slide 19).

Project summary	Measurable Indicators	Progress and Achievements
Output 1. Vegetation changes following reindeer removal from established vegetation monitoring plots quantified and success of the control programme of non-native plants on South Georgia evaluated	1.1 Data from 2 established vegetation monitoring plots analysed in year 1 and year 2 and across the monitoring period to demonstrate change in numbers and frequency of native and non-native plant species 1.2 Data from at least 2 invaded sites (4 plots per site) analysed in year 1 and year 2 and across the monitoring period to demonstrate change in numbers and frequency of native and non-native plant species	Vegetation data from the different field sites have been analysed and changes in vegetation composition, plant height and cover of target non-native and native plant species in herbicide plots determined. These data have provided evidence that the native vegetation is recovering following reindeer removal and that the control programme for non-native plants on South Georgia is working for most Class 1 species (details in Output 1, Section 3.1, Annex 22, Slides 6-9, Annex 31).
Activity 1.1. Agree a Memorandum of Collaboration with GSGSSI, Indigena, Durham University and Kew		Memorandum of Collaboration (Annex 26) agreed and signed by all parties.
Activity 1.2. Review and finalise current methodology, including sites and plots for sampling, in light of planned South Georgia activities and data analyses		Methodology, sites and plots finalised and agreed at Falkland Islands workshop (Annex 16).
Activity 1.3. Project launch and workshop in the Falkland Islands		Project launched and successful workshop held in the Falkland Islands in December 2018 (Figure 1, Annex 25).
Activity 1.4. Discuss and finalise field data protocols at Falkland Islands workshop		Field data protocols discussed and finalised in the Falkland Islands in December 2018 (Annex 23). Implemented during 2018-2019 and 2019-2020 field seasons.
Activity 1.5. Collect data on non-native species distribution at field sites visited in year 1 and year 2		Data collected by field team during 2018-2019 and 2019-2020 field seasons (held in an MS Access database).
Activity 1.6. Analyse data to quantify the success of control methods in year 1 and year 2		Data analysed to quantify success of control methods. This is reported both in the Indigena End of Contract Report (Annex 31) and in the presentation delivered at the GSGSSI online workshop held on 28 October 2021 (Annex 22), aimed at developing a new science strategy and an updated non-native plant management plan to replace the existing one.

Project summary	Measurable Indicators	Progress and Achievements
Activity 1.7. Update excel database and produce a summary report on non-native species distribution		The data is safely stored in an MS Access database and a preliminary summary report was produced (Annex 52). At the most recent steering group meeting we decided to include an additional season of data which will be collected in the field season of 2021-2022 (Annex 15). This will ensure that longer vegetation change trends will be captured.
Activity 1.8. Upload summary report onto GSGSSI and Kew websites and Research Gate		Once the vegetation analysis is complete (with 2021-2022 field data included), a summary report on non-native species distribution will be produced for and uploaded to websites.
Activity 1.9. Prepare scientific paper for open access publication in an international peer-reviewed journal		We are currently preparing a manuscript for submission to a peer-reviewed journal to document the vegetation changes on South Georgia following non-native species removal (based on data from Output 1).
Output 2. The risk of non-native plant species persisting past 2020 estimated	2.1 Viability of seeds from at least 20 invaded sites with a minimum of 5 soil samples of 200 cm3 per site determined	A total of 130 soil samples were processed, with 1,423 seedlings emerging from all samples (Annex 22, Slide 11), exceeding our target of assessing the viability of seeds from at least 5 soil samples from 20 invaded sites. Five Class 1 species were found in soil samples, but these were all restricted to a single site with only one Class 1 species found at two sites (Annex 22, Slide 15). Additional details are given above in the Outcome section of this table.
Activity 2.1. Develop soil sampling protocols		Soil sampling protocols developed in advance of the Falkland Islands workshop and utilised during the two field seasons (Annex 23).
Activity 2.2. Discuss and finalise field data protocols at Falkland Islands workshop		Soil sampling protocols finalised and agreed at the Falkland Islands workshop. Laboratory Standard Operating Procedure developed and agreed by APHA enabling a soil licence (Annexes 35&36) to be obtained for the work to be conducted at the MSB.
Activity 2.3. Collect soil samples from field sites in South Georgia		Five replicates from 26 sites (130 soil samples in total) collected from South Georgia field sites during 2018-2019 (Annex 32) and five replicates from 20 sites (100 soil samples in total) collected from South Georgia during 2019-2020 (Annex 33).

Project summary	Measurable Indicators	Progress and Achievements
Activity 2.4. Transport samples to the MSB for analysis		Samples arrived at the MSB from the first field season on 3 April 2019 and for the second field season on 10 July 2020, respectively, with all the required paperwork to ensure legal compliance with soil import (Annexes 35&36).
Activity 2.5. Process samples in the laboratory by sieving soil and removing seeds		Soil samples collected on South Georgia during the 2018-2019 field season were processed using two different methods, as the first method proved to be too time-consuming. Method 1: Seed extracted from subsamples of soil (5 replicates x 4 sites = 20 samples; Figure 7); extracted seed checked for viability using germination and tetrazolium testing. Method 2: Subsamples of soil from all reps and sites (5 replicates x 26 sites = 130 samples in total) were individually sown onto autoclaved compost and then moistened (Output 2, Section 3.1).
Activity 2.6. Identify species where possible from seeds		Where possible, species were identified from seeds and seedlings. However, identification of some species, especially in the Poaceae, was challenging. Seedling material was therefore collected for identification by molecular methods (see details in Output 2, Section 3.1).
Activity 2.7. Seed germination and tetrazolium tests to quantify seed viability		All seeds extracted from soil (Method 1) were sown on agar and placed into incubators to monitor germination. All soil spread on autoclaved compost in trays was moistened and placed into polyethylene bags and into designated quarantine incubators (Method 2). Incubators were set at 25/10°C with a 12-hour light and 12-hour dark cycle. Seeds were left in germination conditions for a minimum of 8 weeks. Seeds extracted from soil that did not germinate (Method 1) were tested for viability with tetrazolium chloride.
Activity 2.8. Grow on seedlings in a glasshouse at Kew for plant species identification		Seedling identification was not always possible, and seedlings could not be grown on in a glasshouse until flowering, because of quarantine regulations. Seedlings were therefore collected for identification by molecular methods.
Activity 2.9. Analyse data to estimate the proportion of viable non-native seeds in soil samples		

Project summary	Measurable Indicators	Progress and Achievements
		Non-native seeds that germinated to emerge from moistened soil samples were ten times more abundant than native plant species, with non-native *Cerastium fontanum* and *Poa annua* the most abundant species (Annex 22, Slides 12,15).
Activity 2.10. Update excel database and produce a summary report on soil sample analysis and the risk of non-native plant species persisting past 2020		These data have been updated in an excel database on the soil samples and detailed analyses have commenced.
Activity 2.11. Upload summary report onto GSGSSI and Kew websites and Research Gate		Once the detailed analyses are complete, a manuscript on seed persistence in the soil and seed dispersal on South Georgia will be prepared for submission to a peer-reviewed journal for publication, and a summary report on non-native species likely to persist in the soil post-2020 will be produced for and uploaded to websites.
Output 3. The potential for non-native species to spread quantified	3.1 The number of species and number of seeds per species dispersed into at least 5 traps per site each placed in a minimum of 2 invaded sites, 2 native sites and 2 sites recently exposed by retreating glaciers identified 3.2 Likelihood of new areas recently exposed by retreating glaciers being colonised by non-native species, over native species, quantified	With the first field season of seed trap contents, we have met the target of processing at least 5 traps per site for 6 sites. The 30 seed traps collected 742 seeds, of which 211 were empty seed husks. The remaining 531 seeds appeared full. Seeds were identified where possible from seed morphology: 5% were native, 62% non-native (*Taraxacum officinale* and *Cerastium fontanum*) and 33% could not be identified (so unknown). There were no non-native Class 1 seeds identified in the traps. Additional details are given above in the Outcome section of this table.
Activity 3.1. Develop and test seed trap design		Seed trap design extensively researched, and the most appropriate design selected, built, and tested (Figure 4).
Activity 3.2. Agree seed trap sites and set-up protocols at Falkland Islands workshop		Seed trap sites agreed, and set-up protocols discussed at the Falkland Islands workshop in December 2018 (Annexes 23, 37&38).
Activity 3.3. Set seed traps at the beginning of the field season to catch dispersed seeds		Thirty seed traps installed at six different locations on South Georgia at the beginning of the 2018-2019 field season. The same traps were re-installed at the same sites at the beginning of the 2019-2020 field season. These proved to be a successful design and performed well during both field seasons capturing suitable material for analysis.

Project summary	Measurable Indicators	Progress and Achievements
Activity 3.4. Collect seed from seed traps before the end of the field season		All seed traps retrieved at the end of the 2018-2019 and 2019-2020 field seasons and contents successfully decanted into secure bags for transport to the U.K.
Activity 3.5. Transport samples to the Millennium Seed Bank (MSB) for analysis		Samples arrived at the MSB from the first field season on 3 April 2019 and for the second field season on 10 July 2020, respectively, with all the required paperwork to ensure legal compliance with seed import (Annex 41&42).
Activity 3.6. Identify species where possible from seeds		Seed trap contents (5 replicates from 6 sites) collected on South Georgia during the 2018-2019 field season were processed and identified from seeds where possible. Where possible, species were identified from seeds and seedlings. Seedling material was then collected for identification by molecular methods.
Activity 3.7. Seed germination and tetrazolium tests to quantify seed viability		Seed trap contents are being sown to check viability. All seeds extracted from seed traps were sown on agar and placed into incubators at 25/10°C to monitor germination. Germinated seeds were grown on in growth chambers for identification. Seeds were left in germination conditions for a minimum of 8 weeks before they were tested for viability with tetrazolium chloride.
Activity 3.8. Grow on seedlings in a glasshouse at Kew for plant species identification		Seedling identification was not always possible, and seedlings could not be grown on in a glasshouse until flowering, because of quarantine conditions. Seedlings were therefore collected for identification by molecular methods.
Activity 3.9. Analyse data to quantify potential native and non-native species spread		Seeds extracted from seed traps were mostly non-native, with *Cerastium fontanum* and *Taraxacum officinale* the most abundant species (Annex 22, Slide 16).
Activity 3.10. Update excel database and produce a summary report on the potential for non-native species to spread		Seed trap data have been updated in an excel database and detailed analyses have commenced.
Activity 3.11. Upload summary report onto GSGSSI and Kew websites and Research Gate		Once the detailed analyses are complete, a manuscript on seed persistence in the soil and seed dispersal on South Georgia will be prepared for submission to a peer-reviewed journal for publication, and a summary report on species dispersed by wind on South Georgia will be produced for and uploaded to websites.

Project summary	Measurable Indicators	Progress and Achievements
Output 4. Impact of climate change on selected native and non-native plant species in South Georgia estimated	4.1 Germination characteristics of 3 native and 3 non-native plant species at current and warmer temperatures of seeds determined (as a proxy of establishment success) 4.2 Likelihood of non-native success over native species under climate change quantified	Germination in both *Poa* and *Festuca* species pairs was good, with non-native *Poa annua* and *Festuca rubra* seeds germinating more rapidly than native *Poa flabellata* and *Festuca contracta* (Figure 5). In contrast, following a cold stratification period, seeds of native *Deschampsia antarctica* germinated well while *Deschampsia parvula* seed germination was poor. Detailed analyses comparing germination rate, total germination and temperature thresholds are being completed (e.g., see *Poa annua*, Annex 22, Slides 17&18) to enable a better understanding of the differences between species to be able to predict their behaviour under climate change. Additional details are given in Output 4, Section 3.1.
Activity 4.1. Identify non-native and closely-related native species to research the impact of climate change on seed germination and subsequent recruitment in South Georgia		Suitable pairs of native and non-native congeneric plant species selected for thermal gradient plate experiments: *Poa flabellata* (native) and *Poa annua* (non-native); *Festuca contracta* (native) and *Festuca rubra* (non-native); and *Deschampsia antarctica* (native) and *Deschampsia parvula* (non-native).
Activity 4.2. Determine germination requirements for paired native and non-native plant species from SBD or the literature		Germination requirements of native and non-native congeneric plant species checked in the literature and on Kew's Seed Bank Database. *Deschampsia antarctica* requires a cold stratification period prior to germination. A cold stratification period was therefore applied to both *Deschampsia* species before setting up the thermal gradient plate germination experiment.
Activity 4.3. Collect target non-native seed from populations in South Georgia or the Falklands if not available from MSB collections		Seed from both native and non-native target species were collected of all species pairs. Collections of *Festuca rubra* from South Georgia were unfortunately immature and therefore not useable. A collection from the U.K. banked in the MSB was therefore used.
Activity 4.4. Seed germination tests on a thermal gradient plate at the MSB on three closely related species pairs, where one species is native and the other is non-native		Thermal gradient plate seed germination tests of all three species pairs have been completed (Figures 5, 9).
Activity 4.5. Analyse data to determine germination characteristics (e.g. temperature thresholds)		Thermal gradient plate experiments completed, initial analyses undertaken and detailed analyses being completed, e.g. see *Poa annua* (Annex 22, Slides 17&18).
Activity 4.6.		

Project summary	Measurable Indicators	Progress and Achievements
Prepare scientific paper for open access publication in an international peer-reviewed journal		Once the detailed analyses are complete, a manuscript comparing germination characteristics of native and non-native seed plants on South Georgia will be prepared for submission to a peer-reviewed journal for publication.
Output 5. Seeds and fern spores of native plant species of South Georgia collected and stored at the Millennium Seed Bank for ex-situ conservation and seed germination protocols determined	5.1 Spores of at least three fern species and all native seed plants of South Georgia securely banked and at least two thirds (i.e. 17 species) with multiple collections for genetic diversity at the Millennium Seed Bank	We have exceeded the target of native fern and seed plants of South Georgia conserved at the MSB: over both field seasons, 52 collections comprising 22 taxa (21 species; 1 native seed plant hybrid) were collected. All native seed-bearing plants and ferns of South Georgia are now represented in the MSB, with every species being represented by at least two collections except for *Juncus scheuchzeroides*, of which there is a single collection (Annex 22, Slide 19).
	5.2 Seed dispersal and dormancy syndromes identified and seed germination protocols determined for all native species 5.3 Seedling images captured for all native plant species	Seed germination tests have been completed for all native plant species on South Georgia and non-native plant species (for which a seed collection is held at the MSB) to determine germination requirements. These results inform our understanding of seed dormancy characteristics and the conditions required to break dormancy. Germinated seeds have been grown on to produce seedlings for imaging, and seed and seedling images at various stages of development (emergence, seedling, and young plant) have been captured for all species in which germination tests were completed. These data are included in the field guide (Annex 43).
Activity 5.1. Identify suitable populations for seed and fern spore collection		Suitable populations for seed and fern spore collection were identified during the first field season.
Activity 5.2. Collect seeds and fern spores of native plant species of South Georgia for ex-situ conservation at the MSB		In both field seasons, 52 collections comprising 22 taxa (21 species; 1 native seed plant hybrid) were collected. Additional details are given in Output 5, Section 3.1.
Activity 5.3. Transport collections to the MSB for processing and banking		Samples arrived at the MSB from the first field season on 3 April 2019 and for the second field season on 10 July 2020, respectively, with all the required paperwork to ensure legal compliance with the importation of seeds and spores (Annexes 41&42).
Activity 5.4. Produce blog on South Georgia collecting trip for GSGSSI and Kew websites		In addition to the project page, two blogs have been published on the Kew website. These are all detailed with links in Section 7.
Activity 5.5.		

Project summary	Measurable Indicators	Progress and Achievements
Process seed and fern spore collections and produce germination protocols		Seed and fern spore collections from both field seasons have been processed and banked. Seed germination tests have been conducted to produce germination protocols for both native and non-native South Georgia species. Basic germination protocols have been incorporated into the field guide (Annex 43).
Activity 5.6. Identify seed dispersal and dormancy syndromes		Initial analysis of wind dispersal has been completed from seed traps. Following completion of a literature survey, dispersal and germination syndromes will be incorporated into POWO.
Activity 5.7. Photograph seedlings from germination tests and make images available online		Germinated seeds from 56 native and non-native species have been grown on to produce seedlings for imaging, and seed and seedling images at various stages of development (emergence, seedling, and young plant) have been captured for all species in which germination tests were completed. These data are included in the field guide (Annex 43) which will be tested by the field team during 2021-2022 on South Georgia.
Activity 5.8. Upload germination protocols onto the Seed Information Database (SID)		The Seed Information Database (SID) did not meet accessibility requirements and has been taken offline. Data are being incorporated into Plants of the World Online (POWO). Germination protocols will be made available in this new database.
Activity 5.9. Publish a Guide to Seeds and Seedlings of the Plants of South Georgia		The Field Guide to the Seeds and Seedlings of the Plants of South Georgia is currently in a draft format (Annex 43). Following feedback from the field teams, this will be published in 2022.

Annex 3 Standard Measures

Code	Description	Total	Nationality	Gender	Title or Focus	Language	Comments
Training Measures							
1a	Number of people to submit PhD thesis	0					
1b	Number of PhD qualifications obtained	0					
2	Number of Masters qualifications obtained	2	American Irish	Female Male	Using soil seed banks to assess the effectiveness of invasive species control on the island of South Georgia. Conserving South Georgia's native plants: predicting germination trends in a changing climate and the molecular identification of species.	English English	Kaitalin White Calum Sweeney
3	Number of other qualifications obtained	0					
4a	Number of undergraduate students receiving training	1	British	Female	Molecular work for species identification	English	Rachel Day
4b	Number of training weeks provided to undergraduate students	24 weeks	British	Female	Molecular work for species identification	English	Rachel Day
4c	Number of postgraduate students receiving training (not 1-3 above)	0					
4d	Number of training weeks for postgraduate students	48 weeks (24 weeks each)	American Irish	Female Male	MSc project work MSc project work	English English	Kaitalin White Calum Sweeney

5	Number of people receiving other forms of long-term (>1yr) training not leading to formal qualification (e.g., not categories 1-4 above)	0					
6a	Number of people receiving other forms of short-term education/training (e.g., not categories 1-5 above)	1	Chilean	Female	Indigena - invasive species management training in the field	English	Pamela Quilodrán
6b	Number of training weeks not leading to formal qualification	11 weeks	Chilean	Female	Invasive species field training	English	Pamela Quilodrán
7	Number of types of training materials produced for use by host country(s) (describe training materials)	0					
Research Measures		**Total**	**Nationality**	**Gender**	**Title**	**Language**	**Comments/ Weblink if available**
9	Number of species/habitat management plans (or action plans) produced for Governments, public authorities or other implementing agencies in the host country (ies)	3*			1) GSGSSI's 5-year Stewardship Framework 2) GSGSSI's new Science Strategy (in development) 3) GSGSSI's new Non-Native Plant Management Strategy (in development) to replace the existing one		* input via participatory process:
10	Number of formal documents produced to assist work related to species identification, classification and recording.	1*			Field Guide to the Seeds and Seedlings of South Georgia	English	* Draft being tested by field team during the 2021-2022 field season.

11a	Number of papers published or accepted for publication in peer reviewed journals	0, but a minimum of 3 in preparation					
11b	Number of papers published or accepted for publication elsewhere	0					
12a	Number of computer-based databases established (containing species/generic information) and handed over to host country	0					
12b	Number of computer-based databases enhanced (containing species/genetic information) and handed over to host country	1			MS Access database monitoring vegetation recovery in established plots on South Georgia		Kelvin Floyd's database held by Indigena and shared with GSGSSI.
13a	Number of species reference collections established and handed over to host country(s)	0					
13b	Number of species reference collections enhanced and handed over to host country(s)	3 reference collections: 1) Living seeds/ spores; 2) DNA 3) Herbarium specimens					South Georgia has no facilities to store viable seed or spores and so all new collections from this project are held in Kew's Millennium Seed Bank (MSB)

Dissemination Measures		**Total**	**Nationality**	**Gender**	**Theme**	**Language**	**Comments**
14a	Number of conferences/seminars/workshops organised to present/disseminate findings from Darwin project work	1					See Figure 1

Dissemination Measures		Total	Nationality	Gender	Theme	Language	Comments
14b	Number of conferences/seminars/ workshops attended at which findings from Darwin project work will be presented/ disseminated.	7	American	Female	MSc presentation at Kew	English	Kaltalin White
			British	Male	KABam Science seminar at Kew	English	Colin Clubbe
			American	Female	MSc presentation at the Linnean Society	English	Kaitalin White
			British	Female	GSGSSI Stakeholder meeting	English	Rosemary Newton
			Irish	Male	MSc presentation at Kew	English	Calum Sweeney
			British	Female	Intern presentation at Kew	English	Rachel Day
			British & British	Female & Male	GSGSSI Weed Management Workshop	English & English	Rosemary Newton & Wayne Dawson

Physical Measures		Total	Comments
20	Estimated value (£s) of physical assets handed over to host country(s)	0	
21	Number of permanent educational, training, research facilities or organisation established	0	
22	Number of permanent field plots established	0	

Financial Measures		Total	Nationality	Gender	Theme	Language	Comments
23	Value of additional resources raised from other sources (e.g., in addition to Darwin funding) for project work *(please note that the figure provided here should align with financial information provided in section 9.2)*						

Annex 4 Aichi Targets

	Aichi Target	Tick if applicable to your project
1	People are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably.	✓
2	Biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems.	
3	Incentives, including subsidies, harmful to biodiversity are eliminated, phased out or reformed in order to minimize or avoid negative impacts, and positive incentives for the conservation and sustainable use of biodiversity are developed and applied, consistent and in harmony with the Convention and other relevant international obligations, taking into account national socio economic conditions.	
4	Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits.	
5	The rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.	
6	All fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits.	
7	Areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity.	
8	Pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.	
9	Invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.	✓✓
10	The multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.	
11	At least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.	
12	The extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.	
13	The genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity.	

14	Ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.	
15	Ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.	
16	The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization is in force and operational, consistent with national legislation.	
17	Each Party has developed, adopted as a policy instrument, and has commenced implementing an effective, participatory and updated national biodiversity strategy and action plan.	
18	The traditional knowledge, innovations and practices of indigenous and local communities relevant for the conservation and sustainable use of biodiversity, and their customary use of biological resources, are respected, subject to national legislation and relevant international obligations, and fully integrated and reflected in the implementation of the Convention with the full and effective participation of indigenous and local communities, at all relevant levels.	
19	Knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred, and applied.	✓
20	The mobilization of financial resources for effectively implementing the Strategic Plan for Biodiversity 2011-2020 from all sources, and in accordance with the consolidated and agreed process in the Strategy for Resource Mobilization should increase substantially from the current levels. This target will be subject to changes contingent to resource needs assessments to be developed and reported by Parties.	

Annex 5 Publications

Type * (e.g. journals, manual, CDs)	Detail (title, author, year)	Nationality of lead author	Nationality of institution of lead author	Gender of lead author	Publishers (name, city)	Available from (e.g. web link, contact address etc)
Online field guide *	Authors: Carey Kelting, Rosemary Newton, Marcella Corcoran, Kaitalin White, Colin Clubbe Title: Field Guide to the Seeds and Seedlings of South Georgia Year: 2022	British	British (Kew)	Female	Kew online publication	* This will be available for downloading after field testing (Annex 43)

Annex 6 Darwin Contacts

Ref No	DPLUS080
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Annex 7 – Supplementary material (optional but encouraged as evidence of project achievement)

Checklist for submission

	Check
Is the report less than 10MB? If so, please email to Darwin-Projects@ltsi.co.uk putting the project number in the Subject line.	
Is your report more than 10MB? If so, please discuss with Darwin-Projects@ltsi.co.uk about the best way to deliver the report, putting the project number in the Subject line.	
If you are submitting photos for publicity purposes, **do these meet the outlined requirements (see section 10)?**	
Have you included means of verification? You should not submit every project document, but the main outputs and a selection of the others would strengthen the report.	
Do you have hard copies of material you need to submit with the report? If so, please make this clear in the covering email and ensure all material is marked with the project number. However, we would expect that most material will now be electronic.	
Have you involved your partners in preparation of the report and named the main contributors	
Have you completed the Project Expenditure table fully?	
Do not include claim forms or other communications with this report.	