# Darwin Plus Main: Annual Report

To be completed with reference to the "Project Reporting Information Note" (https://darwinplus.org.uk/resources/information-notes)

It is expected that this report will be a **maximum of 20 pages** in length, excluding annexes)

**Submission Deadline: 30th April 2025**

**Submit to: BCF-Reports@niras.com including your project ref in the subject line**

## Darwin Plus Project Information

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|---|---|
| Project reference | DPLUS187 |
| Project title | Using satellite technology to monitor seabird populations at South Georgia |
| Territory(ies) | South Georgia and South Sandwich Island |
| Lead Partner | British Antarctic Survey |
| Project partner(s) | RSPB |
| Darwin Plus grant value | £489,579.00 |
| Start/end dates of project | 01/12/2023 – 30/11/2026 |
| Reporting period (e.g. Apr 2023-Mar 2024) and number (e.g. Annual Report 1, 2) | April 2024-March 2025, Annual Report 2 |
| Project Leader name | Peter Fretwell |
| Project website/blog/social media | Website: South Georgia seabirds from space - British Antarctic Survey (bas.ac.uk)<br>Twitter: @BAS_NEWS, @WildlifeSpace |
| Report author(s) and date | Peter Fretwell, Marie Attard, Richard Phillips, Ellen Bowler.<br>30 April 2024 |

## 1. Project summary

Globally important populations of seabirds breed at South Georgia, but because of the size and remoteness of these islands, monitoring is limited to a few locations. This project will assess the feasibility of using satellite imagery to monitor the status of seabirds across the island group, provide baselines to showcase the recovery of burrowing petrels following the eradication of rodents and reindeer in the mid-2010s, and develop methods that could replace expensive and logistically challenging ground surveys across numerous remote islands worldwide.

## 2. Project stakeholders/partners

The project is led by the British Antarctic Survey (BAS), with the Government of South Georgia and South Sandwich Islands (GSGSSI) as the primary UK Overseas Territory (UKOT) stakeholder. Other project stakeholders include the South Georgia Heritage Trust (SGHT), Royal Society for the Protection of Birds (RSPB), BirdLife International, South Georgia Surveys, and the Agreement on the Conservation of Albatrosses and Petrels (ACAP). Other countries and territories which host populations of the seabird species targeted in the project are also involved.

The project began in December 2023 following the conclusion of the DPLUS132 project. Since the last annual report, we have held 8 in-person team meetings with all BAS researchers named on the project (see **Annex 4.1 to 4.9 for meeting minutes and presentations**). These meetings are held monthly and provide an opportunity for considering the results and discussing next steps in the research.

We have maintained contact with Sally Poncet from South Georgia Surveys and Jen Black from GSGSSI, who co-led the 2023/24 all-islands surveys of wandering albatrosses. Sally is a co-author on a manuscript currently in preparation for this project (**see Annex 4.10 for draft manuscript and 4.11 for supplementary information**). Sally has also contributed original hand-drawn annotated maps from the 1985-88 surveys, which will become one of the project's publicly accessible datasets and given a separate DOI with the Polar Data Centre at BAS.

We planned to hold biannual stakeholder meetings. The first such meeting was held on 1st July 2024, with all BAS project members in attendance (Richard Phillips, Peter Fretwell, Marie Attard, Ellen Bowler, Ashley Bennison), as well as representatives from South Georgia Heritage Trust (SGHT) (Tim Stowe, Alison Neil, Andrew Clarke), BirdLife International (Tammy Davies), GSGSSI (March Belchier) and South Georgia Surveys (Sally Poncet). The meeting minutes (**Annex 4.12**) and presentation slides (**Annex 4.13**) were circulated in advance to attendees, and other stakeholders that were invited but unable to attend: Nathan Fenney (BAS), Sue Gregory (GSGSSI), Jaimie Cleeland (BAS), and Martin Collins (BAS). Jaimie Cleeland, Nathan Fenney, Connor Bamford and Kate Owens (BAS) were involved in the collection of spectral profile data at King Edward Point in December 2024-January 2025 and will be co-authors on the resulting paper.

We decided to delay the next stakeholder meeting until **April 2025**, until all satellite imagery of South Georgia was purchased (completed in March 2025) and fieldwork at King Edward Point was finished (completed in January 2025).

## 3. Project progress

### 3.1 Progress in carrying out project activities

**Output 1 An assessment of whether burrowing petrels can be detected using satellite imagery based on spectral analysis of vegetation colour at Bird Island.**

**1.1 <u>Completed (see last annual report).</u>** Existing data on burrowing petrel distribution and abundance at Bird Island (BI) were collated. A map from the survey of white-chinned petrel burrow densities at BI in 2016/17 was created (see **Figure 1-2** from Annual Report 1 (AR1)).

**1.2 <u>Completed (see last annual report).</u>** We collected new data on burrowing petrel distribution specifically for this project at the Thatcher Peninsula around the BAS research station of King Edward Point (KEP) in December 2023 (annotated photographs showing species distribution around KEP summarised in **Annex 4.14**). GPS coordinates of the white-chinned petrel colonies were recorded, and several areas were revisited in November 2024 to January 2025 to measure the spectral signature of guano-enriched tussock. Colony locations of other focal species were also recorded.

Nathan Fenney and Connor Bamford collected spectral signatures of vegetation around KEP (**Figure 1**) for a few days after taking drone imagery of southern elephant seal colonies for a separate Darwin Plus grant (DPR12S2\1020). They had also planned to take imagery in early November, but unfortunately the vegetation was covered with snow. In November and December, they took spectral profiles for fertilised tussac in areas occupied by white-chinned petrels, Antarctic fur seals and southern elephant seals, as well as unfertilised tussac. The spectral profile collection was completed by Jaimie Cleeland and Kate Owens in January, including scans of areas with a single plant species and plant assemblage representative of South Georgia vegetation over 5 days (see **Annex 4.8** for summary of time allocation and change of sampling design). The spreadsheet log for the fieldwork (**Annex 4.15**) lists all hand-held spectrometer scans. GPS coordinates were taken

with a hand-held GPS for all scans and will be added to the spreadsheet once the file is converted to a readable format.

**Figure 1.** Photograph of BAS field team taking hand-held spectrometer scans of tussac on slope occupied by white-chinned petrels.

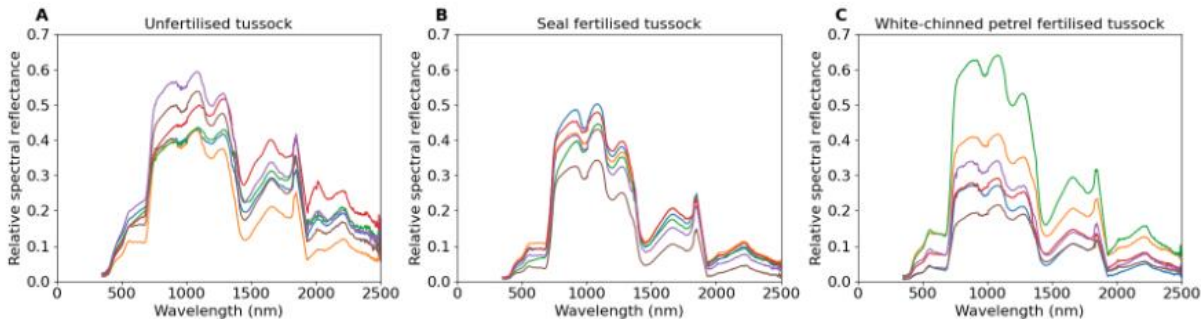


**Figure 2. Reflectance spectra of tussac across wavelengths (350-2500 nm) around King Edward Point** for (A) unfertilised tussac, (B) fertilised tussac occupied by seals, and (C) fertilised tussac occupied by white-chinned petrels. Each coloured line represents a separate scan, with all spectral reflectance values corrected using a standard panel. Data collected using a hand-held spectrometer between November 2024 and January 2025.

**1.3** **Completed**. An 8-band 30cm resolution satellite image of Bird Island (Image ID: 104001008210F900, capture date: 06/03/2023) was purchased from Maxar Technologies in the last annual report. We also tasked and purchased new imagery of Bird Island from the 2024/25 breeding season (Image ID: 10400100A45BD800, 20/02/2025, 30 cm resolution, only east side of island), and one archived image (Image ID: 10400100583C7A00, 23/01/2020, 40 cm resolution).

**1.4** **Completed (see Year 1 half-year report)**: In our 2024 half-year report we concluded that vegetation on Bird Island, in areas with seals or burrowing petrels present, exhibits highest Normalised Difference Vegetation Index (NDVI) values between December and January, according to our analysis of WorldView-3 satellite imagery. Unique NDVI signatures are present for fertilised vegetation at the start of December in areas where both seals and burrows are present and are apparent by late December for areas with only burrows or seals. Therefore, tasking of South Georgia in 2024/25 breeding season prioritised the purchase of cloud-free images from late December and January.

**1.5** **Substantial progress made this reporting period.** A hand-held spectrometer was used to collect spectral profiles of different plant species and assemblages at King Edward Point in November 2024-Jaunary 2025. A total of 100 usable hand-held spectrometer scans were completed by the field team. A full list of vegetation and number of replicates is shown in

**Annex 4.15**. The data will not be used to assess within-season changes in spectral profiles of vegetation but to calibrate 8-band satellite imagery for classifying different vegetation types, including fertilised tussac.

A Python script has been written to pre-process the spectral profiles, and Peter Fretwell organised a 2-day online training "ENVI Advanced Spectral Analytics" workshop, conducted on 11-12th March 2025 on how to use ENVI software for spectral classification (see **Annex 4.16** for workshop schedule and topics covered). Both Peter Fretwell and Marie Attard attended the course, and all slides and video recordings were provided after the workshop. The instructor, Thomas Bahr, has offered to review and provide feedback on analysis of the satellite imagery and spectral profiles from the DPLUS187 fieldwork. We will follow up with Thomas to organise a meeting once we have attempted to analyse the profiles ourselves. Marie is currently writing protocols for analysing the spectral profiles collected this season to identify potential areas occupied by white-chinned petrels based on fertilised tussac signatures.

**Output 2. An assessment of long-term changes in the distribution and densities of burrowing petrels across SG using satellite imagery.**

**2.1 <u>Substantial progress made this reporting period.</u>** We have collated existing data on burrowing petrel distribution and abundance across South Georgia. There were several targeted areas where white-chinned petrel abundance and distribution was recorded (see Activity 1.1).

Existing distribution data for burrowing petrel species from the 1980s was mapped on a 25 $km^2$ grid across South Georgia in the 1996 publication, *South Georgia: An Ecological Atlas* (see **Figure 3** for example). The maps were provided as pdfs, and we have since deposited the original shapefiles in the Polar Data Centre. This dataset has been incorporated into a QGIS project for easy visualisation and an accompanying paper is being prepared for submission to *Scientific Data* (see **Annex 4.10-4.11** for draft manuscript).

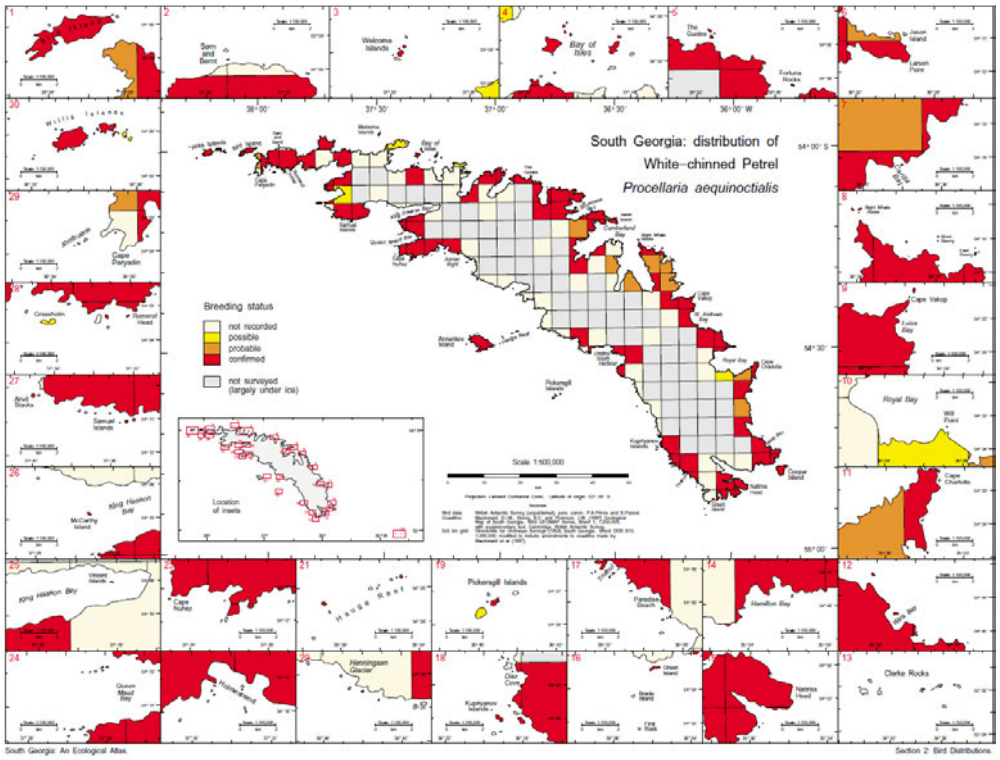


**Figure 3.** Presence-absences of white-chinned petrels in 5 x 5 km grid cells from surveys in 1985-87. The map is from *South Georgia: An Ecological Atlas*. Some inland grid cells with a substantial amount of rock and ice were either not visited or were visited infrequently.

Sally Poncet from South Georgia Surveys has also provided scans of the 131 original, unpublished hand-annotated maps of each 5 x 5 km cell grid used in the 1985-1988 bird

surveys (see **Annex 4.17** for example from a single grid cell), which include additional details about each colony. This information will be stored with the Polar Data Centre as part of the manuscript and given its own DOI. This additional information will be used to gain more precise information on seabird colony locations from this time period. The grid layout is shown in **Annex 4.18**.

We recently learnt of a report (UNEP-WCMC 2018) that has updated seabird distributions for 10 species from *South Georgia: An Ecological Atlas* using data collected after 2000 (see page 20 of report for details) to improve spatial accuracy. The habitat dataset was also revised by the South Atlantic Environmental Research Institute (SAERI) to improve the classification of vegetated areas. Mark Belchier and Jennifer Black have been contacted to find out if the data were published, and whether it could be used for this project.

**2.2 Completed.** Presence-absence data of burrowing petrels in habitat around KEP were collected by Richard Phillips in the 2023/24 breeding season (**Annex 4.14**) and we have access to seabird distribution data collected in the 2023/24 all-islands surveys of black-browed, grey-headed and wandering albatrosses.

**2.3 (and 4.2) Completed this reporting period.** Polygon shapefiles, representing the regions of interest (ROI) (total 2,597 $km^2$ with ocean and 1,829 $km^2$ excluding ocean; **Figure 4A**) were created for the South Georgia coastline, offshore islands (including Bird Island) and islets for tasking VHR satellite imagery through the satellite provider, Maxar Technologies. Each polygon has a simplified shape and must be at least 1 km in width to meet Maxar's rules for polygon acceptance. Tasking for offline orders requires each shapefile to be at least 100 $km^2$ (comes with 15% educational discount), and tasking using MGP Pro required areas of at least 25 $km^2$ (has no educational discount). Therefore, all areas but the four small polygons (<100 $km^2$) were tasked offline. Only imagery with <15% cloud cover was accepted.

The original tasking window was 1$^{st}$ December 2024 - 30$^{th}$ January 2025. As there were still gaps in imagery after this initial window, we extended tasking for an additional month. The cloud-free imagery covered most areas of interest (**Figure 4B**), and gaps in spatial coverage were filled in order of priority:

1. 8 band 40-50 cm imagery (WorldView) from the 2024/25 tasking window (**Figure 4C**). Only 50 cm imagery was available from the same period.
2. 8 band 40-50 cm imagery (WorldView) from the 2021/22-2024/25 breeding seasons (**Figure 4D-E**).
3. 8 band 30 cm imagery (Legion 1 and 2) from the 2024/25 tasking window (**Figure 4F**).

Clerke Rocks and patchy areas on the north side of the mainland were the only area where no cloud-free archived or tasked image was available (Figure 4). Approximate percentage of the AOI cover by each sensor and resolution, alone and in the mosaic is shown in Table 1.

**Table 1.** Percentage of the cloud-free ROI cover for each sensor/resolution type and single mosaic. Total ROI is 1,829 $km^2$ excluding ocean, with 97.98% of AOI captured in mosaic.

| Sensor | Sampling resolution (cm/pixel) | Season captured | Cloud-free area ($km^2$) | ROI cover (%) | Cloud-free mosaic area ($km^2$) | Mosaic AOI cover (%) |
|---|---|---|---|---|---|---|
| WV03 | 30 | 2024/25 | 1161 | 63.49 | 1161 | 63.49 |
| WV02 | 50 | 2024/25 | 898 | 49.11 | 391 | 21.38 |
| WV03 | 40 | 2022/23 | 194 | 10.61 | 54 | 2.95 |
| WV02 | 50 | 2021/22 | 473 | 25.87 | 178 | 9.75 |
| L01, L02 | 30 | 2024/25 | 487 | 26.63 | 7 | 0.41 |
| **TOTAL** | | | | | 1792 | 97.98 |

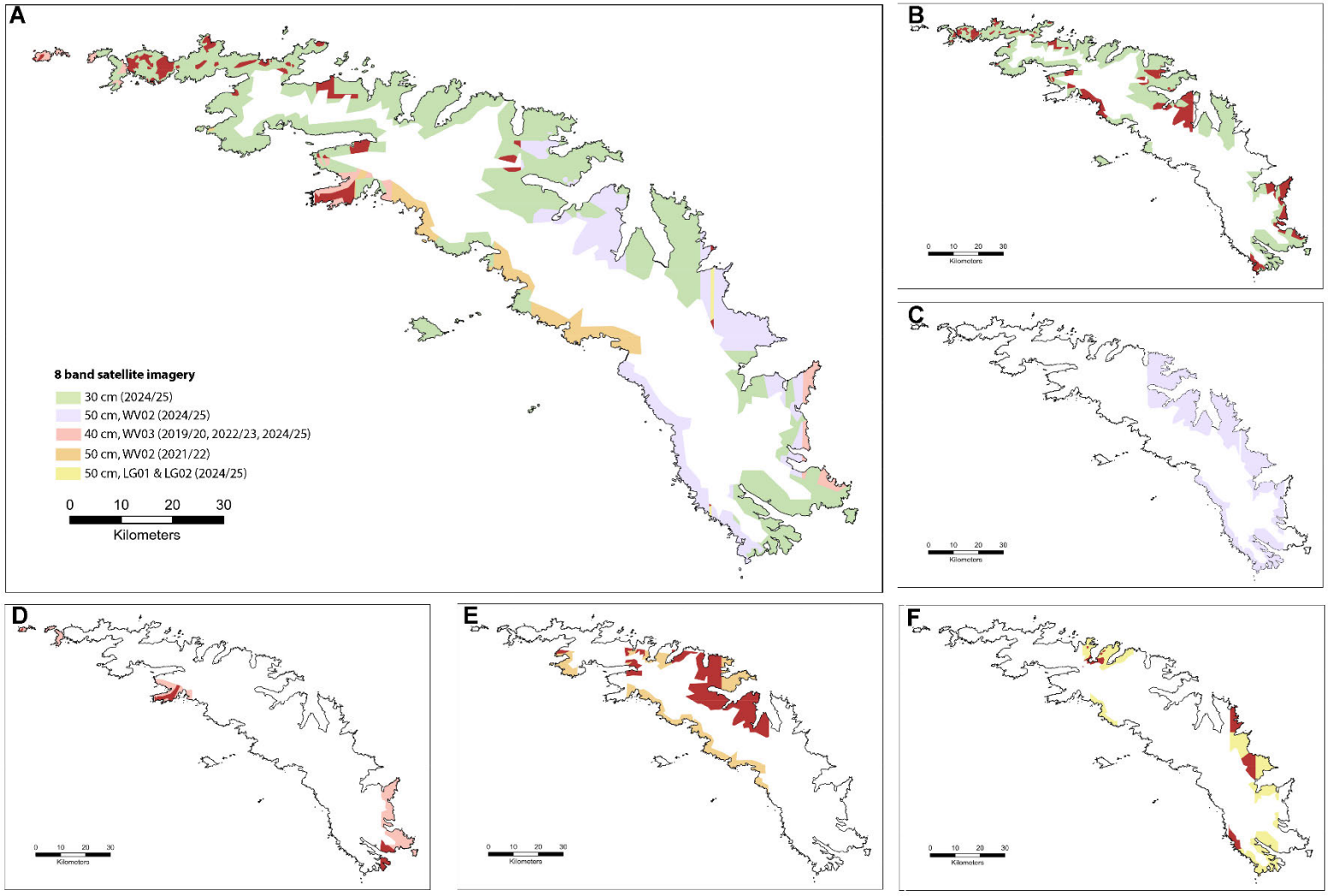


**Figure 4.** Polygon shapefiles and satellite image coverage of South Georgia purchased for this project. Red regions represent cloud obstructed areas of the image. (A) Shapefiles outlining regions of interest (ROIs) for tasking, with a tasking window from 1st December 2024 to 28th February 2025. (B–F) The full extent of each satellite image purchased, shown as green rectangles, with cropping applied to fit the ROIs prior to product delivery. (B) Coverage of 8-band, 30 cm resolution satellite images (WorldView-3) captured during the tasking window. (C) Coverage of 8-band, 50 cm resolution satellite images (WorldView-2) captured during the tasking window. (D) Coverage of 8-band, 40 cm resolution archived satellite images (WorldView-3), including images over Bird Island and Willis Island captured on 23rd January, 25th January, and 6th March 2023. (E) Coverage of 8-band, 50 cm resolution archived satellite images (WorldView-2) from the 2021/22 breeding season (three from January, one from early March). (F) Coverage of 8-band, 30 cm resolution archived satellite images (Legion 1 and Legion 2) captured between 27th December 2024 and 22nd February 2025. The wavelength groupings of Legion imagery differ from WorldView imagery, requiring separate spectral profile analyses. Source: Maxar Search and Discovery © Maxar Technologies 2025.

**2.4 Substantial progress over reporting period**. Methods will be first tested on areas occupied by white-chinned petrels, as they have the greatest chance of success. All 8 band 30-50 cm satellite imagery of South Georgia was purchased in mid-March 2025, including around King Edward Point. The satellite imagery will be calibrated using the hand-held spectrometer data collected during fieldwork, and the spectral profiles will be used to create distinct vegetation categories, including for vegetation fertilised by white-chinned petrels. Distance from coastline, elevation, slope and aspect will be used to filter out areas where only seals occur.

Peter Fretwell organised a two-day "Advanced ENVI spectral analytics" workshop, including how to use used mixed and pure spectral profiles for classifying land. Two BAS researchers on the project (Peter Fretwell and Marie Attard) attended the workshop (**Annex 4.16 for workshop topics covered**). The skills gained from this will be used to create the habitat suitability models.

**2.5 Completed.** See Activity 2.3 for areas tasked and **Annex 4.19** lists all satellite images purchased for archived and tasked orders.

**2.6 In progress.** Currently developing models using relationships between spectral profiles in satellite imagery, and breeding-habitat preferences (Activity 2.4), which will be used to predict presence-absence and relative abundance of burrowing petrels across South Georgia.

**2.7 In progress.** Pending completion of Activity 2.4 and 2.6.

**2.8 Substantial progress over reporting period.** We have drafted a manuscript to publish the shapefiles used to create the 5km-scale seabird distribution map from the 1980s. We aim to submit this manuscript to *Scientific Data* in April 2025. All co-authors have made revisions on the manuscript and we are currently migrating the database (currently stored on Marie Attard's private GitHub project) to the Polar Data Centre, and a DOI will be assigned. We now have the scans of the 131 original hand-drawn annotated grids used to create the 5km-scale seabird distribution map (see **Annex 4.17** for example), which could be used to provide colony-location specific comparisons from satellite imagery from 2024/25 to the 1980s.

**Output 3. An assessment of whether VHR satellite imagery can be used to count mollymawks (black-browed and grey-headed albatrosses), SG shags and giant petrels, and to identify colonies of Wilson's storm petrels and SG diving petrels at Bird Island and elsewhere at SG where ground truthing data available.**

**3.1 Completed in reporting period**. We have completed a detailed ground-truthing survey for Bird Island. This includes distribution data for mollymawks from a UAV survey from December 2023 provided by Sarah Manthorpe (BAS), delivered as polygon shapefiles, in addition to georeferenced nest locations for the subset of colonies at Bird Island and other colonies at South Georgia. The colony extents for mollymawks in **Figure 5** are based on UAV data from the 2003/04 season, though these extents are now expected to be smaller. The UAV imagery can also be used to update the distribution of other focal species.

Previous published data have been used to map the distribution of additional seabird species on Bird Island (see **Figure 5**). Colony extents for macaroni penguins are based on censuses conducted between 1985/86-2003/04. Gentoo penguin colony extents are based on Trathan (1999) and were processed by Herbert (BAS) in 2007. The purple dots in **Figure 5** show the location of South Georgia shag colonies, which occur along the coastline.

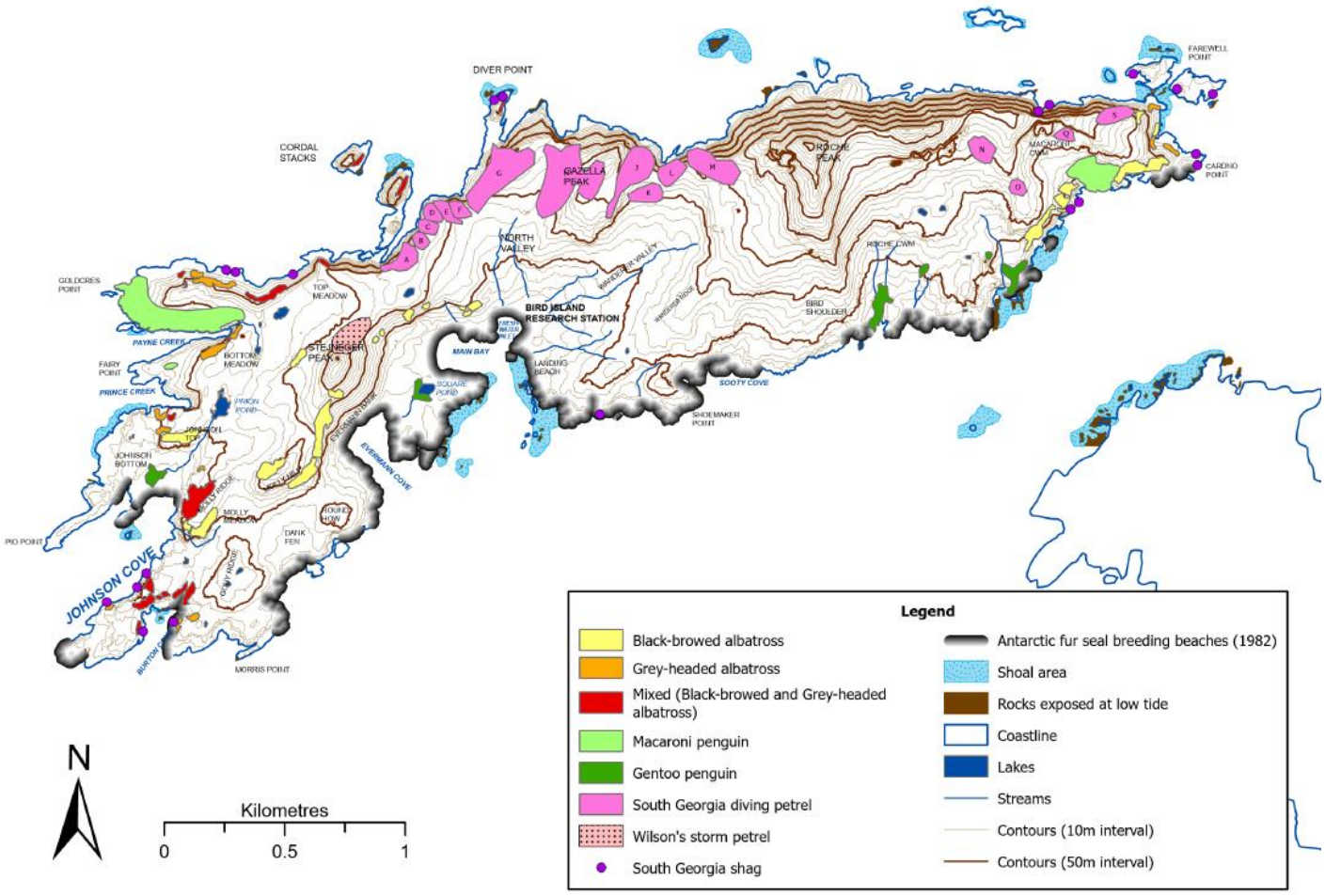


**Figure 5.** Distribution of mollymawks, penguins, South Georgia diving petrels, South Georgia shags and Antarctic fur seals on Bird Island based on previous land-based surveys. See Activity 3.1 for details.

**3.2. Completed.** See Activity 1.3.

**3.3 Substantial progress over reporting period.**

Seabird species that can be detected in 31 cm resolution satellite imagery

Mollymawks: Black-browed and grey-headed albatross colonies are usually situated in tussac on steep slopes of the mainland and offshore islands. Both species are visible in 30 cm satellite imagery (**Figure 6-7**), with manual digitising via blind expert annotations (i.e., based on satellite image without reference to UAV imagery) resulting in areas overlaps of 25% and 12% with ground-truthed data for black-browed and grey-headed albatrosses, respectfully (**Table 2**).

We trialled texture analysis as a method to identify mollymawk colonies. To accomplish this, applied the co-occurrence measures tool (under 'filter' in ENVI GIS software) to the area of interest, which created a texture composite consisting of three layers; homogeneity, variance and mean. Unfortunately, black-browed albatross colonies could not be distinguished using the texture analysis approach. Spectral profiles of mollymawk colonies will be tested to assess whether they have a unique spectral signature to identify colony location and extent.

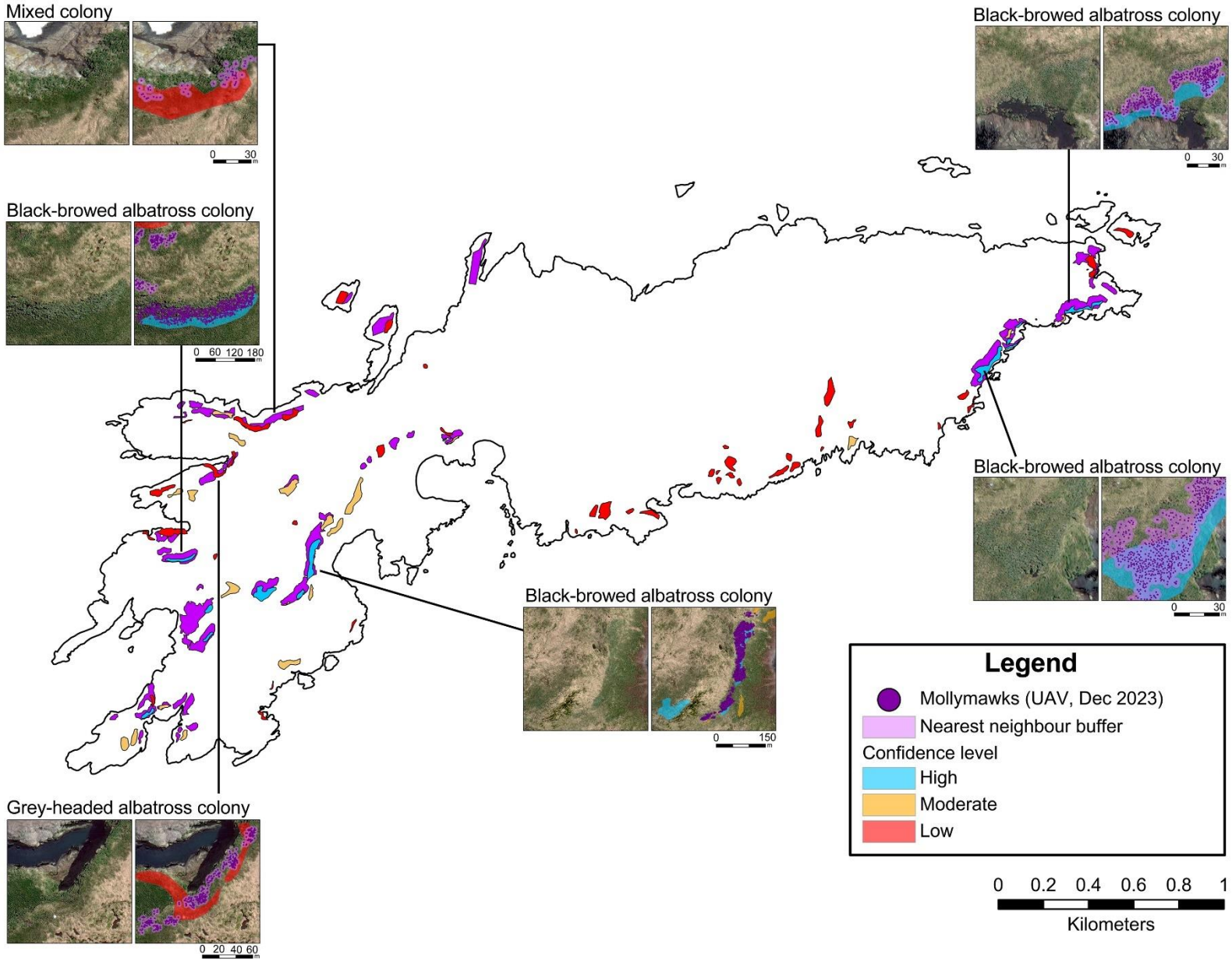


**Figure 6.** Blind expert annotations of mollymawks in satellite imagery and ground-truthed data from drone imagery. The purple dots represent individual mollymawks annotated from UAV imagery, with the purple shaded areas indicating colony extent. The polygons created through blind annotations of the satellite imagery are color-coded based on the annotators' confidence in identifying a mollymawk colony: red = low confidence, yellow = moderate confidence, blue = high confidence.

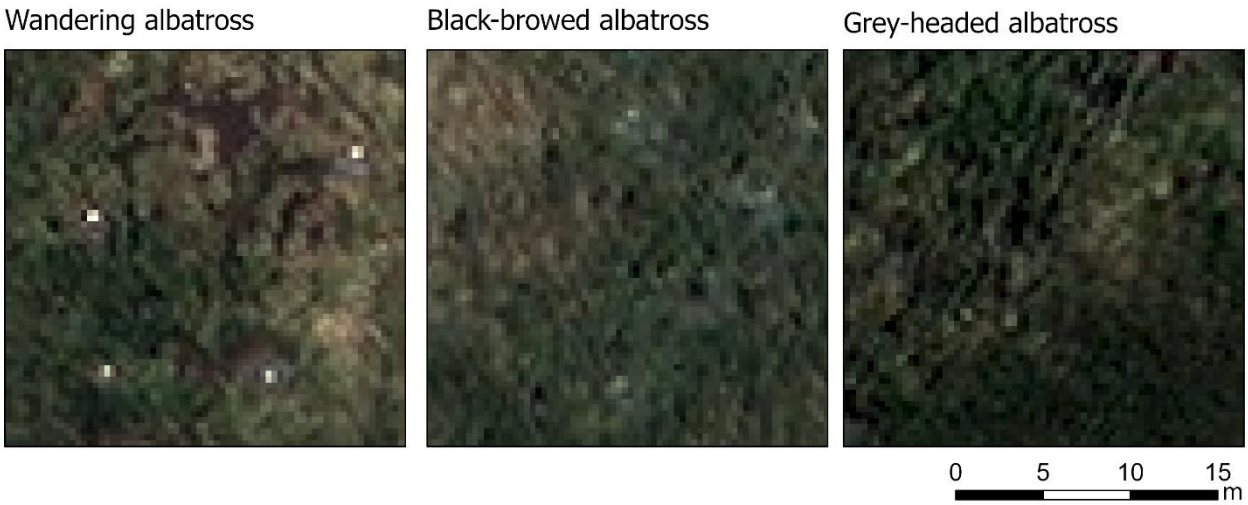


**Figure 7**. Example of wandering albatross, black-browed albatross and grey-headed albatross breeding areas at Bird Island in 31 cm satellite imagery captured on 28 December 2019. Individual birds are shown as bright white dots for wandering albatrosses. Individual black-browed and grey-headed albatrosses appear as faded grey dots based on visual inspection of satellite imagery but will need to be confirmed through comparisons with ground-truthed data.

**Table 2.** Summary of UAV-based colony detections and blind annotator identifications for mollymawks. The table includes the total number of colonies detected via UAV in 2022/23 survey, the number identified independently by a blind annotator using 30 cm resolution satellite imagery taken in the corresponding season, total colony extent from UAV, overlapping areas between UAV and blind annotation datasets, and what percentage of the UAV colony extent was identified in the satellite imagery by the blind annotator.

| Species present at colony | Number of colonies (UAV) | Number of colonies identified (blind annotations) | Total colony extent from UAV ($m^2$) | Overlap area ($m^2$) | Overlap percentage (%) |
|---|---|---|---|---|---|
| Black-browed albatross | 20 | 16 | 77604.83 | 19190.95 | 25 |
| Grey-headed albatross | 13 | 6 | 20989.38 | 2459.60 | 12 |
| Mixed (black-browed albatross and grey-headed albatross) | 13 | 8 | 47557.10 | 6750.01 | 14 |

<u>Seabird species that cannot be detected in 31 cm resolution satellite imagery</u>

- **Giant petrel:** We were unable to see individual giant petrels or their nests in 30 cm satellite imagery of Bird Island; therefore, we will no longer be including giant petrels in our investigation.

- **Antarctic prion, blue petrel and common diving petrel:** Antarctic prions often breed in tussac in the same areas as white-chinned petrels. In other habitats, e.g., gravel plains at Hestesletten, Antarctic prions breed at low densities, and given the smaller volume of guano produced, the areas of enriched vegetation are small and patchily distributed (see example below in **Figure 9**). There is therefore a lower likelihood of detection using VHR imagery. Antarctic prions will therefore be excluded from the current analyses, although will potentially be revisited later in the

project. The same applies to blue petrels and common diving petrels, which also nest in vegetation.

**Figure 9.** Small area of enriched vegetation around Antarctic prion burrow at Hestesletten, South Georgia in late December 2023.

**3.4 Substantial progress over reporting period. “**Blind” expert annotations (i.e. made without reference to ground truth data) of mollymawk locations and extent were completed by Peter Fretwell for archived satellite imagery of Bird Island. The polygon shapefiles created during the blind annotations were compared to the polygon shapefiles, revealing that most black-browed colonies could be identified in the blind annotations, but not grey headed albatross (**Figure 8**).

Tom Hart from Oxford University opportunistically took drone imagery (with a spectral camera attached) behind the King Edward Point facility, where much of the hand-held spectral profiles of tussac in white-chinned petrel colonies were taken by our field team. Richard Phillips will be meeting Tom Hart in late March discuss the potential to use the drone imagery for validating satellite imagery results.

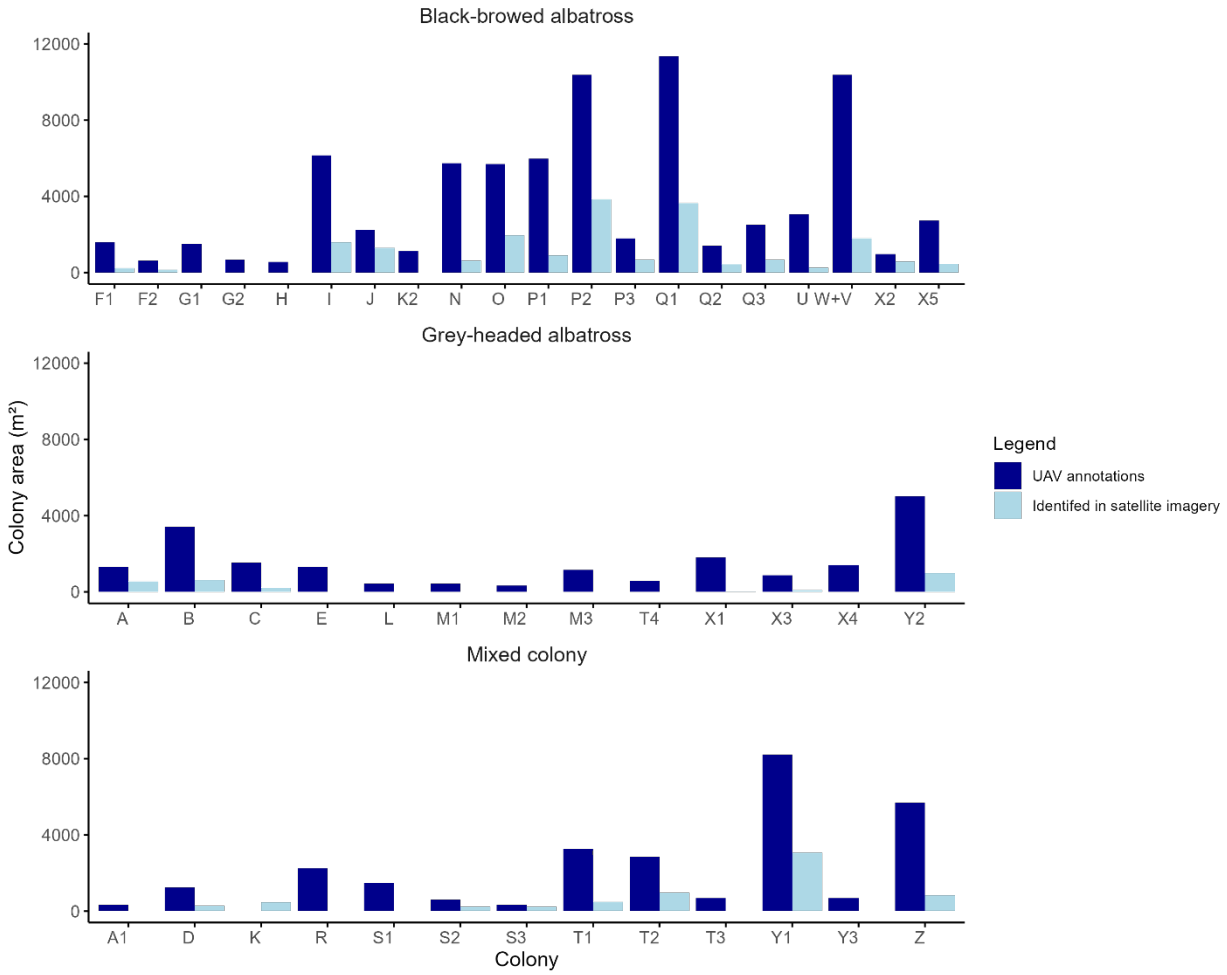


**Figure 8.** Mollymawk colony extent identified by UAV and blind annotations of corresponding satellite imagery captured in December 2022. Colonies are divided into those only containing black-browed albatross (top), grey-headed albatross (middle), and mixed colonies (bottom).

**3.5 Progress over reporting period.** Satellite imagery has been purchased across South Georgia, which will be used to complete expert annotations to develop automated detection methods for species detectable as individuals. We were able to detect black-browed albatrosses in 30 cm satellite imagery, but detection of grey-headed albatrosses was much more difficult (Activity 3.4). We will no longer be investigating giant petrels, as individual birds could not be seen in 30 cm satellite imagery of Bird Island. Visibility of individual South Georgia shags in 30 cm satellite imagery will be tested in the next report period.

**3.6 Progress over reporting period**. Peter Fretwell and Marie Attard have completed a 2-day Advanced ENVI spectral analytics workshop on 11-12th March 2025 to learn how to apply indirect methods such as spectral classification, to apply in classifying guano. Texture analysis has been tested for mollymawk colonies and may be applied later on in this project to assess its viability to identify burrow locations for species not directly detectable.

**Output 4. An archipelago-wide VHR satellite survey of wandering albatrosses, mollymawks and SG shag breeding colonies on SG using methods developed in Output 3.**

**4.1 Completed.** We have access to all abundance and distribution data for seabirds surveyed as part of the 2023/24 all-islands albatross surveys. A manuscript reporting the findings of these surveys has been submitted for publication by Richard Phillips and co-authors.

**4.2 Completed this report period.** See activity 2.3 for details.

**4.3 To commence in next reporting period.**

**4.4 To commence in next reporting period.**

**Output 5. Dissemination and application.**

**5.1 Progress over reporting period.** Held last stakeholder meeting on 1 July 2024 (**Annex 4.12-4.13**), and organising next stakeholder meeting for April 2025. Postponed end of year stakeholder meeting (Dec 2024) until more substantial process with fieldwork data collection and satellite imagery purchase. Talks that describe the project include 6 international conferences and workshops (**Annex 4.20-4.25**), 2 bird club meetings (**Annex 4.28-4.29**) and 1 university seminar series (**Annex 4.30**). A poster was also presented at the 2024 BAS science symposium (**Annex 4.31**).

In regular contact with Sally Poncet (South Georgia Surveys), who has provided survey data for the project, and is co-author on South Georgia Atlas database manuscript.

**5.2. Substantial progress over reporting period.** We are in the process of depositing the database used to create *South Georgia: An Ecological Atlas* in the Polar Data Centre, as part of an upcoming manuscript submission to *Scientific Data*. This will include the original shapefiles with 5 x 5 km seabird, mammal and plant distributions, as well as historical sites, placenames and geological information.

We are preparing two manuscripts as part of the DPLUS132 project using crowdsourcing to manually count wandering albatrosses in satellite imagery at 24 breeding sites across South Georgia. The satellite images used in this campaign were divided into 150 m x 150 m tiles, which will be deposited with the raw and process crowd and expert annotations in the Polar Data Centre to be made freely accessible. The data will be used by our team as a training dataset to develop machine learning methods for automated detection of wandering albatrosses, with potential to be applied to other large seabird species.

**5.3 Ongoing**. We include meeting minutes for monthly DPLUS187 team meetings with BAS researchers on the project (**Annex 4.1-4.9** from this reporting period), as well as biannual stakeholder meetings (**Annex 4.12-4.13**).

5.4 **Significant progress over reporting period.** Over the reporting period, we have prepared three manuscripts for submission, funded by Darwin Plus, and one paper is published:

1. Paper published on deductibility of Tristan albatrosses on Gough Island using 30 cm resolution satellite imagery (DPLUS132) at *Endangered Species Research* (doi: https://doi.org/10.3354/esr01396). This study has provided further insight on best practice for testing detectability of individuals in satellite imagery for other seabird species (DPLUS187).

2. Draft manuscript publishing database used to create *South Georgia: An Ecological Atlas*, including colony-specific and 5 km-grid distribution and abundance of seabirds (DPLUS187). To be submitted in April.

3. Draft manuscript to publish satellite image tiles (tiff format, not georeferenced) and annotations (as pixel coordinates and latitude/longitude) from the Albatrosses from Space GeoHive campaign (DPLUS132 project) for wandering albatrosses across South Georgia. The dataset will be used to develop machine learning-based detection of wandering albatrosses (DPLUS187), depending on project timelines.

4. Drafted manuscript with results from *Albatrosses from Space* GeoHive campaign (DPLUS132 project) for wandering albatrosses to assess count accuracy, which will help inform **Output 4.3** of DPLUS187 project.

Manuscripts 3-4 will be submitted once reviewer comments are received for the 2023/24 all-islands albatross survey, which is separate from this project.

## 3.2 Progress towards project Outputs

***Outputs:***

1. **An assessment of whether burrowing petrels can be detected using satellite imagery based on spectral analysis of vegetation colour at Bird Island.**

We have made excellent progress since the last annual report. We collected spectral profiles for single species and mixed vegetation types during fieldwork at King Edward Point in November 2024-January 2025. Approximately 100 hand-held spectrometer scans were taken, with 3-6 replicates per vegetation type. Spectral profiles collected include tussac fertilised by seals and white-chinned petrels, and unfertilised tussac. Two satellite images were purchased of KEP from this breeding season; one in December and March to examine seasonal variation in vegetation spectral profiles. We have written a Python script to pre-process the spectrometer data, and have attended a 2-day Advanced ENVI Spectral Analytics workshop on 11-12th March on how to use the spectral profiles to classify land features in WorldView-3 (WV03) and Sentinel-2 imagery. Our next steps are to:

1. Using spectral signatures create classifications routines to identify and discriminate fertilised tussock.
2. Convolve and apply this to the WV03 imagery mosaic to map potential habitat.
3. Check these results using existing mapping of petrel nesting locations.

2. **An assessment of long-term changes in the distribution and densities of burrowing petrels across SG using satellite imagery.**

Good progress has been made in preparation for assessing long-term changes in burrowing petrel distributions and densities using satellite imagery. The viability of using satellite imagery to detect areas of burrowing petrels is currently underway, using Bird Island and KEP as our initial study areas (see Objective 1). If successful, these methods will be expanded across SG using imagery collected in the 2024/25 breeding season. In preparation for this, we have (1) Collated survey data (abundance and presence-absence) for burrowing petrels around the Thatcher Peninsula and Bird Island. (2) Recovered the 1980s all-island bird and mammal surveys used to create *South Georgia: An Ecological Atlas*, which we are currently preparing to submit for publication. (3) Purchased 30-50 cm resolution 8 band tasked imagery for the 2024/25 breeding season, and archived imagery from 2021/22-2023/24 to fill in any spatial gaps. (4) Completed fieldwork around King Edward Point to collect hand-held spectrometer measurements of different vegetation assemblages, including vegetation at white-chinned petrel colonies and areas occupied by Antarctic fur seals and southern elephant seals.

3. **An assessment of whether VHR satellite imagery can be used to count mollymawks (black-browed and grey-headed albatrosses), SG shags and giant petrels, and to identify colonies of Wilson's storm petrels and SG diving petrels at Bird Island and elsewhere at SG where ground- truthing data available.**

Blind annotations for mollymawks in the satellite imagery was completed (**Figure 8**). Sarah Manthorpe provided mollymawk nest GPS coordinates using UAV imagery collected in December 2023. The annotated data from UAV and satellite imagery was superimposed over the satellite imagery to determine if we can see each species. Black-browed albatrosses could be identified with the naked eye, but only some of the grey-headed albatross colonies could be seen. Texture analysis function was tested in ENVI to see it could automatically detect black-browed albatross, but was unsuccessful.

We have drafted a dataset manuscript, incorporating crowd and expert annotation data of wandering albatrosses and corresponding tiles from the Albatrosses from Space campaign (funded by DPLUS132) using satellite imagery from 2015- 2022 across South Georgia to use as training dataset to develop automated detection methods for this species, and potentially mollymawks. Maxar has approved the publication of this dataset. The automated detection methods Ellen Bowler developed for her PhD (completed in 2023) on wandering albatrosses will be reevaluated using the larger campaign dataset. Alternative automated detection methods will be considered for development if they are more suitable.

Later in the project, we will investigate imagery of Bird Island to determine if there are spectral signatures of colonies of Wilson's storm petrels and South Georgia diving petrels. This will be based on visual inspection of satellite imagery using different spectral settings. South Georgia diving petrels will be resurveyed on Bird Island if we can see them in satellite imagery. As these

birds produce very small strips of guano and have a patchy distribution, there is a slight chance they can be detected in satellite imagery.

**4. An archipelago-wide VHR satellite survey of wandering albatrosses, mollymawks and SG shag breeding colonies on SG using methods developed in Output 3.**

Maxar provided us with all annotations and image chips (i.e., satellite images divided into a grid) of South Georgia from the Albatrosses from Space campaign (total 11,839 image chips, 150 x 150 m dimensions each with 5 m overlap) as georeferenced tiffs (700 x 700 pixels). We received permission from Maxar to use the non-georeferenced image chips and annotations to further develop AI methods to count wandering albatross. If successful, the same approach may be used for mollymawks if this species can be individually detected and counted. Texture analysis will concurrently be tested as a potential method to detect mollymawk colonies.

Polygons representing some of the mollymawk breeding areas based on recent drone census have been created for Bird Island, alongside blind annotations of colony extents from satellite imagery to test whether black-browed and grey-headed albatrosses can be detected (**Figure 8**).

We compiled South Georgia shag distributions at Bird Island and near KEP from more recent surveys. We were unable to see individual South Georgia shags or their nests, or detect the colony extent, in 30 cm satellite imagery on Bird Island, which may be due to the small colony size. We will make another attempt to do using satellite imagery of the larger colony (30-40 pairs) near KEP. We will also assess whether the South Georgia shag colonies can be detected indirectly from the colour of their guano.

*South Georgia: An ecological atlas* has presence-absence data in 5x5 km grid cells from the 1980s for wandering albatrosses, mollymawks and South Georgia shags (e.g., **Figure 3**), which we are currently publishing as shapefiles and csv files (see **Annex 4.10-4.11** for draft manuscript and supplemental materials).

**5. Dissemination and application.**

We have held monthly in-person meetings with the main BAS researchers on this project (see **Annex 4.1-4.9**), while some were postponed due to staff absence. We organised a hybrid stakeholder meeting on 1st July, and all stakeholder representatives were invited to attend. The minutes, Powerpoint slides and video recording from the meeting were distributed via email to the partners and stakeholders (**Annex 4.13-4.14**).

We are planning to publish three datasets over the coming year:

1. Existing seabird distribution/census data across South Georgia from the 1980s used in South Georgia: An Ecological Atlas will be published alongside the original 131 hand-annotated maps from these surveys as a dataset paper, to be submitted to *Scientific Data* in April.
2. We are currently preparing the *Albatrosses from Space* campaign dataset from DPLUS132 for the NERC Polar Data Centre repository. Our intention is to reuse this dataset to develop automated detection methods for wandering albatrosses across South Georgia for the current project. A draft manuscript has been written.
3. The annotations and satellite image tiles used in manuscript (2) will be published as a separate training dataset, which could be used for automated detection of wandering albatross using machine learning methods.

### 3.3 Progress towards the project Outcome

**Outcome: Baseline abundance data, distribution maps, and new satellite-monitoring protocols are established for multiple species of seabirds across the entire South Georgia (SG) archipelago, improving species management and advocacy.**

The last year of the project included preparing collated abundance and presence-absence data for all study species across South Georgia from the 1980s for publication, tasking and purchase of satellite imagery across South Georgia from December 2024-Feburary 2025.

Visual inspection of mollymawk colony locations in satellite imagery suggest that it may be possible to detect black-browed but not grey-headed albatross colonies. At 30 cm resolution, the resolution is too low to count individual mollymawks, but it may be possible to measure colony extent.

We were unable to confidently identify any South Georgia shag colonies on Bird Island, most likely because these colonies are very small. We have a higher probability of detecting South Georgia shags on KEP as their colonies are larger (~30-40 individuals), which will be tested this year using satellite imagery recently purchased. We have purchased tasked satellite imagery across South Georgia for the 2024/25 breeding season to complete an island-wide census of species that can be indirectly or directly detected in satellite imagery. It is, however, too early to know whether the satellite-monitoring approaches being developed will work for mollymawks, shags and burrowing petrels for a full delivery of the outcome at this stage.

### 3.4 Monitoring of assumptions

The start of the project was delayed until 1st December 2023 while we completed the DPLUS132 project, which ended on 30th November 2023. As such, the Project Implementation Timetable in the DPLUS132 application was shifted back by 6 months. As several months noticed is required for tasking imagery, tasking imagery across South Georgia was postponed until the 2024/25 breeding season.

**Assumption 1:** Cloud-free satellite imagery will be available in 2023/24 and 2024/25. Images will be tasked in 2025/26 for sites that require additional imagery.

**Comments:** Tasking of 8 band 30 cm resolution imagery was postponed until the 2024/25 breeding season, with cloud-free imagery available across most of South Georgia, which were purchased. All remaining gaps in imagery were filled by purchasing 40-50 cm resolution imagery from the Dec 2024-Feb 2025 tasking window, in addition to imagery from 2021/22 to 2024/24.

**Assumption 2:** Fieldwork will be undertaken at Bird Island and around KEP for ground truthing (Outputs 1 and 2).

**Comments:** Fieldwork was undertaken at KEP in the 2022/23 breeding season to record GPS coordinates of white-chinned petrel colonies and take photographs of the colonies at the coastline from a boat. A hand-held spectrometer was used to collect spectral profiles of tussac at white-chinned petrel colonies, seal haul-out sites, in addition to a variety of unfertilised plant species around KEP. A hand-held GPS was used to record coordinates where spectral profiles were taken. The spectral profiles will be used to calibrate satellite imagery in both locations.

**Assumption 3:** Stakeholders will engage with the project and attend project meetings. We are confident of strong stakeholder engagement, as this project builds on existing partnerships, and addresses a priority objective outlined by ACAP and GSGSSI. We will ensure stakeholders are consulted and involved via emails and regular meetings (hosted remotely to ensure maximum attendance).

**Comments:** We contacted a list of stakeholder representatives to ask if they are interested in being involved in the project or want to be informed of updates by attending project meetings or receiving meeting minutes. The first stakeholder hybrid meeting was held in July 2024, with the next one planned for April 2025. We have been in regular email correspondence with Sally Poncet from South Georgia Surveys.

**Assumption 4:** Fieldwork will go ahead in 2023/24 and 2024/25.

**Comments:** Fieldwork using a hand-held spectrometer was conducted in November 2024 to January 2025 to measure spectral profiles of vegetation for the areas we are interested in. Tom Hart from Oxford University flew a UAV-mounted spectral camera across some of the site in January 2025 for an unrelated project, and we have contacted him to see if the imagery gathered could be useful for validating our satellite imagery.

**Assumption 5:** There will be a unique spectral signature for vegetation surrounding seabird burrows, which in combination with data on elevation, aspect and slope can be used to develop automated methods for detecting breeding areas.

**Comments:** In the last annual report, we had extracted the spectral signature for vegetation surrounding white-chinned petrel burrows and Bird Island and used a 2 m resolution DEM to extract other characteristics of these breeding areas (i.e., elevation, aspect, and slope). We will be testing different methods to detect breeding areas using the data collected at KEP over the next several months.

**Assumption 6**: High classification accuracy and reproducibility to allow burrowing petrel nesting areas to be distinguished from areas used by seals at lower elevations.

**Comments:** The NDVI values are very similar between tussac fertilised by white-chinned petrels and seals. Other spectral indices will be tested to see if the spectral profiles can be teased apart this year, based on data collected at KEP.

**Assumption 7**: Existing 31cm-resolution archival imagery of Bird Island, previously purchased by BAS, will also be used. These are clear cloud-free images of the island taken during the breeding season in 2014/15, 2019/20 and 2021/22, and a 15cm-HD uplifted image in 2021/22.

Comments: Some of these images were purchased as 3 or 4 bands. The 4 band imagery can be used to create a NDVI raster using NIR1, while 8 band is needed to create an NDVI raster using NIR2. We were able to include previously purchased archived imagery with at least 4 bands. There was not suitable tasked imagery of Bird Island from 2024/25 breeding season, so we instead downloaded two 8 band 30 cm satellite image of Bird Island from 23$^{rd}$ January and 6$^{th}$ March 2023.

**Assumption 8:** Output 1 will have been achieved, i.e., similar methodology is successful and Bird Island.

**Comments:** We are on schedule for completing activities for Output 1 and do not know yet if the methodology will be successful.

**Assumption 9:** Cloud-free imagery at potential burrowing petrel breeding sites will be obtained in 2024/25. Images will be tasked in 2025/26 for sites that require additional imagery. Cloud-free archived imagery will also be purchased.

**Comments:** Tasking of South Georgia, including potential burrowing petrel breeding sites occurred in December 2024-Feburary 2025. Cloud-free archived image of KEP from 2024/25, and Bird Island from 2022/23 have been purchased. Archived imagery was used for Bird Island due to the lack of cloud-free imagery in this area during 2024/25 breeding season.

**Assumption 10:** Albatross census in 2023/24 will go ahead. If not, existing data will be sufficient for validation.

**Comments:** This assumption has been met. The 2023/24 census went ahead and a manuscript reporting the results has been submitted for publication by Richard Phillips and co-authors.

**Assumption 11:** Cloud-free imagery will be available from Bird Island and elsewhere at SG where ground- truthing data are available. A cloud-free 15cm-HD uplifted imagery of Bird Island from 2021/22 is already available.

**Comments:** There is one cloud-free 30 cm resolution imagery of Bird Island from the 2023/24 breeding season (cat ID: 104001008210F900, date: 6 March 2023), but was captured late in the breeding season. Two mostly cloud-free 40 cm resolution images of Bird Island were purchased from 2022/23 breeding season. Cloud-free imagery was available for most areas tasked across South Georgia, and have been purchased.

**Assumption 12:** For SG shags and giant petrels, individuals can be detected and counted or estimated using VHR satellite imagery. Our preliminary work show that shags can be seen individually in 15cm-HD uplifted satellite imagery and differentiated from penguins by spectral colour based on diet.

**Comments:** This will be tested in Year 3 of this project.

**Assumption 13:** Mollymawks mainly breed in single-species colonies. This is correct at

Bird Island.

**Comments:** Although mollymawks mainly breed in single-species colonies, our seabird distribution map of Bird Island reveal several locations containing both mollymawk species.

**Assumption 14:** Texture analysis can be used to assess colony sizes of mollymawks, SG shags and giant petrels.

**Comments:** Texture analysis of satellite imagery was tested on Bird Island using known locations of mollymawks. This approach was not sufficient for classifying mollymawk colonies from the surrounding area.

**Assumption 15:** Spectral analysis can be used to detect guano and hence identify colonies of SG diving petrels in fine scree and Wilson's storm petrels in rocky scree.

**Comments:** There was insufficient time to collect spectral profiles of guano at KEP. Potential access to UAV imagery, with spectral signatures measured may allow us to determine if guano can be used to detect SG diving petrels in fine screen and Wilson's storm petrels in rocky screen. It may be possible to opportunistically collect spectral profiles of guano at KEP in the upcoming field season, pending available funding.

**Assumption 16:** Shags and mollymawks are visible in 15cm-HD uplifted or 31cm-resolution imagery and AI or image analysis methods can be applied to these species. Previous studies confirm that wandering albatrosses can be counted using WV-3 imagery.

**Comments:** Visual inspection of satellite imagery of Bird Island suggest that mollymawks are visible as grey dots (though we expect that individual birds will be difficult to count), whereas individual shags could not be detected. UAV imagery of Bird Island from December 2023 were used to report the latitude and longitude of individual mollymawks. UAV annotations and satellite blind annotations were superimposed over the satellite images to determine whether the grey dots are mollymawks. This was confirmed for black-browed albatross, while grey-headed albatross colonies were often missed in the blind annotations.

**Assumption 17:** Mollymawks mainly breed in single-species colonies at SG. Can apply species ratios from previous all-islands ground surveys to the few mixed-species colonies, or calculate trends from single-species colonies.

**Comments:** This will be tested in Year 2 and Year 3 of the project, in accordance with the project timeline.

**Assumption 18:** Crowdsourced counts of wandering albatross at SG as part of current research project (DPLUS132) using archived imagery are accurate and can be incorporated in training data. This will be confirmed using multiple observers and expert counts.

**Comments:** We found that the crowdsourced and expert counts of wandering albatrosses using archived satellite imagery across SG are accurate. A draft manuscript has been written, which we aim to submit for publication later this year. We have delayed its submission as we have incorporated additional ground counts from the 2022/23 surveys, which need to be published before we can submit this manuscript. The dataset (i.e., annotations and image chips) from the campaign will be uploaded to the UK DPC repository. Ellen Bowler will attempt to use the image chips and annotations as training data to develop automated detection models for wandering albatross, which will commence in Year 3 of the project.

**Assumption 19:** Outputs will be discussed at relevant stakeholder meetings. The decline in populations of ACAP-listed seabirds is a recognised conservation issue for all stakeholders. As such any measures to mitigate further declines in these populations are a priority for many stakeholders, and a consideration for fisheries and management bodies.

**Comments:** Stakeholder meetings will be organised biannually. The first hybrid stakeholder meeting was July 2024. The second biannual meeting was postponed until April 2025 as we were waiting for fieldwork and satellite purchases to be completed so we could present preliminary results. The next ACAP Advisory Committee meeting (AC15) in May 2026, where we aim to share our findings.

## 4. Project support to environmental and/or climate outcomes in the UKOTs

We are currently in the process of testing new methodologies for species for which there are few, if any data on population trends. This includes burrowing petrels, which are presumed to be expanding in distribution following the rodent and reindeer eradications. So far, we have (1) compared spectral profiles between areas occupied by seals, white-chinned petrels and a combination of both at Bird Island, (2) completed a survey at KEP in 2022/23 to identify white-chinned petrel colonies and other seabird species, (3) collected hand-held spectrometer profiles of vegetation at KEP in 2024/25, (4) used UAV imagery and recent ground surveys (reporting coordinates of nests using handheld GPS) of Bird Island to validate detection of mollymawks in satellite imagery, and (5) tasked and purchased all satellite imagery across South Georgia needed for this project.

This project will contribute to the ACAP Implementation Plan by providing data on seabird population status and trends, including of wandering, black-browed and grey-headed albatrosses at South Georgia, which are among nine global High-Priority populations for ACAP. To achieve this, we have requested permission from Maxar to publish the Albatrosses from Space dataset, which we plan to use to train automated detection models for detected wandering albatrosses. A similar procedure could be applied to mollymawks if we find that individuals can be detected in satellite imagery.

The methodologies currently being tested will ensure minimal disturbance to wildlife and the environment, contributing to net-zero targets by offering a low-carbon alternative to field, boat-based and aerial surveys.

## 5. Gender Equality and Social Inclusion (GESI)

One of the joint lead investigators for the project is female (Dr Marie Attard), as is another member of the project team from the BAS AI lab (Dr Ellie Bowler).

| | |
|---|---|
| Please quantify the proportion of women on the Project Board[1]. | 50% project board: Marie Attard (BAS) and Ellen Bowler (BAS) |
| Please quantify the proportion of project partners that are led by women, or which have a senior leadership team consisting of at least 50% women[2]. | Of the 7 stakeholder representatives that attended the 1 July 2024 stakeholder meeting, 3 (43%) were women: Tammy Davies (BirdLife International), Alison Neil (SGHT), Sally Poncet (South Georgia Surveys).<br>Two women were unable to attend due to other commitments but were sent the meeting minutes and PowerPoint slides. They will also be invited to the next stakeholder meeting: Sue Gregory (GSGSSI) and Jaimie Cleeland (BAS).<br>Our 4-person field team at King Edward Point from November 2024 to January 2025 included 50% women: Jaimie Cleeland (BAS) and Kate Owen (BAS). |

[1] A Project Board has overall authority for the project, is accountable for its success or failure, and supports the senior project manager to successfully deliver the project.

[2] Partners that have formal governance role in the project, and a formal relationship with the project that may involve staff costs and/or budget management responsibilities.

| GESI Scale | Description | Put X where you think your project is on the scale |
|---|---|---|
| **Not yet sensitive** | The GESI context may have been considered but the project isn't quite meeting the requirements of a 'sensitive' approach | |
| **Sensitive** | The GESI context has been considered and project activities take this into account in their design and implementation. The project addresses basic needs and vulnerabilities of women and marginalised groups and the project will not contribute to or create further inequalities. | |
| **Empowering** | The project has all the characteristics of a 'sensitive' approach whilst also increasing equal access to assets, resources and capabilities for women and marginalised groups | X |
| **Transformative** | The project has all the characteristics of an 'empowering' approach whilst also addressing unequal power relationships and seeking institutional and societal change | |

The project team recognise the importance of diversity of experts with respect to age, gender, cultural background, education and specialism in providing a range of perspectives, including incorporation of local knowledge, and experience necessary for carrying out the project plan. We have an equal proportion of men to women on the project board, including an early-career researcher (Ellen Bowler), mid-career researcher (Marie Attard) and two individuals that lead research groups (Peter Fretwell and Richard Phillips).

We have been ensuring that people have enough time to prepare for meetings and will be circulating outline agendas in advance of stakeholder meetings and inviting additional items to include. We will be seeking feedback from project partners and stakeholders during these meetings and reviewing the responses within the context of social inclusion. Those that wish to contribute further to the project will be given opportunities for further involvement. Resources produced from this project, such as the species habitat models and distribution data, will be shared on the SGGIS data portal (https://sggis.gov.gs//) and/or on the NERC Polar Data Centre repository (https://www.bas.ac.uk/data/uk-pdc/data-deposit/), providing easily accessible datasets for governments, NGOs and scientific communities to view, download and use.

## 6. Monitoring and evaluation

Regular project monitoring has so far been conducting through monthly meetings with the named BAS researchers on the project (Peter Fretwell, Marie Attard, Richard Phillips, and Ellen Bowler) and bimonthly in-person meetings between Peter Fretwell and Marie Attard. This will be continued throughout the project. The achievement of milestones has been regularly checked against the 'Implementation Timetable' during these meetings. All our indicators were selected on the basis that they were SMART (specific, measurable, achievable, relevant and time-bound). Part of the monitoring is also the biannual stakeholder meetings which will be held in-person and on zoom. These meetings will start in July this year and stakeholders will receive the minutes of each meeting and presentation slides. Prior to this, we will also be holding an in-person meeting with stakeholders that are able to attend the BAS office in Cambridge. The activities conducted within individual outputs are expected to impact to a considerable degree on the ability to conduct subsequent outputs with regards to whether methodologies (texture analysis, spectral analysis and automated detection methods) are able to detect breeding colonies of each seabird species under investigation. By the end of the project, the team will evaluate the overall effectiveness of applying satellite remote sensing for monitoring each flying seabird species across South Georgia. This will mainly be evidenced by publications in peer-reviewed journals and work reports. We will also discuss with stakeholders a forward work plan

to integrate these methods at South Georgia and potentially other areas beyond the life of the current project.

## 7. Lessons learnt

1. Our initial visual examination of 31 cm resolution satellite imagery suggests that giant petrels, Antarctic prions, blue petrels and common diving petrels cannot be detected. This will be confirmed using different spectral bands.

2. The spectral profile for areas surrounding white-chinned petrel burrows is significantly different to areas containing no seals or petrels. As there is some overlap in spectral profiles in areas where seals are present, we will test whether burrows can be distinguished from seal haul-out areas based on geographical parameters (i.e., slope, elevation and distance from coastline) and soil (patchy bare ground for seals versus homogenous vegetation for burrowing petrels).

3. There are grey dots present in satellite imagery for areas containing mollymawks on Bird Island. We will confirm whether these grey dots are individual birds using annotations from UAV surveys collected in December 2023.

4. We cannot directly detect small colonies of South Georgia shags on Bird Island. We will test whether larger South Georgia colonies are visible at KEP, and if they could be located based on the colour of their guano.

5. Accessing historical census data for key species remains a challenge, as much of it is not digitised or published. Allocating time and resources to digitise and publish this legacy data will significantly enhance accessibility and long-term value, enabling better integration with modern datasets.

6. Unexpected environmental conditions (e.g., snow cover and high wind) poses challenges for collecting hand-held spectrometer data. Future fieldwork should allow additional time to increase the likelihood of favourable conditions. The number of feasible repeats per location was more limited than anticipated due to time constraints, highlighting the need for streamlined protocols and more realistic sampling targets.

7. Delivering consistent training and protocols to field staff proved essential for spectral profile data quality. Future efforts should focus on developing clearer, simplified guidance materials and offering more hands-on remote support where possible.

8. Early coordination and clear communication of target areas and seasonal timing with Maxar technologies ensured optimal image acquisition conditions and coverage.

9. Maxar's online platform MGP Pro is ideal for tasking smaller areas (<50 $km^2$) and purchasing archival satellite imagery less than 25 $km^2$ but does not include an educational discount.

## 8. Actions taken in response to previous reviews (if applicable)

Non-applicable

## 9. Risk Management

No new risks have arisen in the last 12 months, therefore no significant adaptations to the project design have been made this year to address risk.

## 10. Sustainability and legacy

Significant efforts have been made to ensure the sustainability and legacy of the project's outputs. Historical survey data has been digitised and prepared for publication with the Polar Data Centre (PDC) and through a data paper, making it easily searchable and accessible for future studies. Processing protocols developed for a related project on the detectability of Tristan albatrosses (DPLUS132) using open-source software (e.g., Python) have been shared via GitHub, supporting reproducibility and enabling further development within the DPLUS187 project.

Where licensed software such as ENVI will be used – for example, in creating habitat models for burrowing petrels - detailed protocols are being produced to ensure analyses can be repeated by others. VHR satellite imagery of South Georgia collected during the project will be retained by the British Antarctic Survey (BAS) for future internal use, in line with Maxar's licencing agreement. Ongoing engagement with stakeholders has facilitated the sharing of methods and findings across organisations, and their input and involvement has strengthened the likelihood of these approaches being adopted in future monitoring efforts.

## 11. Darwin Plus identity

The Darwin Initiative logo was incorporated into the South Georgia seabirds from space webpage on the BAS website and will be used at conferences and presentations. We have created a X (twitter) account (@WildlifeSpace) for this project.

## 12. Safeguarding

## 13. Project expenditure

**Table 1: Project expenditure <u>during the reporting period</u> (1 April 2023 – 31 March 2024)**

| **Project spend (indicative) in this financial year** | **2023/24 D+ Grant (£)** | **2024/25 Total actual D+ Costs (£)** | **Variance %** | **Comments (please explain significant variances)** |
|---|---|---|---|---|
| Staff costs | [redacted] | | | |
| Consultancy costs | | | | |
| Overhead Costs | | | | |
| Travel and subsistence | | | | |
| Operating Costs | | | | |
| Capital items | | | | |
| Others (Please specify) | | | | |
| **TOTAL** | | | | |

**Table 2: Project mobilised or matched funding during the reporting period (1 April 2023 – 31 March 2024)**

| | Secured to date | Expected by end of project | Sources |
|---|---|---|---|
| Matched funding leveraged by the partners to deliver the project (£) | Nil | Nil | |
| Total additional finance mobilised for new activities occurring outside of the project, building on evidence, best practices and the project (£) | Nil | Nil | |

## 14. Other comments on progress not covered elsewhere

## 15. OPTIONAL: Outstanding achievements or progress of your project so far (300-400 words maximum). This section may be used for publicity purposes.

I agree for the Biodiversity Challenge Funds to edit and use the following for various promotional purposes (please leave this line in to indicate your agreement to use any material you provide here).

**A bright green clue: Fertilised vegetation and satellite mapping of burrowing petrel colonies**

Rats and mice, introduced to South Georgia in the late 18th century by sealers and whalers, rapidly multiplied and preyed on the eggs and chicks of burrow and small ground-nesting birds, severely reducing their numbers. Smaller burrowing petrel species could not breed in rodent-infested areas. Reindeer, introduced by Norwegian whalers between 1909 and 1925, exacerbated the problem by overgrazing, which exposed and collapsed burrow entrances.

To restore wildlife on the main island, South Georgia Heritage Trust carried out an eradication project between 2011 and 2015, using poison bait to eliminate rodents. Glacial barriers helped make the effort successful, and in 2018, South Georgia was declared rodent-free. A separate campaign by the Government of South Georgia and South Sandwich Islands removed reindeer by 2015, allowing vegetation to recover and improving habitats for burrowing petrels.

White-chinned petrels breed along the steep coastline of the main island but generally at lower densities than on the outlying islands. Monitoring remains challenging due to their underground nests, making burrows in dense tussac difficult to count over large areas. It is also unclear where numbers are increasing after rodent and reindeer eradication or if petrels have expanded into new areas.

To address these challenges, a new project funded by Darwin Plus is utilising cutting-edge satellite and spectral imaging technology to map seabird habitats and provide deeper insights into the distribution and recovery of burrowing petrels.

It is well known that tussac around dense colonies of burrowing petrels appears brighter green than the surroundings due to the fertilising effect of the guano. This sparked the idea for the Darwin Plus project: could the presence of fertilised vegetation patches be used to map the recovery of white-chinned petrels and other burrowing petrels across South Georgia using satellite imagery?

In November 2024, a British Antarctic Survey field team visited King Edward Point, South Georgia, to collect spectral profiles from vegetation where burrowing petrels occur using a hand-held spectrometer. The data will be used to calibrate 30-50 cm resolution multispectral satellite imagery collected across the archipelago during the 2024/25 breeding season. The spectrometer emits light onto a surface and measures the reflected wavelengths, providing spectral signatures that help differentiate vegetation types and detect fertilisation.

While the primary goal is to map burrowing petrel colonies using satellite imagery, we will also assess its potential for mapping colonies of other seabirds, such as albatrosses, shags, and penguins.

| File Type (Image / Video / Graphic) | File Name or File Location | Caption including description, country and credit | Social media accounts and websites to be tagged (leave blank if none) | Consent of subjects received (delete as necessary) |
|---|---|---|---|---|
| Photo | Photo_1 | Isolated bright green patches of vegetation further up the slope near King Edward Point can be distinguished from the lower, near-continuous band of enriched | BAS DPLUS187 website: https://www.bas.ac.uk/project/south-georgia-seabirds-from-space/ | Yes |

| | | | | |
|---|---|---|---|---|
| | | vegetation associated with seal haul-outs. Credit – Richard Phillips. | | |
| Photo | Photo_2 | British Antarctic Survey field team (Connor Bamford, Jaimie Cleeland, Kate Owen and Nathan Fenney) taking spectral profiles of vegetation in a burrowing petrel colony at King Edward Point. Credit – Connor Bamford and Nathan Fenney. | BAS DPLUS187 website: https://www.bas.ac.uk/project/south-georgia-seabirds-from-space/ | Yes |

## Annex 1: Report of progress and achievements against logframe for Financial Year 2024-2025

Please note that the logframe was updated in our last half-year report (HYR1), which we have used in this Annual report. The workplan was also revised in HYR1 and has been provided in **Annex 4.32** of the current Annual report.

| Project summary | Progress and Achievements April 2024 - March 2025 | Actions required/planned for next period |
|---|---|---|
| ***Impact***<br>New methodologies enable cost-effective, long-term satellite remote sensing of population status and trends of albatrosses, petrels and shags at South Georgia, leading to informed conservation actions. | Collation of seal, seabird and rodent distribution completed and preparing 1980's survey dataset for publication (**Annex 4.10-4.11**). Satellite remote-sensing methodologies currently being developed for albatrosses, petrels and shags at South Georgia. | |
| ***Outcome*** Baseline abundance data, distribution maps, and new satellite-monitoring protocols are established for multiple species of seabirds across the entire South Georgia (SG) archipelago, improving species management and advocacy. | | |
| 0.1 Counts from VHR satellite imagery provide specific abundance estimates for multiple seabirds across the entire SG archipelago by the project end date. | 0.1 Ongoing. Texture analysis applied to mollymawks to test viability of this method in detecting colonies on Bird Island and was found to be insufficient. We started trialling different methods outlined in section 3.1 to verify if VHR satellite imagery can be used to detect and estimate the abundance of different seabird species on Bird Island and KEP. | 0.1 Use spectral and landscape characteristics for burrowing petrel breeding areas, and texture analysis of mollymawks and SG shags to test the viability of these methods in detecting colonies in Bird Island and KEP. Use different spectral bands to determine if Antarctic Prion, blue petrel and common diving petrel colonies are visible in satellite imagery. |

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| 0.2 By combining spectral classification of vegetation colour and habitat characteristics, maps of areas occupied by burrowing petrels at high densities will be available for the entire SG archipelago by the project end date. | 0.2 Ongoing. Currently comparing spectral profiles vegetation in areas with and without burrowing petrels and/or seals on KEP using hand-held spectrometer data. This dataset will be used to calibrate two KEP satellite images from 2024/25 breeding season, purchased in March 2025. | 0.2 Different algorithms and image detection methods (e.g., rule based feature extraction, random forest) will be used to determine if known burrows can be identified on KEP and Bird Island using landscape information including (1) NDVI from 30 cm resolution satellite image to classify vegetation colour, and (2) slope, elevation, and distance from shore from a 2 m resolution DEM representing habitat characteristics. A portion of known breeding areas at the study sites will be used as the training dataset. |
| 0.3 Develop and access new satellite remote-sensing methods tailored to specific seabird species, including spectral classification of vegetation for burrowing petrels; guano detection for Wilson's storm petrel and South Georgia diving petrels; manual counts of species where individual detection is feasible; and pattern-based area analysis for mollymawks to improve colony detection. Data and methods will be published to ensure long-term uptake and facilitate use elsewhere. | 0.3 Ongoing. Started testing satellite remote-sensing methods for several seabird species. | 0.3 Complete trials of different satellite remote-sensing methods for each seabird species on KEP and Bird Island. |
| 0.4 Engagement with stakeholders (GSGSSI, ACAP, SGHT and RSPB) throughout the project will lead to a commitment to improve the frequency and coverage of seabird population surveys on SG using satellite remote sensing. This engagement will include regular progress updates and culminate a final stakeholder meeting to present findings on each effectiveness of each method developed for satellite-based monitoring of targeted seabird species. | 0.4 Ongoing. Regular discussions via email with Sally Poncet from GSGSSI, who has provided past census data for mollymawks and original hand-drawn annotations of all bird colonies in 1980's surveys to include in an upcoming manuscript submission. Stakeholder meeting held on 1 July 2024, with next stakeholder meeting to be organised in April 2024. Delay in biannual stakeholder meetings as we preferred to wait until all tasked imagery was purchased, and the KEP fieldwork was completed. | 0.4 Contact all stakeholder representatives to ask what degree they wish to be involved and hold biannual stakeholder meetings in person and on zoom. |
| **Output 1** An assessment of whether burrowing petrels can be detected using satellite imagery based on spectral analysis of vegetation colour at Bird Island. | | |

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| Output indicator 1.1 Existing information on burrowing petrel distribution and abundance collated from previous surveys at Bird Island during Y1/2, supplemented by new data collection in December 2023/January 2024. | 1.1 Completed. Collated existing raw data on burrowing petrel distribution and abundance at Bird Island (from 2015/16 census) and KEP (from 2022/23 census). Richard Phillips photographed burrowing areas at KEP from a boat during the 2023/24 season (**Annex 4.14**) to improve accuracy of distribution maps. | 1.1 Use collated data to develop habitat models at Bird Island and KEP to detect burrowing petrels (see Output 1.4). Create spreadsheet with sources of all known surveys/censuses for white-chinned petrels at South Georgia. |
| Output indicator 1.2 Measurements recording spectral profiles of vegetation in areas occupied by different species of burrowing petrels are collected on King Edward Point using hand-held spectrometers in December 2024 to March 2025. | 1.2 Planned and completed fieldwork. The team obtained hyperspectral data using a hand-held spectrometer (**Annex 4.15**) in November 2024 to January 2025. | 1.2 Complete spectral profile measurements of vegetation adjacent to occupied and unoccupied petrel burrows based on UAV imagery collected from Bird Island and/or KEP from December 2024-March 2025. |
| Output indicator 1.3 Hand-held spectrometer data compared with online spectral libraries to determine if they produce a noticeable difference in reflectance by Y2Q4. | 1.3 Ongoing. We have purchased a licence of ENVI, which contains online spectral libraries to compare with hand-held spectrometer data that were collected in 2024/25 field season. We completed an ENVI Advanced Online workshop in March 2025 on analysing spectral data and comparing them to pre-existing spectral libraries (**Annex 4.16**). | 1.3 Compare spectral profile measurements of vegetation adjacent to occupied and unoccupied petrel burrows on Bird Island to online spectral libraries based on data collected using a UAV with a mounted camera and spectrometer. |
| Output indicator 1.4 Geographic object-based analysis (GEOBIA) methods are developed to identify petrel breeding areas on King Edward Point by classifying bright green vegetation (resulting from improved growth because of the nutrients in the guano) by end of Y3Q1. | 1.4 Ongoing – recently started applying GEOBIA methods to burrowing petrel breeding areas. | 1.4 Finalise development of GEOBIA methods to identify white-chinned petrel breeding areas on Bird Island and KEP by classifying bright green vegetation. |
| **Output 2.** An assessment of long-term changes in the distribution and densities of burrowing petrels across SG using satellite imagery. | | |
| Output indicator 2.1. VHR satellite imagery of the entire SG archipelago tasked for December 2024/January 2025. Imagery successfully obtained and purchased by end of Y2Q4. | 2.1 Completed. List of tasked and archived images purchased across South Georgia in **Annex 4.19**. | 2.1 The entire SG archipelago will be tasked from December 2024 to January 2025 and purchased before the next annual report. The South Georgia coastline will be divided |

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| | | into at least 5 polygons and ordered as separate tasking orders to keep each payment under £10k each. In addition, £10k will be added to the MGP pro platform to task smaller areas over a 2+ year subscription. |
| Output indicator 2.2 Habitat suitability models incorporating elevation, slope and aspect are produced, to highlight areas of SG away from Bird Island that may be suitable for nesting by burrowing petrels by Y3Q1. | 2.2 Ongoing. We used 2 m resolution DEM of South Georgia (downloaded from REMA) to extract elevation, slope and aspect of burrowing petrel areas at Bird Island. Distance to coastline will be incorporated into habitat suitability models to help differentiate burrowing petrel breeding areas from seal haul out sites. | 2.3 Habitat suitability models developed and trailed using known locations of burrowing petrels at KEP and Bird Island. |
| Output indicator 2.3 Methods validated at other sites on SG based on existing knowledge of burrowing petrel distribution at KEP and elsewhere, and new survey data collected during 2023/24 albatross census. | 2.3 Ongoing. We purchased 8 band 30 cm resolution satellite images purchased for KEP and Bird Island from Maxar's archive to validate methods. Existing knowledge of burrowing petrel distribution at South Georgia from *South Georgia: An Ecological Atlas*. New survey data collected at KEP from 2022-23 survey – evidence provided in **Annex 4.14**. | 2.3 Methods validated using satellite imagery from KEP and Bird Island using existing knowledge of burrowing petrel distribution at these locations. |
| Output indicator 2.4 Habitat models applied across SG using tasked VHR imagery to map distribution of burrowing petrels at high densities by Y3Q3. | 2.4 Not yet started. Habitat models currently being developed for Bird Island and KEP to see they can be used to detect burrowing petrels using purchased satellite imagery. | 2.4 Determine whether habitat models can adequately detect burrowing petrels on Bird Island and KEP. If successful, this will be applied across SG after tasked images from the 2024/25 season are purchased. |
| Output indicator 2.5 Comparison of distributions of burrowing petrels in VHR imagery with presence-absence at 5km-scale across SG mapped in the 1980s by end of Y4Q1. | 2.5 Ongoing. The 5km-scale presence-absence data from the 1985-87 census has been recovered from the Polar Data Centre. This dataset is being prepared as a manuscript, to be submitted to *Scientific Data* (**Annex 4.10 and 4.11**). Completion of this output indicator pending successful development of satellite remote-sensing methods to locate burrowing petrel breeding areas. | 2.5 Burrowing petrel distributions will be assessed using VHR satellite imagery across South Georgia by Y3Q3 if the methods developed are successful. |

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| Output indicator 2.6 Habitat models made available on open access portals and results disseminated at conferences, through peer- reviewed papers and media outreach by project end date. | 2.6 Not yet started. | 2.6 Habitat models are currently being developed for Bird Island and King Edward Point, and will be applied across South Georgia next year, if successful. |
| **Output 3.** An assessment of whether VHR satellite imagery can be used to count mollymawks (black-browed and grey-headed albatrosses), SG shags and giant petrels, and to identify colonies of Wilsons' storm petrels and SG diving petrels at Bird Island and elsewhere at SG where ground- truthing data available. | | |
| Output indicator 3.1 VHR satellite imagery of Bird Island and elsewhere at SG where colony locations are known, supplemented by new imagery collected in December 2024/ January 2025. | 3.1 Completed. Archived VHR satellite imagery has been purchased for Bird Island and King Edward Point. This has been further supplemented by new imagery collected in December 2024/January 2025 (**Figure 4**). | 3.1 Complete tasking of South Georgia to purchase 8 band 30 cm satellite imagery by April 2024. |
| Output indicator 3.2 Satellite images of breeding areas for each species are assessed and annotated by experts, and results compared with known distributions by Y2Q2. | 3.2 Ongoing. UAV imagery collected in December 2023 at Bird Island, with point annotations for each individual mollymawk. Blind annotations also completed on corresponding satellite imagery from the same breeding season to compare to the UAV annotations (**Figure 8**). | 3.2 Sarah Manthorpe will provide georeferenced nest locations for the subset of mollymawk colonies at Bird Island (and elsewhere at South Georgia) which were surveyed with UAV in December 2023. Data will be superimposed over satellite imagery to determine whether nesting mollymawks can be detected and accurately counted by Y2Q2. |
| Output indicator 3.3 For each species which is detectable as individual birds, expert annotations will be used to develop and compare different automated detection methods (e.g., spectral classification, texture analysis, CNNs) by end of Y2. | 3.2 Ongoing. The vegetations surrounding burrows of white-chinned petrels are much greener and has a significantly different NDVI values compared to areas containing no seals or burrows (**see Figure 4 and table S3 in AR1**). | 3.2 Wandering albatrosses can be detected as individual birds, and AI methods will be further developed using crowd annotations from the Albatrosses. |
| Output indicator 3.4 For each species which are detectable, but resolution restricts accurate counting, the feasibility of different approaches (e.g., spectral classification, texture analysis, CNNs) will be assessed by end of Y3Q1. Texture analysis will be used on mollymawks, SG shags and giant petrels. Spectral analysis will be used to detect guano from SG diving petrels in | 3.2 Ongoing. Visual inspection of satellite images reveals penguin colonies. South Georgia shag individuals cannot be visually detected at Bird Island, possibly due to small colony size. Mollymawks are visible as a speckled pattern, but individual birds cannot be identified. Black-browed albatrosses can be detected with high confidence, while grey-headed albatrosses are more difficult to detect (**Figure 8**). | 3.2 Texture analysis will be tested for the detection of penguin and South Georgia shag colonies at Bird Island and King Edward Point, and a combination of spectral and landscape classifications will be tested for |

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| fine scree and Wilson's storm petrels in rocky scree. | We will test different methods to locate and quantify mollymawk colony extent from satellite imagery. | white-chinned petrels by the end of Y2. |
| **Output 4.** An archipelago-wide VHR satellite survey of wandering albatrosses, mollymawks and SG shag breeding colonies on SG using methods developed in Output 3. | | |
| Output indicator 4.1 VHR satellite imagery of the entire SG archipelago tasked for December 2024/ January 2025 (Y2Q3-Y2Q4). | 4.1 Completed. Online satellite imagery ordering platforms (MGP Pro and One Atlas) were used to task the entire coastline of the main island, as well as smaller islands off the main island (**Figure 4A**). | 4.1 Submit tasking request to Maxar of the entire SG archipelago by October 2024 for tasking window starting December 2025 to end of January 2025. Purchase cloud-free imagery once tasked imagery becomes available. |
| Output indicator 4.2 Collate data on abundance and distribution of target species across SG archipelago by Y2Q1. | 4.2 Completed. Presence-absence 5km-scale data across SG archipelago for all target species in *South Georgia: An ecological Atlas* has been recovered from the Polar Data Centre and is being prepared for publication (**Annex 4.10-4.11**). This will be supplemented by more recent species abundance and distribution across SG archipelago from the 2023/24 all-island albatross census. | 4.2 Update collated data with 2023/24 SG census data for wandering albatrosses and mollymawks when it becomes publicly available. Create spreadsheet listing sources of data for all target species. |
| Output indicator 4.3 For species which can be counted individually, use methods developed in output 3.3 to count species across SG by Y3Q4. | 4.3 Ongoing. Wandering albatrosses can be counted as individuals. Mollymawks in UAV imagery was annotated by Sarah Manthorpe from the biological sciences data management team at BAS to use for ground-truthing (**Figure 4**), and found that mollymawks can be detected, but cannot be accurately counted in 30-cm resolution satellite imagery. | 4.3 Provide further validation for species that can be counted individually. |
| Output indicator 4.4 For species which can be detected indirectly (e.g., through detection of guano), use methods developed in output 3.4 to count species across SG by Y3Q4. | 4.4 Ongoing. We determined that SG shags cannot be counted individually, therefore we will test whether their guano at SG shag colonies can be detected and differentiated from penguin guano in VHR satellite imagery. | 4.4 Confirm whether SG shag and penguin colonies can be detected indirectly through detection of guano, using imagery of Bird Island and KEP. |
| Output indicator 4.5 Validate all island survey results using known distribution data and 2023/2024 all-island albatross census, by Y4Q1. | 4.5 Ongoing. SG albatross census completed by South Georgia Surveys during 2023/24, and field report for wandering albatross census results produced by Sally Poncet. Figures showing abundance and distribution are being worked by Richard Phillips and Liz Mackley for publication. | 4.5 Task and purchase VHR satellite imagery across SG to compare with ground-truth data. |

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| Output indicator 4.6 Results and data from the satellite surveys published and made open source by project end date. | 4.6 Not yet started. Satellite imagery purchased across South Georgia to validate methods, including Bird Island and King Edward Point (**Annex 4.19**). | 4.6 Task and purchase VHR satellite imagery across SG to compare with ground-truth data. |
| **Output 5.** Dissemination and application. | | |
| Output indicator 5.1 Results and recommendations will be shared with stakeholders to inform their conservation and management frameworks, during bi-annual stakeholder meetings, culminating in a comprehensive summary at the final stakeholder meeting. These findings may lead to specific actions, such as the adoption of new monitoring techniques, policy adjustments, and the identification of areas for future research. | 5.1 First stakeholder meeting on 1 July 2024 – list of attendees and those that were invited by could not attend in **Annex 4.12**. Any stakeholder representatives unable to attend were sent the meeting minutes (**Annex 4.12**), video recording of the meeting (can be provided upon request) and presentation slides (**Annex 4.13**). | 5.1 Stakeholder meetings will be arranged for July and December this year. Additional meetings with individual stakeholders will be arranged where needed. |
| Output indicator 5.2 Data deposited in global databases by project end date. | 5.2 Not yet started. Data is being collated on abundance and distribution of target species across SG archipelago and will be included in a data repository by the project end date. | 5.2 Annotated data from satellite imagery will be produced for target species that can be detected directly or indirectly. |
| Output indicator 5.3 Communication of results at two international conferences during Y2 and Y3. | 5.3 Ongoing. Marie Attard presented a talk on albatross detection in satellite imagery at the Ecological Society of America in California, August 2024 (programme here), IPY Planning workshop, November 2024 (programme here), and ESA BIOSPACE25, February 2025 (programme here). Peter Fretwell presented our work on using satellite imagery to detect albatrosses at the SCAR conference in Chile, August 2024 and the International Seabird Group conference in Portugal, September 2024. Richard mentioned the project in three talks: Peterborough Bird Club – March 2025; CEBC-CNRS, Chizé – Sept. 2024; Norfolk Wildlife Trust/Cley Bird Club – Nov 2024.Ellen Bowler presented an overview of the project at the Anglia Ruskin School of Life Sciences seminar series (November 2024). | 5.3 We will present preliminary results at three international conferences this year. Abstracts for oral presentations will be submitted for at least one international conference in 2025. |

## Annex 2: Project's full current logframe as presented in the application form (unless changes have been agreed)

| Project summary | SMART Indicators | Means of verification | Important Assumptions |
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| **Impact:** New methodologies enable cost-effective, long-term satellite remote sensing of population status and trends of albatrosses, petrels and shags at South Georgia, leading to informed conservation actions. | | | |
| **Outcome:** Baseline abundance data, distribution maps, and new satellite-monitoring protocols are established for multiple species of seabirds across the entire South Georgia (SG) archipelago, improving species management and advocacy. | 0.1 Counts from VHR satellite imagery provide specific abundance estimates for multiple seabirds across the entire SG archipelago by the project end date.<br><br>0.2 By combining spectral classification of vegetation colour and habitat characteristics, maps of areas occupied by burrowing petrels at high densities will be available for the entire SG archipelago by the project end date.<br><br>0.3 Develop and assess new satellite remote-sensing methods tailored to specific seabird species, including spectral classification of vegetation for burrowing petrels; guano detection for Wilson's storm petrel and South Georgia diving petrels; manual counts of species where individual detection is feasible; and pattern-based area analysis for mollymawks to improve colony detection. Data and methods will be published to ensure long-term uptake and facilitate use elsewhere.<br><br>0.4 Engagement with stakeholders (GSGSSI, ACAP, SGHT and RSPB) throughout the project will lead to a commitment to improve the frequency and coverage of seabird population surveys on SG using satellite remote sensing. This | 0.1 Data on counts of species in satellite images; results published in peer-reviewed journal; data added to open access portal (e.g. GBIF https://www.gbif.org/).<br><br>0.2 Maps added as layers to interactive SG map (https://www.sggis.gov.gs/); results published in peer-reviewed journal.<br><br>0.3 Data made open access; methods written up in peer- reviewed journal; code published on open-source repository; independent meeting reports will mention the results of the project and commitment to future satellite surveys.<br><br>0.4 Stakeholder meeting minutes and reports; report text to include next steps for updated management recommendations based on new abundance and distribution data. | Cloud-free satellite imagery will be available in 2023/24 and 2024/25. Images will be tasked in 2025/26 for sites that require additional imagery.<br><br>Fieldwork will be undertaken at Bird Island and around KEP for ground truthing (Outputs 1 and 2).<br><br>Stakeholders will engage with the project and attend project meetings. We are confident of strong stakeholder engagement, as this project builds on existing partnerships, and addresses a priority objective outlined by ACAP and GSGSSI. We will ensure stakeholders are consulted and involved via emails and regular meetings (hosted remotely to ensure maximum attendance). |

| Project summary | SMART Indicators | Means of verification | Important Assumptions |
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| | engagement will include regular progress updates and culminate in a final stakeholder meeting to present findings on the effectiveness of each method developed for satellite-based monitoring of targeted seabird species. | | |
| **Output 1** An assessment of whether burrowing petrels can be detected using satellite imagery based on spectral analysis of vegetation colour at Bird Island. | 1.1 Existing information on burrowing petrel distribution and abundance collated from previous surveys at Bird Island during Y1/2, supplemented by new data collection in December 2023/January 2024.<br><br>1.2 Measurements recording spectral profiles of vegetation in areas occupied by different species of burrowing petrels are collected on Bird Island using hand-held spectrometers in December 2024 to March 2025.<br><br>1.3 Hand-held spectrometer data compared with online spectral libraries to determine if they produce a noticeable difference in reflectance by Y2Q4.<br><br>1.4 Geographic object-based analysis (GEOBIA) methods are developed to identify petrel breeding areas on Bird Island by classifying bright green vegetation (resulting from improved growth because of the nutrients in the guano) by Y3Q1. | 1.1 Literature review and list of data sources; maps showing distribution based on current data.<br><br>1.2 Data from hand-held spectrometers; correspondence with field researchers on Bird Island.<br><br>1.3 Data files containing spectral readings of vegetation; plots comparing spectral signatures.<br><br>1.4 Algorithm results assessed using test images; consult expert opinion and peer review process; publication of manuscript detailing the methods and results of study. | Fieldwork will go ahead in 2023/24 and 2024/25.<br><br>There will be a unique spectral signature for vegetation surrounding seabird burrows, which in combination with data on elevation, aspect and slope can be used to develop automated methods for detecting breeding areas.<br><br>High classification accuracy and reproducibility to allow burrowing petrel nesting areas to be distinguished from areas used by seals at lower elevations.<br><br>Existing 31cm-resolution archival imagery of Bird Island, previously purchased by BAS, will also be used. These are clear cloud-free images of the island taken during the breeding season in 2014/15, 2019/20 and 2021/22, and a 15cm-HD uplifted image in 2021/22. |
| **Output 2** An assessment of long-term changes in the distribution and | 2.1 VHR satellite imagery of the entire SG archipelago tasked for December 2024/ January 25. Imagery successfully obtained and | 2.1 and 2.2 List of archival images compiled and downloaded; models produced; baseline data assessed by experts. | Output 1 will have been achieved, i.e., similar methodology is successful at Bird Island.<br><br>Cloud-free imagery at potential |

| Project summary | SMART Indicators | Means of verification | Important Assumptions |
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| densities of burrowing petrels across SG using satellite imagery. | purchased by end of Y2Q4.<br><br>2.2 Habitat suitability models incorporating elevation, slope and aspect are produced, to highlight areas of SG away from Bird Island that may be suitable for nesting by burrowing petrels by Y3Q1.<br><br>2.3 Methods validated at other sites on SG based on existing knowledge of burrowing petrel distribution at KEP and elsewhere, and new survey data collected during 2023/24 albatross census.<br><br>2.4 Habitat models applied across SG using tasked VHR imagery to map distribution of burrowing petrels at high densities by Y3Q3.<br><br>2.5 Comparison of distributions of burrowing petrels in VHR imagery with presence-absence at 5km-scale across SG mapped in the 1980s [17] by Y4Q1.<br><br>2.6 Habitat models made available on open access portals and results disseminated at conferences, through peer-reviewed papers and media outreach by project end date. | 2.2 to 2.4 Map showing distribution; verified at ground survey locations; results assessed by experts.<br><br>2.5 Map data showing the 1980s presence-absence survey; satellite derived map data; comparison statistics; peer review from stakeholders.<br><br>2.6 Published papers; conference proceedings; data visible and available to download on open access sites. | burrowing petrel breeding sites will be obtained in 2024/25.<br>Images will be tasked in 2025/26 for sites that require additional imagery. Cloud-free archived imagery will also be purchased.<br><br>Albatross census in 2023/24 will go ahead. If not, existing data will be sufficient for validation. |
| **Output 3** An assessment of whether VHR satellite imagery can be used to count mollymawks (black-browed and grey-headed albatrosses), SG shags and giant petrels, and to identify colonies of Wilsons' storm petrels and SG diving petrels at Bird Island and | 3.1 VHR satellite imagery of Bird Island and elsewhere at SG where colony locations are known, supplemented by new imagery collected in December 2024/ January 2025.<br><br>3.2 Satellite images of breeding | 3.1 Images downloaded from Maxar; image quality verified by experts.<br><br>3.2 Scientists receive image data; digitized annotation files (point markers and polygons); analysis comparing satellite and ground counts | Cloud-free imagery will be available from Bird Island and elsewhere at SG where ground- truthing data are available. A cloud-free 15cm-HD uplifted imagery of Bird Island from 2021/22 is already available.<br><br>For SG shags and giant petrels, |

| Project summary | SMART Indicators | Means of verification | Important Assumptions |
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| elsewhere at SG where ground- truthing data available. | areas for each species are assessed and annotated by experts, and results compared with known distributions by Y2Q2.<br><br>3.3 For each species which is detectable as individual birds, expert annotations will be used to develop and compare different automated detection methods (e.g. spectral classification, texture analysis, CNNs) by end of Y2.<br><br>3.4 For each species which are detectable, but resolution restricts accurate counting, the feasibility of different approaches (e.g., spectral classification, texture analysis, CNNs) will be assessed by end of Y3Q1. Texture analysis will be used on mollymawks, SG shags and giant petrels. Spectral analysis will be used to detect guano from SG diving petrels in fine scree and Wilson's storm petrels in rocky scree. | 3.3 and 3.4 Automated method results assessed using test data; consult expert opinion and peer review; publication of results. | individuals can be detected and counted or estimated using VHR satellite imagery. Our preliminary work show that shags can be seen individually in 15cm-HD uplifted satellite imagery and differentiated from penguins by spectral colour based on diet.<br><br>Mollymawks mainly breed in single-species colonies. This is correct at Bird Island.<br><br>Texture analysis can be used to assess colony sizes of mollymawks, SG shags and giant petrels.<br><br>Spectral analysis can be used to detect guano and hence identify colonies of SG diving petrels in fine scree and Wilson's storm petrels in rocky scree. |
| **Output 4** An archipelago-wide VHR satellite survey of wandering albatrosses, mollymawks and SG shag breeding colonies on SG using methods developed in Output 3. | 4.1 VHR satellite imagery of the entire SG archipelago tasked for December 2024/ January 2025 (Y2Q3-Y2Q4).<br><br>4.2 Collate data on abundance and distribution of target species across SG archipelago by Y2Q1.<br><br>4.3 For species which can be counted individually, use methods developed in output 3.3 to count species across SG by Y3Q4.<br><br>4.4 For species which can be | 4.1 List of purchased imagery; images checked and verified by experts; results of past surveys shared with project team.<br><br>4.2 Data showing distribution information; literature review; correspondence with SG research groups<br><br>4.4 and 4.5 Results assessed on test images; statistics showing accuracy for each species; report and publish estimated population counts. | Shags and mollymawks are visible in 15cm-HD uplifted or 31cm-resolution imagery and AI or image analysis methods can be applied to these species.<br>Previous studies confirm that wandering albatrosses can be counted using WV-3 imagery.<br><br>Mollymawks mainly breed in single-species colonies at SG. Can apply species ratios from previous all-islands ground surveys to the few mixed-species colonies, or calculate trends from single-species colonies. |

| Project summary | SMART Indicators | Means of verification | Important Assumptions |
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| | detected indirectly (e.g., through detection of guano), use methods developed in output 3.4 to count species across SG by Y3Q4.<br><br>4.5 Validate all island survey results using known distribution data and 2023/2024 all-island albatross census by end of Y4Q1.<br><br>4.5 Results and data from the satellite surveys published and made open source by project end date. | 4.6 Share point shapefiles (identifying location of each individual bird) and satellite image IDs on open access portals and digital repositories; add data to SGGIS. | Crowdsourced counts of wandering albatross at SG as part of current research project (DPLUS132) using archived imagery are accurate and can be incorporated in training data. This will be confirmed using multiple observers and expert counts. |
| **Output 5** Dissemination and application. | 5.1 Results and recommendations will be shared with stakeholders to inform their conservation and management frameworks during bi-annual stakeholder meetings, culminating in a comprehensive summary at the final stakeholder meeting. These findings may lead to specific actions, such as the adoption of new monitoring techniques, policy adjustments, and the identification of areas for future research.<br><br>5.2 Data deposited in global databases by project end date.<br><br>5.3 Communication of results at two international conferences during Y2 and Y3. | 5.1 Text from independent meeting reports, and meeting minutes will discuss the results and plants to implement changes to management frameworks; a paper detailing results will be submitted to working group meetings of ACAP and CCAMLR.<br><br>5.2 Datasets made available online in SGGIS.<br><br>5.3 Abstracts presented in conference programs; results published in peer-reviewed journals. | Outputs will be discussed at relevant stakeholder meetings. The decline in populations of ACAP-listed seabirds is a recognised conservation issue for all stakeholders. As such any measures to mitigate further declines in these populations are a priority for many stakeholders, and a consideration for fisheries management bodies. |
| **Activities**<br><br>1.1 Collate existing data on burrowing petrel distribution and abundance at Bird Island.<br>1.2 Organise collection of new data on burrowing petrel distribution and abundance at Bird Island.<br>1.3 (and 3.2) Task 31-cm image of Bird Island for December 2023.<br>1.4 Arrange measurements of within-season changes in spectral profiles of vegetation in areas occupied by different species of burrowing petrels at Bird Island using hand-held spectrometer. | | | |

| Project summary | SMART Indicators | Means of verification | Important Assumptions |
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| 1.5 Model relationships between spectral profiles from hand-held spectrometer and satellite imagery, and breeding- habitat preferences to predict presence/absence and relative abundance of burrowing petrels at Bird Island.<br><br>2.1 Collate existing data on burrowing petrel distribution and abundance across SG.<br>2.2 Organise collection of presence-absence data of burrowing petrels in habitat around KEP, and in 2023/24 all-islands albatross census.<br>2.3 (and 4.2) Task collection of VHR satellite imagery of the entire SG archipelago for December 2024 - January 2025 window.<br>2.4 Produce habitat suitability models using elevation, slope and aspect to highlight suitable burrowing petrel nesting areas<br>2.5 Purchase tasked VHR satellite imagery of SG archipelago<br>2.6 Apply models using relationships between spectral profiles in satellite imagery, and breeding-habitat preferences (developed in Output 1), to predict presence/absence and relative abundance of burrowing petrels across SG.<br>2.7 Validate distribution models for areas away from Bird Island using available ground-truthing data from elsewhere at South Georgia.<br>2.8 Compare predicted distributions with presence-absence at 5km-scale across SG mapped in the 1980s.<br><br>3.1 Collate data on abundance or distribution of mollymawks, SG shags, giant petrels, Wilsons' storm petrels and SG diving petrels at Bird Island.<br>3.2 (See activity 1.3)<br>3.3 VHR satellite images assessed for presence of each species by experts. Annotations of seabird species are produced either as point markers on individuals, or polygons outlining presence and extent.<br>3.4 Compare expert annotations to ground and UAV survey data to validate results<br>3.5 For species which are detectable as individual birds (potentially mollymawks, SG shags and giant petrels), use expert annotations to develop automated detection methods<br>3.6 For species where individuals are not detectable (e.g Wilson's storm petrel, SG diving petrels), test the use of indirect methods such as spectral classification of guano and texture analysis of burrows<br><br>4.1 Collate data on abundance or distribution of mollymawks, SG shags, giant petrels, Wilsons' storm petrels and SG diving petrels across South Georgia, including in 2023/24 all-islands albatross census.<br>4.2 (see activity 2.3)<br>4.3 Apply methodologies developed as part of 3.3 and 3.4, and in DPLus132 for wandering albatrosses, to count individuals or detect colonies of wandering albatrosses, mollymawks, SG shags, giant petrels, Wilsons' storm petrels and SG diving petrels across South Georgia.<br>4.4 Validate all island survey results by comparing to existing data on abundance and distribution, and to 2023/2024 all-island albatross surveys.<br><br>5.1 Share results and recommendations with stakeholders.<br>5.2 Deposit data in open access web portals. | | | |

| Project summary | SMART Indicators | Means of verification | Important Assumptions |
|---|---|---|---|
| 5.3 Prepare reports for working groups and stakeholders.<br>5.4 Prepare manuscripts for publication in peer-reviewed journals.<br>5.5 Attend national and international conference to present results.<br>5.6 Make results available via websites for public dissemination | | | |

## Table 1 Project Standard Indicators

| DPLUS Indicator number | Name of indicator | Units | Disaggregation | Year 1 Total | Year 2 Total | Year 3 Total | Total to date | Total planned during the project |
|---|---|---|---|---|---|---|---|---|
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## Table 2 Publications

| Title | Type (e.g. journals, best practice manual, blog post, online videos, podcasts, CDs) | Detail (authors, year) | Gender of Lead Author | Nationality of Lead Author | Publishers (name, city) | Available from (e.g. weblink or publisher if not available online) |
|---|---|---|---|---|---|---|
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