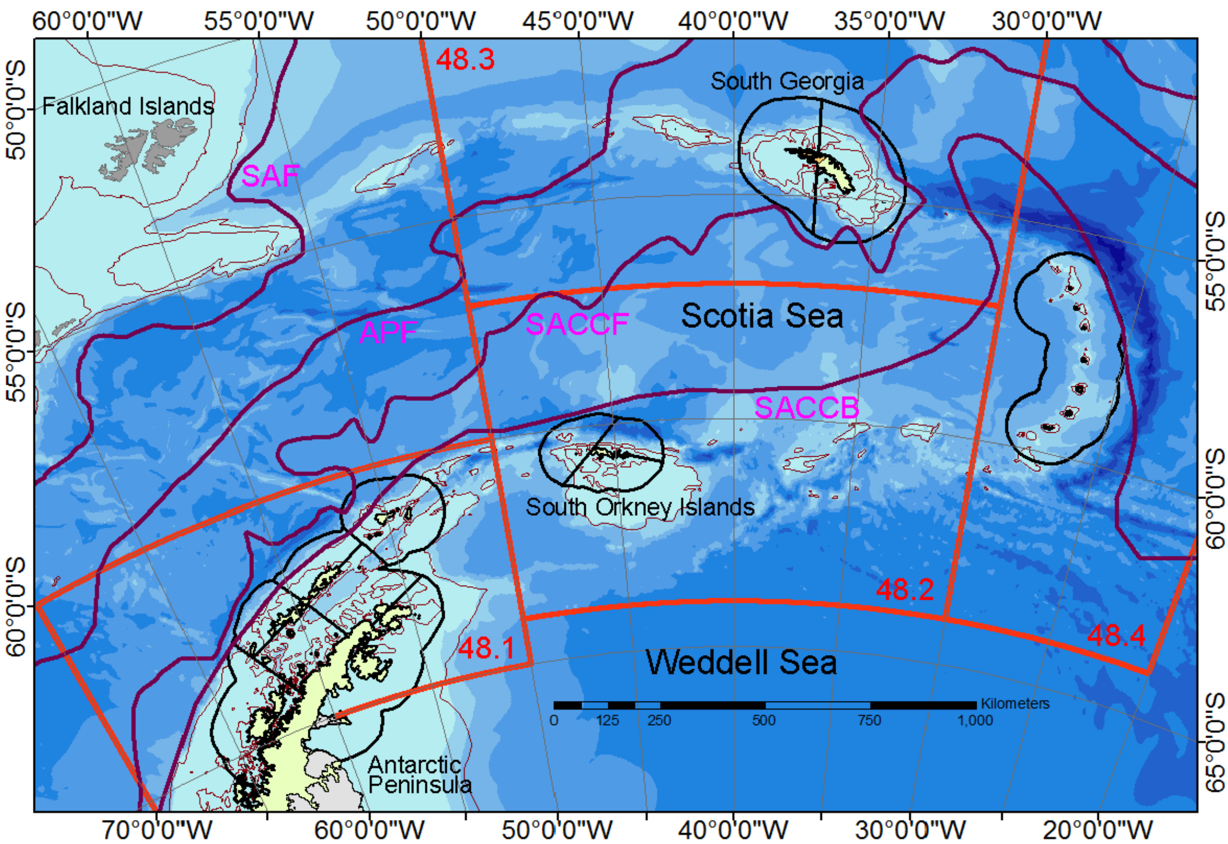
# Darwin Plus:
# Overseas Territories Environment and Climate Fund
# Annual Report

**Submission Deadline: 30th April 2017**

## Darwin Plus Project Information

| | |
|---|---|
| Project reference | DPLUS054 |
| Project title | Managing Antarctic krill fisheries: identifying candidate marine areas for protection |
| Territory(ies) | BAT, SGSSI |
| Contract holder institution | BAS |
| Partner institutions | BirdLife International, ERA |
| Grant value | £99,937.38 |
| Start/end date of project | 1 April 2016 – 31 March 2018 |
| Reporting period | 1 April 2016 – 31 March 2017 17AR2 |
| Project leader name | Philip Trathan, Head of Conservation Biology |
| Project website/blog/Twitter | |
| Report author(s) and date | Philip Trathan |

## 1. Project overview




The fishery for Antarctic krill is managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). CCAMLR's management of krill currently comprises a set of arbitrary decision rules, based on historical fishing levels and operations. These are recognised as being inadequate for managing a fishery that potentially competes with a very broad guild of krill-dependent predators (penguins, other seabirds, seals and whales, as well as fish and squid), especially if the fishery expands in the future. Failure to implement scientific evidence-based measures stems from a high degree of historical mistrust between fishing nations and conservation-minded nations, as well as from the fact that the Antarctic marine ecosystem is highly variable and more complex that generally accepted. This project will help in the formulation of a more scientifically robust management framework by clearly delimiting penguin (a key monitoring group of species used by CCAMLR) resource requirements. It will also contribute to specific spatial protection measures around important seabird feeding locations. This proposal contributes to the Government of the British Antarctic Territory (GBAT) objectives relating to understanding the environment, the challenges it faces and methods for conservation and protection. It also contributes to the Government of South Georgia and the South Sandwich Islands (GSGSSI) objectives to engage in high quality research to underpin management and provide safe and sustainable fisheries to ensure minimal impact on non-target species and habitats, including engaging in CCAMLR. BAT and SGSSI are both UK Overseas Territories. The figure on page 1 of this report shows the area where the krill fishery currently operates. The boundaries of FAO Statistical Subareas 48.1, 48.2, 48.3, 48.4 and 48.5 are shown in red, as are the boundaries of the CCAMLR Small Scale Management Units (SSMU) for the krill fishery in black. The major fronts of the Antarctic Circumpolar Current (ACC) are shown in pink: Southern ACC Boundary (SACCB); Southern ACC Front (SACCF); Antarctic Polar Front (APF); and Sub-Antarctic Front (SAF).

## 2. Project stakeholders/partners

This work contributes to a key objective of the UK Delegation to CCAMLR, namely that nearshore areas of ecological importance should be protected, particularly where the krill fishery operates very close inshore near to ecosystem components that may be adversely affected by harvesting. This objective was highlighted in two papers submitted to the CCAMLR Scientific Committee in 2016 (SC-CAMLR-XXXV/11; SC-CAMLR-XXXV/BG/14). This objective is also important at South Georgia, where the MPA surrounding the islands prohibits krill fishing closer than 12 nm.

The initial focus of the work so far has been within BAT, but our models will have applicability to SGSSI and so will be developed for penguins that breed there, thereby also contributing to the forthcoming SGSSI MPA review in 2018 and development of a research and monitoring plan (see DPLUS069).

We are working with our partners (BirdLife and ERA) to identify analysis methods that will facilitate the identification of marine Important Bird and Biodiversity Areas. This work will be based on the outputs of the preferred habitat models already developed. It is envisaged that a results will be submitted to the CCAMLR Working Group on Ecosystem Monitoring and Management in 2017.

## 3. Project Progress

Since the project started on 1 April 2016 we have successfully recruited a postdoctoral fellow, Dr Victoria Warwick-Evans who has been employed full time at BAS and will be for the duration of this project. Dr Warwick-Evans has been working on the development of preferred foraging habitat models for chinstrap penguins (*Pygoscelis antarctica*), using pre-existing GPS telemetry data and time-depth-recorder dive data. Dr Warwick-Evans has successfully linked the tracking data with the dive data for different colonies at the South Orkney Islands and has also successfully integrated these data with corresponding environmental covariate data for the region. Models have been developed in ArcGIS Geographic Information Software and in the R statistical framework.

A variety of statistical frameworks have been under consideration, including Generalised Additive Models (GAM), Boosted Regression Trees (BRT) and Ensemble Models. After exploring the behaviour of these models in some considerable detail, including by cross validation and evaluating how well they develop projections within and between tracking sites, we decided to develop a final set of models using GAMs.

The results from these models have shown that it is feasible to model the tracking data from different colonies within a common framework, and that individual colonies can be modelled based on the results from the other colonies combined. The sensitivity (the proportion of correctly predicted presences) and specificity (the proportion of correctly predicted absences) values indicates that the models performed well for predicting both the presences and absences of foraging locations. Further details of the model development and results are provided in Annex 3. The results from these models will be presented to CCAMLR WG-EMM in 2017 and then submitted for scientific publication.

Dr Philip Trathan (BAS) has been engaging with all data owners for penguin tracking data (Argentina, Japan, Norway and USA) to acquire tracking data for the Antarctic Peninsula. These data have now been sourced and we are beginning to develop preferred habitat models for the South Shetland Islands and northern Peninsula. We will develop similar models for South Georgia and the South Sandwich Islands later in the project.

Dr Trathan has also developed collaborative links with other Antarctic animal tracking experts through the Scientific Committee for Antarctic Research (SCAR) Expert Group on Birds and Marine Mammals (EGBAMM). This link is extremely beneficial to the project as it ensures that world leading experts are involved in the design of the statistical analyses. We submitted work from this group to CCAMLR in 2016 (WG-EMM-16/14).

Dr Trathan and Dr Claire Waluda (BAS) have also begun to develop krill consumption models for penguins in the Scotia Sea. They are collaborating with Dr Louise Emmerson and Dr Colin Southwell (Australian Antarctic Division) to develop appropriate energetic models in the R statistical framework. These models will subsequently be parameterised using existing CCAMLR Ecosystem Monitoring (CEMP) data. We submitted work to CCAMLR in 2016 (WG-EMM-16/37).

Katarina Lorenz, Dr Colin Harris (ERA), Dr Ben Lascelles, Dr Maria Dias (BirdLife International) and Dr Trathan have also begun to consider how best to delineate marine Important Bird and Biodiversity Areas for penguins in Subarea 48.1 and Subarea 48.2. We submitted work to CCAMLR in 2016 (WG-EMM-16/20). Dr Trathan has also been appointed to the External Advisory Board of MAPPPD (Mapping Application for Penguin Populations and Projected Dynamics http://www.penguinmap.com/) which will facilitate the incorporations and development of robust assessments of penguin populations in our consumption models.

### 3.1 Progress in carrying out project Activities

All of the activities planned have started and are now well underway. The activities and outputs are listed below in 3.2 and Annex 3. The results presented in this report will form the basis of papers sent to CCAMLR in 2017 and then submitted for peer review with high impact ISI-rated journals.

### 3.2 Progress towards project Outputs

We planned a number of activities and outputs during year one of our project; these included:

- Analyse dietary data for various penguin species; this is developing as planned.
- Develop consumption estimates of krill by various penguin species; in 2016, we submitted the first paper to CCAMLR estimating macaroni penguin (*Eudyptes chrysolophus*) prey consumption in the South Georgia region in terms of the mass of krill and fish. This work continues and a further paper on Adélie penguin (*Pygoscelis adeliae*) consumption is planned for submission to WG-EMM this year.
- Develop preferred habitat models for penguins; our modelling work on preferred habitats is developing and we will submit our first papers to WG-EMM this year (see text in question 3, above with additional details in Annex 3).
- Validate models; we have validated our models using an approach based on k-fold cross validation, where k is the number of tracked populations (see text in question 3, above).
- Extend models to sites with only low resolution PTT data and to sites with no tracking data; we are beginning to extend our models to test lower resolution PTT data (see text in question 3, above).
- Engage with stakeholders; we are contributing to stakeholder objectives (see text in question 2, above).

### 3.3 Progress towards the project Outcome

To date, the analyses are on track and we are making good progress. No significant problems or unexpected delays have been experienced.

Dr Warwick-Evans began work in early August 2016, however it is not anticipated that this slightly late start date will have any long-term carry-over effects. Also, due to this slightly late start date, some of the planned travel could not be undertaken during the first year of the project; following agreement by Darwin, this money was carried over (with agreement of Darwin Plus) in order to facilitate the necessary liaison this year.

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

A key issue for CCAMLR, is how to manage krill fisheries at small spatial scales, so that they do not threaten krill-dependent predators. To date, there are no datasets that demonstrate that the krill fishery is having a long-term, irreversible impact upon krill predators. However, without a better understanding of how krill fisheries might impact predators, and under what circumstances, CCAMLR is unlikely to find consensus about how the krill fishery should develop or how areas of ecological importance might be protected in those areas where the fishery operates.

In this context, our study set out to develop a series of habitat preference models for some of the dominant avian species breeding in the Atlantic sector. We sought to identify the preferred habitat used by these species during that time of year when they are constrained to return to land to provision their offspring, a time during which they may be more vulnerable to influences from the fishery. Threats posed by the fishery potentially include the depletion of prey or the disturbance of krill swarm structure that then alter foraging opportunities. Our intention was to identify key areas and key times of overlap in order to highlight where management should be evaluated and considered separately from the more general management framework in order to ascertain the realised level of competition between penguins and the fishery.

Thus, our primary aim was to identify the most parsimonious model which predicts the foraging locations of chinstrap penguins during the three stages of the breeding season. With the further aim of creating models that can be extrapolated to colonies for which no tracking data is available.

Once identified, it will be feasible to monitor both the natural dynamics and variability in these habitats, as well as the magnitude and direction of anthropogenically induced change. This will require an understanding of which priority variables (ecosystem Essential Ocean Variables [eEOVs]) must be observed. Thus, detection of change and attribution of cause is ultimately a complex process, preferably also including the creation and long term study of reference areas where confounding drivers of change (e.g. fisheries and climate) can be separated.

### 3.5 Monitoring of assumptions

We believe that all the initial risks and assumptions are the same and all still hold true. We identified most risks as Low; this proved realistic as we now hold all the necessary data that we need to complete the project.

Only one new unforeseen risk has emerged; this is that CCAMLR has changed the structure and timing of the intersessional meetings which were a key pathway for our project delivery. In particular, WG-EMM is now shorter than previously and therefore the agenda is under increased pressure. We will address this risk by tabling papers as planned, but we might need to also table some papers to CAMLR Scientific Committee which were previously intended for WG-EMM.

## 4. Monitoring and evaluation

The work we are doing shows that the project is already seen as the leading research activity in this area and we have had a number of requests for advice (e.g. from EG-BAMM RAATD and from MAPPPD). The indicators of achievement (both qualitative and quantitative) that we use are the same as originally envisaged, that is, will CCAMLR actually change its management practices in response to our project results. Evidence suggests that our work has already demonstrated impact at CCAMLR:

1. During 2016, the Scientific Committee considered whether the CCAMLR season for the krill fishery should start at a time of year based on ecological events e.g. predator breeding cycles, rather than on a date that is convenient for management. The Scientific Committee recommended further consideration of possible benefits of aligning operation of the fishery with spatial and temporal aspects of local ecosystem operation. The Scientific Committee recognised that the Olympic nature of the krill fishery meant interpretation of seasonal fishing activity required careful evaluation of seasonal patterns and interactions, and consideration of fishing season start date (SC-XXXV Report paragraph 3.12 to 3.16).
2. During 2016, the Scientific Committee noted that the localised effects of krill fishing were increasing and that CM 51-07 should continue for a minimum period of three years. It agreed that a future revision of CM 51-07 should consider how catch limits could be spatially and temporally apportioned within Subareas to avoid negative impacts on predator populations at smaller spatial scales, particularly in Subarea 48.1 (SC-XXXV Report paragraph 3.62 and 3.106).
3. The Scientific Committee further advised that risks associated with the concentration of catches, particularly in coastal areas and during the predator breeding season, might be offset by apportioning the catch at smaller spatial or temporal scales than the Subarea scale. Other mechanisms for reducing risks include the use of coastal buffer zones (SC-XXXV Report paragraph 3.110).

## 5. Lessons learnt

This is the second Darwin Plus grant we have held. The most important lesson has been that the project should be realistic and practical. Careful planning at the project proposal stage has meant that we have been realistic in our expectations.

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

N/A

## 7. Other comments on progress not covered elsewhere

At the end of our first year in this project, we are well placed to finish on time and to have delivered the scientific outputs envisaged. Engagement in the policy arena will now be vital.

## 8. Sustainability and legacy

Both BAT and SGSSI are UKOTs but with no resident population. The true legacy will be in the development of management approaches; the former will be through the international community engaged in CCAMLR, the latter will be directly through GSGSSI.

## 9. Darwin identity

We have incorporated the Darwin Plus logo on talks and presentations and in the acknowledgements of papers; we will continue to promote Darwin Plus in this manner.

## 10. Project Expenditure

**Table 1: Project expenditure <u>during the reporting period</u> (1 April 2016 – 31 March 2017)**

| Project spend (indicative) in this financial year | 2016/17 D+ Grant (£) | 2016/17 Total actual D+ Costs (£) | Variance % | Comments |
|---|---|---|---|---|
| Staff costs | | | 0.0 | |
| Consultancy costs | | | | |
| Overhead Costs | | | 0.0 | |
| Travel and subsistence | | | | Carried forward as agreed by Darwin+ |

| | | | | |
|---|---|---|---|---|
| Operating Costs | | | | |
| Capital items | | | | |
| Others (Laptop computer) | | | 0.0 | |
| **TOTAL** | | | | |

### Annex 3 Onwards – supplementary material (optional but encouraged as evidence of project achievement)

*Outputs to CCAMLR WG-EMM*

- WG-EMM-16/14: Delegation of the United Kingdom - Report on the Second SCAR Retrospective Analysis of Antarctic Tracking Data Workshop.
- WG-EMM-16/16: P. Trathan and S. Hill - Start date of the CCAMLR fishing season for Antarctic krill.
- WG-EMM-16/17: P. Trathan and S. Hill - Spatial aggregation of harvesting in Subarea 48.1, in particular during the summer and close to the coast.
- WG-EMM-16/20: K. Lorenz, C. Harris, B. Lascelles, M. Dias and P. Trathan - A first assessment of marine Important Bird and Biodiversity Areas for penguins in Subarea 48.1 (Antarctic Peninsula, and South Shetland Islands) and Subarea 48.2 (South Orkney Islands).
- WG-EMM-16/37: P. Trathan, L. Emmerson, C. Southwell and C. Waluda - A bioenergetics model assessment of the prey consumption of macaroni penguins in Subarea 48.3.

*Outputs to CCAMLR Scientific Committee*

- SC-CAMLR-XXXV/11: Delegation of the United Kingdom - Precautionary management of the Antarctic krill fishery at small spatial scales in the context of regional climate variability: is no data the same as no impact?
- SC-CAMLR-XXXV/BG/14: Delegation of the United Kingdom - Precautionary management of the Antarctic krill fishery at small spatial scales in the context of regional climate variability: pros and cons of coastal buffers, closed areas and move-on rules.

*Outputs to other meetings*

- Dr Trathan gave the Oates Lecture at the Gilbert White Museum in late February 2017, highlighting the work of this project.
- Dr Trathan gave a presentation at the SCAR EGBAMM RAATD meeting in Aix-en-Provence in early March 2017, highlighting the work of this project.

*Additional details on model fitting for developing penguin preferred habitat models*

In our models, we used environmental covariate data that were either dynamic, static or geometric.

The dynamic covariates were based on daily values of remotely sensed oceanographic data obtained for each tracking period. Mean Sea Level Anomaly (MSLA, an indicator of mesoscale turbulence), Primary Productivity (PP) and Ocean Current (OSC) have all been associated with habitat preferences for pelagic species elsewhere. For each of these dynamic covariates, three values were considered in our analyses. Firstly, in order to gain real-time values which were coincident with the tracking data, daily imagery was averaged across each phase of the breeding period for each year of the study (we subscript these variables as *annual* e.g. $MSLA_{annual}$). Secondly, in order to generate a climatology for these variables over the study period, the mean and standard deviation across the five years coinciding with the tracking data (2011-2016) were calculated for each phase of the breeding season independently (we subscript these variables as *5yrmean* e.g. $MSLA_{5yrmean}$ or *5yrsd* e.g. $MSLA_{5yrsd}$).

The static covariates were developed from high resolution bathymetric data from which slope, aspect and ruggedness (variation in three dimensional orientation) were calculated.

The geometric covariates included variables such as distance from the colony, as these are likely to influence the at-sea distribution of central place foragers during the breeding season. Thus, the distance from the colony, avoiding land, was calculated. Additionally, initial data exploration indicated that penguins showed directional movement towards the shelf edge of the South Orkney Islands peri-insula bathymetric plateau. However this movement was not to the nearest part of the shelf edge, but appeared to be influenced by the density of *Pygoscelis* penguins from other colonies. We therefore calculated a covariate bearing which was the difference between the bearing of each foraging dive from the colony, and the bearing of the nearest point of the shelf edge from the colony, taking into account the density of penguins from other colonies. The at-sea density of *Pygoscelis* penguins from each colony breeding on the South Orkney Islands was calculated using population as a function of distance from colony squared (mathematically: $Density = population/distance^2$). The geometric covariates were then used in a cost-distance analysis from each of the four tracked colonies, applying increasing cost to travel through areas of high penguin density. Subsequently, the geographic distance from each colony, avoiding land, was calculated throughout the study area. The sum of these two values (geographic distance and cost-distance) was used to identify the nearest accessible point of the shelf edge (depth > 500m) for each colony, and the bearing of this point from the colony was calculated. The weighting given to each layer (geographic distance, and cost-distance) was determined iteratively to be 50:50 as this most accurately represented the directional movement of chinstrap penguins towards the shelf edge. Finally, the difference between the bearing of this nearest accessible point from the colony, and the bearing of each foraging dive from the colony was calculated.

Model fitting and selection

For each foraging dive location three control points (pseudo-absences) were randomly selected within the study area; our study areas was defined by the maximum distance travelled from the colony of tracked birds. The probability of foraging dive occurrence was calculated as a function of each of the covariates modelled using GAMs in the R package *mgcv*. The smooth of each covariate was taken, and the maximum number of knots was initially set to 3, and only increased if the model response curve did not fit the raw data. Additionally, model overfitting was further reduced by using cubic regression splines with shrinkage which penalize variables during fitting. Semi-variograms produced using R package *RGeo* showed some autocorrelation in our data, however the cross validation method for model selection provides a conservative approach, and thus this is unlikely to affect our final model.

Model selection followed the forwards stepwise approach, using k-fold cross validation, where k is the number of tracked populations. For each variable, models were constructed using data from 4 of the 5 tracked populations, and evaluated by predicting into the excluded population. Models were evaluated using the area under the curve (AUC), sensitivity (correctly predicted presences) and specificity (correctly predicted absences), which were calculated by generating a ROC curve using R package PROC. The AUC was calculated to test the overall performance of the model and values may range from 0.5 to 1, where a value of 0.5 is no better than random, and a value of 1 indicates a perfect model. Model performance thresholds are generally accepted as; low accuracy (0.5 – 0.7), useful applications (0.7 – 0.9), and high accuracy (> 0.9). Each of the covariates was ranked according to AUC value, and the highest ranking covariate was selected. The remaining covariates were added to the model by turn in order of AUC, retaining the resulting model if the AUC value increased. This process continued until there was no increase in AUC. Correlation between the covariates was considered, however due to the forward stepwise approach only covariates which improved model performance were retained, thus correlation was considered not to be an issue.

AUC values indicated that of the 15 individual predictor variables tested during the initial stages of model selection, the models containing *bearing* best described the foraging locations of incubating chinstrap penguins, however *distance from the colony* best described those in the brood and crèche phases. Including the second highest scoring covariate in subsequent models in addition to the highest scoring covariates improved the AUC value, specificity and sensitivity for all models. There was a considerable decline in model performance between those including the first and second highest scoring variables compared with those using other predictor variables. Including additional covariates in the model therefore did not greatly improve model predictive performance in any of the models. Thus, our final models used only *bearing* and *distance from the colony* in order to predict the location of foraging dives at any point during the breeding season.

Results from these analyses are shown in Figure 1 and Table 1. These indicate the value of the approach and the statistical level of support (AUC, specificity and sensitivity) achieved.

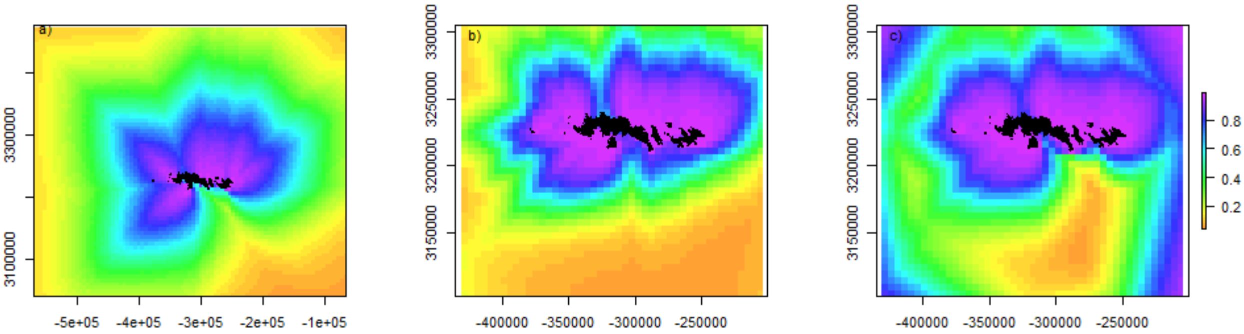



**Figure 1.** *Spatial predictions of the probability of occurrence of all chinstrap penguins breeding on the South Orkney Islands during a) incubation, b) brood, c) crèche. Predictions are from GAMs where distance and bearing from the colony are predictors.*

| | | Variables used in habitat model | AUC | Specificity | Sensitivity |
|---|---|---|---|---|---|
| Foraging locations (GPS and TDR) | Incubation | Bearing | 0.83 | 0.74 | 0.81 |
| | | Distance | 0.80 | 0.73 | 0.80 |
| | | **Bearing and distance** | **0.90** | **0.81** | **0.87** |
| | | Bearing and distance and $MSLA_{5yrsd}$ | 0.89 | 0.80 | 0.85 |
| | Brood | Bearing | 0.82 | 0.77 | 0.81 |
| | | Distance | 0.94 | 0.87 | 0.92 |
| | | **Bearing and distance** | **0.95** | **0.91** | **0.92** |
| | | Bearing and distance and $OSC_{5yrmean}$ | 0.94 | 0.87 | 0.92 |
| | Crèche | Bearing | 0.82 | 0.73 | 0.86 |
| | | Distance | 0.86 | 0.77 | 0.82 |
| | | **Bearing and distance** | **0.91** | **0.79** | **0.93** |
| Travel locations (GPS only) | Incubation | **Bearing and distance** | **0.90** | **0.82** | **0.86** |
| | Brood | **Bearing and distance** | **0.96** | **0.91** | **0.94** |
| | Crèche | **Bearing and distance** | **0.94** | **0.80** | **0.96** |

**Table 1.** *Model performance metrics from GAM models to predict the at-sea foraging distribution of chinstrap penguins breeding on the South Orkney Islands. The highest scoring models for each phase are highlighted in bold. The results are very compelling and suggest that modelling the distribution of penguins will be feasible, including by using relatively simple predictors that can be used for most colonies, including those where no tracking data exist. This was one of the key objectives of this project. Models were evaluated using the area under the curve (AUC), sensitivity (correctly predicted presences) and specificity (correctly predicted absences), which were calculated by generating a ROC curve using R package PROC.*

**Checklist for submission**

| | Check |
|---|---|
| **Is the report less than 10MB?** If so, please email to Darwin-Projects@ltsi.co.uk putting the project number in the Subject line. | Yes |
| **Is your report more than 10MB?** If so, please discuss with Darwin-Projects@ltsi.co.uk about the best way to deliver the report, putting the project number in the Subject line. | No |
| **Have you included means of verification?** You need not submit every project document, but the main outputs and a selection of the others would strengthen the report. | Yes |
| **Do you have hard copies of material you want to submit with the report?** If so, please make this clear in the covering email and ensure all material is marked with the project number. | No |
| Have you involved your partners in preparation of the report and named the main contributors | Yes |
| Have you completed the Project Expenditure table fully? | Yes |
| Do not include claim forms or other communications with this report. | |