The Distribution of the Tiree Twist

(*Periclepsis Cinctana*).

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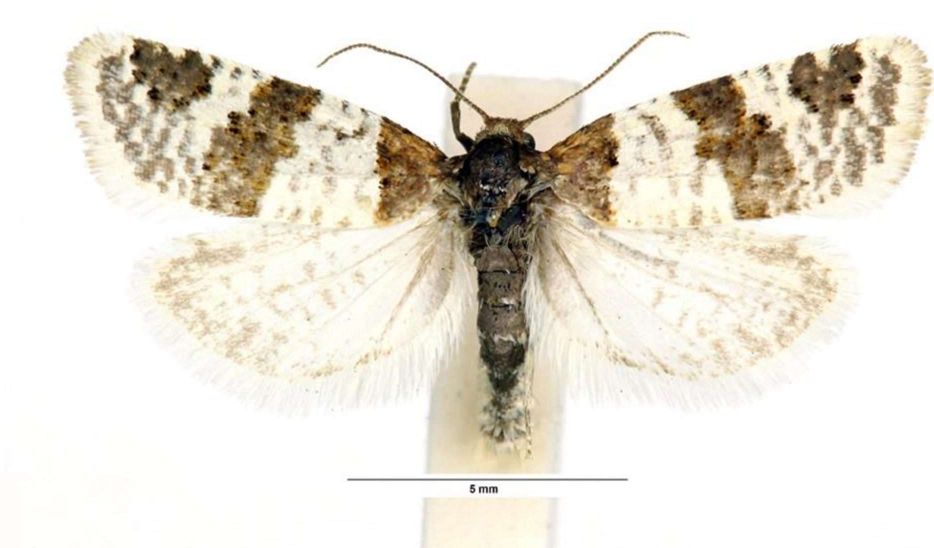
Supervised by Sarah Crowley



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Front cover image (De Prins, 2018)

Table of Contents

List of Figures

List of Tables

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Abstract

The Tiree Twist (*Periclepsis cinctana*) is a moth species which was once found on the chalk downloads of Kent during the 1950s (Hants Moths, 2021). After *P. cinctana* was thought to be extinct to the UK, the species was located on the island of Tiree, Scotland in 1984 (De Prins, 2018). There is little to no research conducted about *P. cinctana* and therefore, this project aims to identify why the species is found on Tiree, so it can be protected, with the use of three hypotheses. The three hypotheses tested were climate, habitat type, and geology of the island to consider whether it is controlling the distribution of *P.cinctana.* The results from the MaxEnt climate model found climate does have an influence on the distribution of *P. cinctana* and rejecting the null hypothesis. The habitat is not restricting *P. cinctana* to Tiree and therefore, the habitat hypothesis was rejected. The geology of Tiree is suitable for *P.cinctana* but more research is required to know whether there is a relationship between dark hornblende and the moth species.

1. Introduction

To know how a species' habitat can change there is a need to understand what factors influence their preferred habitat. This research project will consider the preferred habitat of Tiree Twist (Periclepsis cinctana) in relation to three factors, climate, habitat, and geology.

Habitat choice is when a species spends more time in one habitat than another based on random dispersal (Webster et al., 2012). The habitat preference has previously been thought to be largely influenced by available habitat, with food sources and shelter from predators being more influential than climate (Bevelhimer, 1996). There is a need to understand what influences a species habitat choice to know how to conserve the locations and protect species. Understanding the habitat preference of species is important due to other factors, such as climate change and habitat fragmentation, changing the conditions of habitats.

The current changing climate is altering the habitat of species (Leimu et al., 2010). Since pre-industrial levels, the global temperature of the earth had increased by 1°C in 2017 when the Intergovernmental Panel on Climate Change (IPCC) released the most recent climate report in 2018 (Allen et al., 2018). Alongside the rise in temperature, the changing climate is causing a rise in sea levels globally, a loss of sea ice, and more frequent droughts, storms, cyclones and flooding events (Hoegh-Guldberg et al., 2018). This is having a knock-on effect to the habitats that species are found within, and therefore, changing the conditions species have evolved to survive (Leimu et al., 2010). With changes in conditions, species can either alter the range they are found within to a climatically appropriate location by moving poleward (Parmesan et al., 1999), alter their phenological timing (Parmesan, 2007) or adapt to the changing factors. Without understanding species habitat choice and the factors affecting distribution, it makes it more difficult to determine how climate change will have an impact on species and if it is possible for them to evolve.

Alongside climate change having an impact on species, other anthropogenic actions are affecting species habitats. Habitat fragmentation is the breaking up of habitats due to loss of high quality land which is normally caused by anthropogenic actions (Fahrig, 2003). It is difficult to generalise what the effects of habitat fragmentation are on biodiversity without separating fragmentation from habitat loss (Fahrig, 2003). Difficulties arising from understanding habitat fragmentation identify that without understanding the distribution of a species, it makes it more difficult to know the impacts.

Currently, the understanding of ecosystems and the environments they are found in stems from the study of common species (Kunin and Gaston, 1993). There are numerous studies on common species including their niches, biogeography, interaction with other species as well as others but most species in the world are rare (Kunin and Gaston, 1993). There are many different definitions of rare species from multiple isolated populations to a single restricted population (Drury, 1974). More research on rare species is required to have a greater understanding of ecosystems and their environments. To know how climate change, habitat loss and habitat fragmentation are changing the distribution, and a species preferred habitat, there needs to be more studies on rare species. Common species can be considered more ecologically important but without the study of rare species, it makes the view on ecosystems bias towards common species when considering interactions with humans and conservation efforts (Donaldson et al., 2016; dos Santos et al., 2020; Kunin and Gaston, 1993; Roberts et al., 2016). It is impossible to save an ecosystem without saving every aspect of it (Clark and May, 2002). A greater understanding on how each element and species are involved in an ecosystem is required to then conserve it for the future (Clark and May, 2002; Leopold et al., 1989) and therefore more studies on rare species are needed.

Alongside the bias between studies of rare and common species, there is also a taxonomic bias. There is more research on mammals than any other class (Clark and May, 2002) and the bias becomes more dramatic when considering the research difference between invertebrates and vertebrates (Titley et al., 2017). As there is a greater amount of research projects on vertebrates it means that vertebrates are over represented when compared to their species richness (Titley et al., 2017). More research should be aimed towards invertebrates due to them representing the greatest and largest diversity in animals (Harvey-Clark, 2011). As well as the high diversity in taxa, invertebrates play an important role in the function and sustainability of ecosystems (New, 2005). The greater amount of research on invertebrates will mean that there is a greater understanding of all aspects of ecosystems (Leopold et al., 1989).

Moths are often overlooked and in fact considered more of a pest than important pollinators especially when compared to the species within the same order (New, 2004). Lepidoptera order contains 160,000 named species and therefore making it one of the largest insect orders (New, 2004). Included in the Lepidoptera order are both macrolepidoptera and microlepidoptera with butterflies and larger moths falling into the macrolepidoptera category (New, 2004). Popular common butterflies such as the Peacock Butterfly (*Aglais io*) or Painted Lady (*Vanessa cardui*) are within the lepidoptera order and some conservationists and the general public believe that butterflies are more worthy of conservation than microlepidoptera moths (New, 1991). The important qualities of moths, such as being a pollinator, are often disregarded; species are often considered as pests which should be exterminated (Cook, 2003; New, 2004; Young, 1997). The limited understanding of the importance of moths means that species are disregarded during conservation efforts and research projects; therefore, there is a lack of information about species (New, 2004). The lack of information includes the International Union for the Conservation of Nature (IUCN) with the union disregarding a lot of moth species (New, 2004). The 2003 red list released by the IUCN included only 41 moth species considered to be species at a level of conservation concern (New, 2004). Due to moths and other invertebrates supporting ecosystems, there should be a greater number of studies completed to understand preferred habitat choice so species can be protected and raise the profile of invertebrates to be considered as more valuable species.

This research project is to understand the habitat preferences of the *P. cinctana* (Denis and Schiffermüller, 1775). *P. cinctana* is a moth species which is part of the Tortricidae family and rare to the British Isles (UK Moths, 2021). The species is more common across Scandinavian and western European countries (Aarvik et al., 2000), but it has yet to be evaluated by the IUCN to determine the species risk of extinction. *P. cinctana* prefer calcareous habitats and across Europe the larvae live on a variety of plants within the pea flower family including kidney vetch (*Anthyllis vulneraria*), trefoils (*Lotus corniculatus*) and broom (*Genisteae*) (Aarvik et al., 2000). The early stages of the moth has not been studied in Britain but it is known adults tend to fly during the daytime in July (UK Moths, 2021).

In the United Kingdom (UK), *P. cinctana* was first sighted in Dover, Kent on the chalk downlands where the species gained the vernacular name Dover Twist (Hants Moths, 2021). Eventually, the species was thought to be extinct in the UK after not being sighting since the 1950s. Fortunately, in 1984 the species was sighed on the island of Tiree, the most westerly island in the Inner Hebrides (Pearman and Preston, 2000). The moth species was then not seen until more recently in 2019 where a project led by the Butterfly Conservation found the species on the dark hornblende outcrops of Tiree. The vernacular name for *P. cinctana* is the Tiree Twist which was adopted since the species was found on Tiree. The aim of the project is to collate sighting of *P. cinctana* to discover what is constraining the species to Tiree.

This research project will consider what influences the distribution of *P. cinctana* by assessing three different hypotheses. The project can then be used by the Butterfly Conservation to develop more direct surveys and have a greater understanding where the species could potentially be found. Alongside the surveys, this research project can allow for a greater understanding into how the species can be protected to prevent extinction in the future.

The aim of the research project is to determine what factors are affecting the distribution of *P. cinctana*. There are no current research projects which have been published about *P. cinctana* and therefore making this project the first of its kind. The Butterfly Conservation have completed some surveys on the population in Scotland and analysed potential locations for habitats, but a lot is still unknown about the species and its distribution. The research will take into consideration the climate, habitat type and geology preferences of the moth species when being sighted over the past 50 years to determine what is constraining the species to Tiree.

The first of the hypotheses analysed was climate. Climate is a factor which influences habitat choice (Bevelhimer, 1996). It is important to know to what extent a species habitat choice is influenced by climate as climate change, caused by anthropogenic actions, is a factor altering the conditions of environments (Hoegh-Guldberg et al., 2018). Without knowing how a species is currently adapted to climate it will be more difficult to know how it may change in future climate scenarios (Allen et al., 2018). The climate hypothesis will identify where the ideal climate locations for *P. cinctana* are and whether this is the reasoning why the species is found on Tiree.

The next hypothesis which was explored was to understand whether habitat type is the reason *P. cinctana* is found on Tiree. As there are no studies conducted on the moth species, there is little known about *P. cinctana*. One of the habitat preferences which is known about *P. cinctana* is that the species is found within calcareous habitats (Aarvik et al., 2000). By knowing to what degree habitat type influences the habitat choice for the species of moth it can help guide potential conservation efforts in the future to preserve the preferred habitat.

The final hypothesis focuses on whether geology is the reasoning why *P. cinctana* is found on Tiree. Geology influences the biodiversity of a location (Moriarty and Honnery, 2004) and at the two original sightings on Tiree, from 1984, both observations of *P. cinctana* were found in association with the mineral dark hornblende. Different hornblende minerals are formed under different pressures, temperature and chemical environments within metamorphic and magmatic rocks (Raase, 1974). Dark hornblende is the type of hornblende mineral found on Tiree (BGS UKRI, 2021). The two original moth sightings from 1984 on Tiree identified the connection between the species and geology. By knowing whether dark hornblende is limiting the distribution of *P. cinctana* to Tiree it will identify if geology is a controlling factor in the distribution.

The three hypotheses used within the research project were:

1. Climate is controlling the distribution of *P. cinctana* to Tiree.
2. Habitat type is limiting the distribution of *P. cinctana* to other islands across the Inner Hebrides.
3. Geology is restricting the distribution of *P. cinctana* to Tiree.

2. Study site

The island of Tiree is where the research project is based. Tiree is an island off the west coast of Scotland (figure 1) (Pearman and Preston, 2000). When compared to the UK average, Tiree experiences a high number of hours of sunshine during the late spring and early summer (Sear, 1998). Tiree encounters strong winds due to being surrounded by uninterrupted ocean (Pearman and Preston, 2000; Sear, 1998). By having one of the most maritime climates in Europe, the climate of Tiree varies very little in temperature between the summer and winter moths (Green and Harding, 1983; Pearman and Preston, 2000). The island of Tiree is very flat with only a couple of small hills (Pearman and Preston, 2000). Most of Tiree is less than 10m above sea level but Ben Hynish is the highest point on the island at 141m (Pearman and Preston, 2000). Tiree has very fertile soils and has a great amount of the rare habitat machair (Pearman and Preston, 2000). The machair habitat covers most of Tiree's surface area (Pearman and Preston, 2000). Machair is a habitat type in which the soil is made up of shell-rich blown sand therefore, increasing the amount of calcium carbonate found in the soil and changing the pH (Ritchie, 1976). Other criteria which machair habitats must meet are the grass must have a history of grazing and there are specific plant associations which do not include long dune grasses (Ritchie, 1976). Finally, Tiree is almost completely comprised of Lewisian gneiss rock (Darling, 1955). The rock type does not break down into a good quality soil as it is made up of impervious acidic rock (Darling, 1955).

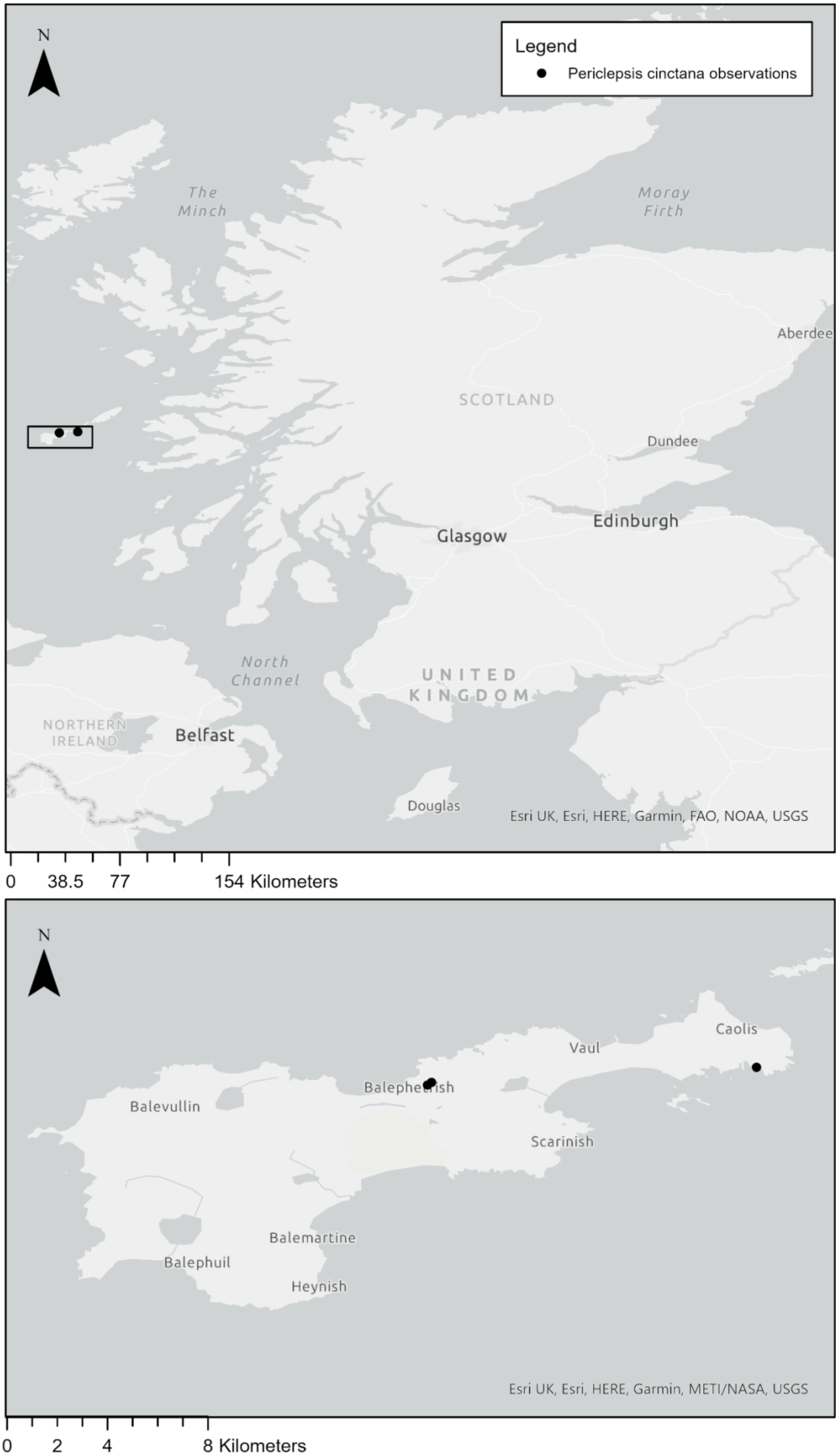


Figure 1. Map identifying the location of Tiree in relation to Scotland. The inset map gives a more detailed view of the island of Tiree and the locations where P.cinctana has previously been sighted.

3. Objects and hypotheses

The methods of the project used a hypothesis-testing approach (Crisp et al., 2011). The research project was an aspect of biogeography with the three hypotheses tested identifying different abiotic factors to determine the distribution of *P. cinctana* (Crisp et al., 2011; Oxford English Dictionary, 2021). The three hypotheses tested were:

1. Climate is controlling the distribution of *P. cinctana* to Tiree (referred to as the climate hypothesis).
2. Habitat type is limiting the distribution of *P. cinctana* to other islands across the Inner Hebrides (referred to as the habitat hypothesis).
3. Geology is restricting the distribution of *P. cinctana* to Tiree (referred to as the geology hypothesis).

To test the hypotheses, observation data was provided by the Butterfly Conservation for the sightings in Scotland, Moths in Kent for records from Kent and Global Biodiversity Information Facility (GBIF) for the sightings of *P. cinctana* elsewhere (figure 2). The climate data which was inputted into the Maximum Entropy (MaxEnt) software was provided by the WorldClim website (Fick and Hijmans, 2017). The information regarding the habitats across Scotland were provided by NatureScot (NatureScot, 2013). Finally, data about the geology of the UK was taken from the DigiMap Geology map (BGS UKRI, 2021).

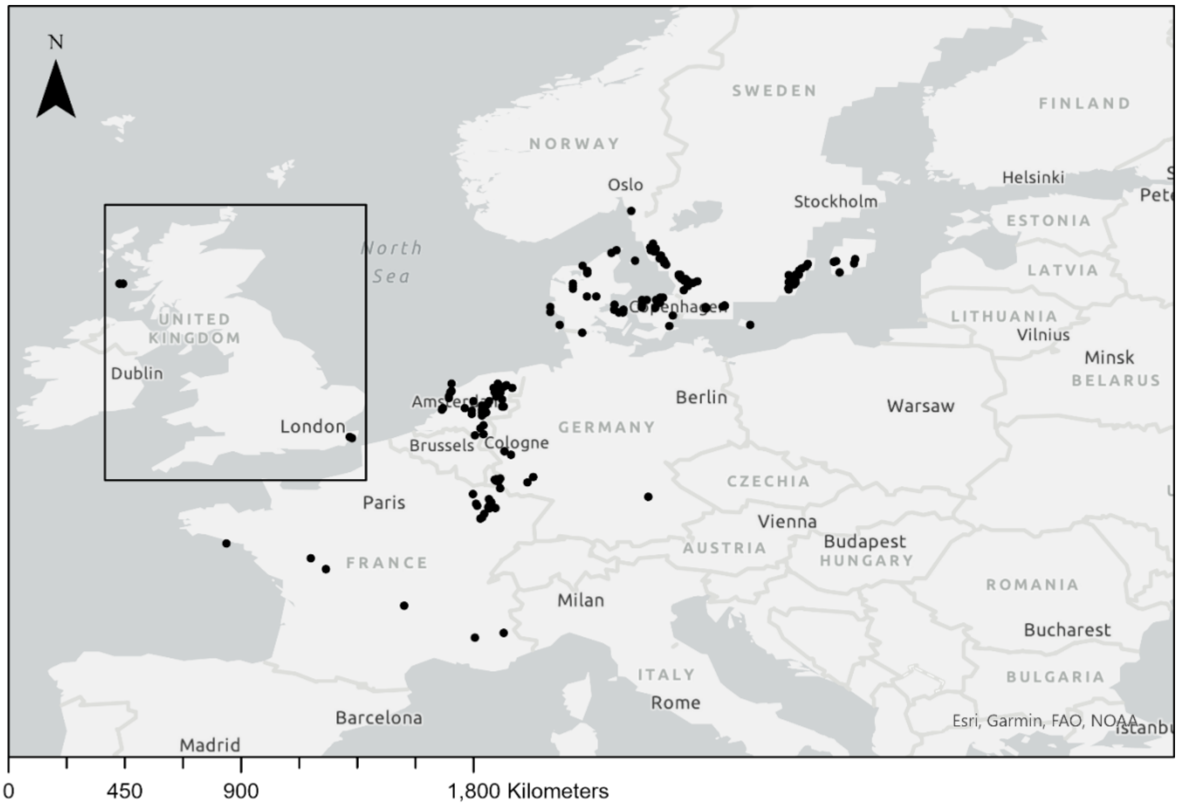


Figure 2. A map identifying the locations of sightings of P.cinctana. The map combines the data provided by the Butterfly Conservation, Moths in Kent and GBIF. The inset map shows in more detail the sightings across the UK.

Legend

- Periclepsis cinctana observations

4. Methods

4.1 Data Collection

Initially *P. cinctana* was a species found associated with calcareous habitats (De Prins, 2018). In 1984 when the species was sighted in two locations on the island of Tiree. *P. cinctana* was sighted at Balephetrish Hill and near Miodar, both sightings were found in association with the mineral, dark hornblende. During June of 2019, the Butterfly Conservation conducted a survey on the island of Tiree to identify whether *P. cinctana* was still present on the island. The survey targeted locations the species had already been observed at with volunteers and Butterfly Conservation employers randomly searching through short heather. The survey found 6 adult moths were present at Balephetrish Hill. In addition to the survey, a resident of Tiree reported a sighting of the species during June 2020 at Balephetrish Hill.

The sightings from Kent were collected from the Moth in Kent group which have data for many moth species throughout the county of Kent.

The data sourced from the GBIF website was the collaboration of all records sighting *P. cinctana* across the globe. The records collected were filtered to be from between 1971 and 2021 and to have coordinates. The observations required coordinate data so the sightings could be mapped and used in the distribution model. The observations were also sightings from 1971 rather than fossils as the climate data used in the model was from 1970-2000 (Fick and Hijmans, 2017).

4.2 Data Analysis

The secondary data was then used to analyse the three different hypotheses and determine which factor is controlling the distribution of the *P. cinctana* on Tiree.

4.2.1 Climate

To address the climate hypothesis, a MaxEnt species distribution model was used. Distribution models are common in biogeography and ecology research (Franklin, 2010; Whittaker et al., 2005). MaxEnt is an effective way and best method to produce a distribution model (Elith et al., 2006; Halvorsen, 2013). MaxEnt distribution models are a widely accepted method across academic research (Halvorsen, 2013). To produce distribution models, MaxEnt uses species presence-only data and compares it to environmental variables across a defined area. The defined area is divided into a grid, to determine whether the species will be found within each aspect of the grid (Merow et al., 2013). To determine whether the species is found within each part of the grid, the software compares environmental variables (Kriticos et al., 2012) of the locations the species were found at to locations it was not found at (Merow et al., 2013).

Depending on how well the variables fit to the species ideal climate, determines how likely the species is found there and therefore, what colour and value the location is on the output map (Merow et al., 2013). The MaxEnt species distribution model for this project used current climate data from across Europe the records of *P. cinctana*. The model determined the distribution of climatically suitable habitats for *P. cinctana* across Europe. The output gave multiple files, including maps, which identified the likelihood the species would be found at locations due to the climate.

Table 1. The different climate variables used in MaxEnt to produce the species distribution model for *P. cinctana* (Kriticos et al., 2012).

Variable Number	Variable
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (×100)
BIO4	= Temperature Seasonality (standard deviation ×100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)

BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

Alongside the maps produced by maxent, an ASC file was created which allowed the raw data to be manipulated in a GIS software. For the *P. cinctana* distribution model, the ASC file was imported into ArcGIS Pro and turned into a raster layer. The raster was a visible layer to show the likelihood locations across Europe were suitable for *P. cinctana* (Young et al., 2011). When added to ArcGIS Pro, the raster layer was easier to analyse and draw conclusions from than the map produced by MaxEnt.

The raster layer of the model was altered with the use of the spatial analysis tool, reclassify, to put the floating-point data of the raster into classification ranges. The classification of the raster data changed the values so the data was integers and could be converted into a vector. Each classification contains a range which is depending on the likelihood *P. cinctana* would be found at a location (table 2). The more likely the species was found at a location the higher the values. The categories were split by equal interval to ensure each category had the same class width. To alter the raster layer into a vector the conversion tool raster to polygon was used. Once converted to a vector, data analysis was undergone to determine the percentage of surface area each classification covers across Europe and the UK and Ireland.

Table 2. The range of values found within each classification category.

Classification	Value range
1	$0 < x \leq 0.2$
2	$0.2 < x \leq 0.4$
3	$0.4 < x \leq 0.6$
4	$0.6 < x \leq 0.8$
5	$0.8 < x \leq 1$

To test how well the distribution model worked a receiver operating characteristic (ROC) curve was produced. The area under the curve (AUC) for the ROC determines if the distribution model worked well. The values range from 0.5 to 1 with 1 being a perfect model. ROC identifies whether the climate data can be used to predict the distribution of a species. To test the ROC the locations the model predicts for the species to be found at is compared to the actual sightings which were inputted. The closer the AUC is to 1 the more likely the model can predict the distribution of the species with the use of climate data.

4.2.2 Habitat

To assess the habitat preferences of *P. cinctana*, the limited sources available were analysed to determine the general preferred habitat of the species (Bland et al., 2015; Kimber, 2021). Once determined that the species is found within calcareous habitats, such as the chalk downlands in Kent (Bland et al., 2015; Kimber, 2021), limestone based habitat in Scotland near the sightings were identified. The habitat layer provided by NatureScot combined habitat survey data from across Scotland to produce a GIS compatible layer with shapefiles of each individual habitat (NatureScot, 2013; Strachan, 2017). With the use of attribute selection in ArcGIS Pro, suitable Limestone-based habitats were extracted from the NatureScot vector layer. *P. cinctana* was observed in association with bird's foot trefoil (*Lotus corniculatus*) which was known for being found within machair habitats in Scotland (Angus, 2006). Machair is a very rare habitat and listed within the EU habitats directive (Redpath-Downing et al., 2013). Machair is a sand based habitat with limestone-rich soils, pH>7, (Angus, 2006) and therefore, matching the habitat preference for *P. cinctana* (Bland et al., 2015; Kimber, 2021). All the machair habitats found within the NatureScot layer were selected by attribute and extracted to create a new layer and identify whether habitat was limiting the distribution of *P. cinctana*.

4.2.3 Geology

P. cinctana has previously been reported to be found in association with dark-hornblende rich rocks (Bland et al., 2015; Butterfly Conservation, 2019). As dark hornblende was found in connection with sightings of in Tiree, the geology layer from Digimap was used to address the third hypothesis of whether the geology of Tiree is a restricting factor. The geology Digimap later contained all the different rock types across the UK. The geology layer was added to ArcGIS Pro where the hornblende attribute was extracted from the layer and exported. Once it was a separate layer, the different locations of dark hornblende across the UK were easier to identify. The known locations of dark hornblende across the UK allowed the geology hypothesis to be analysed.

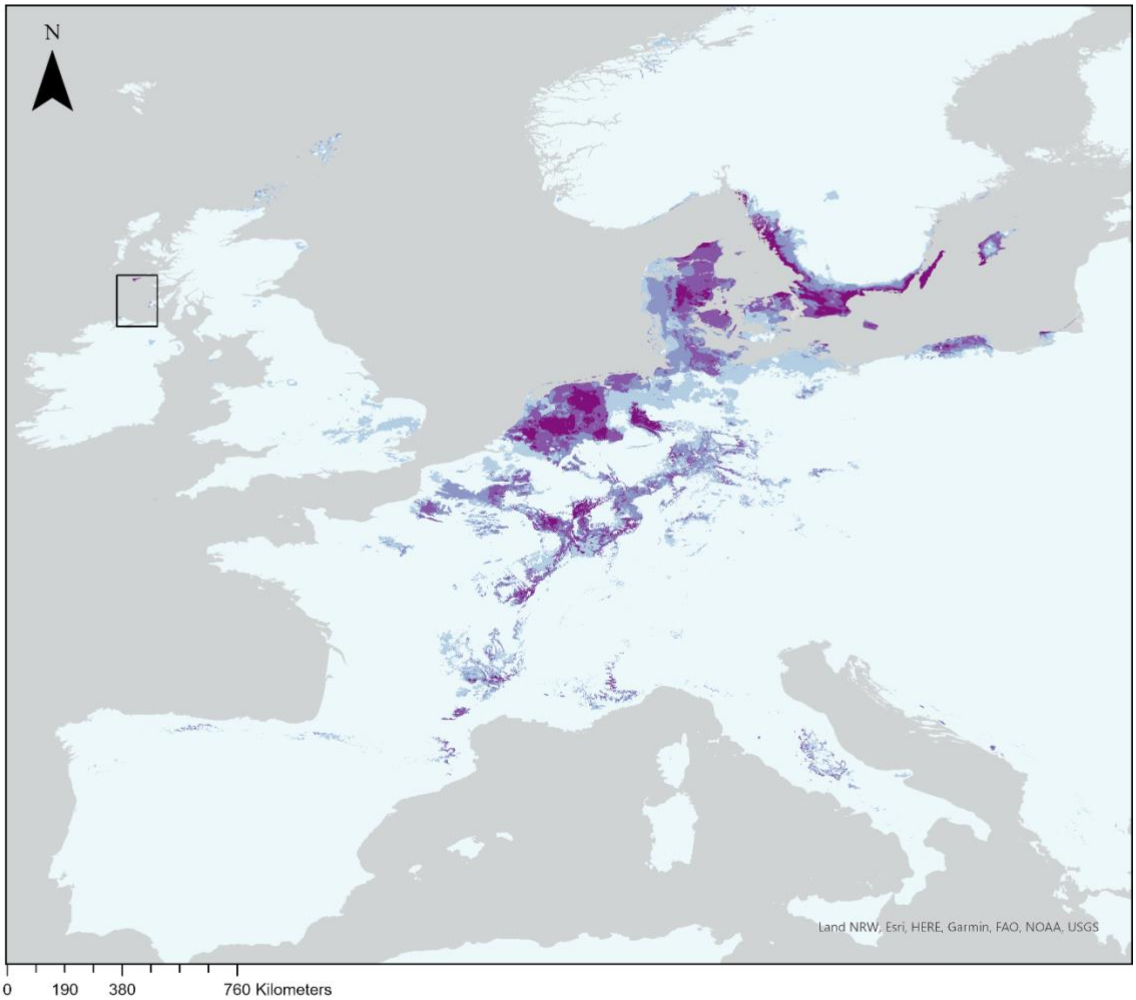
4.3.4 Intersect

To analyse the combination of the climate, habitat type and geology for *P. cinctana* the intersect tool on ArcGIS Pro was used to combine all three layers. By combing the three layers it identified where there was ideal habitat for *P. cinctana* fitting preferred climate, habitat type and geology.

5. Results

5.1 Climate Results

Once completed and turned into a vector, the climate model produced an output map (figure 3). When the model ran, 29 out of the 329 observations failed to work within the climate model.



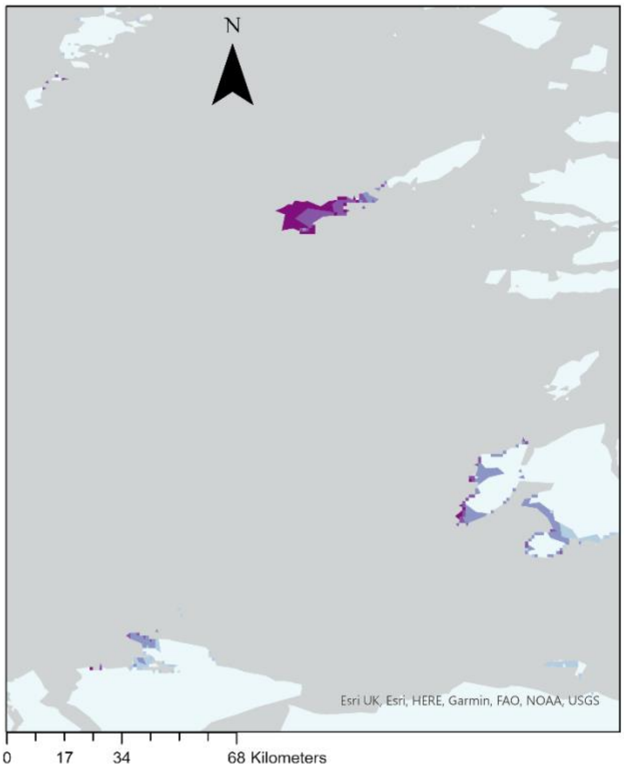


Figure 3. Map showing the classification of the raster layer as a vector. The raster was split into 5 classifications 0< x ≤0.2, 0.2< x ≤0.4, 0.4 < x ≤0.6, 0.6< x ≤0.8, and 0.8< x ≤1. The map shows the distribution of different classifications across Europe. On the inset map of the island of Tiree and surrounding areas, the most climatically suitable places for P.cinctana are the darkest shades of purple. The northern and western parts of Tiree, a location on the island of Islay, and small location on the north coast of Ireland were the most climatically suitable, as being in the fifth classification (0.8< x ≤1).

Legend
P.cincana MaxEnt Climate Model

- 0< x ≤0.2
- 0.2< x ≤0.4
- 0.4 < x ≤0.6
- 0.6< x ≤0.8
- 0.8< x ≤1

Table 3. The results from the analysis of the different classifications. The table identifies that on Tiree category 5 covered the greatest area. On the other hand, in the UK and Ireland and Europe category 1 covered the greatest area.

Classification	Values within classification	Area covered across Tiree (km^2)	Percentage of Tiree covered (%)	Area covered across UK and Ireland (km^2)	Percentage of UK covered (%)	Area covered across Europe (km^2)	Percentage of total map (Europe) covered (%)
1	$0< x \leq 0.2$	0	0	304,163	96.14	10,220,285	96.89
2	$0.2< x \leq 0.4$	0	0	11,620	3.67	133,171	1.26
3	$0.4< x \leq 0.6$	5	6.25	512	0.16	87,491	0.83
4	$0.6< x \leq 0.8$	32	40	69	0.02	78,154	0.74
5	$0.8 < x \leq 1$	43	53.75	46	0.01	29,990	0.28
Total	-	80	100	316,410	100	10,549,091	100

5.1.1 Climate Results across Tiree

Across Tiree there was not a location which fell below the third classification meaning the whole island had values of greater than 0.4.

On the island of Tiree, the fifth category covered the largest area of land. The category covered 43 km^2 of land which was over 50% of the island. The locations which were within category 5 were along the coastline with the majority on the north and west coast. Category 4 covered 40% of Tiree having 32 km^2 of habitat. The third classification was mostly found on the east corner of Tiree covering 6.25% of the island. The areas which were most climatically suitable for *P. cinctana* was category 5 across the north and east coast of Tiree (figure 3).

5.1.2 Climate Results across the UK and Ireland

The results from the climate analysis showed that there were three locations in the UK and Ireland within the fifth category. Category 5 was found across the island of Tiree, on the west coast of the island of Islay, and a small location on the north coast of Ireland. In total, out of the 46km^2 of category 5 found across the UK and Ireland, 43km^2 was on Tiree. Tiree contained the highest value from the distribution model with the data peaking at 0.92 on the island. The combined total of category 5 ($0.8< x \leq 1$)

covered 0.01% of the UK and Ireland. The classification which covered the most land across the UK and Ireland was the first category (0< x ≤0.2). Category one covered 96% the UK and Ireland.

The distribution model showed that in Kent, where *P. cinctana* was found before Tiree, the location from the observations falls into category 2 (0.2< x ≤0.4).

5.1.3 Climate Results across Europe

Across Europe, less than 0.3% of the continent fell into category 5. Locations in category five and therefore climatically suitable for the species, were throughout the Netherlands and Luxembourg, along the south and western coastline of Sweden and across parts of France, Italy, and Germany (figure 3). The classification which had the greatest cover across Europe was category one which were locations least climatically suitable for the *P. cinctana*. Category one covered greater than 96% of Europe. There were locations within France and Germany which fell into category one but contained observations.

5.1.4 Variable contribution

In addition to creating the model, the MaxEnt software produced a table which gave the analysis of the Bioclim variable contribution. As shown in table 4, the greater the percentage, the more the variable determined whether a location was climatically ideal for *P. cinctana*. The analysis of the variables identified that Bioclim7 had the greatest influence on the distribution model with the percentage of 33.1%. As shown on table 1, Bioclim7 definition was temperature annual range (Bioclim05-Bioclim06) (°C). The variable which had the next largest influence after Bioclim7 was Bioclim9 with 13.7% influence. Bioclim9 was the mean temperature of the driest quarter (°C). The variables which had the least influence on the model were Bioclim2, Bioclim6, Bioclim17 and Bioclim18. The variables with the least influence included the precipitation of the driest and warmest quarters, minimum temperature for the coldest week and mean diurnal temperature range. The four Bioclim variables which had the smallest influence on the model had either a 0.1% or 0% influence on the suitable climate distribution for *P. cinctana*.

Table 4. Estimated the relative contribution of the environmental variables to the climate distribution model produced. The percentage contribution identified how much each variable determined ideal locations of *P. cinctana*.

Variable	Percentage contribution (%)
Bioclim7	33.1
Bioclim9	13.7
Bioclim11	11.6
Bioclim10	8.8
Bioclim1	6.4
Bioclim15	5.9
Bioclim4	5.3
Bioclim8	5.2
Bioclim13	4.6
Bioclim5	2
Bioclim19	1.1
Bioclim3	0.6
Bioclim12	0.5
Bioclim14	0.3
Bioclim16	0.3
Bioclim2	0.1
Bioclim6	0.1
Bioclim18	0.1
Bioclim17	0

5.1.5 Testing Accuracy

When testing the training variables, the ROC curve for the distribution model had the AUC value of 0.985 (figure 4).

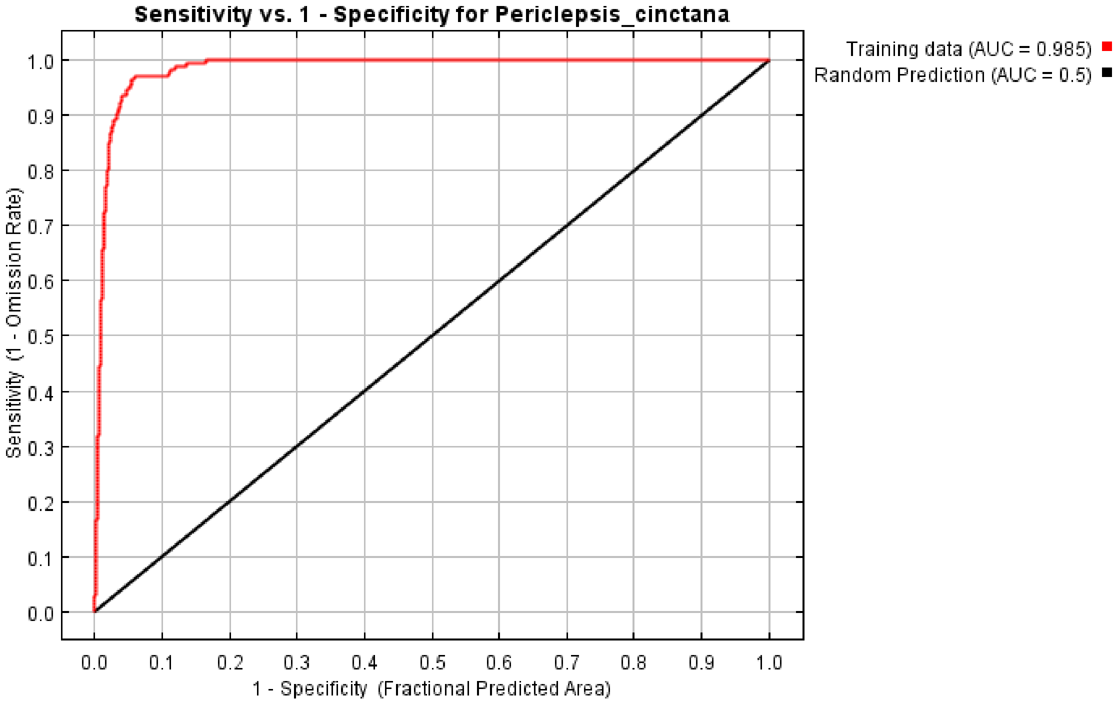


Figure 4. Graph displaying the ROC curve for the *P. cinctana* MaxEnt model.

5.2 Habitat Results

Once the machair polygons were extracted from the NatureScot habitat layer and exported as a new layer, the habitat locations were easier to identify. There was a high availability of machair habitats across the island of Tiree (figure 5). Machair habitat covered 61% of Tiree making it very accessible for *P. cinctana*. The machair habitat was also found on the neighbouring islands, Coll and Gunna, with the part of Coll closest to Tiree mostly the ideal habitat type. Machair habitat covered 177km² of land in Scotland which is 0.07% of the total land area.

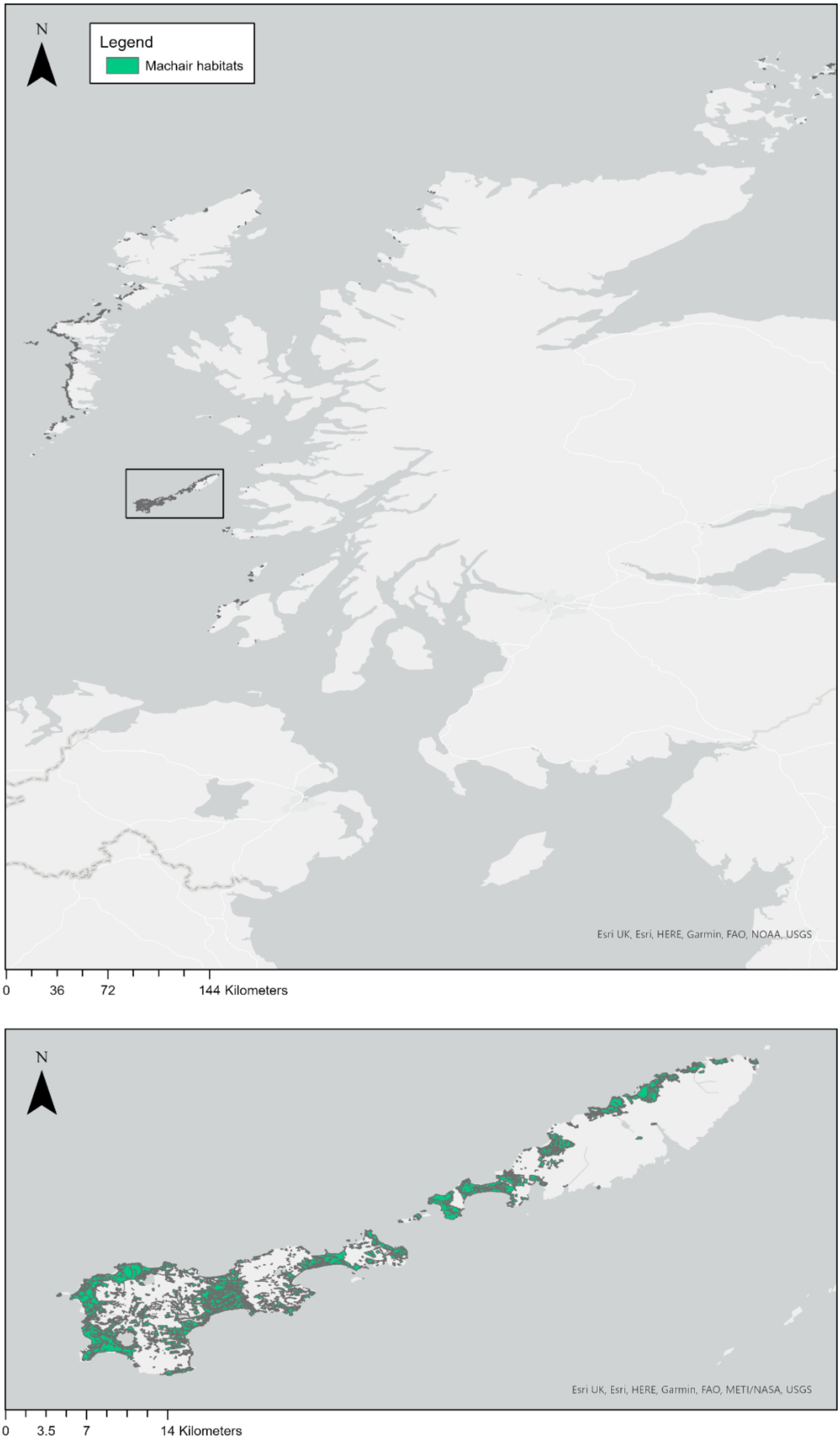


Figure 5. A map displaying the locations of the machair habitat across Scotland in relation to the observations of P.cinctana. The inset map shows the locations of machair on the island of Tiree, Gunna and Coll.

Table 5. The results for machair distribution across Scotland. The greatest percentage of land cover for machair habitat was Tiree with 61%.

Location	Area of Machair (km^2)	Total Area (km^2)	Percentage of land cover (%)
Tiree	47.911	78.481	61.048
Tiree, Coll and Gunna	66.786	154.377	43.262
Scotland	177.632	244,935.795	0.0725

5.3 Geology results

After the locations of the dark hornblende was found and extracted from the Digimap geology layer, it displayed where the mineral was found across Scotland. Dark hornblende covered 7.22% (5.67km^2) of the total area of Tiree (table 6). The total area of dark hornblende covered on Tiree, Coll and Gunna was also 5.67km^2 as the mineral was not found on Coll and Gunna. Across Scotland there was a total of 74km^2 of dark hornblende available and this covered 0.31% of the total area.

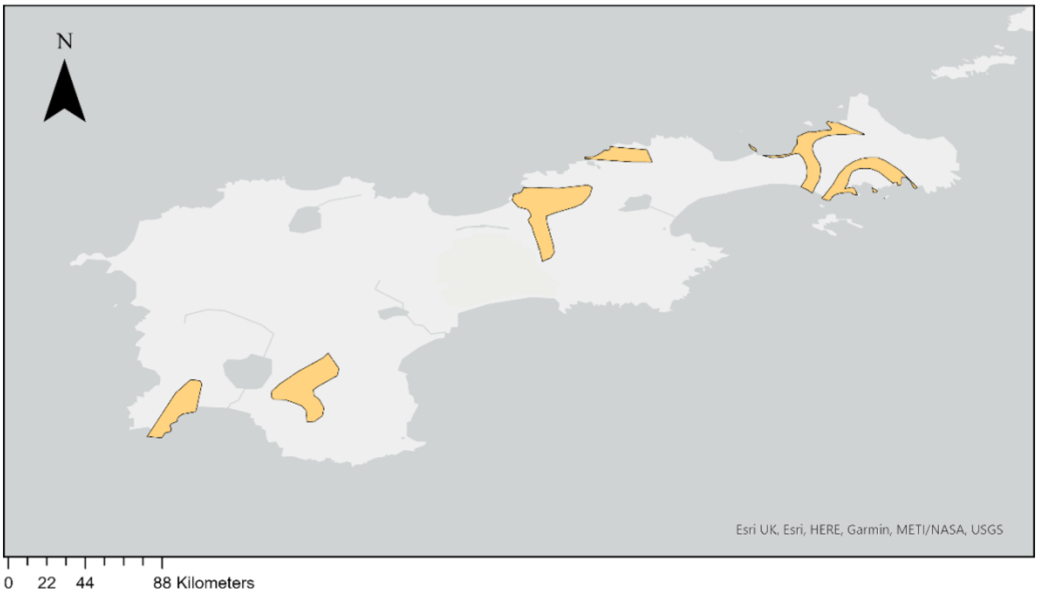


Figure 6. A map displaying the locations of the dark hornblende mineral across Scotland in relation to the observations of P.cinctana. The inset map shows the locations of dark hornblende on the island of Tiree.

Table 6. The results from the geology hypothesis identified 5.7km² of dark hornblende across Tiree was available as habitat for *P. cinctana*.

Location	Area of dark hornblende (km²)	Total Area (km²)	Percentage of area with dark hornblende (%)
Tiree	5.669	78.4812	7.22%
Tiree, Coll and Gunna	5.669	154.377	3.67%
Scotland	74.733	244,935.795	0.31%

5.4 Intersect Results

When combining the preferred habitat, dark hornblende layer and the climate category 5 locations there were only small areas where all three layers intersect (figure 7). The results of the intersect layer were only present on Tiree. Most of the suitable combined habitat was at Balephetrish, where sightings have previously been recorded, and at the south west corner of Tiree.

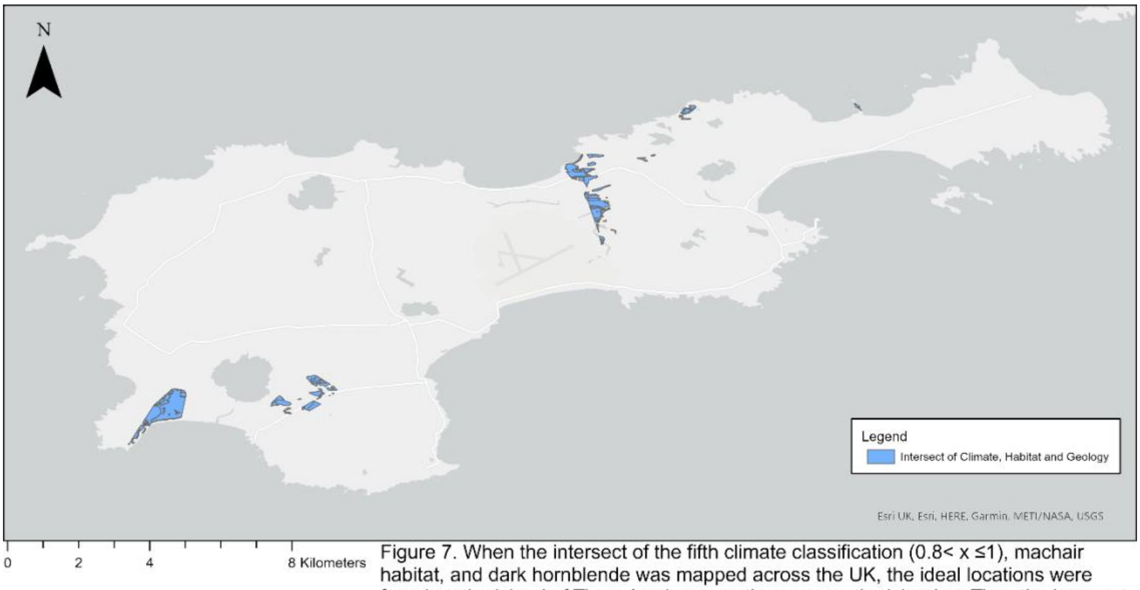


Figure 7. When the intersect of the fifth climate classification (0.8< x ≤1), machair habitat, and dark hornblende was mapped across the UK, the ideal locations were found on the island of Tiree. As shown on the map, on the island on Tiree the intersect locations were concentrated at Balephetrish, Balephuil, and a location on the south west coast of Tiree.

6. Discussion

When reviewing the three different hypotheses, there was not one factor which was solely controlling the distribution of *P. cinctana* in Tiree.

There was enough evidence from the climate analysis to reject the climate null hypothesis and therefore, identify climate influenced the distribution of *P. cinctana* on the island of Tiree. This was known as Tiree was the most climatically suitable location for *P. cinctana* across the UK and Ireland with 53.75% of the island being in category 5. The population of the *P. cinctana* found on Tiree does require specific habitat conditions but the habitat type was in a high abundance across Tiree, Gunna and Coll. The high abundance of machair allowed for the habitat hypothesis to be rejected. Finally, the dark hornblende mineral found on Tiree was available in other locations in Scotland, but it was difficult to determine whether this was too far for the species to travel. When the three hypotheses were combined, Tiree was the only location in the UK which had locations which fit all three variables. There was also a possibility there were other factors outside of the three hypotheses which influenced the distribution of *P. cinctana*.

6.1 Climate

The data presented from the climate model identified that Tiree was very climatically suitable for *P. cinctana*. There were three locations across the UK and Ireland which were very climatically suitable for *P. cinctana*. The locations were on the north coast of Ireland, the isle of Islay and Tiree. The three different locations had values greater than 0.8, which made them very climatically suitable for *P. cinctana*. The climatically suitable locations on the island of Islay and Ireland were small areas when compared to Tiree. The category 5 areas on Tiree covered 43km² of the possible 46km² across the UK and Ireland. Even though Tiree was not exclusively climatically suitable for *P. cinctana*, there were only a small number of other locations which were climatically suitable. These locations also did not cover much space and therefore, it was difficult to know whether they could support a population of *P. cinctana*. The null hypothesis for the climate hypothesis could be rejected as there was evidence to suggest that Tiree was climatically suitable for *P. cinctana* but not enough to determine climate was controlling the distribution.

The MaxEnt model also determined that Bioclim7 had the greatest contribution to the distribution of *P. cinctana*. Bioclim7 was the temperature annual range of a location, and the difference between the max temperature of the warmest month in comparison to the min temperature of the coldest month (Kriticos et al., 2012). As Bioclim7 had the greatest contribution to the model, it aligned with the climate of Tiree as it was one of the most maritime locations in Europe and there was little variation in temperature between summer and winter (Green and Harding, 1983; Pearman and Preston, 2000). This gave greater evidence to support that Tiree was a climatically ideal location for *P. cinctana*.

When testing the model using the ROC curve, the AUC value was 0.985 identifying the model performed very well (Phillips et al., 2008). The value showed that the model could predict the distribution of the species with the use of climate data. The ROC curve provided evidence that the conclusions made about *P. cinctana* were reliable. As the AUC value was 0.985, it was presumed that, even without the 29 observations, which failed when the model was running, the model performed well.

Alongside the rejection of the habitat null hypothesis, it was presumed that the location in Kent, where the original sightings were, was not a climatically suitable location as it fell into the second category. The data from the rest of Europe showed that there were not many climatically suitable locations for *P. cinctana* as 0.3% of Europe fell into category 5. There were places across Europe where the species had been sighted but were not climatically suitable. The sightings with unsuitable locations were found at multiple places across France and Germany. The locations which the species were found at but were not climatically suitable (as values were less than or equal to 0.2) identify potential anomalies. There were sightings at locations which were not climatically suitable and identified other factors played a role in the distribution of *P. cinctana*. The observations of *P. cinctana* found in climatically unsuitable locations identified there were other variables overcoming the unsuitable climate.

6.1.1 Climate Model Limitations

The distribution model for *P. cinctana* used sightings data, which was collected by the Butterfly Conservation, Moths in Kent and GBIF. The data sourced from the GBIF website takes data from a range of sources including amateur naturalists (GBIF.org, 2021). When the sighting records were analysed, many of the data points had not been verified as official observations. Without verification, it was difficult to know whether the records were correct. If the GBIF data was partially incorrect, the distribution model could include some errors and altered the results. Even when the data had the correct identification, the coordinates used could have contained errors. The incorrect coordinates could then have had an impact on the rest of the model. The verification of the coordinates and identification was difficult to check but the use of GBIF data is one of the most widely used observation databases in academic research (Beck et al., 2014, 2012; Jetz et al., 2012; Maldonado et al., 2015).

From the 329-sighting taken from the GBIF website, 29 sightings failed to work when they were inputted into MaxEnt. After the identification of the non-working points, all the observations were located across Scandinavia and most off the coast of Sweden. The observations with coordinate errors could have potentially been down to where the point is being displayed within the map's grid. If the coordinates were not given to a high enough accuracy, the data could have been displayed in an incorrect location. If the coordinates had low accuracy and was sighted close to the coastline, the observation could have been placed off the coastline and then not used within the model. Some of the observations also failed when located on land. The error related to the sightings on land could have been down to the climate model not being in enough detail such as locations were too close to the coast. The climate data could have had a low resolution and followed a coastline with low accuracy. This would mean parts of the coastline would be missed where observations were found at. The low-resolution climate data limited the MaxEnt model and if the results were repeated, a higher resolution climate data should be used.

The climate data used in the model was taken from 1970-2000 and provided by WorldClim (Fick and Hijmans, 2017). The WorldClim data from 1970-2000 was the most recently available climate data. However, if repeated in the future, the use of more recent climate data would make the model more accurate as the occurrence data spanned from 1970 to 2019. Therefore, if the climate hypothesis was repeated in the future, the inclusion of more recent climate data would give a more up to date species distribution when related to climate.

6.2 Habitat

The results from the NatureScot habitat layer showed there was a high abundance of limestone-based habitats on Tiree with 61% of the island made up of machair habitat (NatureScot, 2013). As the machair habitat was found across Coll and Gunna, as well as Tiree, it identified that the preferred habitat type for *P. cinctana* was not limiting the moth species to the island of Tiree. As machair habitat was available on the neighbouring islands of Tiree, the second hypothesis was rejected. This does not mean the habitat type was not restricting the species at other locations but for the population found on Tiree, there was an abundance of machair on Tiree, Gunna and Coll.

Without having a full understanding on how far individual moth species travel throughout their lifetime, it was difficult to conclude whether the islands of Gunna and Coll were too far for *P. cinctana* to travel. The distance between the closest two habitats of machair across the three islands was a direct route of 1.74km. The route was from a habitat of machair on the east coast of Tiree to a small habitat of machair on the west coast of Gunna. The oldest records of *P. cinctana* on the island of Tiree were located near Miodar, on the east coast of the island and was a location with a high abundance of machair habitats. As machair habitat was available on the east coast of Tiree and the sighting of *P. cinctana* at Miodar, it gave evidence that *P. cinctana* could have initially travelled from neighbouring islands to reach Tiree. The preferred habitat type was readily accessible on Coll and Gunna and therefore, the population of *P. cinctana* could have become established on the island of Tiree due to other conditions rather than the abundance of preferred habitat type. The distance between a machair habitat on Tiree to Gunna and the initial sightings of the *P. cinctana* at Miodar supports the rejection of the habitat hypothesis.

6.2.1 Habitat Limitations

The habitat data was taken from 2013 meaning there could have been a loss of habitat over the past 8 years. The loss of habitat, due to rising sea levels and poor habitat management (Angus and Dargie, 2002; Williams et al., 2011), could be more recently constraining *P. cinctana* to Tiree. However, if the research was repeated in the future, the use of more recent habitat data would prevent the limitation from restricting the results in the future.

6.3 Geology

The data from the geology map identified that there was only a small abundance of dark hornblende in the UK which was all found across Scotland. The majority of dark hornblende was on islands off the west and northwest coastline of Scotland. The data collected showed that there were locations of dark hornblende across Scotland but the distance between Tiree and the other locations could have been too far for the *P. cinctana* to travel. One way the moth species could reach the other areas of dark hornblende is if the species is blown off course to the other areas of dark hornblende (Chapman et al., 2008). The closest distance between an outcrop of dark hornblende on Tiree to an area of dark hornblende on a different island was 60km. As previously mentioned, it was difficult to know how far species can travel during a lifetime as it varies a lot between species (Chapman et al., 2008; Chu, 1986; Ravenscroft, 1990). It was difficult to identify whether 60km was too far for the species to travel. The evidence which supports 60km was not too far was the species has either travelled from the initial observation location in Kent to Tiree, a distance of 790km, or from 836km from the closest sighting on mainland Europe.

Alongside the distance between the different dark hornblende habitats, there was also little supporting evidence to conclude the association between *P. cinctana* and dark Hornblende (Bowler, Pers. comm.). When *P. cinctana* was located on the island of Tiree in 1984, both sightings were found in association with dark hornblende. The sightings were the only evidence to support the connection between the geology and *P. cinctana*. Alongside the limited evidence, as most of Tiree is made up of the Lewisian gneiss rock type may not be able to support the preferred habitat of *P. cinctana* and why the species is on outcrops of dark hornblende (Darling, 1955). As there was limited evidence to conclude the connection between the moth species and the mineral, it is difficult to know if the geology was a restricting factor to the population on Tiree.

6.3.1 Geology Limitations

The geology hypothesis was limited by the lack of information on dark hornblende. There was no available data on locations of dark hornblende across Europe and therefore, it was difficult to know whether the observations of *P. cinctana* from GBIF also matched to dark hornblende locations. If the research was repeated, there should be an investigation into whether there is a relationship between dark hornblende and observations across Europe.

6.4 Intersect

When all three variables were combined to form the intersect of the vector layers there were only locations on Tiree which were suitable. The suitable locations identified that potentially, *P. cinctana* was found on Tiree due to the combination of all the conditions combined to form an ideal habitat and therefore, sustain a population.

7. Further Research

As climate was one of the factors isolating *P. cinctana* to Tiree, the Butterfly Conservation could conduct further research on how the species will behave in the future. A future study could give further opportunities into how climate change could potentially impact *P. cinctana*, with the use of predicted climate data. As climate is a difficult factor to control (Jamieson, 2014) or change when preserving a habitat, a predicted climate model will show the Butterfly Conservation where the species could be found after shifting range.

The identification of a location on the north coast of Ireland and the island of Islay as a potential habitat, gives the Butterfly Conservation an opportunity to conduct a desk study to know whether the location fits other habitat preferences. If the conditions in Ireland and Islay fit, a survey could be conducted to know if *P. cinctana* is found there. This survey could potentially identify a new population of *P. cinctana*.

8. Conclusion

To conclude, the distribution of the moth species, *P.cinctana*, is influenced by climate as 53% of Tiree is very climatically suitable. However, there was not enough evidence to accept the climate hypothesis and confirm climate is the only factor controlling the distribution of *P.cinctana* and therefore, the reasoning a population is found in Tiree. The calcareous habitat of machair was not restricting the habitat extent of *P. cinctana* on Tiree due to the abundance of ideal habitat type on the neighbouring islands of Coll and Gunna. The distribution of *P. cinctana* across Tiree could be influenced by the location of dark hornblende but more research is required to understand to what extent this is. By knowing how far the species can travel to other potential habitats and the relationship between *P. cinctana* and dark hornblende, there can a greater insight into how geology is altering the distribution of the moth species. Having a greater understanding of *P. cinctana* on Tiree allows for more targeted conservation work to protect the species for the future.

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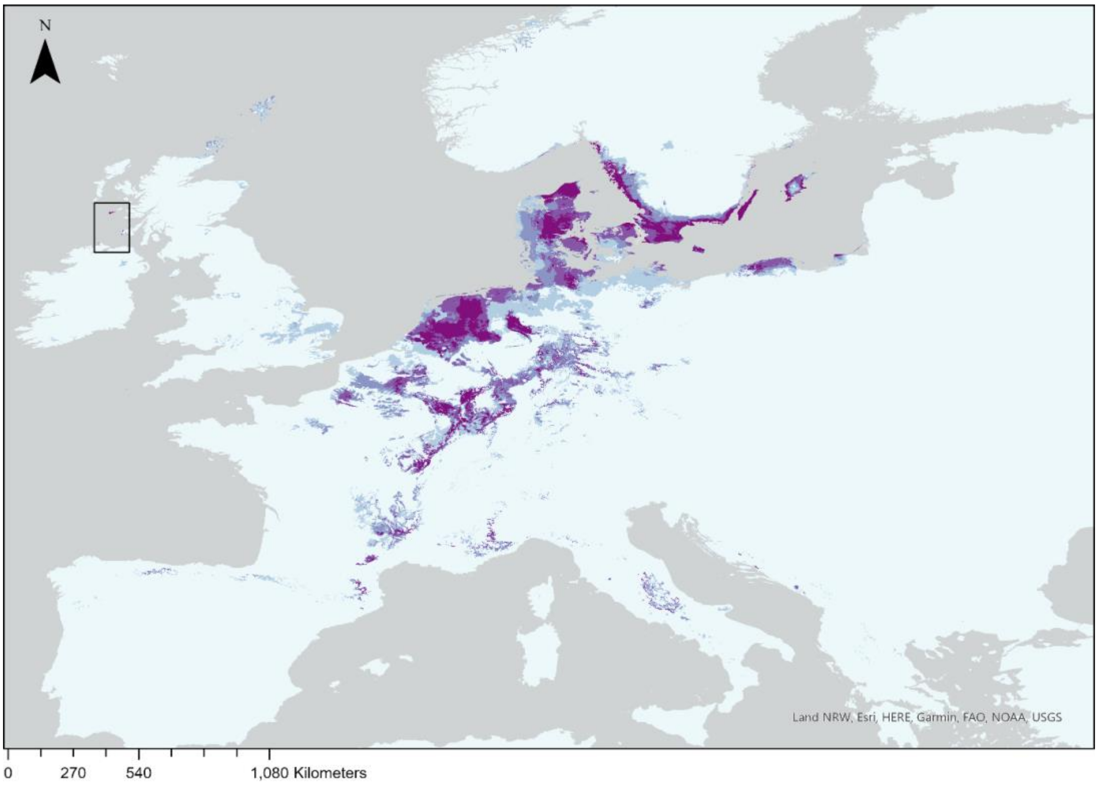
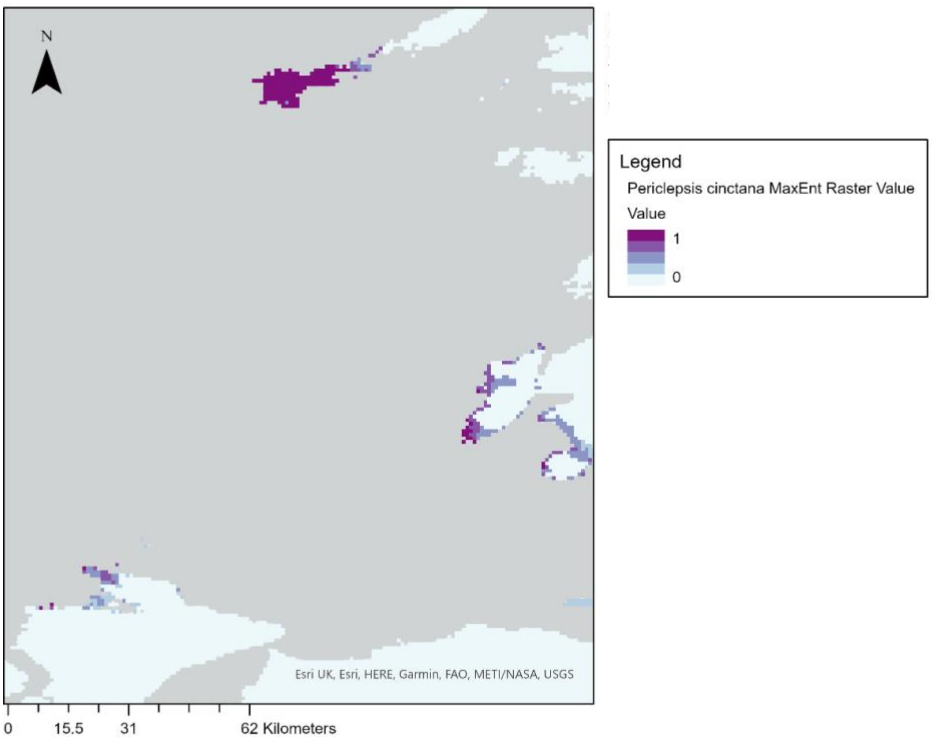
Appendices

Appendix A: Map displaying the values produced by the climate distribution model in MaxEnt as a raster layer.





Appendix B: Ethics Approval

CLES
College of Life and Environmental Sciences
University of Exeter
Penryn Campus
Penryn
TR10 9FE
Telephone: +44 (0)1392 123456
Web: www.exeter.ac.uk

CLES Penryn Research Ethics Committee

Dear Charlotte Willis

Ethics application - eCORN002849
What is the predicted distribution and larval habitat preferences of Kessleria fasciapennel

Your project has been reviewed by the CLES Penryn Research Ethics Committee and has received a Favourable opinion.

The Committee has made the following comments about your application:
Tomas Chaigneau commented, Details amended.

- Please view your application at https://eethics.exeter.ac.uk/CORNWALL/ to see any comments made by the committee.
NB. If you have received a Provisional or Unfavourable outcome you are required to re-submit for full review/confirm that comments have been addressed before you begin your research.

If you have any further queries, please contact me.

Yours sincerely

Dr Nick Royle

Date: 05/05/2021
CLES Penryn Research Ethics Committee

Appendix C: Risk Assessment

Lounge Chair - Self-Assessment Form

-

Name:	**Charlotte Willis**
College/Service & Department:	**CGES - BSC Geography**
Line Manager / Supervisor's Name:	**Sarah Crowley**
Date of Assessment:	**18/11/2020**

- Answer all the questions below (*all the questions have been allocated a score)*
- A total score is generated at the end of the assessment
- Refer to the chart with your total score to determine if any action is required

DSE Component	Y/N or N/A	Action Required / Comments
Chair		
Does the chair offer lower back support in the curve of your spine (lumbar region) when seated in an upright posture?	**y**	
NB: *If not, consider using a cushion or a rolled up towel to create a lumbar cushion for your lower back*		
Can you sit back into the chair using the seat base fully without incurring any pressure behind the knees?	**Y**	
NB: *Seat base is not too deep/long for yo. If no, consider resting your feet on a foot stool or a box*		
Are you able to keep your arms close to the body without the armrests causing an obstruction?	**Y**	
NB: *Try and avoid resting your arms on the armrests when typing so that the shoulders are relaxed when your hands meet the keyboard without the need to hunch your shoulders or reach your arms downwards to operate the keyboard*		
Is the chair comfortable to sit in after adjustments have been made?	**Y**	
NB: *If not, take more frequent fidget breaks by getting up and walking around to stretch your body*		
Monitor		
Is the screen free from glare/reflections?	**Y**	
NB: Some *laptop monitors have basic anti-glare built in as standard*		

Is the information on the screen well defined and easy to read?	**Y**	
NB: *Text can be enlarged using the + bar on the bottom right hand corner of the screen (not very effective with Outlook)*		
Are the images on the screen flicker free?	**Y**	
Do you clean the screen regularly?	**Y**	
NB: *If not, clean the screen with soft cleaning wipes*		
Is the monitor positioned vertically flat or tilted slightly upwards off the vertical?	**Y**	
NB: *Too much upward tilt will increase glare/reflection from artificial lighting and natural daylight*		
Can you adjust the brightness and contrast easily either via the monitor or control panel?	**Y**	
NB: *If not, access settings or type in display settings in the search box at the bottom of the screen or seek advice from your line manager*		
Keyboard		
Is the keyboard at the correct angle to prevent any bending of the wrist (up or down)?	**Y**	
NB: *A laptop keyboard reduces the need to bend the wrists when typing*		
Is your keyboard positioned close to you on your lap to ensure your elbows remain directly under your shoulders when typing?	**Y**	
Is the keyboard clean?	**Y**	

NB: *If not, clean the keyboard with soft cleaning wipes*		
Are the digits clear and not faded?	**Y**	
NB: *If you need a replacement keyboard contact your line manager*		
Trackpad (mouse)		
Do you reduce the time using your trackpad mouse to the lowest period by using keyboard short cuts?	**Y**	
NB: *Refer to the DSE Website for further information on keyboard shortcuts*		
Space and Environment		
Is the lighting adequate?	**Y**	
NB: *Not too bright or too dark*		
Do windows have curtains or blinds fitted to prevent glare and reflection?	**Y**	
Do you use curtains or window blinds to prevent glare and reflection?	**Y**	
Do you find the working environment quiet enough?	**Y**	
Is the temperature comfortable for most of the time e.g. not too hot or too cold?	**Y**	
About You		
Are you free from any upper body pain?	**Y**	
NB: *This means back, neck and shoulders*		
Are you free from any pain in your upper limbs?	**Y**	

NB: *This means elbows, wrists, hands and fingers*		
Do you organise your work to ensure you take more frequent 'fidget' breaks throughout the working day when using the DSE?	**Y**	
NB: *Fidget breaks include comfort breaks and generally standing up and moving from being in a static position*		
Do you feel you understand and can effectively use all of the computer programmes you are required to use as part of your job?	**Y**	
NB: *If not, speak to your line manager to request further assistance*		
Do you have an existing medical condition that you feel is being aggravated by your current workstation set-up?	**N**	
NB: *If yes, speak to your line manager to request further assistance*		
Do you suffer from dry or sore eyes when using your DSE?	**N**	
NB: *Frequently looking away from the screen will encourage increased blinking to lubricate the eyes naturally*		
Do you feel you require extra DSE information or guidance?	**N**	
NB: *If yes, refer to the DSE website and speak to your line manager to request further assistance if required*		
Have you had an eye test in the last 2 years?	**Y**	Eye-care voucher request
NB *If Yes, please wait until it is two years since your last eye test. If No, please use the link above to apply for an eyecare voucher*		
TOTAL SCORE	**0**	

0 – 18 The lounge chair set-up is adequate, however if you have any concerns raise these with your line manager

19 – 40 Contact your line manager for help and advice. Consider whether there are any actions you can take that will improve your score (e.g. clean the screen, creating a lumbar cushion, purchasing or improvising by creating a foot/legrest)?

41+ Contact your line manager in the first instance. Line Manager to contact the Health and Safety Team (safety (safety@exeter.ac.uk) for further advice and/or to request request and arrange a telephone assessment (if required)

Action Plan:

Complete the sections below/overleaf indicating what action is required to address the issues identified in your Self-Assessment.

- Key information must be passed onto your line manager to ensure that action can be taken
- All actions must be agreed with the line manager
- Actions that requires purchasing new equipment must be approved by the line manager and the relevant College/Service key contact
- Action plans must be monitored and completed within a reasonable timeframe

Actions Required	**Responsible Person**	**Date for Completion**
