Investigating Natterjack Toad (*Epidalea calamita*) Habitats in Great Britain: Maxent predictions and Field Analysis.

By
Sergi Bernat i Denny

Abstract

The distribution of Natterjack Toads (*Epidalea calamita*) in Great Britain is influenced by a complex interplay of anthropogenic and environmental factors. In this study a multi-faceted approach, combining maxent modelling and field surveys was used to determine the habitat suitability, and ecological determinants of Natterjack Toad distributions. The maxent model used environmental variables, such as climactic conditions, soil characteristics and land cover data to predict potential habitats across Great Britain. The final model revealed distinct spatial patterns of habitat suitability, with specific coastal regions, associated with high littoral sediment composition experiencing the highest suitability. Validation of the model's predictive performance was provided by a binomial distribution test ($p<0.0001$), and sensitivity vs. 1- specificity data, (training data (AUC = 0.940) test data (AUC = 0.921)). Transects were conducted at North and South Walney Nature Reserves, strategically selected for their respective presence and absence of Natterjack Toads, despite both sites experiencing high habitat suitability. Higher elevation differences in north Walney provided climactic protection from wind speeds to its microhabitats (Pearsons's correlation test $p<0.0001$). The vegetation composition in south Walney correlated with higher average soil moisture (ANOVA $p<0.0203$), which in turn affected ground compactness (ANOVA $p<0.390$), burrowing availability and ephemeral pond presence. A positive correlation between livestock presence and vegetation composition (Kendall's Tau rank correlation test $p<0.039$) at north Walney suggests that livestock activities are not compatible with plant species associated with primary succession. The findings from this study highlighted the importance of field research in supporting species distribution models, the effects anthropogenic factors have on ecosystem health, and the need for holistic conservation and management strategies. Future research of Walney island should prioritise monitoring the health and dynamics of dune profiles and ephemeral ponds.

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1. Introduction

1.1 Background of the Natterjack Toad

The Natterjack Toad (*Epidalea calamita*) has long attracted the European public's attention, its presence as a flagship species should not take away from its ecological significance. Playing vital roles within the food web, regulating insect populations, and acting as habitat engineers; altering microhabitats, affecting the nitrogen cycle, and directly affecting both plant and animal biodiversity (Banks, Beebee and Denton 1993). They have therefore often been used as an indicator species, to identify habitat health, and degradation (Banks, Beebee and Cooke 1994).

The presence of Natterjack Toads within Great Britain (GB) has spanned and been recorded for centuries, with occurrence data available from as far back as 1801 (NBN Trust 2016). Throughout this time, they have developed a great number of adaptations which have allowed them to span from Iberia to as far north as Belarus and Estonia, at altitudes as high as 2500m above sea level (Beebee et al., 2012). Despite this, habitat degradation, human encroachment and fragmentation have caused their UK populations to become confined to a few select coastal environments (Rowe and Beebee 2007).

1.2 Importance of Studying Habitat Distribution

Understanding habitat distributions is imperative in understanding the interactions that occur within ecosystems. Should species like the Natterjack Toad rely on conservation efforts for their in-situ survival (for which there is mounting evidence (Stevens and Baguette 2008; Snep and Ottburg 2008)), understanding the specific environmental conditions crucial for their continued existence is vital. Monitoring changes in species distribution provides information that can be used for predicting environmental shifts and potential habitat degradation. Like most amphibians Natterjack Toads can be very sensitive to such shifts and can therefore be used as early bioindicators for environmental changes (Sumanasekara, Dissanayake and Seneviratne 2015).

Traditional approaches for monitoring species and habitat distributions such as field work and satellite tracking can pose a strain on the already stretched resources within the conservation sector (Leader-Williams and Albon 1988). Predictive models can present a far less economic and time-consuming approach to foresee future and current ecosystem conditions. Such data-driven models can be used to guide conservation efforts and help inform policies and land management within the wider context of conservation (Srivastava, Lafond and Griess 2019).

Unfortunately, the accuracy of these models can only be as reliable as the source data used to predict them (Howard et al., 2014). In many cases this results in predictive models with parts of the picture missing. For instance, due to the seasonal nature of Amphibians, accurate absence data is often not available (Homan, Windmiller and Reed 2004). In any case it is not as reliable as presence data, as proving absence is much harder than presence (MacKenzie et al., 2017). Despite this using presence-only models can result in false absences, bringing into question the reliability of such models (Elith and Leathwick 2009).

2. Literature Review

2.1 Ecology and Behaviour of Natterjack Toads

Between the months of January to April, Natterjack Toads, triggered by increasing temperatures and humidity levels begin their breeding season (Miaud and Sanuy 2005). Males attract females through loud calls, advertising their position and the presence of ephemeral ponds, suitable for spawning (Sinsch 1988). Due to their site fidelity, should a male toad not be within proximity to a suitable area their fitness will decrease (Sinsch 1992). Once mating has occurred, females will lay strings of up to several thousand eggs per string within said ponds (Reyne et al., 2021). This high fecundity within such a confined period causes large fluxes in nitrogen and chlorophyll *a* (Seale 1980). Resulting in ecological progression of coastal environments and supporting a wider range of niche species (Steele et al., 2015; Kelly 2008).

Within just a few short months the eggs hatch and the tadpoles develop completely into terrestrial toads. However, development speeds can vary drastically due to environmental limitations (Rannap et al., 2012). During this time the tadpoles become an invaluable source of food to many species of animals, transferring nutrients and energy between aquatic and terrestrial ecosystems (Montaña et al., 2019). But also acting as suspension-feeders and detritivores themselves, filtering the microenvironments in which they reside (Altig, Whiles and Taylor 2007), although there are studies that classify tadpoles as being nonselective (Seale 1980). Regardless, they act as a seasonally important part of the food web and continue to be important food sources to birds, mammals, and reptiles at every part of their life cycles.

The newly developed Natterjacks will enter a dispersal stage in which they will travel large distances to find a breeding habitat they will stay at for most of their lives (Stevens et al., 2004). This migratory behaviour can be limited by the fragmented environments that are suitable for them, and their ability to travel safely across certain environments (Stevens and Baguette 2008). Meaning isolated populations could lack genetic diversity (Oromi et al., 2012). The positive in this is that there could be habitats that whilst being inaccessible for current populations, could provide potential for reintroduction of the species.

To avoid the heat of the day Natterjack Toads will dig burrows and hunt nocturnally (Denton and Beebee 1992). These burrows air out the soils, create microhabitats, and provide shelter to small animals (Kristensen 2000). This burrowing, combined with their movements also has the potential to inadvertently aid in seed dispersal, propagating plant diversity (Herrera 2002).

2.2 Previous Studies on Natterjack Toad Habitats

Reyne et al., (2023) studied the spatial genetic structure and gene flow between twelve breeding sites in Ireland using Bayesian and non-Bayesian clustering analysis of polymorphic microsatellite loci. They found that connectivity was enhanced by coastal habitats. Whereas riparian densities such as rivers or human influence indexes such as plantations restricted gene flow. They concluded that despite declines in population numbers leading to the regional endangered status of their metapopulation, genetic diversity was still high. I believe that a shifting baseline syndrome could be to blame for such observations, likely due to the low available data on the genetic diversity of the Natterjack Toad of previous generations. Comparative studies found that European Natterjack Toads experience much higher genetic diversity than their UK counterparts (Beebee and Rowe 2000) who are similarly restricted to coastal environments. I would suggest that Reyne et al., (2023) need to reevaluate what high genetic diversity looks like, as in areas of Europe there can be drastic phenotypic variations between individuals on micro-geographic scales, in stark contrast to their own findings (Marangoni 2023). Although further studies are necessary as there is limited genetic baseline data. However, historical distribution data could be used to determine whether European populations could be used as said relative baseline.

The role climate change has played and will play in the population dynamics of *E. Calamita* has not been researched in great depths. It has been suggested that climate change could increase fecundity as well as creating the conditions for earlier spawning seasons (Reyne et al., 2021), and that reduced precipitation could have positive impacts on the most threatened Natterjack populations found at the very edge of their geographical ranges (McGrath and Lorenzen 2010). However, it is also accepted that a change in temperature affects gonadal development, due to the phenotypic plasticity incurred as a result of the external environment (Akashi et al., 2024), affecting the sex ratio of amphibians, and resulting in overall reduction of potential breeding partners under extreme conditions (Edmands 2021). Similarly, the coastal sand dunes that make up large parts of the ecosystems in which Natterjacks are still found, are dynamic and affected by climate conditions such as wind, precipitation, coastal tides, and notably human pressures (Tsoar 2005). These conditions, require a specific balance to result in the sustainable progression of sand dunes, from their active to stable state (Nield and Baas 2008). However, even stable dunes, under longer droughts associated with climate change can reactivate and destabilize (Yizhaq, Ashkenazy, and Tsoar 2009). Jackson, Costas and González-Villanueva (2019) suggested that vegetation cover could be used as an environmental marker to measure the effects changing climactic conditions and localised human practices have on sand dunes, noting the importance of native plant species in the stability and growth of sand dunes, and the protective qualities they provide coastlines.

2.3 Methods and Tools for Species Distribution Modelling

Species distribution models (SDMs) are often used in the field of quantitative ecology to provide a better understanding of how species interact with their environments (Srivastava, Lafond and Griess 2019). They use occurrence and/or absence data, paired with relevant environmental data to predict geographical distributions (Williams et al., 2009). The predictive capacity of these models is determined by the selection and availability of relevant training data, and the performance and development of the used software's themselves (Ahmed et al., 2015). Unfortunately, these models often lack total accuracy as taking biotic interactions into account, and the availability of absence data being limited, can impact their predictive capacities (Lobo, Jiménez-Valverde and Hortal 2010). This, paired with questions over the reliability of presence-only models poses a continued challenge in the field (Elith and Leathwick 2009).

There are a variety of freely available species distribution model software's, with comparative applications. One of the more common SDM tools is Maximum Entropy modelling (Maxent), which can be used to estimate the relative occurrence rate and probability of a species. Although, its wide use within academia can and has resulted in researchers underestimating the importance of input parameters, leading to discrepancies in model's reliabilities (Lissovsky and Dudov 2021). Moreover, alternative software's such as "maxlike" (Royle et al., 2012) can predict occurrence probabilities in non-relative terms, although their reliability has no marked improvement on models run using Maxent (Merow and Silander 2014). Similarly, the use of logistical regression models can be used as an alternative to Maxent under binary conditions, which despite not providing the same adaptability with regards to variable importance, has been shown to produce similar efficiency in modelling within limited ecological niches, although within the same comparative study, Maxent experienced even more limitations than that of the logistical regression model (Saharagard and Ajorlo 2018).

Furthermore, the widespread comparative assessments and previous SDM's using Maxent, provide useful information relating to the calibration and training of the model, when compared to the relatively low available information on the alternative modelling options, making Maxent a more useful/ user friendly tool (Elith and Leathwick 2009).

2.4 Challenges in Natterjack Toad Conservation

Whilst legislation like the Wildlife and Countryside Act (1981), Environmental Protection Act (1990) and Biodiversity net gain (2023) aim to protect species and their environments within the UK, development pressures associated with growing populations and an increasingly capitalist economy threaten habitats and ecosystems around the UK (Sène 2023), with habitat fragmentation being accepted as the primary driver in Natterjack Toad declines (Stevens and Baguette 2008). However, threats like pollution from agricultural and industrial activities also pose a threat to coastal ecosystems, and amphibians which can absorb such pollutants through their permeable skin (Croteau et al., 2008). Furthermore, since the UK's separation from the European Union, uncertainty regarding environmental policies, and the UK's potential to relax environmental law has posed a challenge to ecosystem health, as well as its measurability, due to ambiguity relating to the effect such policy changes may have when compared to population dynamics (Burns et al., 2018; Whelan et al., 2022).

Moreover, changes in ecosystem dynamics due to climate change can affect the sustainability of their ecological ranges. As well as result in the introduction of invasive species, which could predate or compete – either directly or indirectly – with Natterjack Toads (Mainka and Howard 2010). These introductions can also result in the outbreak of infectious diseases such as chytridiomycosis, which has been spreading among amphibians around the globe, resulting in the extinction of several amphibian species (Berger et al., 2016). Such diseases could pose further threats to populations of UK Natterjack Toads due to their limited genetic diversity among isolated populations (O'Brien and Evermann 1988).

3. Aims and Objectives

The aim of this study is to accurately predict the current distribution of Natterjack Toad habitats within Great Britain, by using existing environmental data and Maxent species distribution modelling, so that further field analysis can take place on the underlying factors contributing to the unexpected absences and presences associated with the model. Such resulting data would be used to identify potential management strategies which could mitigate the factors contributing to their absences from otherwise 'ideal' habitats predicted by the Maxent model.

The success of this study will be measured by the acceptance or rejection of two individual hypotheses; ($1H_0$) *The predicted distribution model is no more accurate than a random predicted distribution model*, and ($2H_0$) *There is no difference between environmental factors at sites where Natterjack Toads are predicted to be but aren't and to where they already are confirmed to be.*

4. Methods

4.1 Ethical Considerations

The following methods were reviewed and approved by the Nottingham Trent University ethics committee, in the form of a level 1 environmental ethics form (see Appendix E).

4.2 Maximum Entropy (Maxent) Variable Selection

Entropy is the measure of disorder, randomness, or uncertainty within a system (Bein 2006). Within information systems, entropy is the measure of the average quantity of information produced by a stochastic source of data (Gray 2011). Maxent uses this entropy with the given data, to calculate geographical probabilities in the form of distribution maps (Phillips, Anderson and Schapire 2006). The advantage this entropy provides is that the Maxent models can produce more conservative distributions and consider the relative value of given data (Elith et al., 2011). However, to avoid biases in the model, prior knowledge about the variables can be used to influence the importance they hold in the model (Merow, Smith and Silander 2013). Despite this, using unnecessary data in the model will still affect accuracy and increase computational resource requirements (Elith and Graham 2009). Therefore, considering the use of environmental variables which are most likely to meet the ecological requirements of the target species, whilst avoiding the use of many less relevant factors which could affect the model's interpretability is vital (Elith and Leathwick 2009).

Occurrence data was sourced from NBN Atlas, on the 27th of October 2023. This data provided 40,380 occurrence points, dating back to the year 1800. Providing insights into the historical and current distribution patterns of the Natterjack Toad, as shown by Figure 1. Due to the reliability of some of the data, as well as its relevance in modern predictions, the dataset was narrowed to 365 accepted occurrence points since 1990, to eliminate any outdated and falsely recorded sightings. Occurrence points with a coordinate accuracy above 100m were also eliminated, to maintain accurate training and calibration data for the model, as shown in Figure 2.

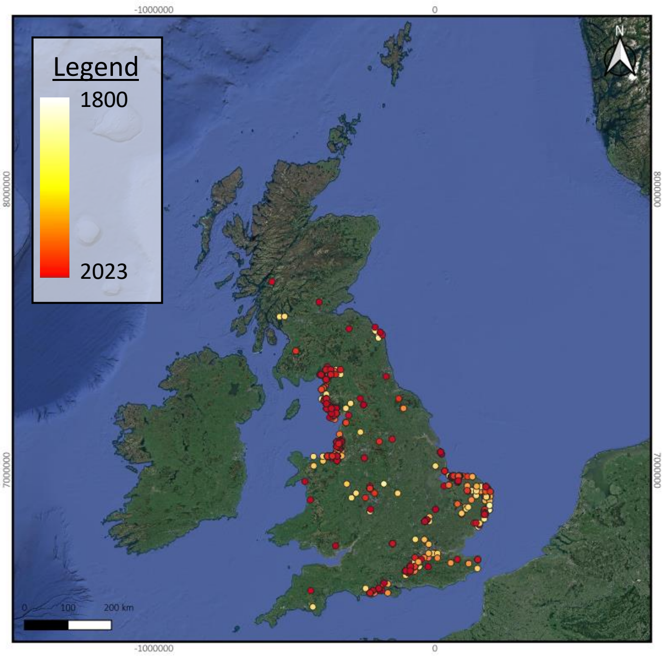

Figure 1. Natterjack Toad Occurrence Points Across Great Britain from 1800 – 2023.

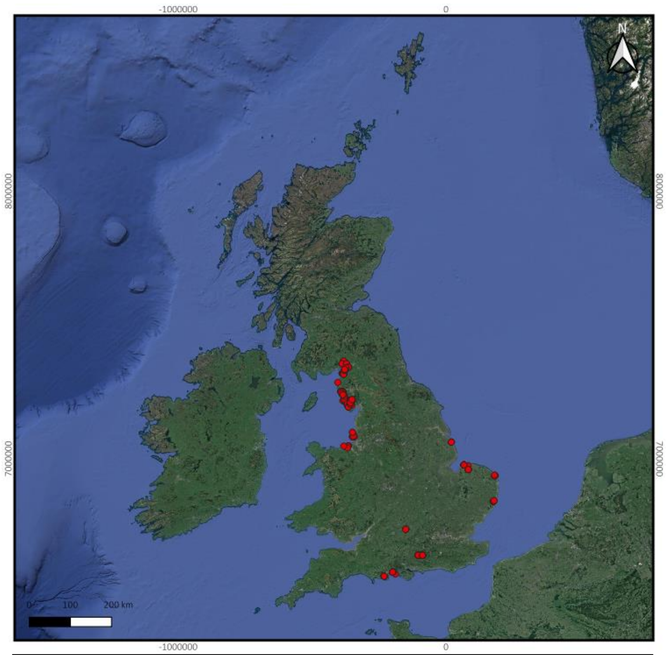

Figure 2. Confirmed Natterjack Toad Occurrence Points Across Great Britain from 1990 – 2023.

The distribution of a species is limited due to specific environmental variables. Variables which could affect the distribution of Natterjacks were selected based on their impact as well as their availability (see Appendix A). Topsoil pH was selected due to its effects on nutrient availability, microbial activity, and vegetation composition. Influencing whole ecosystem dynamics (Stark, Eskelinen and Männistö 2012), and supporting the specific vegetation characteristics of the coastal systems in which Natterjacks reside. Natterjack Toads generally exhibit preferences for sandy acidic soils (pH 5.5-7.5), to sustain their breeding and foraging activities (Beebee 2013). Similarly, soil moisture determines the availability of water used by Natterjacks for breeding, tadpole development and further survivability, as well as highlighting the ability for soils to form and maintain persistent ponds throughout their breeding seasons (García-París, Montori and Herrero 2004). The balance of these variables, and their successful maintenance can be measured by soil carbon concentration, which reflects the organic matter content of the soil and its water retention capacity (Jobbágy and Jackson 2000). High levels of organic matter increase soil fertility and microbial activity, the resulting increase in plant growth can result in the ephemeral ponds they rely on being suffocated by the increased vegetation levels (Zedler 2003). In contrast, low levels of organic matter can result in the degradation of the present vegetation and result in unstable ecosystems which do not provide enough structure or sustenance to maintain their microhabitats (Maun 2009).

The inclusion of climate variables to maxent models provides insights into the ecological requirements of Natterjack Toads (Dawson et al., 2011). Furthermore, Worldclim data has been widely used in maximum entropy models and can provide assurance in its accuracy through comparative models (Fitzgibbon, Pisut and Fleisher 2022). All the data from Worldclim was downloaded at 30 arc-second resolutions, representing current climate conditions, derived from data collected between 1970 to 2000, from between 9,000 and 60,000 weather stations, interpolated using thin-plate splines with covariates, obtained from the MODIS satellite (Fick and Hijmans 2017).

Annual mean temperature measures the thermal conditions that could influence Natterjack Toad populations through metabolic and reproductive processes, the seasonality of such temperatures can influence activity patterns, breeding, and hibernation periods (Oromí, Sanuy and Sinsch 2010). Similarly, adequate annual precipitation will alter the availability of water resources, essential for maintaining wetland habitats and supporting vegetation, the variance of precipitation is crucial in providing consistent dry burrowing availability, and the availability of breeding ponds in wetter seasons (Lannoo 2005).

Elevation on the other hand, represents topographical variations across the landscape, influencing microclimatic conditions and heterogeneity (Chiu et al., 2020). These differences affect shelter availability, drainage networks and resource availability (Pickett and Cadenasso 1995).

Similarly, land cover types can be used to categorically show ideal habitat preferences by grouping habitats into the same category due to their shared surface characteristics, determined by satellite imagery (Foody 2002). The land cover map used was sourced from the EDINA Environmental Digimap service, which provides mapping data from the UK Centre for Ecology and Hydrology, the classes for which were based on the Biodiversity Action Plan Broad Habitats (Jackson, 2000), as seen in Figure 3 and Appendix 2.

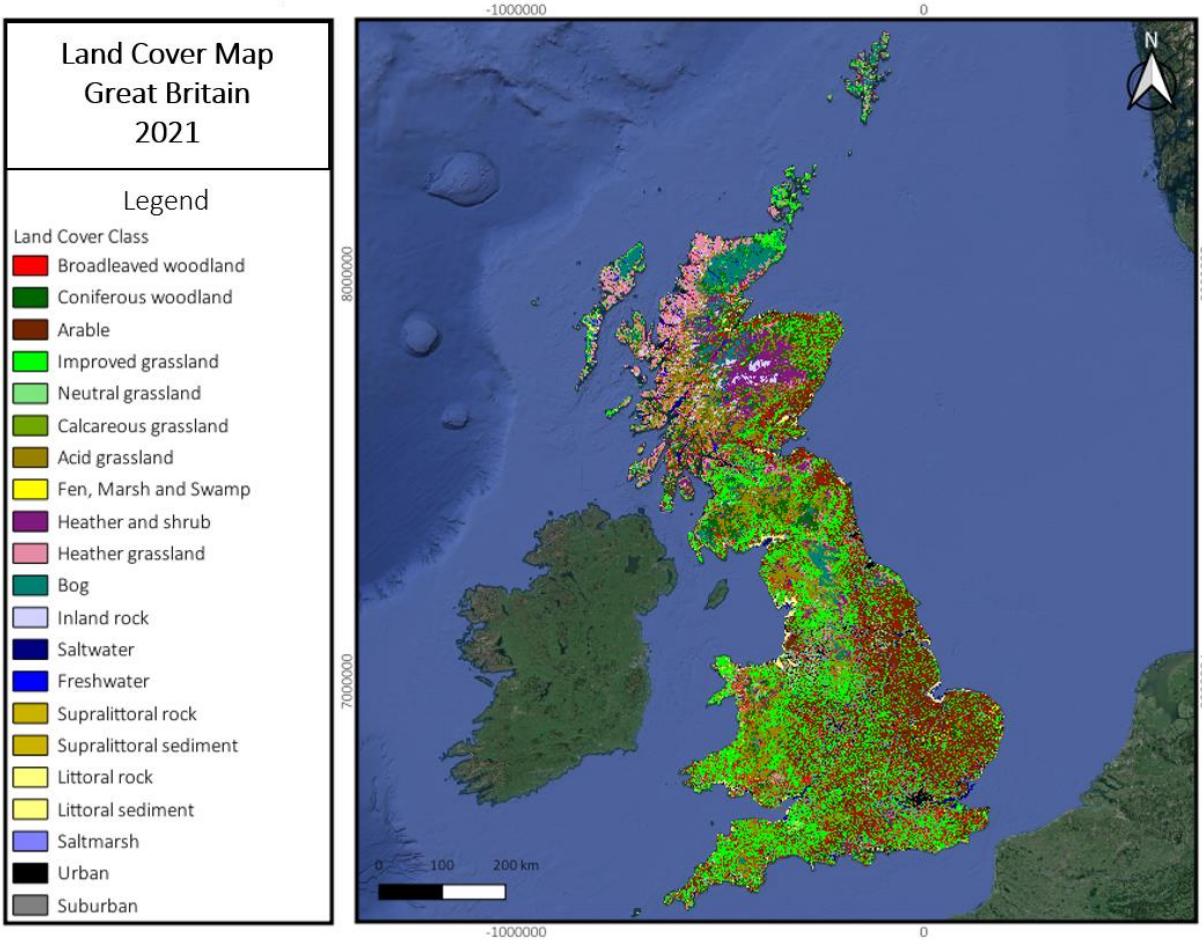

Figure 3. GB Land Cover Map, EDINA Environmental Digimap (2021).

4.3 Maximum Entropy Modelling

Data processing techniques and their resulting geographical dimensions must be kept consistent so that maxent can keep interpolation techniques similarly consistent. This minimizes the biases and inconsistencies associated with unprocessed heterogeneous datasets, increasing model accuracy (Hijmans et al., 2005). As such, the occurrence records and environmental variables first needed to be transferred into QGIS (Version 3.34.1) where their coordinate referencing systems (CRS) were aligned to WGS 84 (CRS84). Using the Geospatial Data Abstraction Library (GDAL) OSGeo4W shell, all vector files were converted to ASCll format, extracting the relevant bands, before being reuploaded to QGIS as raster's. Similarly, the land cover map was reprojected into two separate layers, each representing a single band containing relevant information. These bands were then recombined into a singular layer, represented by a single band for use in maxent. Using the QGIS tool Warp (reproject) all the layers were given the same resolution of 0.0004 for consistency in maxent. The smallest layer (carbon concentration) was then reprojected as a vector layer using the Polygonize (raster to vector) tool in QGIS. This layer was used as a mask layer in the Clip raster by mask layer tool, on every layer in the dataset, so that their geospatial information could be kept consistent. Finally, the tool Align rasters was used to ensure there were no discrepancies in the geospatial data of any of the layers.

Once all the layers were checked in QGIS to contain all the relevant information, and they were in the correct format, RStudio (Version 2023.12.0+369) was used to determine the optimal maxent settings for use, following the tutorial from Banta (2019):

- Firstly, the packages “rJava”, “ENMeval” and “raster” were installed into RStudio using the command: “install.packages(“package”, dependencies = TRUE)”.
- The packages were then loaded using “library(package)”.
- The maxent software was then transferred into a file that could be identified by the “dismo” package of RStudio, the target file was identified by running the command; “system.file(“java”, package=”dismo”)”.
- All the environmental layers were then transferred into RStudio as raster’s using the following command: “layer <- raster(layer.asc)”, so that they could be stacked using; “env <- stack(layers)”.
- Following this the occurrence records were loaded in using: “natterjack <- read.csv(“natterjack.csv”)[,-1]”
- The command: “length(which(!is.na(values(subset(env)))))” was used to show the potential number of background points the data has available.
- As there were many more that 10,000 background points the command; “bg <- xyFromCell(dens.ras2, sample(which(!is.na(values(subset(env, 1)))))). 10000, prob=values(dens.res2)[!is.na(values(subset(env, 1)))]” was used.
- ENMeval was then used to cross validate the data using: “enmeval_ressults <- ENMevaluate(natterjack, env, method=”randomkfold”, kfolds = 10, categoricals=c(3), algorithm=’maxent.jar’, bg.coords = bg)” - the number 3 representing the categorical variable from the land cover.
- The results from which were then extracted from RStudio into a file using: “write.csv (enmeval_results, “enmeval_results.csv”)”
- The row with the lowest delta.AICc value (0) represented the ideal predicted maxent settings, features and the regularization multiplier.

Maxent (Version 3.4.4) was then used to run the species distribution model several times, continually using the occurrence and environmental variables to calibrate it, whilst addressing any potential errors in running the model, to optimize predictive performance, and consider variable importance.

A binomial test is a statistical test that would be used to determine the probability that the results from the Maxent model were randomly generated, by comparing the occurrence frequencies expected by a binomial distribution under a specific probability value (Agresti and Franklin 2007), it does this by using the binomial probability formula:

$$P(X = k) = \binom{n}{k} \times p^k \times (1 - p)^{n-k}$$

Where:

k = probability of obtaining a specific number of occurrences

n = number of independent trials

p = probability of occurrence

(1-p) = probability of absence

P(X=k) = probability of obtaining k successes

4.4 Study Area Selection Criteria

The study areas were selected based on several criteria. Firstly, areas which showed potential habitat suitability were assessed, considering their heterogeneity and similarity to areas which had presence data, to provide a research area which could be compared to, and represent as many of the other potentially suitable environments as possible. Following this, the accessibility of the areas was considered and compared to determine logistical feasibility, such as accessibility to accommodation, road networks and legal site requirements. The resulting research areas were then used to select comparative areas, which already support Natterjack Toads, while taking the selection criteria into account, as well as relative proximity to the first site.

4.5 Field Analysis Approach

The field research methods were selected to complement the maxent model by providing specific, empirical data on the habitat characteristics associated with Natterjack Toad presence and absence data, whilst taking the multidimensional nature of Natterjack Toad habitats into consideration. As such the following methods were used to determine habitat suitability:

- Transects were selectively used to compare two areas; one which had Natterjack Toads present, and another which did not, despite the model predicting relatively favourable conditions in that area.
- Transects measured plant density and diversity, to compare habitat health and similarity.

- Soil properties, such as moisture, penetrative resistance and topography would be measured and compared.
- Wind speeds were measured to predict sustainability and protective functions of dynamic environments like sand dunes.
- And anthropogenic impacts on the habitat, such as litter accumulation, human disturbance, and livestock presence were measured.

Such research was considered important and suitable for the collection of environmental data that could be integrated with the empirical data from the maxent model, to validate, and refine the approach to habitat modelling, through missing ecological information.

Due to time constraints, field research would have to be undertaken in a short space of time. Both sites would be assessed within a 1-day period. Although, this would provide relative consistency in climate conditions (Gotelli and Ellison 2004). Transects would be established to encompass as much of the heterogeneity each environment provides as possible. All the data collection techniques would be standardized, to maintain consistency between sites. Similarly, the same equipment would be used for both transects:

- 0.5 x 0.5m quadrat - to measure plant diversity and density.
- Kestrel anemometer - to measure wind speeds, the maximum wind speed measured over a 10sec period was used.
- Field Scout TDR 350 - to measure soil moisture.
- Pocket Penetrometer – to measure ground compactness.
- 30m tape measure - to measure the distance between the peaks and troughs of dunes.
- Clinometer – to measure the gradient between the peaks and troughs for further dune profiling.
- Stopwatch – to measure the elapsed time when conducting livestock and people counts.

The counts would take 5min at each transect point, to give a reasonable amount of time for data collection, whilst mitigating time constraints, and providing consistency. The peaks and troughs of the observable landscape would act as the data collection points, along a continuous straight line, this would provide a range of microhabitat conditions and analysis of the structure and profile of each transect, as well as maintaining repeatability.

5. Maxent Predictions of Natterjack Toad Distribution

5.1 Results and Interpretation of Species Distribution Model

The generated habitat suitability model was transferred from the Maxent results folder as an ASCII file into QGIS for visualisation as a raster, imposed over satellite imagery of Great Britain, as shown in Figure 4.

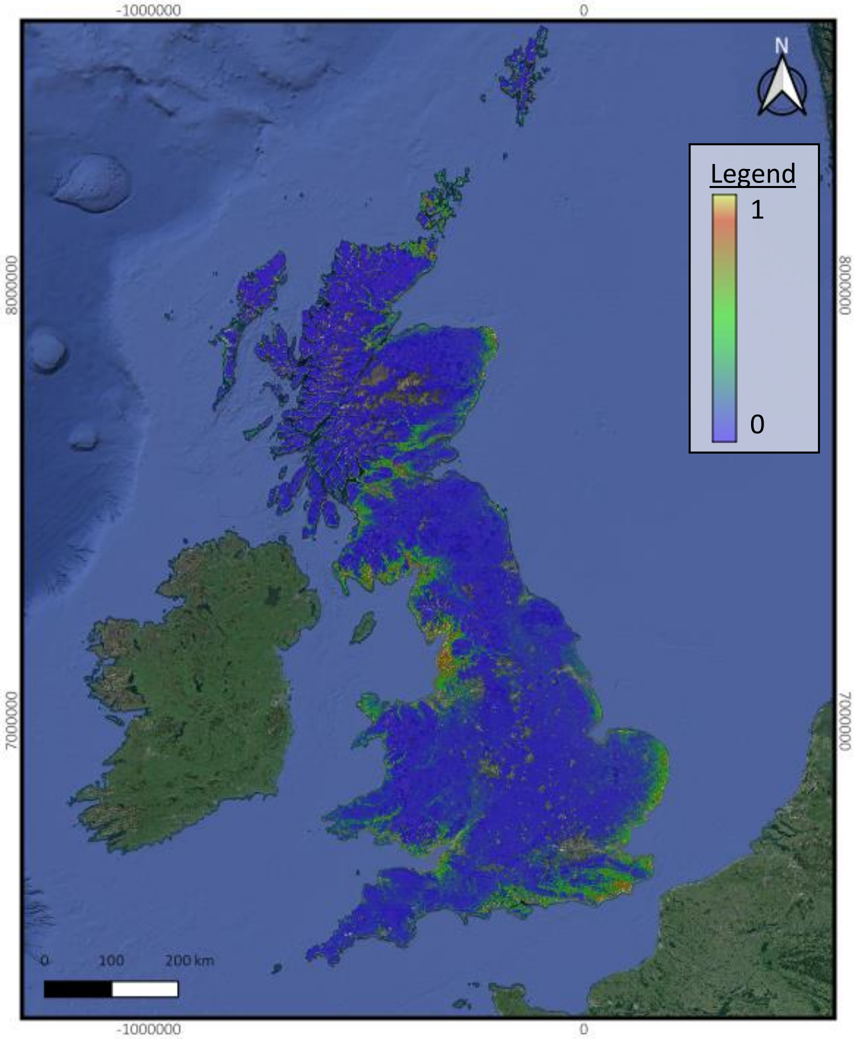

Figure 4. Maxent Species Distribution Map. Legend shows predicted habitat suitability (1 being the most probable, and 0 the least)

The model shows clearly defined spatial patterns, with the southeast and northwest of England's coastal habitats experiencing the most suitability, in line with the occurrence data. The model also predicted habitat suitability in some regions of Wales, southwest England, and Scotland, all of which similarly fall within a proximity to the coast. The only area of high suitability not closely affiliated to coastal regions appears to be the found in the south of Scotland, close to a dense network of lochs and rivers, just to the north of Edinburgh and Glasgow. In contrast, landlocked areas of high elevation, and coasts without nearby estuaries or littoral sediment experience lower habitat suitability.

5.2 Maxent Model Performance

The Maxent model provides metrics which can be used to measure the accuracy of the model run, in the form of two graphs. Firstly, a graph representing the relationship between the predicted probability threshold and the omission rate of the model, i.e. showing the rate at which the model fails to predict the presence of the species (See Figure 5).

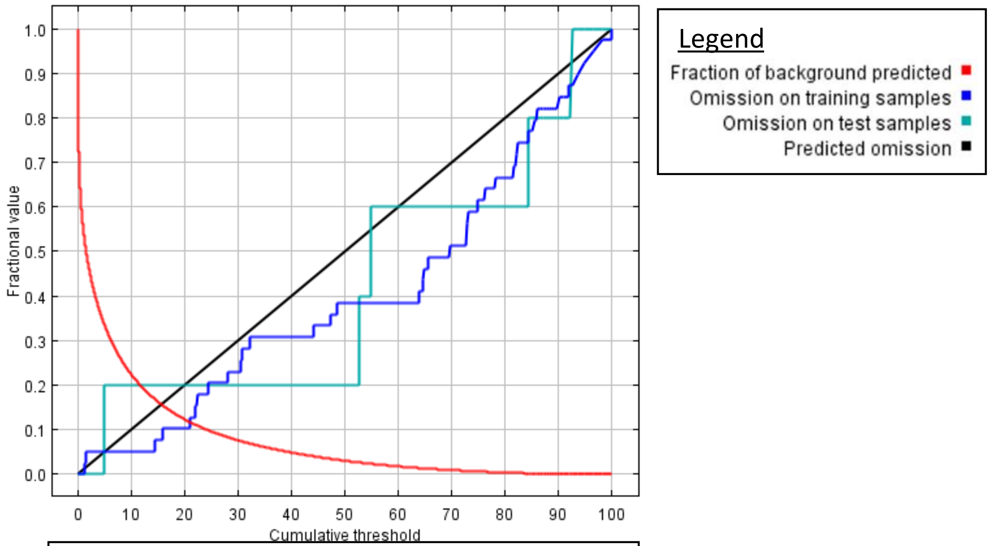

Figure 5. Maxent model Omission Rates

Figure 5 shows the omission rates of the training and test sample curves fall below the predicted omission rates, giving confidence in the accuracy of the model, and the data used. Secondly, Maxent creates a graph used to represent the sensitivity of the model, by measuring the proportion of correctly predicted presences, and comparing them to its specificity, which measures the rate at which the model incorrectly predicts presences. From this data it can produce two AUC (area under the receiver operating characteristic curve) values (See Figure 6).

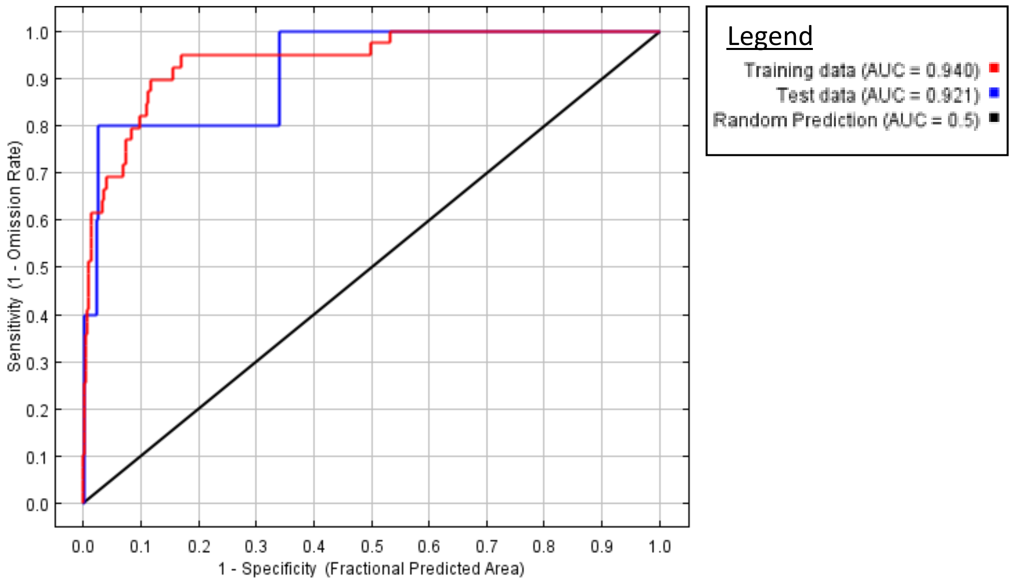

Figure 6. Sensitivity vs. 1 – Specificity of Maxent model

The two AUC curves are labelled as: Training data, which is a measure of the model's ability to distinguish between the presence and absences of the training data, and Test data, which is a measure of the model's generational ability. The values each of these curves has, can vary from 0 to 1. Should the values exceed 0.5 the model is considered more accurate than a random one. Therefore, the 0.940 and 0.921 respectively, indicate the model to be higher performing than a random one.

IBM SPSS Statistics (Version 29.0.2) was used to perform the binomial distribution test, to assess the Maxent model, with a resulting p-value of <0.0001. Meaning, it has a confidence level of 99.99%, that the correctly predicted habitat suitability is significantly higher than that of a randomly predicted model. Due to this, the null hypothesis $1H_0$ is rejected and the alternative is accepted.

5.3 Field Site Selection

Field sites with high habitat suitability, despite not having Natterjack Toad presences provide the best opportunity to understand the limitations of the model and the intrinsic mechanisms resulting in the species' absence (Muscarella et al., 2014). As such, sites which met the selection criteria were compared and it was decided that Walney island provided the ideal study area (see Figure 7).

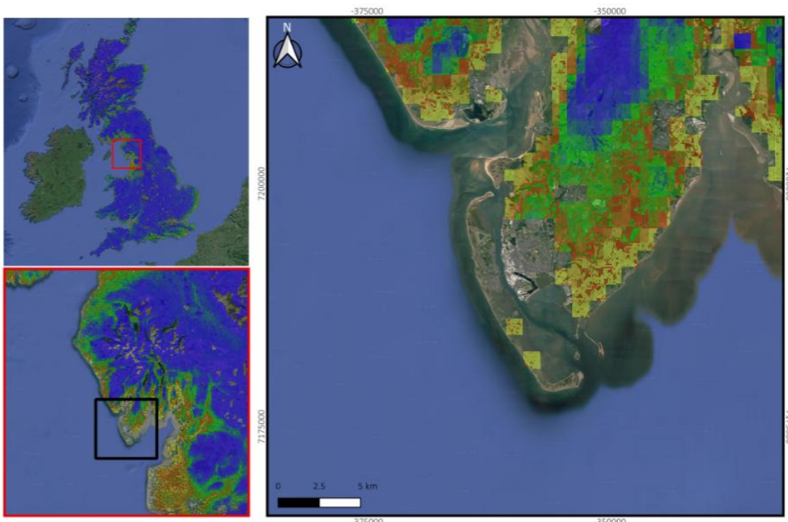

Figure 7. Maxent Species Distribution of Walney Island

The relatively large size of the island, and central town (Vickerstown) separating the north Walney, and south Walney nature reserves provides the potential for habitat diversity, and heterogeneity, making the findings from the field surveys comparable to many other sites. Moreover, their proximity provides valuable insights into the evolution of the two habitats, and how the habitat fragmentation associated with Vickerstown could have affected the survivability of the Natterjack Toad species who were once present and now extinct in south Walney (see Figure 8).

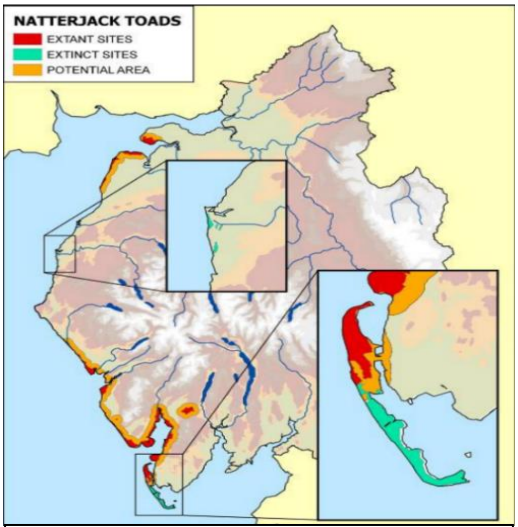

Figure 8. Distribution Map of Natterjack Toads in Cumbria. (*Source: Cumbria Biological Data Network 2010*)

The transects positions were chosen to measure comparative habitats based on satellite imagery, with the first transect points starting at the base of the first dune on the western coast of the island, they would then both move east, so that the protective qualities of the dunes could be measured against the western prevailing wind (see Figure 9).

Figure 9. Satellite imagery of Transects.

6. Field Analysis: Investigating Unexpected Natterjack Toad Locations

6.1 Climate Conditions and Dune Profile

The recorded gradient and distances between the peaks and troughs of the dunes were used to create profiles of the transects. This was done by finding the elevation gain for each point, using the measured distance from the previous point, and the angle to the next point to represent the Hypotenuse and the angle between the adjacent side, so that the opposite sides length could be calculated, using; sin (θ) = Opposite (*o*)/Hypotenuse (*h*). Which can be rearranged to; $0 = h \times \sin(\theta)$. Once the elevation and opposite side had been worked out, the Pythagorean theorem; $a = \sqrt{h^2 - o^2}$ (Adjacent = √Hyoptenuse² - Opposite²), was used to calculate the distance from each point along a flat plain so that the profile of the dunes could be mapped. (see Figures 10 and 11).

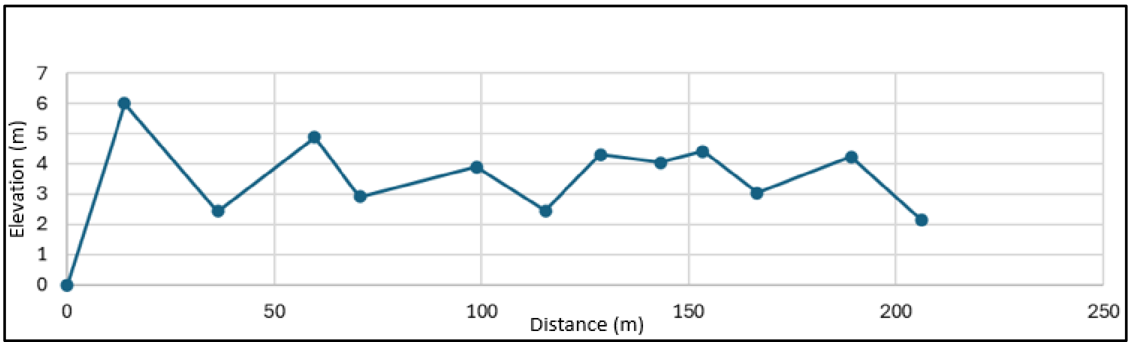

Figure 10. Sand Dune Profile of South Walney Transect

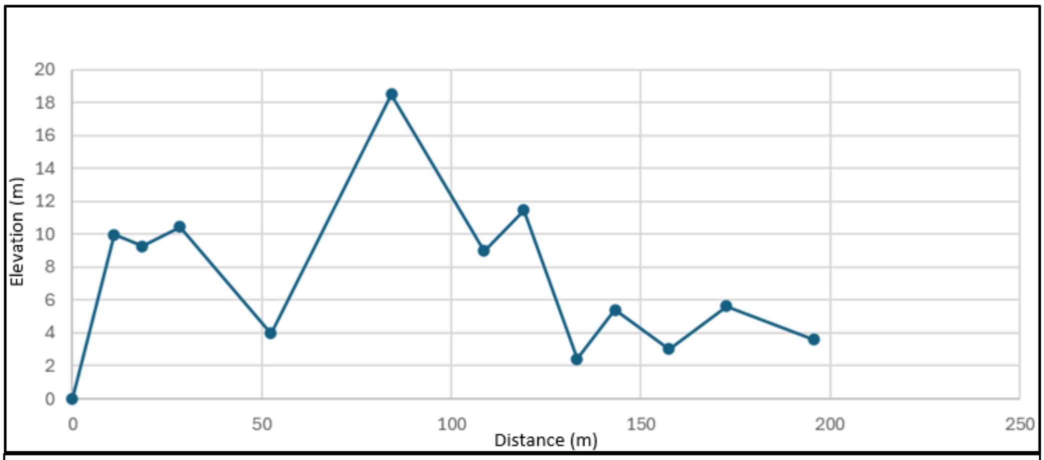

Figure 11. Sand Dune Profile of North Walney Transect

The resulting profiles depict what was experienced during the field study, which consisted of much steeper gradients, taller peaks and pronounced slacks in the northern transect, when compared to the much flatter terrain of the southern transect.

Using the kestrel anemometer the wind speed at each point was recorded (see Figures 12 and 13), so that the protective qualities of the dunes could be measured, to see if the previous points relative elevation affected the strength of the prevailing wind.

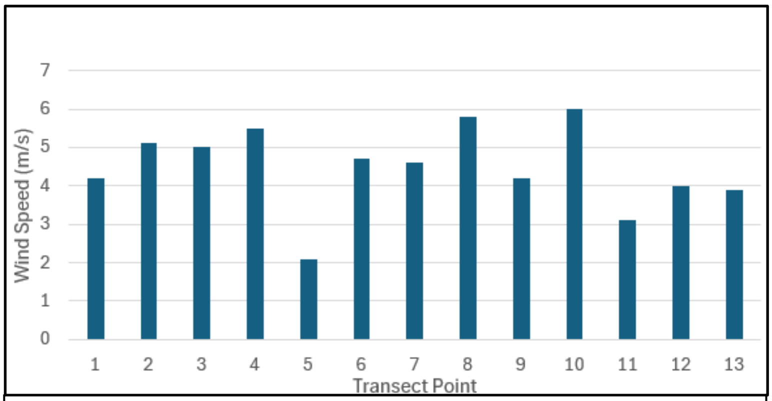

Figure 12. Wind Speed along the South Walney Transect

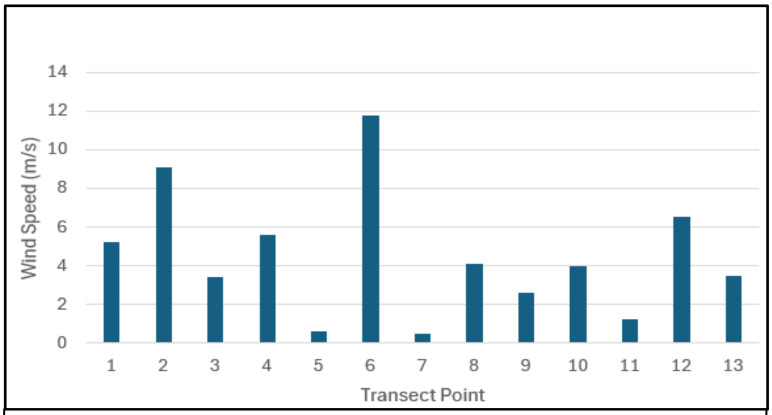

Figure 13. Wind Speed along the North Walney Transect

Figures 12 and 13 both appear to follow the same pattern, in which the peaks experience higher wind speeds when compared to troughs, and the further east the transect moves the lower the wind speeds get. Having said that there are key differences, with south Walney experiencing more consistent wind speeds, whilst north Walney experiences more drastic differences, with a maximum wind speed of 11.8m/s (6 m/s faster than the southern maximum), and a minimum wind speed of 0.5m/s (1.6 m/s slower than the southern minimum). Suggesting the larger dune peaks absorb/ deflect the wind energy, sheltering the slacks.

A paired T-test was used to measure if there was a significant difference between the wind speeds at the troughs of both transects ($t = -3.7211$, $df = 5$, and $p = 0.0137$). The low p-value means that there is a significant difference in wind speed at the troughs of both transects.

To measure if the elevation changes were to blame for such observations, the wind speed for each point was compared to the elevation of the previous point (as a measure of shelter from the wind) using R studio. Firstly, a Shapiro-Wilk test was used to test for deviations from normality, for which all variables gave a p-value of >0.05, indicating a normal distribution. To identify the association between the two continuous and normally distributed variables a Pearson's correlation test was used for both transects. Firstly, the northern transect was tested with the following results: $t = 7.99$, $r = 0.924$, $df = 11$, $p = <0.0001$. The correlation coefficient (r) represents the strength of the linear relationship between the two variables, with $r = 1$ being a perfect positive correlation and $r= -1$ being a perfect negative correlation. As such the r- value of 0.924 suggests a strong positive, linear correlation between wind and the elevation of the previous transect point. Moreover, the t-value of 7.99, paired with the 11 degrees of freedom and a p value of <0.0001 means the correlation can be considered statistically significant. Furthermore, with an r^2 value of 0.85, it can be concluded that 85% of the variability in wind speed at each transect point can be accounted for by the elevation difference of the previous point.

The results of the Pearson's correlation test from the southern transect similarly showed a positive correlation between elevation and wind ($t = 1.71$, $r = 0.458$, $df = 11$, $p = 0.115$). The t-value of 1.71, with 11 degrees of freedom and the p-value of 0.115 suggest the observed correlation is not statistically significant as it does not meet the 95% confidence interval, falling short at 88.5%. To quantify the variability in wind speed that can be explained by the elevation of the previous point, the r^2 value was calculated, it showed a value of 0.21, indicating that 21% of the wind speed can be explained by the linear relationship with the previous transects point elevation.

6.2 Soil and Vegetation Characteristics

Two soil metrics were used to measure the microhabitat conditions: ground compactness (Figures 14 and 15), relevant to the stability and ease of burrowing, and soil moisture (Figures 16 and 17), relevant to the stability of ephemeral ponds and vegetation dynamics.

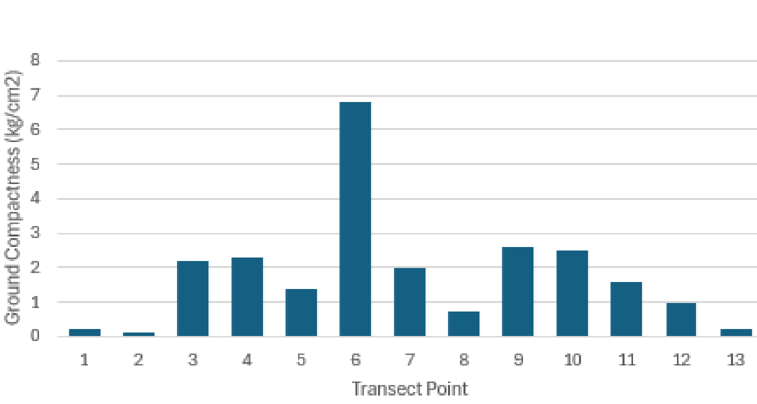

Figure 14. Ground Compactness along the South Walney Transect

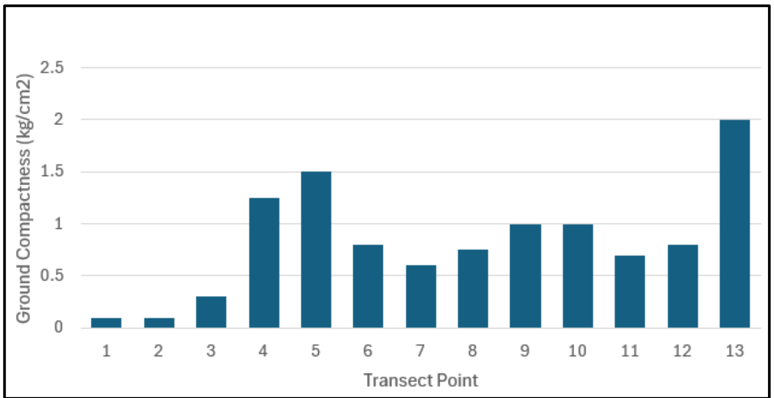

Figure 15. Ground Compactness along the South Walney Transect

Figures 14 and 15 show both sites experienced comparable ground compactness values for the first 2 transect points closest to the western coast of the island. However, as the transects progressed they both increased at different rates, with the third transect point for the south already increasing beyond the maximum value of any point in the northern transect, the average compactness for the southern transect was 1.82kg/cm², compared to the northern transect which had an average ground compactness of 0.84kg/cm² (46% of the southern average). Moreover, whilst the ground compactness for the northern transect gradually increases throughout, the southern transect reaches a peak at point 6 (6.8kg/cm²), before gradually lowering to levels comparable to the starting point for both.

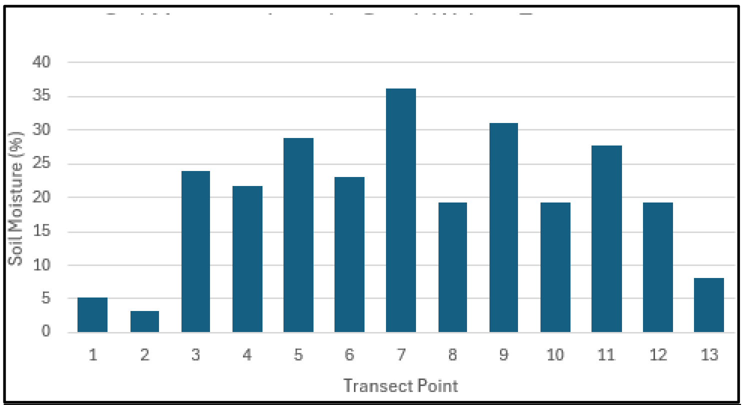

Figure 16. Soil Moisture along the South Walney Transect

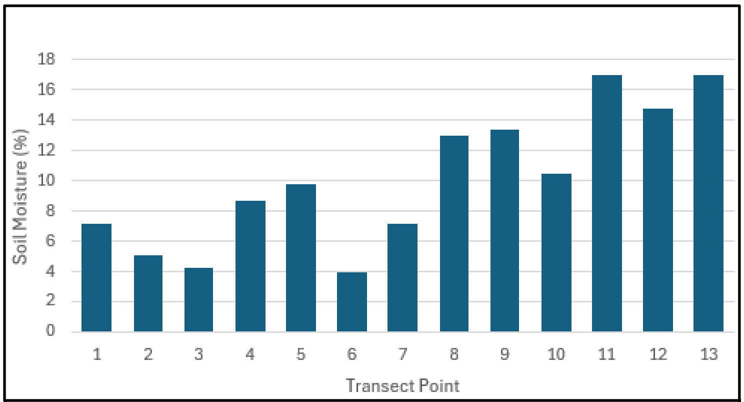

Figure 17. Soil Moisture along the North Walney Transect

Figures 16 and 17, showing soil moisture along each transect appear to experience very similar patterns to that of ground compactness, with south Walney showing a gradual increase, to a much higher peak than that of north Walney, followed by a gradual decrease. Whereas north Walney experiences a consistent gradual increase in moisture levels. However, when visualising soil moisture across the transects, the difference in moisture levels at the peaks and troughs of the transects are much more apparent, with higher moisture levels associated with troughs.

The vegetation was categorized based on their roles within the ecological succession of sand dunes, primary species were categorized by their root structures and their nature as extremophiles such as Lyme and Marram grass, which bind the littoral sediments of the dunes, providing structure and stability, whilst maintaining the soft soils associated with the burrowing activities of Natterjacks (Maun 2009). All other vegetation, characterised by its increased nutrient and carbon requirements, were classified as secondary species. The recorded vegetation densities and vegetation compositions can be seen in Figures 18 and 19.

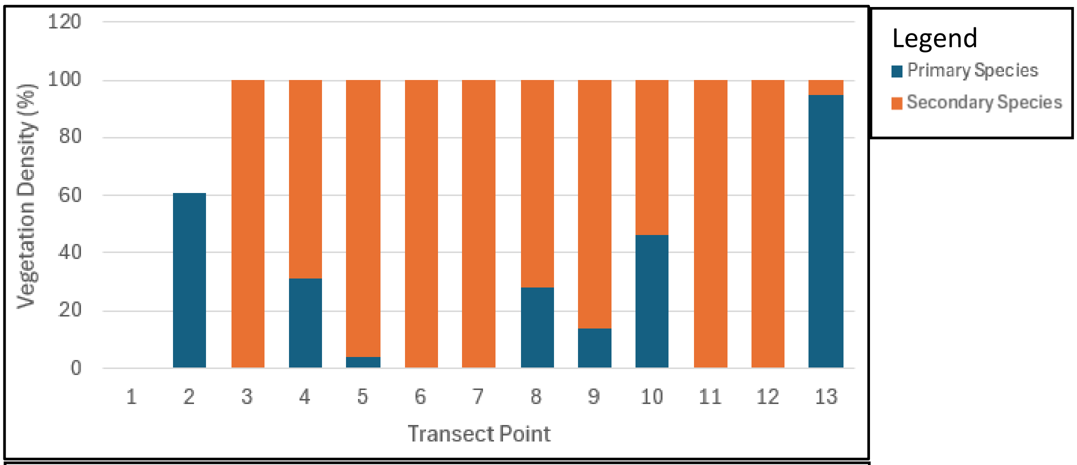

Figure 18. Vegetation Density and Composition along the South Walney Transect

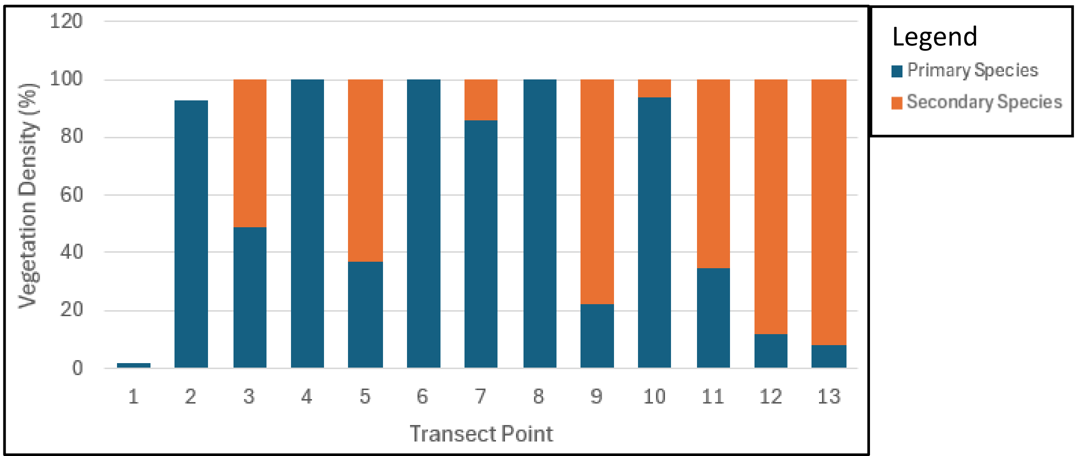

Figure 19. Vegetation Density and Composition along the North Walney Transect

Both transects showed a range of species (see appendices C and D). However, north Walney experienced higher densities of primary species overall, with secondary species gradually becoming more prominent further along the transect, in line with natural sand dune succession. In contrast, south Walney does not show signs of a gradual succession, experiencing equal to or higher densities of secondary vegetation across all but 2 transect points.

To understand the impacts secondary species could have on the soil characteristics of their respective habitats, R studio was used to conduct a two-way analysis of variance (ANOVA) test, in which soil moisture and compactness were used as the independent variables and secondary species density was used as the dependent. The results for soil moisture showed an f-value of 7.911 and a p-value of 0.0203, meaning the soil moisture is statistically significant ($p < 0.05$). Whereas the resulting f-value and p-value of ground compactness were not statistically significant ($f = 0.817$, $p = 0.554$). Moreover, the interaction effect of soil moisture and compactness had an f-value of 0.817 and a p-value of 0.390, meaning the interaction between moisture and compactness cannot be considered statistically significant.

6.3 Anthropogenic Disturbances

Anthropogenic disturbances were measured in the form of three counts: livestock, people, and litter, to compare the effects they had on their surrounding environments (see Figures 20 and 21).

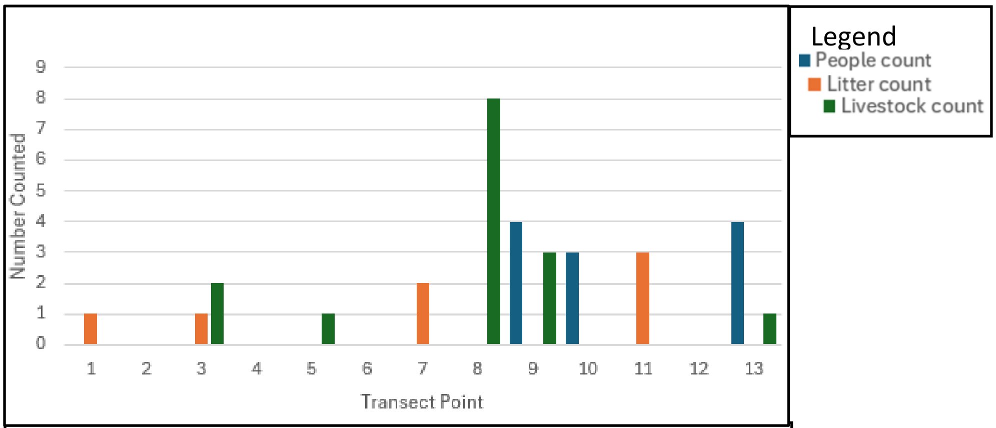

Figure 20. Anthropogenic Disturbance Counts – South Walney

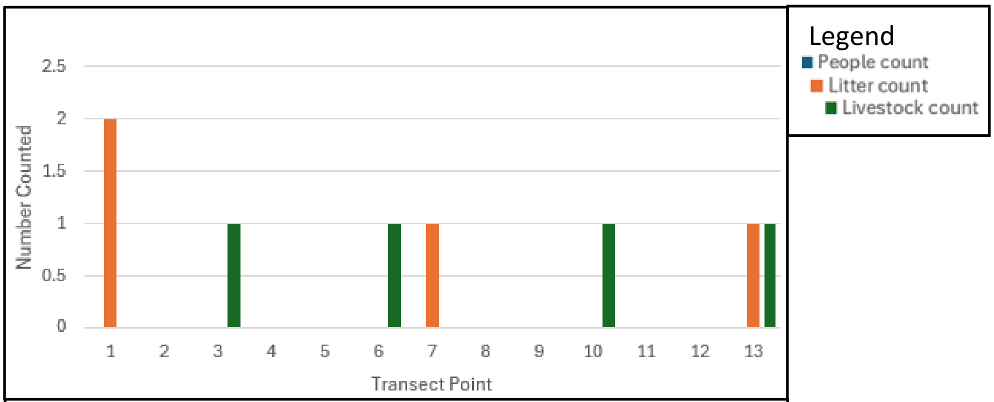

Figure 21. Anthropogenic Disturbance Counts – North Walney

Both Figures 20 and 21, appear to show a similar pattern, in that most of the anthropogenic disturbances are recorded in the troughs of the dunes, apart from a few anomalies such as the 8th transect point in the south, which recorded 8 livestock animals. However, the number of anthropogenic disturbances counted in the south far exceeds the number counted in the north in all categories, especially in terms of the people count, in which no individuals were found in the north.

Due to the nature of the interaction's livestock have on dune ecosystems, a Kendall's Tau rank correlation test was used to identify a correlation between livestock presence and secondary vegetation density in the north and south of Walney island. With a z-value of 1.592, 11 degrees of freedom and a p-value of 0.111, it can be concluded that there is no statistical significance between the livestock presence and secondary vegetation density of the southern transect, although there is a positive correlation. In contrast, the results from the northern transect showed a z-value of 2.063 and a p-value of 0.039, again with 11 degrees of freedom, meaning there is a statistically significant correlation between the two variables.

7. Discussion

7.1 Maxent Model Performance

The selected environmental variables used in the Maxent model provided a comprehensive overview of the ecological requirements associated with the Natterjack Toad. However, the variable selection could have been refined and improved further, with the addition of a few select variables. Firstly, the addition of vegetation data, such as NVDI data, could have provided further insights into the microhabitat conditions needed for Natterjacks, and affected the importance the land cover map provided, by creating continual data boundaries within the categorical data of the land cover map. Unfortunately, gaining access to such data for Great Britain proved difficult, and it was considered the land cover maps vegetation data to be sufficient. Similarly, the use of hydrological data, such as distance to water sources, has been used in many comparative amphibian studies (Dodd 2010). Unfortunately, the lack of available data meant the model ran without it, once again relying on the large water sources associated with the land cover map. Whilst the introduction of such data could have improved the model's performance, by providing a more comprehensive representation of the ecological requirements associated with Natterjacks, the introduction of too much or irrelevant data also has the possibility of increasing the models' computational requirements, and result in overfitting (Elith et al., 2006). This occurs when the model takes random fluctuations in the data into account, resulting in less accurate predictions. Moreover, given the distribution of Natterjack Toads within Great Britain, there is little evidence to suggest that distance from smaller inland sources of water would be of importance to the distribution.

However, had the model been expanded to encompass the rest of Western Europe, distance from nearby water sources would have become more important, due to their ecological ranges not being confined to coastal climates (Homan, Windmiller and Reed 2004). This would also have impacted the training data for the model, with elevation gain being less restricting to the ranges. Indeed, using spatial distribution records from European Natterjack Toads could have provided a greater understanding of inland habitats that could be restored for reintroduction programmes. However, due to the comparative genetic diversity of British and European Natterjacks being so different, it would be questionable to say that British Natterjacks are still adapted to inland environments, especially given comparable coastal areas such as south Walney have seen reducing population sizes and extinctions. Moreover, the computational requirements for predicting such a large area would have resulted in the use of larger spatial resolutions, impacting the accuracy of the model. As such it can be concluded that whilst the model does not perfectly predict favourable conditions for the European Natterjack Toad, its use in modelling the distributions of British Natterjacks is far higher.

Similarly, the lack of available absence data often poses a challenge to species distribution models, and this model is no different, and may have affected the accuracy of the Land cover map, as all the categories not containing occurrence data are treated equally, as such the proximity to urban and suburban environments may have been inflated in the results. Moreover, many urban areas, including major cities were removed from the geographical ranges of the model, due to the requirements for all the environmental layers to have the same geographical dimensions when running a Maxent model, which could have influenced the results.

Overall, it could be argued that the selection of environmental variables used in the model could have been improved. However, the accuracy of the results when compared to a random model, suggest a very high performing model. According to Jiang et al., (2018) models with AUC values of between 0.5 and 0.7 are considered poor performing, whereas models with AUC values between 0.7 and 0.9 indicate moderate performance, and any AUC values above 0.9 indicate high performance. Therefore, the 0.940 and 0.921 respectively, indicate the model to be of high performance and accuracy. This is supported by the $p<0.0001$ value given from the binomial distribution test, which showed the amount of correctly predicted habitat suitability was far higher than that of a random model.

7.2 Climactic Conditions and Dune Profile

Due to the proximity of north and south Walney, both sites experience very similar temperature, precipitation patterns and prevailing wind direction. However, the structural differences associated with dune profiles could impact wind speeds and alter microclimatic conditions (Masselink and Gehrels 2014). The variation in wind speeds at the troughs of the dunes between the two sites was shown to be statistically significant using a paired t-test with a p-value of 0.0137, confirming that the physical habitat characteristics could be impacting wind speeds at these troughs. To measure if the relative elevation gain or loss from the previous transect point influenced wind speed - and therefore the profile - a Pearson's correlation test was used for each sites data. The results from the northern site revealed a statistically significant correlation between the previous transect points elevation and the wind speed of the next. Moreover, the r^2 value of 0.85 meant that 85% of the variability in wind could be accounted for by the previous points elevation. In contrast, the results for the southern site sowed a p-value of 0.115, which whilst not meeting the 95% confidence interval to be considered statistically significant, does show the same pattern. However, with an r^2 value of just 0.21, only 21% of the wind speed in south Walney can be associated with the elevation of the previous transect point. However, that does not mean the dune profile is not to blame for such observations, as surrounding elevation changes, or lack thereof, paired with vegetation changes could be impacting the direction of wind currents, posing challenges to the usefulness of 2D landscape profiles, especially in landscapes that don't experience comparable elevational changes to north Walney. Nonetheless, it is evident from the results in north Walney that the hight of the peaks and depth of the slacks greatly influences the wind speed in the microclimates of sand dunes.

The increased wind speeds associated with the relatively unprotected troughs of south Walney pose many challenges to the Natterjack Toad, especially given the strong winds associated with coastal prevailing winds (Komar 1977). Firstly, strong winds can create habitat fragmentation, in the form of barriers to movement, such as blowouts of unstable dunes (Durán and Moore 2013), restricting movement between breeding and foraging sites, and isolating populations (Fahrig 2003). These blowouts also destabilise the landscape, and uproot keystone species like marram grass, affecting burrowing availability and vegetation cover, and thus safety from predators and climactic conditions (Maun 2009). Secondly, there is a desiccation risk associated with wind speeds, as higher wind speeds result in higher evaporation rates (Monteith and Unsworth 2013). This loss of moisture can result in the loss, or reduction in size of the ephemeral ponds needed for breeding (Beebee 1995), as well as increasing energy expenditure, not only in travelling to, and competing for new breeding sites, but also through maintaining skin hydration (Reading 2007).

7.3 Soil and Vegetation Characteristics

As previously alluded to, Natterjack Toads require very specific soil conditions to support their burrowing activities (Beebee 1996). Studies have shown that compacted soils increase the resistance, and energy expenditure of burrowing amphibians (Semlitsch and Bodie 2003). Given the higher ground compactness associated with south Walney, the availability of stable, uncompacted soils could be a limiting factor in the distribution of Natterjack Toads. Furthermore, these compacted soils could be posing limitations to percolation rates and soil oxygen availability of the site (Hillel 2003), impacting both the organisms that live in the soils and the habitats vegetation diversity, as shown by the relatively high secondary vegetation densities of south Walney when compared to north Walney.

Additionally, it is also possible for these differences in vegetation to affect soil composition, due to their structural characteristics, (Wardle et al., 2004). Whilst species like marram grass have deep root layers linked by rhizomes – which stabilise the structure of the dunes -, and long curved leaves used to collect new sediment seasonally, increasing the dune profile (Maun 2009), other species blanket the ground, reducing the levels at which new sediment is collected, as well as gradually increasing soil carbon concentrations, associated with species further along the sand dune succession process, resulting in a positive feedback loop (Carter and Woodroffe 1994). This increase in carbon concentration can enlarge the spaces between soil particles, increasing water retention and moisture levels (Six et al., 2004). This correlation between soil moisture and compactness on plant diversity was shown by the p-value of 0.390, as part of the ANOVA test, which whilst not showing a statistical significance, does show the same correlation. Moreover, the results from the ANOVA test measuring the correlation between soil moisture and vegetation density of such species was shown to be statistically significant.

Whilst both sites have secondary and primary vegetation, the distribution patterns of these species could be impacting habitat suitability. In line with general sand dune progression, north Walney showed increased secondary vegetation densities and moisture levels in the troughs of the dunes, which due to the high percolation rates of the soils associated with the dune peaks, can result in these troughs acting as water collection points, which once saturated can form the ephemeral ponds suitable for Natterjack breeding (Mack 2003). In contrast, south Walney showed continually high secondary species densities, meaning it would take a much larger quantity of water to saturate the soils, and so limit the number of ephemeral ponds and their seasonal presence (Bendix and Hupp 2000).

Overall, the data shows clear evidence that there is a significant difference between the environmental factors at north Walney and south Walney. Therefore, the null hypothesis $2H_0$ is rejected and the alternative is accepted.

7.4 Anthropogenic Disturbance

If these physical characteristics are to blame for the extinction of Natterjack Toads in South Walney, it is important to know what caused this divergence from the historical sand dune habitats, whether it was natural sand dune succession, or if the higher levels of anthropogenic disturbances were to blame. The Kendall's Tau rank correlation test in north Walney showed a statistically significant difference in the vegetation dynamics in areas where livestock were found, whilst the test in south Walney showed the same correlation. It is possible that such correlations may not be due to the impact the livestock has had in Walney island, and instead show the selective nature of livestock for secondary plant species (Milchunas and Lauenroth 1993). However, over time livestock will add to the carbon content of the soils, through defecation and eventual death (Conant, Klopatek and Klopatek 2000). These carbon rich soils will be more suitable to secondary species and result in premature succession (Güsewell 2004). Similarly, the damages to keystone species like marram grass, through grazing and trampling of the dunes, could result in instabilities and eventual blowouts of the dunes (Maun 2009) resulting in smaller dune profiles, and as previously mentioned, less protection to the dunes microhabitats (Adam 1993). It is therefore possible that whilst North Walney is currently suitable for Natterjacks, that given time, the grazing activities of livestock in the area could destabilise the sand dunes.

Similarly, whilst no people were sited in north Walney, the presence of litter suggests that people do visit the area. Although not to the same degree as south Walney, this human presence could have similar effects to livestock with regards to the trampling effect of the dunes, as well as increasing pollutants through various activities. Moreover, north Walney Nature Reserve is open 24hrs a day, and requires no entrance fee. In contrast, south Walney Nature Reserve is open 7hrs a day, and has an entrance fee of £3 per person. Such business practices could provide capital that could be used for the conservation efforts in south Walney. Although, due to the proximity of the sites, they could also result in more people visiting the northern site, leading to increased degradation in the north. As such a holistic approach to both sites should be considered, as their sustainability could be linked.

7.5 Field Work Limitations

Most of the field work limitations arose due to the time constraints of the study. Taking one day to take all the measurements meant both sites were studied at different times, with south Walney being studied earlier in the day, due to the opening times of the site, and north Walney being studied later. This could have impacted the climate conditions affecting the study. Fortunately, there was no precipitation at either site during the study. However, temperature changes, as well as the time delay since it last rained, could have affected the soil moisture (Western, Grayson, and Blöschl 2002), as well as human activities.

On the other hand, had time not been a limiting factor, taking measurements for each transects on separate days could have resulted in greater climactic variations. As such, a multi-day study taking measurements simultaneously at each transect would have provided better comparisons. Although, due to equipment and personnel limitations that would not have been possible and could have resulted in discrepancies in data collection techniques, and therefore reliability. A multi-day study taking results over a large space of time, in different seasonal conditions could have also provided more reliable data, and assuming the same limitations to equipment and personnel, conducting fieldwork at the sites, at alternating times of day cyclically could have been a better option.

Another limitation to the study, was the two-dimensional nature of the transects, which despite aiming to encompass the heterogeneity of the habitats, lacks in its holistic representation. As shown by the inability to show statistical significance of elevation on wind speeds in the southern transect. Multiple transects at each site could have given a better overview, although time would have still been a factor. Had a 3-dimensional modelling system been available for in-situ data collection, this could have provided a more accurate representation of the differences between the habitats.

7.6 Implications for Habitat Management and Conservation

The findings from this study highlight the need for holistic conservation and management efforts to target ecosystem health. Firstly, the impact anthropogenic factors have on Walney are evident, as such the agricultural practices on the island will have to be re-evaluated, taking all stakeholders into account. Secondly the accessibility of both sites should be considered, limiting encroachment through restricted accessibility to vulnerable sites, and providing habitat connectivity between the two sites. Moreover, the restoration of sand dunes, vegetation and dune profiles is crucial for increasing the habitat suitability of south Walney. Measures such as revegetation of native plants, with sand fencing and trapping techniques can be used to promote natural dune formation. Furthermore, this study highlights the need for more publicly available environmental data for habitat modelling, so that more comparative, rigorous studies can be conducted.

7.7 Future Research Directions

Future research of Walney Island should prioritise environmental monitoring efforts, using metrics such as the health and dynamics of ephemeral ponds and dune profiles as environmental indicators. The data from this study could also be supported with further maxent models and field analyses. Within the wider context of Natterjack Toad conservation, comparative studies on the genetic profiles, and evolutionary dynamics of European and British Natterjack Toads, could provide further insight into environmental requirements, with implications for future introduction programmes, and genetic baseline data.

Further refinement of the methods, and capabilities of species distribution modelling, incorporating more environmental variables and more accurate data could be approached. Research into the use and training of AI run models could be used to develop many more comparative models, overcoming the limitations of human-run models, such as time and financial constraints.

8. Conclusion

The maxent modelling approach to this study provided valuable insights into the habitat suitability, and ecological factors affecting Natterjack Toad distributions in Great Britain. It highlighted the needs for more publicly available data, and the uses species distribution modelling can have in conservation. It also showed the importance of field research in supporting these results and measuring the usefulness of the models.

Findings from the field surveys underscored the issues with such models, and the effects anthropogenic disturbances, and habitat fragmentation have on Natterjack Toads. As well as the importance of conservation and restoration efforts of coastal ecosystems, particularly sand dunes, and the ephemeral ponds, which serve as critical breeding and foraging habitats.

Overall, this study provides the foundation for informed conservation and management strategies. Whilst emphasising the need for holistic approaches to conservation and collaboration between researchers and stakeholders. It also provides the basis and opportunity for further research into Natterjack Toad ecology, and the uses of species distribution modelling in informing conservation actions and policymaking.

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10. Appendices

10.1 Appendix A; Environmental Variables used in Maxent Model

Variable	Data Format	Data Source
Topsoil carbon concentration	Vector	NERC Environmental Information Data Centre
Topsoil pH levels	Vector	NERC Environmental Information Data Centre
Topsoil moisture levels	Vector	NERC Environmental Information Data Centre
Annual mean temperature	Raster	WorldClim 2.1
Temperature seasonality	Raster	WorldClim 2.1
Temperature annual range	Raster	WorldClim 2.1
Annual precipitation	Raster	WorldClim 2.1
Precipitation seasonality	Raster	WorldClim 2.1
Precipitation of driest quarter	Raster	WorldClim 2.1
Precipitation of wettest quarter	Raster	WorldClim 2.1
Isothermality	Raster	WorldClim 2.1
Elevation	Raster	WorldClim 2.1
GB Land cover map 2021	Raster	EDINA Environmental Digimap Service

10.2 Appendix B; Land cover map classes

Land Cover Class	Description
Broadleaved Woodland	Broadleaved woodland is characterised by either mixed or yew woodland ecosystems. To be included tree cover must be above 20% with a height of over 5m. Or a tree cover of over 30%, with a canopy height of less than 5m.
Coniferous woodland	These are characterized by semi-natural woodland populations with a land cover of over 20%
Arable and Horticulture	This is a broad category encompassing, annual crops, perennial crops, and recently ploughed land.
Improved Grassland	Improved grassland experiences higher productivity than semi-natural grasses and does not experience the same seasonal degradation.
Neutral Grassland	Contains semi-improved grasslands used for arable practices such as silage.

Calcareous Grassland	Grasslands which form on soils with alkaline conditions.
Heather; and Heather grassland	Land where the heather cover is above 25%.
Fen, Marsh, and Swamp	This class contains, fen, fen meadows, rush pasture, swamp, flushes, and springs. Due to detection issues, it is possible the size of this category is undervalued.
Bog	Contains, ericaceous, herbaceous, and mossy swards in areas with a peat depth of over 0.5m.
Saltwater	Predicted using RF classifier from context raster's.
Freshwater	Water bodies are mapped with varying accuracy based on the size of the body (larger bodies are more accurate).
Inland Rock	Characterized by exposed rock surfaces larger than 0.25 ha.
Urban; and Suburban	Urban is characterised by dens urban environments like city centres, with little vegetation cover, whereas suburban experience a mix.
Supralittoral Rock	Coastal class including vertical rocks, boulders, and cliff faces.
Supralittoral Sediment	Characterized by sand dunes, which can stabilise, supporting vegetation.
Littoral Rock	Characterised by rocky coastlines within maritime zones
Littoral Sediment; and Saltmarsh	Littoral sediment is comprised of sediment of any combination within an intertidal zone, it differs from supralittoral due to its lack of vegetation support. Whereas, a saltmarsh is an area of coastal vegetation which is flooded by seawater.

10.3 Appendix C; Raw Data for South Waney

Transect point	1	2	3	4	5	6	7	8	9	10	11	12	13
Wind Speed (m/s)	4.2	5.1	5	5.5	2.1	4.7	4.6	5.8	4.2	6	3.1	4	3.9
Ground Compactness (kg/cm2)	0.2	0.1	2.2	2.3	1.4	6.8	2	0.7	2.6	2.5	1.6	1	0.2

Distance to next point (m)	15.2	22.8	23.4	11.2	28.1	16.7	13.4	14.5	10.2	13.1	22.8	17.2	0
Gradient to next point (°)	23	-9	6	-10	2	-5	8	-1	2	-6	3	-7	0
Soil Moisture (%)	5.2	3.3	23.9	21.7	28.9	23.1	36.2	19.2	31.1	19.2	27.8	19.2	8.2
People count	0	0	0	0	0	0	0	0	4	3	0	0	4
Litter count	1	0	1	0	0	0	2	0	1	0	3	0	0
Livestock count	0	0	2	0	1	0	8	0	3	0	2	0	1
Vegetation Density (%)	0	61	100	100	100	100	100	100	100	100	100	100	80
Vegetation Diversity	0	1	3	7	6	4	4	5	5	4	6	4	3
Primary Species	0	1	0	2	1	0	0	2	1	1	0	0	2
Primary Species Density (%)	0	100	0	31	4	0	0	28	14	46	0	0	95

10.4 Appendix D; Raw Data for North Waney

Transect point	1	2	3	4	5	6	7	8	9	10	11	12	13
Wind Speed (m/s)	5.2	9.1	3.4	5.6	0.6	11.8	0.5	4.1	2.6	4	1.2	6.5	3.5
Ground Compactness (kg/cm2)	0.1	0.1	0.3	1.25	1.5	0.8	0.6	0.75	1	1	0.7	0.8	2
Distance to next point (m)	14.8	7.6	9.9	24.9	35	26.2	10.8	16.7	10.4	14.4	15.4	23.3	0
Gradient to next point (°)	41	-5	7	-15	25	-22	13	-34	18	-10	9	-5	0
Soil Moisture (%)	7.2	5.1	4.3	8.7	9.8	4	7.2	13	13.4	10.5	17	14.8	17
People count	0	0	0	0	0	0	0	0	0	0	0	0	0
Litter count	2	0	0	0	0	0	1	0	0	0	0	0	1
Livestock count	0	0	1	0	1	0	0	0	1	0	0	0	1

Vegetation Density	2	93	100	100	100	100	100	100	100	100	100	100	100
Vegetation Diversity	1	1	3	1	3	2	2	1	3	2	4	3	4
Primary Species	1	1	1	1	1	2	1	1	1	1	2	1	1
Primary Species Density (%)	100	100	49	100	37	100	86	100	22	94	35	12	8

10.5 Appendix E; Ethics Form

School of Animal, Rural and Environmental Sciences
Environmental Ethics Level 1 Checklist Form

UG and PG projects ONLY

Complete the following questions on this page concerning the project. You must complete all questions. The *yes* column tick marks have been included to help you complete the form electronically: either keep the tick in the *yes* column or move the tick to the *no* column as you answer each question. Once all questions have been answered, you should undertake the corresponding action outlined at the bottom of this page.

Name and student N number: Sergi Bernat i Denny (N0898457)

Supervisor: Alex Dittrich

Project Title: Investigating Natterjack Toad (*Epidalea calamita*) Habitats in Great Britain: Maxent predictions and Field Analysis

	Yes	No
Does the study require licences or specific permissions for use of designated or protected sites or materials (e.g. Sites of Special Scientific Interest (SSSIs), Special Areas of Conservation (SACs), Special Protection Areas (SPAs), Nature Reserves, Areas of Outstanding Natural Beauty (AONBs) National Parks, Ramsar Sites)?		✓
Does your study require access to private land for which permission will **not** be sought?		✓
Does your study involve the release of any substance into the environment that is not naturally present, or at unnaturally high volumes, concentrations?		✓
Does your study involve the release into the environment of any animal (if yes please complete animal ethics checklist), plant or other organism previously taken off site (e.g. samples taken to the laboratory and then returned)?		✓
Does your study involve the release into the environment of any pollutant at intensities which may cause public nuisance or ecological disruption (e.g. light, noise)?		✓
Does the research include the removal from the environment of any animal (if yes, please complete animal ethics checklist), protected plant, or a quantity of material likely to cause public nuisance?		✓
Does the study include the removal from the environment of any substance likely to cause disruption to the environment or nuisance for users of that environment?		✓
Does the project involve manipulation of any habitat, including any waters, at an intensity likely to cause more than momentary disruption?		✓
To the best of your knowledge, will the project cause any negative environmental consequences?		✓

If you have answered YES to any of the above questions above this project will be considered Level 2. You should complete the ethics review form on Worktribe.

If you have answered NO to all questions this project will be considered Level 1. Please complete the second page of this document.

Outline of basic methodology (to ensure compliance):

Conduct 2 Transects, one in the south and one in the north of Walney Island, in order to measure sand dune progression, ecosystem dynamics and suitability of the ecosystem to the Natterjack Toad.

The Transects shall measure the following:

- Litter count.
- Number of people, dogs and farm animals passing each point within a 2min time frame.
- Ground compactness using Longchamp penetrometer.
- Soil moisture using FieldScout TDR Soil Moisture meter.
- Wind speed measured by Kestrel anemometer.
- Distance from peaks and troughs measured by Clinometer.
- Vegetation diversity and density measured using Quadrat sampling.

Signature of applicant: Sergi Bernat i Denny

Signature of supervisor: Alex Dittrich

Date: 7th Feb 2024

This form must be signed and dated by the student and supervisor. The student must submit the completed form with the supervisor's signature to the relevant module dropbox. By signing this form, the staff member indicates that they agree with its content. If anything changes, it is the supervisor's responsibility to notify the ethics committee and take the appropriate steps. The ethics committee has not assessed the project. It is the responsibility of the supervisor to ensure the project meets the levels of research integrity expected by the University and set out in the Code of Practice for Research, accessible here.

10.6 Appendix F; Risk Assessment

1. Risk Assessment

Risk Assessors Name	Sergi Bernat i Denny
Accountable Managers Name	Alex Dittrich
Date of Completion	
Location	Walney Island
Task, Process or Activity Description	Multiple Transects
Persons at Risk – Affected Groups	Sergi Bernat i Denny

Ref	Potential Hazard	Existing Controls	Impact	Likelihood	Risk Level	Additional Controls Required	Impact	Likelihood	Risk Level
1	Uneven terrain and ground conditions	Use of appropriate protective clothing and footwear	2	3	6	Conduct site assessment prior to transect setup	2	2	4
2	Negative encounters with people and dogs	Establish clear communication with local community	1	2	2				
3	Potential conflicts with farm animals	Caution/appropriate distance around farm animals	2	2	4	Limit sudden movements to avoid spooking them	2	1	2
4	Unsafe use of measuring equipment	Training on safe and proper use of equipment	1	2	2	Regular maintenance and calibration of equipment	1	1	1
5	Exposure to variable weather conditions	Monitoring weather forecasts	2	3	6	Appropriate clothing selection availability taken to site	1	3	3
6	Non-compliance with SSSI regulations	Minimal impact methodology	1	1	1	Careful movements avoiding environmental damage	1	1	1

2. Actions Required

Ref	Action to be taken	Action Owner	Date to be completed	Actual Completion Date
1				
2				
3				
4				
5				
6				

This risk level has been reduced as low as is reasonably practicable

3. Approval and Change Log

		Date
Assessors Signature	Sergi Bernat i Denny	7th Feb 2024
Managers Signature	Alex Dittrich	7th Feb 2024

Review Number	Description of any changes	Date of Review	Assessors Name	Manager Name
1st Review				
2nd Review				
3rd review				
4th Review				
5th Review				

4. Risk Matrix

LIKELIHOOD	Chance	Probability	Time period
Likely (Score 4)	More than 75%.	More likely than not to occur.	Likely to occur at least once in a three-month period.
Possible (Score 3)	40-75%.	Fairly likely to occur.	Likely to occur once in a one-year period.
Unlikely (Score 2)	10-40%.	Has happened before, but unlikely again.	Unlikely to occur in a one-year period.
Rare (Score 1)	Less than 10%.	Has never happened before.	Unlikely to occur in a five-year period.

IMPACT	Safety
Minor (Score 1)	Minor incident causing injury possibly requiring first aid treatment/ disease to one or more persons.
Serious (Score 2)	Significant injury could result in short term absence from work / disease causing short-term issue to one or more persons.
Major (Score 4)	Major injury possibly requiring hospital attention / disease causing long-term issue / disability to one or more persons.
Extreme (Score 6)	Fatality or life-threatening injury / disease to one or more persons.

		Impact			
		Minor (Score 1)	Serious (Score 2)	Major (Score 4)	Extreme (Score 6)
Likelihood	Likely (Score 4)	4 – Acceptable but keep under review	8 – Consider implementing additional controls to reduce the risk	16 - Risk is unacceptable and additional controls MUST be implemented	24 – Risk is unacceptable and additional controls MUST be implemented
	Possible (Score 3)	3 - Acceptable but keep under review	6 - Consider implementing additional controls to reduce the risk	12 - Consider implementing additional controls to reduce the risk	18 - Risk is unacceptable and additional controls MUST be implemented
	Unlikely (Score 2)	2 - Acceptable but keep under review	4 - Acceptable but keep under review	8 - Consider implementing additional controls to reduce the risk	12 - Consider implementing additional controls to reduce the risk
	Rare (Score 1)	1 - Acceptable but keep under review	2 - Acceptable but keep under review	4 - Acceptable but keep under review	6 - Consider implementing additional controls to reduce the risk

5. Sharing the Risk Assessment

All Risk Assessments should be shared with the people listed in the persons affected section (section 1). There is a signing sheet available within the resources section of the H&S Sharepoint.