Cyfoeth Naturiol Cymru
Natural Resources Wales

Spatial Conservation Status Modelling of the Great Crested Newt in South Wales

Fletcher DH, Arnell AP, French GCA and Wilkinson JW
Amphibian and Reptile Conservation Trust

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Mae’r astudiaeth hon yn adeiladu ar waith modelu gofodol blaenorol, yng Ngogledd Cymru a Phowys, ar gyfer y fadfall ddŵr gribog. Mae’r ymchwil yn defnyddio modelu cydraniad uchel (25m) i ddatblygu mapiau a metrigau ar gyfer madfallod dŵr cribog mewn 12 Awdurdod Unedol yn Ne Cymru (Blaenau Gwent, Pen-y-bont ar Ogwr, Caerffili, Caerdydd, Merthyr Tudful, Sir Fynwy, Castell-nedd Port Talbot, Casnewydd, Rhondda Cynon Taf, Abertawe, Bro Morgannwg a Thorfaen). Mae amcanion y prosiect yn cynnwys asesu: i) dosbarthiad hysbys, ii) cynefin addas, iii) ardaloedd targed ar gyfer arolygon, iv) poblogaethau pwysig o ran cysylltiad rhwng metaboblogaethau, v) ardaloedd creu pyllau dŵr/cynefin a vi) Targedau Poblogaeth Leol ar gyfer pob awdurdod unedol.

Casglwyd cofnodion cydraniad uchel diweddar (1990-2011) ar gyfer madfallod dŵr cribog ac, ar ôl eu glanhau, defnyddiasom 149 i gynrychioli poblogaethau hysbys. Defnyddiasom feddalwedd modelu dosbarthiad MaxEnt, ynghyd â 24 haen amgylcheddol, ac is-set o 108 o gofnodion wedi’u hidlo ar sail ofodol, i gynhyrchu amcangyfrif o’r tebygolrwydd o allbwn presenoldeb. Ar sail yr allbwn hwn, a rhwystrau hysbys, cawsom arwynebedd gwrthiant i gyfrifo pellteroedd Llwybr Cost Leiaf a choridorau rhwng poblogaethau hysbys. Rhedwyd meddalwedd theori graff, Conefor, â’r pellteroedd hyn i gynhyrchu mynegrifau tebygolrwydd o gysylltiad (dPC) er mwyn amlygu poblogaethau pwysig ar gyfer cynnal cysylltiad rhwng metaboblogaethau. Er mwyn amffinio ardaloedd targed creu pyllau dŵr, dewisasom ardaloedd â dwysedd pyllau isel o fewn cynefin addas wedi’i fodelu ac o fewn dynodiad Cynllun Datblygu Unedol priodol. Pennwyd ffigurau targed poblogaeth leol i leihau effeithiau colli pyllau dŵr tybiedig yn y gorffennol ym mhob awdurdod unedol, gan ddefnyddio 1843 fel dyddiad cyfeiriol, cyfraddau colli pyllau dŵr lleol a data cyfredol am byllau dŵr. Dosrannwyd y targedau hyn i ardaloedd creu pyllau dŵr priodol o fewn byfferau wedi’u pwysoli ar sail cost o amgylch poblogaethau hysbys, neu o fewn coridorau rhyngddynt.

Cynhyrchodd profion model MaxEnt werthoedd derbyniol o uchel (>0.7) ar gyfer yr ardal o dan y gromlin nod gweithredu derbynnydd (ROC). Gan nad oedd llawer o gofnodion mewn Awdurdodau Unedol unigol, adeiladwyd a phrofwyd y model MaxEnt â chofnodion o bob un o’r 12 Awdurdod Unedol

Cynhyrchodd y Targedau Poblogaeth Lleol argymelledig ar gyfer creu pyllau dŵr ffigurau realistig a chyraeddadwy (<10 pwll dŵr ym mhob cilometr sgwâr), pan gawsant eu dosrannu i ardaloedd targed priodol, ar gyfer y rhan fwyaf o’r Awdurdodau Lleol. Fodd bynnag, ychydig iawn o ardaloedd sydd ar gael mewn rhai Awdurdodau Lleol ac mae hynny’n dangos bod angen cynllunio gofodol rhanbarthol er mwyn gwella a chynnal statws madfallod dŵr cribog yn Ne Cymru.

2. Executive Summary

This study builds on previous work, in North Wales and Powys, on the spatial modelling of the great crested newt. This research utilises high resolution (25m) modelling to develop maps and metrics for great crested newts in 12 South Wales Unitary Authorities (Blaenau Gwent, Bridgend, Caerphilly, Cardiff, Merthyr Tydfil, Monmouthshire, Neath Port Talbot, Newport, Rhondda Cynon Taff, Swansea, The Vale of Glamorgan and Torfaen). Project aims include assessing: i) known distribution, ii) suitable habitat, iii) survey target areas iv) important populations for metapopulation connectivity, v) pond/habitat creation areas and vi) Local Population Targets (LPTs) for each unitary authority.

We compiled high resolution, recent (1990-2011) great crested newt records and, after cleaning, used 149 to represent known populations. We used the distribution modelling software, MaxEnt, along with 24 environmental layers and a subset of 108 spatially filtered records, to produce an estimated probability of presence output. From this output, and known barriers, we derived a resistance surface for calculating Least Cost Path distances and corridors between known populations. We ran graph theory software, Conefor, with these distances to produce probability of connectivity indices (dPC) to highlight important populations for maintaining metapopulation connectivity. To delimit pond creation target areas, we selected low pond density areas within modelled suitable habitat and within an appropriate Unitary Development Plan (UDP) designation. We set local population target figures to mitigate putative historical pond losses in each unitary authority, using a reference date of 1843, local pond loss rates and current pond data. We apportioned these targets to appropriate pond creation areas within cost weighted buffers surrounding known populations, or within corridors between them.

MaxEnt model testing produced acceptably high values (>0.7) for the area under the receiver operating characteristic (ROC) curve. Due to limited record numbers in individual Unitary Authorities, we built and tested the MaxEnt model with records from all 12 Unitary Authorities

The recommended Local Population Targets for pond creation produced realistic and achievable figures (<10 ponds per square km), when apportioned to appropriate target areas, for most Local Authorities. However, some LAs have only negligible areas available indicating the need for regional spatial planning in order to enhance and maintain great crested newt status in South Wales.

3. Introduction

Wales has failed to meet both its own biodiversity targets and those of EU 2010 (National Assembly for Wales Sustainability Committee, 2011). The recent report on biodiversity in Wales (ibid.) recommends (among many other things) that new, accountable and enforceable biodiversity targets are established by the end of 2011. Development of local FCS concepts for European Protected Species (EPS) like the great crested newt will contribute to these targets through exploration of habitat creation in the context of local Unitary Development Planning (UDP). This approach also aims to provide tangible targets for informing public decision making.

This project follows on from other recent attempts to describe the status of great crested newts (*Triturus cristatus*) in Wales (ARC and Cofnod, 2010, Arnell and Wilkinson, 2011), Scotland (Wilkinson et al., 2014), England and the UK (Wilkinson et al., 2011), and to apply the concept of Favourable Conservation Status (FCS). This concept essentially involves determination of current status in terms of (i) range, (ii) population, (iii) habitat and (iv) future prospects for a given species in a given area, and assessment of whether or not this status is "favourable" by establishing Favourable Reference Values (FRVs) for these elements of FCS. FCS is at the heart of the European Habitats Directive (Directive 92/43/EEC). The concept is further developed here by finer-scale examination of great crested newt presence in an area, or likelihood of presence, habitat suitability and connectivity, target areas for survey and habitat/pond creation, and restoration of FCS; the ultimate goal being to develop draft Spatial Conservation Status Strategies for great crested newts in the 12 Unitary Authorities that make up the study area. The overarching concept will enable current and favourable conservation status to be defined at country, county and site levels. This is consistent with the application of Conservation Objectives for Natura 2000 sites being based on FCS at site based levels. It also ensures consistent and transparent assessment of land management and land use change at local (county/site) levels.

Specifically, the aim of this project is to develop a "tool kit" for local planners that is informative of great crested newt presence and the relative importance of populations and habitat in the context of UDPs. This tool kit includes spatially-explicit information in the form of GIS-based mapping (layers) and spreadsheets that will inform conservation priorities and action, land-use planning and other things such as derogation licensing. With better information on these elements, the FCS of great crested newts should be more easily restored at local level, contributing to an overall improvement in status for the species in Wales and in a way that is both transparent and demonstrably achievable.

This is the third and final regional modelling exercise in Wales covering the country's core great crested newt range (Anglesey, NE Wales, Powys and South Wales between Gower and Monmouthshire). The integrated results will enable the first objective Wales-wide assessment of great crested newt status for the country.

4. Methods

4.1. Software

All analyses took place using Excel, ArcGIS v.10.2 and additional software listed below. We formatted all GIS layers to British National Grid projection.

4.1.1. Stand-alone software

- Conefor v.2.6. Graph theory software for modelling importance of habitat patches for landscape connectivity (www.conefor.org).
- MaxEnt v.3.33k Species distribution modelling software (www.cs.princeton,edu/~shapire/maxent).

4.1.2. ArcGIS tools

- Linkage Mapper Toolbox v. 7.8. Tools for creating Least Cost Paths and Corridors (code.google.com/p/linkage-mapper).
- Hawth's Tool. Specialist vector and raster editing tools for ecological analysis (www.spatialecology.com).
- Jenness tools: Repeating shapes v.1.5, Land Facet Corridor Designer (TPI tool) v. 1.2., Conefor Inputs tool v.1.0, Export to Circuitscape Tool v.1.0 (www.Jenessent.com).

4.2. Data sources used

4.2.1. Great crested newt records within study areas

- A) All available great crested newt records from the core study area (Gower to Monmouthshire), including records from South East Wales Biological Records Centre (SEWBReC).
- B) Great crested newt records from within a 5 km buffer bordering the core study area (from Herefordshire and Gloucestershire).

4.2.2. Environmental datasets

- C) Bioclimatic layers: downloaded free from www.worldclim.org (accessed 09/2011; see Hijmans *et al*, 2005 for info).
- D) Elevation data: ASTER GDEM V1 produced by NASA and METI and downloaded free from jspacesystems.or.jp/ersdac/GDEM/E (accessed 08/2011).
- E) Land Cover: GB Land Cover Map 2007 (LCM2007) and licensed by CCW (received 09/2011; see http://www.cis-web.org.uk/home/ for info).
- F) OS MasterMap data including pond polygons, roads and buildings derived from Ordnance Survey (OS) and licensed by NRW (see http://www.cis-web.org.uk/home/ for info).
- G) OS Open Data layers including Meridian 2, Boundary-line, 1:250,000 colour raster and OS Street View. Free public sector information licensed under the Open Government Licence and downloaded from www.ordnancesurvey.co.uk (accessed 01/2011).

4.2.3. Unitary Development Planning Layers

- H to S) Unitary Development Plan (UDP) and/or Local Development Plan (LDP) layers from each of the Local Authorities within the core South Wales study area (Blaenau Gwent, Bridgend, Caerphilly, Cardiff, Merthyr Tydfil, Monmouthshire, Neath Port Talbot, Newport, Rhondda Cynon Taff, Swansea, The Vale of Glamorgan and Torfaen).

4.2.4. Study areas

There were 12 Unitary Authorities of interest (Blaenau Gwent, Bridgend, Caerphilly, Cardiff, Merthyr Tydfil, Monmouthshire, Neath Port Talbot, Newport, Rhondda Cynon Taff, Swansea, The Vale of Glamorgan and Torfaen) but spatial analyses included a 5km buffer to incorporate cross-border functional connectivity. For the study area we used the high water boundary OS dataset (Dataset H) to limit analysis to terrestrial areas.

4.2.5. Record collation

Great crested newt presence data (records from 1990-present) were received from SEWBReC, for the 12 Unitary Authorities, and from Hereford and Gloucestershire Biological Records Centres, for the 5 km boundary overlap into those corresponding counties of England.

We filtered all records by date including those since 1990, to represent populations most likely to be extant and temporally coincident to the land cover layer (Dataset E) and pond dataset (Dataset F). We removed records marked as site centroids, unless within 10m of a pond.

We used the number of figures for each British National Grid reference as a proxy for record accuracy. Where record locations were stored as separate 6 figure Easting and Northing values, we used the number of zeros at the end of each to estimate accuracy. We removed all records with an estimated accuracy of 1km and 10km from further analyses, and all duplicate grid references. As models were required at 25m resolution, we aimed to include only records estimated to be accurate to 25m or less.

4.2.6. Environmental layers

We used 24 environmental layers for MaxEnt modelling, comprising bioclimatic layers, land cover, pond density and topography. We converted each to ASCII format at 25m resolution, clipped to the extent of the study areas and aligned to the Land Cover Map 2007 (Dataset E).

4.2.7. Bioclimatic layers

Preliminary models using 19 bioclimatic variables (Dataset C; see also Appendix A) at 1km resolution produced a coarse MaxEnt output with marked variation between adjacent 1km squares. We chose to smooth these from approximately 1km down to 25m resolution, using spline interpolation from the centre of each raster cell. The original resolution of approximately 1km was itself derived using a, more complicated, spline interpolation technique by Hijmans et al. (2005).

4.2.8. Land Cover
To incorporate the effect of land cover we used the Land Cover Map 2007 (Dataset E) as this was the most recent dataset available for the extent of the study areas at the required resolution. This dataset comprised 23 land cover classes (see Appendix B) and was used as a categorical input for MaxEnt modelling; the subsequent output was used to derive a resistance to movement surface. A previous CCW research report on great crested newt modelling (ARC and Cofnod, 2011) included a soil dataset in the modelling process, and highlighted a strong visual association between Stagnogley (pond forming) soil types and great crested newt presence. Land Cover Map 2007 (LCM2007) already incorporates soil data for distinguishing between specific land cover classes and, considering the costs of high resolution soil data, we felt the combination of LCM2007 and pond density would be sufficient.

4.2.9. Pond density
OS Mastermap is the most comprehensive and spatially explicit resource for deriving inland water body data for Great Britain (Dataset F). We extracted ponds from OS Mastermap using the same process as Stuart Ball (in litt.), by selecting all inland water bodies between 50m2 and 750m2 with a ratio of polygon area to bounding-box area, of below 3.5. This produced a pond dataset with a size range suited to great crested newt ecology (Oldham et al., 2000); however, this process has the potential for errors (see Discussion and Arnell and Wilkinson, 2011). We used the centre-point (centroid) of each pond polygon to calculate the density of ponds in the surrounding 1km (a reasonable dispersal distance for great crested newts), for each 25m raster cell.

4.2.10. Topography
We rescaled the elevation layer (ASTER GDEM - Dataset D) to 25m resolution, from an original resolution of approximately 30m, and from this derived Slope and Aspect layers using the Spatial Analyst extension in ArcMap. We produced a Topographical Position Index (TPI) layer from the elevation to distinguish ridges and valleys using the Jenness tool for ArcGIS (see Software section).

4.3. The MaxEnt modelling process

Presence only (as opposed to presence-absence) modelling is consistent with the ad-hoc species datasets available for the two study areas. We used Maximum Entropy or “MaxEnt” software as it requires presence-only data and is consistently competitive with the highest performing species distribution modelling methods (Elith et al. 2006), as well as being robust to small sample sizes. MaxEnt is a machine-learning method that has been developed in statistical mechanics and utilised in a software application specifically for species distribution modelling. The maximum entropy principle states that the probability distribution that is most spread out (i.e. with maximum entropy), subject to known constraints, is the best approximation of an unknown distribution (for a full statistical explanation see Elith *et al*., 2011). Most importantly for use in this study, the estimated probability of presence output from this software provides an objective method of assigning costs of travelling through various habitat types (an important aspect of assessing functional connectivity).

To limit the effects of spatial autocorrelation (Segurado *et al*., 2006) on the MaxEnt model and its subsequent testing, the cleaned set of records were spatially filtered to limit the minimum distance between records to 500m. This distance was a compromise between sample size and potential bias from spatial autocorrelation. To achieve this we made a grid of 1km-wide hexagons and randomly selected one record per hexagon using Hawths Tool (see Software section). Where selected records were closer to each other than 500m we randomly chose one of the pair for inclusion.

We used 75% of the spatially filtered records to train the models and 25% to test the models, with 4 replicates and a random seed such that for each replication, a different set of training and test records would be used. We chose 1000 maximum iterations of the optimization algorithm, but kept all other model parameters at their default settings. Models were evaluated using the AUC (area under the curve) value for the Receiver Operator Characteristic (ROC) curve, a widely used threshold-independent test of model performance (Franklin, 2004). We converted each study area boundary into binary ASCII files for use as masks to delimit analyses in MaxEnt.

4.3.1. Suitable habitat

To delimit the areas of suitable habitat we converted the ASCII file outputs from MaxEnt into raster format for use in ArcGIS software. Determining precise threshold values for presence/absence was not feasible with the presence only methods used in this study. Choosing thresholds for this type of modelling depends generally upon the specific aims of the study (Liu *et al.,* 2005). We used the minimum training presence to delimit ‘suitable habitat’ for great crested newts as this was the lowest value for which all training records were correctly predicted by the model (and therefore a reasonable proxy for suitable habitat). For the purposes of delineating ‘most suitable habitat’ (core habitat), we used the equal training sensitivity and specificity threshold. This higher threshold produces a more focused output and (as the name suggests) is a compromise between model sensitivity and specificity. A further (10% training presence) threshold was also used to provide an additional category for survey targets and selecting pond creation target areas (see below).

4.4. Survey targets

We prioritised survey targets for OS pond polygons using suitability metrics for the area surrounding each pond. We used the focal statistics tool in ArcMap for the estimated probability of presence layer to derive a new raster layer that summarises, the values from the original layer within a 250m radius. We used the point to sample tool to sample values from this new raster, for each pond centroid. From these values we categorised survey targets using the three thresholds used in this study, the minimum training presence, 10% training presence and equal sensitivity and specificity. We omitted ponds below the lowest threshold or within 100m of known records, as they are likely to be unsuitable or may have associated records. As survey aims can vary, we used a cost weighted distance buffer around known records to allow remote survey targets (i.e. far away from known records) and local survey targets to be distinguished. In addition, we calculated the Euclidean (straight line) distance from each pond to the nearest known great crested newt record, up to a maximum of 5km to provide an accompanying figure for practical use.

4.5. Connectivity

4.5.1. Resistances

For each study area we created resistance (to movement) layers by using the reciprocal of the estimated probability of presence output from MaxEnt, and multiplying values by 100 so they were in the range frequently used for calculating Least Cost Paths (Rayfield *et al*., 2010). This process allowed us to avoid basing the resistance layer solely upon expert opinion, as is common in landscape connectivity studies (Ray *et al*., 2002). Some potential barriers to movement were not fully represented in the MaxEnt modelling however, so we manually added these to the final resistance layer (Decout *et al.,* 2012). These features were taken from OS MasterMap and Meridian datasets (Datasets F and G respectively), which we converted into raster format and combined with the inverted probability of presence layer (see Table 1 for values). To avoid gaps occurring in linear features when converting from vector into raster format, we formatted raster cells to be included if they overlapped barrier features to any extent. So that none of the resistance layers contained cells with zero resistance to movement we increased all values by 1 in the final resistance layers.

Table 1. Resistance values used to produce the final resistance layer for each study area.

GIS raster layers	Resistance value
Inverted probability of presence*	1 – 101
B-roads, minor roads, tracks, small rivers	101
Motorways, A-roads, railways, large rivers, lakes,	501

*see above resistances paragraph for details.

4.5.2. Least cost paths

We calculated Least Cost Paths (LCPs) and Cost Weighted Distances (CWD) using existing records, the resistance layer (see above) and the Linkage Mapper toolbox for ArcGIS (see Software section). This software allowed paths to be calculated and mapped between populations that are within a user-specified distance, limiting processing time to a few days and avoiding unfeasible processing times for paths that are unlikely to be used (ranging from weeks to many months). For both study areas a 2000m Euclidean maximum distance was used, as well as cost weighted distances equivalent to travelling 2000m in most suitable habitat (96359 Cost-Weighted Distance units).

4.5.3. Connectivity indices

We used the graph theory software Conefor (see Software section) to highlight populations that are likely to be most important for connectivity. Graph theory has been used for a variety of applications, including geography and computer science and recently has been employed to provide estimates of connectivity between habitat patches at landscape scale (Minor and Urban, 2007; Saura and Rubio, 2010; Urban and Keitt, 2001). This software is able to calculate a connectivity index (dPC) for each population, which is comprised of the habitat quality/patch size of each patch (dPC intra), the patches' contribution to connecting between patches (dPCconnector) and the position of the patch within the network (dPCflux) (Saura and Rubio, 2010).

We carried out analyses for each study area by inputting the Cost Weighted Distances between populations (i.e. the Cost Weighted Distances of the Least Cost Paths). We calibrated the model using a Cost Weighted Distance equal to the cost of moving through most suitable habitat (see Suitable habitat section above) for 250m. We used a probability of 0.5 to correspond to this 250m value as this was the average dispersal distance used in the spatially explicit modelling study by Griffiths (2004), and based upon data from Kupfer and Krietz, (2000). Based on this, the software calculates a negative exponential dispersal kernel (Saura and Pascal-Hortal, 2007; Saura and Rubio, 2010) as an approximation of the likelihood of a species dispersing a given distance.

To incorporate habitat quality for each population we used bilinear interpolation (the four nearest raster cells) on the resistance layer and inverted the result. This aimed to incorporate nearby unsuitable habitat, such as buildings or roads.

4.6. Targeting pond and habitat creation

We targeted pond creation in: a) great crested newt suitable habitat plus b) low pond density areas, and c) areas that were practical to build ponds in, such as outside built up areas and in designated conservation zones. We did not use the suitable habitat layer produced from the main MaxEnt models, as used in the previous steps in this project, as this would be biased to high pond density areas. Instead, we repeated the MaxEnt modelling but omitted the pond density layer as an input, in order to derive areas of great crested newt suitable habitat irrespective of pond density. We used the 10% training presence threshold for denoting suitable habitat as previous thresholds were felt to be either too inclusive or exclusive for denoting pond creation areas.

We created a point layer using pond centroids from the OS pond dataset and, with the point density tool in ArcMap and a circular radius of 564.19m (from $A=\pi r^2$), we created pond density per km^2 layers for both study areas. From this we selected areas with pond densities of less than four ponds per square kilometre as used previously in (Wilkinson *et al*, 2011: Arnell and Wilkinson, 2011) and based upon work by Oldham *et al.,* (2000).

We collected Unitary Development Plans (UDPs) for all relevant, Unitary Authorities, in order to further inform pond and habitat creation allocation and incorporate current planning information from these areas. From these layers we removed any designation with poor pond creation potential, including areas planned for intensive development. We separated remaining areas into; a) those that were likely to be practically viable for future pond creation and b) areas where pond creation potential was unknown. The unknown category encompassed any designation where pond creation potential was hard to discern and areas without UDP designation.

4.7. Local Population Targets

Favourable Reference Values (FRVs) are targets set to denote the point at which Favourable Conservation Status is reached. On the scale of site, county or region, these are referred to as Local Population Targets (LPTs). We set these targets for each unitary authority with reference to recent work in North Wales by Gleed-Owen

(2007) and using the decline in number of ponds of 37% between 1843 and 2007. We chose 1843 as the historical reference point for baseline pond numbers as this was the earliest period from which reliable data were available (see Gleed-Owen, 2007). In the absence of accurate figure specifically referring to South Wales pond-loss, these data were used as a proxy and in order to demonstrate that targets can be set.

We compared present day c.2011 pond numbers to the baseline data for each unitary authority to calculate optional targets: i) restoring all ponds lost since 1843, ii) restoring the number of occupied ponds (15.5% of total number of ponds; Wilkinson *et al.*, 2011) theoretically lost, and iii) restoring the number of *high quality* ponds theoretically lost. For the final option we used the great crested newt habitat suitability index (HSI) (Oldham *et al.*, 2000) as a proxy for pond quality. To calculate final targets we used the overall percentage of ponds (24%) with an HSI of >0.7, from data where HSI was systematically recorded (see Wilkinson *et al.,* 2011).

5. Results

From an original 1,382 records available for the study area (see Figure 1a), the cleaning process left 246 reliable, pond-associated (within 100m of a pond in the ponds dataset), great crested newt presence records for further analysis. The spatial filtering process left 206 records for MaxEnt modelling, each more than 500m apart: (see Fig. 1d).

The final model achieved a mean test AUC value of above 0.79 (SD = 0.033) despite the relatively low number (206) of presence points used for model training. The variables contributing most to the model outputs (Fig. 2) were (in order of importance) pond density, Bio15 (seasonality of precipitation), landcover type, slope, and then other bioclimatic variables (equating to the fact that rainfall in the warmest months of the year can influence newt breeding success). Of lowest importance to the model were the variables acid grassland and urban cover.

South Wales has quite extensive areas of habitat suitable for great crested newts (Fig. 3), especially in the east of the region. The most suitable habitat (as evidenced by both model outputs and known record locations) occurs patchily within the Local Authorities of Bridgend, Vale of Glamorgan, Cardiff and Newport, with large patches also evident in Monmouthshire and (e.g.) Caerphilly. Isolated patches of very suitable habitat also occur on Gower (Swansea).

This patchiness of habitat influences connectivity and is reflected by the pattern seen in Cost Weighted Distance buffers (Fig. 4), similar to the pattern observed in Powys model outputs (Arnell & Wilkinson 2013a) and in contrast to North East Wales (Arnell & Wilkinson 2013b) where buffers form a more contiguous area connecting together ponds, despite the urbanization there.

Large numbers of ponds to target for surveys occur throughout the region (Fig. 5), reflecting both the amount of suitable habitat and the fact that the region is (generally) very under-recorded – especially outside the urban centres. The sparse (known) distribution of great crested newt records is also evident from the small number of least cost paths and corridors (within the ~2km threshold) between populations (see Figures 6 and 7). This reduces the proportion of functionally connected populations modelled in Conefor, few being highlighted as having a high importance for metapopulation connectivity (Figure 8). In the context of a region that (for Wales) has a high proportion of urbanized areas, however, identification of these few key locations should prove beneficial for maintenance of the species' status there, especially if further (local) modelling is carried out to inform planning and mitigation.

The pond loss rates used (extrapolated from North East Wales loss rates to demonstrate the approach) suggest a cumulatively large number of ponds may have been lost from South Wales since 1843. For putative pond restoration options see Option 3 in Tables 2 and 3). Importantly, some Local Authorities have only negligible areas available for pond creation – this is discussed further below.

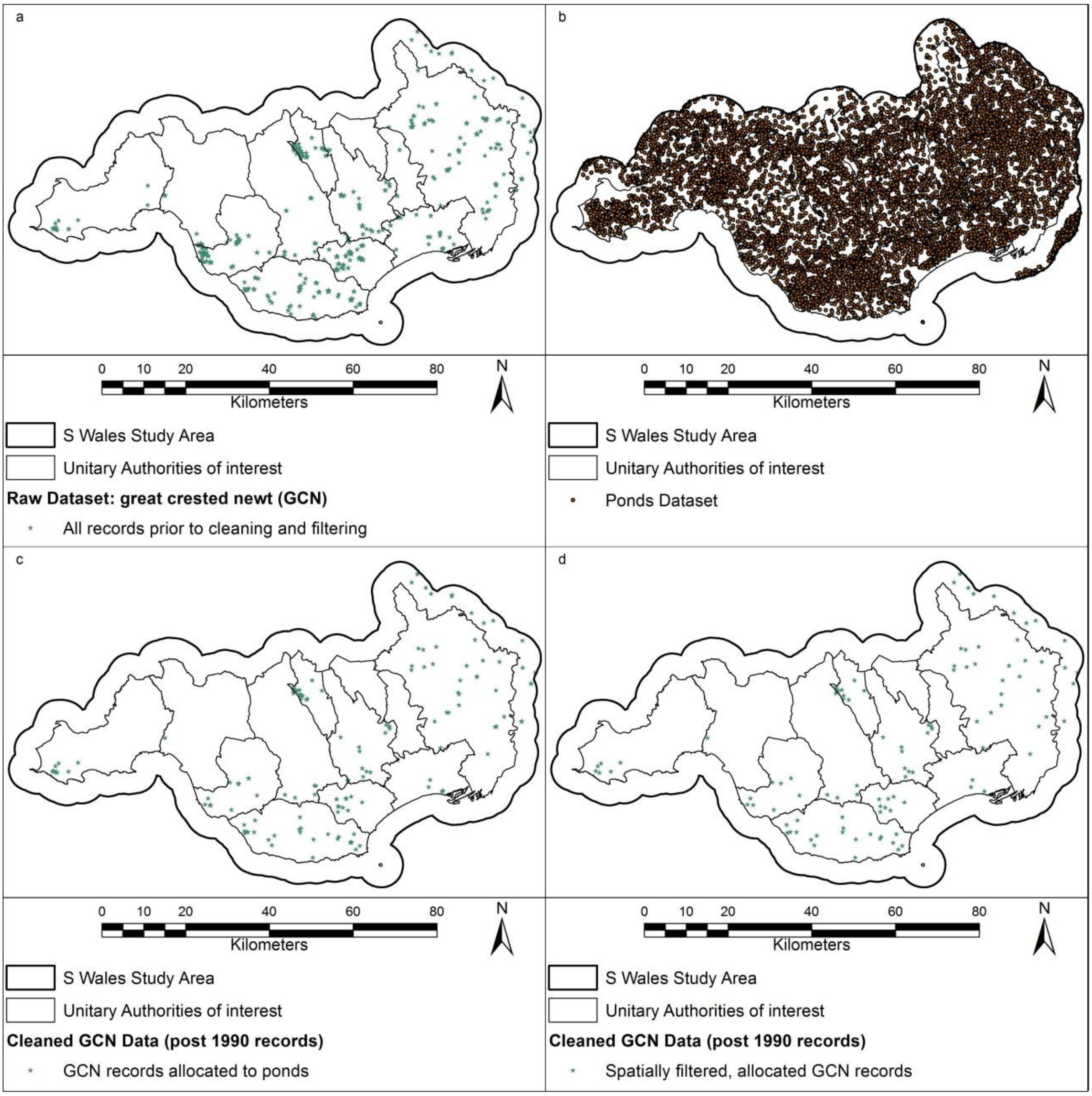

Figure 1. Known distribution of great crested newts in the South Wales study area, for: a) Raw dataset containing all collated records prior to filtering and cleaning, b) Ponds Dataset, c)1990 – present cleaned great crested newt presence records, and d) 1990 – present records, spatially filtered to >500m apart, to limit autocorrelation bias in MaxEnt modelling.

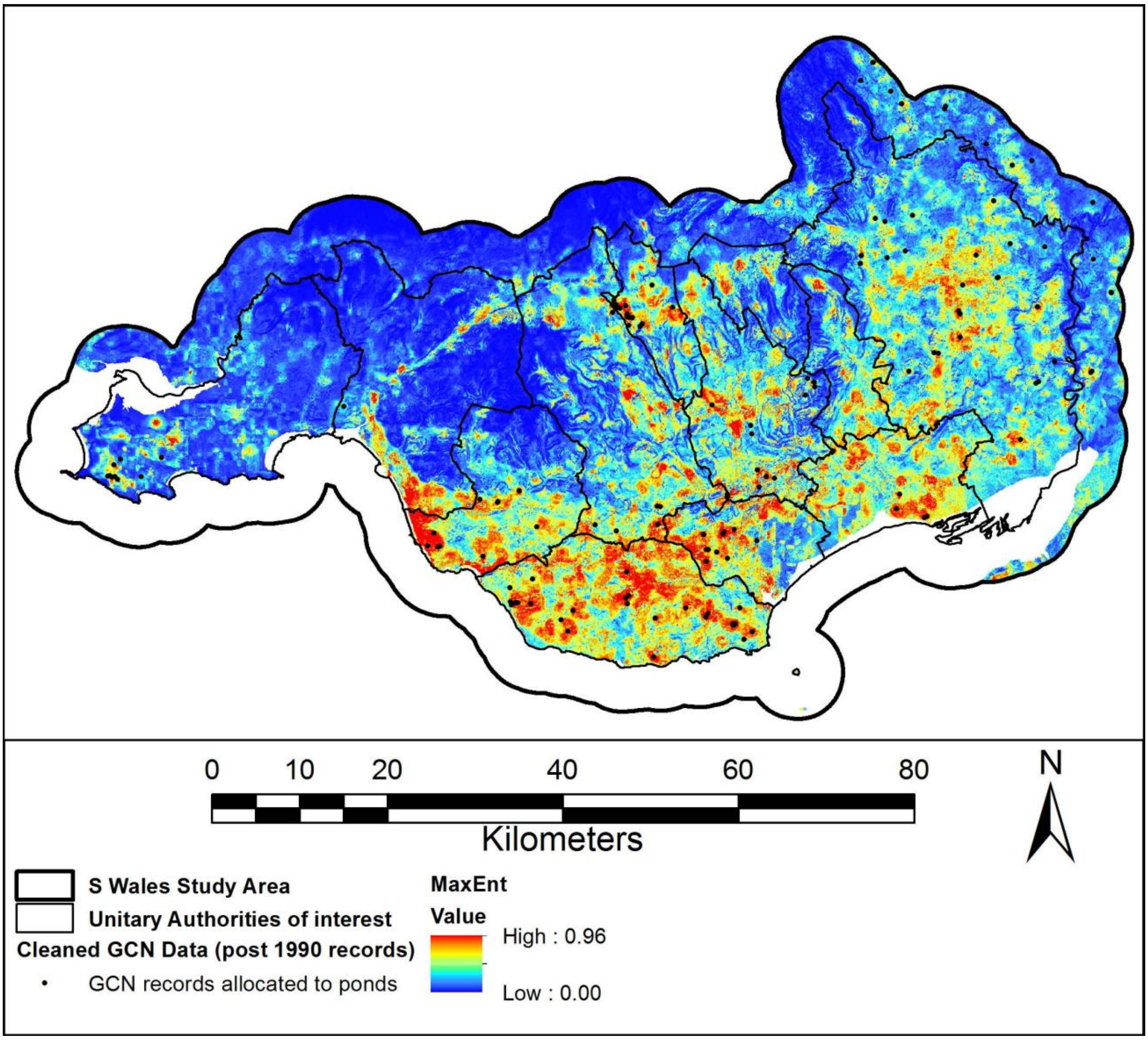

Figure 2. The estimated probability of presence of great crested newts throughout the South Wales study area: MaxEnt model raw output along with great crested newt records from 1990 to 2011.

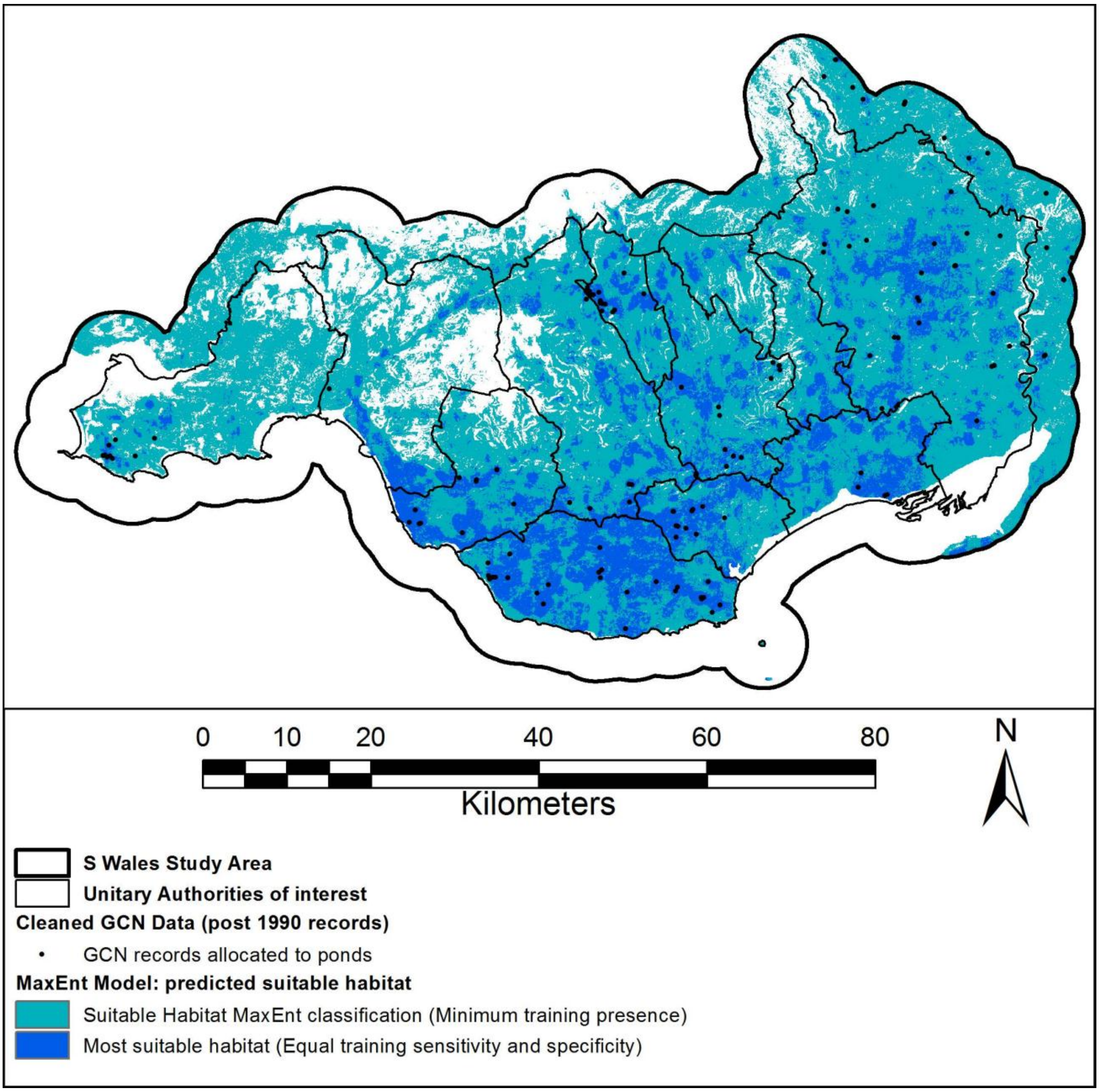

Figure 3. Predicted habitat for great crested newt in the South Wales study area: MaxEnt models with minimum training presence and equal training sensitivity and specificity thresholds, used to denote suitable and most suitable habitat (core habitat) respectively.

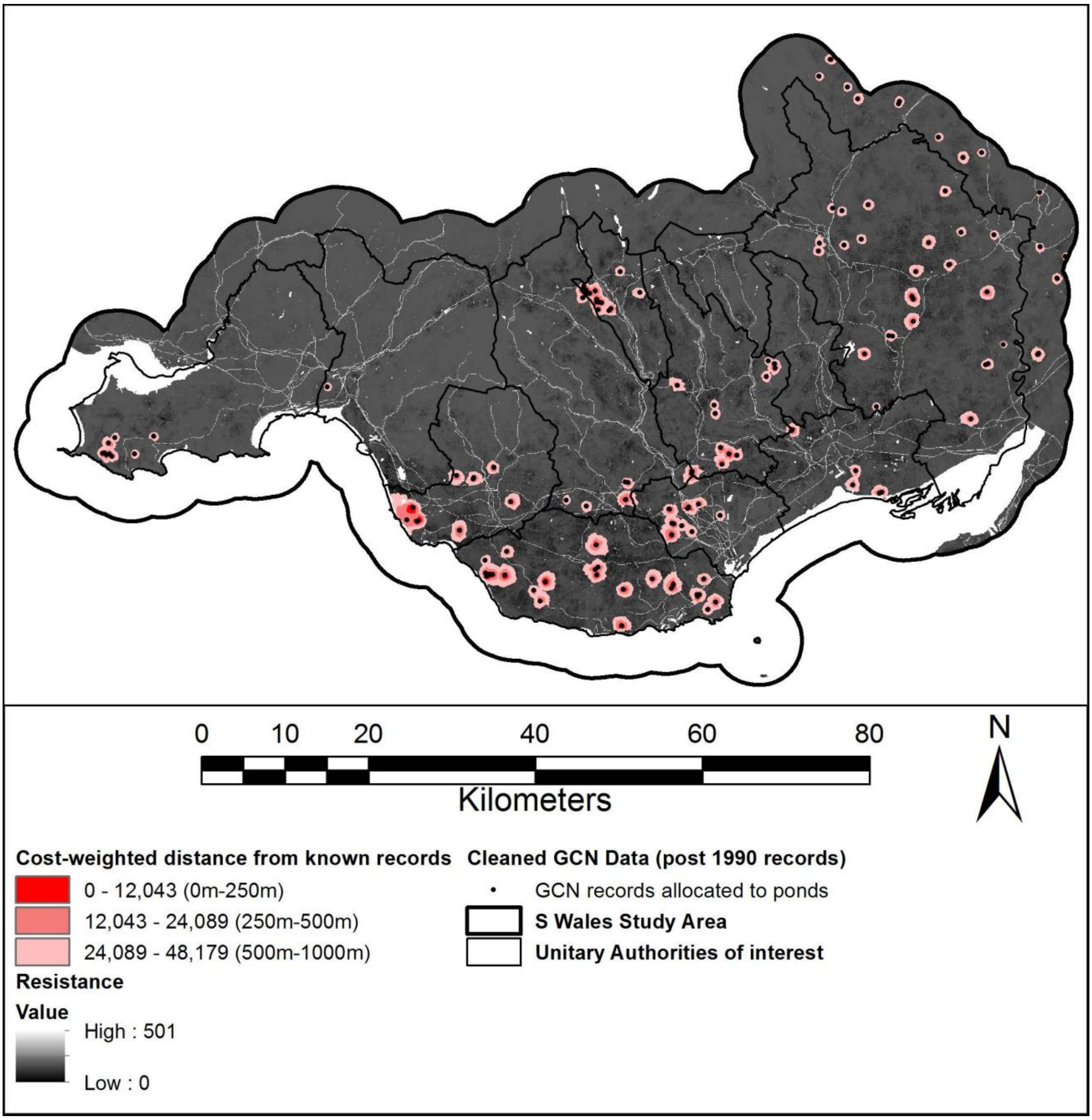

Figure 4. Cost Weighted Distance from known great crested newt records from 1990 – 2011: calculated from known migration thresholds and a resistance layer combining the inverse of the MaxEnt model output with known barriers to great crested newt movement.

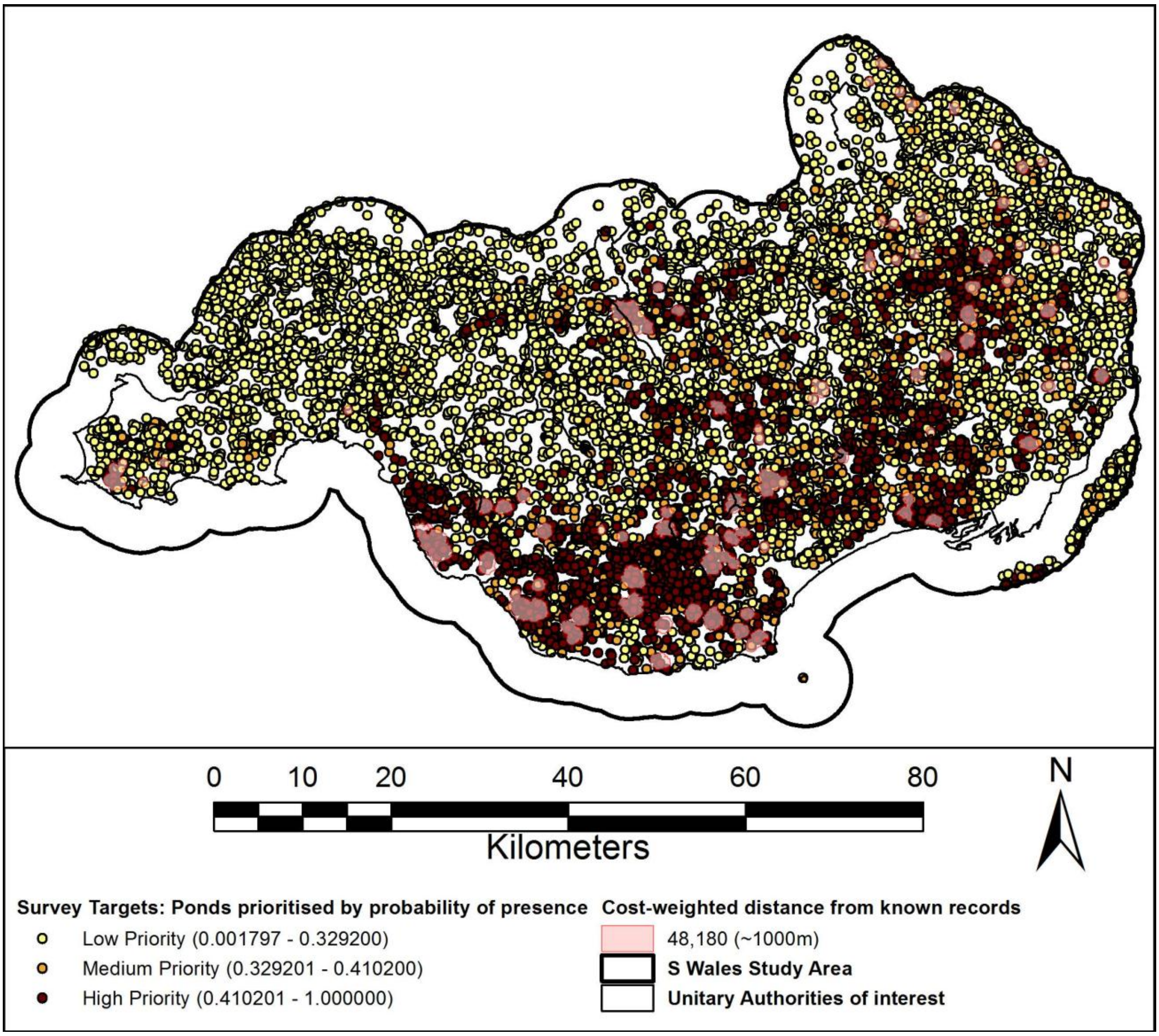

Figure 5. Great crested newt survey targets: ponds within South Wales study area prioritised by the average estimated probability of presence (from MaxEnt), within a 250 m radius. A cost weighted buffer (~1000m), highlights areas that are theoretically well-connected to known records.

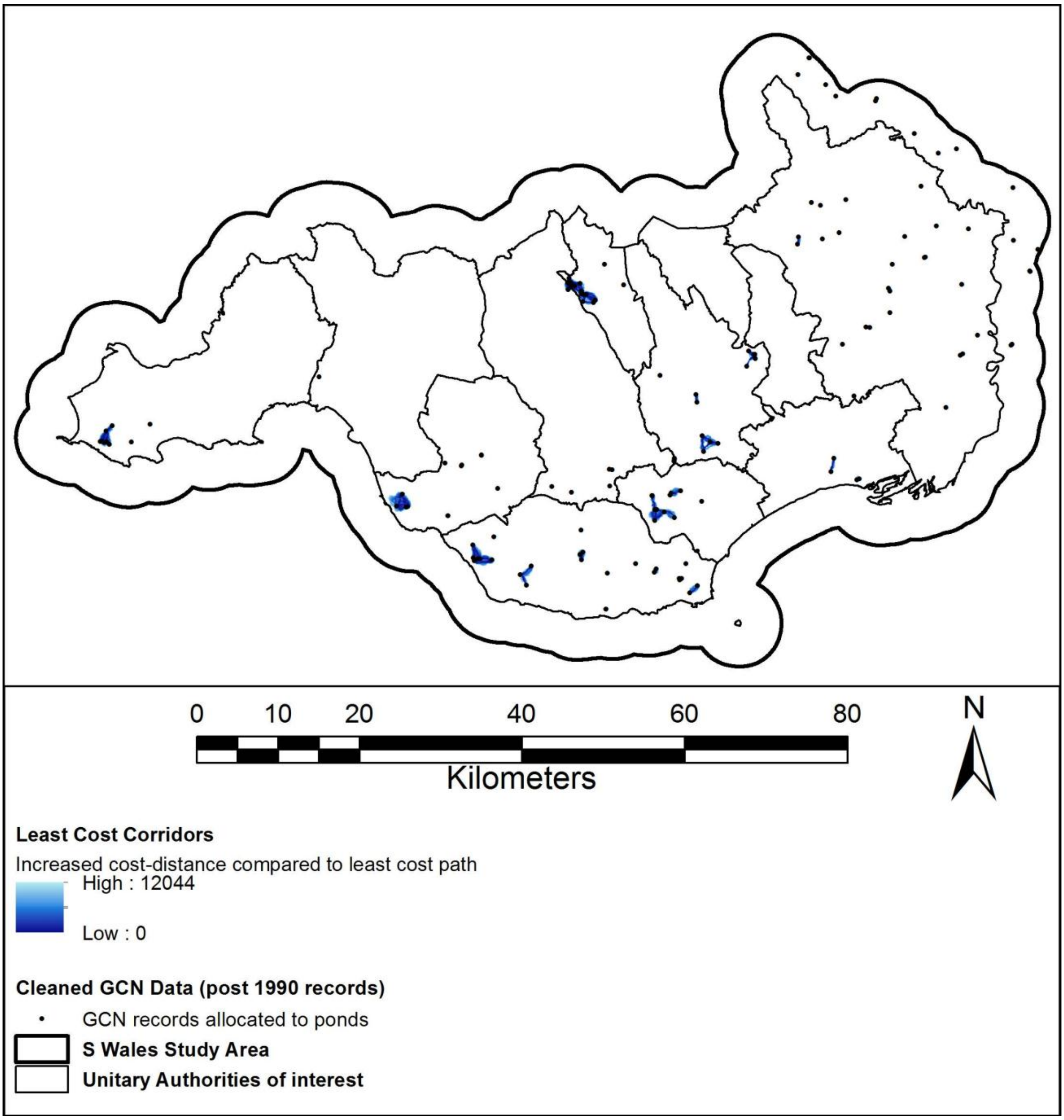

Figure 6. Least cost corridors between known great crested newt records (1990 – 2011). Corridor widths were limited to a maximum Cost Weighted Distance of 12044 (~250m), above that of the Least Cost Path. Least Cost Path lengths were limited to a cost weighted equivalent of 2km.

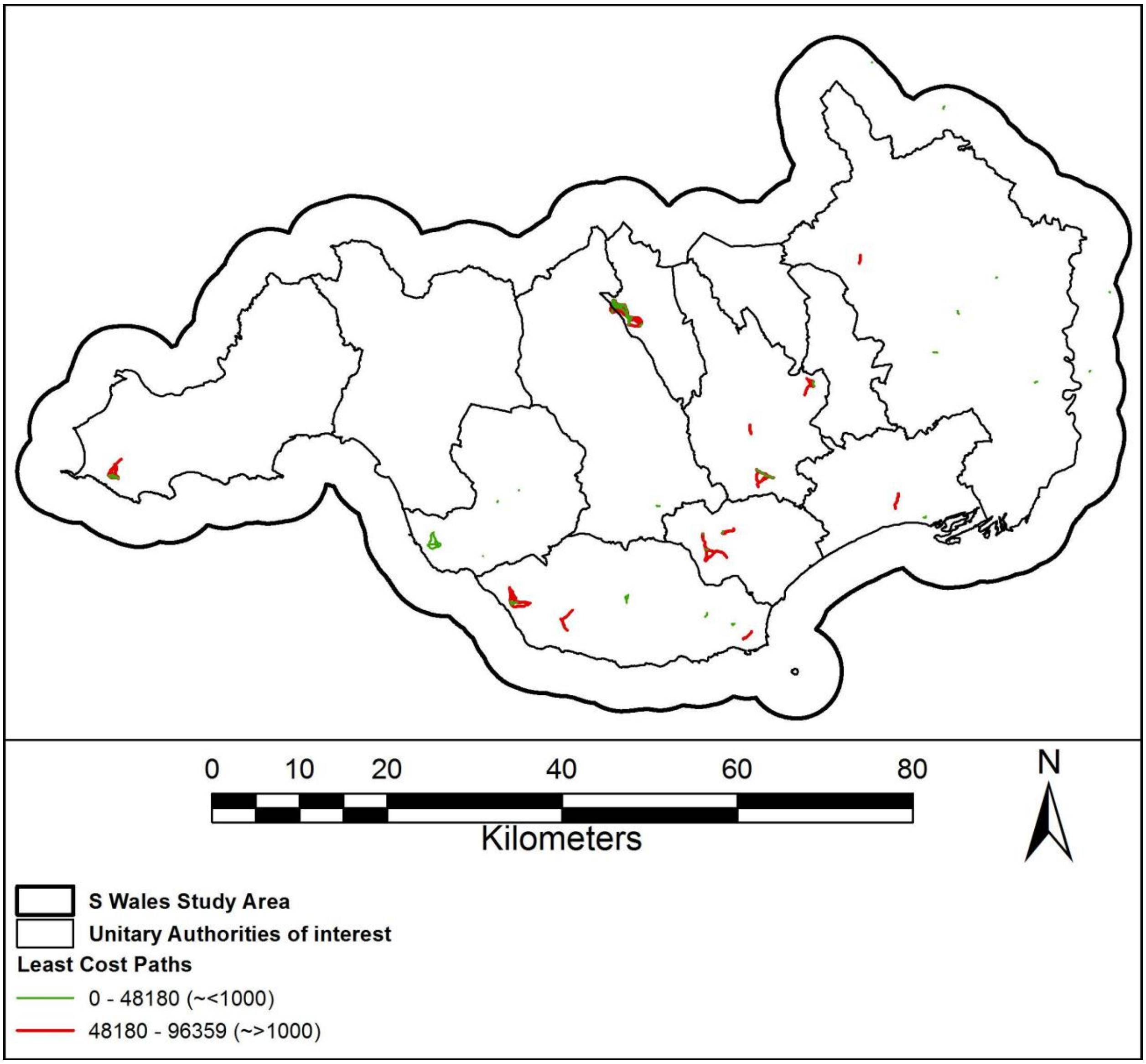

Figure 7. Least Cost Paths between nearest neighbour great crested newt records (1990 to 2011), in the South Wales study area. Paths are displayed by length, in Cost Weighted Distance, and limited to a cost weighted equivalent of ~2000m, to reduce processing time.

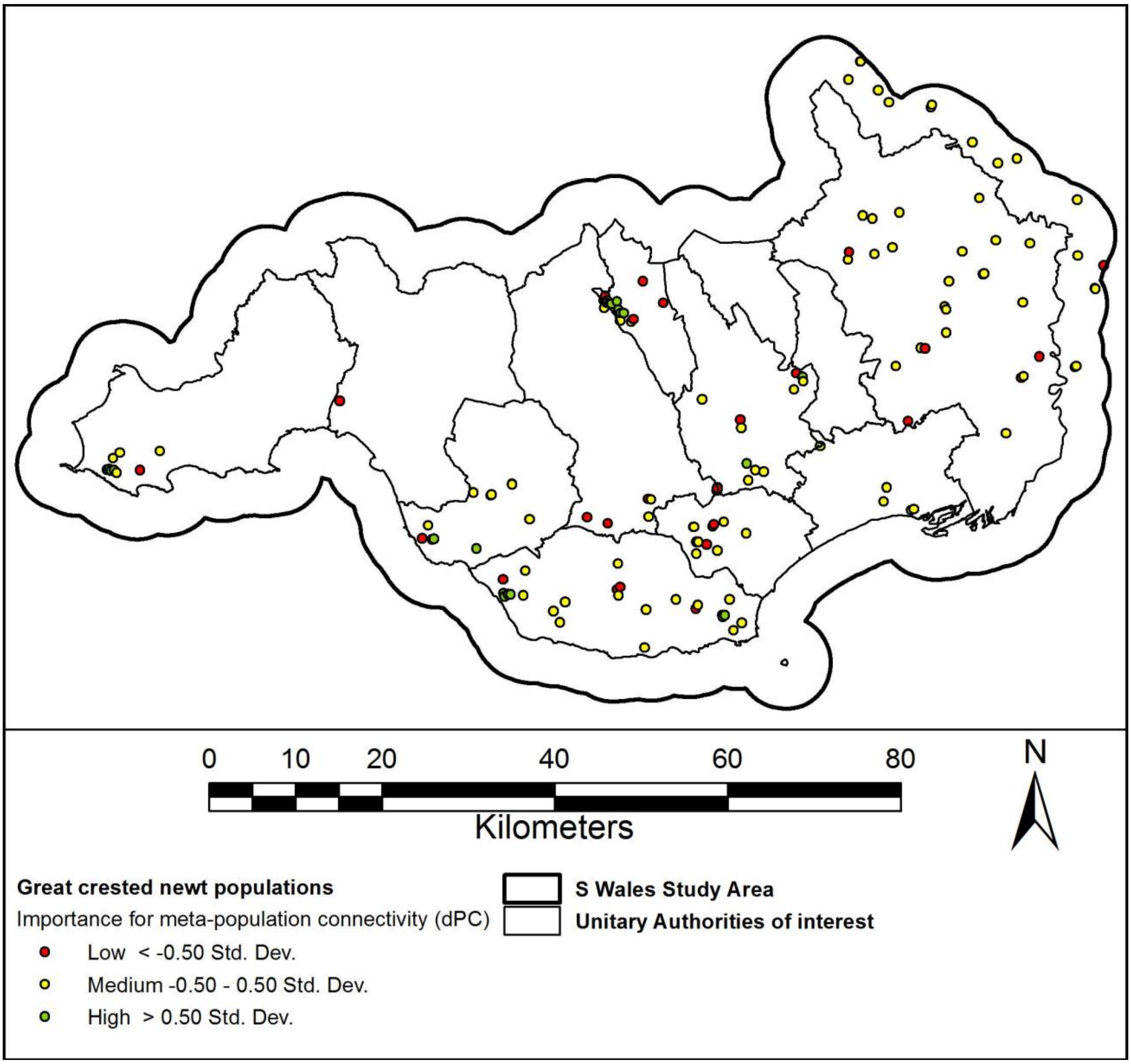

Figure 8. Great crested newt populations according to their contribution to metapopulation connectivity. Probability of connectivity (dPC) index was calculated using graph theory software, Conefor, and the cost weighted distances along Least Cost Paths.

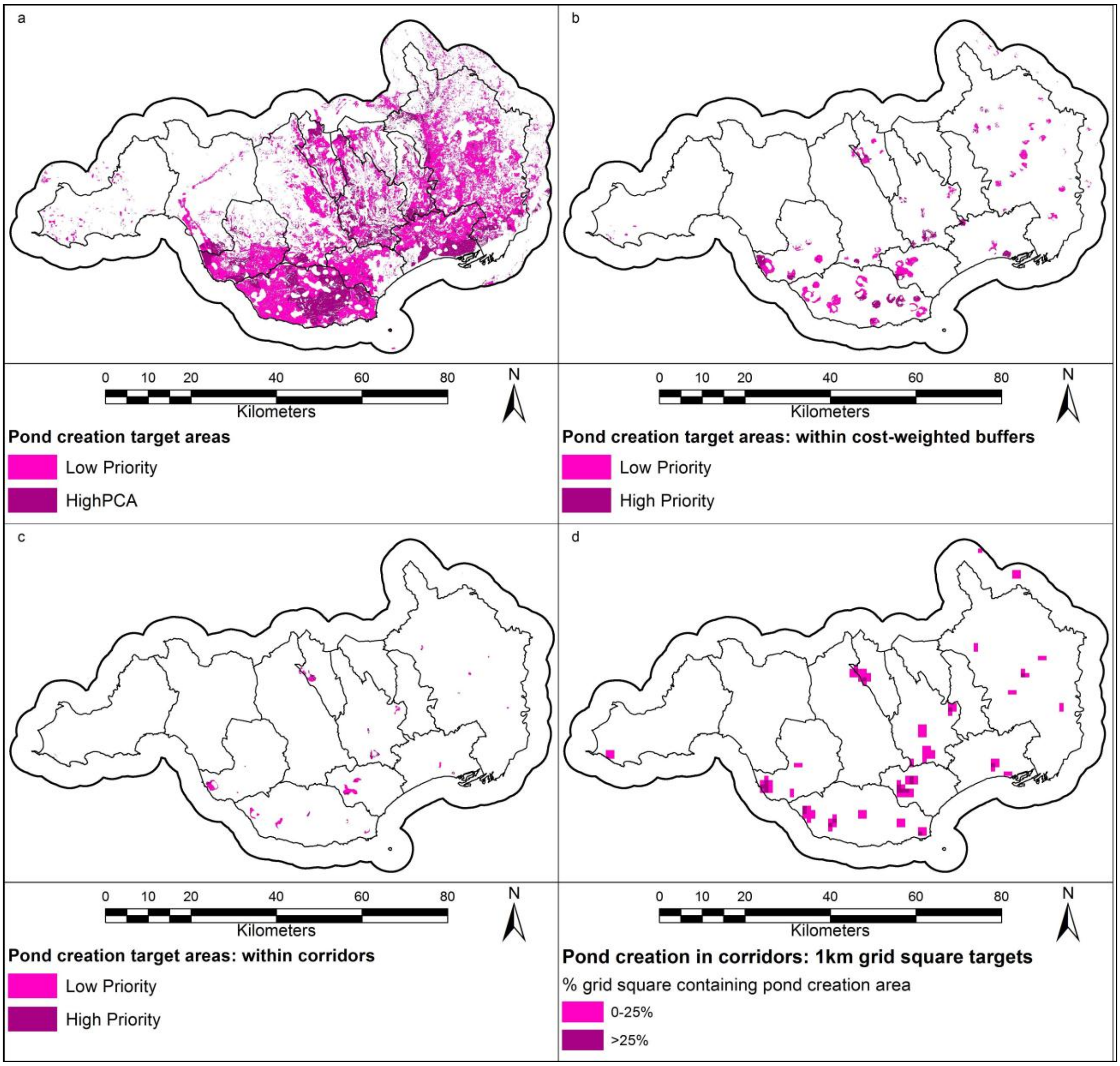

Figure 9**.** Potential pond creation areas within a) the South Wales study area: b) a cost weighted buffer (~1000m) around known great crested newt records, c) Least Cost Corridors, and d) pond creation areas within corridors by proportional area of 1km grid squares.

Table 2. Mitigation approaches. These are based on restoration of theoretical 1843 figures including: option 1, restoration of the total number of ponds; option 2, restoration of the number of great crested newt occupied ponds theoretically lost; option 3, restoring number of ponds with high HSI (>0.7). See text for full explanation.

Focal area	# of ponds 2007	# of ponds 1843	# of ponds 2011	Option 1	Option 2	Option 3
Blaenau Gwent	163	259	336	77	12	19
Bridgend	318	505	551	46	7	11
Caerphilly	383	608	819	211	33	51
Cardiff	225	357	477	120	19	29
Merthyr Tydfil	186	295	470	175	27	42
Monmouthshire	1448	2298	2462	164	25	39
Neath Port Talbot	741	1176	1408	232	36	56
Newport	354	562	817	255	40	61
Rhondda Cynon Taff	598	949	1614	665	103	160
Swansea	591	938	1147	209	32	50
The Vale of Glamorgan	739	1173	1238	65	10	16
Torfaen	234	371	544	173	27	41
Whole study area	5980	9492	11883	2391	371	574

Table 3. Recommended pond mitigation option (Option 3). The corresponding area for each unitary authority and increase in number of ponds per km^2 needed to fulfil this mitigation option are also shown for each of the three alternative pond creation area categories. Alternative cost weighted buffers utilise pond creation areas without incorporating pond density.

Focal area	**Option 3**	**Pond creation areas**					
		Corridors		**Cost weighted buffers**		**Alternative cost-weighted buffers***	
		Area km^2	Pond creation per km^2	Area km^2	Pond creation per km^2	Area km^2	Pond creation per km^2
Blaenau Gwent	19	**<1**	**NA****	**<1**	**NA****	**<1**	**NA****
Bridgend	11	3.40	3.27	17.43	**0.64**	20.73	0.54
Caerphilly	51	2.69	18.81	9.05	5.60	9.87	5.13
Cardiff	29	5.15	5.59	13.48	2.13	15.48	1.86
Merthyr Tydfil	42	3.16	13.29	6.65	6.31	9.40	4.46
Monmouthshire	39	**<1**	**NA****	17.82	2.20	22.44	1.75
Neath Port Talbot	56	**<1**	**NA****	**<1**	**NA****	**<1**	**NA****
Newport	61	**<1**	**NA****	5.97	10.25	6.65	9.20
Rhondda Cynon Taff	160	**<1**	**NA****	5.56	28.68	7.14	22.33
Swansea	50	**<1**	**NA****	**<1**	**NA****	1.59	31.61
The Vale of Glamorgan	16	4.10	3.81	37.75	0.41	52.00	0.30
Torfaen	41	**<1**	**NA****	**<1**	**NA****	**<1**	**NA****
Whole study area	574	20.61	27.84	114.76	5.00	145.48	3.94

** Value omitted, as selected area is <1km^2 and so too small to provide meaningful targets.

6. Discussion

This modelling study has been carried out as the third step in creating regional models of great crested newt distribution and other spatial metrics in their core range in Wales (see also Arnell & Wilkinson 2013a; 2013b for Powys, and North East Wales and Anglesey). The combined outputs will contribute to a status assessment, according to the principles of FCS, for great crested newts in the whole of Wales (in prep.).

Despite containing significant population centres, records of great crested newts from South Wales are relatively sparse, reflecting past under-recording as well as a patchy distribution in the region. Nevertheless, the final MaxEnt model achieved a mean test AUC value of above 0.79 (very good model fit; *sensu* Fielding & Bell, 1997). The distribution of great crested newts in South Wales, based on the data currently available, can therefore be said to show a similar pattern to that observable in Powys (Arnell & Wilkinson, 2013a) and the determinant variables (notably pond density) are compatible with those seen in other regions. Most of the most suitable habitat for great crested newts, however, occurs in the southern authorities of South Wales – both (generally speaking) lower in elevation and more urbanized – leading inevitably to planning conflicts. New recording efforts (some of which are underway through ARC's projects in the area) and further, more localized models including fine-scale quantification of node (pond) importance and connectivity paths will further elaborate means by which population status in the region can be maintained and enhanced.

In contrast to previous Wales models, however, culminating in suggested pond restoration figures, several Local Authorities in South Wales have negligible amounts of habitat deemed (under the same criteria as in previous modelling) to be suitable for pond creation (Table 3) under different scenarios. We refrain here from reapportioning suggested pond creation targets to neighbouring authorities but this potential problem does emphasize the need for integrated, possibly regional but certainly cross-boundary spatial and/or conservation status plans in order to restore and thence maintain the status of great crested newts at a relevant regional scale. In two Local Authorities, the pond creation targets under some scenarios are already rather high (20 – 30 ponds per km^2) and would probably also benefit from a regional mechanism for target reapportionment. Note also that other areas (e.g. Monmouthshire) may have more land which could be designated for pond creation as and when further zoning is conducted (and hopefully with regional considerations borne in mind).

Recommendations for further developing and improving these modelling approaches are provided by Arnell & Wilkinson 2013a; 2013b and are not repeated here.

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9. Appendices

Appendix A. Table of 19 Bioclimatic variables (www.worldclim.org) used in the MaxEnt modelling.

ID	Bioclimatic 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

Appendix B. Table of the 23 land cover classes from the Land Cover Map 2007 used as categorical data in the Maxent modelling.

Number	Habitat types
1	Broadleaved Woodland
2	Coniferous Woodland
3	Arable and Horticulture
4	Improved Grassland
5	Rough Grassland
6	Neutral Grassland
7	Calcareous Grassland
8	Acid Grassland
9	Fen, Marsh and Swamp
10	Heather
11	Heather Grassland
12	Bog
13	Montane Habitats
14	Inland Rock
15	Saltwater
16	Freshwater
17	Supra-littoral Rock
18	Supra-littoral Sediment
19	Littoral Rock
20	Littoral Sediment
21	Saltmarsh
22	Urban
23	Suburban

Data Archive Appendix

Data outputs associated with this project are archived at xxxx on server–based storage at Natural Resources Wales.

The data archive contains:
The final report in Microsoft Word and Adobe PDF formats.

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