Mapping farmland wader distributions and population change to identify wader priority areas for conservation and management action

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Introduction

Many birds have declined across Scotland and the UK as a whole (Balmer et al. 2013, Eaton et al. 2015, Foster et al. 2013, Harris et al. 2017). These include five species of farmland wader; oystercatcher, lapwing, curlew, redshank and snipe. All of these have all been listed as either red or amber species on the UK list of birds of conservation concern (Harris et al. 2017, Eaton et al. 2015).

Between 1995 and 2016 both lapwing and curlew declined by more than 40% in the UK (Harris et al. 2017). The UK harbours an estimated 19-27% of the curlew's global breeding population, and the curlew is arguably the most pressing bird conservation challenge in the UK (Brown et al. 2015). However, the causes of wader declines likely include habitat loss, alteration and homogenisation (associated strongly with agricultural intensification), and predation by generalist predators (Brown et al. 2015, van der Wal & Palmer 2008, Ainsworth et al. 2016).

There has been a concerted effort to reverse wader declines through habitat management, wader sensitive farming practices and predator control, all of which are likely to benefit waders at the local scale. However, the extent and severity of wader population declines means that large scale, landscape level, collaborative actions are needed if these trends are to be halted or reversed across much of these species' current (and former) ranges. Landscape scale management across multiple land holdings is likely to be most advantageous for waders. This has the potential to increase the availability of suitable habitat and enable wide ranging predators to be effectively controlled across areas under multiple ownership, management type and land use (e.g. van der Wal & Palmer 2008, Ainsworth et al. 2016, Newey et al. 2016). However, to be effective, such effort needs to be targeted at areas where it is likely to be of greatest benefit. Relevant factors to take into account in determining these areas include current and potential levels of collaboration between the owners, managers and interest groups operating within them, as well as the size and trends of breeding wader populations. Collaborative conservation efforts and resources should therefore be focused on areas where wader populations have the best capacity to recover. Attempting to recover wader populations in areas where they have been locally extinct or occur at very low numbers may be unsuccessful in the short term, particularly in situations where productivity in nearby areas is typically low. Resources may be more effectively used to maintain strong populations, or to stabilise and build declining but extant populations.

To enable informed decision-making and to allow government agencies, environmental non-government organisations, private land owners and tenants to identify 'priority' areas it is necessary to map the distribution, and recent population changes, of waders across Scotland. Here we build on Newey et al. (2017) and use the Breeding Bird Atlas (Balmer et al. 2013) data to map the distribution of five species of wader; curlew, lapwing, oystercatcher, redshank, and snipe and to illustrate how their numbers have changed between 1990 and 2010.

Aim

To map the distribution and population change of farmland wading birds in Scotland and to identify geographic patterns of changing abundance.

Methods

Datasets

Maps illustrating spatial variation in relative abundance, and abundance change, were based on the outputs of predictive models. These models described the relationship between environmental variables and either recent abundance and change in occupancy (a measure of relative abundance). Abundance and occupancy information were derived from fieldwork for national bird atlases conducted in 1988-91 (Gibbons et al. 1993, hereafter BA1990) and 2008-11 (Balmer et al. 2013, hereafter BA2010). During these atlas surveys, volunteers recorded birds in a sample of tetrads (2 km × 2 km), making two 1-hour visits to each tetrad. In BA1990 observers simply listed the species encountered, whereas in BA2010 they counted the number of individuals encountered. For this reason, although abundance of each wader species in 2010 can be estimated directly from the number of birds encountered on atlas surveys during this period, a similar approach cannot be taken to estimate change in abundance between atlas periods. This was estimated as change in the probability of occupancy (whether or not birds occurred in tetrads), which is the basis of the relative abundance change maps presented by Balmer et al. (2013) (see below).

All subsequent analyses and maps are at the tetrad resolution. For each wader species, the abundance in each surveyed tetrad was based on the maximum count in either of the BA2010 survey visits. It should be noted that atlas surveyors recorded all individuals they detected regardless of whether or not there was any evidence that these were actively breeding. This resulted in the inclusion of (sometimes large) non-breeding flocks of some species in the atlas data (e.g. Curlew). To limit the influence of these records, any counts from outside the known breeding range of a species were set to zero. Despite this, a small proportion of wader counts were very large (e.g. up to 400 Curlew or 250 Golden Plover per tetrad) indicating that some non-breeding flocks within the breeding range (off duty and non-breeding flocks of these species can form, particularly in upland areas) had been included. Tetrad counts were therefore capped at 15, following the convention adopted in previous analyses of these data (Border et al. 2018) and the fact that the vast majority of counts in breeding areas (99% for Curlew) were below this value.

Because counts were not available for BA1990 data, we also estimated probability of occupancy from occurrence data and used this as a measure of relative abundance. This metric (expressed as the proportion of surveyed tetrads in each hectad where the species was found) was used as a hectad-level measure of relative abundance in order to generate the abundance change maps shown in BA2010. Simulations and pilot fieldwork for the atlas confirmed that a positive relationship does exist between these two metrics but it is a curved relationship that varies between species and is less sensitive to increases in abundance at the upper end of the scale for very common species (see Balmer et al. 2013). For the species considered here this is unlikely to be a problem, but should be borne in mind for extending this work to other, commoner species.

For each atlas period, an occurrence value was calculated for each wader species. All surveyed tetrads were assigned an occurrence value of 1 for species recorded in the tetrad, and a value of zero where a species was not recorded. For tetrads covered in both surveys, occurrence values from BA1990 were subtracted from occurrence values from BA2010 to yield a measure of change in occurrence. This took 3 possible values: -1 (tetrads where species were recorded in BA1990 but not in BA2010), 1 (tetrads where species were recorded in BA2010 but not BA1990), and 0 (where the recorded status of species was the same in both survey periods).

Environmental data

Land cover data came from the 1-km square percentage cover summary of the 2007 Land Cover Map (LCM) from the Centre for Ecology and Hydrology (Morton et al. 2011). Land cover categories within the LCM data set were combined to create six broader categories: i) semi-natural non-acid grassland (comprising neutral grassland, set aside grassland, calcareous grassland, bracken and fen, marsh and swamp); ii) acid grassland iii) mountain, heath and bog (comprising bog, dwarf shrub heath, montane habitat, and inland bare ground); iv) arable land; v) improved grassland and vi) woodland (comprising broadleaved, mixed and conifer woodlands). For each variable, a weighted (by area) average of the values for each of the relevant 1 km squares was calculated for each tetrad.

Mean elevation in each tetrad was calculated as the average of elevation values taken from a 100 m resolution DEM of Great Britain collected between 1970 and 1980 (OS Landform Panorama dataset, https://www.ordnancesurvey.co.uk/opendatadownload/products.html). Easting and northing (in numerical OS national grid format) were also included as variables in the model.

Modelling

We used bird and environmental variable data for all tetrads in Scotland where atlas surveys were carried out, as described above, to build models that we used to predict bird data for tetrads that weren't surveyed. The random forest classifier described by Breiman (2001) was used to build these models. A random forest is a classifier consisting of a larger number of regression trees. A regression tree recursively partitions a dataset; repeatedly subdividing based on thresholds values of explanatory variables that best explain variation in the dependent variable. The predicted value for each terminal node (or 'leaf') of the tree is simply the sample mean of the dependent value for all datapoints in that subdivision. In a random forest, each regression tree is based on a bootstrapped dataset, generated by sampling the original dataset with replacement. For any given datapoint, the predicted values for each tree are averaged to yield a prediction from the whole random forest. The R package randomForest (Liaw & Weiner 2002) was used to generate random forest models for relative abundance (as reflected by tetrad counts) and change in probability of occupancy, for all tetrads in Scotland. The default settings were used, with the number of regression trees set at 500, and the number of variables sampled as candidates for each tree set at 3 (derived as p/3, where p is the number explanatory variables included in the full model, which in this case was 10).

Mapping Bird Atlas Data

In order to derive maps from modelled, tetrad-level values of relative abundance and change in probability of occurrence, we plotted tetrad level values of abundance using the R package tmap (Tennekes 2018). Modelled abundance values consistent with areas where there was no breeding evidence of any category at the 10 km scale (possible, probable or confirmed – see Balmer et al. 2013 for definitions) were set to 'zero'. We did this by identifying the cut-off value (below which abundance values set to zero) that was most effective at separating tetrads in 10km squares with breeding evidence from those in 10km squares with no breeding evidence. First, a series of plausible cut-off values was generated, ranging from a minimum of 0 to the maximum modelled abundance value for a tetrad in a 10km square with no breeding evidence. was determined) by finding the value that maximised chi-squared in a contingency table. This For each of these candidate cut-off values, a contingency table of tetrad frequencies was drawn up. The rows of the contingency table separated tetrads according to the presence or lack of breeding evidence at a 10 km scale. The columns of the table separated tetrads according to whether their modelled abundance values were higher or lower than the candidate cut-off value. The best cut-off was identified as the value for which the chi-squared value calculated from this contingency table was maximised. The same approach was taken with occupancy change data, setting predicted values to zero when they were consistent with values in 10 km squares where there no breeding was found in either BA2010 or BA1990. In order to minimise the influence of high predicted abundance values in a few squares on the distribution of colour categories in the map, predicted abundance was double-log-transformed before mapping.

The tetrad-level modelled values of abundance and occupancy change were also used to produce combined maps of abundance and decline. These maps only displayed areas of decline (i.e. where modelled change in occupancy was negative), with all other areas displayed as white. The colour (blue, green or red) of tetrads in these maps reflected the level of abundance in the most recent survey. The tone (from light to dark) reflected the size of decline between 1990 and 2010. Thus, a light red tetrad indicated where modelled abundance was high, and there had been a small decline. A dark blue square indicated where there had been a large decline leaving few or no birds.

Local Atlas Maps

The maps of relative abundance and population change show modelled values that are based on the Breeding Bird Atlas surveys. While these probably represent statistically robust inferences, they are associated with the restrictions, already highlighted, associated with single visit surveys and model based predictions. To partly act as a check on the robustness of these modelled based inferences we make partial reference to local atlas data of curlew and lapwing for northeast Scotland and Tayside and Fife. These local atlases draw upon and benefit from data from multiple sources, but are not based on systematic surveys. However, they can be used for qualitative checking that the analyses of the bird atlas data identify hotspots of wader abundance shown by one or more local sources. Details of the local atlas methods and results are shown in Appendix 1.

The resulting maps do not allow us to accurately assess the distribution or population changes at the level of individual tetrads. We therefore describe the distribution and population changes in broad geographic terms. In the results we make regular reference to the Scottish Local Authorities (The

Local Government etc (Scotland Act) 1994[1,2]), the borders to refer to the areas north of the English-Scottish border, and the central belt – to refer to the area around and between Edinburgh and Glasgow (including, the Lothians, Edinburgh, North Lanarkshire, Glasgow, and North Ayrshire). In addition, we use the terms; Southern Uplands to refer to the area of uplands north of the English-Scottish border and south of the central belt, the Central Uplands to refer to what is commonly known as the Grampian Mountains, that is the uplands north of the Highland Boundary Fault and south of the Great Glen, and the North West Highlands to refer to the upland areas north of the Great Glen.

Results

Species Summaries

Detailed species accounts are provided below, here we provide brief summaries for each species.

- Curlew: In 2010 curlews remain widespread throughout southern Scotland and the central belt, eastern uplands, north-east mainland, Hebrides, Orkney and Shetland in 2010. However there had been widespread and in many cases severe declines in distribution throughout their former range by 2010. Declines were least severe in the Southern Uplands, central belt, Angus Glens, Strathspey and Deeside. Populations in the northern Hebrides, Orkney (except Hoy) and Shetland also appear to have suffered limited declines, with relative abundance in these areas remaining high.
- Lapwing: In 2010, lapwings were widespread throughout the central belt and Southern Uplands, but notably absent from the west of Dumfries and Galloway and South Ayrshire. The species was locally abundant in the Lammermuirs and upland areas to the west. North and east of Stirling, lapwings were widespread and abundant throughout Stirling, Perth and Kinross, Angus, Aberdeenshire, Moray and the eastern and north-east Central Uplands, and particularly abundant in the Angus Glens, Deeside, Strathspey, and Caithness. Between 1990 and 2010 lapwing distributions underwent moderate to severe declines throughout their range with particularly marked declines in Dumfries and Galloway, and South and North Ayrshire where the species is now scarce or absent from most areas. Declines were less severe in the Lammermuirs and hills to the west. Within the Central Uplands and Northwest Highlands lapwing distributions declined moderately over some large areas, but were stable or even increased in others (particularly Deeside and Strathspey). Lapwing distributions in the Hebrides, Orkney and Shetland were generally stable or showed moderate declines, except for north-west Lewis where there were severe declines and few birds now remain.
- Oystercatcher: Throughout much of its range the oystercatcher was generally stable. Distributions in some areas declined, but apart from the severe declines on the Rhins of Galloway and along the Solway Firth, as well as in some small areas along the north east coast, declines were small to moderate. Levels of oystercatcher abundance remain relatively high in many areas.
- Redshank: On the mainland in 2010, redshanks were widespread but occurred at low abundance throughout much of their range. Areas of moderate abundance remained in the Lammermuirs, Angus Glens, north east Aberdeenshire, Strathspey and parts of Caithness,

[1] https://www.legislation.gov.uk/ukpga/1994/39/contents/enacted
[2] http://www.lgbc-scotland.gov.uk/maps/

and redshanks were widespread and abundant in the Outer Hebrides, Orkney and Shetland. Between 1990 and 2010 redshank distribution underwent moderate to severe declines in most of the borders, central belt, Perth and Kinross, Angus, Aberdeenshire, Moray and eastern Highland. Distributions in western Highland, where redshanks are present at low density, appear to have been broadly stable. However, apparent increases in some small and isolated areas (e.g. Lammermuirs, and Strathspey) should be treated with caution. Redshank populations in the Outer Hebrides, Orkney and Shetland appear to be stable or moderately increasing though here, too, they are declining in some areas.

- Snipe: Snipe were widespread throughout Scotland in 1990, though occurred at low abundance over much of their range. They were largely restricted to and certainly most abundant in upland areas. Snipe occurred at very low abundance through the lowlands and arable areas of South Ayrshire, Dumfries and Galloway, the Lothians, Fife, Perth and Kinross, Angus, east Aberdeenshire, and much of Moray. Snipe were also absent from areas of extensive upland and mountainous areas. Snipe underwent slight and moderate declines throughout the borders, Southern Uplands, and central belt. Though there were slight to moderate increases in the Lammermuirs and hills to the west. Throughout Highland, south Moray and west Aberdeenshire, snipe distributions remained stable or increased moderately. There were also some slight or moderate declines, most notably around Cape Wrath. Snipe distributions in the Hebrides were generally stable or showed slight to moderate increases though there were also some small areas of decline. Snipe distributions on Orkney underwent moderate declines throughout much of the archipelago, but with increased slightly in some small and isolated areas. Snipe distributions on Shetland were largely stable or slightly increased, but with a suggestion of small declines in parts of north Mainland and north Yell. However, care is needed in interpreting the results from these predominantly coastal areas, as many tetrads are represented by very small areas of land.

Curlew

Distribution and (relative) abundance

In 2010 curlews occurred widely throughout the southern uplands and central belt, with a high abundance recorded around the Lammermuirs and hills to the west (Fig. 1(a)). However, north of the central belt, curlews were largely confined to the east (approximately north and east of Stirling, or east of 4°W). Within the Central Uplands curlews occurred mostly in the east and north-east, being most abundant around the areas of Stirling (the county), Perth and Kinross, Angus, western Aberdeenshire (Deeside), southern Morayshire (Strathdon), south of Inverness (northern Monadhliath and Strathspey). They were also found in high abundance along the east coast north of the Moray Firth; Cromarty Firth, Dornoch Firth, Strath Kildonan and north towards Wick. There was a particularly high abundance on the north east mainland, and along the north coast and Strath Halladale, Strath Naver, and around Kyle of Tongue. Similarly, curlews were widespread in the Hebrides and occurred at moderate to high relative abundance on Islay, parts of Mull, Tiree, South Uist and North Uist. Curlew were widespread and highly abundant throughout Orkney and Shetland.

In contrast, curlews were absent or occurred at low abundance in West-, Mid- and East- Lothian, and along much of the Scottish-English border as well as in some parts of Argyll and Bute, and Dumfries and Galloway. They were also absent or at low abundance throughout the western extent of the Central Uplands and North West Highlands. Likewise, they were absent or occurred at low abundance on Arran, Jura, the eastern side of Mull, Skye and, most of Lewis and Harris, except for the coastline in the north-west.

Distribution change (1990 – 2010)

Throughout their mainland distribution curlews showed widespread decline in occupancy between 1990 and 2010 (Fig. 1(b)). While, in some areas, the distribution appeared stable or to have increased, these were largely confined to areas of Caithness (e.g. Kyle of Tongue east of Strath Halladale) and south-east Highland (e.g. along the Findhorn, Strathspey, Strathdon, and Deeside) (Fig. 1(b)). There were notable declines in the central belt and areas of Dumfries and Galloway and the Scottish Borders (Fig. 1(b,c)). Curlew distributions in the southern Hebridean islands up to and including south Mull showed severe declines, while those on northern Mull and further north fared better. The distribution of curlew on mainland Orkney appeared to be stable or showed only a small reduction in numbers (Fig. 1(b,c)). In contrast, distribution declines on Hoy were severe leading to very low occupancy and, in some areas, a complete absence of curlew. The species distribution on Shetland showed limited declines and remained fairly stable with relative abundance remaining high (Fig. 1(b,c)).

In many areas where curlews have declined, current populations are now low (Fig. 1(c)). Throughout much of its range curlews are now at very low numbers or were absent in many previously occupied areas by 2010 (Fig. 1(c)). Areas within the range occupied in 1990 where there are now few or no birds remaining include west and south Dumfries and Galloway, South Ayrshire and North Ayrshire, East Lothian and the parts of the Scottish Borders, south and east of the Lammermuirs (Fig. 1(c)). There were also severe reductions in occupancy and now low populations (though not to extinction), along the north-east coast and low ground of Angus, Aberdeenshire and north Moray (Fig. 1(c)). Declines appear to have been less severe in the uplands of the Angus Glens (Glenn Isla, Glen Prosen, Glen Clova), Deeside and Strathdon (Fig. 1(c)). Though, as elsewhere on the mainland, curlew declined in occupancy many areas of the Southern Uplands, declines appeared to be less severe south of the central belt (Fig. 1(c)).

Lapwing

Distribution and (relative) abundance

In 2010, lapwings were abundant in the Lammermuirs and Moorfoot Hills to the west, and in the Tweed Valley (Fig. 2(a)). There were also areas of high relative abundance in North Lanarkshire and the north-east region of South Lanarkshire towards the Pentland Hills. North of the central belt, lapwings were largely confined to the north and east of the Central Uplands and Northwest Highlands. They were widely distributed throughout south-east Stirling, Fife, Perth and Kinross, Angus, Aberdeen, Aberdeenshire, and Moray. The species was also found at high abundance in areas of the Angus Glens, Deeside, Strathdon, Strathspey, the central Monadhliath (Findhorn River) and northern Monadhliath (Stratherrick and Strathnairn) as well as in the coastal areas of north-east Aberdeenshire, and the north coast of Moray. North of Inverness there were areas of high abundance around the Cromarty Firth, Dornoch Firth, Strath Fleet, Strath Brora, Strath Kildonan, and the north-east mainland. Along the north coast, areas of high abundance were associated with the larger river valleys; Strath Halladale, Strath Naver, and Kyle of Tongue. With the exception of Hoy, lapwings were widespread and numerous throughout Orkney and Shetland as well as along the Atlantic coasts of North Lewis and Harris. However, of all the Hebridean islands they were most abundant in the Uists, Coll, Tiree and Islay. In contrast, lapwings were absent or occurred at low abundance in the west of the North West Highlands, western parts of the Central Uplands and much of Argyll and Bute and southern parts of South Ayrshire, western Dumfries and Galloway and parts of the Southern uplands between Peebles and Langholm.

Population change (1990 – 2010)

With a few exceptions lapwing occupancy underwent widespread decline throughout their range between 1990 and 2010 (Fig. 2(b)). Lapwing distributions in the Southern Uplands and central belt appear to have declined most, with exceptional declines in Dumfries and Galloway, North-, South-, and East- Ayrshire (Fig. 2(b,c)). There were also severe declines to low or zero occupancy in the Scottish Borders and Lothians, though occupancy in some isolated areas of the Lammermuirs numbers were stable or increased (Fig. 2(c)). Lapwing distributions also declined in large parts of the Central Uplands and Northwest Highlands, though declines were generally less severe than in the central belt and Southern Uplands (Figs 2(b,c)). Areas of stability occurred throughout Aberdeenshire and Moray, and there were distribution increases in some (relatively small and isolated) areas of the Angus Glens, Deeside, Strathdon, Strathspey and central and northern Monadhliath, and the north-east mainland (Fig. 2(b)). There were also moderate declines in Orkney, though lapwing populations here were moderately abundant in 2010 (Figs 2(b,c)). There were some isolated pockets of decline in Shetland, but these were not severe (Figs 2(b,c)). Similarly, there were moderate to severe declines (though not to extinction) throughout the Hebrides (Figs 2(b,c)).

Oystercatcher

Distribution and (relative) abundance

Oystercatchers were very widespread and abundant throughout the Southern Uplands and central belt, though notably absent or at low abundance in some areas of Dumfries and Galloway and South Ayrshire (Fig. 3(a)). The species also occurred very widely and at high to very high levels of relative abundance throughout Falkirk, southern Stirling, Perth and Kinross, Angus, Aberdeenshire and Moray. Relative abundance of oystercatcher was particularly high along Glen Isla, Glen Prosen, Glen Clova and Glen Esk and the low ground to the east of the Angus Glens. Oystercatchers were also notably abundant in Deeside, Strathspey, and Strathdearn and Strathnairn in the Monadliadh. North of the Great Glen, mainland populations with high to very high abundance were largely confined to Cromarty Firth, Dornoch Firth, Strath Fleet, Strath Bora, and Strath of Kildonan. There was also a large area of high abundance on the north-east mainland in Caithness. Strath Halladale, Strath Naver, Kyle of Tongue, Loch Hope, Strath More, and Loch Eriboll also supported moderate to high numbers of Oystercatcher. Oystercatchers were also numerous along the mainland west coast from Cape Wrath south to the Stranraer peninsula with some notable areas of high abundance on the Assynt peninsula, Loch Broom, and Loch Torridon and the Applecross peninsula. Oystercatchers were common throughout the Hebrides, though occurring at higher abundance along the coastline. The species was ubiquitous and abundant on Orkney (except for in the north west part of Hoy) and was particularly abundant throughout Shetland.

Distribution change (1990 – 2010)

The Scottish oystercatcher distribution has generally, although the change map shows areas of regional and localised decline and increase distributed throughout its range (Fig. 3(b)). Along the English-Scottish border and in the Southern Uplands there were pockets of moderate to severe decline along the coast and inland of the Solway Firth (e.g. Wigtown Bay, Kirkcudbright Bay, Blackshaw Bank) and on the Stanraer peninsula, where declines were particularly severe and populations likely declined to extinction (Figs 3(b,c)). There were pockets of distribution increase in some areas of the Scottish Borders (the Lammermuirs and Tweed Valley), Mid Lothian, West Lothian, and North Lanarkshire, south Fife and west Stirling (Fig 3(b)). However, there were notable declines in east Fife. Areas of distribution change in the north-east were too sparse to identify many distinct areas of marked change, butdistrbutions in small areas of Deeside, Strathspey and Caithness appear to have increased.

The largest contiguous extent of decline occurred in north east and north Aberdeenshire and along the north coast of Moray, Black Isle, Cromarty Firth and Dornoch Firth. However, there was only a moderate decline over this large area so the population did not decline to zero and the area was interspersed with areas of distribution increase (Fig. 3(c)). Oystercatcher distribution on Orkney appeared stable, albeit with areas of decline on the western mainland and Westray and Stronsay Firths.

Redshank

Distribution and (relative) abundance

Redshanks were widespread but sparsely distributed throughout Scotland in 2010 (Fig. 4(a)). They were most numerous along the coast of the Solway Firth, Firth of Forth, Firth of Tay, and along the east coast of Angus, the east and north coasts of Aberdeenshire, the Beauly Firth, Cromarty Firth and Dornoch Firth, and along the east coast of Highland. They were particularly abundant on the north east mainland, Caithness, around Lybster, Wick and Thurso. Areas of relatively high abundance on the mainland included the Lowther Hills, Moorfoot Hills, Lammermuirs Hills, Glen Esk, Strathbogie, and Strathspey. Apart from on Hoy, redshanks were abundant throughout Orkney and Shetland. Redshanks occurred at low abundance in the Inner Hebrides except on Tiree where they were very abundant. Redshanks occurred at moderate abundance in the north of Lewis, but at quite low abundance in the south of Lewis and on Harris. However, they were abundant on the Uists as well as on other Outer Hebridean islands.

Distribution change (1990 – 2010)

Redshank distributions that occurred at very low abundance in eastern Highland and Argyle and Bute appeared largely stable between 1990 and 2010 (Fig. 4(b)). However, it should be noted that assessment of change in small pockets of occupancy is very difficult. With a few isolated exceptions redshank appear to have declined in distribution across much of their range along the Scottish-English border, Southern Uplands, central belt, Perth and Kinross, Angus, Aberdeenshire, Moray and eastern and north east Highland. Although there are large areas of moderate decline where redshanks probably still persist, many areas of declines in Dumfries and Galloway, the Scottish Borders and central belt appear to have been severe and redshanks are probably now extinct in areas of Lanarkshire, West Lothian, and south east of Dumfries and Galloway (Fig. 4(c)). Large areas of moderate decline through Perth and Kinross, Angus, Aberdeenshire and Moray are interspersed with localised patches of severe decline which probably represent areas where redshank are locally extinct. While some small and isolated areas may have experienced population increases (e.g. in the Lowther Hills, Lammermuirs, Strathmore, Deeside and north east Aberdeenshire) (Fig. 4(b)) caution is needed interpreting these apparent trends. Redshank numbers in the Inner Hebrides appear to have been generally stable. Redshank numbers increased in the north of Lewis and North Uist, but declined in central Lewis. Redshank distribution has generally increased throughout Shetland.

Snipe

Distribution and (relative) abundance

Snipe were widespread across Scotland, but (at least on the mainland) generally occurred at greater abundance in the uplands than in the lowlands (fig. 5(a)). In the borders, Southern Uplands, and central belt snipe were most abundant in the Lowther Hills, Pentland Hills, Moorfoot Hills, Cheviot Hills, and particularly abundant in the Lammermuirs. North of the central belt, snipe occurred at low abundance along the coast through the lowlands of Fife, Perth and Kinross, Aberdeenshire, and Moray. Snipe occurred at moderate abundance throughout the Perthshire hills, Angus Glens, and Central Uplands. However, their abundance was lower in some of the more extensive areas of high ground in the Cairngorm Mountains, Monadhliath, the Glen Feshie Hills, Torridon hills, and other mountain ranges, such as the Fisherfields, to the west. On the mainland, snipe were most abundant in the Flow Country of Caithness. Snipe were widespread and abundant throughout the Hebrides, but most abundant on Tiree and the Outer Hebrides. They were also abundant throughout most of Orkney, and very abundant throughout Shetland.

Population change (1990 – 2010)

Between 1990 and 2010 snipe underwent moderate to severe declines throughout much of their southern distribution in Dumfries and Galloway, the Scottish Borders, East Ayrshire and South Lanarkshire (Figs 5(b,c)). In parts of west and south east Dumfries and Galloway, declines were sufficiently severe to have resulted in the local loss of snipe in these areas (Fig. 5(c)). However, there appear to have been some distribution increases in the Lammermuirs and other hills to the west (Fig. 5(b)). North of the central belt, snipe populations appear to have been largely stable or increased throughout much of the Central Uplands and Northwest Highlands, though there were declines in some small and isolated parts of this areas. There were marked declines in some areas around Glen Esk, lower Strathspey, and most notably around Cape Wrath and Strath Shinary. Snipe numbers in the Hebrides were more or less stable, though with notable areas of moderate decline on Islay, north-west Skye, and North Uist, and some areas of moderate increase on Mull, and south Lewis. Between 1990 and 2010 the snipe distribution on Orkney underwent extensive declines, but because of the high occupancy at the start of this period, numbers remained relatively high (Fig. 5(c)). The snipedistributions of Shetland remained stable or showed slight to moderate increases, though there were also slight declines in some areas (Fig. 5(b)).

Comparison with local atlas data

A rigorous comparison of the results of the analyses of bird atlas data and local atlas data is beyond the scope of the current work and would be confounded by the inclusion of bird atlas data in the results of local atlas data. For curlew in northeast Scotland both the bird atlas and local atlas data show that are most abundant in west Aberdeenshire and south Moray (Figs. 1(a), A1(a)). Similarly, a comparison for lapwing shows that both atlases indicate lapwing are most abundant in west and the northeast coat of Aberdeenshire, south Moray (Figs 2(a), A1(b)). Local atlas and the breeding atlas data from Fife and Tayside both show that both curlew (Figs 1(a), A1(c)) and lapwing (Figs 2(a), A1(d)) are most abundant in the Angus Glens, and upland areas to the west of Perth.

Discussion

Farmland waders have undergone severe and widespread declines in the UK and now represent some of the highest bird conservation priorities. This analysis supports previous findings (Harris et al.

2017, Eaton et al. 2015, Balmer et al. 2013, Foster et al. 2013) that farmland waders have undergone widespread ad often severe declines. However, our analysis also shows where declines have been less severe and where distributions appear stable or increasing.

The main patterns of abundance and change described in this report are based on high quality and reliable information. However, care should be taken not to place too much emphasis on modelled values within individual tetrads. At this resolution, atlas survey data (being based on 1 hour of recording within an area of 4 km^2) are inherently noisy, with substantial variation between atlas counts for different squares being due to random chance. Although the modelling process will have had the effect of smoothing out some of this noise, modelled values should not be interpreted literally as meaning that a particular square has an especially high or low value. Where similar values of modelled data are spatially aggregated, suggesting patches of high or low values, interpreting these as representing real patterns on the ground is likely to be justified. One caution to note in this context is that, despite the measures we have taken to reduce the influence of large, non-breeding flocks on our models, spatial patterns of abundance in some coastal areas with confirmed breeding may be influenced by the presence of non-breeding birds. Finally, measures of relative abundance for Snipe may not be comparable with those for other species. This is due to the fact that this species is likely to have been detected much less reliably, when present, than other species of breeding wader. However, intra-specific assessment of spatial patterns in relative abundance and change should be reliable. In addition, a visual comparison with local atlas data for curlew and lapwing for northeast Scotland and Fife & Tayside show no major differences.

The severe and widespread decline of farmland waders has triggered intense conservation efforts to halt and ultimately reverse these declines. This includes the Scottish Government's current Agri-Environment Climate Scheme (AECS) that promotes land management practices that protect and enhance Scotland's natural heritage, improve water quality, manage flood risk and mitigate and adapt to climate change[3], support the delivery of the 2020 Challenge for Scotland's Biodiversity, while supporting agricultural production. This includes significant investment in measures designed to benefit the waders of conservation concern. In the current SRDP, the eligibility for funding for AECS options has been targeted, so that the money is allocated to areas where it is more likely to have beneficial impacts. Previous analyses show that in general, wader-related AECS options are more likely to be taken up in areas where waders are present and, to a lesser degree, that the more waders there are, the more likely it is that wader options will have been taken up (Newey et al. 2018). However, the extent and severity of wader declines and the urgent need for effective conservation means that better targeting of a range of conservation measures from national government AECS schemes to local wader conservation initiatives will be needed and will need to be targeted where success and benefits are most likely. Here we have mapped the distribution and population changes of the five priority farmland waders to provide information to better inform the targeting of wader conservation measures.

Conservation efforts for waders are more likely to be successful where there is still an effective breeding population or in areas of suitable habitat surrounded by areas that maintain a healthy breeding population. Therefore, while the constraints of the data and analyses mean that it is not possible to identify precise localities the analysis can be used to identify broad geographic areas

[3] https://www2.gov.scot/Topics/farmingrural/SRDP

where conservation and management efforts could be targeted. For example; although curlew and lapwing populations have declined throughout much of their ranges, populations appear to be stable or increasing in parts of Deeside, Strathspey, and north-east Aberdeenshire indicating that these areas are at least able to support these species and suggests that conservation actions may benefit waders in these areas. Similarly, though oystercatchers have undergone widespread declines, the analyses suggest that populations in the central belt, Angus and Aberdeenshire, where there was pattern of localised moderate declines and increases, there are likely areas with beading birds that may respond to management and act as source populations to repopulate suitable aras. All five of the species included in these analyses show high abundance and healthy populations in Caithness and Shetland, and conservation efforts in these areas might best be aimed at securing and expanding the range of these populations in the wider landscape.

The results of these analyses can be refined to suit different research and management needs, and the requirements of specialist stakeholder groups. In particular, we envisage that the cooling maps, that indicate both the severity of decline and remaining breeding population can be tailored to better meet the needs of different stakeholder groups by, for example, defining zones. These could be based on categories defined by threshold levels of both abundance and change, potentially incorporating information from other relevant sources such as land use or elevation. Such zones could be used to classify large areas according to relevant information related to wader populations, and aimed at planning and directing the activities of one or more groups of stakeholders.

The results of the current analyses can also be compared and contrasted with a wide range of other spatial data sets, to explore and assess environmental and management landscape level correlates of population change. Overlaying distribution and population change maps with data on land use, intensity of management, SRDP targeting, land potential, and for example renewable energy development, and wader conservation projects all have the potential to better inform management and conservation actions by allowing stakeholders to see where limited resources might best be targeted.

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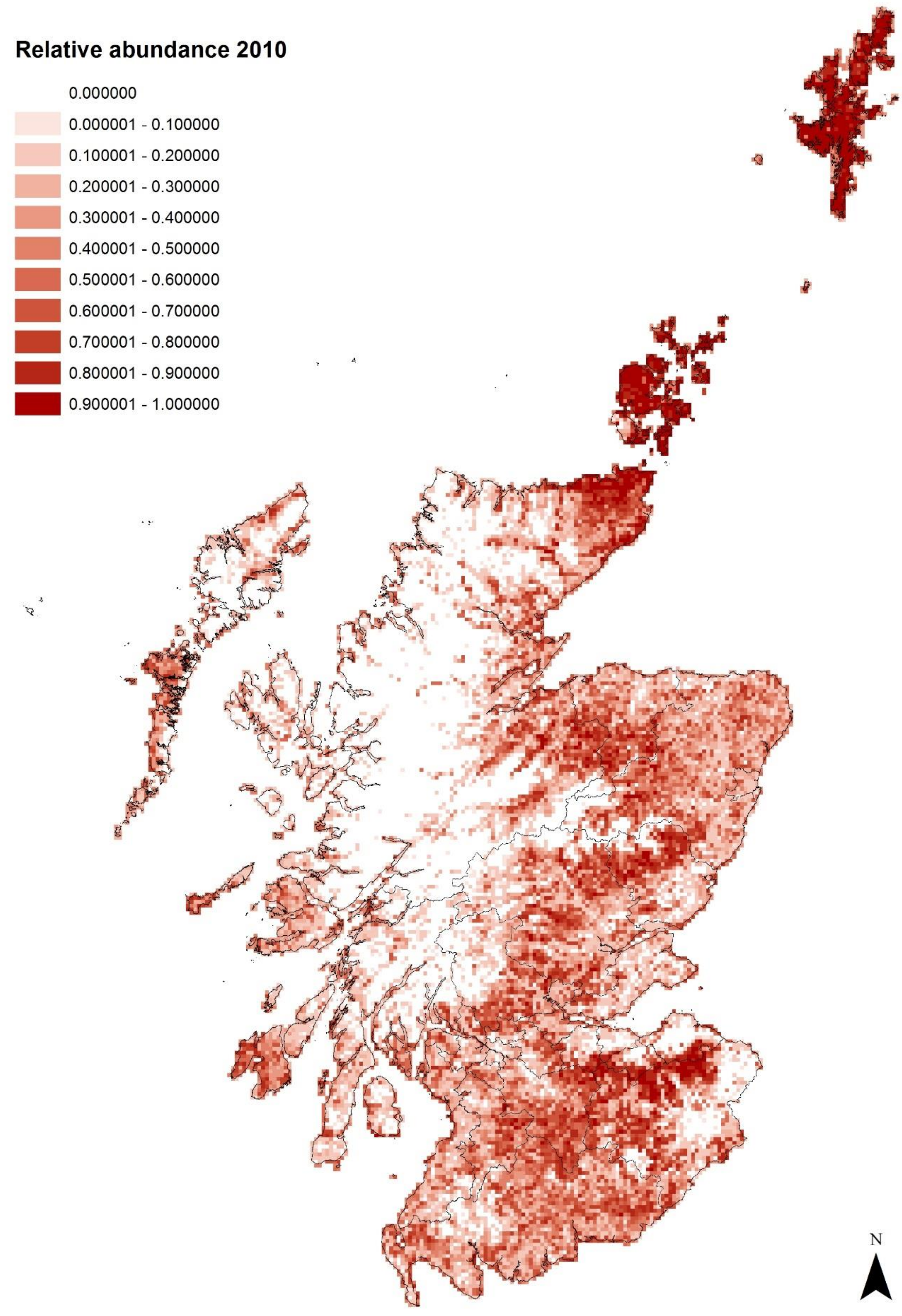
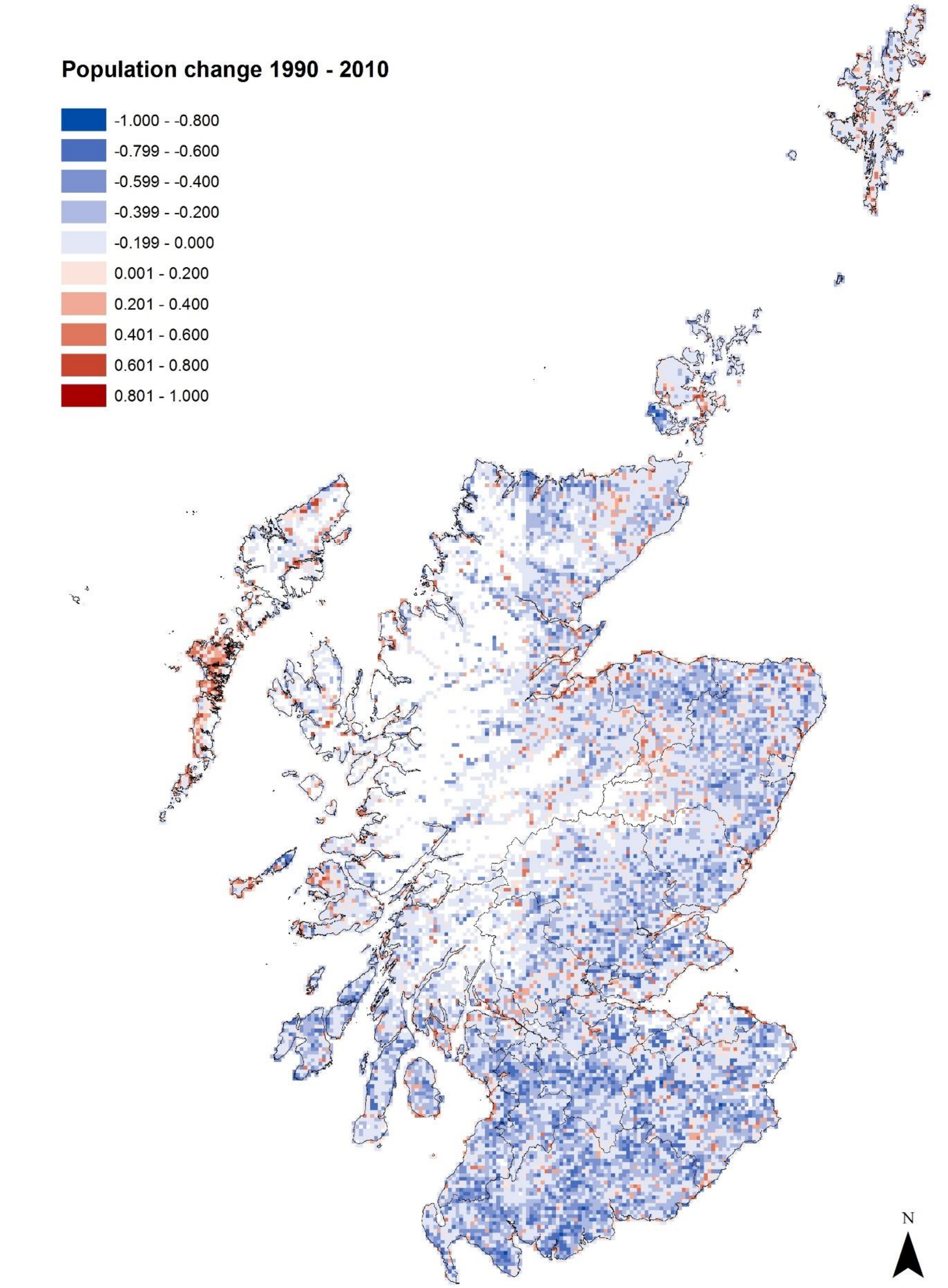
Figures

1(a). Curlew – Modelled relative abundance in 2010



1(b). Curlew – estimated distribution change from 1990-2010.



1(c). Curlew – estimated population cooling (percentage decline in occupancy and remaining population)

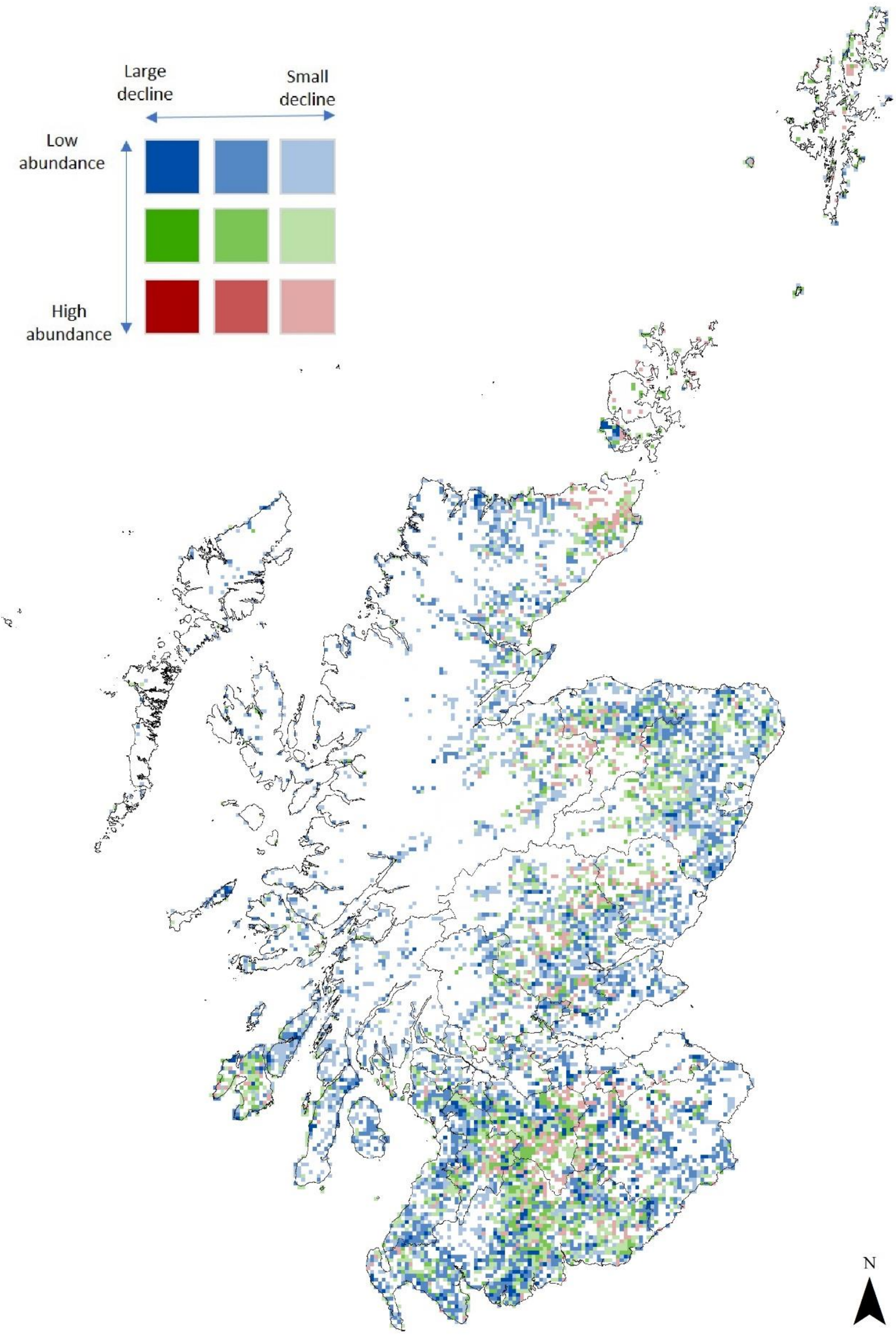
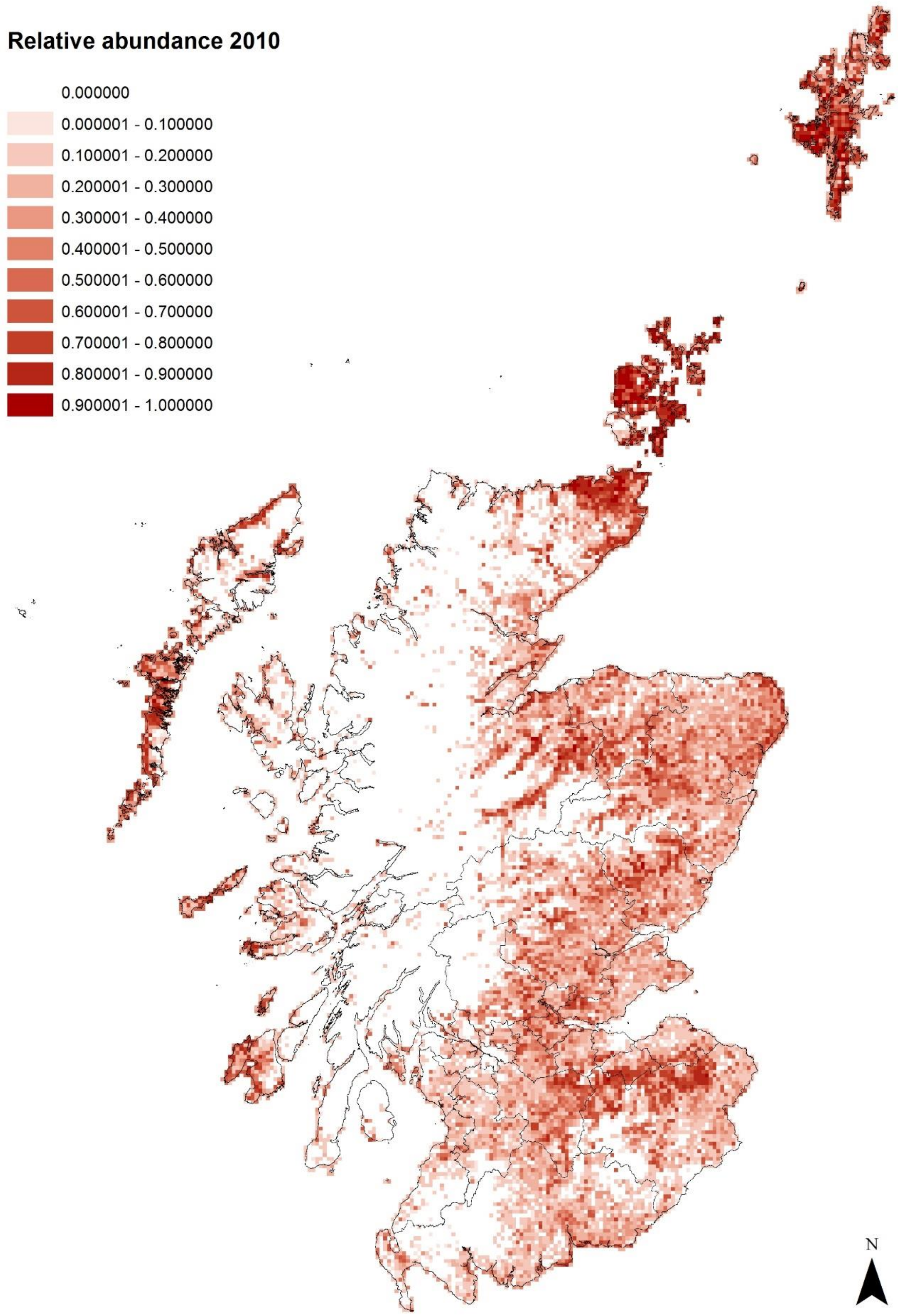
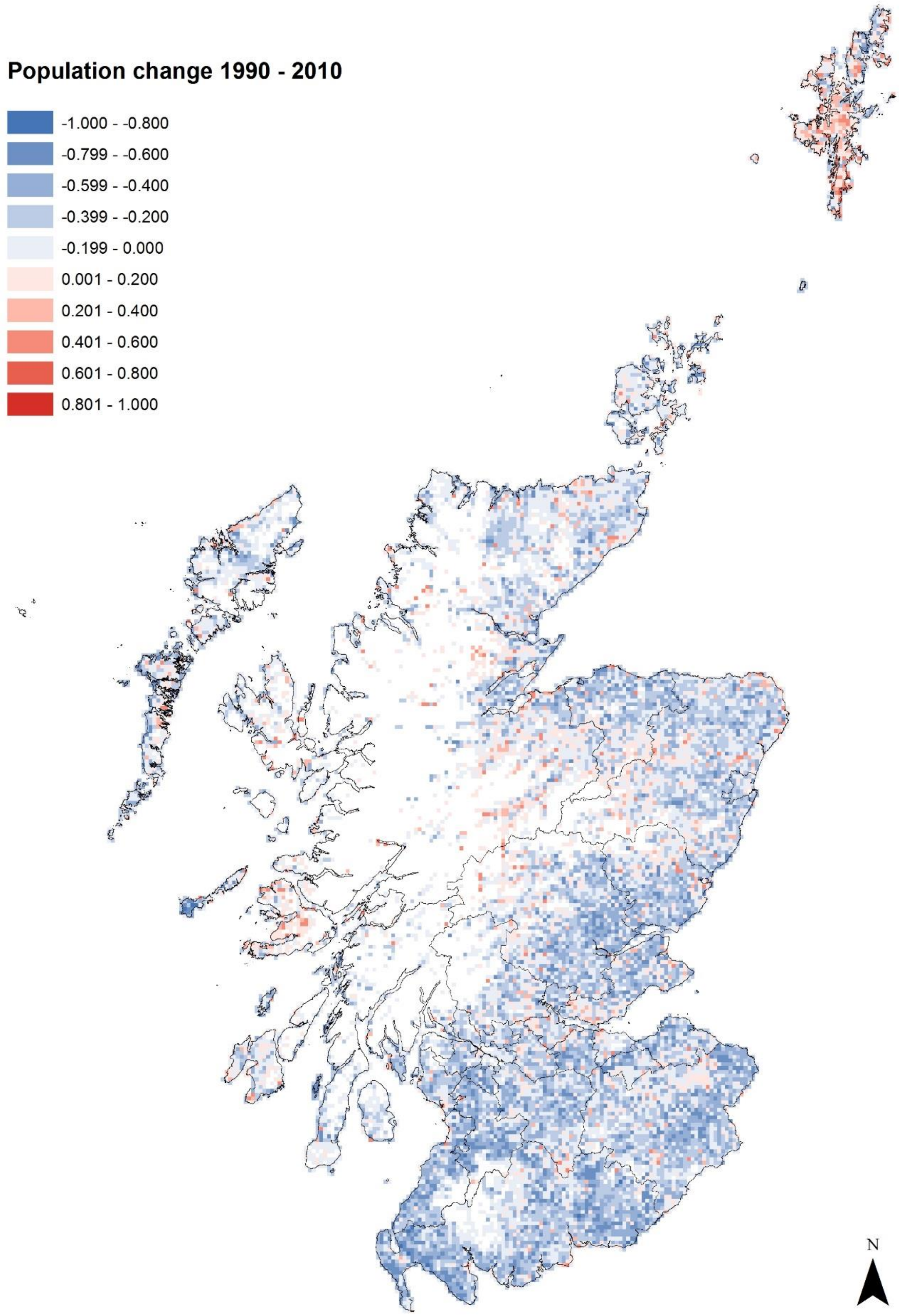


Figure 2. (a) modelled distribution, (b) estimated distribution change between 1990-2010, and (c) estimated population cooling showing the estimated percentage decline and severity of population declines, for lapwing for each breeding bird atlas survey tetrad in Scotland.
2(a). Lapwing – Modelled relative abundance in 2010



2(b). Lapwing – estimated distribution change from 1990-2010.



2(c). Lapwing – estimated population cooling (percentage occupancy decline and remaining population)

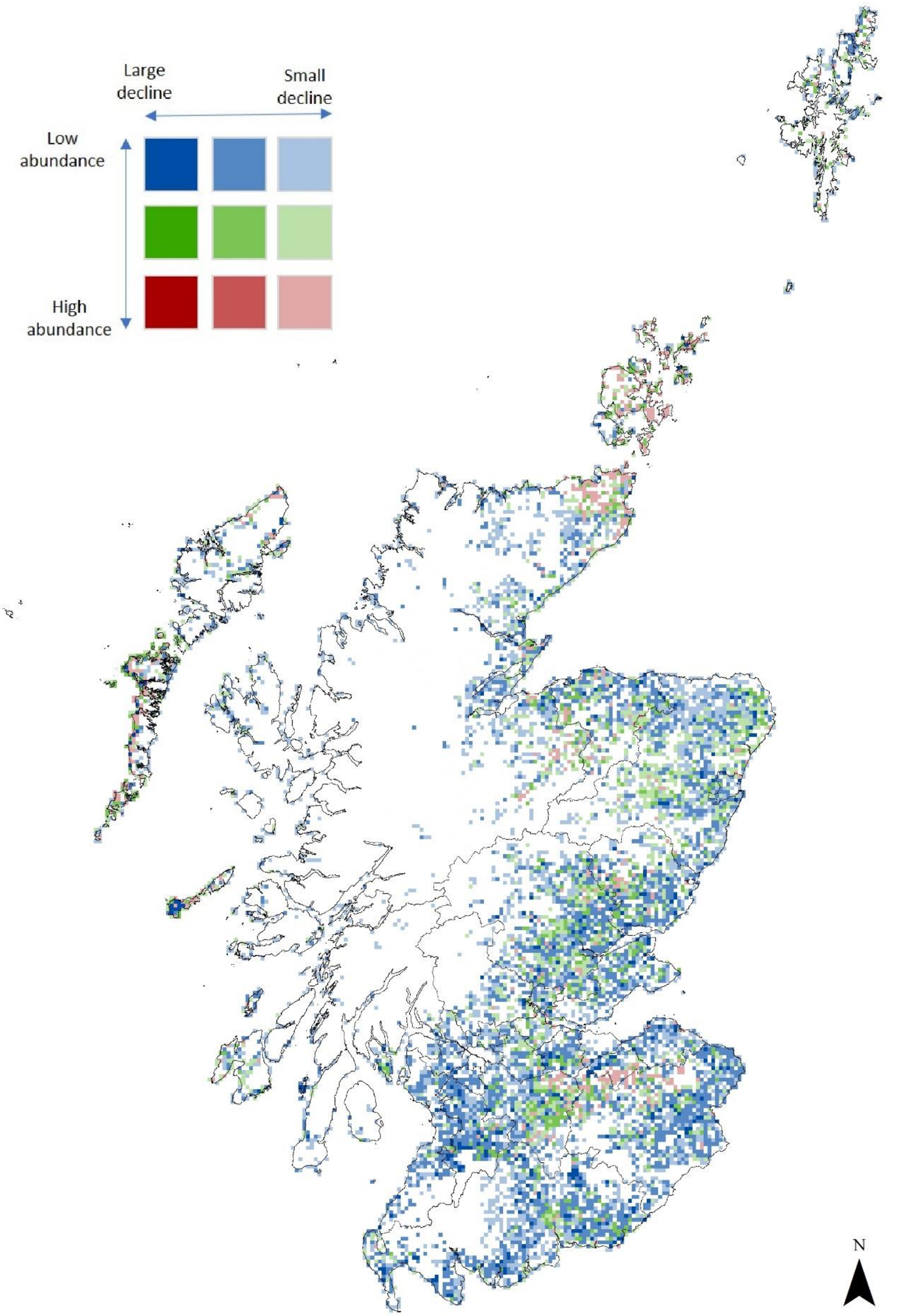
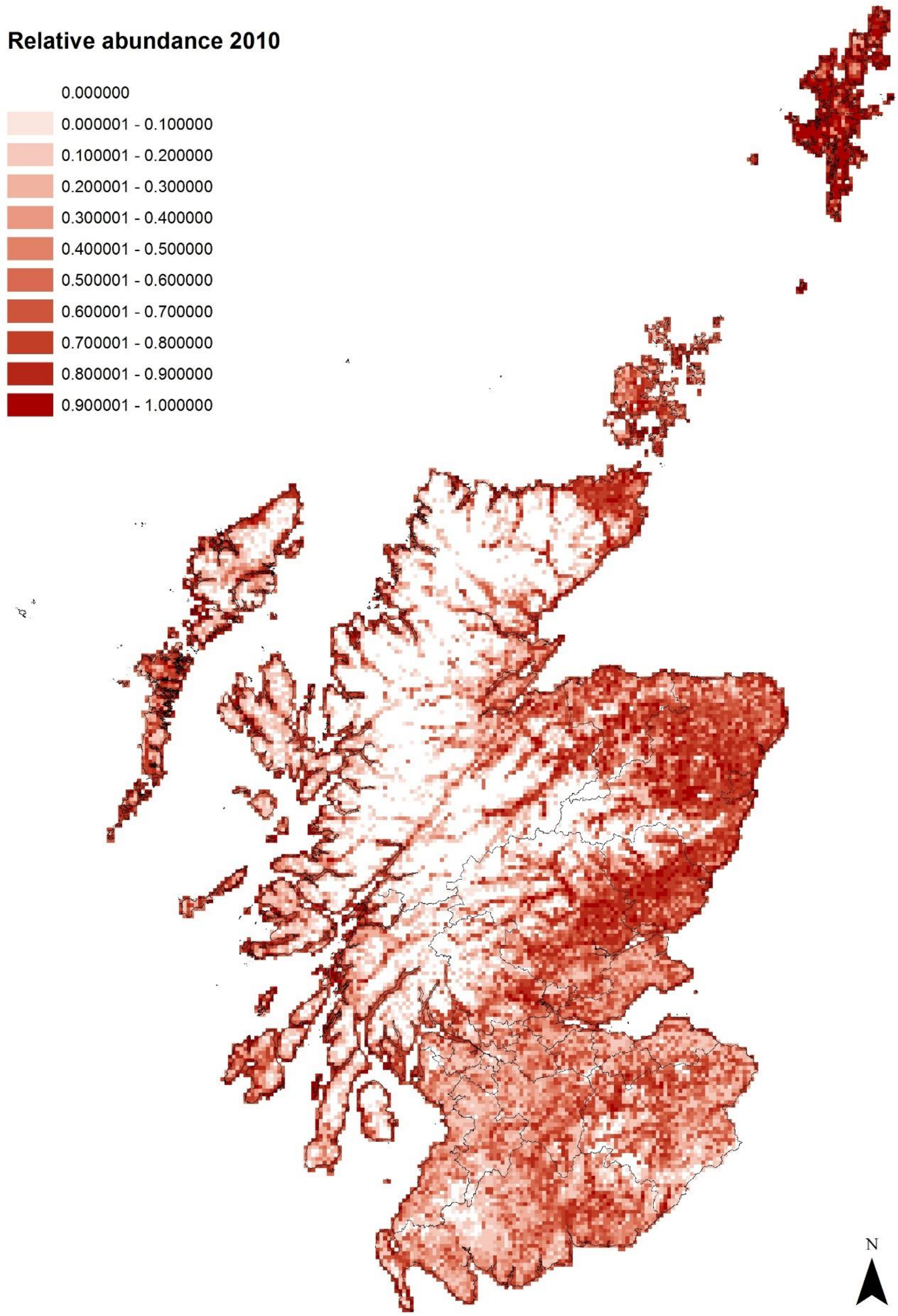
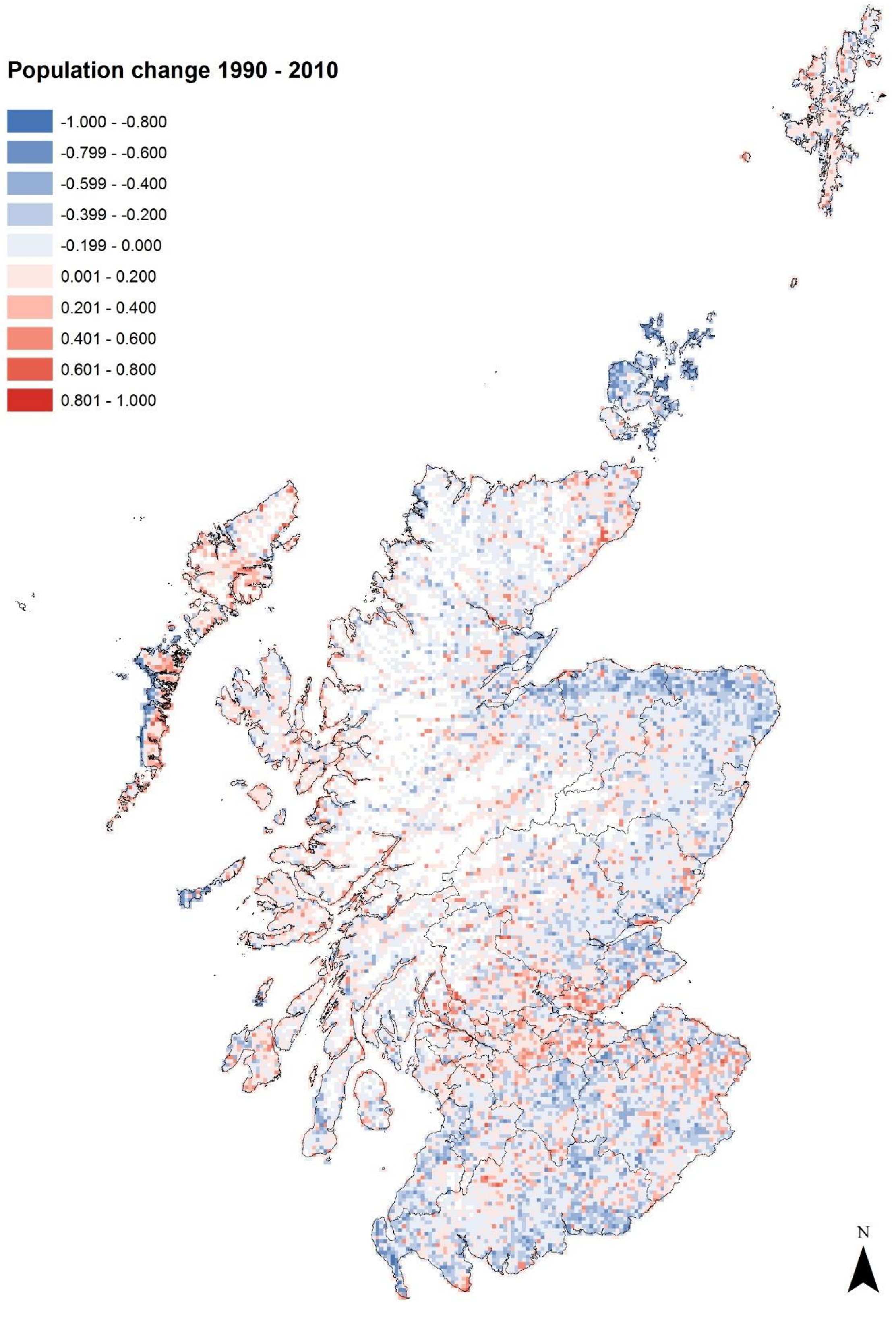


Figure 3. (a) modelled distribution, (b) estimated population change between 1990-2010, and (c) estimated population cooling showing the estimated percentage decline and severity of population declines, for Oystercatcher for each breeding bird atlas survey tetrad in Scotland.
3(a). Oystercatcher – Modelled relative abundance in 2010



3(b). Oystercatcher – estimated population change from 1990-2010.



3(c). Oystercatcher – estimated population cooling (percentage decline and remaining population)

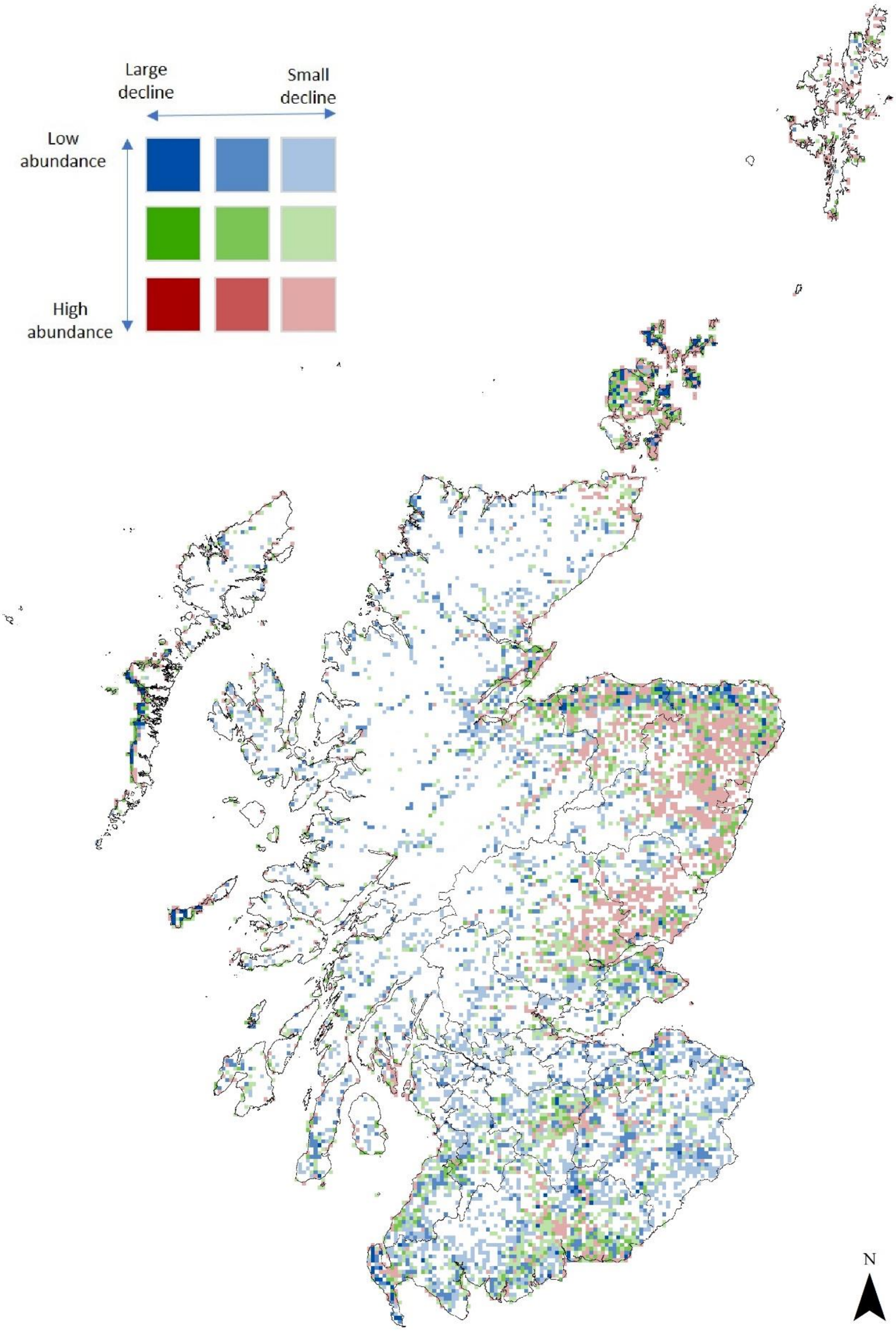
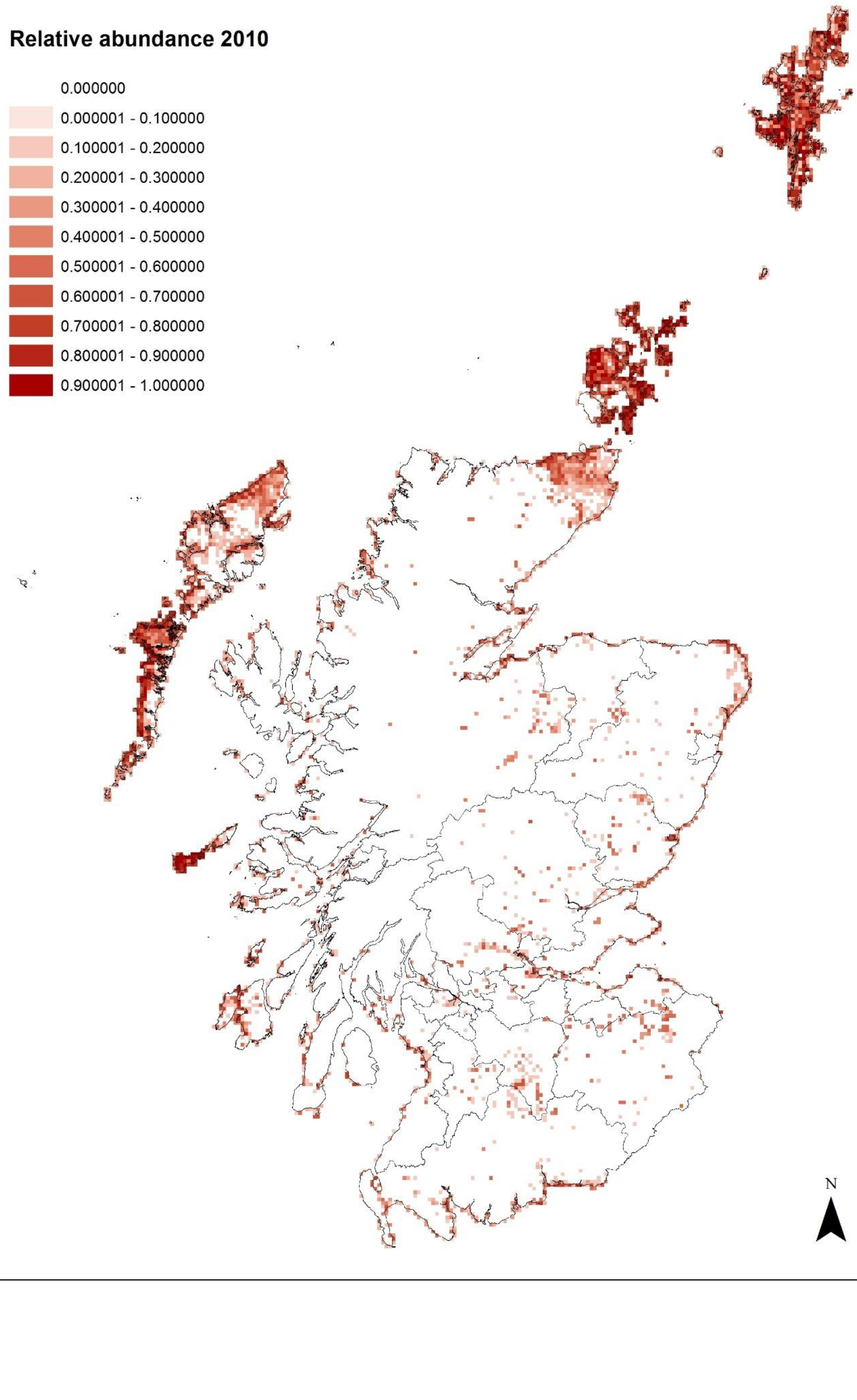
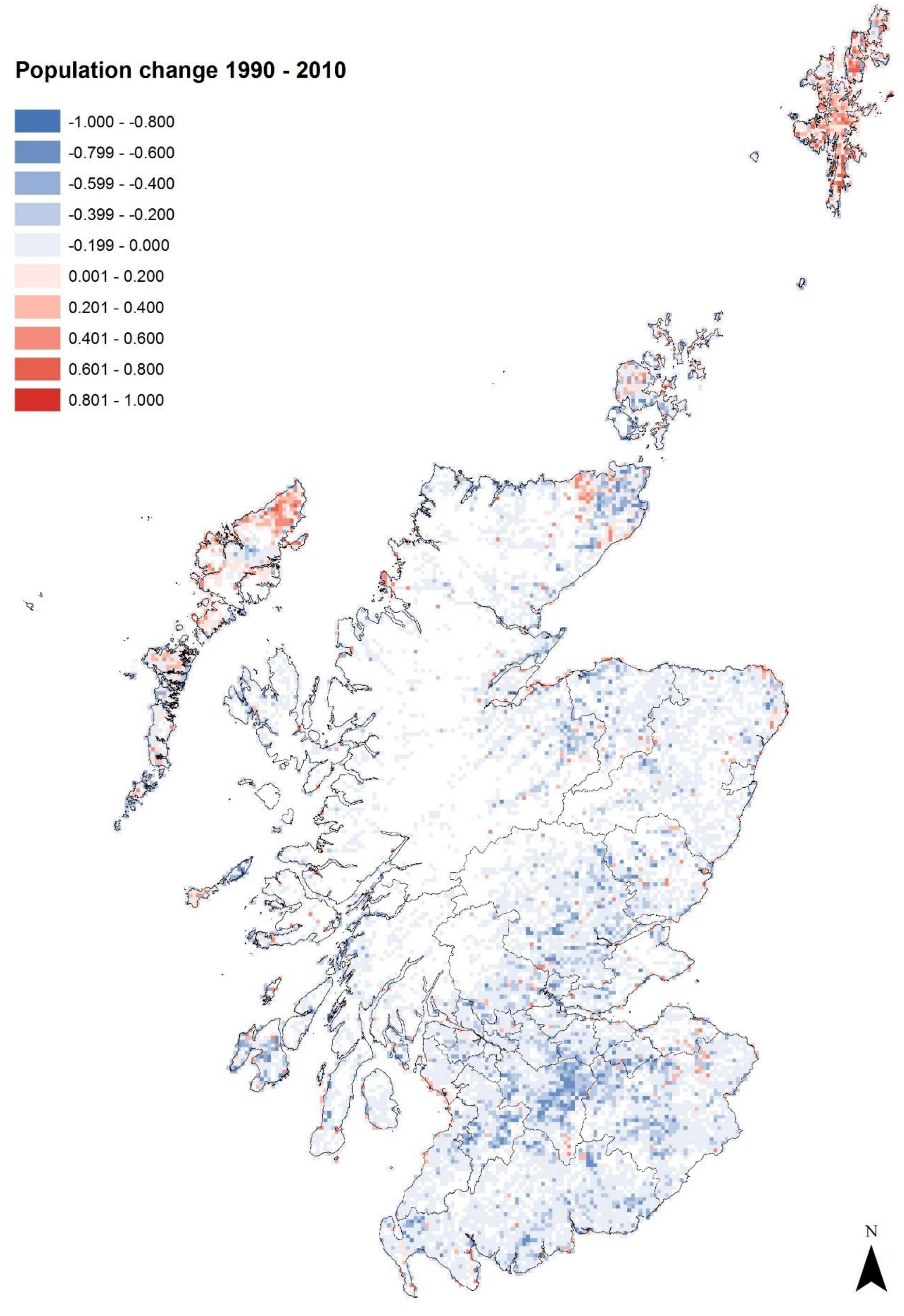


Figure 4. (a) modelled distribution, (b) estimated population change between 1990-2010, and (c) estimated population cooling showing the estimated percentage decline and severity of population declines, for redshank for each breeding bird atlas survey tetrad in Scotland.

4(a). Redshank – Modelled relative abundance in 2010



4(b). Redshank – estimated distribution change from 1990-2010.



4(c). Redshank – estimated population cooling (percentage occupancy decline and remaining population)

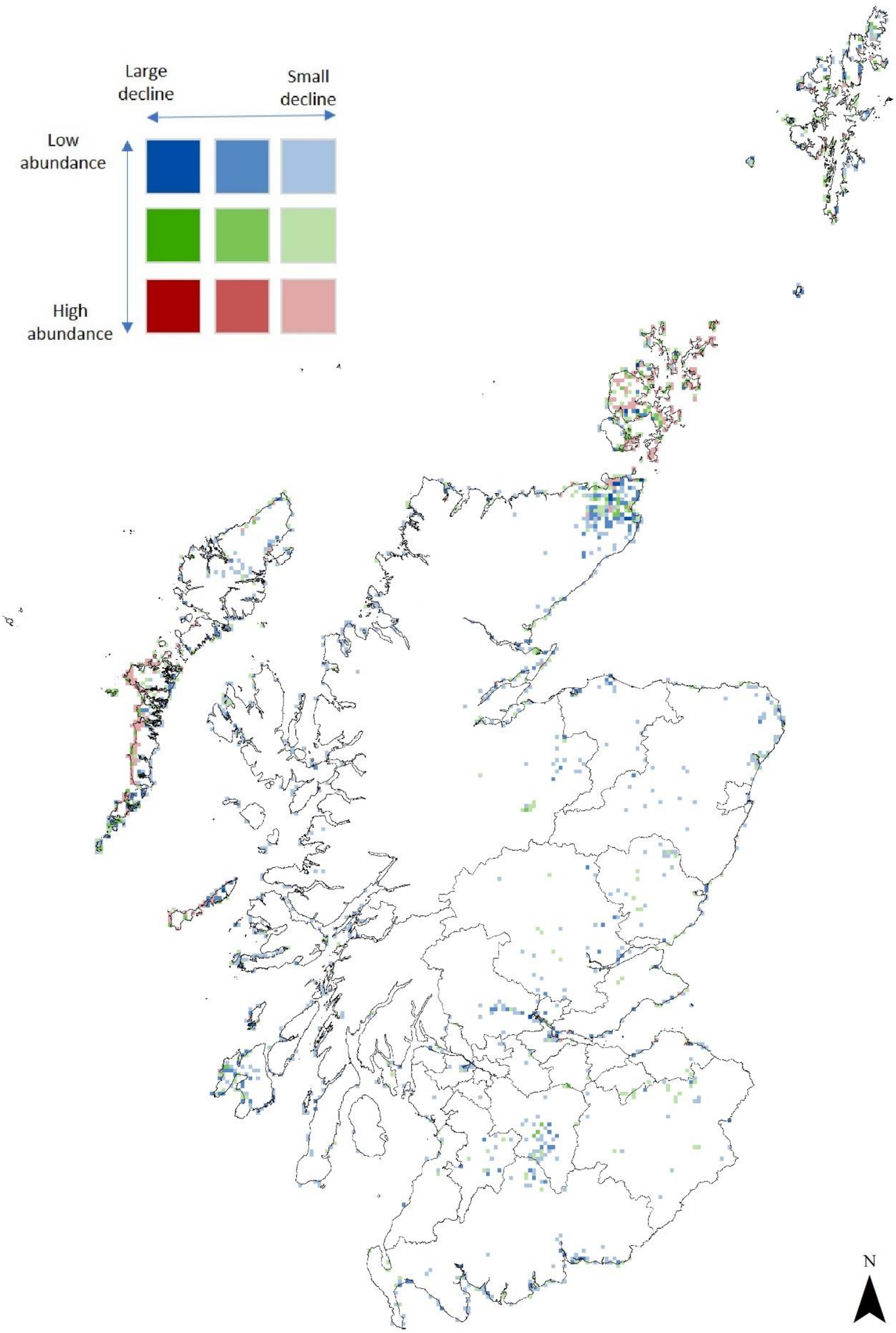
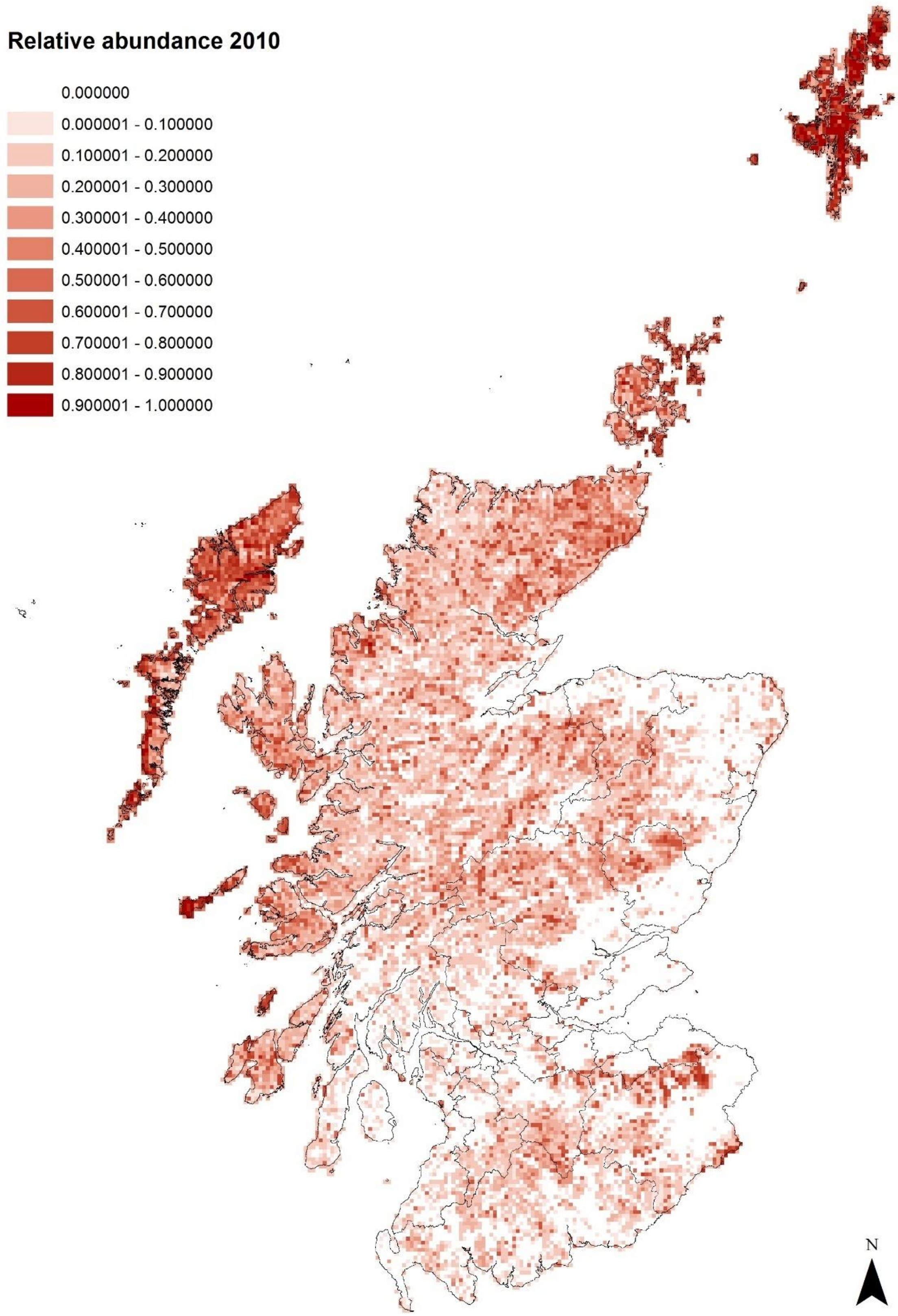
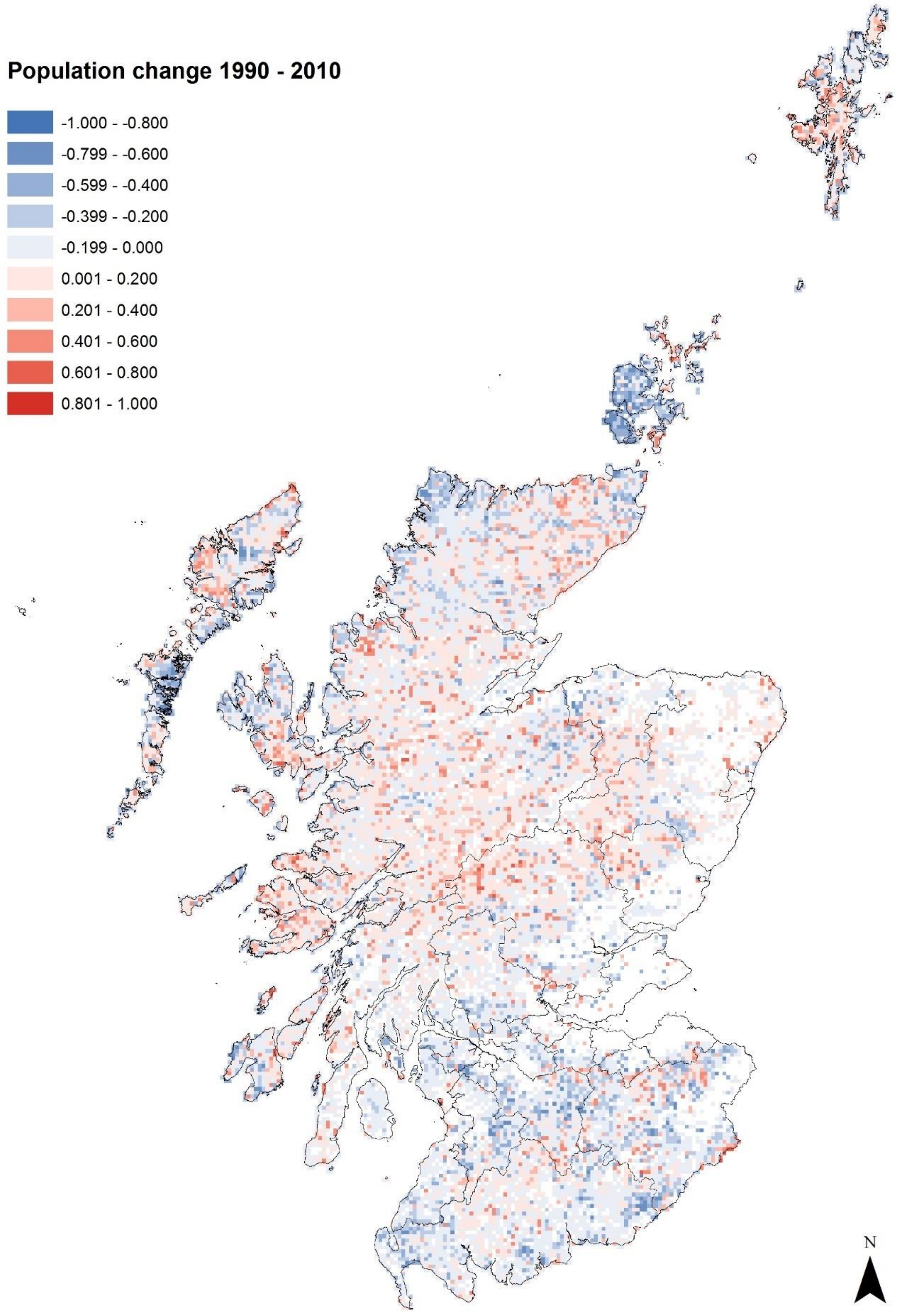


Figure 5. (a) modelled distribution, (b) estimated population change between 1990-2010, and (c) estimated population cooling showing the estimated percentage decline and severity of population declines, for snipe for each breeding bird atlas survey tetrad in Scotland.

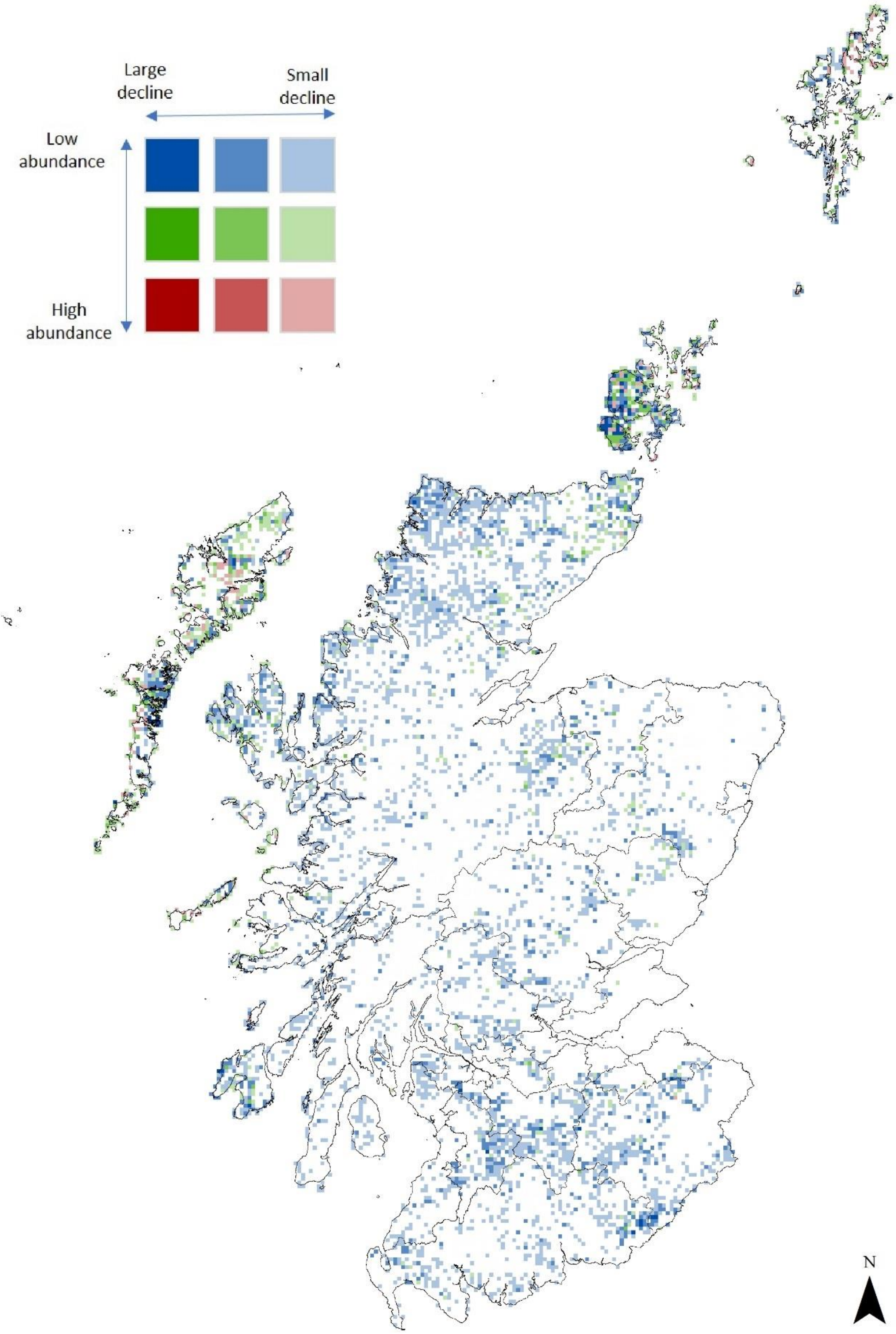
5(a). Snipe – Modelled relative abundance in 2010



5(b). Snipe – estimated distribution change from 1990-2010.



5(c). Snipe – estimated population cooling (percentage decline and remaining population)



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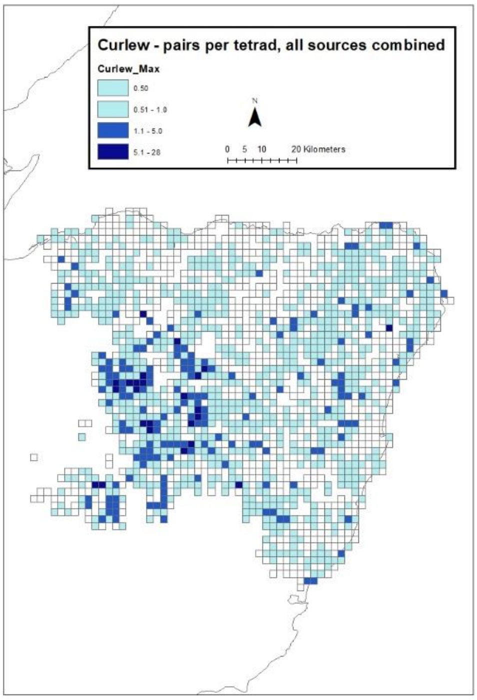
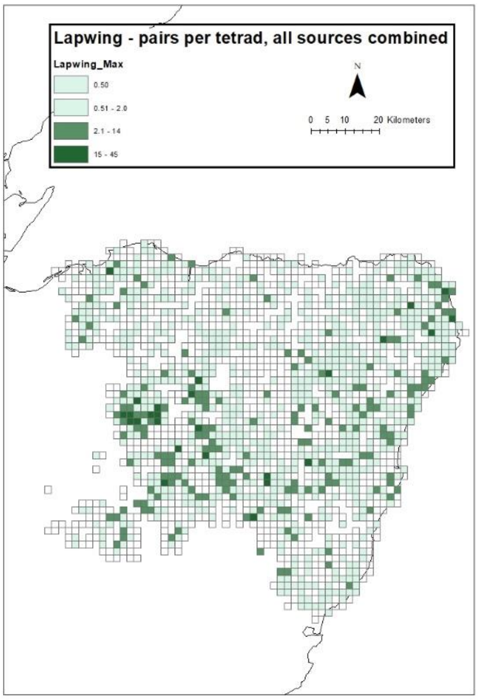
Appendix 1: Local Atlas Data and Comparisons

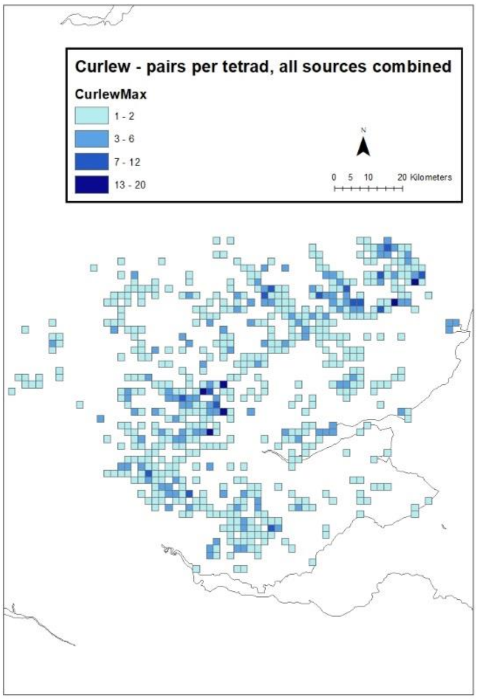
A1a. Curlew – Northeast Scotland



A1b. Lapwing – Northeast Scotland



A1c. Curlew – Fife & Tayside



A1d. Lapwing – Fife & Tayside

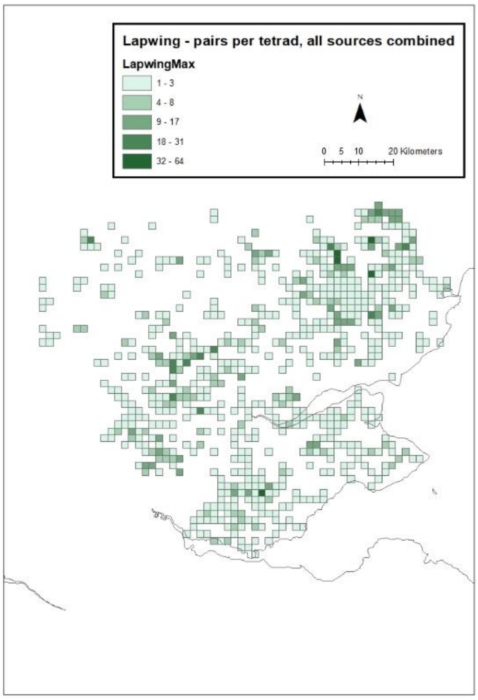


Figure A1. Abundance of (a) curlew and (b) lapwing in northeast Scotland, and (c) curlew and (d) lapwing in Fife & Tayside based on local bird atlas data.