

Report on the observed climate, projected climate, and projected biodiversity changes for *Ragain?s vings* under differing levels of warming

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Contents

Acknowledgements	3
Executive Summary	4
Supporting Information	6
Overview	7
Climate	7
Average Monthly High Temperature (usually the temperature of mid- to late-afternoon) .	8
Average Monthly Temperature	9
Average Monthly Low Temperature (usually the temperature just before dawn)	10
Precipitation	11
Drought/Waterlogging	12
Population	13
Landcover changes	13
Biodiversity	14
Local Extinction Risk	14
Species Richness Remaining	15
Refugia	24
Adaptation Effort	34
More Detailed Information	43
Climate	43
Climate Variables	44
Population Data	46
Landcover Changes	47
Biodiversity	47
Developing robust adaptation plans in the light of climate projection uncertainties	49
Literature Cited	50

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Executive Summary

Climate change threatens the world's major centres of biodiversity, jeopardising many of the collective conservation and development efforts and investments to date. Observed changes, and the amount of climate change that society and ecosystems are already committed to, indicate that climate change is already damaging ecosystems and livelihoods, and that the amount of damage is increasing over time.

Protected Areas have long played a role in the maintenance and conservation of biodiversity. They appear as Target 3 in the Convention on Biological Diversity's 2030 Kunming-Montreal Global Biodiversity Framework with a recommendation of setting aside 30% of each country's land for biodiversity. However, many protected areas were not specifically set aside for biodiversity and many conservation strategies have largely been developed under the assumption that the world's climate will stay static (i.e., not change). A changing climate in tandem with other existing and future human pressures means there is a high risk that these strategies will fail in their goals.

Outside of a few areas, and/or specific protected areas, access to protected area specific information on observed climate changes, projected climate changes, and how biodiversity is projected to change, have not been readily available. Extraordinary outside pressures (e.g., resource extraction) can drastically limit the ability of an area to persist under the additional pressures from climate change – or to act as a refugium for species under increasing levels of climate change.

Reducing biodiversity's vulnerability to climate change requires an understanding of the projected magnitude of the risks. These can be estimated from models of the climatic range relationships of more than 135 000 species of terrestrial fungi, plants, vertebrates, and invertebrates as we have done in the Wallace Initiative. In areas where future climate change is projected to exceed the modelled climatic tolerance of many species, the species currently present may not be able to persist into the future. On the other hand, there are places where the climatic tolerance of most species is not exceeded by projected climate change, and we classify these as refugia (areas remaining climatically suitable for >75% of the terrestrial biodiversity in that area). **These may be the best places to protect to conserve biodiversity (also known as no-regrets action) in the future despite climate change (i.e., arks).**

It is not just the species that are being conserved, but also the ecosystem services they provide. For example, acting as seed banks, providing natural food resources, nurseries for wild species, and homes for pollinators, as well as performing important processes that have large scale benefits such as carbon storage, air purification, water collection and purification, flood mitigation and soil conservation (Price et al., 2024b).

The Wallace Initiative classifies *Ragain's vingis* in the Republic of Lithuania as being in the bottom 13% of all non-marine protected areas in the World for projected overall biodiversity resilience to climate change at 4 °C warming above pre-industrial.

Between 2000 and 2010, the area surrounding the *Ragain's vingis* (within 15 km of the border) has seen an decrease in human population of close to 2229 and this is predicted to decrease to 37 258 by 2050 and to 32 451 by 2100 (SSP2).

Satellite data show that, between 1992 and 2020, the area within the boundaries has seen changes in land cover, with main changes in land cover types *Cropland*, *rainfed*(-1.1%) and *Tree cover, broadleaved, deciduous, closed to open* (>15%)(+1.1%) (Table ES1). Overall, the biodiversity (see report for a breakdown of taxa) is projected to see species richness remaining to drop to 70.6% at 1.5 °C, 60.4% at 2 °C, 39.4% at 3 °C, and 30.4% at 4 °C (Figure ES1).

Most nations have stated their aim to meet the Paris Accord climate change targets of the United Nations – limit global warming to 2 °C and make efforts to limit warming to 1.5 °C. However, the

reality is far different. Country's current pledges for reducing greenhouse gas emissions would lead to a world that is approximately 2.7 °C - 3.5 °C warmer than pre-industrial. If countries do not meet their pledges then greater warming may occur, so it is still very important to consider how to conserve biodiversity in a 4 °C warmer world.

Table ES1: Percent land cover in 1992 and 2020, and change in land cover at 300 m resolution (ESA CCI) within *Ragain? s vingis*.

Land cover class	% in 1992	% in 2020	change (%)
Cropland, rainfed	13.90	12.83	-1.07
Herbaceous cover	1.07	1.60	0.53
Mosaic cropland (>50%)/natural vegetation (tree, shrub, herbaceous cover) (< 50%)	15.51	14.97	-0.54
Tree cover, broadleaved, deciduous, closed to open (>15%)	3.21	4.28	1.07
Tree cover, needleleaved, evergreen, closed to open (>15%)	0.53	0.00	-0.53
Tree cover, mixed leaf type (broadleaved and needleleaved)	0.00	0.53	0.53
Mosaic tree and shrub (>50%)/herbaceous cover (<50%)	2.14	2.14	0.00
Grassland	44.92	44.92	0.00
Shrub or herbaceous cover, flooded, fresh/saline/brakish water	1.07	1.07	0.00
Water bodies	17.65	17.65	0.00

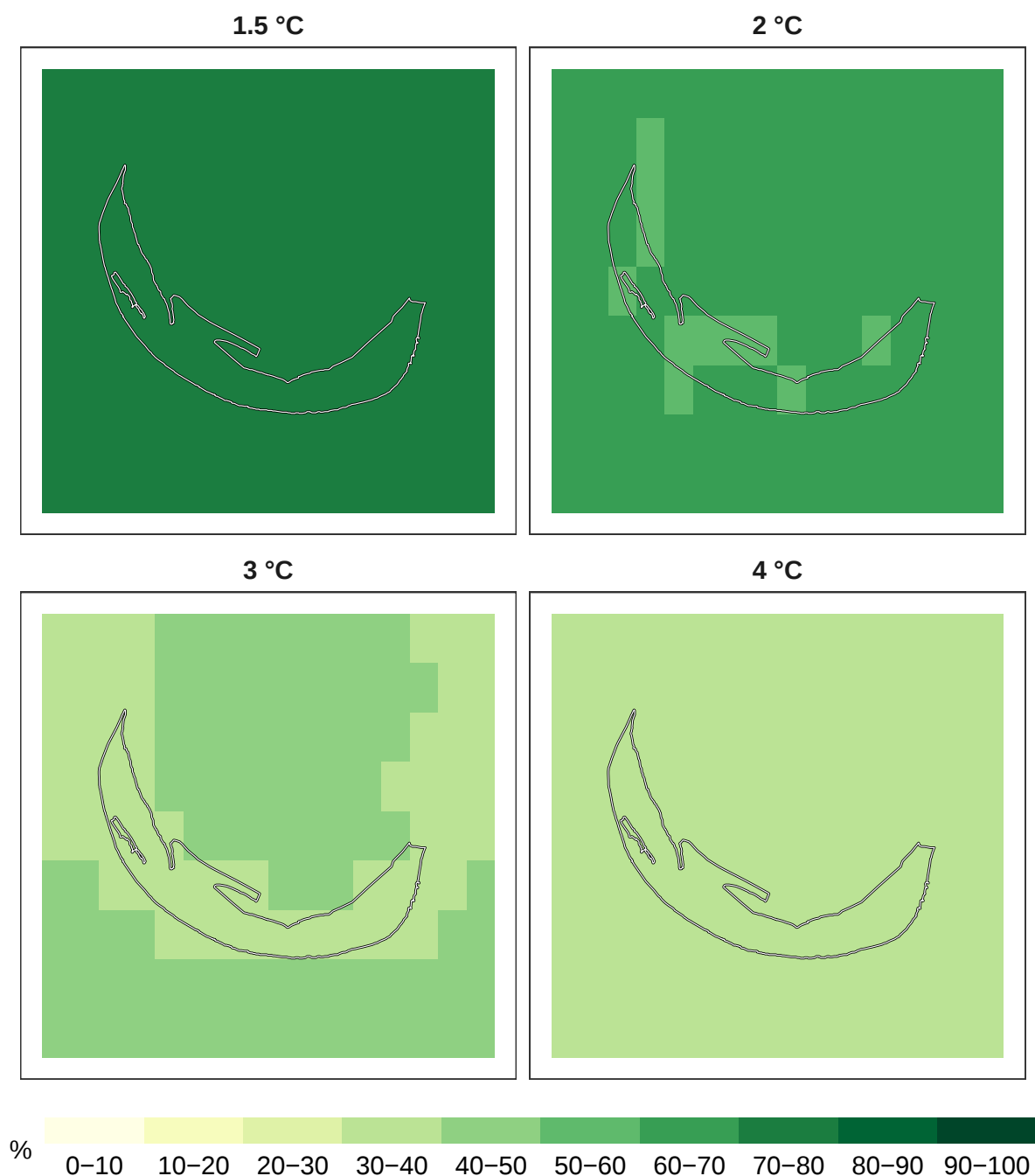


Figure ES1: Percent overall biodiversity remaining at 1 km resolution.

Supporting Information

This report is one of thousands prepared as part of the Wallace's pARCs (protected area refugia to climate change) project — identifying climate change refugia in countries and protected areas. It is hoped that providing information on what the projected impacts are to a protected area can be a first step for the park managers to assist them in preparing for a climate changed world.

The data and methods underpinning these reports have been published in the peer reviewed literature (Price et al., 2024a; Warren et al., 2018a,b) and are similar to the approach originally developed for analyses prepared for World Wildlife Fund to underpin their publication 'Wildlife in a Warming World' (WWF, 2018). Each of our reports provides information on the observed changes in the climate,

the projected changes in climate, the refugia potential, and the 'adaptation effort' (that is, the size of the climate change challenge faced by professionals in trying to preserve existing biodiversity) for biodiversity within the boundaries of the protected area (as defined by the World Database on Protected Areas; UNEP-WCMC and IUCN, [2024](#)). The report is accompanied by highly detailed information about interpreting the report.

Overview

The tables and figures below provide data extracted for the area listed in the title of the report. Brief interpretive information is provided in the headings and the captions, including the spatial resolution of the data. More detailed information can be found at the end of the tables and figures and this has been hyperlinked back to the appropriate place in the document if you are reading it online.

Climate

The climate data below are averaged over 30-year time periods. The spatial resolution is 0.5° latitude x 0.5° longitude.

Average Monthly High Temperature (usually the temperature of mid- to late-afternoon)

Table 1: Observed Average Monthly High Temperature (°C) with a comparison of the amount of change occurring between 1961-1990 and 1991-2020. Warmest refers to the warmest year in the 30-year period, coolest to the coolest year. In the warmest column, yellow shading indicates a temperature equal to that occurring approximately one in every three years (> 1 SD) compared to 1961-1990; red shading indicates a temperature equal to or greater than that occurring one in every twenty years (>2 SD) compared to 1961-1990. One way of looking at this is these years could be seen as “proxies” for what an average year in the future looks like.

Month	1961-1990			1991-2020			Difference 91-20 to 61-90
	Coollest	Average	Warmest	Coollest	Average	Warmest	Average
Jan	-9.5	-2.2	3.3	-7.1	-0.7	3.1	1.5
Feb	-8.0	-1.3	5.4	-4.7	0.2	4.3	1.4
Mar	-0.4	3.4	8.1	-0.1	4.9	9.3	1.4
Apr	8.6	10.7	14.2	8.8	12.5	16.3	1.8
May	13.3	17.6	20.7	15.1	18.2	22.8	0.6
Jun	18.2	20.9	24.0	18.3	21.3	25.4	0.4
Jul	18.0	21.8	24.6	20.1	23.4	26.4	1.6
Aug	19.1	21.4	24.1	19.3	23.0	26.5	1.6
Sep	13.7	16.7	20.9	13.5	17.6	20.2	0.9
Oct	7.7	11.0	14.0	7.4	11.1	14.6	0.0
Nov	0.3	4.5	7.6	-0.6	5.0	7.6	0.5
Dec	-5.1	0.0	3.0	-4.7	1.0	5.6	1.0

Table 2: Projected Changes in Average Monthly High Temperature (°C) - Yellow shading indicates when the new average is equal to that occurring approximately one in every three years (> 1 SD) compared to 1961-1990; red shading indicates when the new average is equal to or greater than that occurring one in every twenty years (> 2 SD) compared to 1961-1990.

	Scenario					
Month	1.5 °C	2 °C	2.5 °C	3 °C	3.5 °C	4 °C
Jan	1.7	2.5	3.3	4.0	4.8	5.5
Feb	1.7	2.4	3.1	3.8	4.6	5.3
Mar	1.7	2.4	3.1	3.8	4.5	5.2
Apr	1.4	2.0	2.7	3.3	3.9	4.5
May	1.2	1.8	2.3	2.8	3.4	3.9
Jun	1.4	2.0	2.6	3.2	3.8	4.5
Jul	1.8	2.5	3.3	4.0	4.8	5.6
Aug	1.8	2.7	3.5	4.3	5.1	5.9
Sep	1.7	2.5	3.2	4.0	4.7	5.5
Oct	1.6	2.3	3.0	3.7	4.4	5.1
Nov	1.6	2.2	2.9	3.6	4.3	5.0
Dec	1.7	2.4	3.1	3.9	4.6	5.3

	1961-1990			1991-2020			Difference 91-20 to 61-90
Month	Coollest	Average	Warmest	Coollest	Average	Warmest	Average
Jan	-17.9	-7.4	-0.3	-13.2	-5.1	0.0	2.3
Feb	-15.2	-7.0	0.5	-11.0	-4.8	-0.1	2.2
Mar	-8.8	-3.3	1.6	-7.4	-1.8	1.7	1.5
Apr	-0.4	1.8	3.8	0.7	2.9	5.3	1.0
May	3.9	6.9	9.5	4.8	7.2	10.6	0.4
Jun	8.4	10.4	12.7	8.5	10.8	13.1	0.4
Jul	10.3	12.1	15.5	10.8	13.3	16.0	1.2
Aug	10.2	11.6	13.5	10.7	12.8	14.9	1.2
Sep	6.3	8.2	10.3	6.2	8.9	10.4	0.7
Oct	0.5	4.4	7.0	1.6	4.6	8.2	0.2
Nov	-4.7	0.0	3.6	-5.2	0.8	3.5	0.8
Dec	-11.3	-4.7	-0.8	-10.3	-3.0	2.1	1.7

	Scenario					
Month	1.5 °C	2 °C	2.5 °C	3 °C	3.5 °C	4 °C
Jan	2.3	3.3	4.3	5.3	6.3	7.3
Feb	2.2	3.1	4.1	5.1	6.0	7.0
Mar	1.9	2.7	3.5	4.4	5.2	6.0
Apr	1.4	2.1	2.7	3.3	3.9	4.6
May	1.3	1.8	2.4	2.9	3.5	4.0
Jun	1.3	1.9	2.5	3.1	3.7	4.3
Jul	1.5	2.2	2.9	3.5	4.2	4.9
Aug	1.6	2.3	3.0	3.6	4.3	5.0
Sep	1.5	2.2	2.9	3.5	4.2	4.9
Oct	1.5	2.2	2.8	3.5	4.1	4.8
Nov	1.7	2.5	3.2	4.0	4.8	5.5
Dec	2.1	3.0	3.9	4.8	5.8	6.7

Drought/Waterlogging

The drought metric used here measures severe meteorological drought (SPEI12, -1.5). It is the metric often used when looking at potential drought issues for agricultural and natural lands. The metric looks at droughts developing over the preceding 12 months before the 'counting' begins. Thus, an area identified as having a maximum drought duration of 12 months has been in drought for up to 24 months. The values in the table are calculated for the 30-year period for the observed or warming level given. Waterlogging is the reverse of the drought metric (SPEI12, +1.5) and is an indication of areas having excess moisture for extended periods, potentially leading to waterlogged soils.

Table 9: Observed number of months in severe drought or waterlogged in a 30-year period with a comparison of the amount of change occurring between 1961-1990 and 1986-2015.

	1961-1990	1986-2015	Difference 86-15 to 61-90
In drought	25	11.6	-13.4
Waterlogged	18	24.2	6.2

Table 10: Observed maximum number of consecutive months in severe drought or waterlogged in a 30-year period with a comparison of the amount of change occurring between 1961-1990 and 1986-2015.

	1961-1990	1986-2015	Difference 86-15 to 61-90
In drought	14	3	-11
Waterlogged	17	8	-9

Table 11: Changes in number of months in severe drought or waterlogged in a 30-year period.

	1.5 °C	2 °C	2.5 °C	3 °C	3.5 °C	4 °C
In drought	16.1	25.4	38.5	54	73.2	90.8
Waterlogged	1.7	1.5	1.1	0	0.0	-0.2

Table 12: Changes in maximum number of consecutive months in severe drought or waterlogged in a 30-year period.

	1.5 °C	2 °C	2.5 °C	3 °C	3.5 °C	4 °C
In drought	4.2	4.9	5.7	7.4	9.4	20.9
Waterlogged	-1.4	-3.2	-4.2	-5.0	-5.3	-6.2

Population

Table 13: Projected population for the years 2010 through 2100 at a 1 km² spatial resolution. These data are provided both in terms of the population within the protected area boundary, and those within an area including a 15 km wide buffer zone around the boundary. The data from 2000 and 2010 are interpolations of observed population sizes, the other periods are projections of future change in a 'middle-of-the-road' scenario with historical patterns of development continued through the 21st century.

Area	2000	2010	2030	2050	2070	2090	2100
Within region	303	232	199	169	145	126	118
Region plus buffer	42,654	40,425	38,843	37,258	35,689	33,655	32,451

Landcover changes

Table 14: Percent landcover in 1992 and 2020, and change in landcover (300 m resolution). These figures are provided to assist in understanding how landcover has changed over time as this may have had immediate biodiversity implications in the area.

Landcover class	% in 1992	% in 2020	change (%)
Cropland, rainfed	13.90	12.83	-1.07
Herbaceous cover	1.07	1.60	0.53
Mosaic cropland (>50%)/natural vegetation (tree, shrub, herbaceous cover) (< 50%)	15.51	14.97	-0.54
Tree cover, broadleaved, deciduous, closed to open (>15%)	3.21	4.28	1.07
Tree cover, needleleaved, evergreen, closed to open (>15%)	0.53	0.00	-0.53
Tree cover, mixed leaf type (broadleaved and needleleaved)	0.00	0.53	0.53
Mosaic tree and shrub (>50%)/herbaceous cover (<50%)	2.14	2.14	0.00
Grassland	44.92	44.92	0.00
Shrub or herbaceous cover, flooded, fresh/saline/brackish water	1.07	1.07	0.00
Water bodies	17.65	17.65	0.00

Taxa	1.5 °C	2 °C	3 °C	4 °C
Biodiversity	29.4	39.6	60.6	69.6
Plants	21.4	26.4	43.2	53.1
Ferns	10.4	17.2	35.0	47.9
Mosses	29.8	36.2	56.1	71.3
Pines	14.0	20.0	40.4	51.2
Flowering plants	18.6	22.4	36.4	46.2
Magnoliopsida	18.3	22.0	35.6	45.6
Liliopsida	20.3	23.6	37.8	47.6
Grasses	22.2	25.0	36.7	47.6
Lilies	44.2	46.4	73.4	85.2
Orchids	17.2	20.4	36.4	45.9
Palms	NA	NA	NA	NA
Vines	NA	NA	NA	NA
Timber species	9.6	13.2	24.7	41.0
Animals	40.9	54.6	76.5	82.7
Arthropoda	42.7	57.0	79.5	85.7
Arachnida	32.1	43.5	73.4	84.0
Spiders	31.6	43.5	74.9	85.7
Insecta	43.3	57.7	79.8	85.8
Bees	21.2	29.0	59.9	71.3
Beetles	49.4	65.8	86.7	90.9
True Bugs	33.5	53.2	75.2	82.6
Flies	53.0	63.4	80.0	88.4
Lepidoptera	50.6	59.3	78.4	84.2
Butterflies	12.8	19.0	46.4	59.0
Moths	53.9	62.7	81.7	86.6
Dragonflies	25.8	39.1	80.9	88.9
Pollinators	58.1	67.6	83.9	87.8
Chordata	11.3	14.2	23.4	30.2
Amphibia	27.1	32.0	54.5	54.5
Aves	10.9	12.7	19.9	24.2
Mammals	13.1	17.0	36.1	54.9
Reptiles	16.6	16.7	30.0	38.9

Species Richness Remaining

Figures 1 to 9 show the average percent of the species (species richness) *remaining* within the boundaries of the area (also depicted on the map as a solid black line) for selected groups. This shows the spatial variability in the potential patterns of loss.

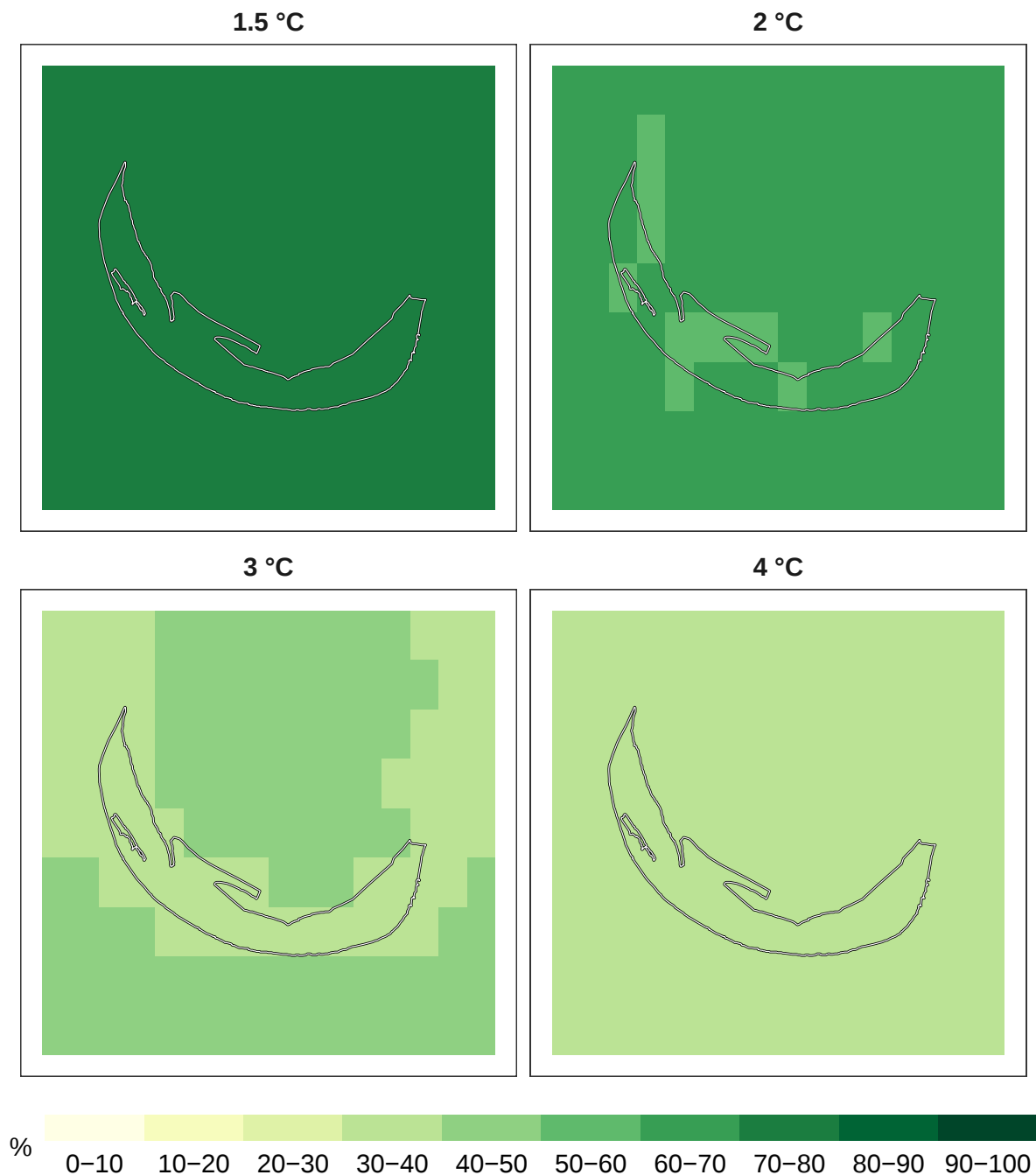


Figure 1: Percent overall biodiversity remaining at 1 km resolution.

Plants

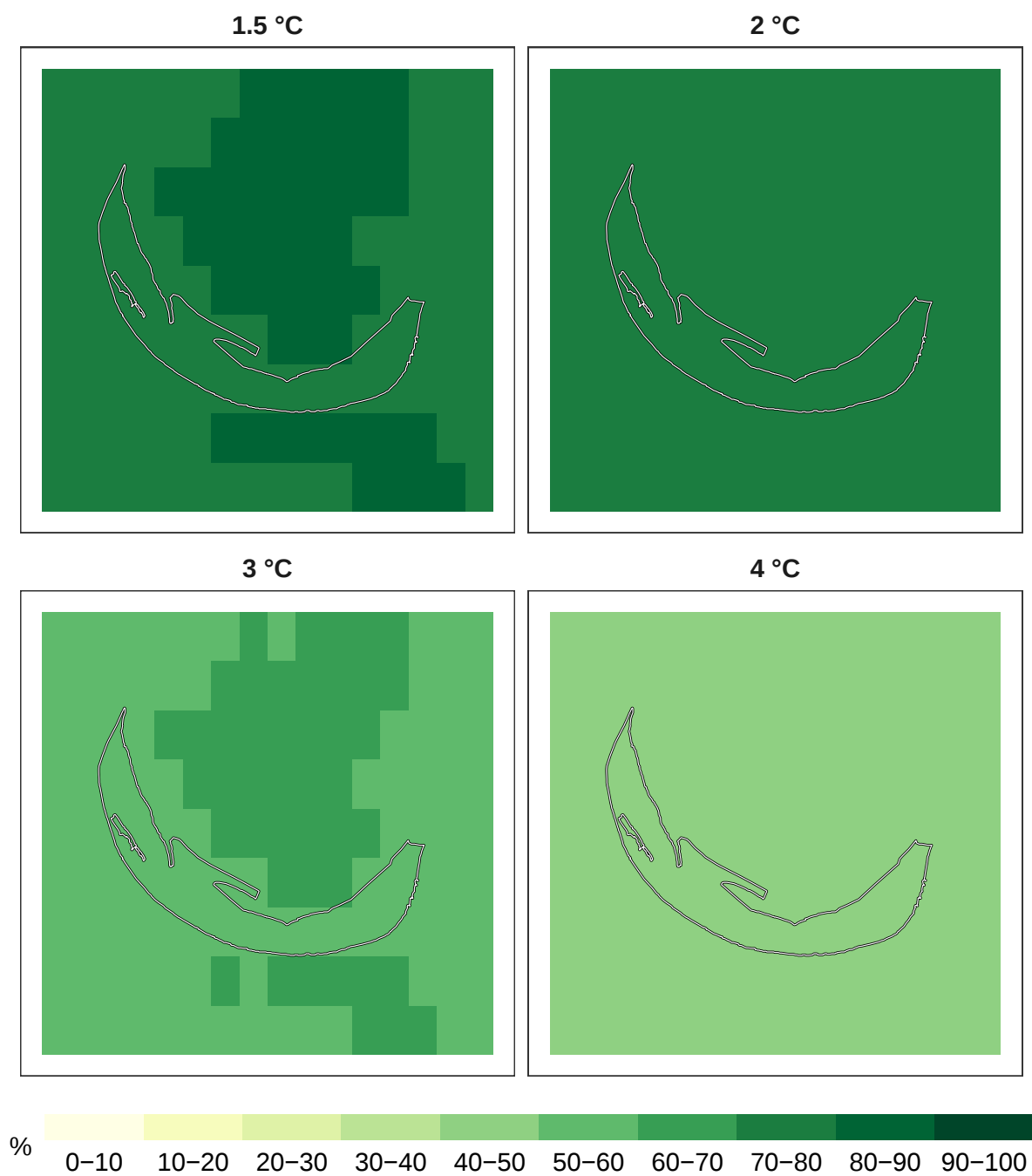


Figure 2: Percent plants remaining at 1 km resolution.

Amphibians

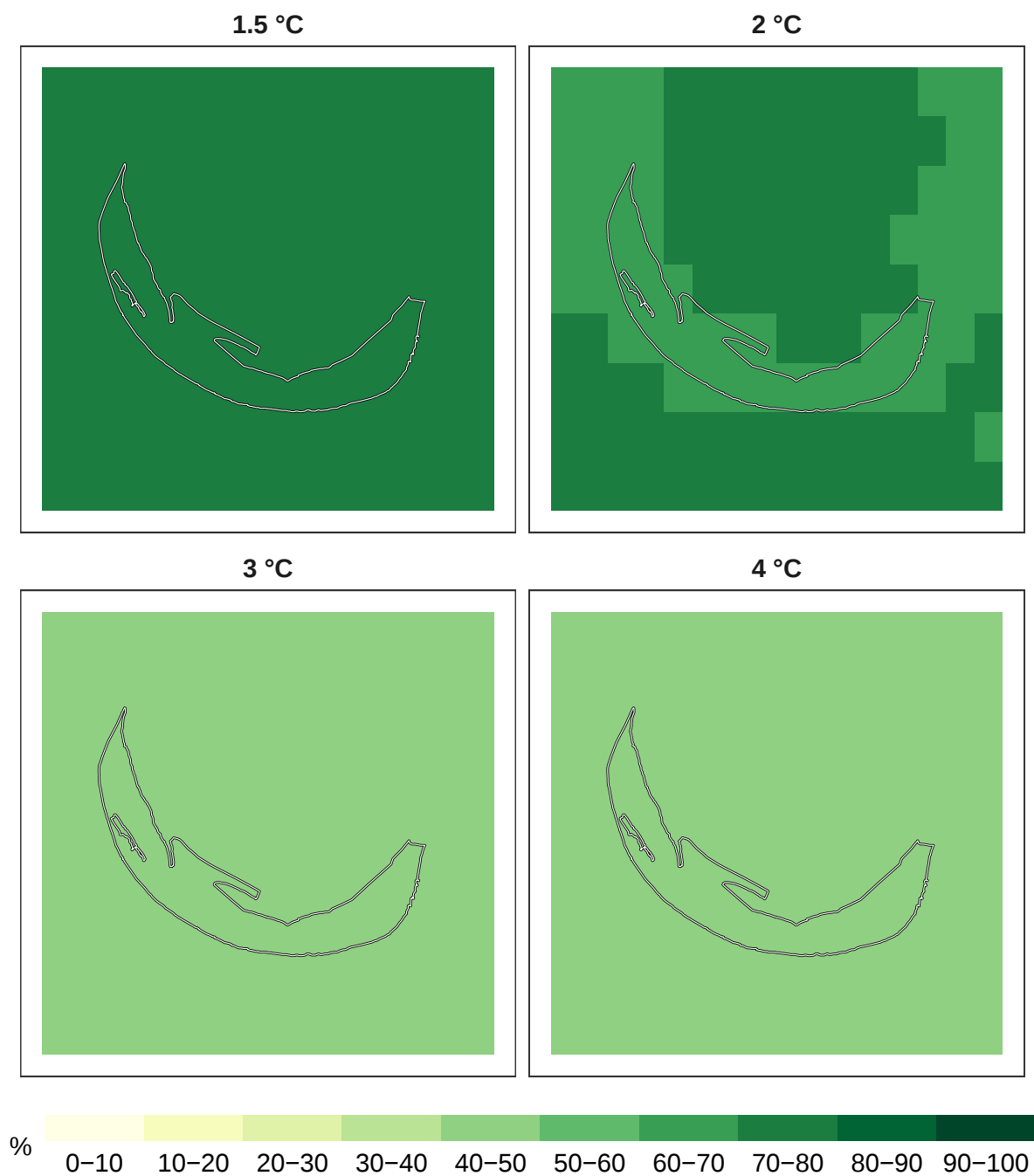


Figure 3: Percent amphibians remaining at 1 km resolution.

Birds

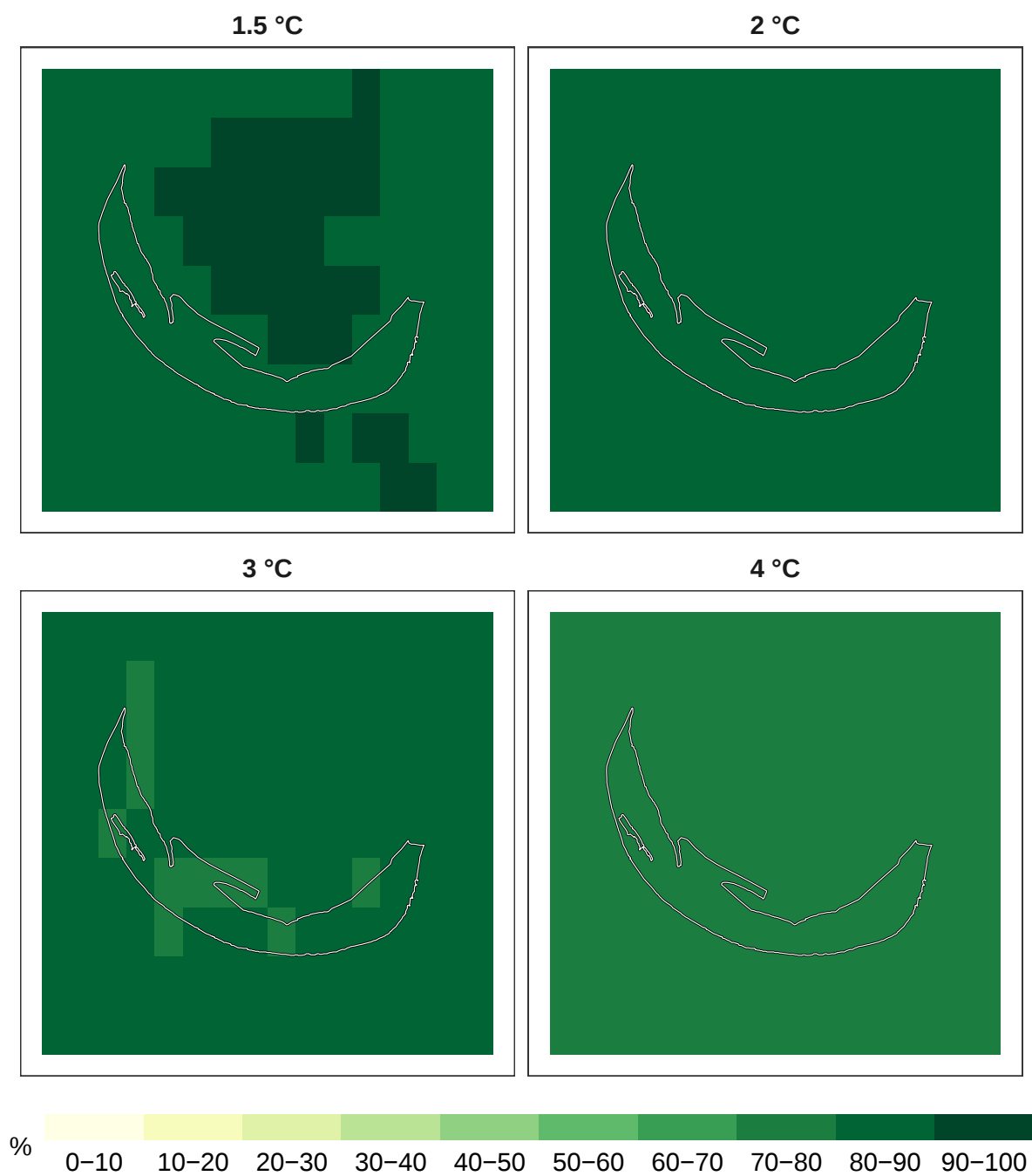


Figure 4: Percent birds remaining at 1 km resolution.

Mammals

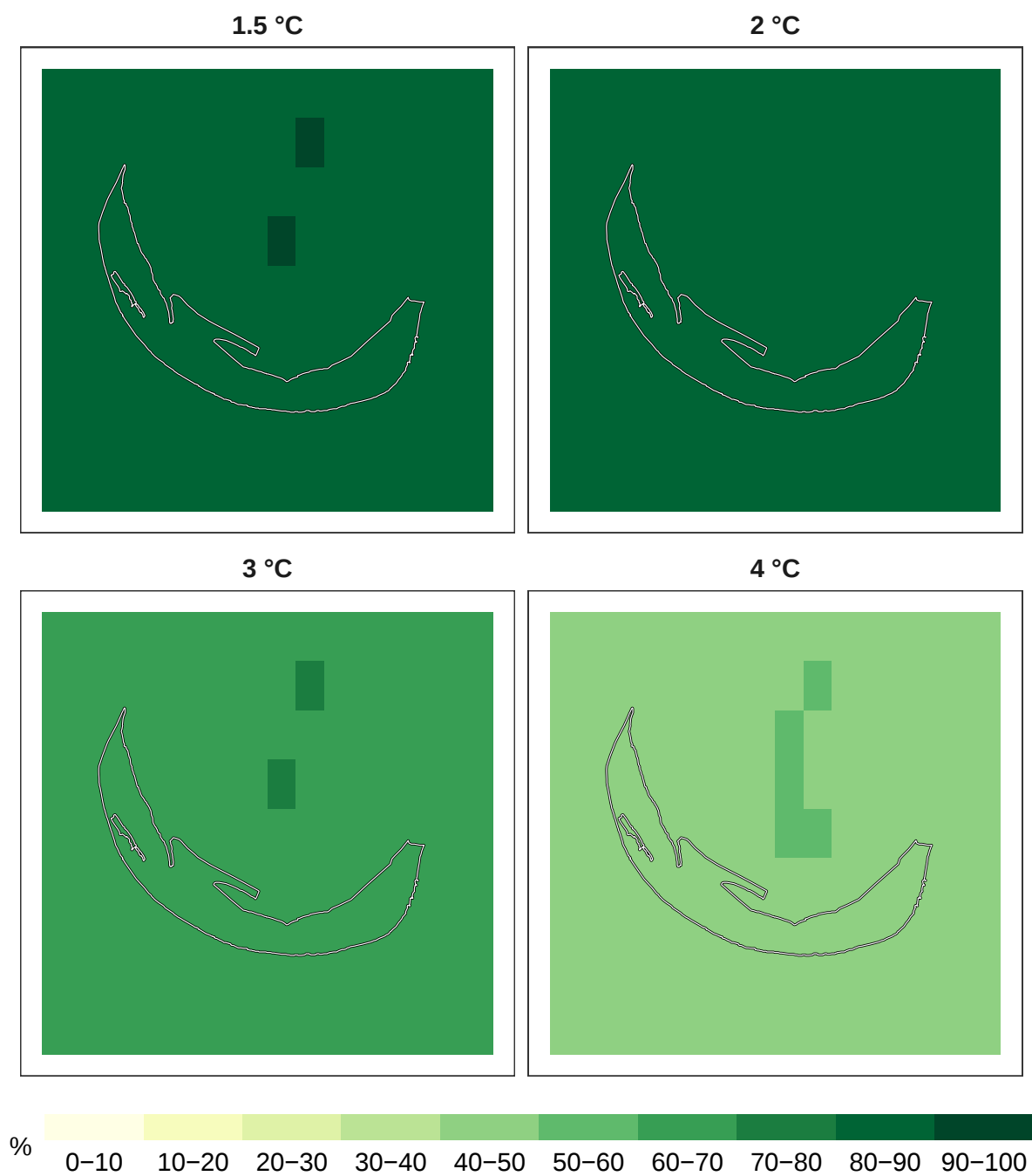


Figure 5: Percent mammals remaining at 1 km resolution.

Reptiles

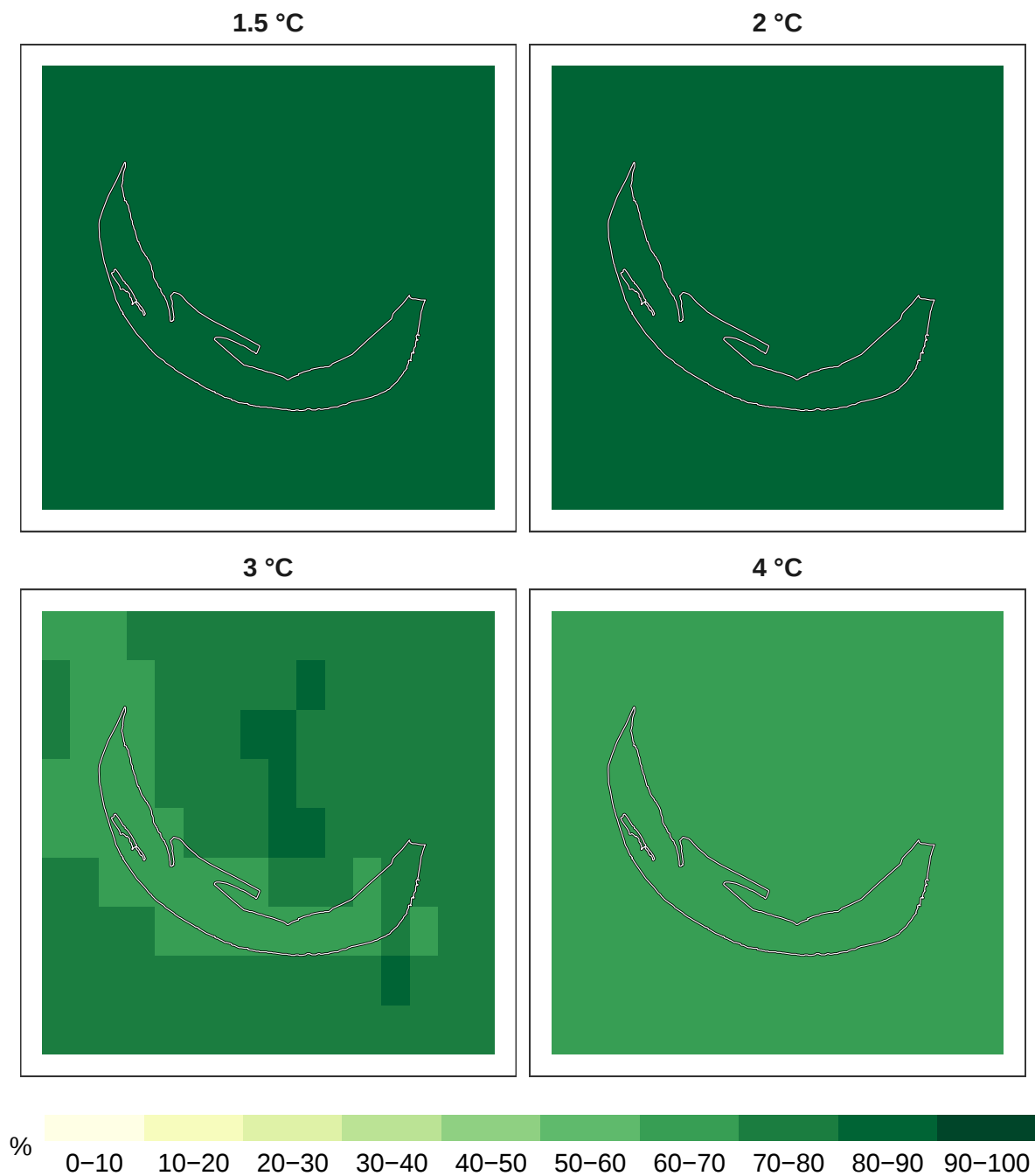


Figure 6: Percent reptiles remaining at 1 km resolution.

Insects

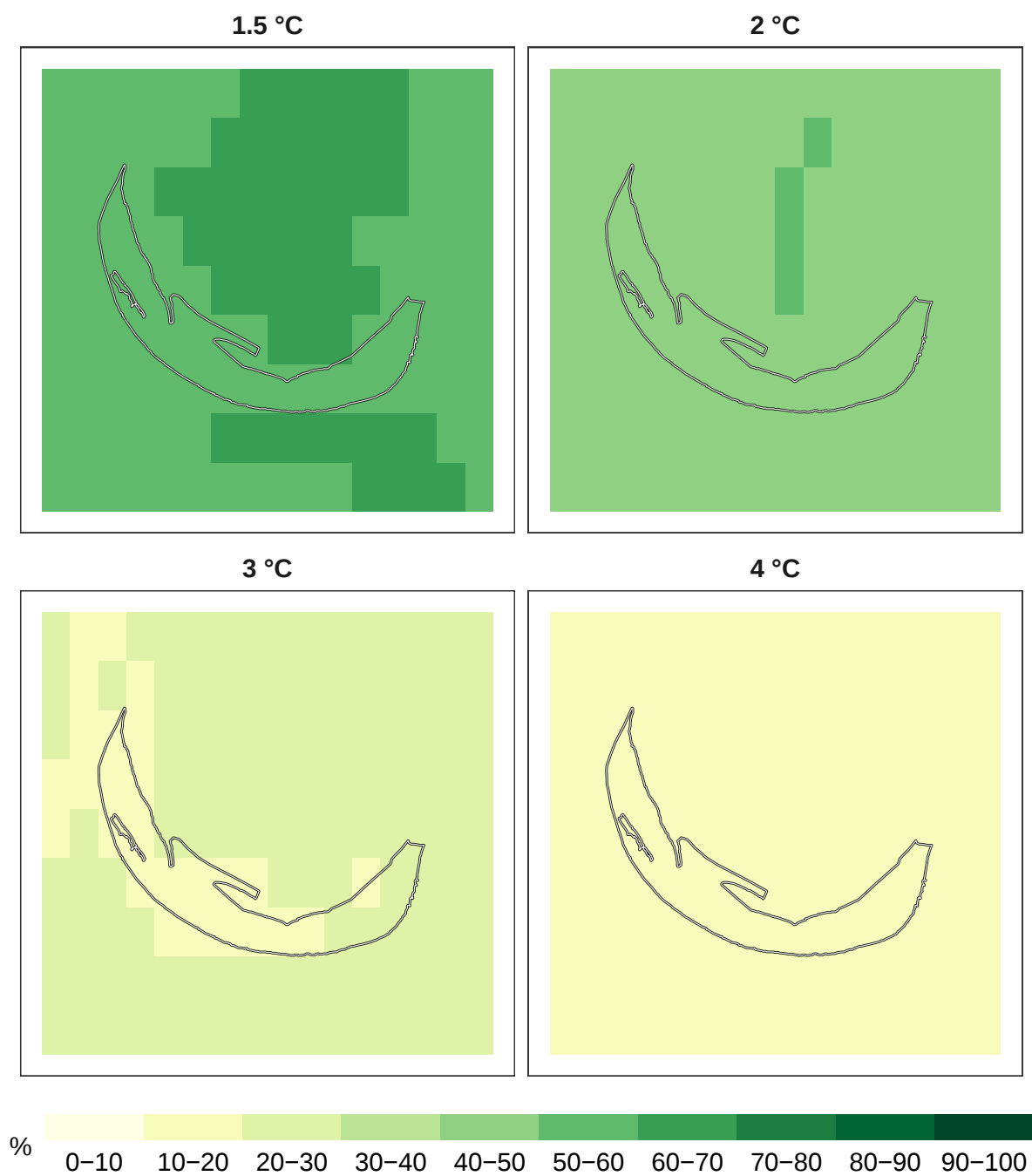


Figure 7: Percent insects remaining at 1 km resolution.

Pollinators

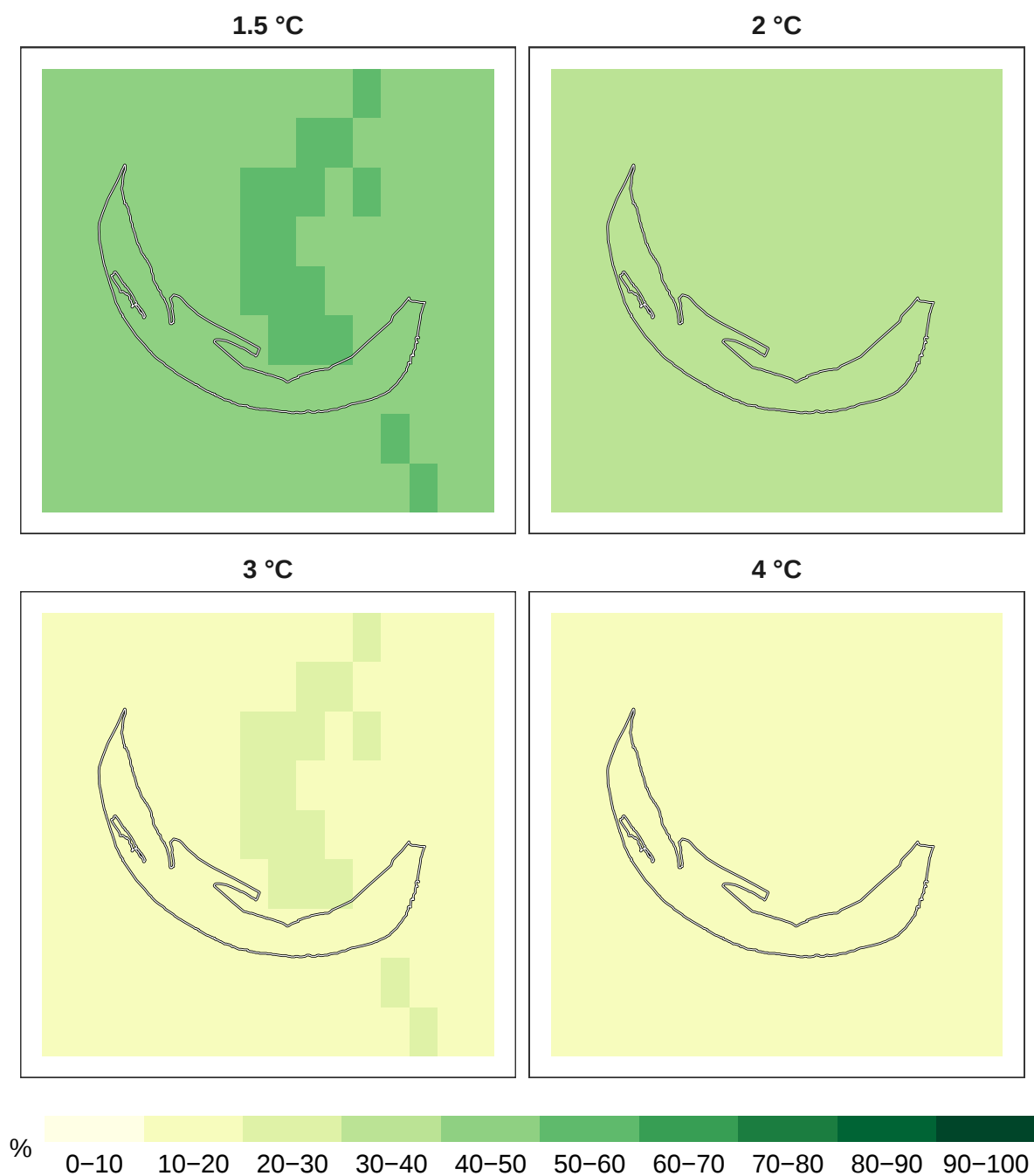


Figure 8: Percent pollinators remaining at 1 km resolution.

Timber species

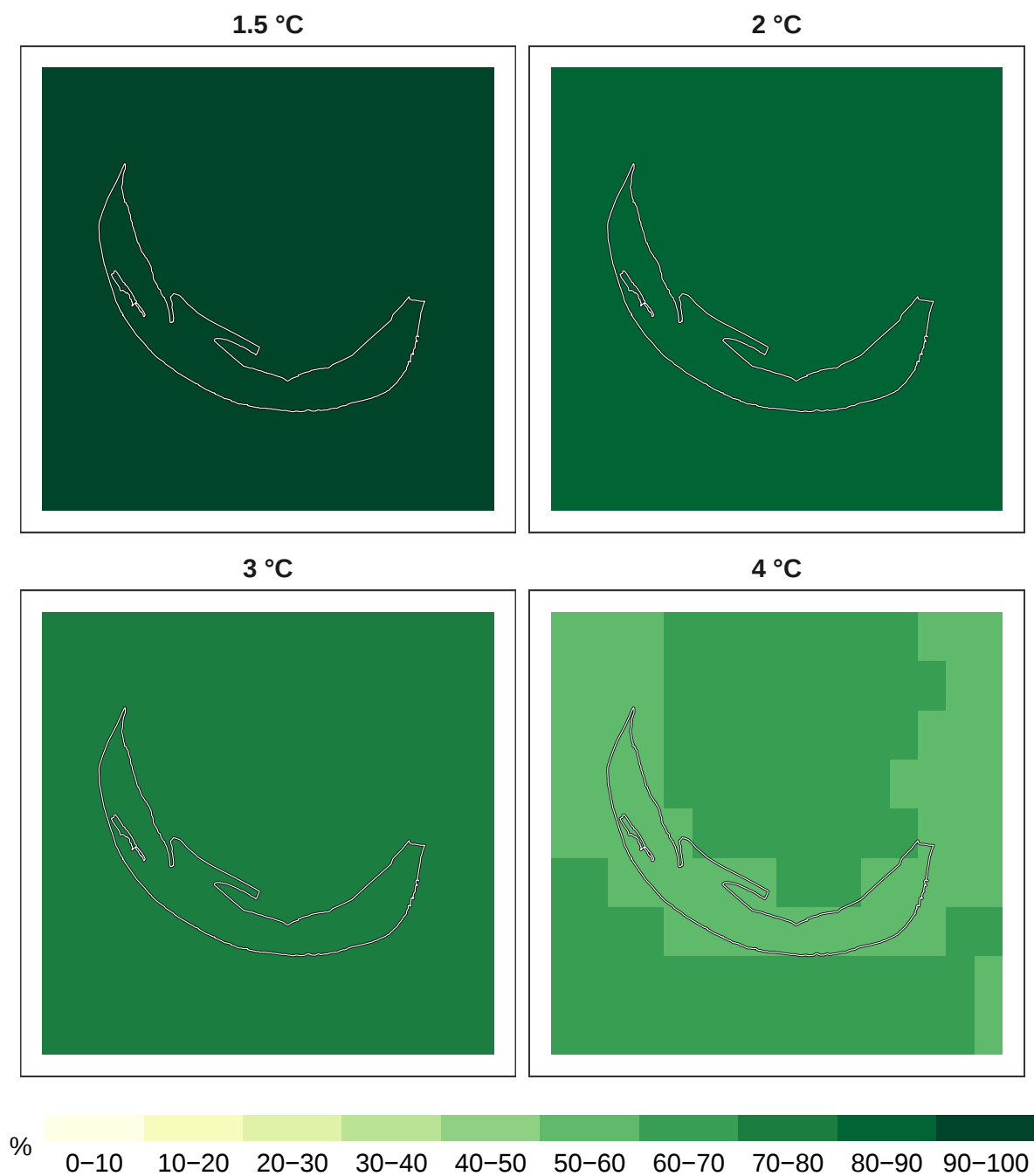


Figure 9: Percent timber species remaining at 1 km resolution.

Refugia

Table 16 shows the percent of the area remaining a climatic refugium for different groups of species. Climatic refugia are defined as areas remaining climatically suitable for >75% of the species in each group. The two columns, for each warming level, are >0 (meaning at least one climate change model projects that the area is a refugium) and >10 (meaning that at least half of the models project an area is a refugium). The shading is – darker green, >75% of the area is a refugium; medium green, 50%-75% of the area is a refugium; light green, 25%-50% of the area is a refugium; and white, less than 25% of the area is a refugium.

Figures 10 to 17 show the number of climate models agreeing that a particular pixel (cell) is a refugium for the taxa indicated. These maps provide a spatial representation of the agreement in the models (or areas with potentially lower uncertainty) to be refugia for the different groups as well as how this potentially varies within the area under study.

Table 16: Percentage of area remaining a climatic refugia (i.e., remaining climatically suitable for > 75% of the species across > 11 climate models) for different taxonomic groups at 1km resolution.

Taxa	1.5 °C		2.0 °C		3.0 °C		4.0 °C	
	> 0	> 10	> 0	> 10	> 0	> 10	> 0	> 10
Biodiversity	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0
Plants	100.0	100.0	100.0	1.5	0.3	0.0	0.0	0
Ferns	100.0	100.0	100.0	100.0	100.0	0.0	100.0	0
Mosses	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Pines	100.0	100.0	100.0	100.0	100.0	0.0	100.0	0
Flowering plants	100.0	100.0	100.0	9.1	100.0	0.0	13.7	0
Magnoliopsida	100.0	100.0	100.0	9.1	100.0	0.0	13.7	0
Liliopsida	100.0	100.0	100.0	1.5	100.0	0.0	0.0	0
Grasses	100.0	100.0	100.0	1.5	100.0	0.0	0.0	0
Lilies	100.0	0.0	100.0	0.0	100.0	0.0	0.0	0
Orchids	100.0	100.0	100.0	100.0	100.0	0.0	100.0	0
Palms	NA	NA	NA	NA	NA	NA	NA	NA
Vines	NA	NA	NA	NA	NA	NA	NA	NA
Timber species	100.0	100.0	100.0	100.0	100.0	0.3	100.0	0
Animals	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0
Arthropoda	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0
Arachnida	100.0	0.0	100.0	0.0	0.0	0.0	0.0	0
Spiders	100.0	0.0	100.0	0.0	0.0	0.0	0.0	0
Insecta	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0
Bees	100.0	100.0	100.0	0.0	0.3	0.0	0.0	0
Beetles	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0
True Bugs	100.0	0.0	0.3	0.0	0.0	0.0	0.0	0
Flies	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0
Lepidoptera	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0
Butterflies	100.0	100.0	100.0	100.0	100.0	0.0	0.0	0
Moths	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0
Dragonflies	100.0	1.5	100.0	0.0	0.0	0.0	0.0	0
Pollinators	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0
Chordata	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0
Amphibia	100.0	0.0	100.0	0.0	0.0	0.0	0.0	0
Aves	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100
Mammals	100.0	100.0	100.0	100.0	100.0	0.0	13.7	0
Reptiles	100.0	100.0	100.0	100.0	100.0	13.7	100.0	0

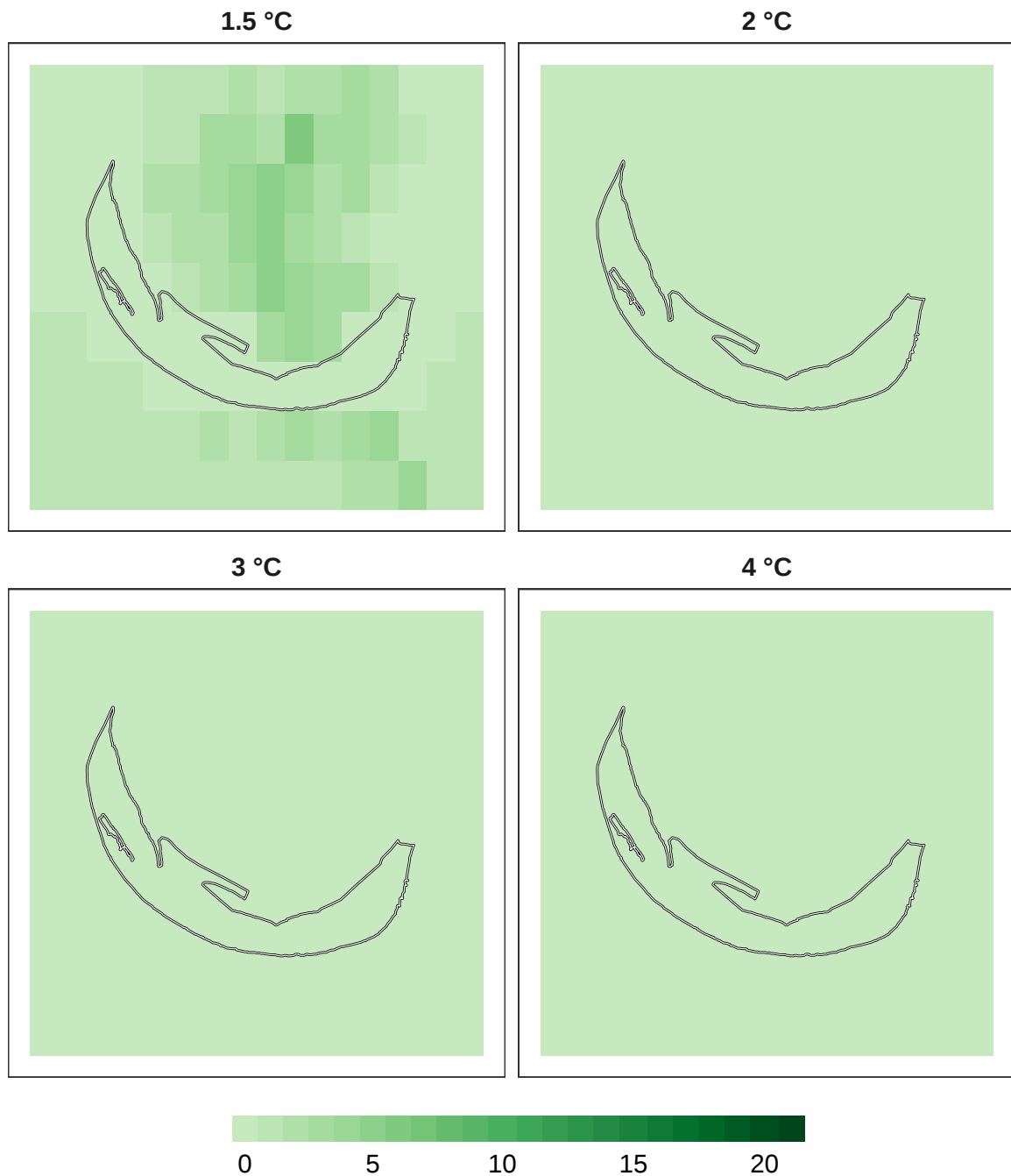


Figure 10: Number of models in agreement for overall biodiversity refugia at 1 km resolution.

Plants

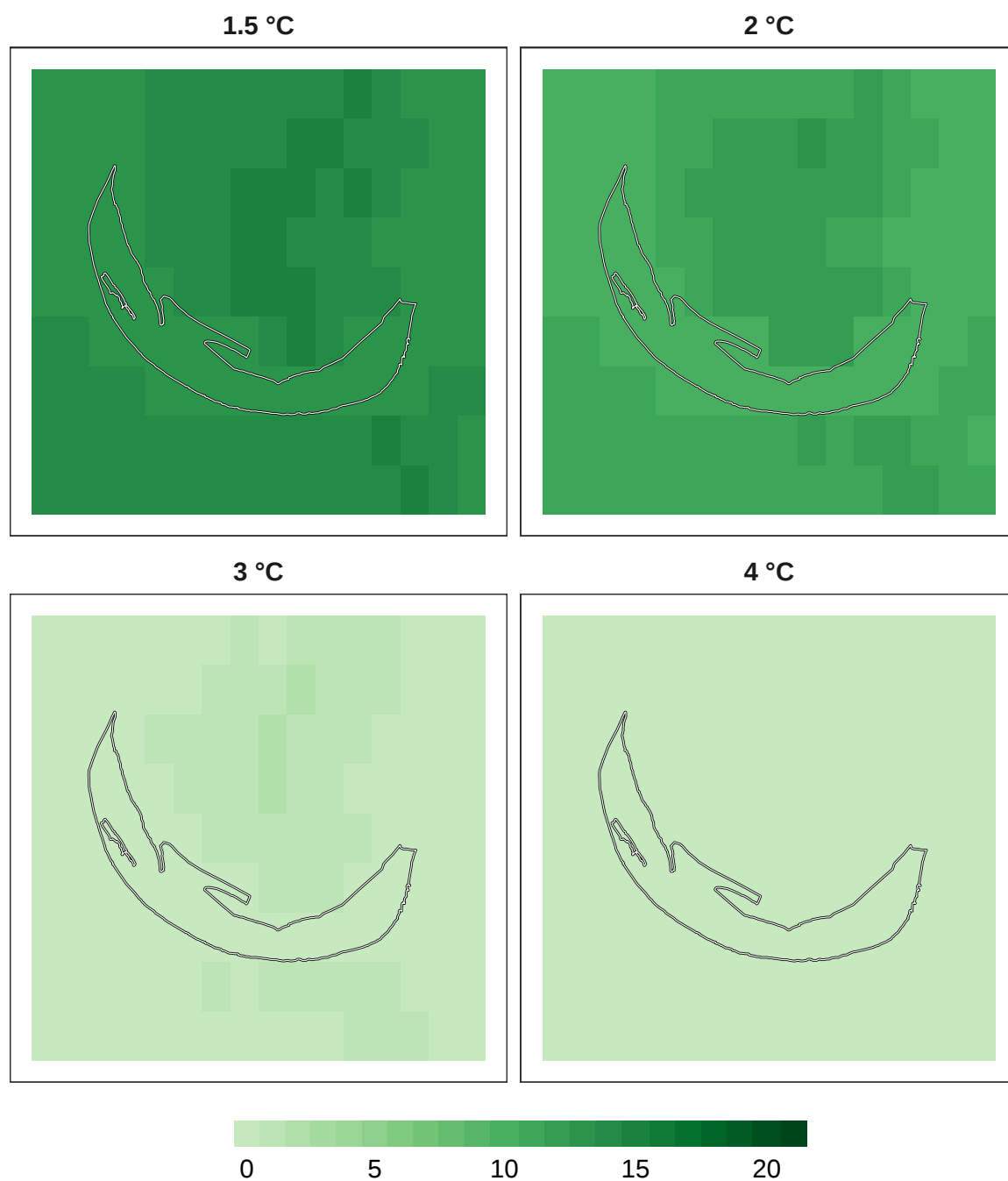


Figure 11: Number of models in agreement for plant refugia at 1 km resolution.

Amphibians



Figure 12: Number of models in agreement for amphibian refugia at 1 km resolution.

Birds

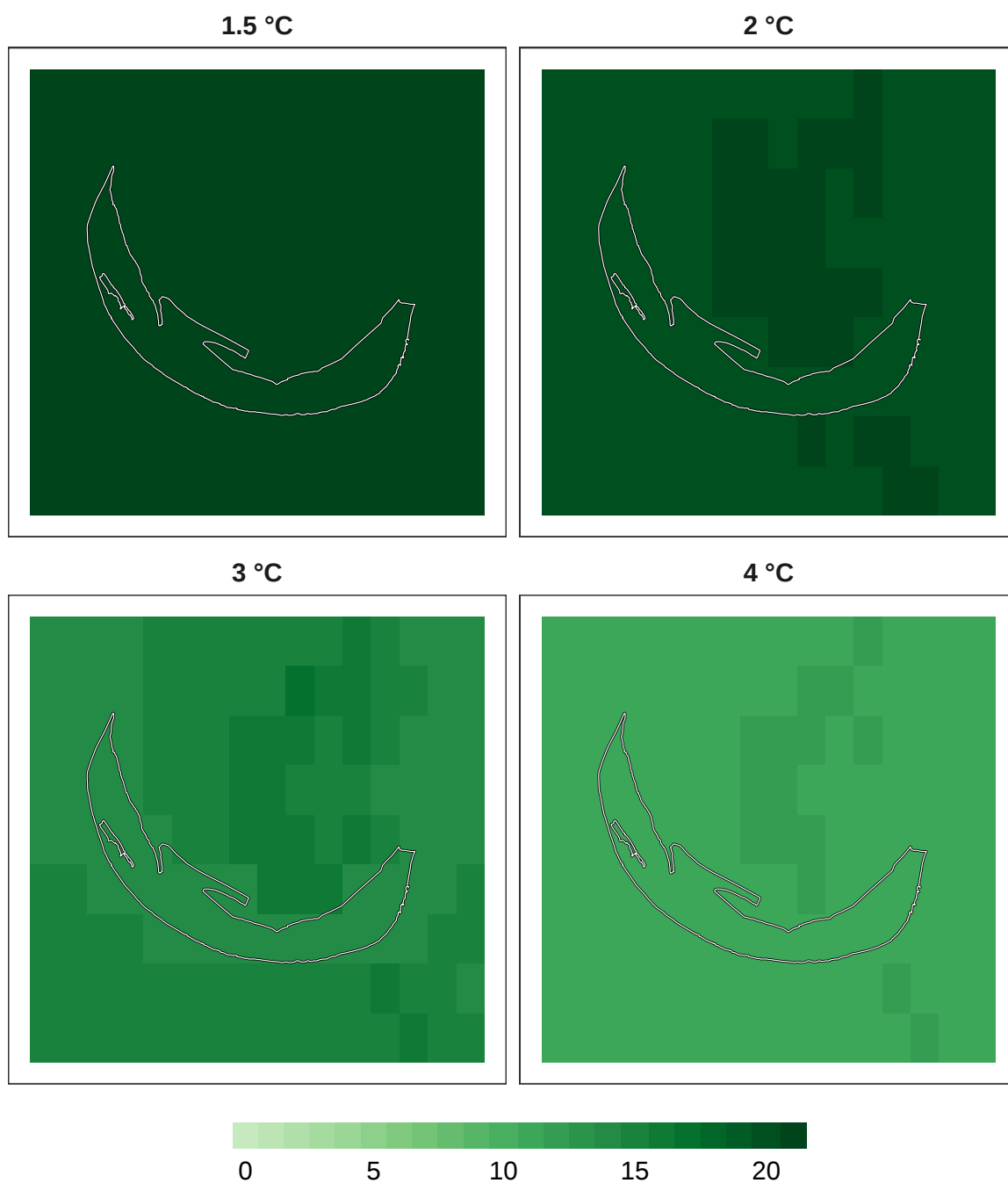


Figure 13: Number of models in agreement for bird refugia.

Mammals

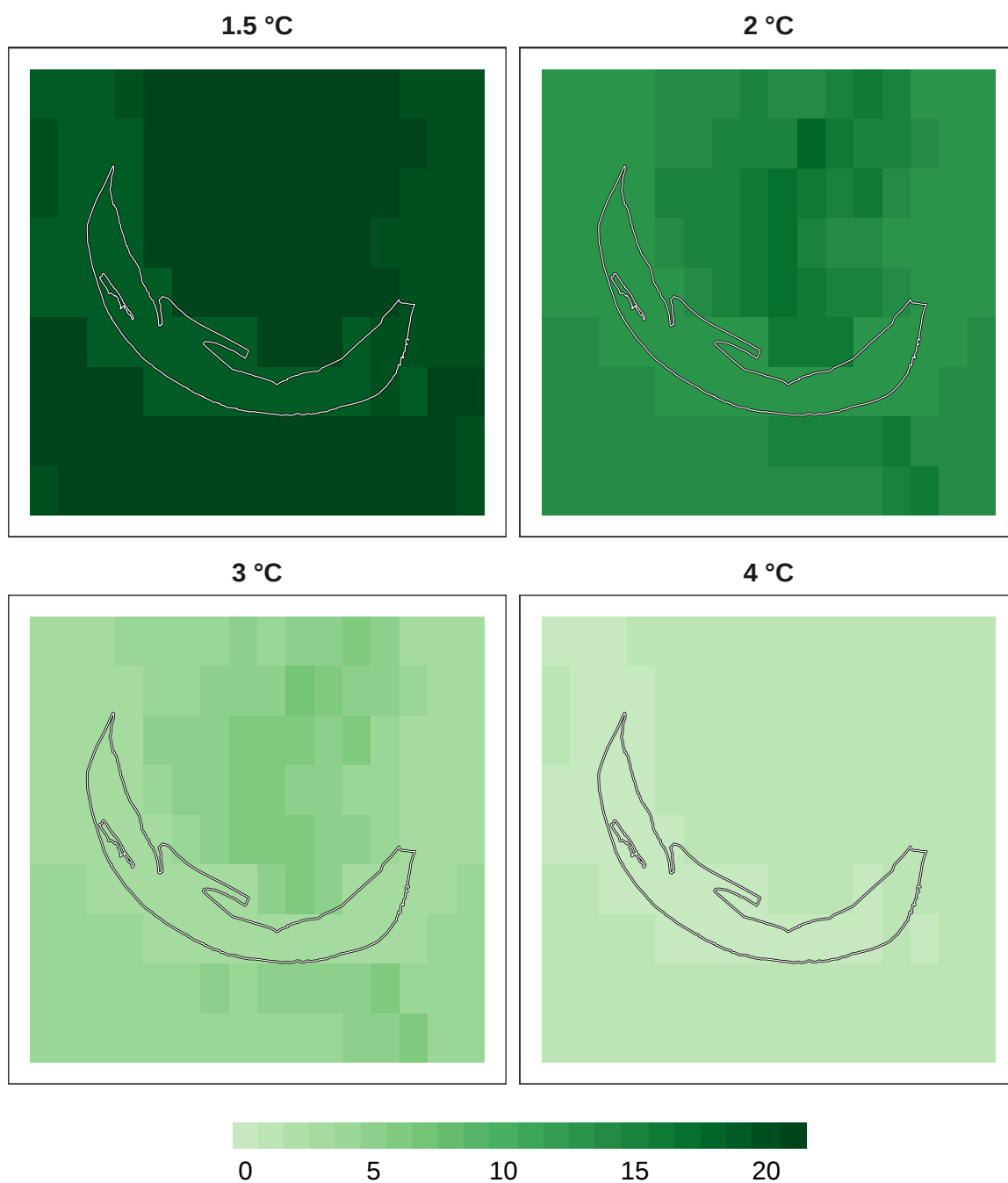


Figure 14: Number of models in agreement for mammal refugia at 1 km resolution.

Reptiles

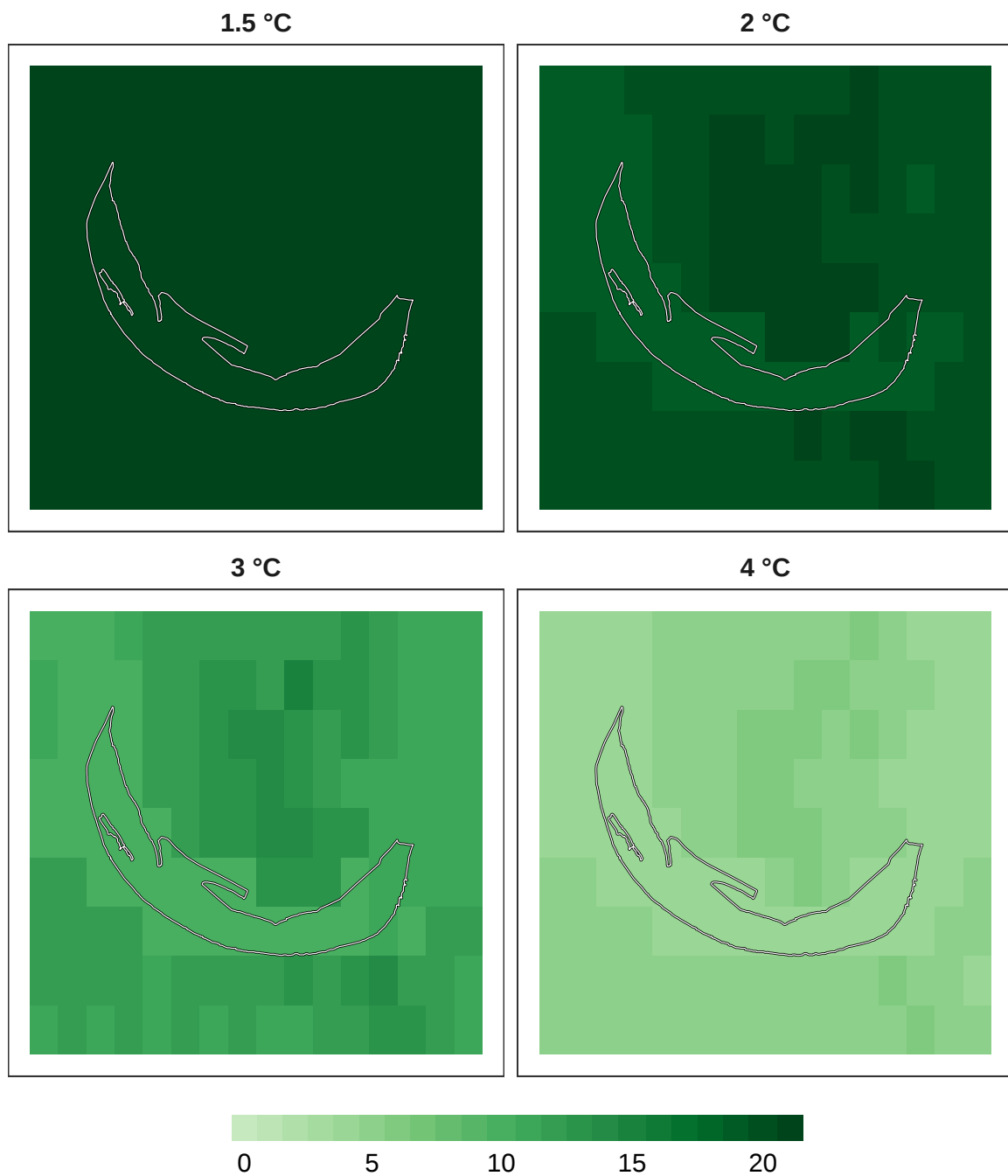
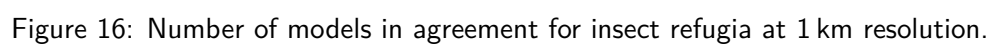
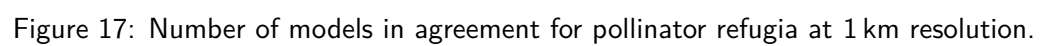


Figure 15: Number of models in agreement for reptile refugia at 1 km resolution.





Adaptation Effort

Figures 18 to 25 present a spatial representation of the potential 'adaptation effort' that might be needed to maintain at least 75% of the species modelled. Adaptation effort is a combination of the number of climate models (+ 1 to 21) projecting an area is a refugia well as the number of climate models (- 1 to -21) projecting the area to be an Area of Concern (becomes climatically unsuitable for >75% of the species) in each pixel. One way of looking at this is to consider areas with high values (+18 to +21) as being less exposed to climate change and thus potentially more resilient. Business-as-usual conservation, especially if coupled with building resilience around extreme climates (e.g., drought, heat waves) might be a reasonable adaptation approach to take. As the score drops, increasingly greater amounts of adaptation might be needed to maintain the existing species composition. Once the adaptation effort drops into the negative zone, adaptation to maintain existing species is likely to become increasingly difficult. At a score of -15 to -21 the best approach might be to consider facilitating change as opposed to putting large efforts into trying to maintain existing species. Scores this low indicate that the area becomes climatically unsuitable for a large percentage of species.

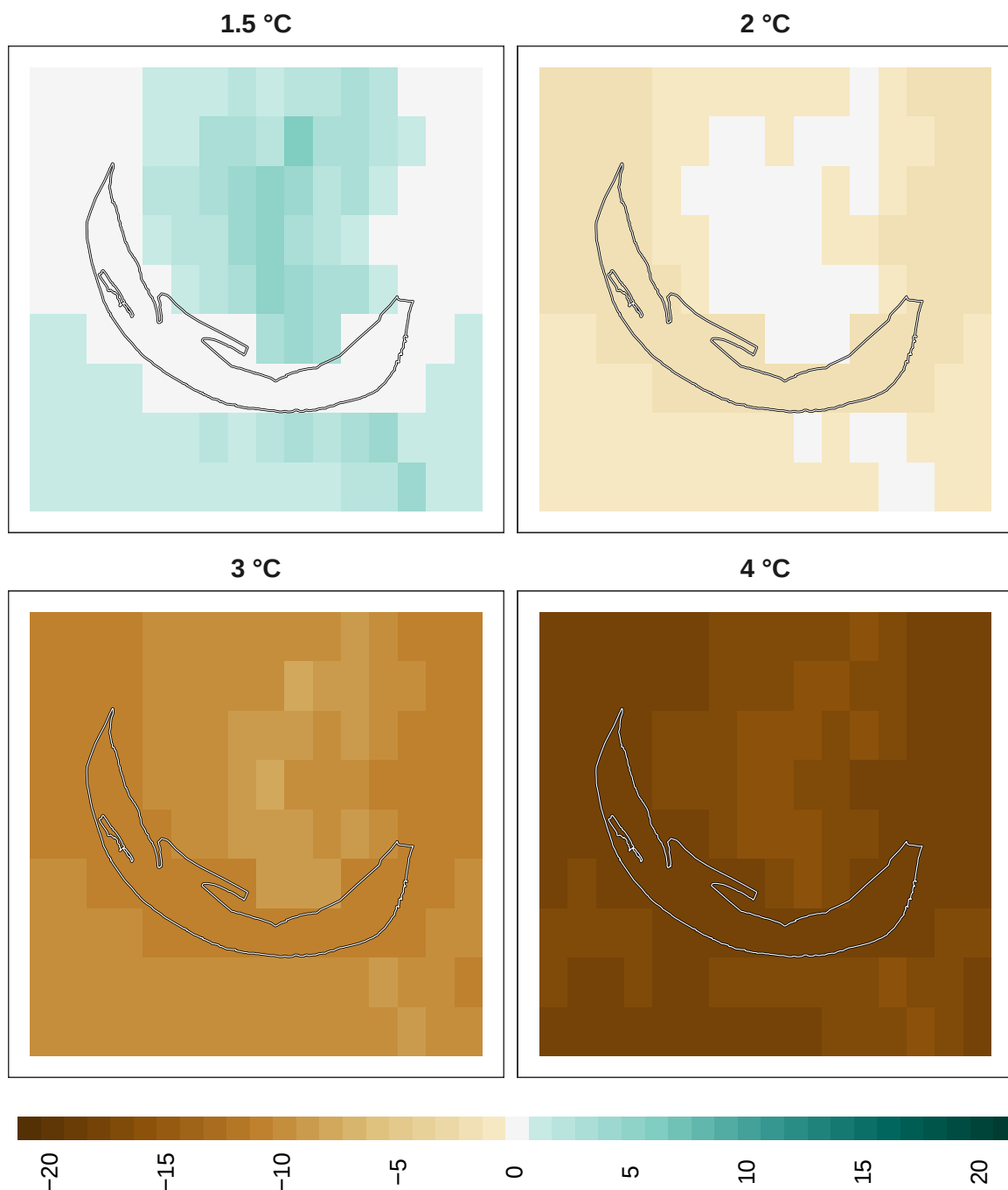
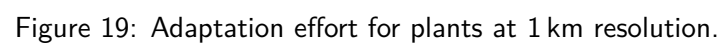


Figure 18: Adaptation effort for overall biodiversity at 1 km resolution.



Amphibians

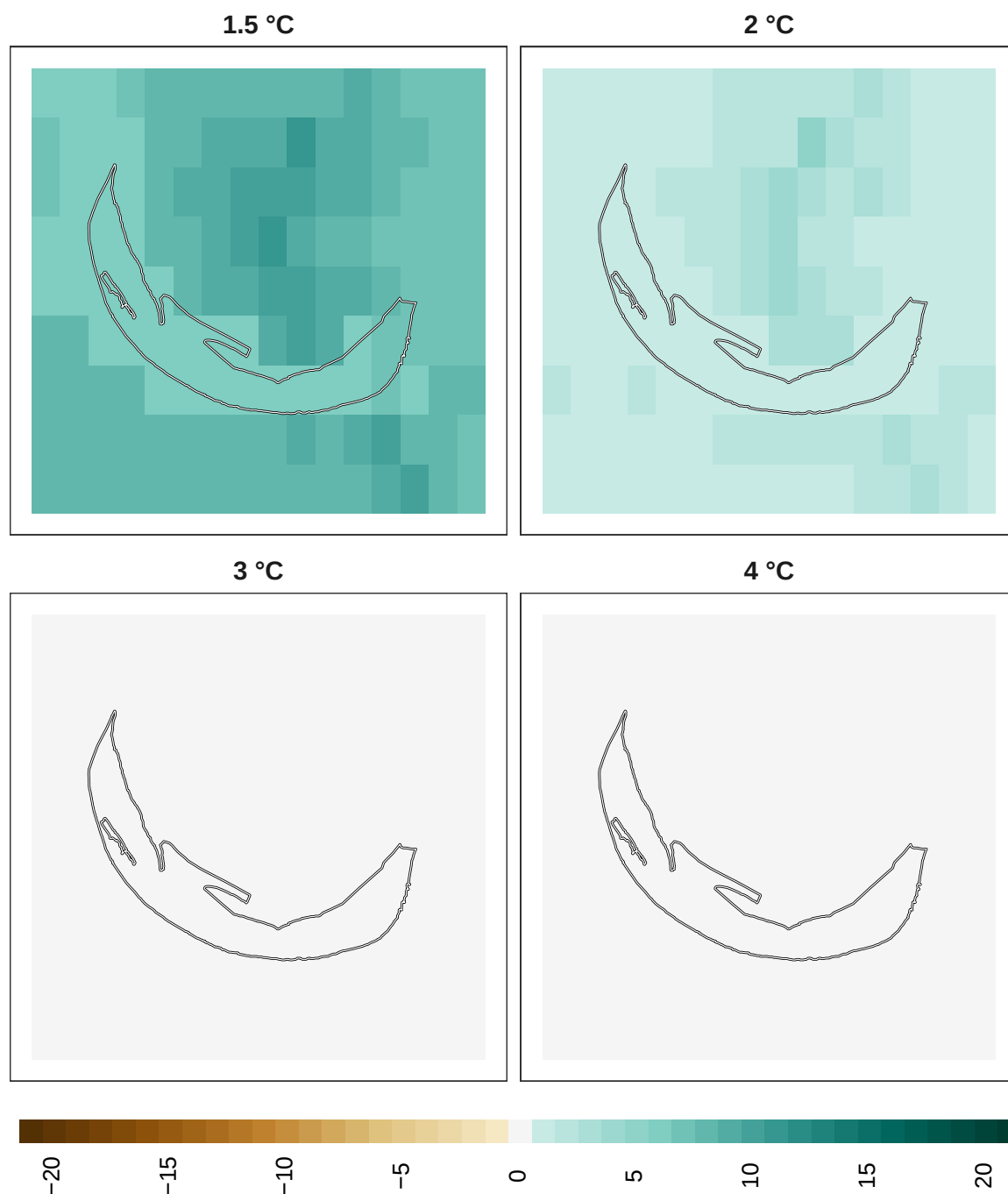


Figure 20: Adaptation effort for amphibians at 1 km resolution.

Birds

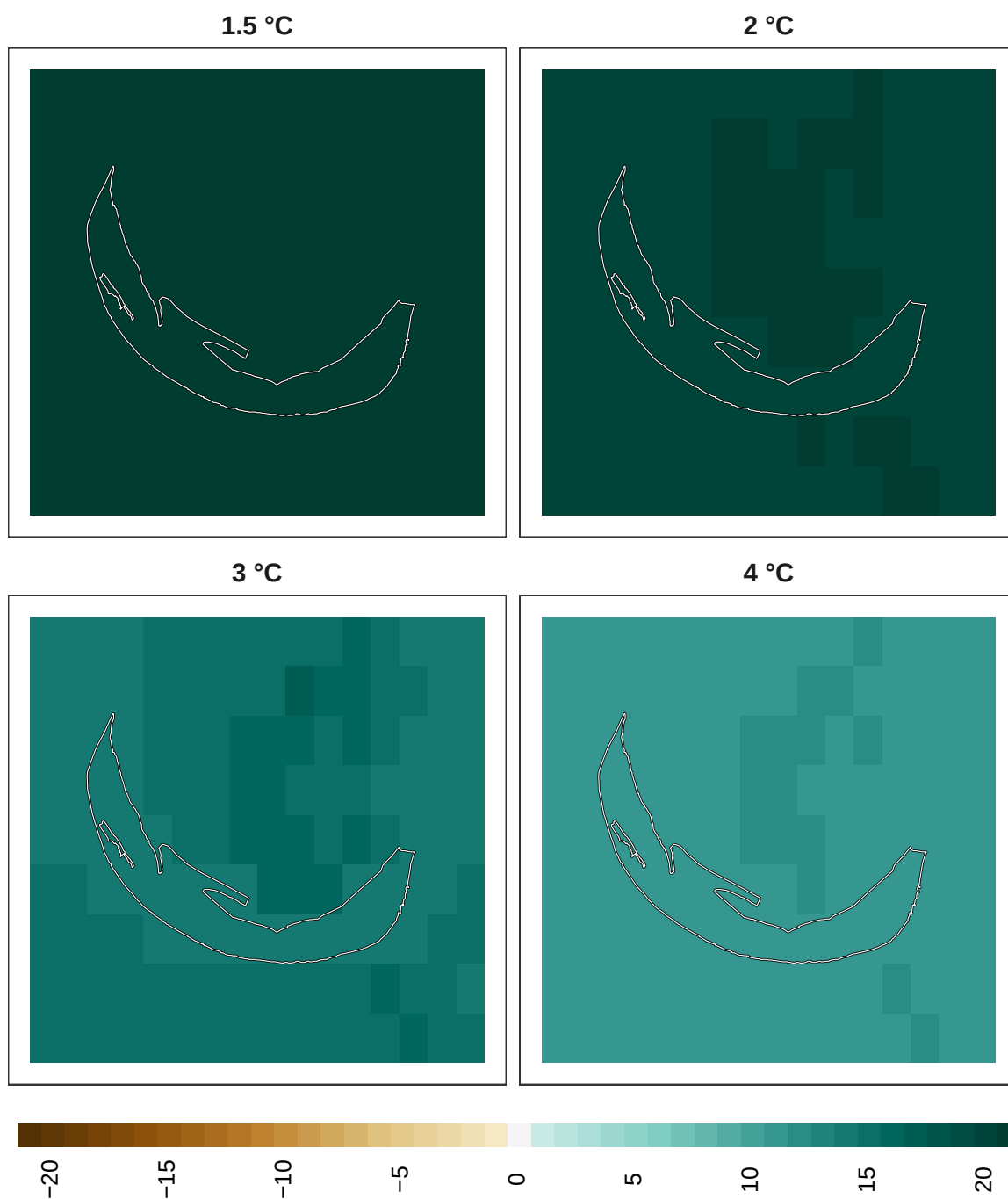


Figure 21: Adaptation effort for birds at 1 km resolution.

Mammals

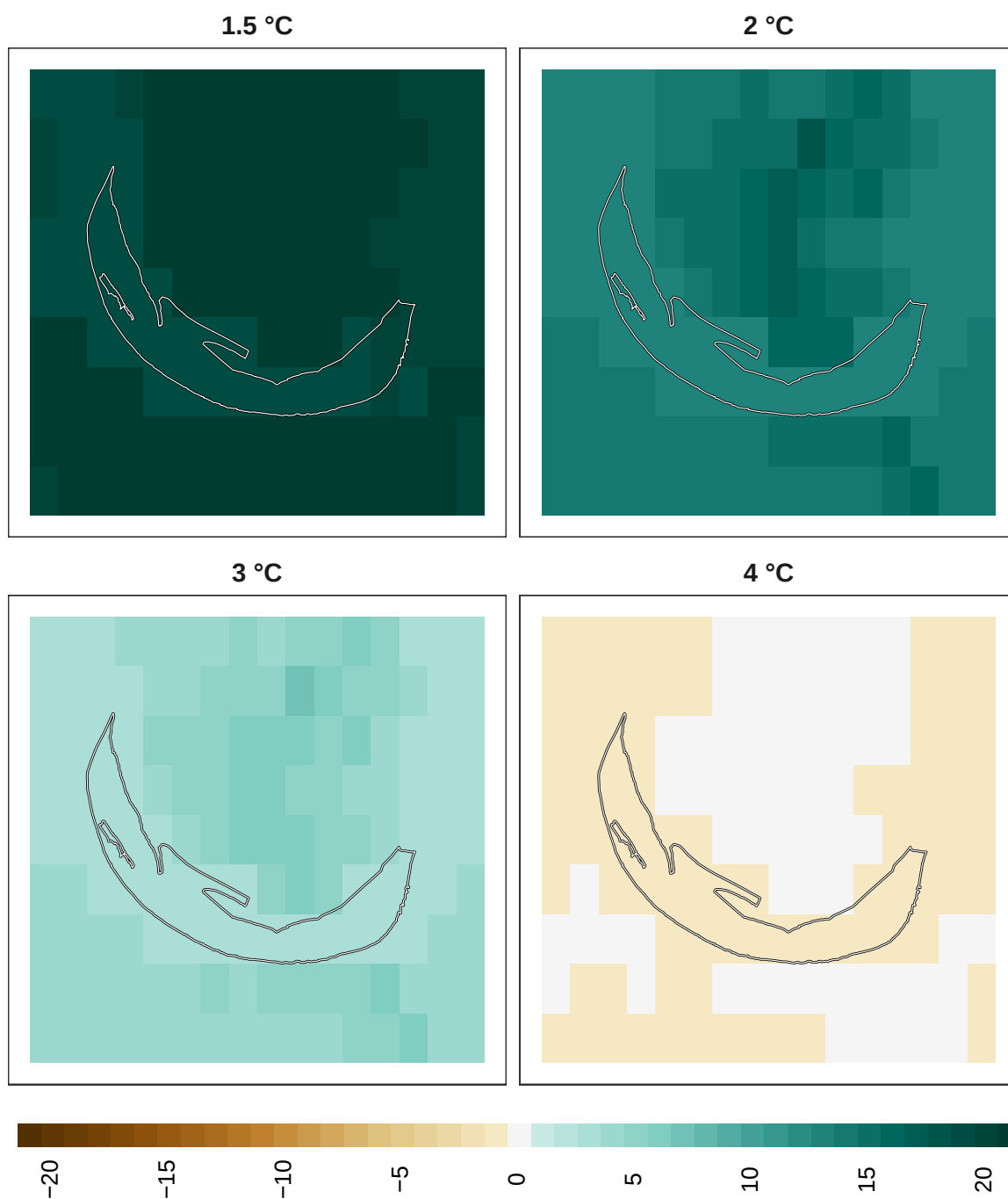


Figure 22: Adaptation effort for mammals at 1 km resolution.

Reptiles

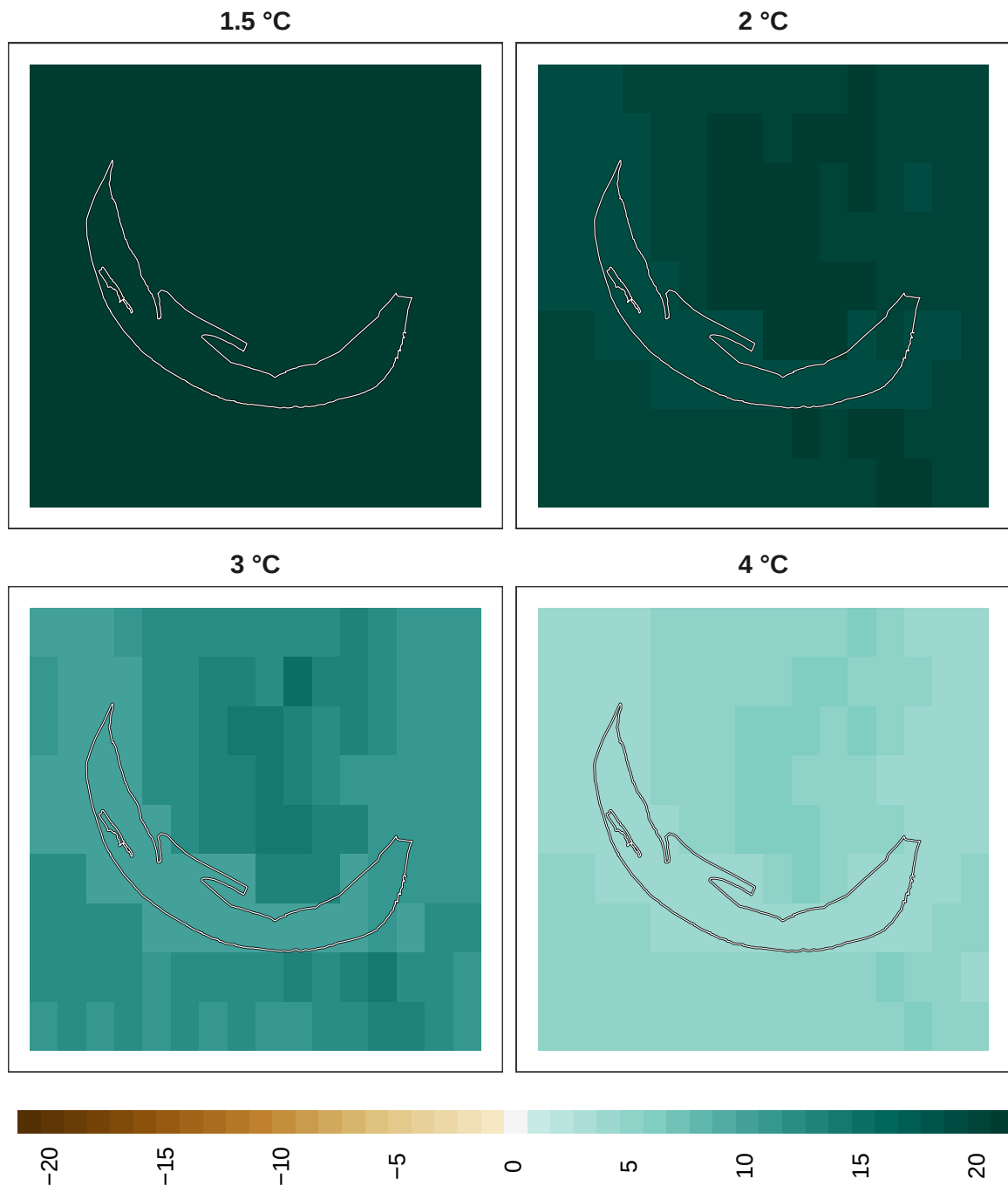


Figure 23: Adaptation effort for reptiles at 1 km resolution.

Insects

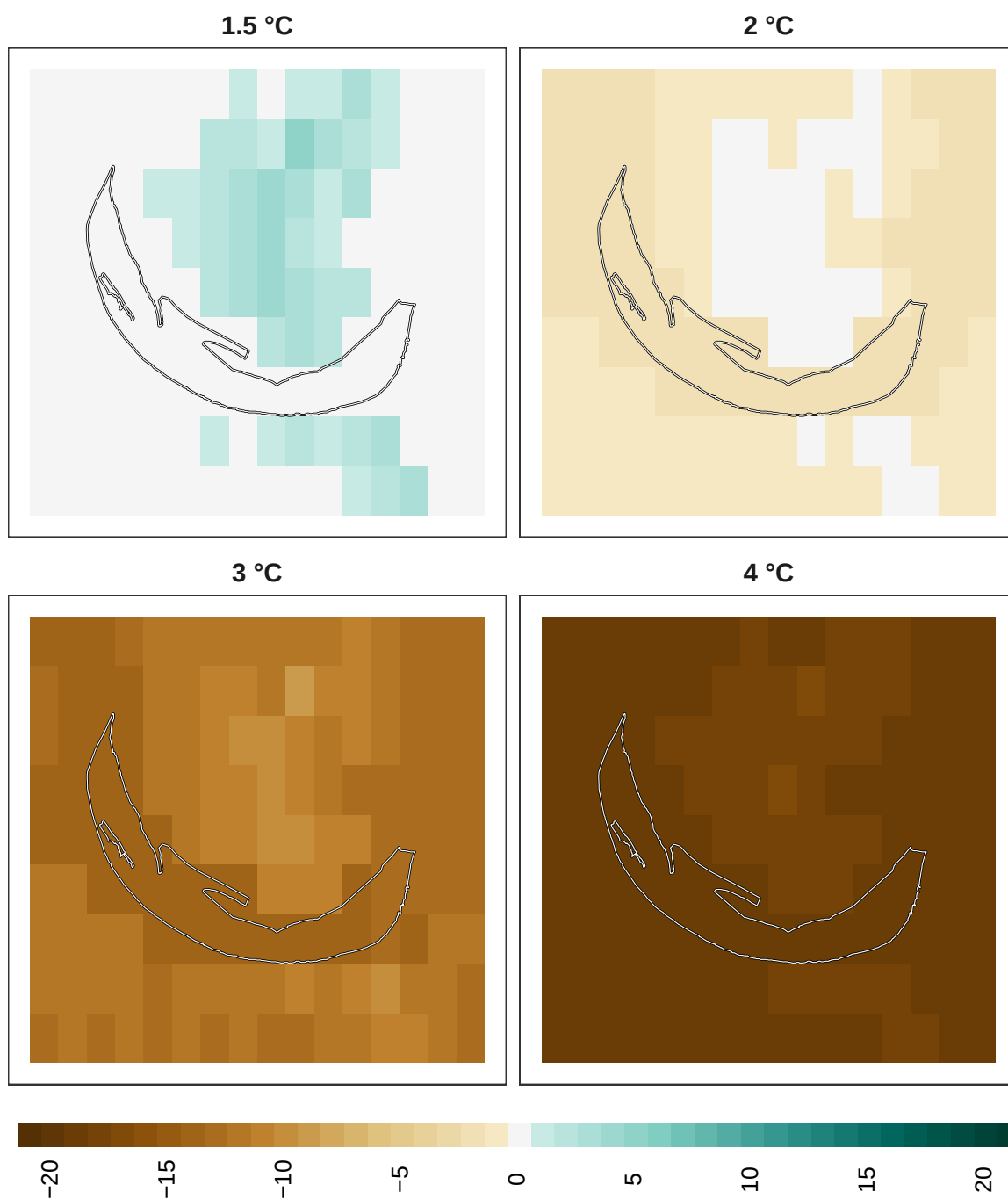


Figure 24: Adaptation effort for insects at 1 km resolution.

Pollinators

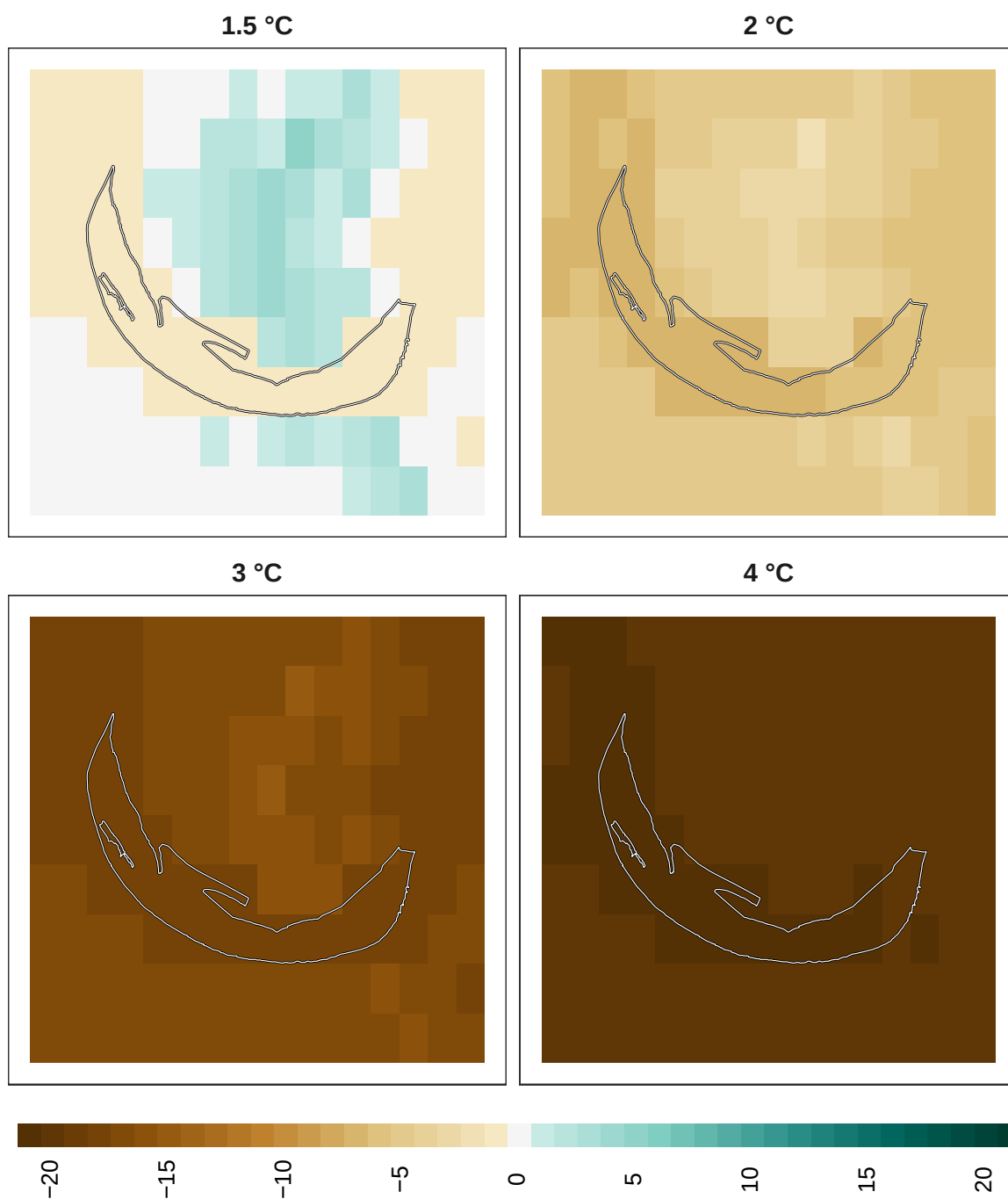


Figure 25: Adaptation effort for pollinators at 1 km resolution.

Price, J., Forstenhäusler, N., Graham, E., Osborn, T.J., and Warren, R. (2024) Report on the observed climate, projected climate, and projected biodiversity changes for *Ragain?s vings* under differing levels of warming. Report of the Wallace Initiative.

The projected climate change data are expressed as quantified changes, typically called anomalies (e.g., degrees of temperature rise, millimetres of precipitation), relative to the baseline climate of 1961–1990. For example, an anomaly of 2.3°C means that the temperature is projected to be 2.3°C warmer than the 1961–1990 average. In preparing these reports, these projected changes are generally averaged across the 21 patterns, and then compared against the observed baseline, as well as to the standard deviation in the observed (1961–1990) baseline.

The tables of projected results give the projected monthly average changes in the different climate variables, tied to the corresponding projected global temperature rise (also referred to as specific warming level). The warming levels used in this report are: 1.5°C (Paris Accord's aspirational goal); 2°C (upper limit of Paris Accord goals); 2.5°C; 3°C; 3.5°C (approximately the range of warming projected if countries meet their Intended Nationally Determined Contributions and make no additional improvements); and 4°C as a Business as Usual (BAU) pathway if temperature trajectories follow their current trajectory. In general, many impacts are tied to an amount of warming and its accompanying climate change and are not strongly dependent on time (as different scenarios reach the same temperature 2°C at different times). This approach is used to aid the reader in determining potential projected changes depending upon agreed (and followed) global policies from international negotiations. The projected climate change model data presented here is provided for different warming levels as averages of 30-year periods.

Climate Variables

This report provides information on observed (Tables 1, 3, and 5) and projected values (Tables 2, 4, and 6) of three terrestrial seasonal temperature variables — high, average, and low. The data does not give the maximum temperature of each day but the average value of these ~30 daily high temperatures, to give the monthly average high (usually mid- to late-afternoon). This is similar for the monthly average low (usually right before dawn) temperature.

For observed data, differences between the two observed time periods, 1961–1990 and 1991–2020, are provided. Two additional metrics are also provided — the average of each of the vari-

ables in the warmest year and the coolest year. In other words, for a given 30-year period the warmest/coolest/average monthly temperature (for low, high and average) were calculated. As previously mentioned, this is not derived from the extremes of daily data but is rather an indication of how warm the 'warmest' overall month was and how cool the 'coolest' overall month was. This can be viewed as the warmest month and coolest month observed (and thus experienced by the people and biodiversity in the area) in the 30-year period of 1961–1990 and for 1991–2020. Given the size of spatial area analysed, the warmest year may not have been the same year in every part of the area.

Precipitation

Also provided are observed and projected values for terrestrial precipitation (Tables 7 and 8). As for temperature, for a given 30-year observational period, the wettest monthly average and the driest monthly average are also provided. This is often driven by exceptionally wet or dry years, so the variability is much greater than with temperature and the number of 'extreme' years (i.e., > 2 SD) are fewer. For future projections of precipitation, when averaging across the 21 GCM patterns used, the median is used rather than the mean as the median is a better measure of central tendency. Finally, summary statistics are provided giving the difference between 1961–1990 and 1991–2020 for average precipitation to show what changes (if any) may have already been observed. Unlike temperature, the average precipitation projections in the future rarely exceed the wettest or driest years of the past (>1 or >2 SD). The extremes in one direction or another may become more common (and true extreme events will also usually become greater and more common) but the median does not shift by that much.

Note on interpreting projected precipitation changes — While looking at climate change projections for temperature is relatively straightforward, it is less so for precipitation. For a given area, patterns of change from some GCM models will project a wetter future whilst others will project a drier one, as illustrated in Figure 12.22 of IPCC's Working Group I report (IPCC, 2013), which presents the degree of concurrence of the sign of projected precipitation change across models. In general, GCMs tend to project that wet areas in mid- and high-latitudes become wetter, and dry, low latitude areas become drier as climate changes, and there is high confidence that "the contrast of seasonal mean precipitation between dry and wet regions will increase in a warmer climate over much of the globe" (IPCC, 2013). However, there is a great deal of variation in the details and there are some parts of the world where model agreement on the sign of precipitation change is poor. This means that use of an overall mean, or even median, change across models could potentially lead to maladaptive responses and planning. Care must be taken in deciding how these climate changes might turn into impacts. One overview on how climate impact drivers can turn into impacts can be found in the IPCC Working Group 1 Fact Sheet on Biodiversity and Ecosystems (https://www.ipcc.ch/report/ar6/wg1/downloads/factsheets/IPCC_AR6_WGI_Sectoral_Fact_Sheet_Terrestrial_Freshwater_Ecosystems.pdf).

The following provisions should also be kept in mind:

1. Depending on the size of the area/park analysed the changes may not be the same, or even in the same direction in all parts of the park (mostly true for larger areas). Thus, some parts might currently be being observed to be becoming drier, while others are becoming wetter. However, some parts of this study only look at the area as an overall average so some levels of important detail may be lost.
2. The monthly differences may be in different directions. So, some months might become wetter while others become drier in the same area of study. IPCC gives "high confidence that the contrast between wet and dry seasons will increase over most of the globe as temperatures increase" (IPCC, 2013, p. 1079).

- ## Role of elevation and topography

Drought

Waterlogging

Population Data

Price, J., Forstenhäusler, N., Graham, E., Osborn, T.J., and Warren, R. (2024) Report on the observed climate, projected climate, and projected biodiversity changes for *Ragain?s vngis* under differing levels of warming. Report of the Wallace Initiative.

Figures 1 to 9 show the species richness remaining in each 1 km cell within the boundaries of the area under study (also depicted on the map as a solid black line) for selected taxa. This shows the spatial variability in the potential patterns of loss.

Table 16 shows the percent of the area remaining a climate refugia for the taxa. We define a climate refugia as an area remaining climatically suitable for >75% of the species in those taxa. The two columns, for each level of warming, are >0 (meaning at least one climate change model projects that the area is a refugia) and >10 (meaning that more than 10 models, out of 21, project the area remains a refugia). The shading is – darker green, >75% of the area is a refugia; medium green, 50–75% of the area is a refugia; light green, 25–50% of the area is a refugia; and white, less than 25% of the area is a refugia.

The biodiversity refugia map is the minimum models in agreement between the plant and animal refugia.

Figures 18 to 25 present a spatial representation of the potential 'adaptation effort' that might be needed to maintain at least 75% of the species modelled (i.e., area remains climatically suitable) in each ~1km pixel. Adaptation effort is a combination of the number of climate models (+ 1 to 21) projecting an area is a refugium (remaining climatically suitable for >75% of the species) as well as the number of climate models (- 1 to -21) projecting the area to be an Area of Concern (becomes climatically unsuitable for >75% of the species) in each pixel. One way of looking at this is to consider areas with high values (+18 to +21) as being less exposed to climate change and thus potentially more resilient. Business-as-usual conservation, especially if coupled with building resilience around extreme climates (e.g., drought, heat waves) might be a reasonable adaptation approach to take. As the score drops, increasingly greater amounts of adaptation might be needed to maintain the existing species in that pixel. While micro-refugia (areas <1km) might be available, the amount of habitat available as micro-refugia would be less than the pixel. Once the adaptation effort drops into the negative zone, adaptation to maintain the existing species is likely to become increasingly difficult. At score of -15 to -21 the best approach might be to consider facilitating change as opposed to putting large efforts into trying to maintain existing species. Scores this low indicate that the area becomes climatically unsuitable for a large percentage of species. While this does not preclude micro-refugia, large areas (and potentially the area of conservation interest) would appear to be transforming. In the case of an area where restoration or reforestation is planned, then consideration might be given to planting the species that might be expected to move into the area, given enough time (considering species with similar structure and native, if possible). This type of adaptation begins to make the new 'habitat' that species from surrounding areas will need to autonomously adapt to climate change.

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a refugium for. With increasing warming, fewer areas remain refugia, more areas become areas of concern, and adaptation effort increases (i.e., becomes more negative).

Developing robust adaptation plans in the light of climate projection uncertainties

Climate change adaptation experts recommend an iterative risk management approach, particularly where climate change projections or future vulnerability is uncertain. Conceptual approaches for prioritising potential adaptation options might include: (i) implementing low cost ‘no regret’ adaptation plans, such as removal of concomitant stresses; (ii) in areas where it is unclear whether drying or wetting is projected, creating adaptation plans relating to changes in management to incorporate future projected climate change that remain flexible (e.g., either to adaptively manage or plan for both wetting and drying, or to be able to switch rapidly from managing/planning for wetting to what is needed for drying). Since climate change generally includes increases in climate variability, even in a future wetter climate, there may still be more droughts. This implies that adaptation to changes in precipitation needs to incorporate flexibility on both long and short timescales to cater for both wetting and drying in areas where the sign of precipitation projection differs across models. Even in areas where the sign of precipitation change is consistent between models (e.g.~positive), increases in climate variability on shorter timescales may still imply a need to cater for increased short-term drying. (iii) avoiding implementing plans that lock in the system to being able to cater for only the present day climate, (thus ignoring warming) or catering only for wetting (when actually drying may occur).

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