



A decision-support tool to guide strategic tourism management: Mapping and modelling tourism pressure and opportunities for sustainable tourism in four UNESCO Biosphere Reserves

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1. Context

1.1. About the BioCultural Heritage Tourism project

The BioCultural Heritage Tourism project is an EU Interreg project involving four UNESCO Biosphere Reserves (North Devon Biosphere Reserve, Brighton and Lewes Downs Biosphere Reserve, Réserve de Biosphère Iles et Mer d'Iroise and Réserve de Biosphère Marais Audomarois) (see maps in Appendix 1) and two resource partners, Pas-de-Calais Tourisme and the University of Exeter. The collaborative project started in April 2018 and ends in December 2021. The project has sought to address the impacts of overtourism in the Biosphere Reserve by using the concept of BioCultural Heritage Tourism (BCHT), which is about celebrating the connections between humans and the natural world around us. The project has three main themes: tourism management, business engagement and the development of new tourism experiences. The work discussed in this report related to the theme around tourism management – or 'Masterplanning' as it was called on the project. The decision support tool we have developed is designed to support and inform decisions about how to manage visitor pressures, and to identify where there might be opportunities for developing sustainable tourism in the future.

1.2. Tourism management aims

One premise of the BCHT project was that tourism benefits and dis-benefits were unevenly distributed across the Biosphere Reserves (BRs). Partners saw tourism creating negative impacts in highly visited places in their region's, but at the same time, recognised that tourism brought a range of economic, social and sometimes even environmental benefits to those areas. The question was how to manage tourism across these regions in a way that would mitigate some of the negative impacts and enhance the positive.

The aim of tourism management ('Masterplanning') theme was to create a GIS modelling decision-support tool to guide strategic tourism decision-making in the four participating UNESCO Biosphere Reserves. We have developed a decision-support tool was designed to identify areas where there is existing tourism pressure (based on available data) and that can suggest areas where there might be opportunities for sustainable tourism development. The model aims to inform discussions about tourism planning by providing visual depictions of tourism pressures and opportunities. We intended for pressure and opportunity 'heat' maps⁷ to be used to inform discussions about strategic planning for the future of tourism and support decision-making.

1.3. Limitations of modelling

The model we have created is a system of numerically scoring different environmental and human factors that contribute to tourism pressure and opportunity. We have therefore ascribed numbers to some complex and subjective concepts, such as 'habitat sensitivity' and 'tourism pressure'. Giving quantitative form to at least partially qualitative concepts is not unproblematic. We have attempted to overcome subjectivity by using stakeholder input in the scoring process, and by using a regression analysis to test the extent to which different factors contribute to tourism pressure and opportunities.

Modelling forces us to define the assumptions and contributing factors that influence decision-making. We would argue this helps make decision making more transparent and we hope it will

⁷ A heat map is a representation of data in the form of a map or diagram in which data values are represented as colours. For this project they show either sites / areas of tourism pressure or opportunity. Here for reasons of accessibility (e.g. including those with colour vision deficiency) we have avoided using conventional red-green colour spectrums.

facilitate debate about sustainable tourism development in the Biosphere Reserves. However, we acknowledge that no model can account for the full complexity of decision making. Our model does not, for instance, include political factors that shape tourism development. It is also limited by the availability of data. But the model does include data for 29 factors influencing tourism pressure and opportunity. We invested substantial time in identifying and creating datasets to include as part of the model, as well as in obtaining the extensive stakeholder inputs, in order to maximise the model's effectiveness and relevance.

1.4. Defining tourism pressure and opportunity

The model creates heat maps of 'tourism pressure' and 'opportunities for future tourism development'. By 'tourism pressure' we mean the tourism pressure attributed to that 25m grid square by the model from a variety of sources (see below - this is an aggregate score based on the combination of all the data layers) as set out in Table 3 (Human factors influencing tourism table). The data layers that contribute to this score comprise:

- **management** (including environmental designations);
- **access** (including transport infrastructure, open access areas and paths / rights of way);
- **businesses** (including food & drink, cycle hire and water sports); and
- **attractions & amenities** (including heritage sites, archaeological sites and key tourism attractions).

The scoring was formulated using regression analysis of the participatory GIS data compiled by environmental stakeholders / experts indicating areas experiencing high 'tourism pressure' (see further details below).

By opportunities for future tourism development, we mean opportunities for well-managed, sustainable tourism – this includes new tourism experiences based on BCHT principles.

2. Development of the modelling method

Section 2 gives an overview of the project process used to develop the model. In Section 3, you can find details of each stage and sub-stage within the modelling method itself.

2.1. Project phases

The process of developing the model has been collaborative, iterative and experimental. The initial idea of a model was Andy Bell's (North Devon Biosphere Reserve). Carolyn Petersen and Tim Wilkinson from the University of Exeter have worked with the North Devon Biosphere Reserve, project partners and with Nick Bearman (Geospatial Training Solutions), to develop a method, pilot the method and generate outputs.

The initial idea for the model was discussed at two Research Seminars with academics and tourism experts with the four Biosphere Reserves. The first of these was held in Paris in April 2019, and the second in London in Feb 2020. At these events, ideas for the design of the model were discussed and changes were suggested.

At the 2019 Paris research seminar, we agreed to develop '10 maps' (see Table 1) for each Biosphere Reserve depicting available data about tourism. This highlighted data gaps for some partners. We later used this list of 10 maps to inform the 'Human factors influencing tourism' (see Table 3) and list of data sources.

Table 1: List of 10 maps

Map no.	Description (UK)	Could include information about
1	Land cover	Types of land cover Habitats
2	Protected areas	European, National, regional and local designations
3	Tourist facilities (including businesses?)	Tourism business location Visitor centres Car parks Public toilet facilities
4	Tourist routes, trails and access	Walking / cycling trails Boat tour routes Roads Disabled access Public open space Bus routes Train routes and stations
5	Hot spots for biodiversity	Species biodiversity heat map(s) Local nature reserves Nesting sites?
6	Cultural and historic sites	Archaeological sites Historic buildings Churches/ Cathedrals Museums
7	Visitor numbers	At specific sites Attendance at events

		Eco-counter data
8	Development	Planned developments (large projects etc)
9	Pressures and ecological vulnerability of sites	Flood risks Drought risks Vehicle congestion Sea level rise Water pollution Air pollution
10	Activities	Location of relevant activities

At the 2020 London seminar, partners fed back on a proposal from Tim Wilkinson and Andy Bell about a scoring system that could be used to develop a model. While broadly supporting the concept and method, partner’s highlighted an issues with the idea that tourism pressure and opportunity could be characterised by a single scale with pressure at one end, and opportunity at the other. Through discussion we developed the idea of two independent scores; one for pressure and one for opportunity. Partners also raised the issue of seasonality impacting tourism pressures and opportunities. We subsequently developed the scoring system to incorporate these suggestions.

In late 2019, Exeter University contracted Nick Bearman at Geospatial Training Solutions⁸ to implement the model using QGIS - an open source, geographical information systems software platform. In the process of implementing the idea of the model on GIS, we developed and reshaped ideas within the parameters of QGIS and as new data sources were found or supplied. We ran a pilot of the model with data from North Devon Biosphere Reserve in 2020. Following this we made various adjustments including carrying out regression analysis to determine the human tourism factor scores (rather than using ‘expert’ knowledge as initially in the pilot model); adding and / or consolidating data layers (e.g. visitor numbers data; coastal designations) and adjusting the scale and colour scheme to better show up the contrast and features.

2.2. Scenarios

In parallel to the development of the model, three scenarios for the future of tourism in the Biosphere Reserve were developed through 2019 and 2020. These were created by University of Exeter in conjunction with managers of the four Biosphere Reserves and through work with an illustrator, Paul Dowling of Dowling Design⁹. We called the three scenarios: Business as Usual, Less Regulation and Responsibility and Custodianship. For further details of these please see Appendix 3. For a quick summary, see Table 2 below.

Table 2. Summary of Scenarios

Scenario name	Summary
Business as Usual	<ul style="list-style-type: none"> • Tourism centred on honey pot sites • Visitor pressure issues • Seasonal peaks in visitor numbers and tourism business income • Gradual decline in the quality of environmental assets
Less Regulation	<ul style="list-style-type: none"> • Over-development • Increasing visitor numbers

⁸ <https://geospatialtrainingsolutions.co.uk/>

⁹ <https://dowling.biz/profile>

	<ul style="list-style-type: none"> • Businesses making more • Visitor spend not contributing to the local economy • Rising visitor pressures erode natural environments • Rising Resident – Visitor tensions
Responsibility and Custodianship	<ul style="list-style-type: none"> • Spreading the benefits of tourism across the region • More green infrastructure and travel options • More visitor spend staying in the local economy • Restoring the environment • Visitor giving, e.g. time, skills, payback schemes

3. The modelling method

3.1. Introduction

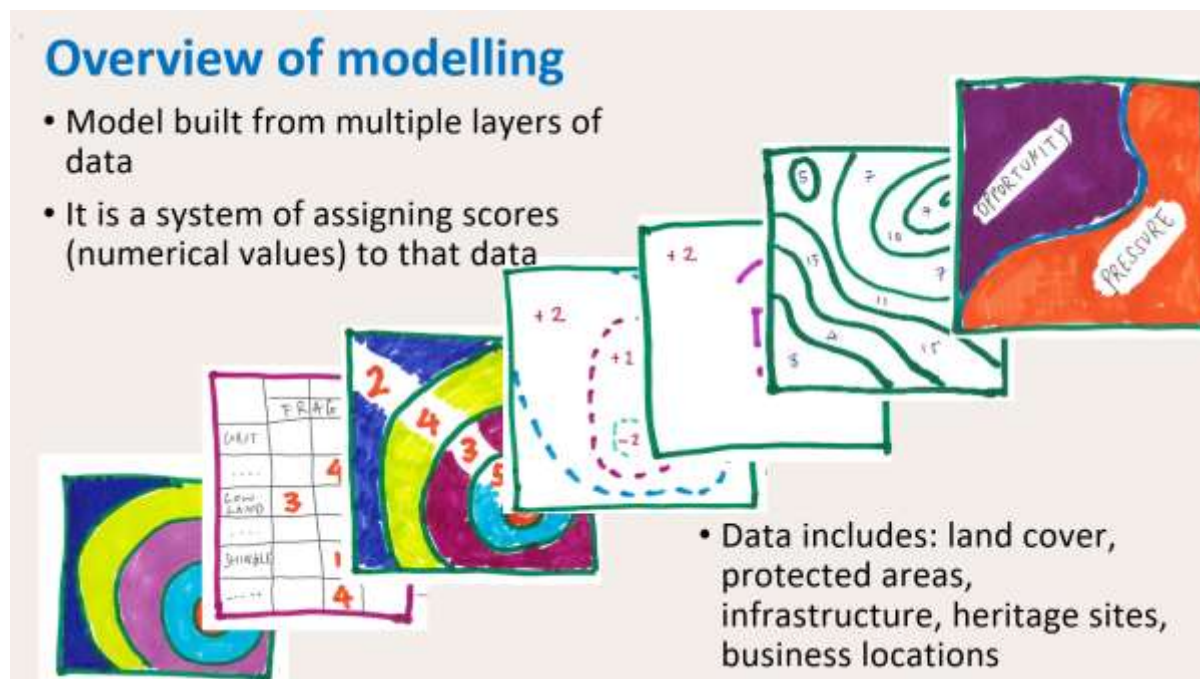
The model is made up of a combination of spatial layers (containing geographical data). These include land cover data, boundaries of protected areas, road networks, bus routes, historic and heritage sites, visitor centres and locations of businesses. In the model we assigned scores to the data using input from stakeholders, Biosphere Reserve managers and a statistical process called regression analysis. Figures 1 and 2 give a visual overview of how the model works

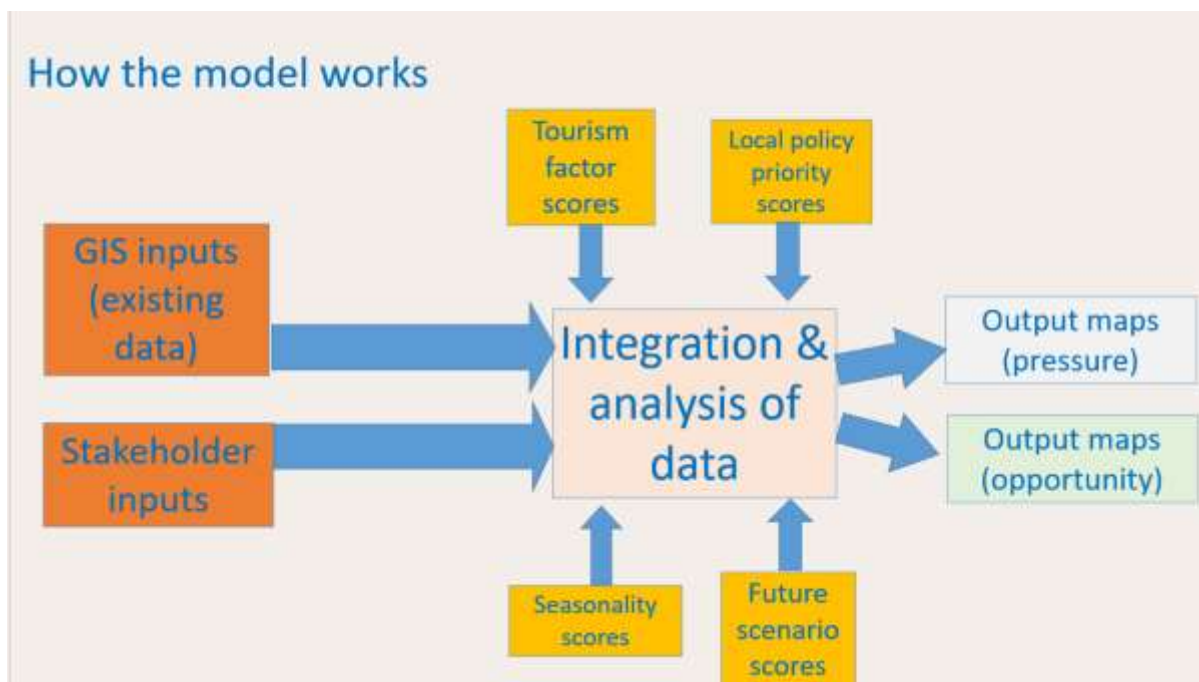
In short, the method for creating the model was:

- Gathering **existing GIS data** from a variety of sources;
- Obtaining **stakeholder inputs** (e.g. on environmental sensitivity of relevant habitats; identifying sites / areas of tourism pressure and opportunity);
- **Identifying tourism factors** and sub-factors that contribute to tourism pressure and opportunity and for which GIS data layers are available for the BR;
- **Integrating and analysing** existing and stakeholder data (including regression analysis), supplemented with local policy priority scoring and seasonality scoring (by BR managers) and future scenario weightings (see below);
- Producing **output maps**.

In the following section, we describe each stage of the process

Figure 1. Overview of multiple GIS layers and of process





The model draws on nine phases which we describe in detail below:

- Obtaining and collating existing data (3.2)
- Scoring the environmental sensitivity of habitats (3.3)
- Creating a Habitat Sensitivity Score (3.4)
- Seasonality – modification of Habitat Sensitivity Score (3.5)
- Scoring of human factors (Opportunity and Pressure Scores (3.6)
- Stakeholder identification of areas of tourism pressure and opportunity (3.7)
- Compiling data layers (3.8)
- Regression analysis (3.9)
- Policy Weighting (3.10)
- Combining and modifying scores (3.11)
- Baseline map output (3.12)
- Weighting opportunity and pressure in the scenarios (3.13)

3.2. Obtaining and collating existing data

We collated existing and available geographic data through online review, liaison with staff at project partner organisations and stakeholders in their networks. The model uses these data sources (see Table 3)¹⁰. These data sources were grouped into the factor table.

Where we had data gaps, we sought to fill these. For instance (UK version¹¹):

Table 3. Human Factors influencing tourism and the sub-factors that comprise them and data sources

Factor	Subfactor	Data source
Management	SSSI (UK only)	Defra Magic Map
	RAMSAR	Defra / Natural England
	Natura 2000 (incl. SPA and SAC)	Protected Planet / Defra Magic Map

¹⁰ Various data sources subject to copyright – see acknowledgements for further details.

¹¹ Alternative data sources were used for the French BRs in some cases depending on availability.

	National Park	Protected Planet
	National Nature Reserve	Protected Planet
	Regional Nature Reserve (France only)	Protected Planet
	Local nature reserve	Protected Planet
	Area of Natural Beauty (AONB)	Protected Planet
	Marine nature reserve	Protected Planet
	Agricultural land	Defra Magic Map
	Heritage coast	Protected Planet
	Biodiversity (species) hotspot	National Biodiversity Network Trust
Access	Roads (major)	Ordnance Survey
	Traffic count	Data.gov.uk ¹² (limited data available)
	Cycle path	Devon County Council / Brighton and Hove County Council / data.dft.gov.uk / National Cycle Network
	Footpath (major)	Devon County Council / Brighton and Hove City Council / E. Sussex County Council / W. Sussex County Council
	Bus routes and bus stops	Devon County Council / Brighton and Hove City Council / E. Sussex County Council / W. Sussex County Council
	Railway station	Ordnance Survey
	Disabled access	OpenStreetMap / WheelMap
	Open access / accessible woodland / CRoW	Ordnance Survey / Devon County Council / Defra
Business clusters	Food and drink	TripAdvisor / Devon County Council / OpenStreetMap
	Cycle hire	OpenStreetMap
	Adventure centre, water sports school	OpenStreetMap
	Local Business (France only)	N/A
Significant local tourism attractions and amenities	Archaeological sites	Historic England – Scheduled Monuments
	Heritage sites	Historic England – Heritage at Risk layer
	Visitor centres	Devon County Council / Brighton and Hove County Council / BLDBR
	Key tourism attractions (e.g. the Big Sheep)	NDBR and BLDBR staff – expert / local knowledge
	Visitor numbers	TripAdvisor – key sites and most popular sites in BR

¹² Data downloaded from: <https://data.gov.uk/dataset/208c0e7b-353f-4e2d-8b7a-1a7118467acc/gb-road-traffic-counts>

	Car parks	Devon County Council / Brighton and Hove County Council
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3.3. Scoring the environmental sensitivity of habitats

Habitat Sensitivity Score

A list of habitats was compiled using data combined from Corine Land Cover 2018 and the Defra Priority Habitats Inventory (from the Defra Magic Map) tailored to each BR (with input from BR staff). Expert stakeholders (primarily environmental managers / experts) from within each Biosphere Reserve were asked to score environmental fragility and tourism sensitivity of the habitats in the Biosphere regions. This was to establish which of the habitats identified were perceived as most sensitive to tourism by experts. Data was collected in an interview where an interviewer went through a matrix with the participants (see Table 4 for matrix). The matrix comprised a list of habitats in the Biosphere Reserve and columns to provide scores for a habitat's environmental fragility (scale of 1-3) and sensitivity to tourism (scale of 1-5). Following completion of the interview, we multiplied the environmental fragility score with the tourism sensitivity score, to make a *Habitat Sensitivity Score*. This score was then assigned to habitat types on data layers on QGIS.

Table 4. Example of Habitat Sensitivity Scoring Matrix (NDBR)

Habitat / environment type	Environmental fragility ranking			Habitat sensitivity score
	Not fragile	Fragile	Very fragile	
Bare rocks	1	1	1	1
Blanket bog	1	1	5	15
Broad-leaved forest	1	2	1	4
Coastal and floodplain grazing marsh	1	1	5	15
Coastal saltmarsh	1	1	5	15
Coastal sand dunes	1	1	3	9
Complex cultivation patterns	1	3	1	6
Coniferous forest	1	1	1	2
Deciduous woodland	1	3	1	6
Discontinuous urban fabric	1	1	1	1
Estuaries	1	2	1	4
Fragmented heath	1	3	1	6
Good quality semi-improved grassland	1	2	1	4
Grass moorland	1	2	1	4
Intertidal flats	1	2	1	4
Lowland calcareous grassland	1	3	1	6
Lowland dry acid grassland	1	3	1	6
Lowland fens	1	3	1	6
Lowland heathland	1	3	1	6
Lowland meadows	1	3	1	6
Maritime cliff and slope	1	3	1	6
Mineral extraction sites	1	1	1	1
Mixed forest	1	2	1	4

Moors and heathland	1	2	1	4
Mudflats	1	2	1	4
Natural grassland	1	1	4	12
Parkland and wood pasture	1	2	1	4
Pastures	1	2	1	4
Peat bogs	1	1	5	15
Purple moor grass and rush pastures	1	1	3	9
Reedbeds	1	1	1	2
Salt marshes	1	4	1	8
Sea and ocean	1	3	1	6
Traditional orchard	1	2	1	4
Transitional woodland-shrub	2	1	1	2
Upland flushes, fens and swamps	1	1	3	9
Upland hay meadow	1	3	1	6
Upland heathland	1	2	1	4
Water bodies	1	3	1	6

The interviews with stakeholders had varying levels of uptake across the Biosphere Reserves (see Table 5 for number of participants) for reasons of local capacity and staffing. The RBIMI scores were created through reaching consensus in a workshop with input from stakeholders and Biosphere Reserve staff.

Table 5. Number of internal stakeholder participants completing matrix and participatory GIS mapping

Biosphere Reserve	Number of stakeholders who completed matrix
North Devon (NDBR)	7
Brighton and Lewes Downs (BLDBR)	9
Marais Audomarois (RBMA)	3
Iles et Mer d'Iroise (RBIMI)	6

Seasonality – modification of Habitat Sensitivity Score

Following feedback at the London Research Seminar in 2020, we added a seasonal dimension to the Habitat Sensitivity Scores. We added two season periods into the model. These were broadly identified by partners as summer months and winter months. The rationale for altering habitat sensitivity according to season is that experts highlighted that sensitivity varies through the year, for instance when there are ground nesting birds. A single score was considered inadequate. We deliberated on splitting the year into four seasons to give the opportunity for seasonal impacts on habitat sensitivity, but decided this was impractical as it would have multiplied the number of output maps beyond what was manageable.

The scores for seasonal sensitivity were compiled using a basic matrix that listed habitat types and provided a column to identify which habitats were more sensitive. The scores were decided by Biosphere Managers, who scored each habitat for whether it was more sensitive or not during the two seasonal periods (see Table 6).

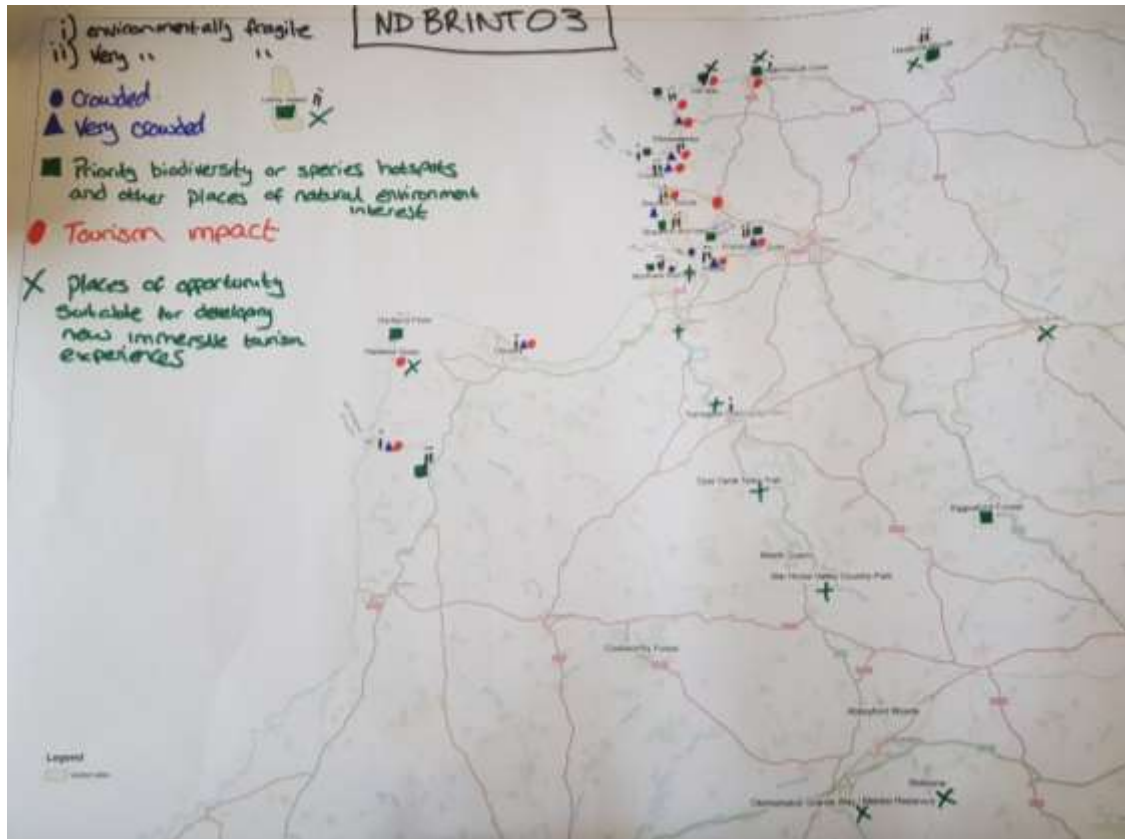
Table 6. Example Table (NDBR) for seasonal adjustment to Habitat Sensitivity Score

NDBR Habitat / environment type	More sensitive in summer (2 = Yes / 1 = No)	More sensitive in winter (2 = Yes / 1 = No)
Bare rocks	1	1
Blanket bog	1	1
Broad-leaved forest	2	1
Coastal and floodplain grazing marsh	1	2
Coastal saltmarsh	1	2
Coastal sand dunes	1	1
Complex cultivation patterns	1	1
Coniferous forest	1	1
Deciduous woodland	2	1
Discontinuous urban fabric	1	1
Estuaries	1	2
Fragmented heath	1	1
Good quality semi-improved grassland	1	1
Grass moorland	2	1
Intertidal flats	1	2
Lowland calcareous grassland	1	1
Lowland dry acid grassland	1	1
Lowland fens	1	1
Lowland heathland	2	1
Lowland meadows	1	1
Maritime cliff and slope	2	1
Mineral extraction sites	1	1
Mixed forest	1	1
Moors and heathland	1	1
Mudflats	1	1
Natural grassland	2	1
Wood-Pasture and Parkland	1	1
Pastures	1	1
Peat bogs	1	1
Purple moor grass and rush pastures	2	1
Reedbeds	2	1
Salt marshes	1	2
Sea and ocean	1	1
Traditional orchard	1	1
Transitional woodland-shrub	1	1
Upland flushes, fens and swamps	1	1
Upland hay meadow	2	1
Upland heathland	2	1
Water bodies	1	1

3.4. Stakeholder identification of areas of tourism pressure and opportunity

During the stakeholder interviews, we also asked participants to draw areas of tourism pressure and opportunities for future tourism development onto maps. We then digitised these into GIS format (and merged the individual digitised stakeholder layers together).

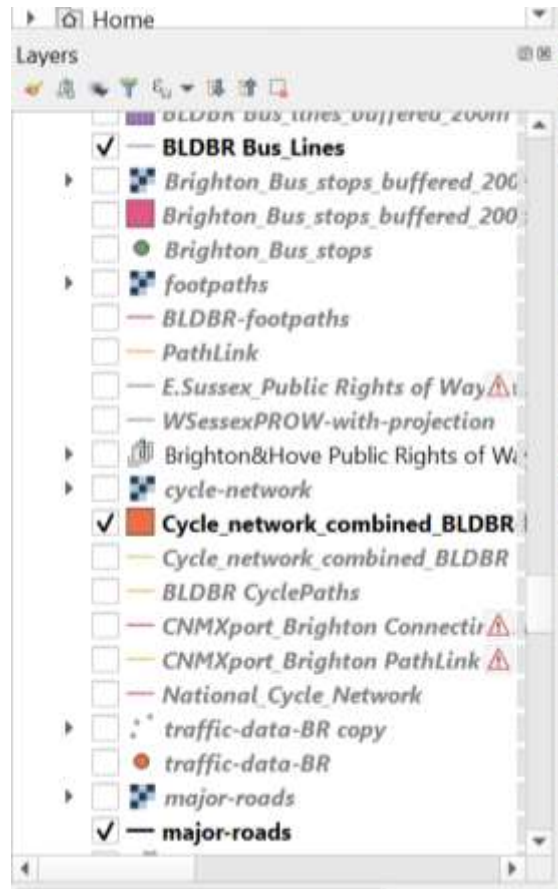
Figure 2. Example (NDBR) participatory GIS map output from stakeholder interview



3.5. Compiling data layers

We compiled existing data layers and data from stakeholders on QGIS.

Figure 3. Example (BLDBR) of selected access data layers - transport (UK) – QGIS output



3.6. Scoring of human factors (Opportunity and Pressure Scores)

We identified four sets of human tourism factors (see Table 7 below) which influence tourism pressure and opportunity in the BRs. Each of these factors which were broken down into sub-factors, or features, 29 in total. Scoring was created for each sub factor/ feature for both opportunity and pressure: a) for how much it contributed to an opportunity it offered for sustainable tourism (1-10 scale) and b) for how much it contributed to tourism pressure (1-10 scale). These are the *Opportunity Score* and *Tourism Pressure Score*.¹³

Table 7. Human factors influencing tourism

Factor	Description
Management	Factors influencing the management of tourism, such as landscape designations
Access	How sites are accessed and associated infrastructure, such as roads, footpaths, open access areas
Businesses	The location of businesses servicing tourism, such as cafes, pubs, restaurants.

¹³ For the purposes of the NDBR pilot model only, 4 researchers (plus 1 environmental manager) independently scored each of the 29 sub-factors/ features for pressure and opportunity. This process was, of course, subjective. We discussed independent scores and agreed an overall pressure and opportunity score for each sub-factor/ feature. These scores were used to create the pilot model maps but were not used in the final models as they were replaced by the regression analysis scores combined with the local policy weightings (see below).

Attractions and amenities	Sites with tourism appeal including visitor attractions and heritage sites. This included facilities and amenities such as car parks and visitor centres
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3.7. Regression analysis

We carried out stepwise regression analysis using R/RStudio to identify which tourism factors explained or predicted the areas that were identified as an area of opportunity or pressure by stakeholders in the participatory mapping exercise. This was undertaken for each Biosphere Reserve. This created a list of regression scores for both pressure and opportunity, such as (see Table 8).

Table 8. Example (NDBR tourism pressure) regression analysis table, with the relative contribution of layers to areas, policy weighting and overall weighting

Sub-factor	Full model	Sig	1 st Step	Sig	2 nd Step	Pr(> z)	Sig	NDBR Policy weighting	Overall weighting
Adventure centre, water sports school	0.03861 2		NA	NA	NA	NA	NA	0	0.0
Key tourism attraction	- 0.09787		- 0.09791		NA	NA	NA	0	0.0
Heritage coast	3.44823 7	***	3.44823 8	***	3.4482 41	< 2e-16	***	1	3.4
SSSI	2.52896 2	***	2.52896 2	***	2.5289 35	< 2e-16	***	1	2.5
Disabled access	2.42962 3	***	2.42960 7	***	2.4288 29	< 2e-16	***	1	2.4
Bus route	2.19954 1	***	2.19954 5	***	2.1993 65	< 2e-16	***	1	2.2
Local nature reserve	1.83169 1	***	1.83168 2	***	1.8318 37	< 2e-16	***	1	1.8
TripAdvisor visitor Numbers	1.73191	***	1.73191 4	***	1.7123 6	< 2e-16	***	2	3.4
Marine nature reserve	1.71027 6	***	1.71027 7	***	1.7103	< 2e-16	***	1	1.7
Food and drink	1.45025 5	***	1.45033 6	***	1.4496 21	< 2e-16	***	1	1.4
National Park	1.43175 7	***	1.43175 6	***	1.4317 46	< 2e-16	***	1	1.4
Footpath (major)	1.32714 5	***	1.32714	***	1.3271 46	< 2e-16	***	1	1.3
Heritage sites	1.20379 6	***	1.20377 3	***	1.2034 52	< 2e-16	***	2	2.4

Cycle path	1.10408 6	***	1.10407 4	***	1.1039 31	< 2e-16	***	1	1.1
Car park	0.54396 9	***	0.54394 4	***	0.5430 07	< 2e-16	***	2	1.1
Roads (major)	0.52248 5	***	0.52248 6	***	0.5223 81	< 2e-16	***	2	1.0
Species biodiversity	0.50689	***	0.50688 9	***	0.5068 92	< 2e-16	***	2	1.0
AONB	0.41001 7	***	0.41001 7	***	0.4100 06	< 2e-16	***	1	0.4
Railway station	0.08942 8	**	0.08941 2	**	0.0898 92	0.00408	**	1	0.1
Agricultural land	- 0.25288	***	- 0.25287	***	-0.2528	< 2e-16	***	1	-0.3
Cycle hire	- 0.28019	*	- 0.28025	*	- 0.2936 3	0.03697	*	1	-0.3
Open access	-0.5387	***	-0.5387	***	- 0.5386 9	< 2e-16	***	1	-0.5
Visitor centre	- 0.71098	***	-0.711	***	- 0.7072 4	4.60E- 07	***	1	-0.7
Archaeologic al sites	- 0.74142	***	- 0.74141	***	- 0.7413 7	< 2e-16	***	1	-0.7
Natura2000	- 1.92531	***	- 1.92531	***	- 1.9252 8	< 2e-16	***	1	-1.9
National Nature Reserve	- 12.4037		- 12.4037		- 12.403 7	0.2685		0	0.0
[Intercept]	- 4.90143	***	- 4.90143	***	- 4.9014 8	< 2e-16	***		

N.B. Initial weighting was 1 for all sub-factors except for species biodiversity (1-9).

3.8. Policy Weighting

The regression results were reviewed with Biosphere Reserve managers and the policy weighting scores (0-3) compiled by BR managers according to local policy priorities (based on local knowledge and expert judgment by BR managers of what the local policy priorities are). We used a scale where 0 = not relevant; 1 = weak policy priority for BR; 3 = strong policy priority for BR. See Table 8 above for the policy weighting.

3.9. Combining and modifying scores

The policy weighting was then combined with (multiplied by) the (2nd step) regression score to give an overall weighting score for each sub-factor (see Table 8) for both opportunity and pressure. This

was then inputted into the model, combined with (multiplied by) the *Habitat Sensitivity Score* (see Appendix 2 for further technical information on the method).

3.10. Baseline map output

We created a baseline map on the basis of the scores. See Figure 4 for example. The scale represents an aggregate score of tourism pressure. The darker the colour, the higher the pressure.

Figure 4. Example baseline map output (NDBR pressure summer).

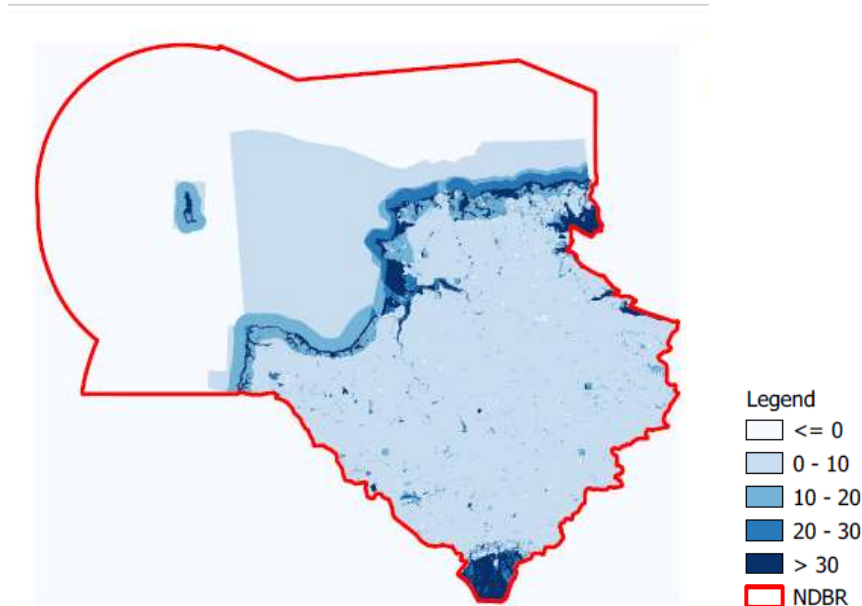


Image created by MOPST (github.com/mopst)¹⁴.

3.11. Scenarios – weighting opportunity and pressure

We translated the future scenarios we had co-designed on the project into pressure and opportunity weightings, to explore how areas of opportunity and pressure might look in the future. We agreed that the scenarios represented these implications for pressure and opportunity (see Table 8).

Table 9. Pressure and opportunity implications for future scenarios

Scenario	Pressure	Opportunity
Less Regulation	Much more	Much less
Business as usual	More	Less
Responsibility and Custodianship	Less	More

We then converted these qualitative measures into weights (see Tables 9 and 10). We applied the weighting at the level of the factors (i.e. groups of data layers), so all scores given to sub-factors/ data layers in that group were given that score.

¹⁴ All model and module output maps created by Mapping Opportunity & Pressures for Sustainable Tourism (MOPST) - Nick Bearman supported by the Interreg EU England Channel Region funded BioCultural Heritage Tourism project, Devon County Council and the University of Exeter.

Table 10. Numerical scoring of pressure and opportunity implications of scenarios

Scenario	Factor	Agreed opportunity for sustainable tourism (including BCHT) multiplier (1 to 3)	Agreed pressure multiplier (1 to 3)
Profit (no control) (much more pressure; less opportunity)	Management	0.5	2
	Access	0.33	3
	Business Clusters	0.5	3
	Historic/ heritage	0.5	3
	Tourism attractions / amenities	0.33	2
	Visitor nos	0.33	3
Business as usual (slightly less opportunity; more pressure)	Management	1	2
	Access	1	2
	Business Clusters	1	2
	Historic/ heritage	0.5	2
	Tourism attractions / amenities	1	2
	Visitor nos	1	2
Custodianship (sustainable tourism) (less pressure; more opportunity)	Management	2	0.5
	Access	2	0.5
	Business Clusters	2	0.5
	Historic/ heritage	2	0.5
	Tourism attractions / amenities	2	0.5
	Visitor nos	2	0.5

Results

4.1. List of GIS model output maps

Please see Table 11 below for output maps (applicable to all BRs)

Table 11. List of tourism pressure and opportunity heat maps

Map	Pressure/ Opportunity	Season
Baseline	Pressure	Summer
		Winter
	Opportunity	Summer
		Winter
Business as Usual scenario	Pressure	Summer
		Winter
	Opportunity	Summer
		Winter
Less Regulation	Pressure	Summer
		Winter
	Opportunity	Summer
		Winter
Responsibility and Custodianship	Pressure	Summer
		Winter
	Opportunity	Summer
		Winter

4.2. Output maps showing areas of opportunity and pressure for scenarios

16 output maps in total were produced for each BR – 4 for the baseline outputs (with no scenario weightings applied) (pressure summer, pressure winter, opportunity summer, opportunity winter) and 4 per scenario (as above) for each of the 3 scenarios. The summer output maps (baseline plus three scenarios) are included below. See Appendix 4 for the full set of output maps.

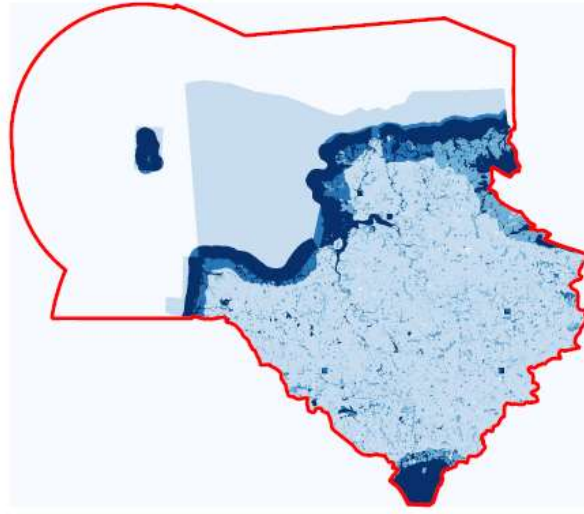
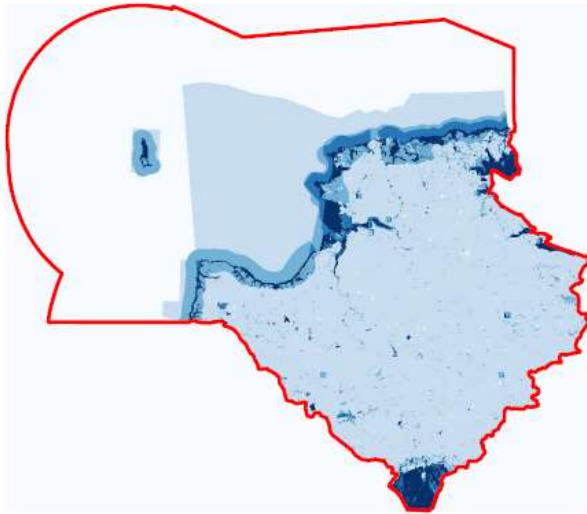
4.3. North Devon Biosphere Reserve

North Devon Biosphere example output maps¹⁵

NDBR Pressure Summer Outputs Maps – Baseline and all three scenarios

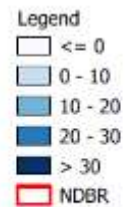
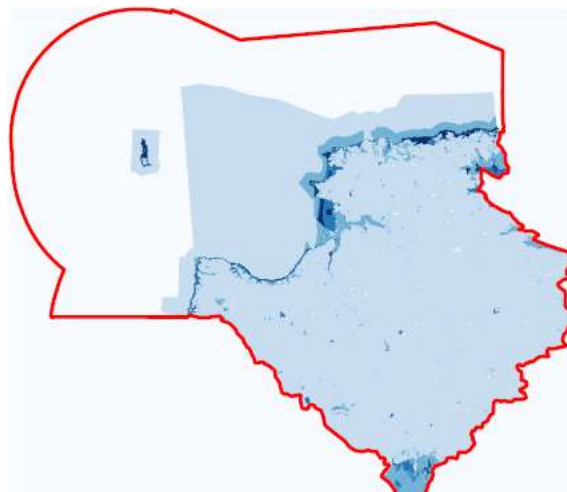
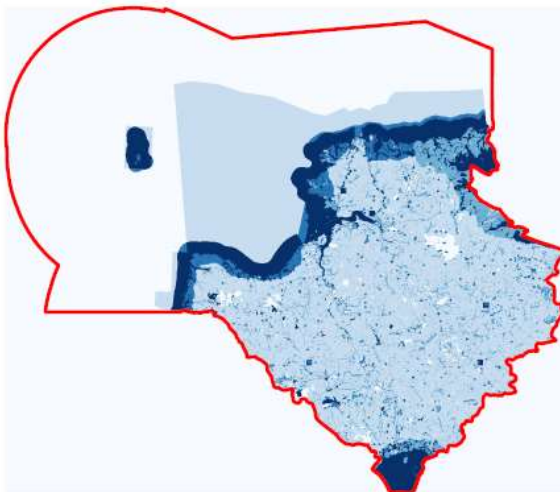
Baseline

Business as usual



Less regulation

Responsibility and custodianship



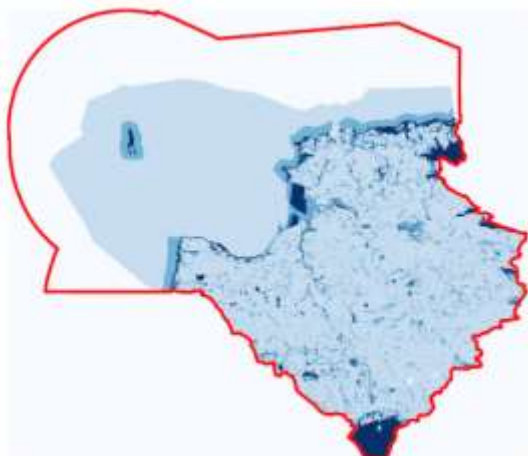
Created by MOPST (github.com/mopst)¹⁶

¹⁵ For full set of output maps see Appendix 4

¹⁶ All model and module output maps created by Mapping Opportunity & Pressures for Sustainable Tourism (MOPST) - Nick Bearman supported by the Interreg EU England Channel Region funded BioCultural Heritage Tourism project, Devon County Council and the University of Exeter.

NDBR Opportunity Summer Output Maps – Baseline and all three scenarios

Baseline



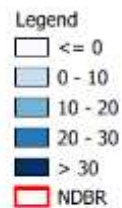
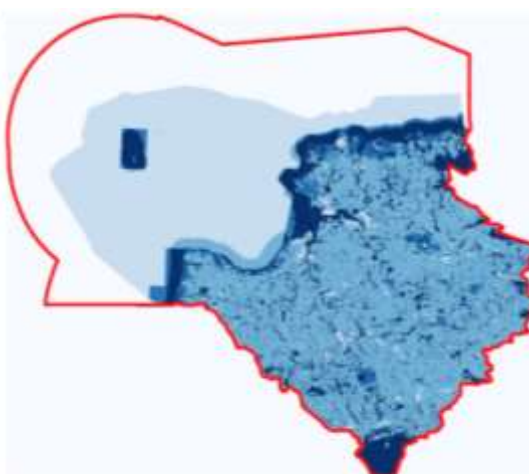
Business as usual



Less regulation



Responsibility and custodianship

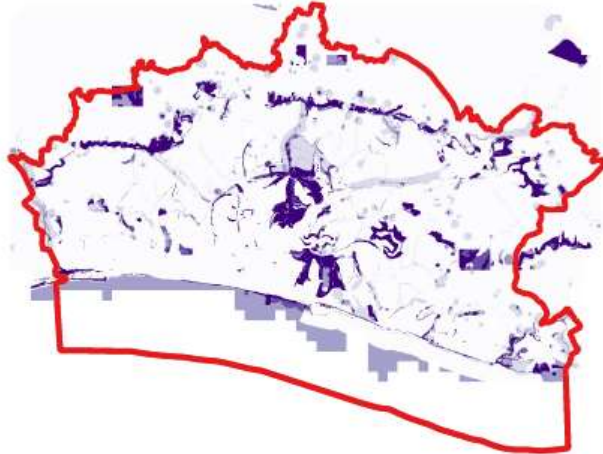
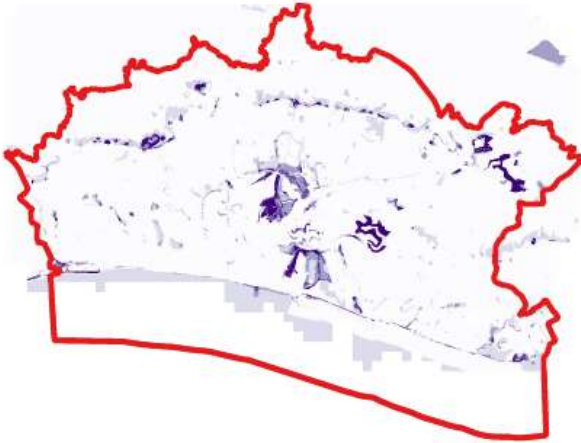


4.4. Brighton and Lewes Downs (the Living Coast)

BLDBR Pressure Summer Output Maps – Baseline and all three scenarios

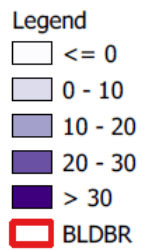
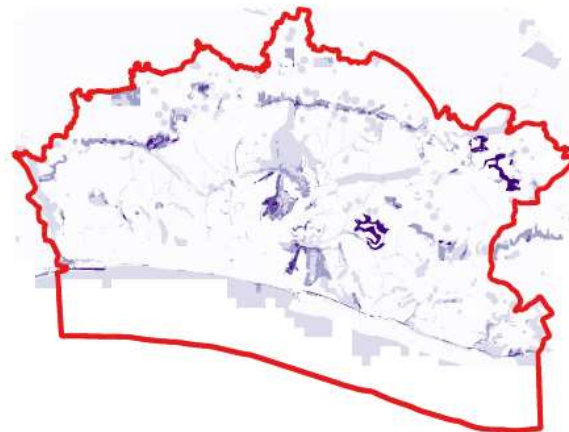
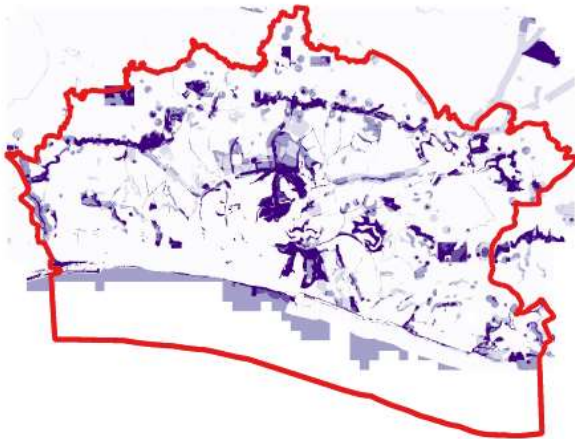
Baseline

Business as usual



Less regulation

Responsibility and custodianship



Created by MOPST (github.com/mopst)

BLDBR Opportunity Summer Output Maps – Baseline and all three scenarios

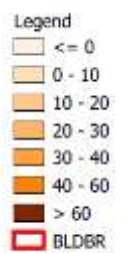
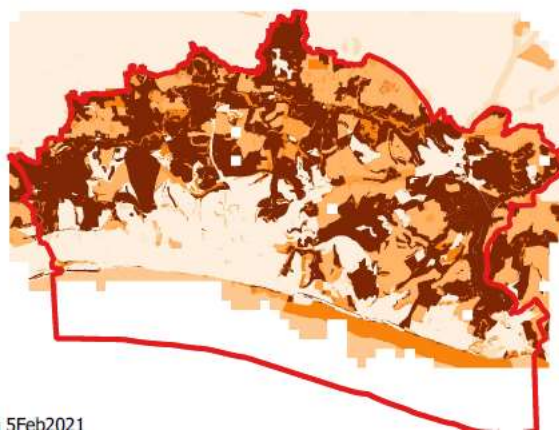
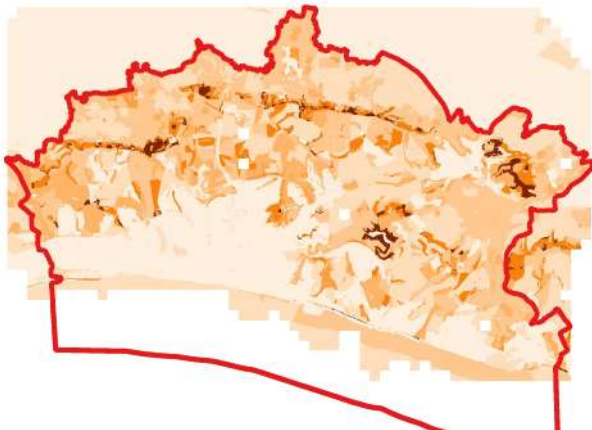
Baseline

Business as usual



Less regulation

Responsibility and custodianship



la 5Feb2021

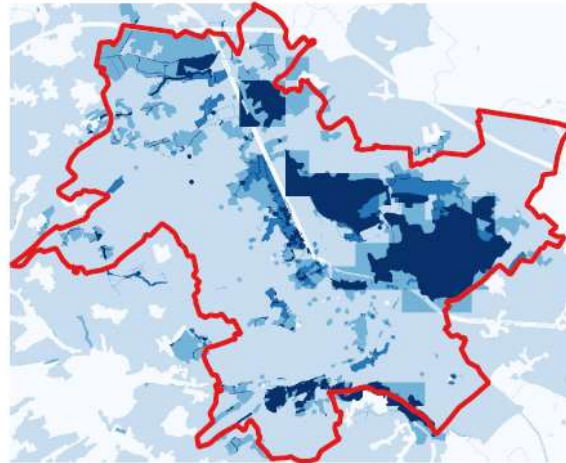
Created by MOPST (github.com/mopst)

4.5. Réserve de Biosphère Audomarois

RBMA Pressure Summer Output Maps – Baseline and all three scenarios

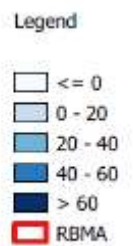
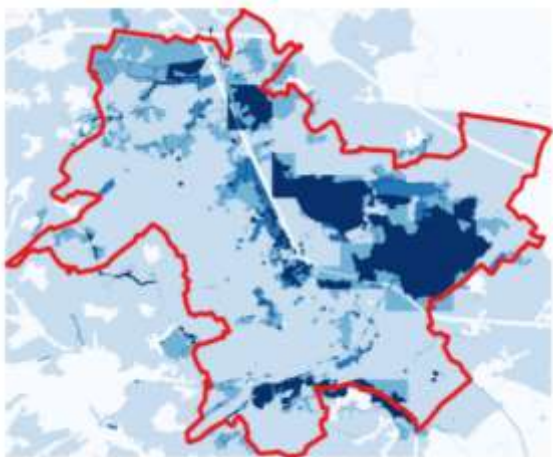
Baseline

Business as usual



Less regulation

Responsibility and custodianship



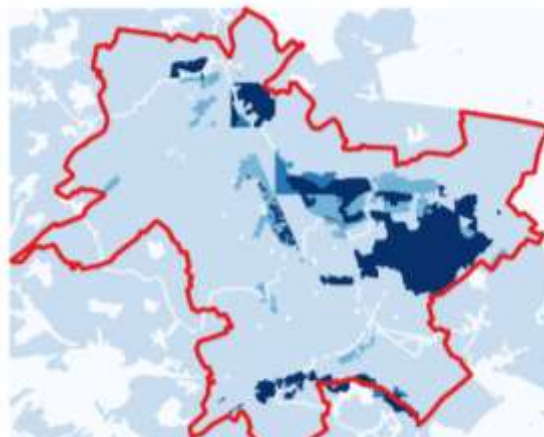
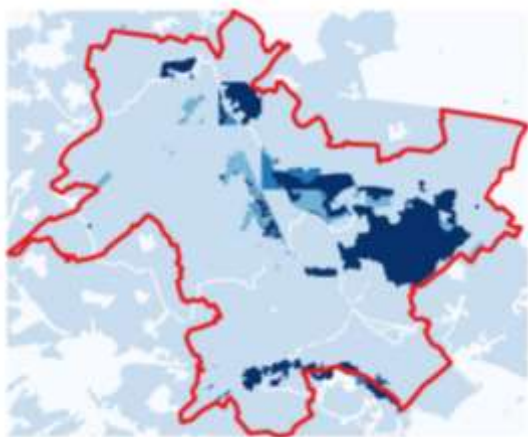
Created by MOPST (github.com/mopst)

N.B. Due to limitations in the data these maps focus on the land-based areas not the waterways (see BR map in Appendix 1). These maps are still subject to updating of input data.

RBMA Opportunity Summer Output Maps – Baseline and all three scenarios

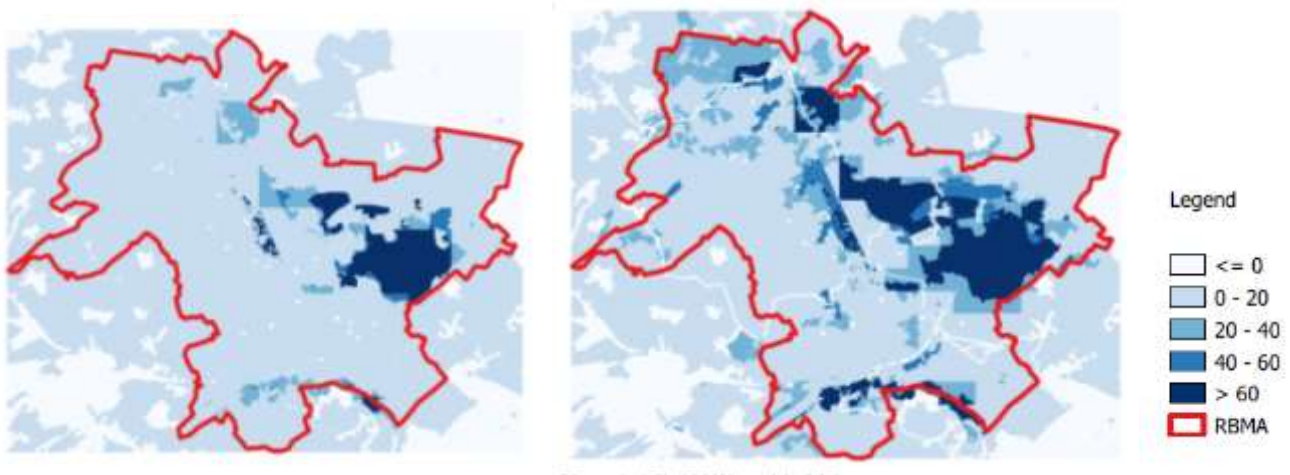
Baseline

Business as usual



Less regulation

Responsibility and custodianship



Created by MOPST (github.com/mopst)

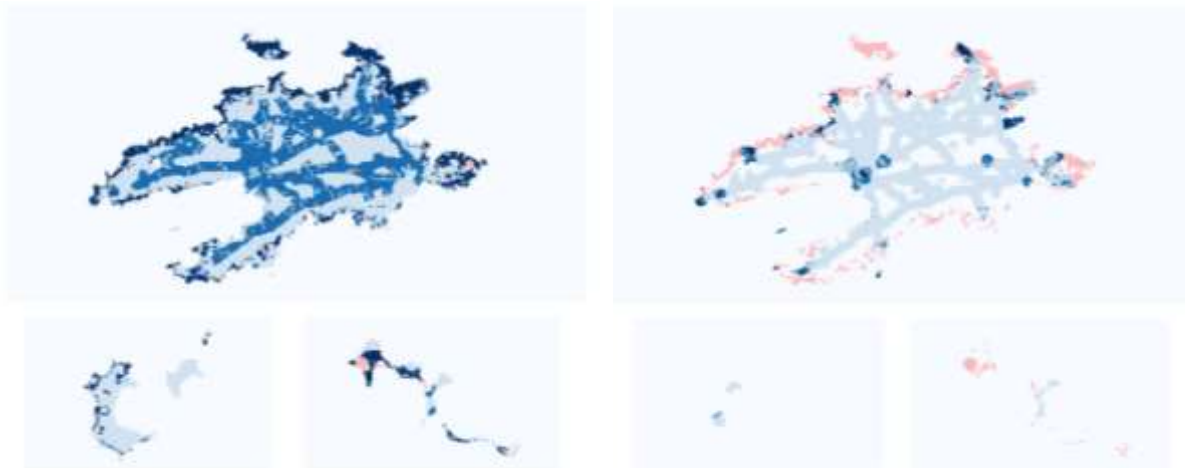
N.B. Due to limitations in the data these maps focus on the land-based areas not the waterways (see BR map in Appendix 1). These maps are still subject to updating of input data.

4.6. Réserve de Biosphère Iles et Mer d'Iroise

RBIMI Pressure Summer Output Maps – Baseline and all three scenarios

Baseline

Business as usual



Less regulation

Responsibility and custodianship



Created by MOPST (github.com/mopst)

N.B. Due to limitations in the data these maps focus on the islands (land-based areas) not the marine areas. These maps are still subject to updating of input data (including recalibrating negative values).

RBIMI Opportunity Summer Output Maps – Baseline and all three scenarios

Baseline

Business as usual

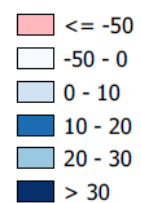


Less regulation

Responsibility and custodianship



Legend



Created by MOPST (github.com/mopst)

N.B. Due to limitations in the data these maps focus on the islands (land-based areas) not the marine areas. These maps are still subject to updating of input data (including recalibrating negative values).

5. Discussion

5.1. Discussion of findings

The key overall findings include the following:

1. Both the UK BR pressure and opportunity output maps emphasise key features that differ slightly across the BRs and scenarios but broadly include:
 - Environmental designations – particularly the National Park and SSSIs; with some local nature reserves highlighted;
 - Access characteristics including open access and bus routes and bus stops.
2. The fact that both pressure and opportunity maps emphasise some of the same areas and characteristics raises management issues and questions – including exactly what kind of management is required for sustainable tourism opportunities – and this needs to be decided in conjunction with BR managers and the relevant environmental experts (see below). There are likely to be some areas that will need to remain off limits to visitors (or with reduced numbers) due to the environmental fragility of the sites.
3. Discussion and review of local areas in greater detail in conjunction with the BR managers would be hugely beneficial in order to maximise the effectiveness of any future updates and iterations of the model (and ArcGIS Python Toolbox & QGIS Plugin).
4. For the French BRs, the output maps are still subject to updating of inputs therefore the overall findings are still under discussion. The initial feedback from BR managers indicates that:
 - For RBMA the land-based pressures and opportunities are well-indicated in the model; but the waterways have not been adequately integrated due to limitations in the participatory GIS map inputs (e.g. lack of inclusion of sufficient stakeholders knowledgeable about these areas).
 - For RBIMI the areas of tourism pressure shown in the model are broadly endorsed by the BR managers as consistent with their experience. However, a slightly different question was asked of stakeholders during the interviews instead of tourism opportunities – i.e. which areas stakeholders like to visit – so the areas indicated in the participatory GIS inputs are not necessarily representative of tourism opportunities as has been implemented by the other BR GIS models¹⁷. This would therefore benefit from further updating of participatory GIS inputs to make this consistent with the other BRs.

5.2. Limitations

Numbers of participants

We used regression analysis to determine the tourism factor scores based on inputs by up to ten individual participatory stakeholders (digitised GIS maps of tourism pressure and opportunity) for each BR – primarily environmental managers and local experts. In further iterations these could be expanded to include inputs from more (and different) stakeholders with environmental and other relevant types of expertise.

¹⁷ The same instructions and guidance notes were issued to all Biosphere Reserves (in French and English), however, in some cases these were interpreted differently according to the local context and BR priorities.

Visitor numbers

We did not have complete visitor number data for Brighton and Lewes Downs BR¹⁸ but used a combination of sources including TripAdvisor. For some of the Biosphere Reserves (BRs) this data has been collected using eco-counters (e.g. French BRs) and other local data sources etc. e.g. North Devon BR are looking to collect this info through a local visitor App (currently under development).

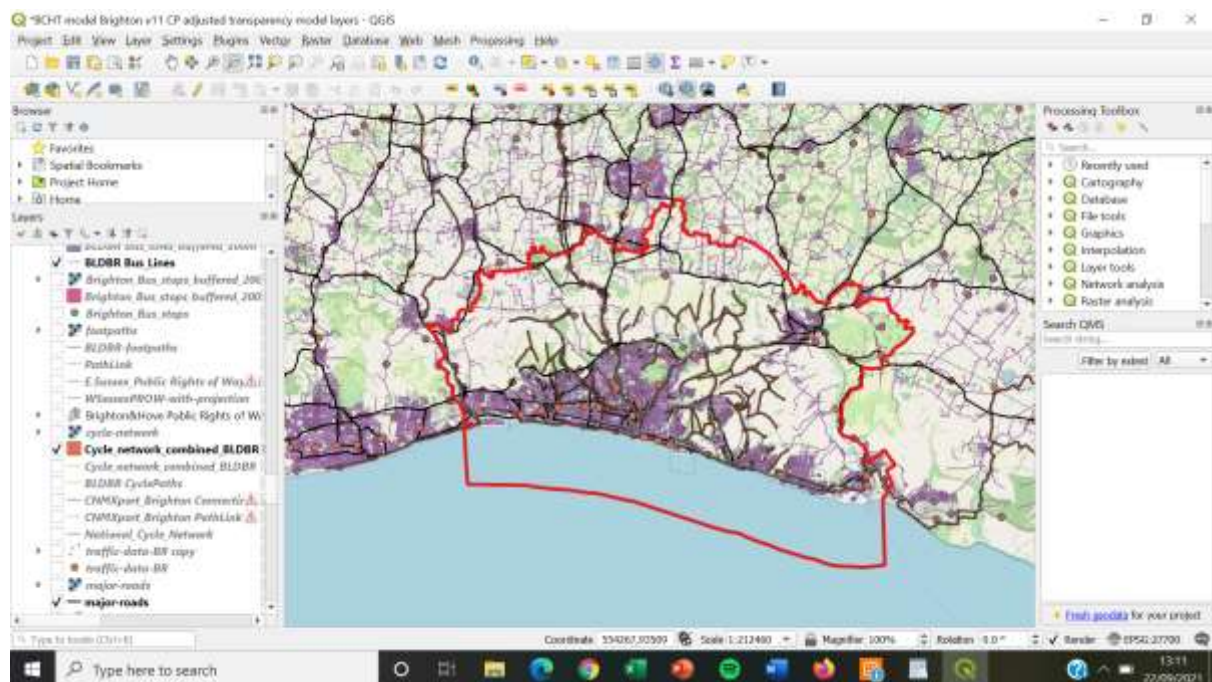
A brief note on coastal / offshore areas

The coastal and offshore areas highlighted in the model outputs are based on a combination of the marine conservation zone designation and the (merged) areas of tourism pressure and opportunity identified by stakeholders and drawn onto the map (later digitised) – as outlined above.

Integration of transport data

The QGIS screenshot below illustrates the types of transport layers that were included in the model (subject to multiple copyright and intellectual property).

Figure 5. QGIS BLDBR model example screenshot showing selected transport layers including roads, bus routes, cycle routes and traffic count points



N.B. footpath data is included in the model but not shown here.

Costs

The costs associated with implementing this are staff time (preferably someone with GIS expertise; 3 – 6 months depending on expertise) and time to find and assemble the GIS data layers. All of the data used in this model was either open access or obtained through data sharing agreements with

¹⁸ We had originally envisaged we would be able to obtain visitor numbers data from Google (but were unable to secure this data). Plus we had planned that visitor numbers data for the 10 key survey sites in BLDBR would be collected as part of the visitor survey contract, but unfortunately the contractor was unable to deliver this. This data was (at least partially) collected for NDBR for the visitor survey sites.

public bodies (e.g. Ordnance Survey; Brighton and Hove City Council etc), but there may be additional costs associated with obtaining specific types of data (e.g. accurate visitor numbers).

5.4. Dissemination and further development

Increasing the transferability of the GIS model – creation of an ArcGIS Python Toolbox

In addition to the model, the BCHT project has produced an ArcGIS Python Toolbox (see github.com/mopst) – a transferable version suitable for implementing in other areas (including other Biosphere Reserves). This was completed by Nick Bearman (Geospatial Training Solutions), supported by North Devon Biosphere Reserve, Devon County Council and the University of Exeter.

Using this, areas will be able to input their own local data, policy priorities and tourism features etc. As much of this process as possible will be automated, and the Toolbox and related information will be freely available via GitHub (github.com/mopst) with an open source license. In addition, a similar toolbox using QGIS is also in the process of construction and will be made available via GitHub.

Further development and updating of GIS inputs

The model is relatively easy to update and add to as required when updated information is available (any changes to input layers necessitate rerunning the regression analysis and inputting the new values and then rerunning the model).

Care should be taken to ensure that all particularly fragile sites are identified, in conjunction with BR managers and environmental experts, and that these are accurately reflected in the model. Other useful future updates include additional, more accurate visitor number data, when this becomes available (potential sources include from a Visitor App, e.g. as is being developed in NDBR; or Google Maps data / Strava Metro data).

Scalability and development of the model

The model would be easy to scale up to larger areas providing the GIS data is available for the whole area of interest. The GIS module is envisaged as a transferable model for areas to input their own data.

Other suggestions for development include integrating economic tourism information.

5.5. Feedback on the model

Feedback on the model was sought via presentations (and Q&As) at a number of project conferences, workshops and external dissemination events, involving key stakeholders both external and internal to the project, including policy makers, planners, tourism experts and managers, and local businesses etc. Where possible the feedback was used to improve iterations of the model and inform implementation of the model as a decision-support tool in order to maximise its relevance and impact.

Feedback obtained on implementation of the model

The initial feedback from key stakeholders at the project conferences and workshops indicates that extensive engagement and partnership working will be required in each BR in order for the model/ArcGIS Python Toolkit to be used as a decision-support tool. This will need to be accompanied by dissemination of clear methodological information demonstrating the robustness of the method to the satisfaction of the key stakeholders.

In addition, key questions and issues remain in the two UK BRs that such a tool can only inform rather than solve, such as:

- What best practice looks like and what management measures are in place for sites to be classed as ‘well-managed’ tourist sites;
- What incentives, facilities and / or measures can best be implemented at local or strategic level to attract visitors towards sites identified as appropriate, not fragile and less visited;
- How to implement the tool at a larger scale (e.g. regional) in conjunction with multiple partners ensuring adequate data is available for the whole area (and in the context of changing Destination Management Organisation structures);
- How best to influence the planning process in an appropriate timescale, including planning decisions about tourist accommodation in a changing pandemic-influenced housing and accommodation environment (and uncertainties around long-term trends on staycationing and towards deregulation of the planning process);
- Overcoming the lack of comprehensive up-to-date and accurate visitor numbers data in some cases (see suggestions for sources above);
- How to balance the needs of local people and tourists, including the need for tourist facilities, with overcrowding (and accompanying traffic infrastructure issues) at ‘honeypot sites’ as well as particular pressures on coastal areas;
- The need for strategic integration (and balancing) of tourism, environment, housing / accommodation, (sustainable) transport infrastructure, traffic management and employment policies as well as rural / economic and business recovery / development policies;
- The Covid-19 pandemic / Brexit has highlighted issues such as labour and skills shortages as well as poor employment pay and conditions in some parts of the tourist industry, which this model is not equipped to address;
- How to integrate implementation of the model with other initiatives such as Nature Recovery Networks, Landscape Character Assessments, Carbon mapping etc;
- How to build on synergies with the UK’s 2021 Tourism Recovery Plan, the Environment Bill, and to capitalise on increased interest in environmental sustainability and the post-Covid tourism drive to ‘build back better / greener’;
- How to ensure the conservation of fragile sites (e.g. incorporating the concept of carrying capacity?) while ensuring equity of access and maximising the health and wellbeing benefits of visiting the outdoors.

6. Conclusions and towards implementation as a decision-support tool

Feedback from stakeholders and policy-makers demonstrates the potential of the model to serve as a useful decision-support tool, but indicates that further dissemination and partnership working is needed, along with clear dissemination of methodological information and discussion around key issues including those outlined above.

6.1. Next steps

- Finalising and dissemination of information on the method (i.e. this report and a related publication);
- Completion of the ArcGIS Python Toolbox and dissemination via a suitable platform (GitHub.com);
- Further discussion with planners about integration of information from the model into local and neighbourhood plans;
- Ongoing strategic discussion and partnership working with key organisations and stakeholders including BR managers, Tourism Destination Management Organisations, local authorities (County and City Councils) – including various relevant departments, National Park Authorities, Local Nature Partnerships, Planners, Environmental managers; transport managers etc;
- Integration of updated visitor number data when available; and
- Ongoing discussion and policy advocacy work around key issues identified by stakeholders above.

6.2. Future work

A number of directions are under discussion for future research, including writing / finalising of publications relating to project outputs, following up on engagement with and suggestions for development from stakeholders (as above); and further collaboration with project partners. However, some of these will be dependent on securing follow-on funding.

Appendix 1: Maps of Biosphere Reserve areas

Appendix 1.1: North Devon Biosphere Reserve (NDBR) Boundary Map



Source: © OpenStreetMap (OSM Standard) with NDBR boundary applied.

Appendix 1.2: Brighton and Lewes Downs Biosphere Reserve (BLDBR) Boundary Map



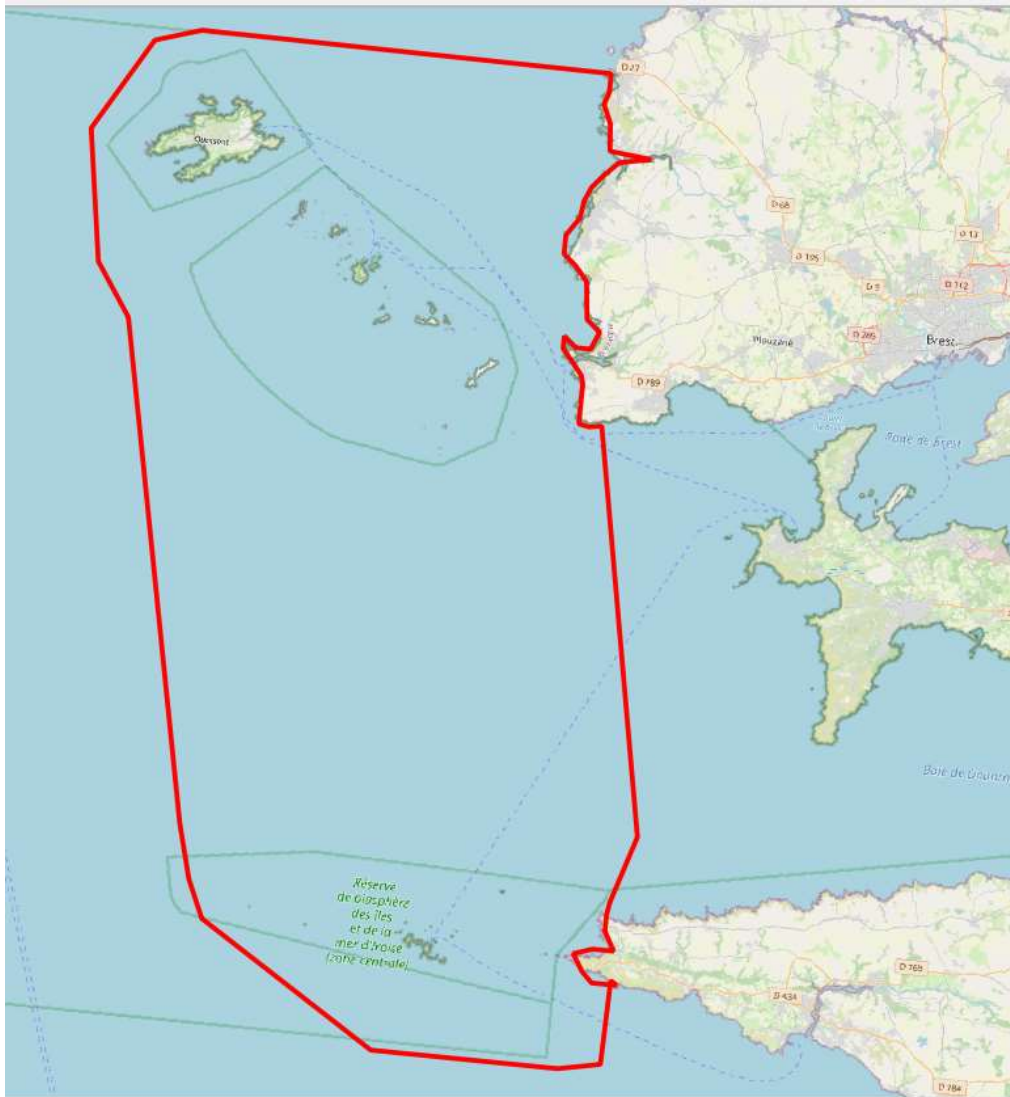
Source: The Living Coast (<https://thelivingcoast.org.uk/map>)

Appendix 1.3. Réserve de Biosphère Marais Audomarois (RBMA) Boundary Map



Source: © OpenStreetMap (OSM Standard) with RBMA boundary applied.

Appendix 1.4. Réserve de Biosphère Iles et Mer d'Iroise (RBIMI) Boundary Map



Source: © OpenStreetMap (OSM Standard) with RBIMI boundary applied.

Appendix 2: QGIS technical method for model

This appendix outlines the technical setup used for developing the model for background information. If you want to run the model on your own data, the easiest way to do this is to use the ArcGIS Python Toolbox or QGIS Plugin, see github.com/mopst for more details.

Appendix 2.1. Technical Setup

Software / File Management

This was completed using QGIS 3.10.11. Any 3.10.x or later version should work, and later versions shouldn't be that different. Previous versions are always available at <https://qgis.org/downloads/>. R (version 4.0.2, <https://cran.r-project.org/>) and RStudio (version 1.3.1093, <https://rstudio.com/products/rstudio/download/#download>) was used to run the modelling work. This was run on Windows 10 in Nov 2020 to Jan 2021.

Files (spatial and non-spatial data) are stored in OneDrive at Devon County Council, accessed through Andy Bell. All folder references refer to the OneDrive shared folder root as `BCHT Masterplanning - Documents\`. The OneDrive app was used to sync data from the folder on to my computer. This syncs files on demand, which is helpful, as the full folder is ~31GB.

Naming conventions include the date, version number and initials (e.g. `Factor table COMBINED mdfd 23Jun2020 012 NB.xlsx`). Any previous versions are usually moved to the archive folder in the files current location. Versioning on SharePoint was generally not used.

GIS Processing

All GIS and data processing has taken place on a local machine (laptop): specification Intel Core i7-10850H @ 2.70 Ghz, 32GB RAM. The exception is the regression model for the North Devon Biosphere Reserve. This was completed on an AWS RStudio Server session because of the file size (see regression analysis section for more details).

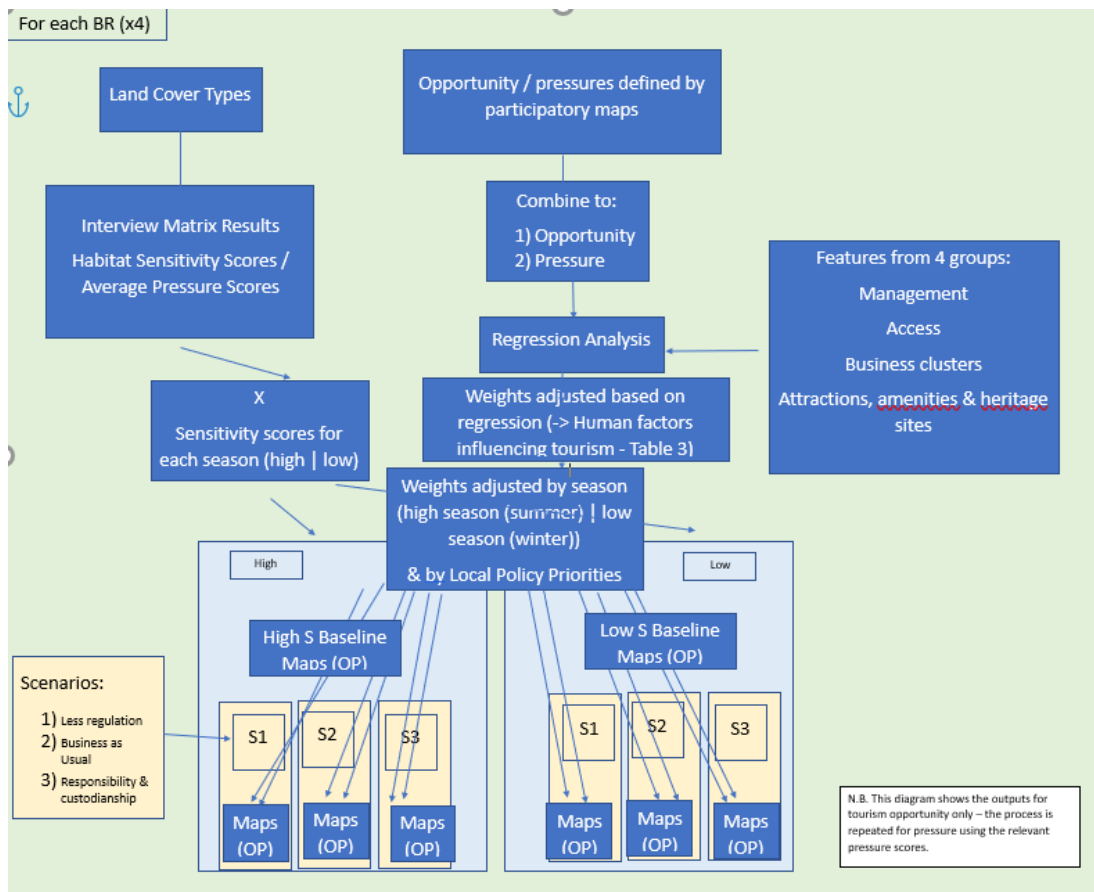
Data

Data used is listed in `List of GIS data sources 09Dec2020 0025 NB.xlsx`. Layer names [column B: Description of layer (matches layer name in QGIS)] matches the layer name used in QGIS Layers.

Data for North Devon (NDBR) and Brighton and Lewes Down (BLDBR) are in British National Grid (27700). Data for RBMA and RBIMI are in RGF93 Lambert 93 (2154). A projected coordinate system is needed for some of the spatial analysis tools (e.g. buffers) used in data preparation.

Appendix 2.2. Overall Process Flowchart

(Version: Modelling logic v8 3Nov2021 CP.docx)



Appendix 2.3.Detailed Methodology

1. Data Preparation

Key input data include land cover types, opportunity and pressure maps and features split into four cluster groups.

Land Cover Types

This data builds on phase 1 of the project. Land cover data are provided (based on CORINE, supplemented with Phase 1 habitat data for the UK BRs) with a measure of sensitivity provided for each land cover type (02-Working-Data-non-spatial/tmp-lookup-table-land-cover/, based on Interview matrix results for mapping_29Jan2021_007 NB.xlsx). RBIMI provided their own land cover data (carto-cemo-2017) with matching sensitivity measures.

Seasonality

Information on how the seasonality impacted the sensitivity was provided (02-Working-Data-non-spatial/Seasonality results) with either a weighting on 1 (no change) or 2 (more sensitive in a specified season, usually summer) provided. Seasonality was joined to sensitivity and land cover in R using the habitat environment type. Any missing data (where seasonality wasn't

provided, usually very small areas) was assumed to be 1. RBMA said all land cover types were more sensitive in the summer.

The spatial data (currently in vector format) is exported as a Geopackage (e.g. 03-Working-Data-spatial/model/rbma/land_cover_vector_reduced_v2.gpkg) and converted to raster format in QGIS (RBMA_land_cover_summer.tif and RBMA_land_cover_winter.tif).

Data Preparation

The regression model is used to generate coefficients for all of the sub-factors used in the overall model. The factors and sub-factors are as follows (see Tourism Factor Table):

Tourism Factor Table:

Factor	Subfactor
Management	SSSI
	RAMSAR
	Natura 2000 (incl. SPA and SAC)
	National Park,
	National Nature Reserve
	Regional Nature Reserve (France only)
	Local nature reserve
	AONB
	Marine nature reserve
	Agricultural land
	Heritage coast
	NBN species layer – species (biodiversity) hotspot
Access	Roads (major)
	Traffic count
	Cycle path
	Footpath (major)
	Bus route
	Railway station
	Disabled access
	Open access / accessible woodland / CROW
Business clusters	Food and drink
	Cycle hire
	Adventure centre, water sports school
	Local Business (France only)
Significant local historic / heritage feature / tourism attractions / amenity	Archaeological sites
	Heritage sites (heritage at risk layer?)
	Visitor centre
	Key tourism attraction (e.g. the Big Sheep)
	TripAdvisor visitor Numbers
	Car park

In the regression model, we are using the sub-factors to predict the interview results. The interviews used maps for participants to hand draw on areas of pressure and opportunity in their BR (e.g. 03-Working-Data-spatial\Maps NDBR digitising from interviews). These were digitised and combined into one prediction layer (one for pressure and one for opportunity).

The data used to predict these was the sub-factor data listed above. The sources are listed in List of GIS data sources 09Dec2020 0025 NB.xlsx, summarized in Data availability by BR 13Jan2021 008 NB.xlsx, and specified for each BR in Factor table
 combined <DDmmYYYY NN PP>.xlsx. Each sub-factor was extracted as a raster grid, with a resolution of 25m. Raster cell values are 0 (not present) or 1 (present).

In some cases individual data layers were merged into one layer for each sub-factor prior to converting to raster format (using the Merge function within QGIS; using the BR boundary layer to delimit the area).

Input and output files are stored in:

- 03-Working-Data-spatial\GIS NDBR project files\
 - BCHT model North Devon v8 CP.qgz
 - BCHT model Brighton v7 CP.qgz
- 03-Working-Data-spatial\GIS French BRs project files\
 - RBMA-model-v6-NB.qgz
 - RBIMI-project-file-v7-CP.qgz

They are grouped in the factor groups (Management, Access, Business Clusters, Heritage).

Raster layer creation process:

1. Make sure layer is already saved in 27700 (British National Grid) CRS. Mostly they will be vector layers, saved as a GeoPackage.
2. If you merge vector layers, you may get an error about UNIQUE identifiers. To get around this, open the attribute table, turn on editing, delete the FID column, turn off editing, save, and export – this should work.
3. Use Rasterize (vector to raster) tool to convert layer to raster
 - a. Input: layer we are converting
 - b. A fixed value for burn-in: 1
 - c. Output raster size units: Georeferenced units
 - d. Width/horizontal resolution: 25
 - e. Height/vertical resolution: 25
 - f. Output extent: use layer extent:
 - i. *This varies depending on the BR. We used:*
 - ii. NDBR: opportunity-major-roads-v3
 - iii. BLDBR / RBMA / RBIMI: the BR outline file from /03-Working-Data-spatial/GIS BCHT BR layer/BCHT-BR-layers.gpkg.
 - iv. *It doesn't really matter, as long as for each BR, the template is the same. Existing raster datasets could be used as a template in the future.*
 - g. Assign a specific no-data value: change to blank
 - h. Pre-initialize the output image with value: 0

- i. Run function
4. Temporary layer will be created, confirm range is correct (look at highest and lowest values in Layers window) and that data seems reasonable.
 - a. If range is not correct, we need to correct display.
 - b. Right click layer, choose Properties
 - c. Under Symbology, expand Min / Max value Settings
 - d. Change Accuracy from Estimate (faster) to Actual (slower).
 - e. Choose Apply. Min and Max should update.
5. Right click on temporary layer, choose Export > Save As.
 - a. Save as GeoTiff layer
 - b. E.g. 03-Working-Data-spatial\regression-analysis\blddb-
data-v1\management\agricultural.tif
 - c. *You can save the raster layer as a raster layer within a GeoPackage, which would be a much smaller file.*

2. Regression Model

The next step is running the regression model in RStudio. The data for this is stored in 3-Working-Data-spatial/regression-analysis, split by BR. The files with scripts in are:

- NDBR-regression-analysis-v3-NB-2020-12-11.R #NDBR
- NDBR-regression-analysis-v4-NB-2021-01-06.R #BLDBR
- RBMA-regression-analysis-v1-NB-2021-01-19.R #RBMA
- RBIMI-regression-analysis-v1-NB-2021-01-22.R #RBIMI

The models for BLDBR, RBIMI and RBMA were run on the laptop (see spec above). The model for NDBR was too big to run on this laptop, so AWS / RStudio Server was used (see below).

The R script is well commented, here are some specific notes (based on RBIMI-regression-analysis-v1-NB-2021-01-22.R, regression-analysis.Rproj RStudio project file):

- Line 26: read in and check pressure and opportunity maps
- L34: read in and check Management Factor data
 - *Note all BR's except NDBR have raster values of 0 (not present) and 1 (present). NDBR data needs to be reclassified (see model section for more details).*
- L57: read in and check Access Factor data
- L80: read in and check Business cluster Factor data
- L95: read in and check Heritage Factor data
- L115: convert data from Raster Grid to Vector (note this is a vector as in R, a 1 dimensional matrix, not vector as in the GIS data structure, see `?as.vector`).
- L157: remove some intermediate variables not required
- L210: run pressure model.
 - This comprises of a NULL model (pressure only) and then the FULL model (all variables, remember to check the variables included against the variables available)
 - `summary(pre.model.full)` provides the detailed output for the model
 - `ptm <- proc.time()` # Start the clock! And `proc.time()` - `ptm` # Stop the clock are used to time the procedure.

- Next step is to run the stepwise regression, this is the most time consuming section. It starts with the full model, and moves backward, removing each variable in turn. Typical time (RBMA, RBIMI, BLDBR) is 20 min.
- The stepwise model will say which variables are removed. You will need to re-run the model with the specific variable removed (e.g. L251) to get the coefficients.
- Results from regression stored in `2021-01-19-regression-results-rbma.txt` and written up in `Regression analysis outputs 29Jan2021 020 NB.xlsx`.
- L283: repeat the same process as above for Opportunity.

North Devon BR / AWS / RStudio Server

When running the stepwise regression for NDBR, I got this error message:

Error: cannot allocate vector of size 2.5 Gb

This means the computer does not have enough RAM to cope with this model. I think it is due to how the stepwise regression is run, because of the large size of the North Devon BR (i.e. number of 25m raster cells). There may be a better way to re-write the code to run this effectively, but for this project I opted to use a larger, more powerful computer.

The key requirement is RAM, and a machine with 64GB RAM worked fine. I used Amazon Web Services (AWS) for this, but other setups would work. It ultimately cost about ~£150 in fees in the end.

AWS offer a service called EC2 (Elastic Compute 2) which allows you to setup a virtual machine with a customized specification. I used a z1d type machine, and then come in different sizes. I used z1d.2xlarge, which has 8 vCPU and 64 GB RAM. The cost for this is US \$2.422/hr. As we are working in RStudio, it was easiest to use a RStudio Server Image (Amazon Machine Image (AMI) RStudio Server Pro Standard for AWS). RStudio Server is a program that allows you to run RStudio through a web browser tab. Working with the image allowed me to not to worry about setup or security (although it did cost an additional \$2.334/hr).

- To setup, follow the instructions for AWS EC2 instance.
- Go to console.aws.amazon.com/console/home
- Choose EC2, Instance, Launch Instance.
- Search for RStudio Server Pro Standard for AWS in AWS Marketplace
- Follow through wizard, choosing type (z1d.xlarge), storage (~100GB should be ok).
- For security, make sure you add your external IP address (Google what is my IP?) to the security group to allow access via SSH (port 22) and web (Custom TCP / 8787).
- Run, and wait for it to launch (1-2 min).
- Visit http://<ec2_instance_public_dns>:8787 in your browser to access the rstudio ide
- Log in with the username "rstudio-user" and the instance_id of the instance as the password
- Once logged in, please set a new password for this user:
 - Click the "Tools" menu dropdown
 - select "shell"
 - type "passwd" into the shell
 - enter the current password (instance_id) and the new password twice, hitting the enter key after each entry.

- This will get you to the RStudio Server page. Use the upload tool to upload the previously saved RData file.
- Run the regression
- Use the monitor tools in AWS Console to see how it is processing. You can also use htop though SSH access if you wish.
- Wait for code to run.
- Save RData / console output when done.
- Turn off instance.

3. Updating coefficients with BR weighting

After typing up coefficients into the spreadsheet, discuss with BRs about their policy weightings (0, 1, 2, 3). 0 will remove that data from the model. The weightings used are the coefficients multiplied by the policy weighting. These are stored in `Regression analysis outputs 29Jan2021 020 NB.xlsx`.

4. Running model (R script)

The final step is collating all of the data together and generating the maps. This was completed in RStudio, and the data etc. are in `03-Working-Data-spatial\model`. There is no RStudio project file for this, the example used here is `BLDBR-model-v2-NB-2021-01-27.R`. The version number (v2) is the same series as the number in the final output files (e.g. `OpportunitySummer-v1.tif` and `Opportunity Summer 2021-01-27-v2.pdf`). From `BLDBR-model-v2-NB-2021-01-27.R`:

- Line 11: read in shape file (land cover types) and remove unnecessary columns
 - *RBIMI uses different landcover data, but the sensitivity and seasonality data match this different land cover data.*
- L19: read in land cover sensitivity values and remove unnecessary columns, keep the relevant BR.
- L30: join land cover data and land cover sensitivity data
- L36: read in and multiply by seasonality score by land cover. (Options are 'summer' and 'winter' (periods defined by BR) and weighting of 1 or 2). If there are any missing scores (usually small fragments of land) then these will be given a weighting of 1.
- L59: save summer and winter layers as geopackage (`land_cover_vector_reduced_v1.gpkg`), convert to raster files in QGIS (using same template as before, e.g. BR outline) and read back into R.
- L71: save data snapshot.
- L75: read in sub-factor data from raster files (same source files as used in regression model)
- L87: all data (except NDBR data) has the value of 1 (present) and 0 (absent). These need to be reclassified to the sub-factor weightings based on the discussions with the BR (see above).
 - The code for this is:
 - `SSSIpressure <- subs(SSSI, data.frame(id=c(0,1), v=c(0,1.4)))`
 - Where `c(0,1)` specifies the from values and `c(0,1.4)` specifies the to values, so 0 is changed to 0 and 1 is changed to 1.4 in this case.
 - This is done for pressure and opportunity for each sub-factor

- L142: the values are checked by plotting the data to check the spatial distribution (does it look sensible?) and is the maximum value correct? (should be the weighting specified above).
- L169: the data are then summed and plotted
- L179, L248 and L287: the process above is repeated for Access, Business clusters and Heritage factors.
- L349: factors summed together
- L356: apply calculation for each season
- L368: save snapshot
- We now have the baseline data (OpportunityWinter-v2.tif / OpportunitySummer-v2.tif / PressureWinter-v2.tif / PressureSummer-v2.tif).
- L379: read in scenario weightings
- L389: create the scenario folders before running the next bit of code (or remove old data if needed)
- L394-413: check the file paths and update if needed if changing BR
- L425: update weightings for all of the sub-factors (these should match those specified in L87 to L287)
- L381 to L554: this is a loop, highlight and run it all together.
 - The loop will run 3 times (Profit, Business as usual, Custodianship)
 - It will apply each sub-factor scenario weight to the data and reclass it
 - It will apply the seasonality weighting (L531-L540)
 - It will save the data (L543-546). Update the version number here if needed.
 - As the loop runs, it will provide updates.

This will have created 4 maps (OpportunityWinter-v2.tif / OpportunitySummer-v2.tif / PressureWinter-v2.tif / PressureSummer-v2.tif) for each scenario (\scenario-business-as-usual, \scenario-custodianship, \scenario-profit).


5. Output maps

The final step is to take Tif files and add them into QGIS. For example, Working in RBIMI-model-v8-NB.qgz. The data are grouped by scenario and we can apply symbology to the maps.

Experimentation will need to be done to find the correct values. Scale must be the same across all the pressure maps for each BR, to allow comparison.

Common settings:

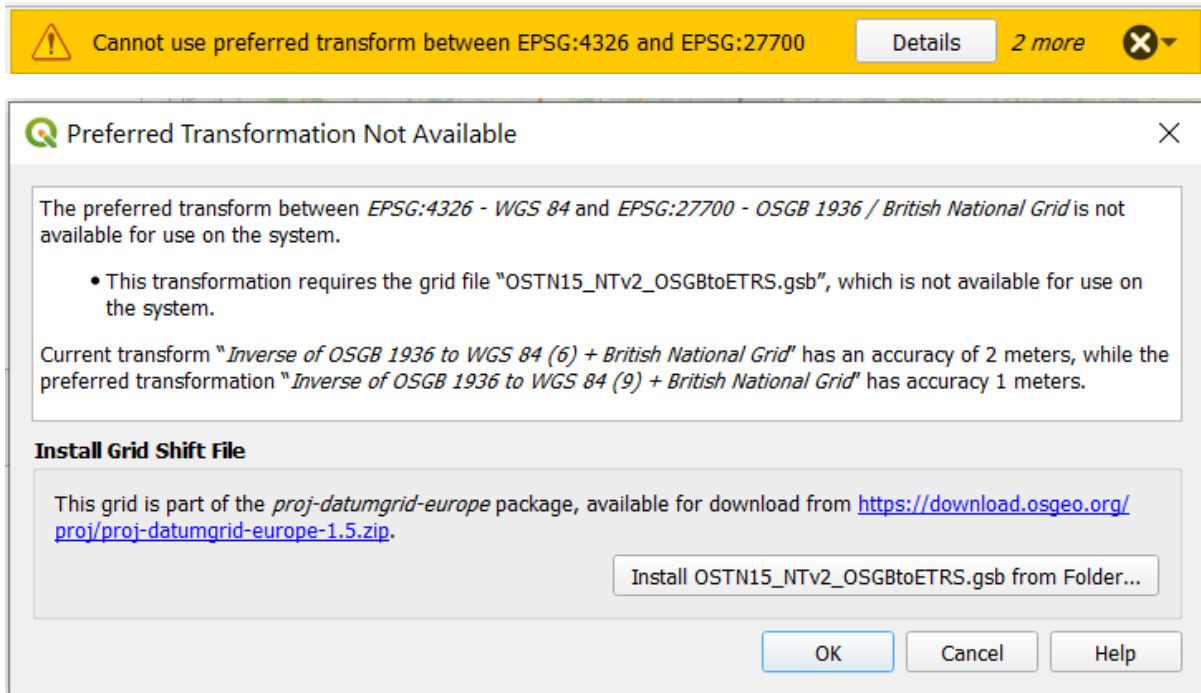
- Classes: <=0, 0-20, 20-40, 40-60, >60
- Classes: 5
- Interpolation: Discrete
- Mode: Equal Interval
- Colour Ramp: Blues

In Layout, the templates are done by pressure/opportunity, summer/winter. When updating the map layout, show the relevant map in the main window (e.g. Opportunity Summer Baseline). Open the layout window, select the relevant map, untick Lock Layer Lock layer click refresh  and then

recheck Lock Layer. This will update the map. Repeat for each of the 4 maps. Then save and export as PDF.

6. Troubleshooting

When working in QGIS, particularly if you are using QGOS 3.16 or later, you may get this error message when opening some of the project files:



This is saying that QGIS cannot reproject from 4326 (Lat-Long) to 27700 (British National Grid) using its' preferred method (transformation).

There are many different ways of reprojecting data from one coordinate system to another. They will often have different accuracies. If you read the error message you can see it says:

"Current transform "Inverse of OSGB 1936 to WGS 84 (6) + British National Grid" has an accuracy of 2 meters, while the preferred transformation "Inverse of OSGB 1936 to WGS 84 (9) + British National Grid" has accuracy 1 meters."

This means the transformation it is currently using has an accuracy of 2 meters, while the one it wants to use has an accuracy of 1 meter. This can be solved in two ways:

1. Download the zip file from the link provided, unzip it and click the button to install the required file.
2. Ignore it. *We can happily ignore this issue because we are working with 25 meter resolution raster data. If the source data are off by 1 meter or 2 meters, it won't make any difference to the analysis. Just click 'Cancel'.*

If you install the file and it still complains, then just ignore it.

Appendix 2.4. Details and weightings for scenarios used in the model

The scenarios, along with their accompanying illustrations, are provided in full detail in the relevant Scenarios documents – below are the technical details and values used in the model only.

Change of weighting for scenarios – summary

Scenario	Pressure	Opportunity
Profit (no control)	Much more	Much less
Business as usual	More	Less
Custodianship (sustainable tourism)	Less	More

Scenario agreed weightings – numerical

These weightings were applied to each of the factors in the Factor Table, by multiplying the relevant scores. We therefore used these figures to modify all subfactors in each Factor theme in the Factor Table.

Scenario	Factor	Agreed opportunity for sustainable tourism (including BCHT) multiplier (1 to 3)	Agreed pressure multiplier (1 to 3)
Profit (no control) (much more pressure; less opportunity)	Management	0.5	2
	Access	0.33	3
	Business Clusters	0.5	3
	Historic/ heritage	0.5	3
	Tourism attractions / amenities	0.33	2
	Visitor nos	0.33	3
Business as usual (slightly less opportunity; more pressure)	Management	1	2
	Access	1	2
	Business Clusters	1	2
	Historic/ heritage	0.5	2
	Tourism attractions / amenities	1	2
	Visitor nos	1	2
Custodianship (sustainable tourism) (less pressure; more opportunity)	Management	2	0.5
	Access	2	0.5
	Business Clusters	2	0.5
	Historic/ heritage	2	0.5
	Tourism attractions / amenities	2	0.5
	Visitor nos	2	0.5

Appendix 3. Scenario outlines with images

Business as Usual

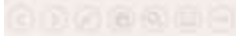
- Tourism centred on honey pot sites
- Visitor pressure issues
- Seasonal peaks in visitor numbers and tourism business income
- Gradual decline in quality of environmental assets

Responsibility and custodianship

- Spreading the benefits of tourism across the region
- More green infrastructure and travel options
- More visitor spend staying in the local economy
- Restoring the environment
- Visitor giving e.g. time, skills, payback schemes

Less regulation

- Over-development
- Increasing visitor numbers
- Business making more
- Visitor spend not contributing much to the local economy
- Rising visitor pressures erode natural environments
- Resident – Tourist tensions



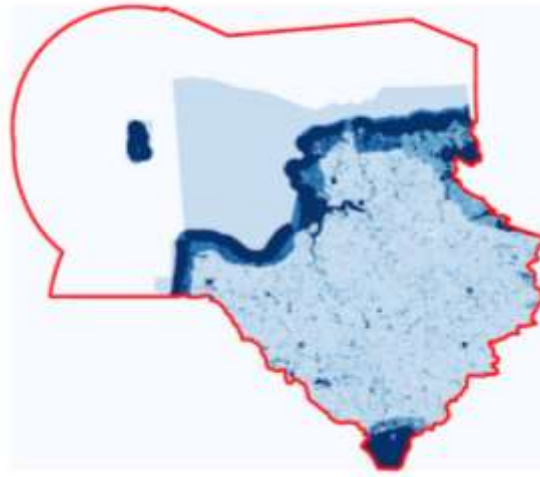
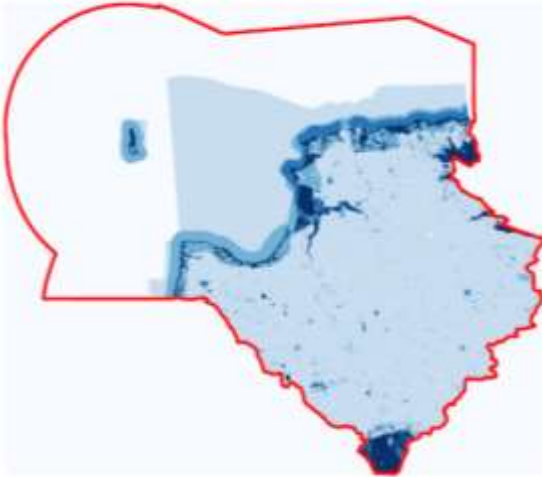
Appendix 4. Full set of GIS modelling output maps (heat maps)

North Devon Biosphere Reserve Output Maps

NDBR Pressure Summer – Baseline and all three scenarios

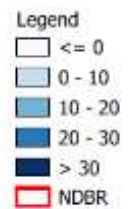
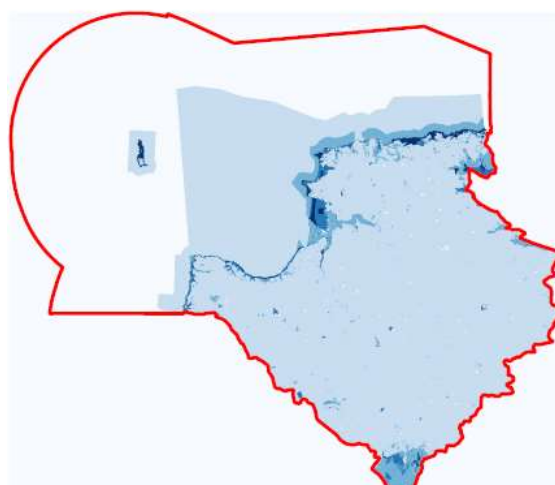
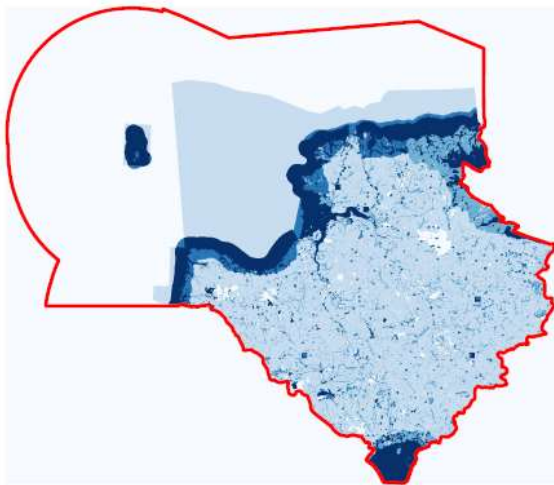
Baseline

Business as usual



Less regulation

Responsibility and custodianship



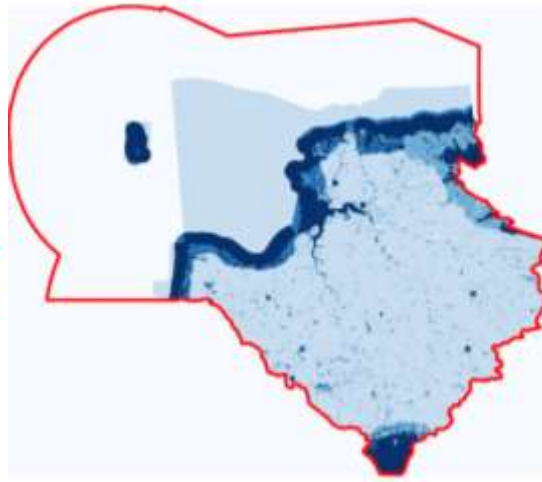
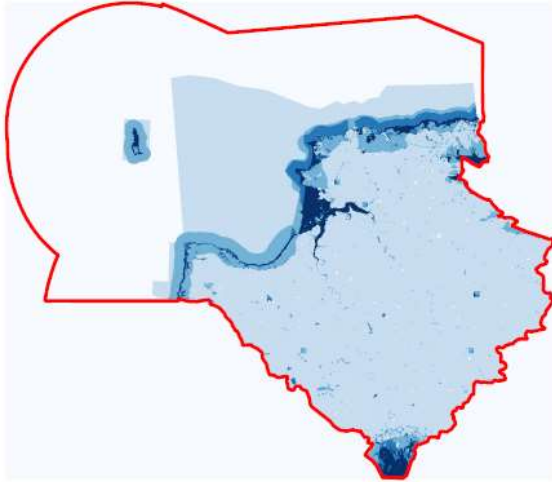
Created by MOPST (github.com/mopst)¹⁹

¹⁹ All model and module output maps created by Mapping Opportunity & Pressures for Sustainable Tourism (MOPST) - Nick Bearman supported by the Interreg EU England Channel Region funded BioCultural Heritage Tourism project, Devon County Council and the University of Exeter.

NDBR Pressure winter – Baseline and all three scenarios

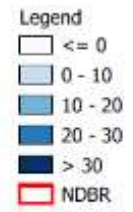
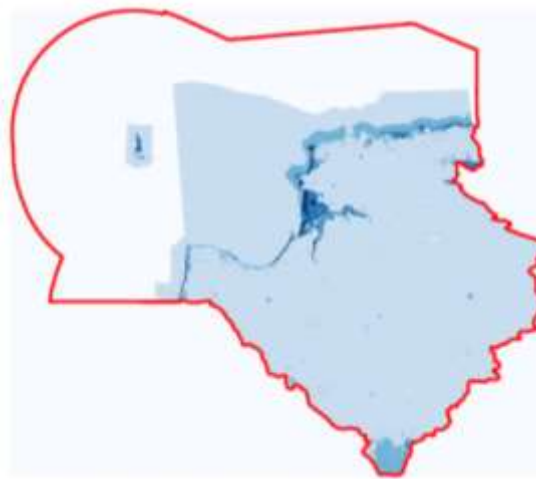
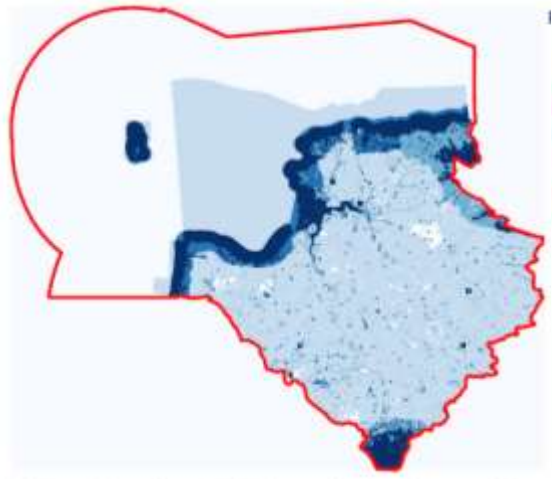
Baseline

Business as usual



Less regulation

Responsibility and custodianship

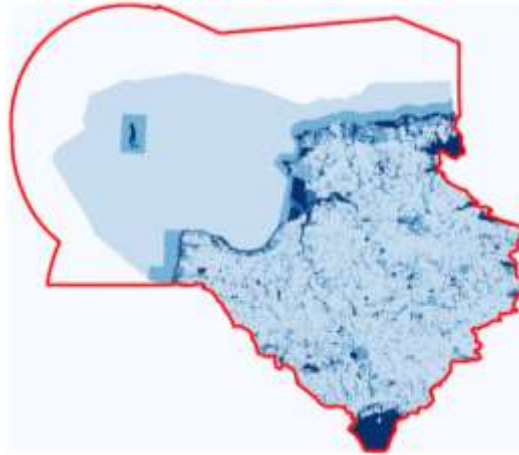
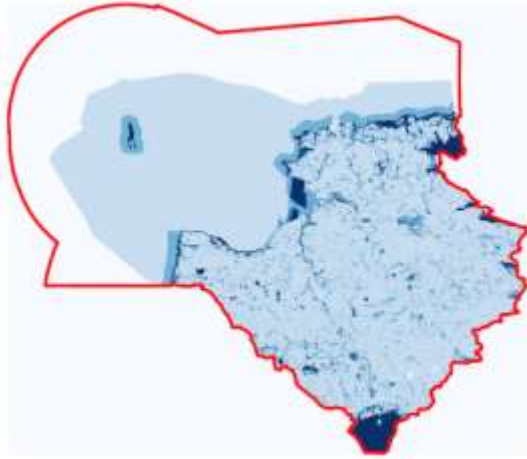


Created by MOPST (github.com/mopst)

NDBR Opportunity Summer – Baseline and all three scenarios

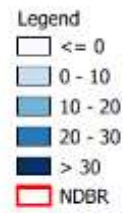
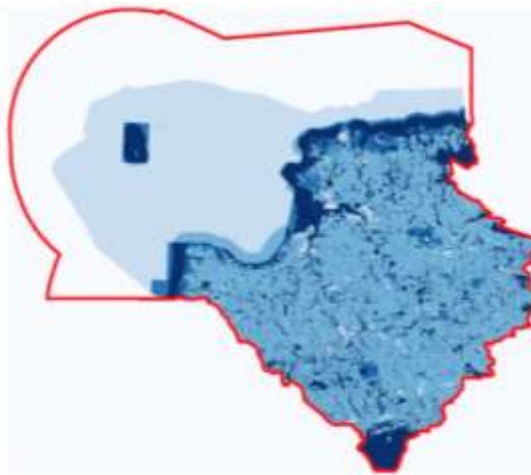
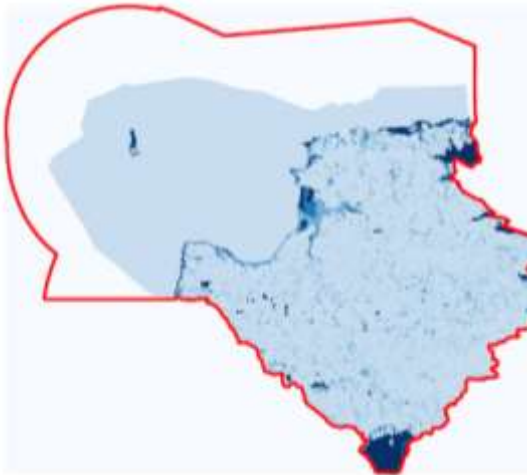
Baseline

Business as usual



Less regulation

Responsibility and custodianship

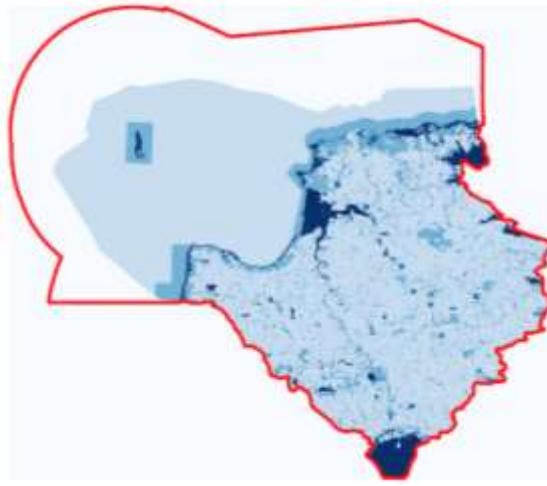
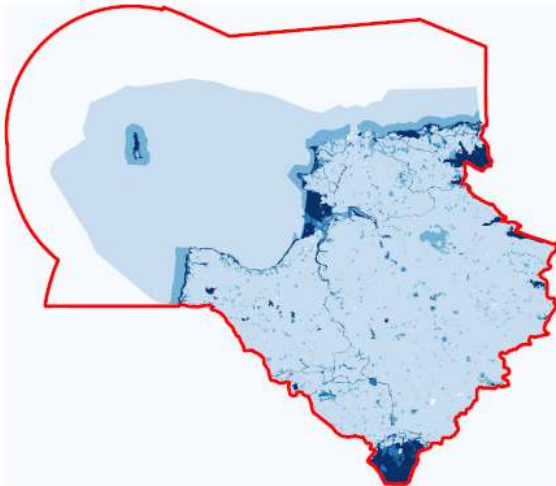


Created by MOPST (github.com/mopst)

NDBR Opportunity Winter – Baseline and all three scenarios

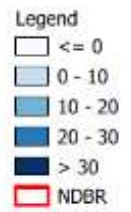
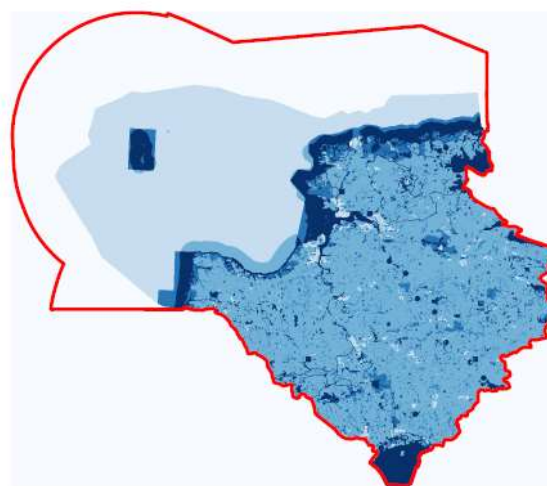
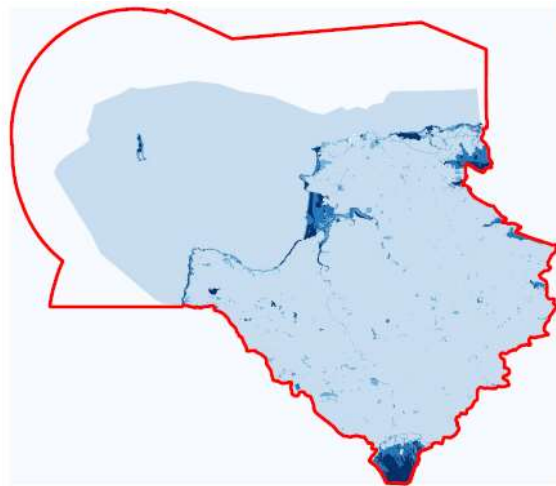
Baseline

Business as usual



Less regulation

Responsibility and custodianship



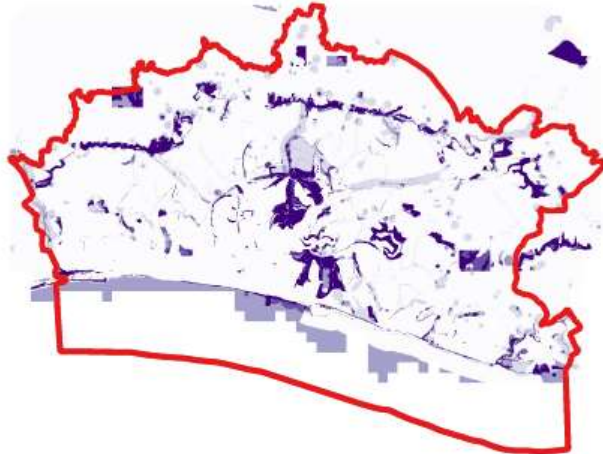
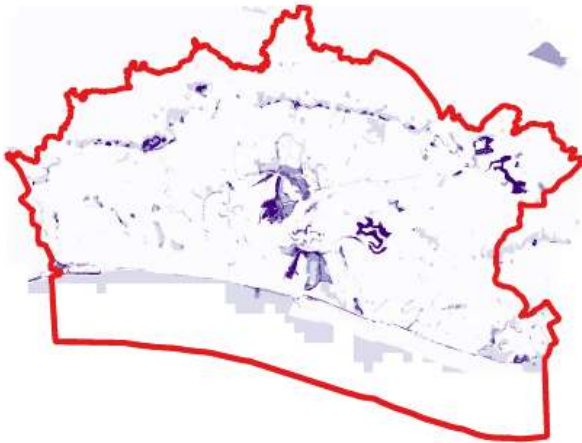
Created by MOPST (github.com/mopst)

Brighton and Lewes Downs (the Living Coast) Output maps

BLDBR Pressure Summer – Baseline and all three scenarios

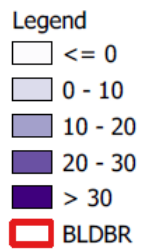
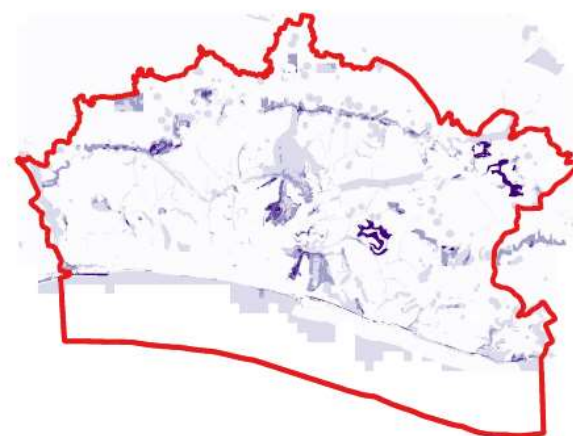
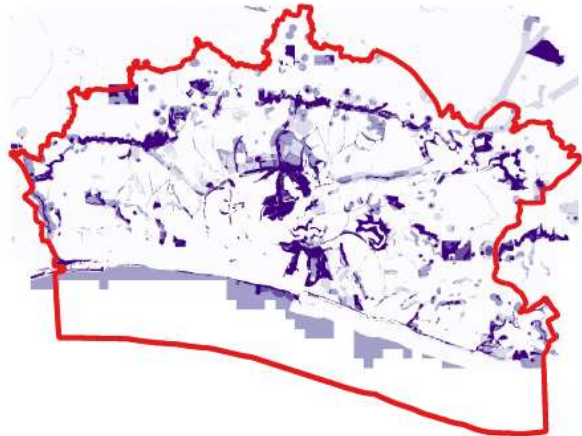
Baseline

Business as usual



Less regulation

Responsibility and custodianship

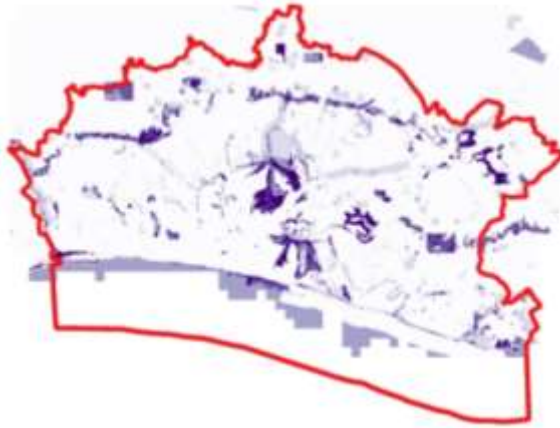
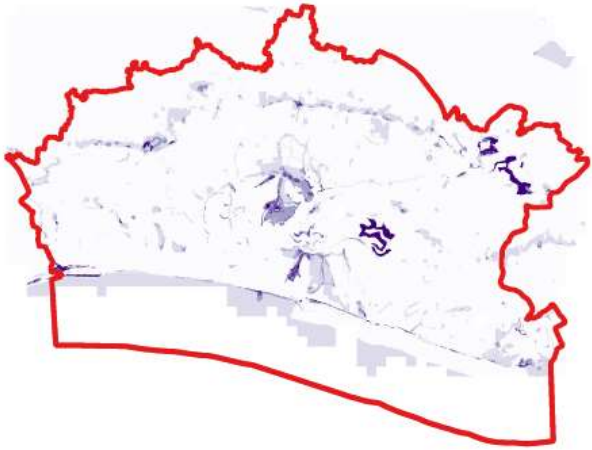


Created by MOPST (github.com/mopst)

BLDBR Pressure Winter – Baseline and all three scenarios

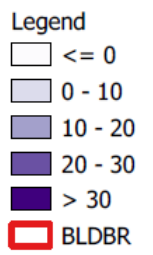
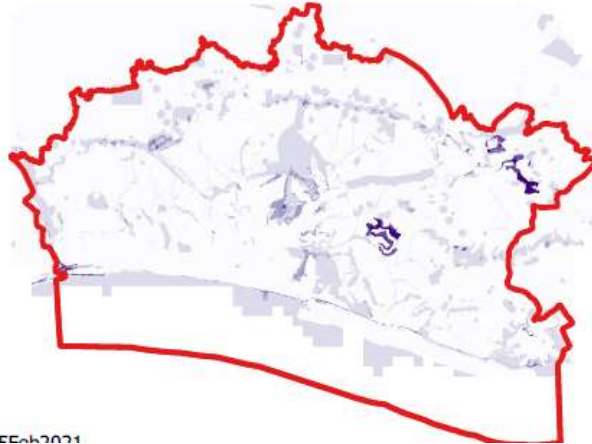
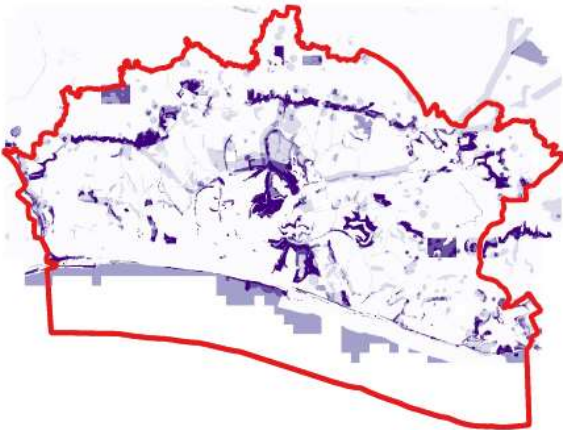
Baseline

Business as usual



Less regulation

Responsibility and custodianship



EE-6-2021

Created by MOPST (github.com/mopst)

BLDBR Opportunity Summer – Baseline and all three scenarios

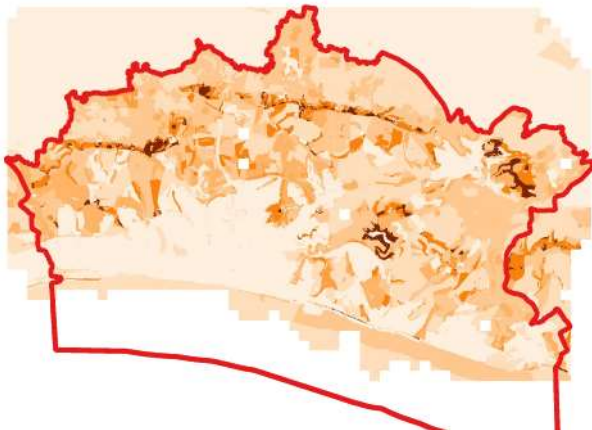
Baseline



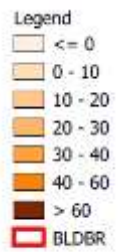
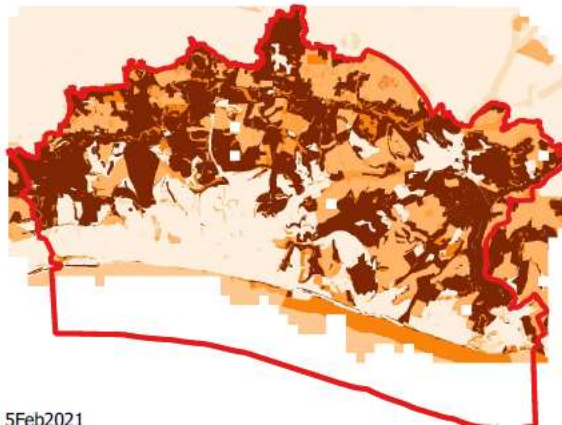
Business as usual



Less regulation



Responsibility and custodianship



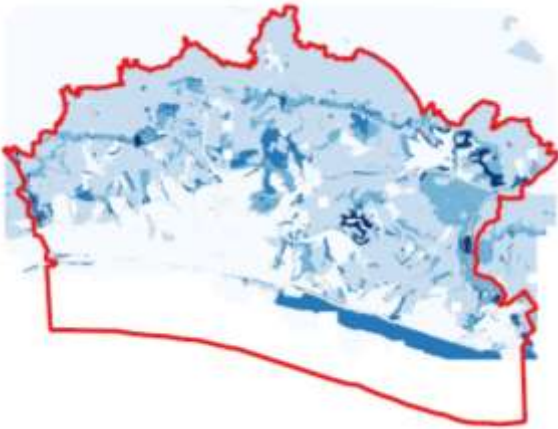
la 5Feb2021

Created by MOPST (github.com/mopst)

BLDBR Opportunity Winter – Baseline and all three scenarios

Baseline

Business as usual

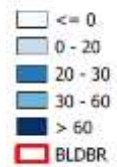


Less regulation

Responsibility and custodianship



Legend



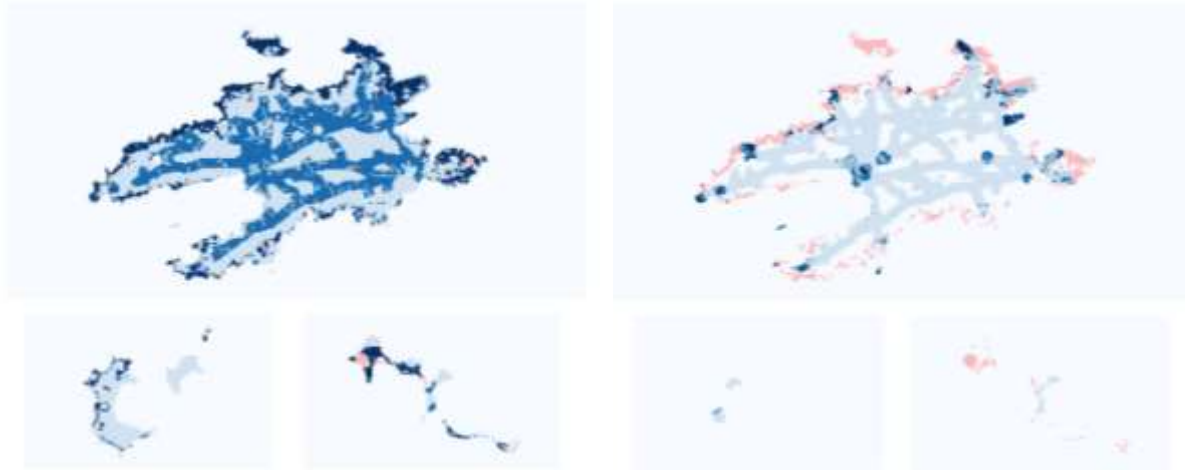
Created by MOPST (github.com/mopst)

N.B. Note the different scale and colour scheme to opportunity summer here (same scale as pressure).

RBIMI Pressure Summer – Baseline and all three scenarios

Baseline

Business as usual



Less regulation

Responsibility and custodianship

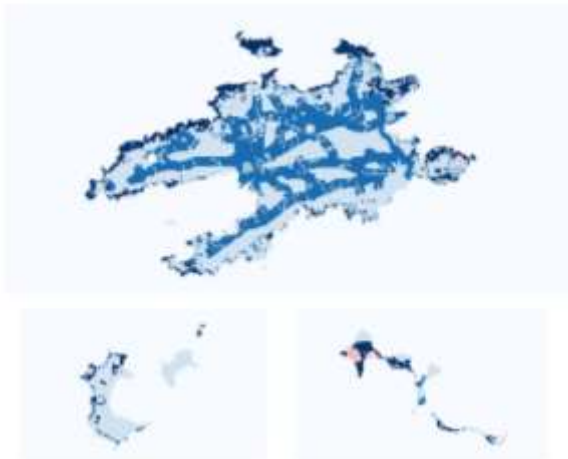


Created by MOPST (github.com/mopst)

N.B. Due to limitations in the data these maps focus on the islands (land-based areas) not the marine areas (see BR map in Appendix 1). These maps are still subject to updating of input data (including recalibrating negative values).

RBIMI Pressure Winter – Baseline and all three scenarios

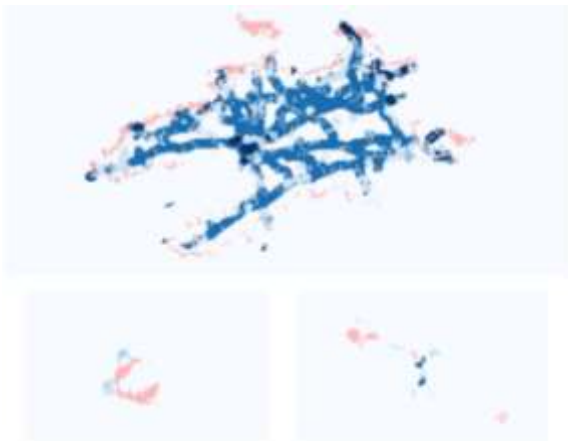
Baseline



Business as usual



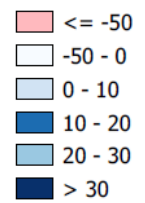
Less regulation



Responsibility and custodianship



Legend



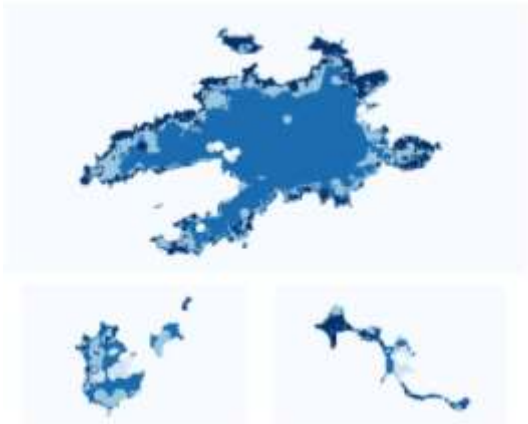
Created by MOPST (github.com/mopst)

N.B. Due to limitations in the data these maps focus on the islands (land-based areas) not the marine areas (see BR map in Appendix 1). These maps are still subject to updating of input data (including recalibrating negative values).

RBIMI Opportunity Summer – Baseline and all three scenarios

Baseline

Business as usual

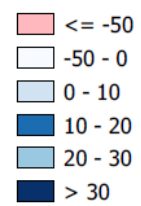


Less regulation

Responsibility and custodianship



Legend



Created by MOPST (github.com/mopst)

N.B. Due to limitations in the data these maps focus on the islands (land-based areas) not the marine areas (see BR map in Appendix 1). These maps are still subject to updating of input data (including recalibrating negative values).

RBIMI Opportunity Winter – Baseline and all three scenarios

Baseline

Business as usual

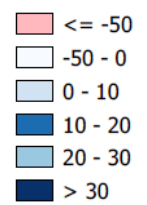


Less regulation

Responsibility and custodianship



Legend



Created by MOPST (github.com/mopst)

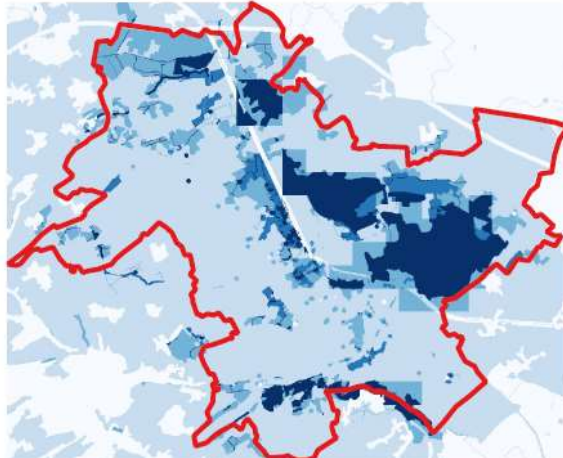
N.B. Due to limitations in the data these maps focus on the islands (land-based areas) not the marine areas (see BR map in Appendix 1). These maps are still subject to updating of input data (including recalibrating negative values).

RBMA Pressure Summer – Baseline and all three scenarios

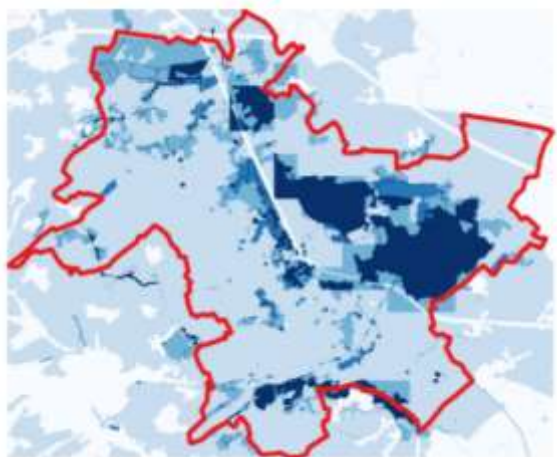
Baseline



Business as usual



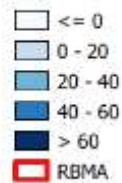
Less regulation



Responsibility and custodianship



Legend



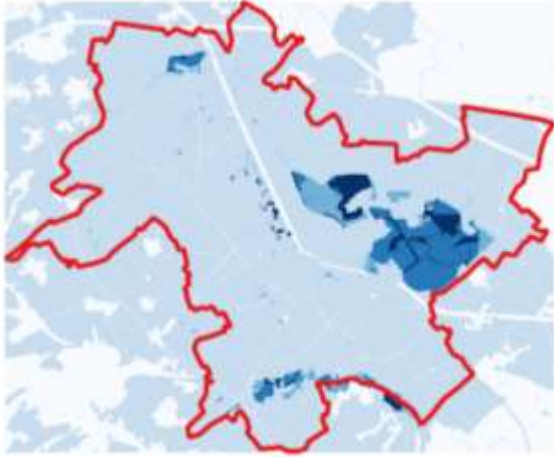
Created by MOPST (github.com/mopst)

N.B. Due to limitations in the data these maps focus on the land-based areas not the waterways (see BR map in Appendix 1). These maps are still subject to updating of input data.

RBMA Pressure Winter – Baseline and all three scenarios

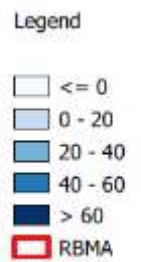
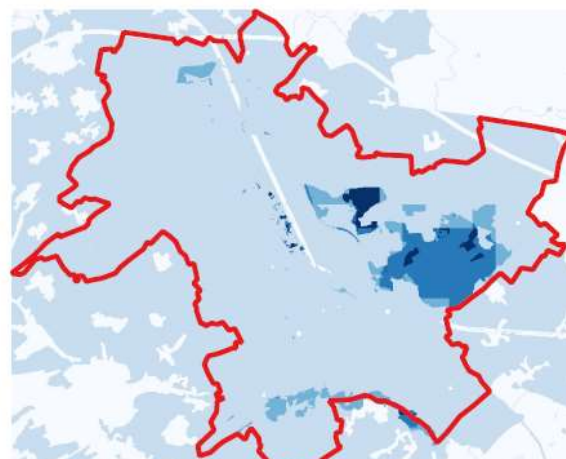
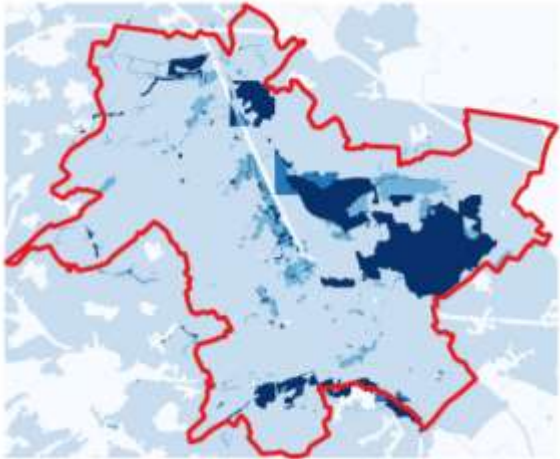
Baseline

Business as usual



Less regulation

Responsibility and custodianship



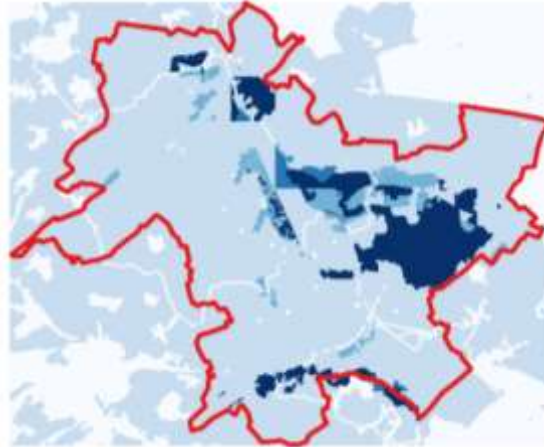
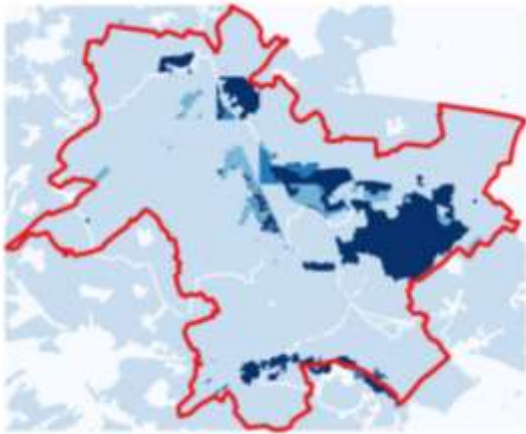
Created by MOPST (github.com/mopst)

N.B. Due to limitations in the data these maps focus on the land-based areas not the waterways (see BR map in Appendix 1). These maps are still subject to updating of input data.

RBMA Opportunity Summer – Baseline and all three scenarios

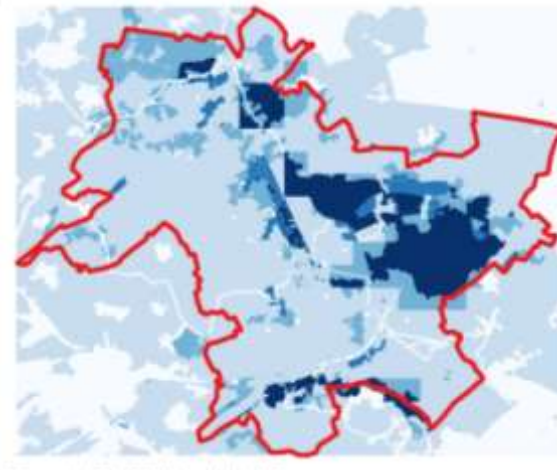
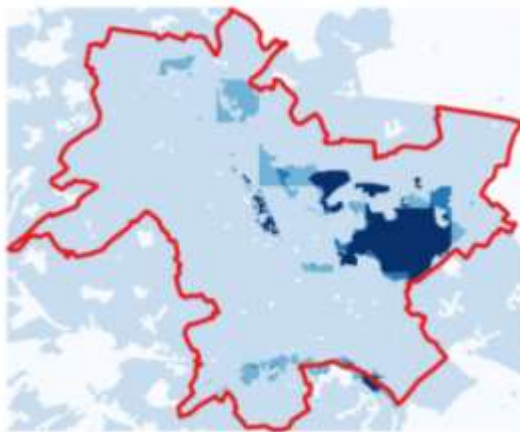
Baseline

Business as usual

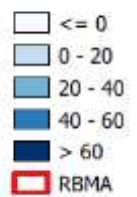


Less regulation

Responsibility and custodianship



Legend

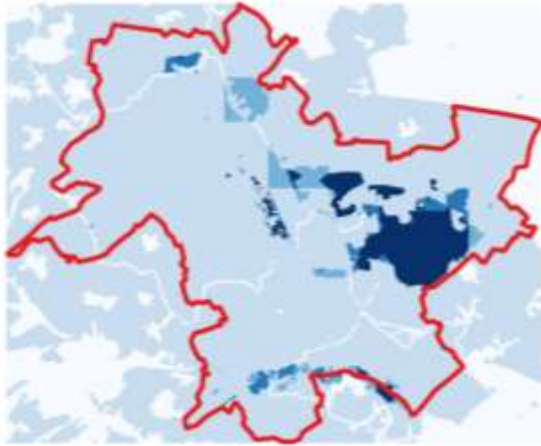


Created by MOPST (github.com/mopst)

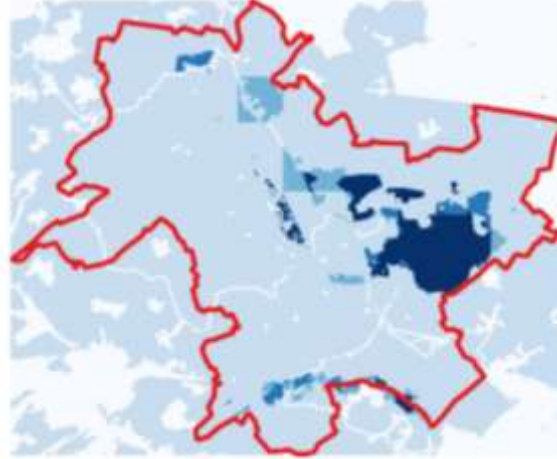
N.B. Due to limitations in the data these maps focus on the land-based areas not the waterways (see BR map in Appendix 1). These maps are still subject to updating of input data.

RBMA Opportunity Winter – Baseline and all three scenarios

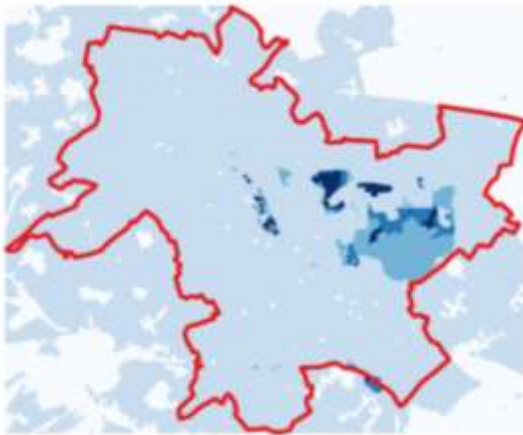
Baseline



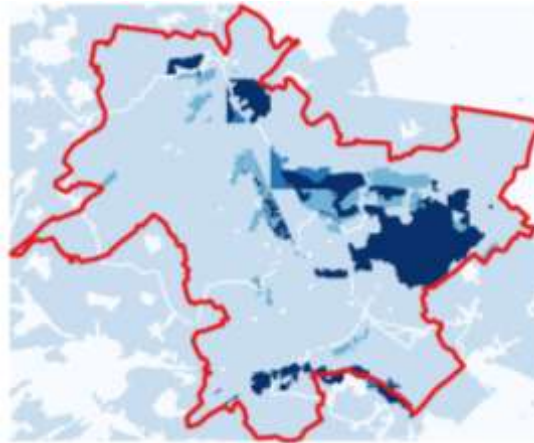
Business as usual



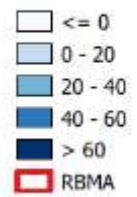
Less regulation



Responsibility and custodianship



Legend



Created by MOPST (github.com/mopst)

N.B. Due to limitations in the data these maps focus on the land-based areas not the waterways (see BR map in Appendix 1). These maps are still subject to updating of input data.