OpenBeaverNetwork and Beaver Habitat Index

Data summary report (South West)

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Introduction

This document accompanies the OpenBeaverNetwork (OBN) and Beaver Habitat Index (BHI) datasets for the South West region of England which have been provided to the Wildlife Trust in partnership with the University of Exeter (UoE). Also included are summary statistics (as polygon spatial vector) of the OBN for each SW county, as defined by the Office for National Statistics, and for Environment Agency (EA) Water Body areas. The purpose of this document is to briefly outline modelling methods and to describe the structure and contents of the data to enable interrogation and interpretation by Wildlife Trust colleagues. These data are derived from open source products and are therefore free to share with acknowledgement of Graham et al. (2020).

Dataset Inventory

Data has been provided in the file titled 'OpenBeaverNetworkSouthWet.zip.' It contains six files/subdirectories which are described in Table 1. All datasets are spatial and projected in OSGB36 (EPSG:27700) coordinate reference system.

Table 1:The name and contents of the data folders located in 'OpenBeaverNetworkSouthWet.zip'

Folder/File Name	Content Description
BeaverNetwork_SouthWest.gpkg	The BeaverNetwork dataset for the South West of England region in Geopackage (.gpkg) format. It is a Polyline spatial vector dataset containing attributes for beaver dam capcity/suitabilty, estimated dam numbers, forage suitability, hydrometric/topographic variables such as stream power, gradient and stream width.
BeaverNetwork_SouthWest.zip	The same BeaverNetwork dataset in ESRI Shapefile (.shp) format. All contituent files are stored in a compressed (.zip) folder.
BeavNet_CountySumm_SouthWest.gpkg	Summarised BeaverNetwork data for county regions in GeoPackage format.

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Folder/File Name	Content Description
BeavNet_CountySumm_SouthWest.zip	Summarised BeaverNetwork data for county regions in "zipped" ESRI shapefile format.
BeavNet_EA_WaterBods_SouthWest.gpkg	Summarised BeaverNetwork data for Environment Agency Water Body Areas in GeoPackage format.
BeavNet_EA_WaterBods_SouthWest.zip	Summarised BeaverNetwork data for Environment Agency Water Body Areas in "zipped" ESRI shapefile format.
bhi_SouthWest.tif	Fine (High) resolution (10 m) Beaver Habitat Index for the South West region. in Geotiff (.tif) format.
bhi_1km_SouthWest.tif	Coarse (Low) resolution (1 km) Beaver Habitat Index for the South West region. in Geotiff (.tif) format.

Beaver Habitat Index (BHI)

Vegetation is important for classifying beaver habitat (Göran Hartman 1996; F. John, Baker, and Kostkan 2010; Pinto, Santos, and Rosell 2009; St-Pierre et al. 2017). It was therefore critical to establish a reliable Beaver HabitatIndex (BHI) using nationally-available spatial datasets. No single dataset contained the detail required to depict all key vegetation types. Therefore, a composite dataset was created from:

- The Centre for Ecology and Hydrology (CEH) 2019 land cover map (LCM) (Morton et al. 2020) . This provides landcover classification at a resolution of 20m, derived from Sentinel 2 data using a random forest method. This dataset has been updated from the 2015 landcover map, used in our previous modelling work (Graham et al. 2020).

- Copernicus 2018 10 m tree cover density (TCD) (Copernicus 2020) provides a percent tree cover density estimate which is derived from sentinel 2A + B satellite imagery using a random forest classification system. This dataset has been updated from the Copernicus TCD 2015, used in prior modelling work.

- The National Forest Inventory (NFI) Woodland Map (Forestry Commission 2019) which includes woodland areas with an area > 0.5 ha and a minimum width > 20m. It is a partially derived from digitised Ordnance Survey (OS) MasterMap data but also includes additional woodland areas identified from other remotely sensed data sources.

- The (OS) VectorMap District (Ordnance Survey 2021) is a digitised spatial vector product, from which we extract the surface water areas, which include larger river channels (c.a. >4 m wide) and still water bodies. This dataset and the NFI replaces the OS VectorMap Local data used in Graham et al., (2020).

Vegetation datasets were assigned suitability values (zero to five). Zero values were assigned to areas of no vegetation e.g., buildings and values of five were assigned to favourable habitat e.g. deciduous woodland. Values were assigned based on a review of relevant literature (Gallant et al. 2004; Haarberg and Rosell 2006; Jenkins 1979; Nolet and Rosell 1994; O'Connell et al. 2008), field observation and comparison with satellite imagery. Vector data were converted to raster format (resolution of 10 m). TCD data were warped (using cubic-spline transformation) from coordinate reference system (CRS) EPSG:3035 to EPSG:27700 to align with converted vector layers.

An inference system was used to combine these raster datasets to create the Beaver Forge Index (BHI) (Graham et al. 2020). The workflow prioritises the reliability followed by the highest value data. Examples of highly suitable land (graded 5) include broad-leaf woodland, mixed woodland and shrub; examples of suitable vegetation (graded 4) include shrub and marsh; examples of moderately suitable (graded 3) include coniferous woodland, shrub and unimproved grassland; examples of barely suitable (graded 2) include reeds, shrub and heathland and boulders, neutral grassland; examples of unsuitable (graded 1) include heather, acid grassland, unimproved grass and boulders, bog; examples of no accessible vegetation (graded 0) include shingle and sand, buildings, rock, urban, freshwater and saltwater.

Whilst vegetation is a dominant factor in determining habitat suitability for beaver, so is proximity to a water body (Gurnell 1998) . Beavers use water bodies both for security and to access foraging areas. It is thought that most foraging occurs within 10 m of a watercourse/body (Haarberg and Rosell, 2006), and rarely above 50 m (Stringer et al. 2018) . However, greater foraging distances have, on occasion, been observed (Macfarlane et al. 2017) and 100 m has been accepted as a maximum distance in which the vast majority of foraging occurs. Therefore, areas >100m from a river bank or still waterbody were classified as No Data (NA) due to its inaccessibility.

Table 2: provides definitions for the BHI values. A value of five represents vegetation that is highly suitable or preferred by beavers and that also lies within 100 m of a waterbody. Zero scores are given to areas that contain no vegetation or are greater than 100 m from a waterbody. It is important to note that the model considers terrestrial habitat, where foraging primarily occurs, and therefore watercourses themselves are also scored zero.

BHI Values	Definition
0	Not suitable (no accessible vegetation)
1	Not suitable (unsuitable vegetation)
2	Barely Suitable
3	Moderately Suitable
4	Suitable
5	Highly Suitable

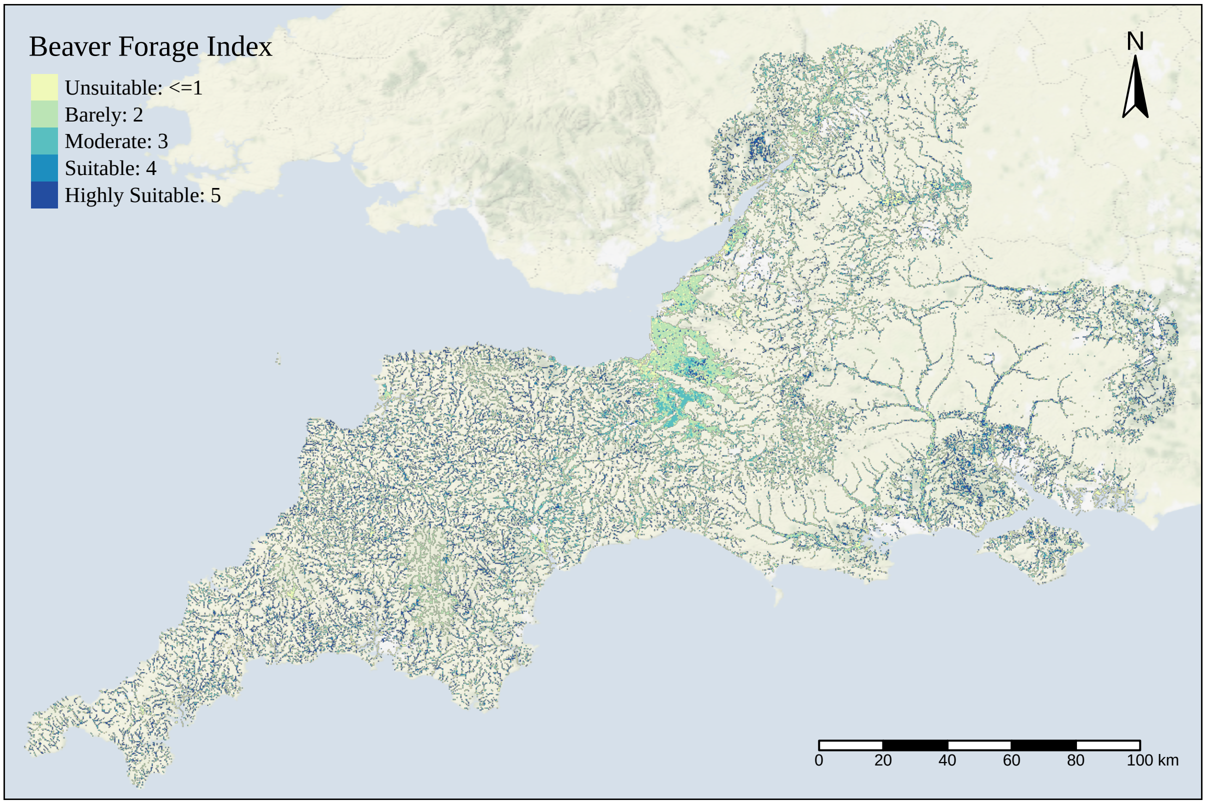

Figure 1: Beaver Habitat Index (BHI) full resolution (10 m). Ranges from 0-5 describing the suitability of forage within 100 m of inland water (i.e. rivers and lakes).

The BHI has a resolution of 10 m. Therefore at a large scale, as shown in Figure 1, it can be hard to interpret. Therefore we also provide the BHI at a resampled resolution of 1km (Figure2). This aids interpretation at the regional/national scale.

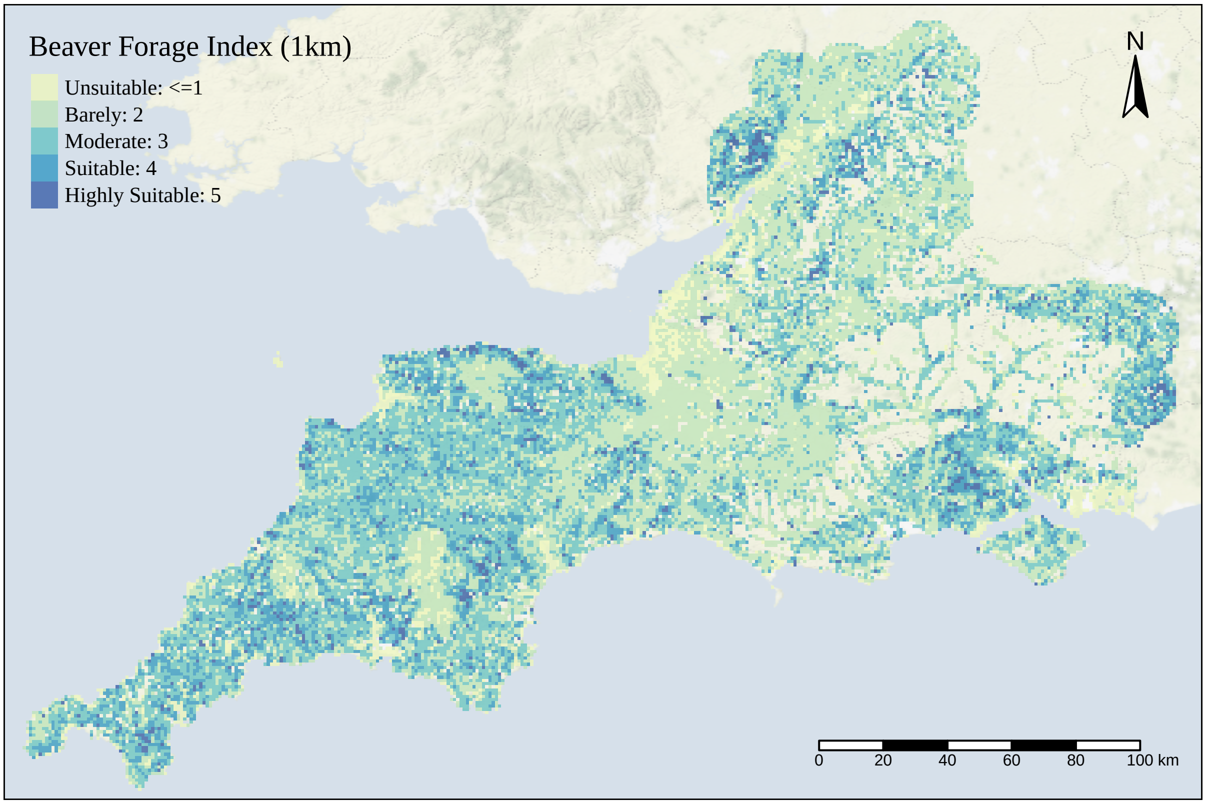

Figure 2: Beaver Habitat Index (BHI) resampled to 1 km resolution . Ranges from 0-5. . . }

Beaver Dam Capacity

Beavers are well known as ecosystem engineers (Gurney and Lawton 1996; G. Hartman and Tornlov 2006) due to their ability to build dams, construct lodges, fell trees, excavate canals and burrow into banks. Of these behaviours, it is dam construction that has the most pronounced effect on the surrounding landscape by impounding water behind the structures which often results in the formation of complex and diverse wetland systems. Beavers construct dams for two main reasons: (i) to increase the depth of water surrounding a dwelling, such as a lodge or burrow, in order to submerge the entrance (Gurnell, 1998) and (ii) to increase the ease of movement within a territory to access areas of desirable vegetation and evade predators (Campbell-Palmer et al. 2016).

The construction of beaver dams can help to restore natural function within riverine and riparian systems by: (i) attenuating peak flood flows and extending lag times by increasing storage capacity and surface roughness(Nyssen, Pontzeele, and Billi 2011; Puttock et al. 2017; Puttock et al. 2021); (ii) maintaining base flow by storing water during dry periods and raising local ground water tables Gibson and Olden (2014); (iii) capturing fine sediment and storing nutrients(Butler and Malanson 1995; de Visscher et al. 2014; Lizarralde et al. 1996; Puttock et al. 2018); (iv) aggrading incised channels, promoting floodplain reconnection(Pollock et al. 2014) and enhancing channel complexity (S. John and Klein 2004); (v) increasing habitat heterogeneity and biodiversity (Law, McLean, and Willby 2016; Stringer and Gaywood 2016).

Although beavers offer some promising benefits, from an ecosystem service perspective, their industrious behaviour can also cause considerable conflict where valuable infrastructure or farmland is impacted (Schwab and Schmidbauer 2003). Many of these conflicts can be rectified or managed in such a way that minimises damage whilst ensuring the welfare of the animals (Campbell-Palmer et al., 2016). An understanding of where dams are likely to be constructed is important for the effective management of these conflicts, especially in the context of GB where Beaver populations are expanding.

The Beaver restoration assessment tool (BRAT) was developed in North America (Macfarlane et al., 2017) to determine the capacity for river systems to support Beaver dams. The BRAT model has been further deployed in a range of different river systems to aid both Beaver recolonisation and beaver dam analogue led restoration. The BRAT model not only provides an invaluable tool for designing effective, empirically based, restoration strategies but it also indicates where Beaver dams might be constructed and therefore where they may cause potential management/conflict issues. The BRAT model is structured around a river network, calculating a range of environmental factors for each reach which are evaluated using fuzzy logic which factors in the considerable uncertainty that is associated with beaver habitat/dam suitability. Furthermore, it provides a range of output values to predict the dam capacity which has implications for beaver preference towards a given location.

We have therefore used the BRAT framework to develop an optimised beaver dam capacity (BDC) model for Great Britain (Graham et al. 2020). The model infers the density of dams that can be supported by stream reaches (110 m ± 50 SD) across a catchsment. Using low-cost and open-source datasets, the following attributes are calculated for each reach: (i) stream gradient, (ii) low (Q80) and high flow (Q2) stream power, (iii) bankfull width, (iv) stream order, and (v) the suitability of vegetation, within 10m and 40m of the bank, for beaver dam construction. These controlling variables are combined using a sequence of inference and fuzzy inference systems which follow an expert-defined rules system that allows for the considerable uncertainty often associated with these types of complex ecological processes.

Each reach was classified for dam capacity using five categories from none, defined as no capacity for damming to pervasive where a maximum capacity of 16-30 dams could theoretically be constructed in a km of channel. It is important to note that the model assumes both reach and catchment population carrying capacity for beaver. Therefore, in reality the maximum number of dams indicated in a category class is unlikely to occur. A full list of BDC classifications is included in Table 2.

Table 2: BDC classifications and definitions.

BDC Classification	Definition
None	No capacity for damming
Rare	Max capacity for 0-1 dams/km
Occasional	Max capacity for 1-4 dams/km
Frequent	Max capacity for 5-15 dams/km
Pervasive	Max capacity for 16-40 dams/km

BeaverNetwork-South West

The BeaverNetwork-SouthWest model provides a synthesis of both the BHI and BDC models. For each reach there are therefore estimates for the forage suitability within 10 and 40m of the river bank and the dam capacity for the reach. In addition to these data, information for the probability of forage and dam construction and the number of dams which is estimated for the reach (including confidence limits) based on observed foraging/dam building behaviour as demonstrated in Graham, et al. (2020). The probability of forage/dam construction was calculated using binomial Bayesian modelling and dam number estimates were calculated using regression analysis (zero-inflated negative binomial model). Predictions for reach scale dam counts should only be considered as a sum at the (sub) catchment scale (>= 5km^2).

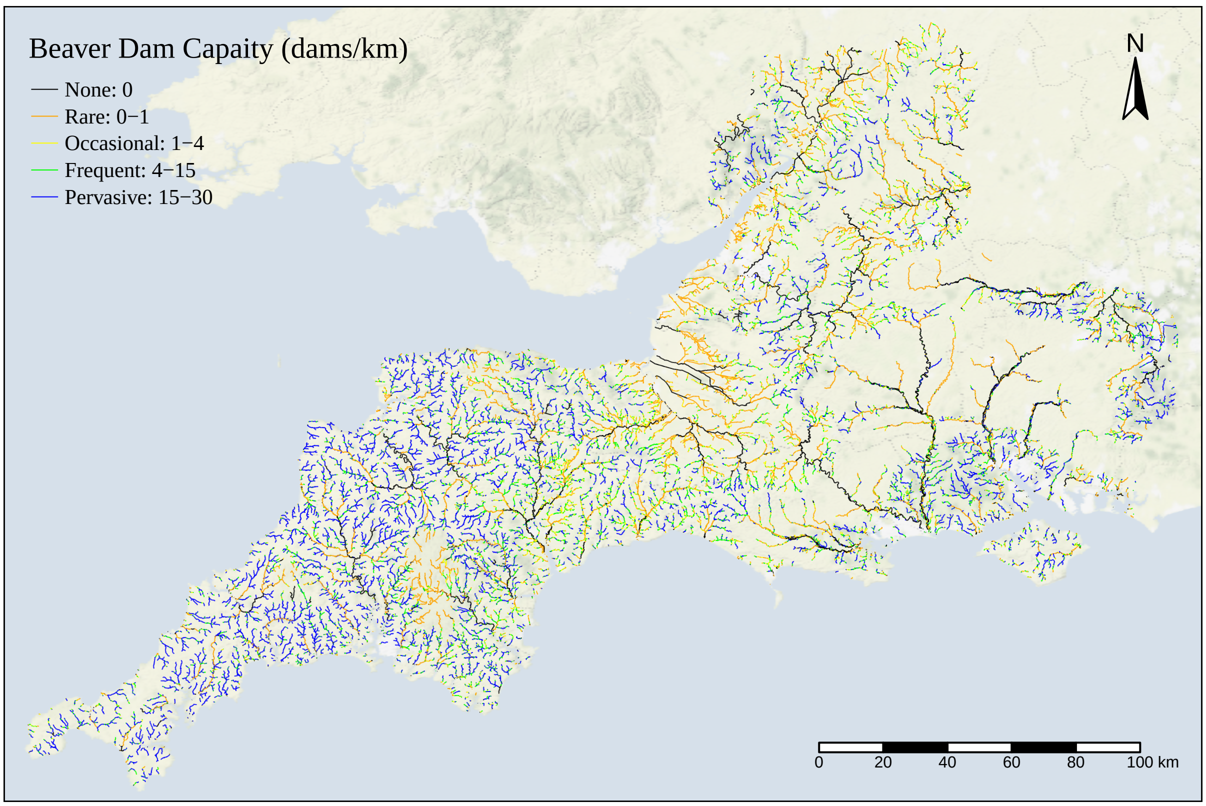

Figure3: BeaverNetwork-SouthWest displaying Beaver Dam Capacity data for all reaches.

Table 3: Description of variables provided int the OpenBeaverNetwork-SouthWest dataset.

Variable Name	Variable Full Name	Description
BDC	Beaver Dam Capacity (dams/km)	The maximum dam density that can be supported in a given reach. See (Graham et al., 2020; Macfarlane et al., 2017). Though individual reaches may reach capacity, whole catchments are extremely unlikely to reach capacity. For estimating (sub)catchment scale dam counts use 'Est_nDam'.
BDC_cat	Beaver Dam Capacity Category	A categorical string assigned based on the BDC value: (0 = None, 0-1 = Rare, 1-4 = Occasional, 4-15 = Frequent, 15-30 = Pervasive)

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Variable Name	Variable Full Name	Description
BFI_10m	Beaver Forage Index score within 10m of bank	The mean of the upper 50% of Beaver Forage Index (BFI) values within 10m of the river bank. The Beaver Forage Index describes the suitability of a given vegetation type as beaver forage. Range from 0-5.
BFI_40m	Beaver Forage Index score within 40m of bank	The mean of the upper 50% of Beaver Forage Index (BFI) values within 40m of the river bank. This Metric is preferred over the 10m buffer when considering foraging habitat.
BFI_cat	Beaver Forage Index (Suitability) Category	A categorical value assigned based on BFI_40m to describe the forage preference of beaver for a particular vegetation type /landcover. (0-1 = Unsuitable, 1-2 = Low, 2-3 = Moderate, 3-4=High, 4-5 = Preferred)
V_BDC	Vegetation Beaver Dam Capacity (dams/km)	The maximum density of dams that can be supported in a given reach, considering vegetation only. No hydrologic of geomorphic parameters are used here. This intermediate metric may be useful in some instances to evaluate vegetation but we recommend the use of BDC to evaluate dam capacity and BFI_40m to evaluate forage suitability.)
Dam_Prob	Probability of dam construction (mean)	The probability that a given reach will be dammed by beaver, assuming that beaver are active in the reach (Graham et al., 2020).
Dam_ProbLC	Probability of dam construction (Lower 95% Credible interval)	The lower 95% credible interval for the probability of dam construction, assuming that beaver are active in the reach.
Dam_ProbUC	Probability of dam construction (Upper 95% Credible interval)	The upper 95% credible interval for the probability of dam construction, assuming that beaver are active in the reach.
For_Prob	Probability of Beaver Foraging (mean)	The probability that beaver will forage in a given reach, assuming that beaver are active within the catchment (Graham et al., 2020).
For_ProbLC	Probability of Beaver Foraging (Lower 95% Credible interval)	The lower 95% credible interval for the probability of beaver foraging, assuming that beaver are active within the catchment.
For_ProbUC	Probability of Beaver Foraging (Upper 95% Credible interval)	The upper 95% credible interval for the probability of beaver foraging, assuming that beaver are active within the catchment.
Est_nDam	Estimated Number of dams (mean)	The estimated number of dams in a given reach, if beaver are active within it. This value is to be used to quantify the likely number of dams that may occur at the sub-catchment scale (ca. >= 5 km2) as a minimum (Graham et al., 2020). For estimating the number of dams that may occur in a single reach (or beaver territory), 'BDC' is a more appropriate metric.
Est_nDamLC	Estimated Number of dams (Lower 95% Confidence limit)	The lower 95% confidence limit of dam estimates for a given reach. See 'Est_nDam' description for further info.
Est_nDamUC	Estimated Number of dams (Upper 95% Confidence limit)	The upper 95% confidence limit of dam estimates for a given reach. See 'Est_nDam' description for further info.
Length_m	Reach Length (m)	The length of a given river reach.
Width_m	Reach Width (m)	The mean width of a given river reach.
Slope_perc	Reach slope (%)	The mean slope of a given river reach.
Drain_Area	Contributing Drainage Area (km2)	The flow accumulation area for a given reach: i.e. the total area from which water flows into a reach.
Str_order	Stream Order (Strahler)	The stream order of a given reach, calculated using the Strahler method (Strahler, 1957)
Q2_Flow	Flow at Q2 (m^-3 s^-1)	The estimated flow for a given reach at the Q2 exceedance level (98th percentile)
Q80_Flow	Flow at Q80 (m^-3 s^-1)	The estimated flow for a given reach at the Q80 exceedance level (20th percentile)
Q2_StrPow	Stream Power at Q2 (watts/m)	The Total Stream power for a given reach at the Q2 exceedance level.
Q80_StrPow	Stream Power at Q80 (watts/m)	The Total Stream power for a given reach at the Q80 exceedance level.

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Variable Name	Variable Full Name	Description
reach_no	Unique Reach ID number	Integer to identify individual reaches.

Regional summary statistics

A range of summary statistics were calculated at two different scales (county and EA Water Body Area) by carrying out a spatial join between the BeaverNetwork features and the regional polygons. A range of summary statistics, described in Table 4, were derived to provide regional understanding. A selection of these summary statistics are presented as a facet plot in Figures 4 and 5 and as bivariate choropleth maps in figures 6 and 7.

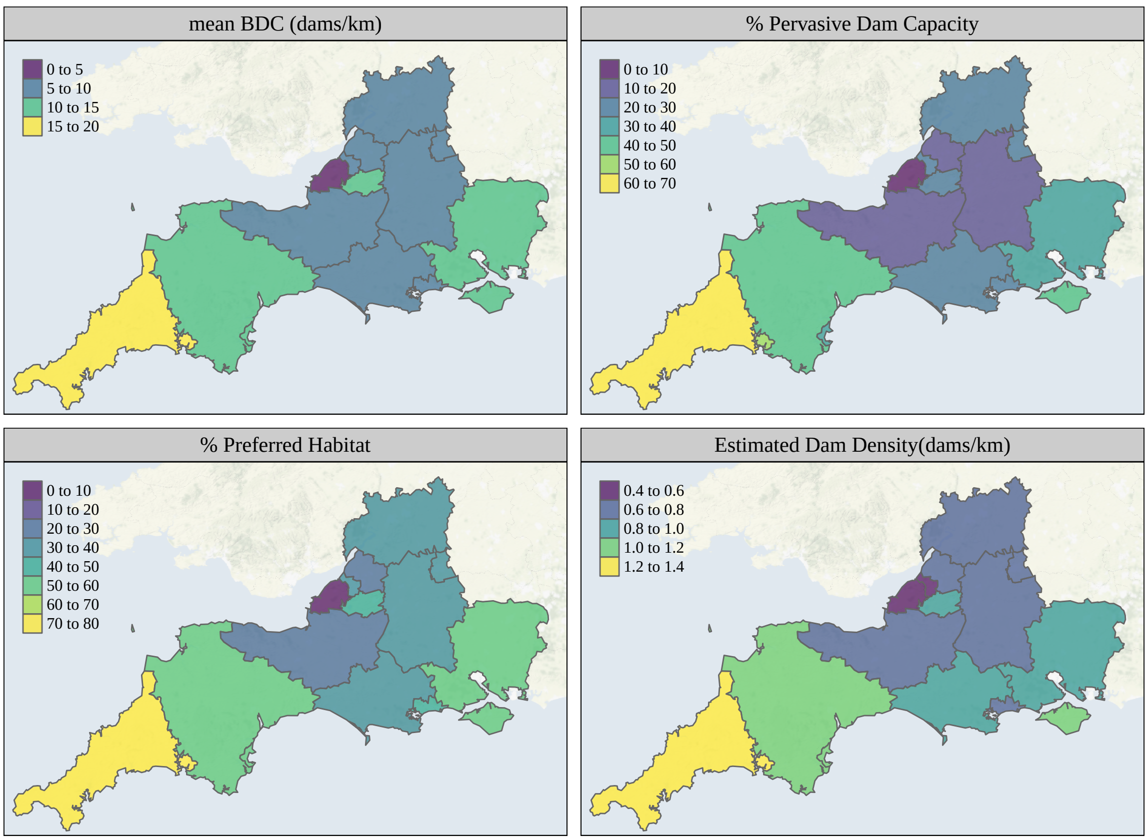

Figure 4: Summary satatistics for South West Counties. This figures serves as an example for the types of satistics that can be derived for regions.

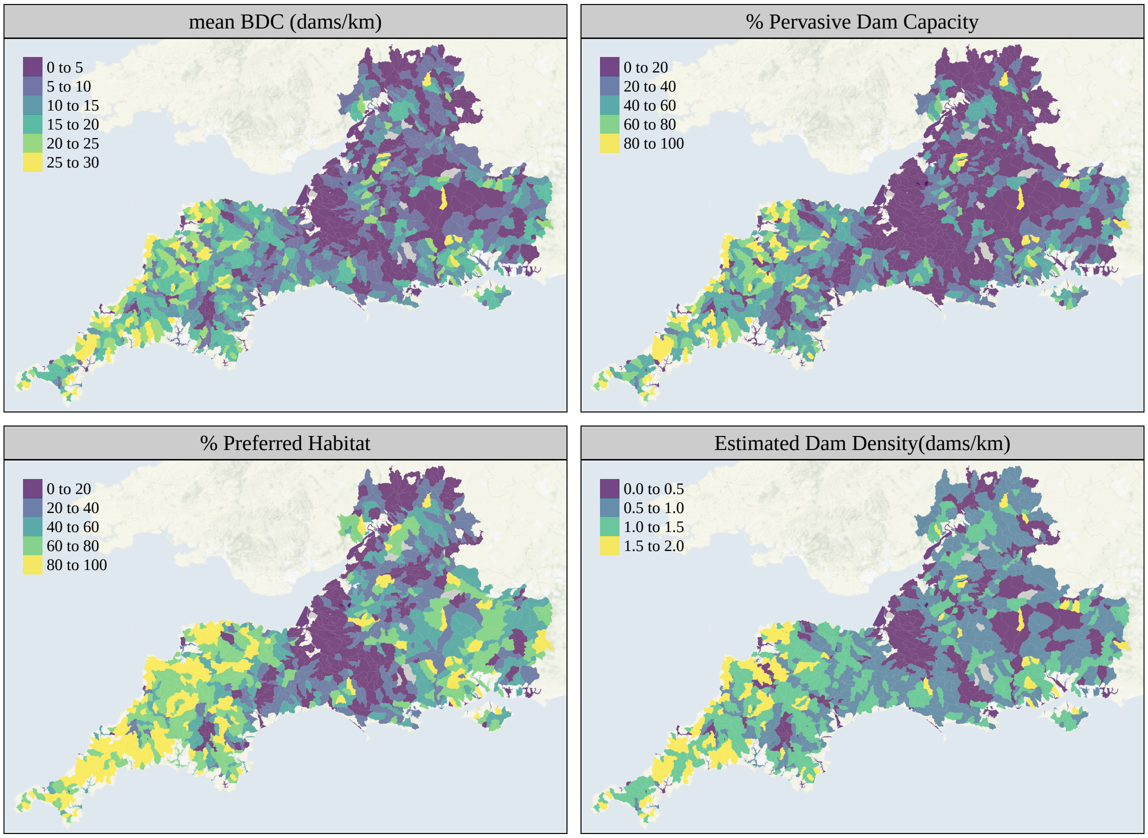

Figure 5: Summary satatistics for South West EA Water Body Areas.

Figures 4-7 serve as examples of how this data may be used to evaluate the data in a regionalised manner. Each facet in figures 4 and 5 represent a single summarised variable from the OBN. However, we can also select or prioritise different regions for beaver reintroduction or management based on the interaction of multiple factors. Figures 6 and 7 compare the estimated dam density (under carrying capacity) with the proportion of the river network with preferred forage (within 40 m of the bank). Here, we can make inferences on how landuse and topographic differences in regions can influence the potential imapact of beavers.

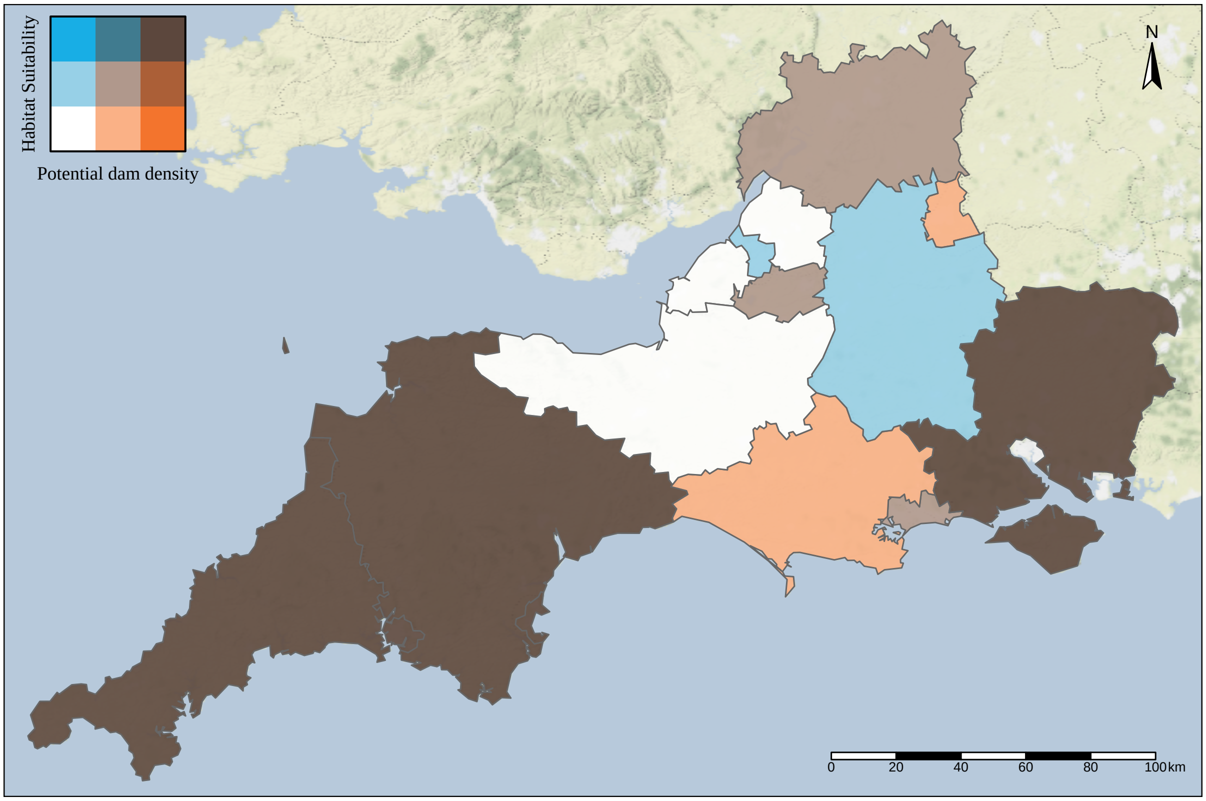

Figure 6: Bivariate map comparing habitat suitability (% preferred Habitat) and potential dam density (The estimated density of dams at population capacity) for SW counties

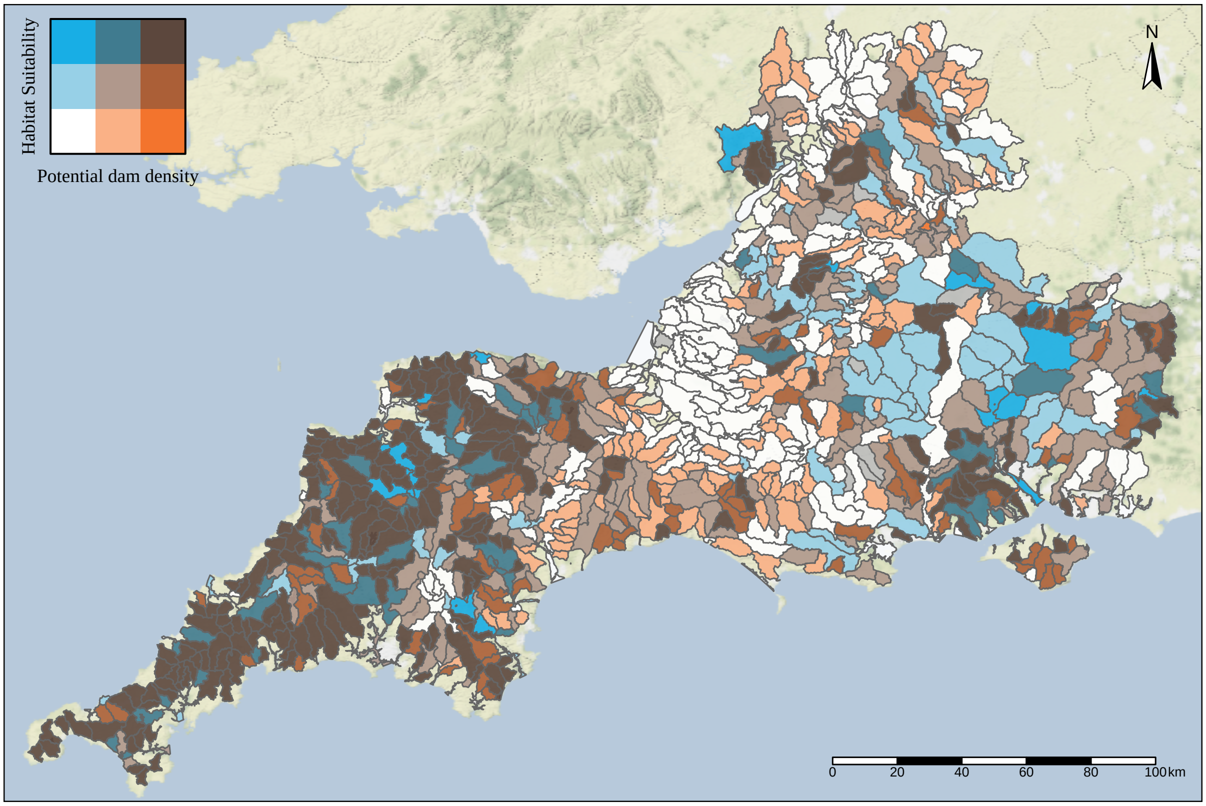

Figure 7: Bivariate map comparing habitat suitability (% preferred Habitat) and potential dam density (The estimated density of dams at population capacity) for EA Water Body areas.

Table 4: Description of variables provided with the county summary polygon file

Variable Name	Variable Full Name	Description
BDC_TOT	Total Beaver Dam Capacity (n dams)	The Beaver dam Capacity of the region (n dams). For areas larger than a single beaver territory, it would not be expected to see a system at (or even close to) dam capacity. For estimating dam numbers at or greater than the catchment scale use "Est_nDam".
BDC_MEAN	Average Beaver Dam Capacity (dams/km), weighted by reach length	The average Beaver Dam Capacity across the region. Reach length is used as a weighting as reach lengths vary.
BDC_STD	Beaver Dam Capacity standard deviation (dams/km), weighted by reach length.	The standard deviation of Beaver Dam Capacity within the region. Provides an understanding of BDC variability. Weighted by reach length.
BDC_P_NONE	Proportion of river network in "None" BDC category (%)	The percentage of the river network, within the area of interest, which has no capacity to support dams.
BDC_P_RARE	Proportion of river network in "Rare" BDC category (%)	The percentage of the river network, within the area of interest, which has the capacity to support 0-1 dams/km.

(continued)

Variable Name	Variable Full Name	Description
BDC_P_OCC	Proportion of river network in "Occasional" BDC category (%)	The percentage of the river network, within the area of interest, which has the capacity to support 1-4 dams/km.
BDC_P_FREQ	Proportion of river network in "Frequent" BDC category (%)	The percentage of the river network, within the area of interest, which has the capacity to support 4-15 dams/km.
BDC_P_PERV	Proportion of river network in "Pervasive" BDC category (%)	The percentage of the river network, within the area of interest, which has the capacity to support 15-30 dams/km.
BDCkm_NONE	Length of river network in "None" BDC category (km)	The length of the river network, within the area of interest, which has no capacity to support dams.
BDCkm_RARE	Length of river network in "Rare" BDC category (km)	The length of the river network, within the area of interest, which has the capacity to support 0-1 dams/km.
BDCkm_OCC	Length of river network in "Occasional" BDC category (km)	The length of the river network, within the area of interest, which has the capacity to support 1-4 dams/km.
BDCkm_FREQ	Length of river network in "Frequent" BDC category (km)	The length of the river network, within the area of interest, which has the capacity to support 4-15 dams/km.
BDCkm_PERV	Length of river network in "Pervasive" BDC category (km)	The length of the river network, within the area of interest, which has the capacity to support 15-30 dams/km.
BFI40_P_UN	Proportion of river network with "unsuitable" beaver forage (%)	Percentage of river network, within the area of interest, where the mean of the upper 50% of BFI raster cell values, within 40m of the bank, is <= 1.
BFI40_P_LO	Proportion of river network with "low suitability" beaver forage (%)	Percentage of river network, within the area of interest, where the mean of the upper 50% of BFI raster cell values, within 40m of the bank, is 1 > 2.
BFI40_P_MO	Proportion of river network with "moderate suitability" beaver forage (%)	Percentage of river network, within the area of interest, where the mean of the upper 50% of BFI raster cell values, within 40m of the bank, is 2 > 3.
BFI40_P_HI	Proportion of river network with "high suitability" beaver forage (%)	Percentage of river network, within the area of interest, where the mean of the upper 50% of BFI raster cell values, within 40m of the bank, is 3 > 4.
BFI40_P_PR	Proportion of river network with "preferred" beaver forage (%)	Percentage of river network, within the area of interest, where the mean of the upper 50% of BFI raster cell values, within 40m of the bank, is 4 > 5.
BFI40km_UN	Length of river network with "unsuitable" beaver forage (km)	Length of river network, within the area of interest, where the mean of the upper 50% of BFI raster cell values, within 40m of the bank, is <=1.
BFI40km_LO	Length of river network with "low suitability" beaver forage (km)	Length of river network, within the area of interest, where the mean of the upper 50% of BFI raster cell values, within 40m of the bank, is 1 > 2.
BFI40km_MO	Length of river network with "moderate suitability" beaver forage (km)	Length of river network, within the area of interest, where the mean of the upper 50% of BFI raster cell values, within 40m of the bank, is 2 > 3.

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Variable Name	Variable Full Name	Description
BFI40km_HI	Length of river network with "high suitability" beaver forage (km)	Length of river network, within the area of interest, where the mean of the upper 50% of BFI raster cell values, within 40m of the bank, is 3 > 4.
BFI40km_PR	Length of river network with "preferred" beaver forage (km)	Length of river network, within the area of interest, where the mean of the upper 50% of BFI raster cell values, within 40m of the bank, is 4 > 5.
Est_nDam	Estimated Number of dams	The estimated number of dams that may be built, assuming that all reaches within the area of interest contain beaver activity.
Est_nDamLC	Estimated Number of dams (Lower 95% Confidence limit)	The lower 95% confidence limit for estimated number of dams that are likely to be built within the area of interest.
Est_nDamUC	Estimated Number of dams (Upper 95% Confidence limit)	The Upper 95% confidence limit for estimated number of dams that are likely to be built within the area of interest.
Est_DamD	Estimated dam density	The estimated dam density (dams/km) within the area of interest, assuming that all reaches contain beaver activity.
Est_DamDLC	Estimated dam density (Lower 95% Confidence limit)	The lower 95% confidence limit for estimated dam density (dams/km) within the area of interest.
Est_DamDUC	Estimated dam density (Upper 95% Confidence limit)	The Upper 95% confidence limit for estimated dam density (dams/km) within the area of interest.
TOT_km	Total length of river network (km)	Sum of all channel lengths within are of interest.

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