A spatially explicit model of beaver river-floodplains: understanding drivers and mapping opportunities for restoration

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Summary

This study describes the first national comprehensive model of beaver dam likelihood and associated floodplain development. The subsequent delineation of areas reflecting overall opportunities and conflict reveal that the reintroduction of *Castor fiber* into Switzerland implies a net benefit from a landscape restoration perspective. Though this is the case measured at the national-scale, we identified concentrated regions of potential land-use conflict where mitigation and management should be focussed. The development of similar models in other contexts, for example, where planned beaver reintroductions are being prepared, could help maximise landscape restoration goals whilst minimising undesirable land-use conflicts which may harm conservation efforts.

KEYWORDS: Beaver, Reintroduction, GLM, Ecosystem Services

1. Introduction

The Eurasian Beaver (Castor fiber) has expanded its range considerably since reintroduction efforts first began in the 1940s and 1950s and the species is now found in more than 30 countries across Europe with more than 1.5 million individuals (Yanuta et al., 2022). Beavers are a highly influential mammalian ecosystem engineer, heavily modifying rivers and floodplains and influencing hydrology, geomorphology, nutrient cycling, and ecology (Larsen et al., 2021; Wohl, 2019). Damming behaviour by beavers can provide important ecosystem services including increased surface and subsurface water storage, increased carbon and nutrient storage, increased aquatic primary production, and increase biodiversity on a reach scale. Given the extent of the impact of damming behaviour on ecosystem services, effective models that can help to anticipate such impacts would allow scientists and practitioners to harness synergies and avoid conflicts in anthropogenic landscapes. We present such a model, delineating suitable locations for beaver damming behaviour and the resulting expected impounding of water based on an extensive dataset on beaver dam locations and riparian environment characteristics for Switzerland. We use the size and location of modelled beaver floodplains to predict areas of potential conflict and opportunities, characterised as a function of land-use and land-cover (conceptualised in Figure 1).

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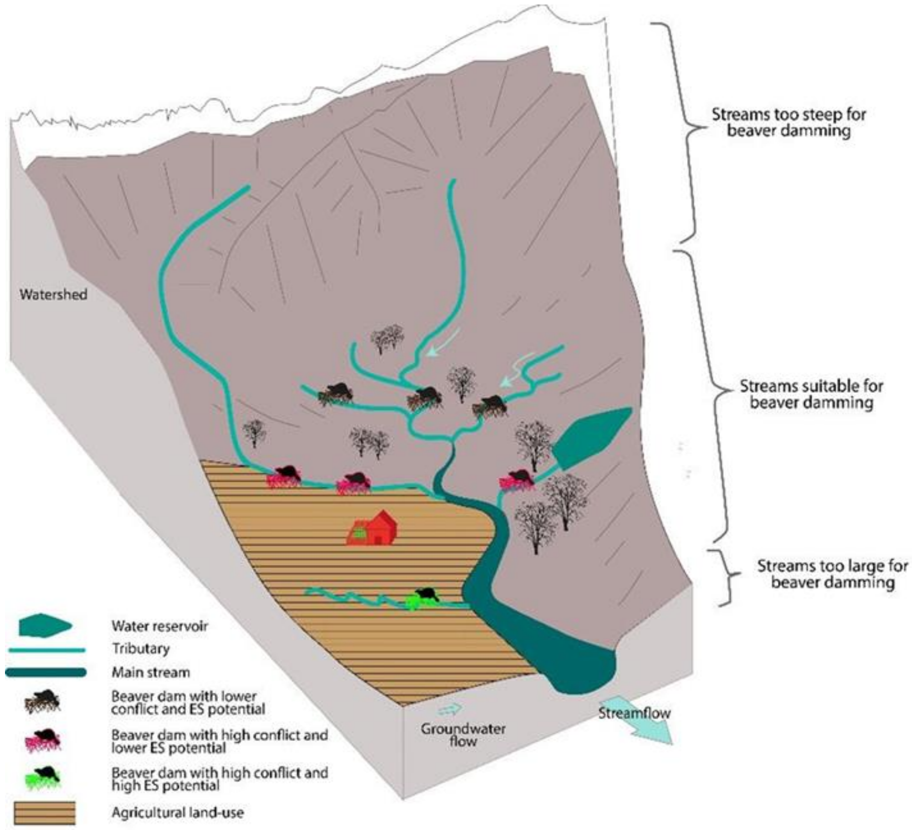

Figure 1. Zonation of beaver impacts at the catchment scale showing areas associated with potential conflict and delivery of ecosystem services (ES).

2. Methods

We used an extensive dataset of beaver dam locations for Switzerland. This dataset consists of 2931 dam locations mapped during surveys of the whole of Switzerland between 1993 and 2022. We created candidate predictor variables using data on river networks and eco-geomorphology for Switzerland from the Swiss Federal Office for the Environment (FOEN, 2023). For all river sections, we calculated channel gradient, terrain slope, channel width, discharge, stream power as well as the proportion of major land-covers (forest, arable, grassland, urban) for a range of buffer widths around stream channels: (100-5000m). River discharge was calculated by first delineating watersheds for each reach in the stream network using pour points and a 25m DEM, executed in the Whitebox package in R (Wu and Brown, 2022). Mean discharge was then estimated by calculating total runoff into each river catchment from monthly precipitation data.

True absence data were not available so we generated pseudo-absence points snapped to each section of the river network that did not intersect with known dam locations. This resulted in approximately 140,000 pseudo-absences. From these, an appropriate final number for modelling was ascertained by running consecutive models and sequentially adding 1,000 pseudo-absence points until the model performance statistic stabilised. We extracted the eco-geomorphological data to the presence and pseudo-absence locations and trained distribution models using i) a general linear model (GLM) and ii) random forest. The GLM was parameterized in base R (R Core Team, 2023) and the random forest model was implemented though the Ranger package (Wright and Ziegler, 2017). To test the relative influence of terrain versus land-cover, we ran terrain-only and land-cover-only models. Accuracy was assessed via a spatially partitioned cross-validation approach using a blocking method that divided the study area into a grid with presence and pseudo-absence points divided into six folds (regions). We used the best performing models and built a final prediction model to divide the entire river network into sections deemed suitable and not suitable, adopting a 0.5 threshold for determining predicted presence/absence of beaver dams. For streams with high dam suitability, we delineated potential floodplain impacts through an objective statistical procedure based on high resolution terrain data (2 m resolution). To estimate potential beaver floodplain extent, we first masked the 2m digital elevation model (DEM) at a distance of 100 m perpendicular to suitable dam locations (the 50 m river sections). This is based on the experience that beaver meadows in Switzerland do not extend more than 50 m away from the main river, and beaver feeding trails are rarely longer than 30 m (Gable et al., 2023). We then identified the lowest point on the river section and raised this by 0.5 metres (chosen according to median dam height). The estimated floodplain extent was then delineated by selecting all cells in the masked DEM below this height. Figure 2 gives an example of the model output for an existing beaver pond complex in Marthalen, Switzerland.

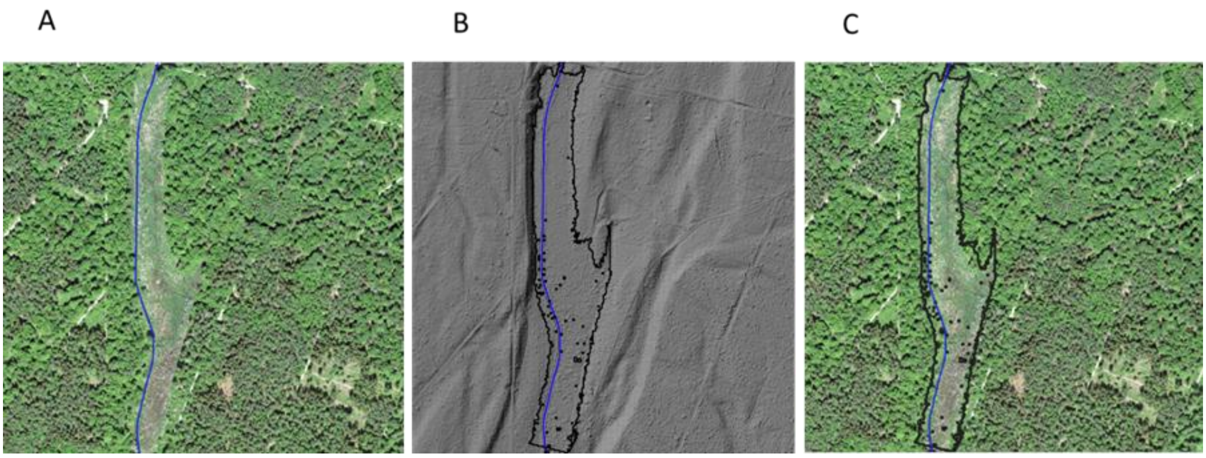

Figure 2 Delineation of floodplain area. A: stream channel, B: delineation of surrounding beaver floodplain (hill-shade image reflecting local topography is shown), C: aerial photo of the same section.

2.2 Identifying the location and extent of positive and negative outcomes related to beaver pond development.

Estimated floodplain areas were assigned values reflecting opportunities and potential conflicts. Opportunities reflect increases in plant, invertebrate and vertebrate abundance and richness as a function of beaver reintroduction (Law et al., 2016 Orazi et al., 2022), increased water quality and storage. Potential conflict arises with proximity to areas of productive land-use, especially settlement areas, transport networks and agriculture. All areas related to these land-uses were assigned negative outcome scores if they were spatially co-incident with the beaver floodplain model. The land-use classes assigned values as follows:

Table 1 Land-use impacts ("+" denotes opportunity; "-" denotes conflict; "0" denotes negligible impact).

Land-use	Impact
Forest	+
Lakes	0
High productivity farmland	-
Low productivity farmland	+
Grasslands/meadows	+
Urban	-
Quarry/mines	-
Rivers	+
Urban Green Spaces	-
Fruit crops	-
Scrub	+
Wetlands	+
Flood protection infrastructure	-
Rail	-
Other urban (developing land, rubbish dumps etc.)	-

Results

The dam distribution modelling revealed that stream geometry attributes exhibited the greatest explanatory power for predicting dam occurrence. The area under curve (AUC) statistic for terrain-only and land-cover-only models was 0.97 and 0.82 respectively. Primary constraints on beaver dam probability were channel gradient, stream power and channel width. Optimal model performance was achieved through the inclusion of channel gradient, mean channel width, stream power, and percentage cover by woodland, urban land-use and grassland within 100 m of the channel. Although the Random Forest model (AUC= 0.99) performed better than the GLM (AUC=0.97) validated against the entire dataset, models were comparable when assessed by spatial cross-block validation. The random forest exhibited over-fitting erroneously predicting damming in very large rivers. Channel gradient was by far the strongest predictor of dam occurrence with high associated dam probability (Figure 3A).

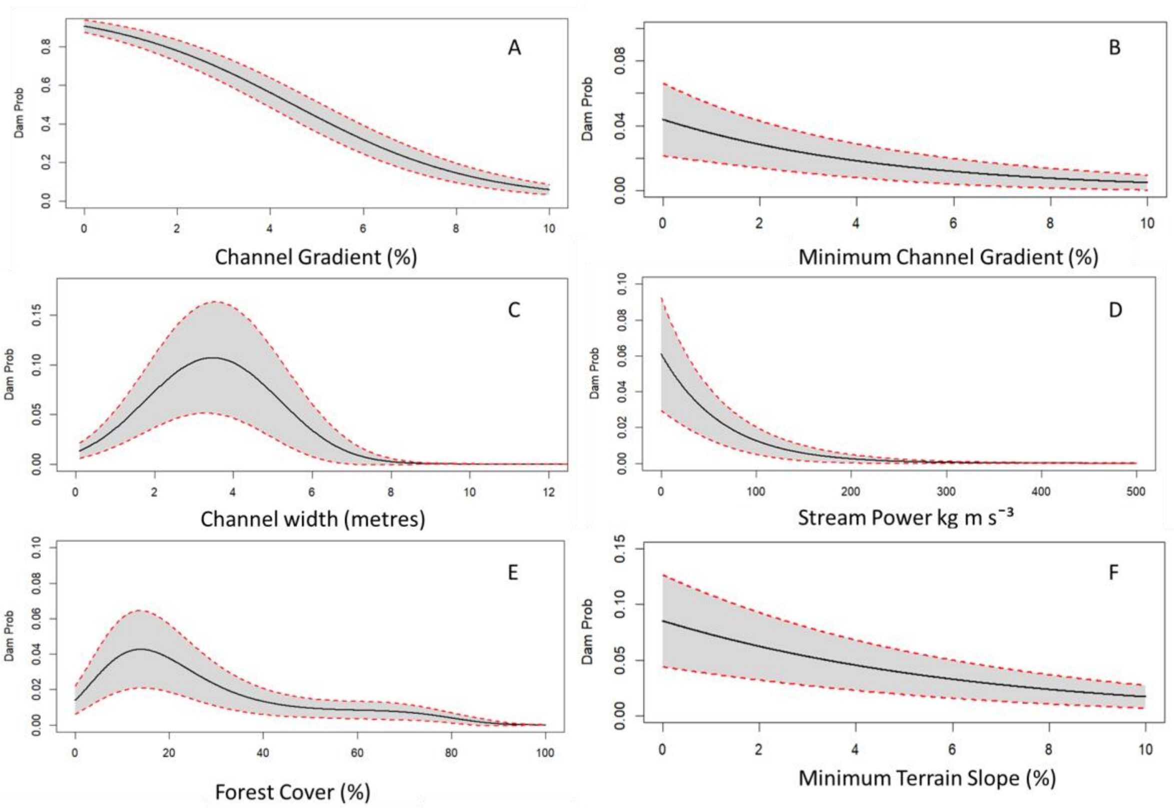

Figure 3 Model response plots. A: Channel Gradient, B: Minimum Channel Gradient, C: Channel Width, D: Stream Power, E: Forest Cover, F: Minimum Terrain Slope Values on the x-axis relate to predictor variables with the contribution to dam probability on the y-axis. Grey zones represent 95% confidence intervals.

Figure 4A shows the distribution of areas associated with net opportunity (area of opportunity > area of conflict) versus net conflict for Switzerland divided into 1km² squares.

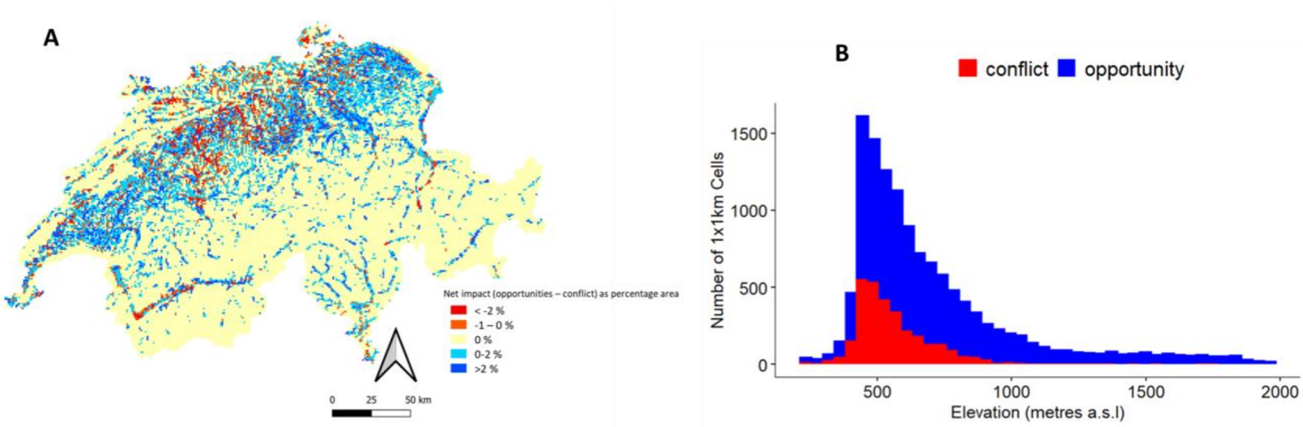

Figure 4. A: beaver floodplain outcomes. Negative values denote cells with greater conflict than opportunity and positive values denote cells with greater opportunity than conflict. Numerical values represent this net impact as a percentage of the cell (e.g. if 2% of the cell represents areas of opportunity and 1 % represent conflict, the net (positive) impact is 1%). **4B**: distribution of areas of high and low opportunities and conflicts based on modelled floodplains within 1 km grids.

4. Discussion

This study describes the first national comprehensive model of beaver dam suitability and associated floodplain development. The subsequent delineation of areas reflecting overall opportunities and conflict revealed that the reintroduction of *Castor fiber* into Switzerland implies a net benefit from a landscape restoration perspective. Though this is the case measured at the national-scale, we identified concentrated regions of potential land-use conflict where mitigation and management should be focussed. The development of similar models in other contexts, for example, where planned beaver reintroductions are being prepared, could help maximise landscape restoration goals whilst minimising undesirable land-use conflicts which may harm conservation efforts.

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