1 Strategic planning for restoration and conservation

River restoration projects need to meet many ecological and societal needs. Strategic planning can help to prioritize project goals at both the cantonal and the local scale. This chapter focuses on methods for restoration planning based on models and genetic analyses of various organism groups, which make it possible to reconstruct past and project future colonization processes along rivers. The planning tools discussed here help to determine if currently protected areas are sufficient for the long-term conservation of riparian species.

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1.1 Challenges for conservation and restoration planning

River restoration planning is challenging, as the development of terrestrial and aquatic habitats, as well as the colonization of these habitats by species, depends on connectivity along rivers (Fig. 1). This has been acknowledged in the Swiss Biodiversity Strategy, which emphasizes an exchange of individuals and genes (FOEN 2017b) via a functioning ecological infrastructure that forms a network of sites. Protected areas, such as Emerald areas or Biotopes of National Importance, as well as sites with limited human activity, such as game reserves, are important nodes in these networks. These nodes can provide various types of habitat for species, e.g. sanctuaries enabling short-term persistence or providing temporary shelter, or refugia supporting long-term survival despite changing environmental conditions (see Chapter 5; Rachelly *et al.* 2023).

To understand such networks of habitats and the processes which help to maintain the links between nodes in these networks, it is necessary to have spatially explicit data on current and predicted species occurrences and habitat distributions, as well as species dispersal abilities. While data defining the broad ecological niche is available for many species at the national scale, regional information on the presence of target species can vary considerably in availability and quality. Extensive field studies mapping all presence points of a species in Switzerland are not feasible. Nonetheless, to ensure effective planning, spatially explicit data at a large scale is necessary.

1.2 Why use models for restoration planning?

Ecological models make it possible to fill information gaps regarding the distribution of species. Based on existing species records, this approach helps planners to understand the correlation between ecological factors and species presence,

Figure 1

Diverse riparian habitat along the Moesa river in the Mesolcina valley (GR). The connectivity of open gravel banks between densely vegetated areas along rivers can be investigated using field studies, genetic analyses and simulations of dispersal between habitats.

Photo: S. Fink

reproduction and dispersal (see Box 2 on ecological models and Chapter 2; van Rooijen *et al.* 2023), and it can be applied to project species distributions in space and time. This type of ecological model can also be used to assess the most important factors determining suitable habitats for a species, and can enable projections to other areas based on their environmental conditions, without data on the actual presence of the species in those areas. The applied statistical procedures assume that core processes that define the distribution of a species depend on ecological conditions, including both biotic and abiotic factors.

Box 2: Ecological models

Ecological models are based on target species information, which can be obtained from the Swiss Information Centre for Species (*www.infospecies.ch*) or from field studies (Fig. 2). For target species which have been investigated in a Red List project, the detailed presence and absence data for various sites in Switzerland provides a solid basis for modelling.

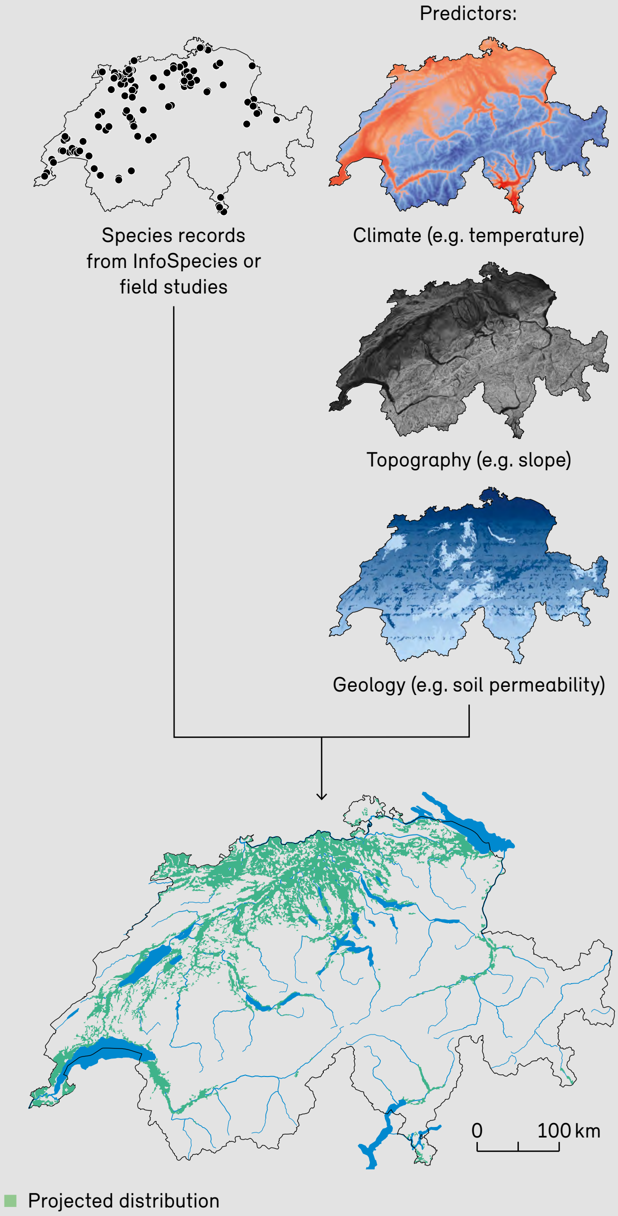
Every model needs a suitable set of predictors (environmental variables used to predict an event, situation or other variables). In the examples presented in this chapter, climatic, geological and topographic predictor data have been chosen to represent the species niche.

For plants, average temperature during the growing season and terrain slope (a proxy for incoming radiation) might be important factors, while for fungi, average annual temperature and precipitation might be the main factors to consider. Georeferenced environmental data is available at the national scale.

Modelling algorithms are available as open source packages in the free software environment R (*https://cran.r-project.org*). Many books on habitat modelling are available (e.g. Guisan *et al.* 2017). Habitat suitability maps can be transformed by applying a threshold to predicted species distribution maps.

Figure 2

Ecological models link species records (top left) and predictor layers (top right) in a statistical approach to map the projected distribution of a species (below).



Source: WSL

Figure 3

(a) Morchella semilibera was identified using a method in which fungi with a riverine affinity are detected as typical riparian species. (b) Based on species records (black dots), species presence (green areas) was projected in currently protected areas (areas outlined in red), but more frequently in currently unprotected areas along the Aare river in the canton of Bern.

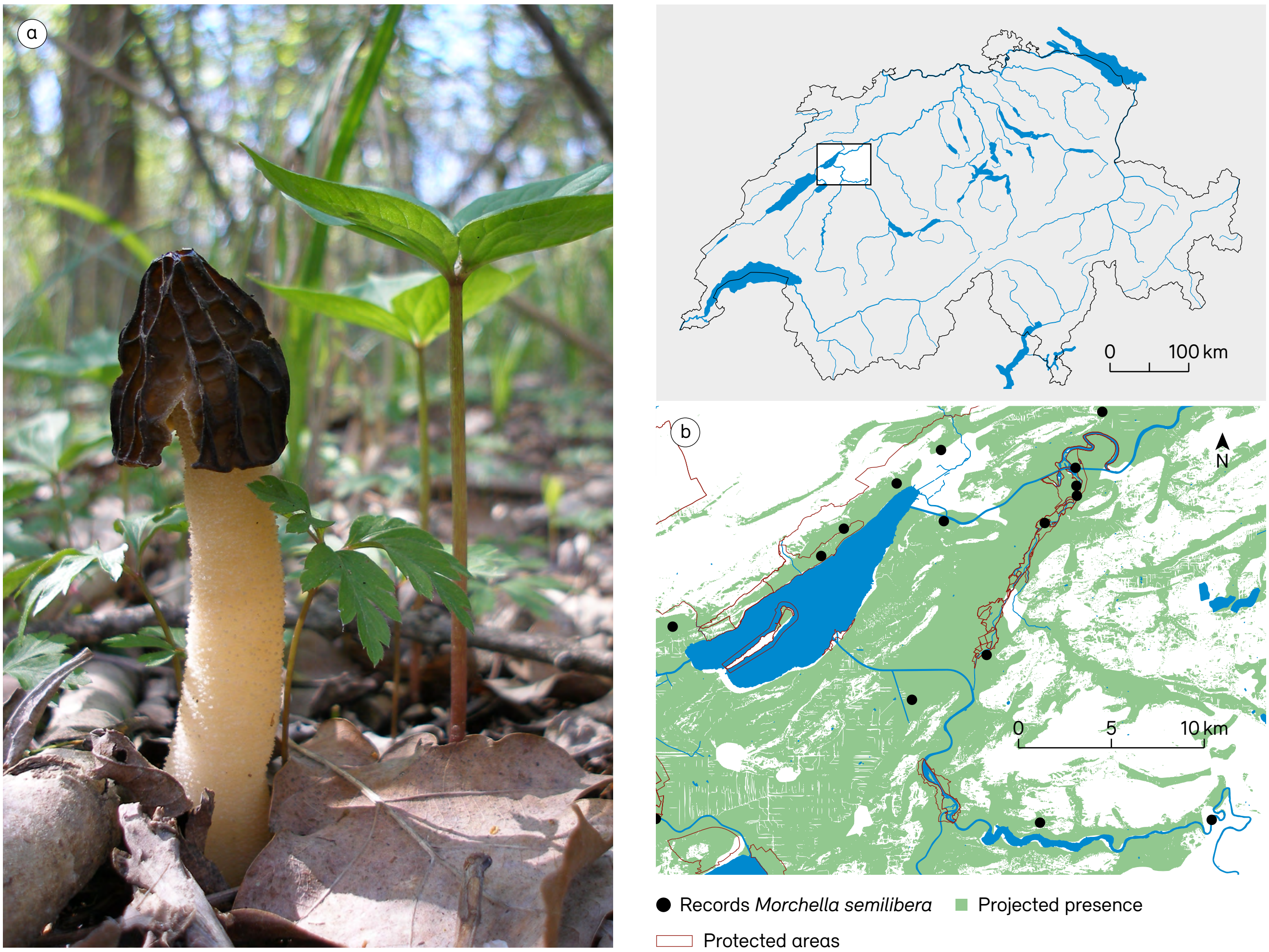


Photo: A. Gross, Figures: WSL

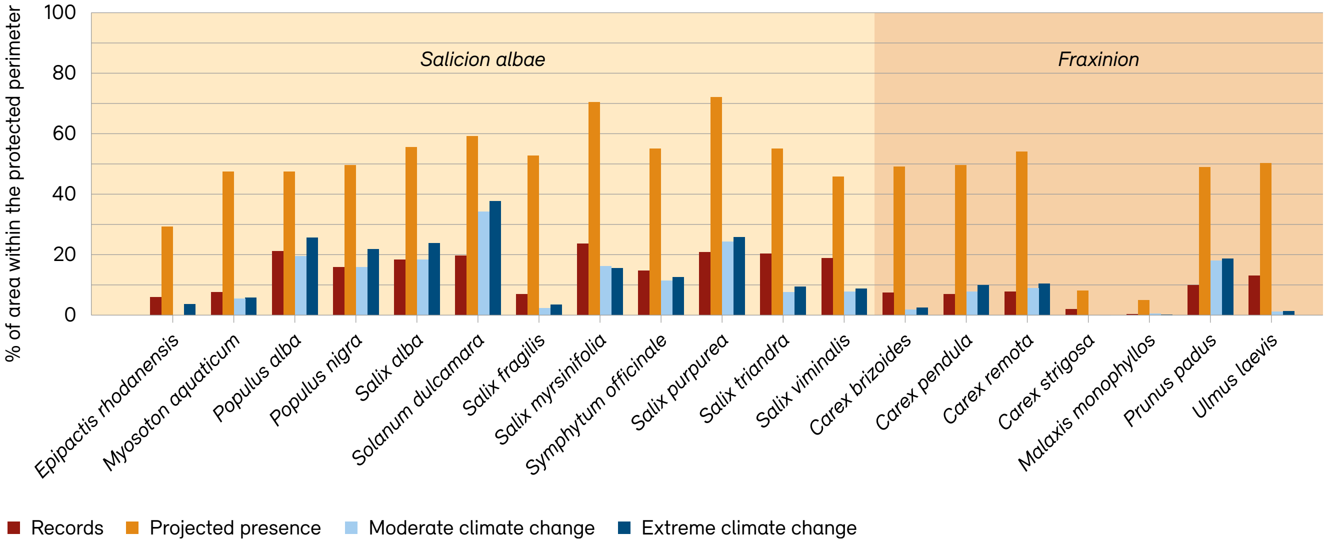
1.3 Application of ecological modelling in planning projects: example using fungi

Restoration projects mainly focus on a few groups of species of flora and fauna, and rarely consider other organisms such as fungi. Fungi occur in many habitats within the mosaic of floodplains; they play important roles in ecosystem processes, such as the decomposition of organic matter, and they can, as mycorrhizae, form a symbiosis with plants. Despite these important functions, fungi are underrepresented in planning guidelines. Fungi are important contributors to biodiversity in floodplain forests and other ecosystems, but they are difficult to track due to the limited seasonal visibility of their fruiting bodies. Data on fungal species presence is thus scarce in many regions of interest. Ecological models based on species records collected across Switzerland by a large community of volunteer mycologists can help us to overcome these limitations.

A list of typical riparian fungi occurring in Switzerland does not exist. In a recent study, spatial information from individual records was therefore used to identify species with a large

Figure 4

Floodplain forest species of the Salicion albae and Fraxinion plant communities have all been recorded within Floodplains of National Importance (red). The area within the floodplain perimeter which is projected to be suitable under current conditions is generally large (orange). Under both moderate (light blue) and extreme (dark blue) climate change scenarios, considerably fewer cells are forecasted for species' presence in the future (2084–2093).



Source: WSL

number of occurrences close to rivers (Fink *et al.* 2021). The resulting list of abundant species with high riparian affinity was evaluated with the help of data from the literature on their ecology, e.g. by identifying host tree species that are also typical of riparian habitats or soil substrates (e.g. sand) that are necessary for the species' growth. One of the typical species identified was *Morchella semilibera*, a saprobic species frequently found on turf or humus and associated with riparian plants. An ecological model was then used to project suitable habitats for this species along rivers (Fig. 3).

A network of connected habitats for riparian species should include existing areas with high biodiversity. The role of Swiss habitats that are currently protected (e.g. Floodplains of National Importance, Emerald habitats) was assessed by comparing the amount of suitable habitat within the protected perimeter to the amount of suitable habitat outside the protected areas. The models projected considerably more suitable habitat for fungi in unprotected compared with currently protected areas, which underlines the importance of including currently unprotected areas in conservation plans for riparian fungi (Fig. 3). The potential role of these candidate areas for species conservation should also be considered for other organisms within the same habitat (see the guild system, FOEN 2021a). Additionally, considering these areas could help to compensate for competing interests between species with opposing needs within already protected areas (Jöhl *et al.* 2020).

1.4 Restoration planning: temporal and spatial scales

Dynamic riparian areas frequently undergo changes, and populations of species may become extinct locally as a result of erosion (e.g. pioneer vegetation), flooding (e.g. macrozoobenthos), or habitat drying (e.g. small ponds along rivers for amphibians). Given their adaptation to dynamic habitats, specialized species can also benefit from dynamics such as repeated floods, which help them to outcompete less-adapted species. Hydrodynamic events will likely become more intense as climate change progresses, with more extreme floods and longer subsequent dry periods (Pistocchi and Castellarin 2012; FOEN 2021b). This is an important aspect to consider for the conservation planning of riparian habitats.

Figure 5

*(a) The lichen Coniocarpon cinnabarinum and (b) a comparison of the number of records of this species on individual trees in human-impacted (blue) and near-natural (green) floodplain forests in two habitat plots (A, B) along the Töss river (ZH) in 2018. The difference between the natural and human-impacted sites was significant in both plots (** p<0.01, *** p<0.001).*

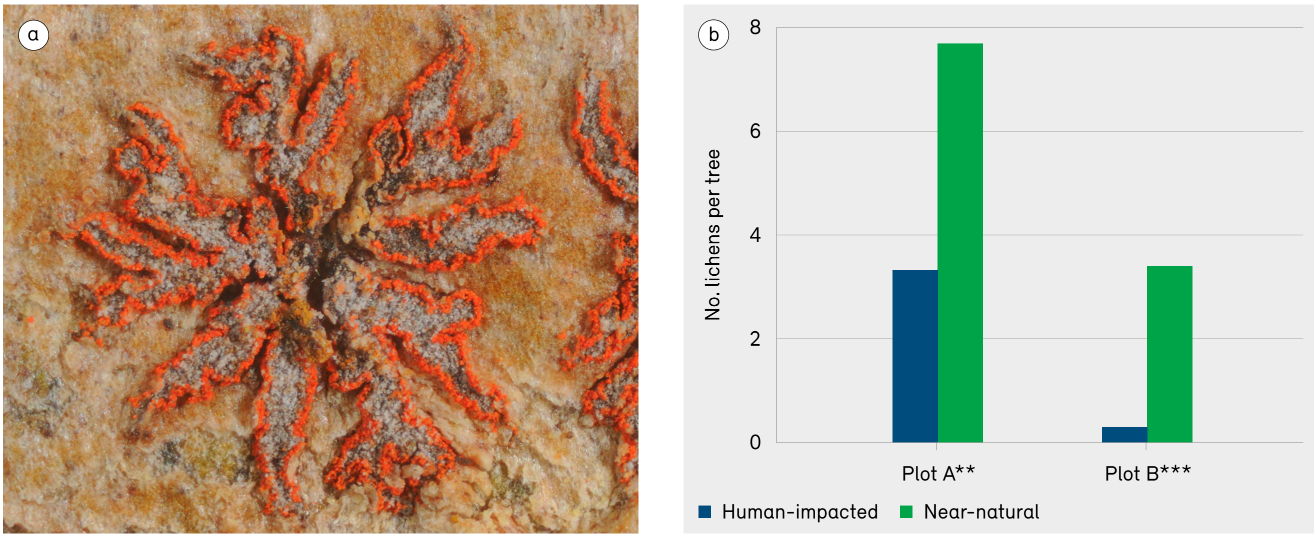


Figure adapted from Streit (2018), Photo: C. Scheidegger

The modelling approach enables us to project the fate of riparian systems under various climate scenarios. Although the results are subject to many uncertainties, they help us to visualize the extent of changes in available habitat or projected species distributions based on the magnitude of environmental fluctuations, e.g. in precipitation or temperature. This is pertinent information, as temperature changes affect multiple habitats and species. For example, terrestrial plant species are impacted by warmer, drier conditions during their growing season and aquatic fauna face reduced available habitat area with increasing water temperature.

Ecological model projections to future climate conditions that include simulations of the spread of species from current sites to currently unoccupied but suitable habitats support investigations of spatial and temporal networks. This has been demonstrated for floodplain forest plants, which form important communities along rivers: plants of the *Salicion albae* (softwood) vegetation type stabilize gravel banks against erosion, and *Fraxinion* (hardwood) forests are important for flood retention. These habitats harbour many threatened species, but are frequently at risk of fragmentation due to the limited space in riverscapes. The loss of habitat and species is predicted to accelerate under climate change, with species projected to find less suitable habitat area even within currently protected Floodplains of National Importance (Fig. 4). Therefore, management strategies to prevent accelerated loss (e.g. enhancement of water and sediment availability) must be considered now to ensure the survival of these plant communities in the future. Additionally, restoration projects should ensure sufficient space for floodplain forest establishment.

1.5 Habitat structure and shape

While models can help us to decide where conservation or restoration should be prioritized, additional information on the structure and shape of natural or near-natural habitats is necessary to maximize restoration and conservation success. Natural or restored floodplain forests provide habitat for highly specialized organisms such as lichens. The species aggregate *Coniocarpon cinnabarinum*, including the closely related *C. fallax*, grows on young ash trees (*Fraxinus excelsior*) and occurs mainly within floodplains. A study of the distribution of *C. cinnabarinum* along the

Figure 6

The genetic structure of Myricaria germanica populations along the Inn river and its tributaries suggests a connected habitat network. The proportions of genetic diversity assigned to three main clusters (orange, red, blue) are shown for each population. The diversity of two new populations (circles with a dashed outline) along the relocated Flaz tributary (brown line) is high. The assignment of plants in these two populations to the various clusters indicates the occurrence of water-mediated long-distance dispersal of seeds or plant parts downstream, as well as short-distance dispersal via wind or pollen.

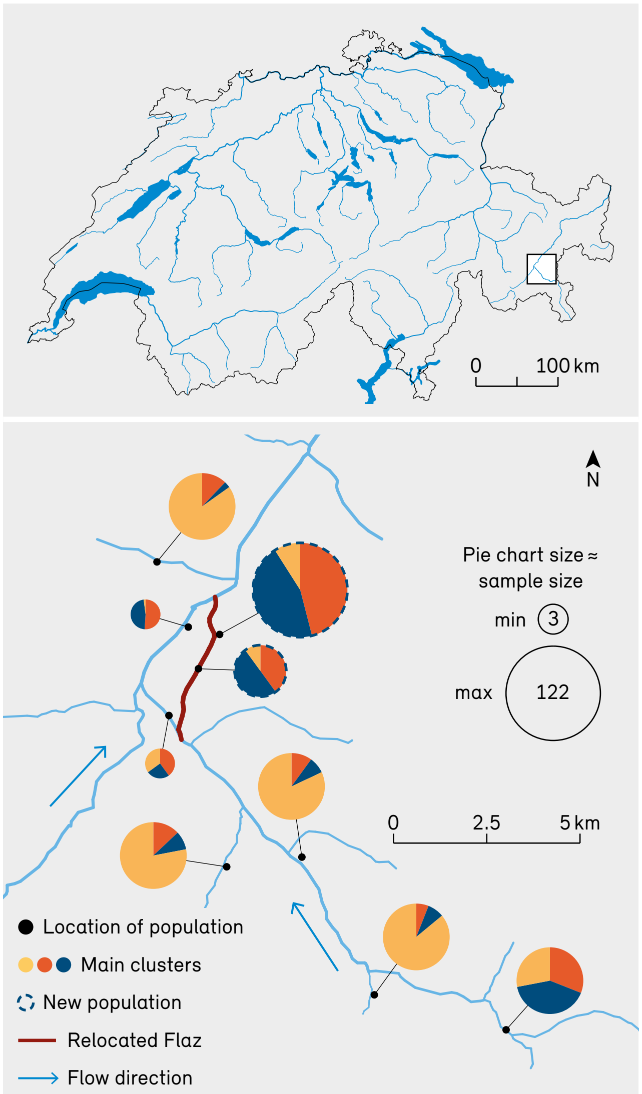


Figure adapted from Wöllner *et al.* (2021)

Töss river (ZH) showed that dynamic floodplain forests harbour more individuals than non-natural forests (Fig. 5; Streit 2018). For the presence of the *Coniocarpon* aggregate, the rare flooding of the floodplain forest is important for nutrient (see also Chapter 6; Conde *et al.* 2023) and light provision within the forest, as it causes the die-back of less-adapted understorey plants.

A study on lichens occurring on alder trees in the Albula catchment (GR) had the aim of identifying whether the shape of a grey alder floodplain forest influences lichen species diversity. For this purpose, floodplain patches about 60 m in both length and width were compared with hedge-shaped floodplains with lengths of up to 200 m but widths of only 10–20 m (Breitenmoser 2014). The mean number of lichen species per tree in the two floodplain types indicated that diversity is higher in floodplain patches, as they provide better connectivity in all directions between habitat trees and a better microclimate with higher humidity. This information is important for restoration planning, as it suggests that higher lichen diversity can be achieved in grey alder floodplains forests with more patch- than hedge-shaped habitats.

These examples demonstrate that not only habitat availability but also habitat shape is important to consider in restoration planning. This information on shape parameters, as well as on the structure within habitats (e.g. old or young trees, understorey presence or absence; for information on the importance of habitat structure for other species see Chapter 8; Takatsu *et al.* 2023), can be implemented in models, as done by Dymytrova *et al.* (2016) for lichens using information on forest stands.

1.6 Connectivity is crucial for successful restoration

The currently available riparian habitats are generally critically small, and connectivity between habitats therefore has to be ensured for species to spread among habitat patches. For sessile plants or species with a limited dispersal ability, such as wingless beetles, connectivity between habitats can only be maintained if the habitats are either spatially close or accessible by rare long-distance dispersal, e.g. by birds or water. Within a network of habitats along rivers, information on both habitat availability for and dispersal distances of target species with limited mobility is crucial for conservation efforts.

1.7 The use of genetic information to assess connectivity

Genetic analyses help us to indirectly assess the connectivity of populations of riparian species and especially immobile plants, as connected populations are genetically more similar than those that are not linked. Population genetics is also useful for understanding target species when dispersal vectors, such as water or birds, are difficult to track. Analysis of the genetic structure of populations within a network along rivers involves the assessment of the overall genetic diversity and the differentiation among populations. Such an analysis considers vegetative dispersal (when plant parts re-root in a new habitat), seed dispersal, and the contribution of pollen-mediated gene flow (e.g. by insects, which transport pollen to flowers on another plant individual).

Genetic analyses of populations of the German tamarisk (*Myricaria germanica*), a riparian shrub species growing on gravel banks and representative of pioneer vegetation, revealed a network of connected populations along the Inn river (GR) and its tributaries Flaz, Ova da Bernina and Ova da Morteratsch (Fig. 6; Wöllner *et al.* 2021). Even the relocation of the Flaz tributary near Samedan to the other side of the valley did not disrupt the connectivity of German tamarisk populations: the population that established along the relocated tributary contributed to the local genetic diversity.

Data on genetic relatedness between populations helps us to identify maximum possible dispersal distances along a river network. Examples of relocated rivers and information on dispersal events responsible for the colonization of the new habitat are especially informative. This data can be used in simulation studies to model connectivity, also in other river networks or habitats.

1.8 Riverscape restoration planning: aspects to consider when using models

The complexity of river restorations can be reduced in models to understand the major processes expected to influence the success of measures. By considering different scenarios, the impact of the changing climate, as well as limited dispersal, can be simulated. While most modelling frameworks for decision-making use a single target species, combinations of results on various species can help us to predict which habitats are most suitable for entire communities.

As ecological modelling is a statistical approach, some precautions have to be taken. Data needs to be verified before use, and model evaluations using statistical procedures are necessary. The ecological interpretation of modelling results requires expert knowledge because overestimations of habitat suitability are frequent, as not all factors can be considered in a model (e.g. microhabitats are not defined in this approach).

Ecological models have several advantages over e.g. single-site field studies. By understanding core processes related to habitats for target species, they make it possible to focus on regional instead of local planning, based on larger-scale projections. Data on many organisms can be combined and factors influencing the establishment of communities can be identified. Projections based on future scenarios can help us to adjust planning so that specialized species survive while less-adapted and invasive species remain at low densities, even under changing climate conditions and land use. Models therefore support strategic regional planning for successful species conservation and habitat restoration.

Box 3: In practice – Maximization of the potential for biotope and species protection

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Restoration efforts are generally beneficial to biodiversity. However, the degree to which the improvement potential is realized depends to a large extent on the baseline survey and the definition of goals concerning biotope and species protection. It is crucial that these aspects are addressed at an early stage of the project, and that the planning of measures involving solutions to conflicting goals is conducted as a close collaboration between the project managers and the ecological expert.

Restoration projects are key elements of any ecological network. Riverscapes are often biodiversity hotspots and have important linking functions. In order to fulfil this critical function, it is essential that an ecological expert establishes the overarching regional and local objectives for the protection of biotopes and species at the beginning of the planning phase of a restoration project. This work results in a list of target species and target habitats (Table 1) and ideally also a distribution map indicating priority habitats and species that are closely linked to the project area. Additionally, conflicting goals within the planned measures for biotope and species protection should be specified and recommendations for prioritizations should be included.

In a next step, the project managers and the ecological expert work together in the early stages of the project (Preparation and Briefing or Concept Design) to evaluate the potential for improvement within the project perimeter and to find solutions to possible conflicts concerning objectives in biotope and species protection. In the Concept Design and Planning Application stages, the planning of restoration measures should be aligned as closely as possible with the target habitats and target species, including their connectivity requirements, and any conflicts between objectives should be resolved. Elements that are important in facilitating such a well-developed planning process are the specification of the objectives of biotope and species protection in the project planning documents and the development of concepts for visitor guidance and site maintenance, as well as a monitoring plan.

Table 1

Excerpt from a list of target species and target habitats for planning a restoration project. The habitat information is used by hydraulic engineers and ecologists for the collaborative planning of hydrological requirements and of morphological and ecological structures within the restoration site perimeter. Key additional information for implementation is listed in the column 'Measures'. Likewise, the target percentage of area of each habitat type within the project perimeter is an important tool for practitioners.

Target species			**Target habitat**		
English name	**Latin name**	**Number***	**Habitat**	**Measures**	**Target percentage of area within project perimeter**
Summer water starwort Eurasian water shrew	*Callitriche cophocarpa* *Neomys fodiens*	1.2.2	Tributary/backwater with weak flow	· Hydrological dynamics must exist	20%
Common sandpiper Little ringed plover	*Actitis hypoleucos* *Charadrius dubius*	3.2.1.0	Alluviums with gravel and no vegetation, no flooding in summer	· Hydrological dynamics must exist · Protection of species from disturbance by humans and dogs during breeding season	10%
Lesser centaury Common sandpiper Little ringed plover	*Centaurium pulchellum* *Actitis hypoleucos* *Charadrius dubius*	3.2.1.1	Alluviums with silt/fine material and pioneer vegetation	· Hydrological dynamics must exist · Protection of species from disturbance by humans and dogs during breeding season	20%
Eurasian water shrew Alpine long-eared bat	*Neomys fodiens* *Plecotus macrobullaris*	6.1.3	Dynamic grey alder floodplain forest	· Periodically high water levels required · Structurally complex forests used as hunting areas, standing dead wood	30%

*compare to Delarze and Gonseth (2015)