Specialised Master's Program in Environmental Sciences

Spatiotemporal dynamics of a riparian plant along three floodplains in the Swiss Alps

Master thesis

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Cover: “Rhäzünser Aue” with *Myricaria germanica* plants. Hinterrhein (2017). Andrea Wiedmer.

Abstract

Floodplains include mosaics of different habitats and host many plant and animal species. One species which grows in this habitat is the riparian shrub *Myricaria germanica* (German Tamarisk), which is dependent on highly dynamic habitats. However, human intervention in river systems has led to alternation of floodplain dynamics, often causing them to become much more stabilised than they are naturally, which lead to a decline of many riparian species, including *M. germanica*.

According to the concept of "Shifting mosaic steady state" habitat composition and abundance of habitat types in natural floodplains stay stable over ecological periods. Therefore, this concept can be used to investigate the functionality of floodplains.

In this study, habitat composition dynamics of three floodplains in the Alpine Rhine catchment (CH) were investigated over 41 years and analysed together with distribution maps of *M. germanica*. Comparison of habitat composition maps based on six aerial photographs reveals large fluctuation in habitat type abundance. There is a trend towards late successional vegetation stages in all study areas. Disconnection of gravel banks, due to lowering of the river bed, led to vegetation succession. Gravel mining, dammed discharge and bank stabilisation has likely directed this change. These results show that the study areas are not in a shifting mosaic steady state, and the observed floodplain dynamics are the reason why *M. germanica* populations fluctuate. Two populations (Cauma and Zizers-Mastrils) were smaller in 2017 compared to a survey from 1974. In addition, all three study areas experienced erosion at the edges. The positive population development of the third floodplain (Rhäzüns) can be attributed to the complex floodplain structure, length and width.

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Content

1 Introduction

Floodplains, with their high level of spatiotemporal heterogeneity, belong to the most species-rich ecosystems known (Ward et al. 1999). Many floodplain species occur only at high abundance in riparian areas (Knopf 1985; Soderquist & Mac Nally 2000). The ecological integrity of floodplains is maintained by dynamic interactions between water, sediment, aquatic–terrestrial landforms and biotic elements, which control the functional processes and biodiversity patterns within the riparian zone (Steiger et al. 2005).

Different studies (Arscott et al. 2002; Van Der Nat et al. 2003; Whited et al. 2007; Zanoni et al. 2008) have shown, that the coarse composition (number of habitat types) and abundance (the relative proportion of different habitat types to total floodplain area) of habitat elements in natural floodplains remain relatively constant over ecological periods. This fundamental process attribute of unregulated river ecosystems (Stanford et al. 2005) is described as "Shifting mosaic steady state" (Bormann & Likens 1979; Ward et al. 2002; Hohensinner et al. 2005). Doering et al. (2012) suggested this concept as potential indicator for detecting landscape transformation and human impacts on floodplain ecosystems.

In the last centuries, natural river dynamics and morphology have been greatly modified by channelisation, gravel mining and hydropower production, which led to degradation, loss and fragmentation of natural floodplain habitats (Tockner & Stanford 2002). In Switzerland, about a quarter of the rivers are in poor ecomorphological condition (Swiss Geoportal 2016). Therefore, there is an urgent need for improving the quality of river habitats, adjusting flood control and bed-load balance. For the investigation of quality of riparian zones and hydrogeomorphological functionality of rivers, pioneer community species can be used as representative indicators (Dufour et al. 2007).

As a characteristic shrub species of riparian habitats, *Myricaria germanica* (L.) Desv. (German Tamarisk) is a good model species for investigating the dynamics of riparian habitats (Ellenberg & Leuschner 2010). The species grows on gravel banks along rivers and, due to its low competitiveness, in late successional stages it is dependent on an intermediate flood frequency (Alp et al. 2011). This riparian species is threatened in many parts of Europe (Korneck et al. 1996; Rossi et al. 2013; Bornand et al. 2016). Over the last 150 years, the species experienced a large population reduction (Endress 1975) due to human exploitation and habitat degradation. This lead to a fragmentation of *M. germanica* within the entire Alpine region. The species is often isolated and concentrated at high-altitudes especially along small alpine rivers (Kudrnovsky & Höbinger 2015).

Myricaria germanica can migrate bidirectionally via water, wind and/or animals (Werth & Scheidegger 2014) but wind-mediated dispersal is limited, because most of the seeds fall next to the mother shrub (Fink et al. 2017). The species shows no continuous population within a river, populations are subdivided. In the Rhine catchment, *M. germanica* persists as a metapopulation (Werth & Scheidegger

2014). German Tamarisk fulfils an important ecosystem function as a gravel bank stabiliser because it has a significantly increased belowground biomass compared to other species which leads to a strong anchoring in the substrate (Lavaine et al. 2015).

So far, no study has investigated the spatiotemporal dynamics of a riparian plant within an isolated floodplain habitat; therefore, the aim of this study is to contribute knowledge about the interaction between floodplain dynamics and occurrence of *M. germanica*. This research project complements the knowledge about the population dynamics at local scale within riparian zones and about the condition of floodplains of national importance. In addition, this investigation is of great importance for tracking population dynamics of a riparian shrub species over a large time scale. Planned rehabilitation of hydro-power stations may lead to changes in floodplain dynamics; therefore, this study is a valuable situation analysis, which can be consulted after restoration of discharge and sediment transport to detect changes.

The investigation was conducted at three floodplains in the Alpine Rhine catchment in the canton of Grisons. Two of them belong to the floodplains of national importance: "Cauma" at 'Vorderrhein' and "Rhäzünser Rheinauen" at 'Hinterrhein'. The third one, "Rheinauen Zizers-Mastrils" at Alpine Rhine, is a potential candidate for the inventory. The historical occurrence of German Tamarisk is known from 1974 and 2007 for Rhäzüns and Zizers-Mastrils, and for Cauma from 1974. The two populations along the Alpine Rhine and 'Hinterrhein' belong to few remaining large populations in Switzerland.

This study assesses habitat dynamics and directional changes of the three floodplains. Although, the water can flow naturally within the floodplains, the discharge and bed-load balance are changed, therefore my hypothesis for this study is that the floodplains are not in a 'shifting habitat mosaic steady state'. In addition, this study evaluated population dynamics of *M. germanica* over 43 years. Due to the isolation of the floodplains and restrictions in habitat area, I hypothesised that *M. germanica* population size and number of colonised sites within the study areas declined.

Change in abundance of habitat types and floodplain dynamics were investigated in a spatiotemporal analysis using classified aerial photos from 1973 to 2014 and discharge measurements. Data about the occurrence from Endress (1975), Kolly (2007) and field data from 2017 were compared and analysed together with the classified aerial photos.

This study is part of the project "River Habitat – sediment dynamic and connectivity" within the research focuses "Applied, practice-oriented research in the field of hydraulic engineering and ecology", a project in collaboration between the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), EAWAG aquatic research, Swiss Federal Institute of Technology in Zurich (ETH) and Swiss Federal Institute of Technology in Lausanne (EPFL).

2 Method

2.1 Study areas

In this study, the dynamics of three natural to semi natural floodplains were investigated. The three river sections were chosen based on the good availability of data about *Myricaria germanica* occurrence and because of their extended occurrence at these floodplains compared to most other sites in Switzerland. All three study areas have similar environmental factors, which allow to compare the situation of *M. germanica* between sites with different sizes and river morphology.

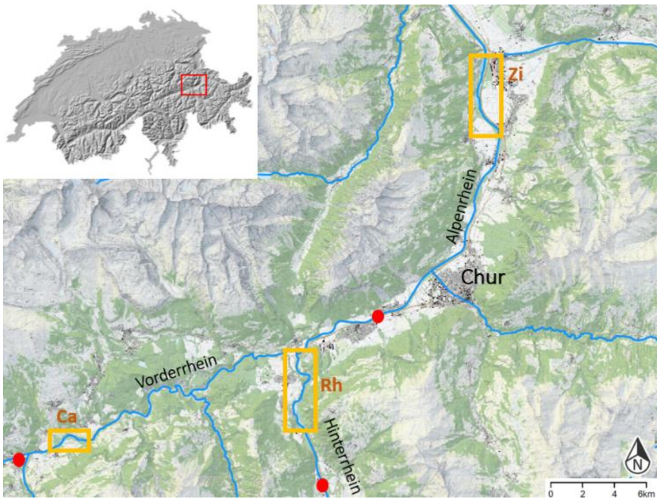
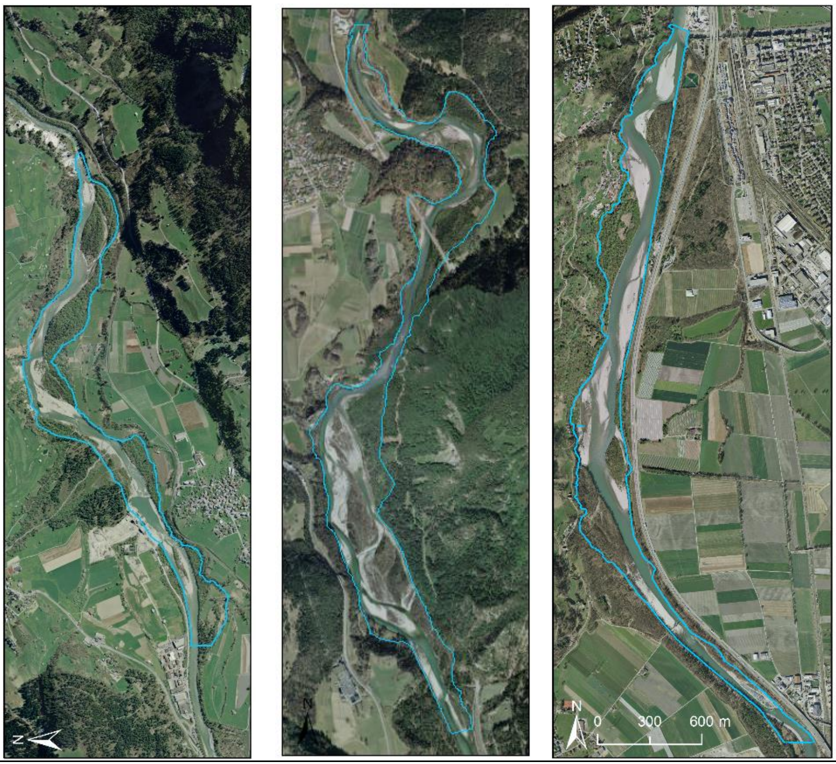


Figure 1. *Overview map of the three study areas. The orange rectangles mark the three river sections and the red dots indicate where the closest discharge measurement stations are located. Ca = Cauma; Rh = Rhäzüns; Zi = Zizers-Mastrils. Source: Bodies of water on the 1:2,000,000 survey map (FOEN 2007); swissTLM-Map (swisstopo 2016); swissALTI3D © 2017 swisstopo (5704000000).*

The floodplains are situated in the sediment transfer zone of the Alpine Rhine catchment in the Alps of canton Graubünden (Figure 1). They are between 3.3 - 4.9 km long, up to 230 – 350 m wide and braided or have multiple channels with longitudinal, transverse and point bars with eroding banks. The floodplains are up- and downstream artificially restricted due to river regulations with levees. They show a deficit of sediment caused by dams, retention basin and sediment mining but their ecomorphology is less affected and hence still semi-natural (Table 1). Discharges of the rivers are influenced by dams upstream of 'Hinterrhein' and 'Vorderrhein'. An investigation of the mean annual maximum discharge before and after the construction of large reservoirs showed a reduction by 20 to 40 % discharge (Hunziker, Zarn & Partner AG 2014). Upstream dams led to a discharge shift from summer to winter and flood events get damped (Hunziker, Zarn & Partner AG 2014). The natural flow regime is "glacial nival" and "alpine nival" for all three sites (Swiss Geoportal 2016) with highest discharge during snow and glacier melt in spring/summer.

The study areas were restricted to the riparian zone, the terrestrial landscape along the river which is influenced by elevated water tables or flooding, over four decades. In this study, the current slope map of the digital elevation model (swissALTI3D 2017, Swisstopo (5704000000)) served as a basis to determine the study area. As boundary slope equal or higher 20 degrees was used to exclude bank protection and cliffs from the study. Orthophotos from 1973 and 2014 were used to complete the dynamic area and to exclude roads and other infrastructure found over the whole study period. The study area Rhäzüns was additionally split into a 'natural' and 'regulated' parts according to their river morphology and investigated separately (Appendix 8).

Table 1. *Description of study areas with the most current aerial photo of the floodplain. Source: Swissimage © 2014 swisstopo (5704000000)*



Floodplain	**Cauma**	**Rhäzünser Rheinauen**	**Rheinauen Zizers-Mastrils**
River	Vorderrhein	Hinterrhein	Alpine Rhine
Size [ha]	58.5	121.3	96.7
Length [km]	3.3	4.9	4.6
Ecomorphology F (Swiss Geoportal 2016)	natural	natural	little affected - levees on the right channel side
Sediment (Hanus et al. 2014)	affected	affected	affected
Discharge affected by large reservoirs (Hunziker, Zarn & Partner AG 2014)	since 1969	since 1960	since 1969
Hydropeaking (Hanus et al. 2014)	affected	affected	affected
Discharge measurement station	2033 Vorderrhein – Ilanz	2387 Hinterrhein - Fürstenau	2606 Rhein - Domat/Ems

2.2 *Myricaria germanica* distribution

Historical recordings

For investigating the population dynamics of *Myricaria germanica*, historical distribution data from two different studies in 1975 and 2007 were consulted (Endress 1975; Kolly 2007).

In regard to a highway construction project along the 'Hinterrhein', Endress (1975) mapped the *M. germanica* occurrence along the rivers in the catchment of Rhein in the canton of Graubünden between 1972 and 1974. He revisited locations with historical recordings and with suitable habitats for *M. germanica*. Records were marked in a national map (1:25000) from 1966 or 1967 with notes to the estimated population size and occurrence of juvenile plants. For the purpose of this study, the recordings were transferred to orthophotos from 1973.

In 2007, the Zizers-Mastrils and Rhäzüns were assessed by Kolly (2007) as part of her bachelor thesis. She recorded the locations where adult *M. germanica* occurred and the number of individuals. Gravel banks with *M. germanica* evidence in 1972 to 1974 were revisited and all newly developed gravel banks. The locations of occurrence were marked on an orthophoto of 2005. For the purposes of this study the locations were assigned to a more accurate orthophoto of 2008.

Due to deviations between national maps from 1966/1967 to orthophoto 1973, and orthophoto 2005 to orthophoto 2008, the exact location could not be reconstructed completely for both Endress' and Kolly's data. In cases of uncertainty locations were draw on the closest gravel bank with open shrub to closed shrub vegetation (for example see Appendix 1). Therefore, the colonised area may be enlarged and slightly shifted in the new maps and were thus not compared between surveys.

Current distribution

Data about the current distribution of *Myricaria germanica* were collected between beginning of March and middle of April in 2017. For the on-site inspection on the floodplain, a permission from the office of nature and environment of Grisons was available (Appendix 2).

At each study site, *M. germanica* was searched along the waterfront, on gravel banks, in shrub vegetation and along the edge of dense forests. Priority was set to gravel banks and open shrub vegetation, at these vegetation types the entire surface was recorded. Due to high water levels or shoreline obstruct by cliffs, not all locations could be visited. Therefore, some waterfronts had to be searched with a binocular. A detailed map, showing the locations, which were visited or investigated from distance, can be found in the Appendix 4.

Coordinates with accuracy better than three metres and age class, as well as habitat type were taken from each *M. germanica* individual (Figure 2, Table 2 and for field protocol see Appendix 3). In the case of dense stands with evenly distributed plants a polygon was drawn around the stands (for an example see **Figure 2**) and the estimated number of individuals per age class was recorded. A group of plants was characterised as dense when there was no way to get through the group of plants or when there were hundreds of plants evenly distributed in the same habitat type. Four habitat types (primary vegetation, shrub open, closed shrub and forest) and thee age classes were distinguished in the field (**Table 2**). Given that *M. germanica* is able to disperse clonally by vegetative shoots (Staffler 1999), it was not possible to identify each independent individual. Therefore, each plant was counted after one metre, regardless of clonality.

Juvenile plant of age class 1

Plant individuals of age class 2

One adult individual, age class 3

One old adult plant, age class 3

Separate recorded adult plants

Dense *M. germanica* stand, recorded with a polygon

Figure 2. *Pictures from field work 2017, Rhäzüns.*

Table 2. *Description of field parameters.*

Habitat types	
	▪ **Primary vegetation:** mainly herbaceous plants ▪ **Shrub vegetation:** shrub +/- 6 m; dominant species: *Salix, Myricaria germanica, Hippophae rhamnoides* • Closed shrub: one shrub after the other, hard to pass • Open shrub: with a lot of open space, easy to pass ▪ **Forest:** trees dominate; characteristic species: *Salix alba, Alnus incana, Alnus glutinosa, Fraxinus excelsior, Quercus robur, Pinus*
Age class	
	▪ **Age class 1:** Juvenile plant; < 20 cm, little branched ▪ **Age class 2:** Few years old; 21 - 60 cm, few lignify branches ▪ **Age class 3:** Adult individual; > 61 cm, a lot basal branched

2.3 Analysis of spatiotemporal dynamics

Aerial photographs

A set of six aerial images per study area, covering a total time span of 41 years, was used to assess spatiotemporal changes in the landscape mosaic. The aerial photographs were selected based on the availability in a certain time, if possible with about eight years between images. Eight years were chosen because this time interval is long enough that all habitat types can evolve. Other criteria were that the images were captured during growing season with normal water discharge and that they had good spatial resolution. The six suitable aerial photographs for each site were ordered from swisstopo (Federal Office of Topography). Nine of 19 aerial photographs had no spatial reference and needed to be orthorectificated before classification (Appendix 5).

Orthorectification was conducted with the tool 'Imagine Photogrammetry' from ERDAS Images 2016 (Version 16.00.0000 Build 650) using eight to ten ground true points (street intersection) and as reference the current Swissimage (2014, swisstopo (5704000000)) and digital elevation model (swissALTI3D 2014, swisstopo (5704000000)). During image rectification, each photograph was resampled to 0.25 m or 0.5 m resolution (depending on the initial resolution of the aerial photo) (**Table 3**). Rectification with the 'Block Triangulation' calculation resulted in a root mean square error of < 1.76 m (except for rh_1973 and ca_1973 with 2.5 and 2.9 m respectively).

Table 3. *List with all orthorectificated aerial photographs from Swisstopo (Licence Nr. 5701359841) with flight date and estimated discharge during recording (mean discharge in the morning, afternoon or at noon, depending on the estimated day time). Four discharge rates are unknown. Pixel = pixel size after orthorectification, ca = Cauma, rh = Rhäzüns; zi = Zizers-Mastrils; bw = black-white.*

Image	**Flight date**	**Film type**	**Pixel**	**Main Discharge** [m2/s]
ca_1973	26.06.1973	bw	0.25	
ca_1984	27.06.1984	bw	0.25	75.82
ca_1990	13.07.1990	bw	0.5	54.35
ca_1997	25.08.1997	bw	0.5	48.48
ca_2008	09.09.2008	color	0.5	62.25
ca_2014	13.03.2014	color	0.25	16.25
rh_1973	09.08.1973	bw	0.25	
rh_1985	23.07.1985	bw	0.5	62.73
rh_1990	13.07.1990	bw	0.25	67.38
rh_1990	20.07.1990	bw	0.25	95.13
rh_1999	25.07.1999	color	0.25	32.27
rh_2008	09.09.2008	color	0.5	82.86
rh_2014	13.03.2014	color	0.25	16.68
zi_1973	26.06.1973	bw	0.25	
zi_1985	23.07.1985	bw	0.25	
zi_1990	23.08.1990	bw	0.25	63.01
zi_1997	22.07.1997	bw	0.5	193.88
zi_2008	06.05.2008	color	0.25	151.59
zi_2014	12.03.2014	color	0.25	61.00

Classification

Seven habitat types were classified for each orthophoto (Table 4). A preliminary investigation revealed that the aerial photography quality of the black and white images was too low for object-oriented image classification, therefore habitats were delineated using 'heads-up' digitising (manually drawing polygons around habitat elements) in ArcGIS 10.3. To ensure constant identification, an interpretation key was created (Appendix 6). Tone and colour differed between images, but texture, pattern, shadow and size remained the same. There are no site and context specific criteria for distinguishing habitat types. 'Minimum mapping unit' was set to 7 m, according to the image resolution.

It was not possible to determine positional and classification accuracy for these classifications. One way to determine accuracy would be to investigate direction of change between successive images (e.g. water to forest). But because each change combination was realistic between consecutive images (within five to twelve years), it was not possible to identify misclassification by studying the change of habitat type. In addition, there was no current orthophoto that allowed to check positional and classification accuracy together with a field survey.

For statistical analyses, shape files were converted in a 0.5 m raster, using for each study area a default raster grid (for detailed raster extent settings see Appendix 7) with Swiss coordinate system "CH1903/LV03" to assure that each pixel cell was exactly at the same location in every year. Raster conversion was conducted with R package 'raster 2.5-8' (Hijmans et al. 2016).

In subsequent analyses, shrub dense and forest were considered together, due to difficulty in distinguish them because of similar tone/colour, texture and patterns. In addition, water and gravel bank areas were merged, as they represent the highly flow-disturbed active tract where vegetation cannot establish. Their respective areas depend on the flow rate when the aerial photos were taken.

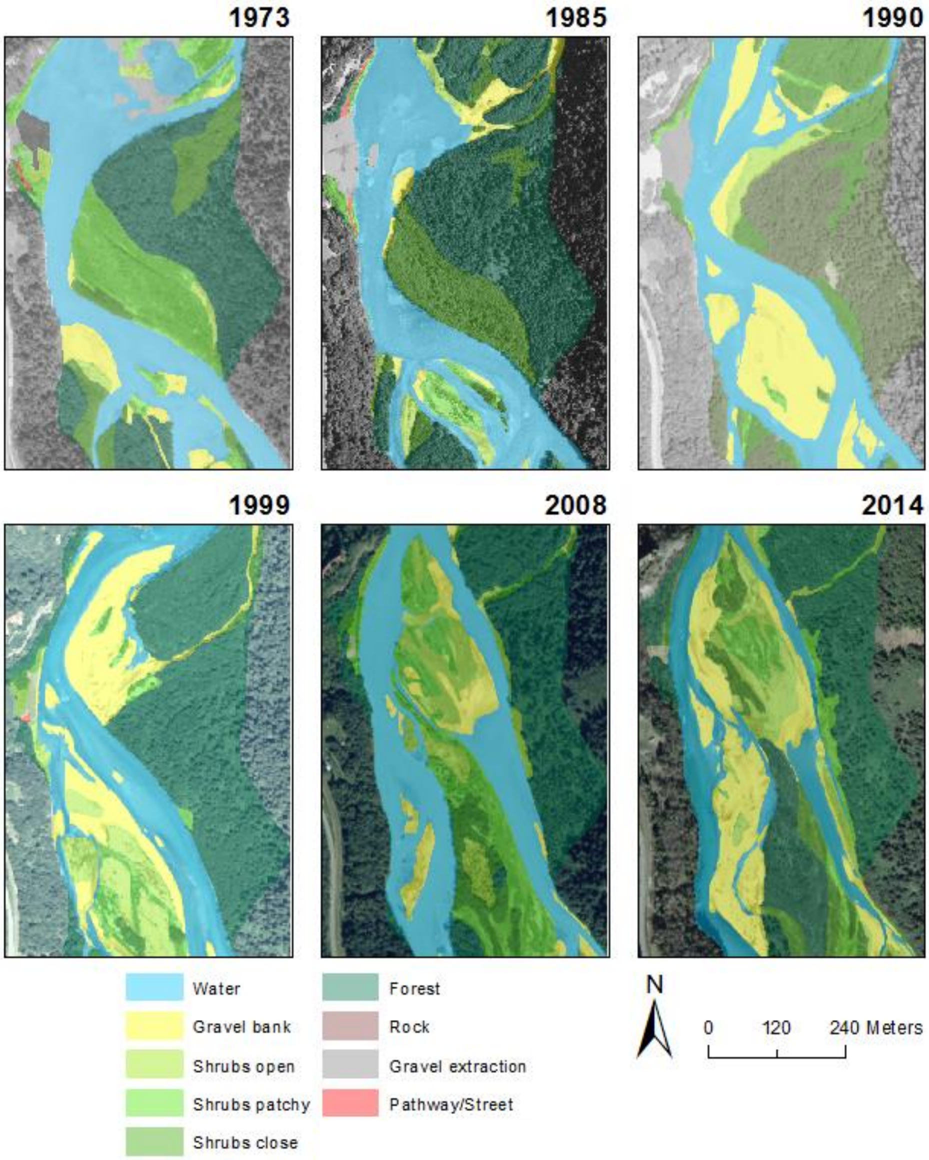
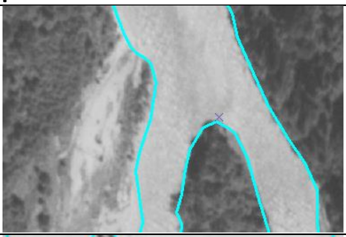
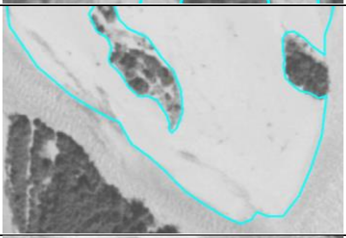
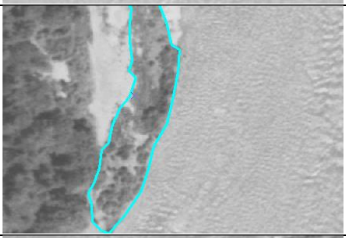
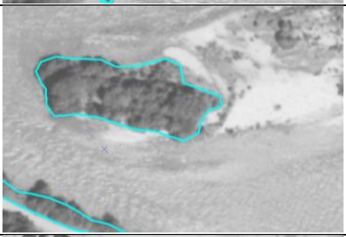
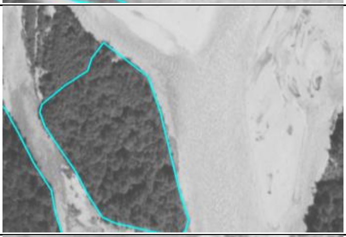
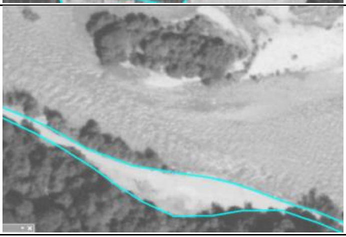


Figure 3. *Habitat classification section of all six orthophotos of Rhäzüns. Source: Aerial images black-white/colour © 1973 - 1999 swisstopo (5704000000) and Swissimage © 2008 & 2014 swisstopo (5704000000)*

__Table 4.__ Description of habitat types with image examples.

Habitat type	Description	Example
Water	Water body (main stream and tributaries)	
Gravel bank	Gravel surface without vegetation	
Primary vegeta-tion - Shrub open	Plants (herbs and shrubs) with scattered distribution. Cover ratio: < 34 %	
Shrub patchy	Shrubs arranged in clusters. Between groups gravel or primary vegetation. Cover ratio: 35 < 90 %	
Closed shrub	Dense shrub stands. Without open spaces. Cover ratio > 91 %	
Forest	Dense vegetation with large trees	
No Habitat	Artificial areas as agriculture, gravel extraction, bank protection, roads and rock	

Habitat composition

Habitat composition (water/gravel bank, primary vegetation/shrub open, shrub patchy, closed shrub, forest and no habitat) between orthophotos within a study area was quantified to test the hypothesis of the 'Habitat mosaic steady state' concept.

To detect differences in floodplain complexity and spatial distribution of *Myricaria germanica* between study areas, shoreline length was examined. The length of the shoreline can be used to quantify suitable habitat for *M. germanica*. Because the German Tamarisk often occur along the shoreline (Gostner et al. 2017).The species can find suitable water and light conditions along the waterfront.

Shoreline describes the ecotone between water and terrestrial habitats. For calculation the shoreline length in this study, water and gravel bank polygons (highly active area) were extracted and dissolved using R package 'rgeos 0.3-23' (Bivand et al. 2017). The polygon edge represents the shoreline. Line length calculation was afterwards conducted in ArcGIS 10.3. For statistical analysis the proportion of shoreline to centreline was used ('Shoreline length per river km') and compared within and between study areas with a 'Fitted Linear Regression Models' from R package 'stats 3.4.1' (R Development Core Team 2017).

To identify directional habitat changes over 41 years, statistical analysis was conducted. Therefore, the correlation between percentage of closed vegetation (closed shrub and forest) and shrub (open and patchy shrub) area and date of aerial photograph were calculated using the 'Fitted Linear Regression Models' from R package 'stats 3.4.1' (R Development Core Team 2017).

Habitat changes

To detect differences in habitat compositions between years, each consecutively classified image was compared. Hence, rasters were reclassified (Table 5) with the R package 'raster 2.5-8' (Hijmans et al. 2016) so that each possible direction of change could be distinguished. Change detection was conducted using the basic R functions, where the latter image was subtracted from the prior one ('cell-by-cell comparison'). For further analyses, the new raster were reclassified into progression (prevailing trajectory onwards; involves vegetation growth), regression (prevailing trajectory backwards; involves the destruction of vegetation by lateral channel erosion or the sediment deposition which buries vegetation), stable (no changes), change to natural habitat (from an artificial habitat to a natural habitat) change to artificial habitat (from a natural habitat to an artificial habitat as paths, gravel extraction etc.). The proportion of change was compared between study areas in relation to river width, length of study area and river morphology. Most dynamic locations were detected by summing up the number of progression and regression steps per pixel.

Table 5. *Reclassification of habitat types for habitat change detection.*

Habitat classification	Reclassification	Description
1	1	Water
2	1	Gravel bank
3	10	Primary vegetation & Shrubs open
4	100	Shrubs patchy
5	1'000	Shrubs close
6	1'000	Forest
0, 7	10'000	No habitat (e.g. Rock, Agriculture, Pathways, Gravel extraction), unknown

Moreover, the habitat changes were analysed considering number of flood events with recurrence of one or more years between subsequent images, length of time interval and chronology of aerial photographs. Discharge data from the closest measurement station of the main river were provided by the Federal Office for the Environment – Department Hydrology. Discharge of small tributaries confluent between measurement station and study area were not considered. Correlation between area per changing type and independent variables listed above, were analysed using the 'Fitted Linear Regression Models' from R package 'stats 3.4.1' (R Development Core Team 2017).

2.4 Spatiotemporal distribution of *Myricaria germanica*

To identify different population sizes between surveys within a study area, the number of *Myricaria germanica* individuals, grouped by age class, was summarised. The survey of 2017 was used to estimate the proportion of *M. germanica* individuals found in each habitat type.

Not only the number of total *M. germanica* individuals within a floodplain gives an impression of the probability that a plant can persist in the area, also the number of location matters. Therefore, the number of *M. germanica* occurrence within a study area was counted and compared between surveys. German Tamarisk occurrence on the same gravel bank was counted as one location.

For spatial analyses, *M. germanica* polygon were converted to random point feature in ArcGIS 10.3. To reach a more or less even distribution of points within the polygon (because polygons were only draw around even distributed *M. germanica* stands) an approximate minimum distance between points was calculated using the formula 'sqrt (Polygon area/Number of *M. germanica*) * 0.2'.

To detect spatial patterns of *M. germanica* along the water course, plot samples were taken along the centreline. Centreline was calculated for the dynamic part of floodplain over all aerial photos. Dynamic floodplain over the last 45 years (habitat types: water, gravel bank, open vegetation) was merged, the originated boundary was generalised and used for calculating centreline with the R package 'cmgo 0.1.5' (Golly 2017) in R (version 3.4.1). Based on the output line feature, 50 m width plots were drawn in a

90 degrees angle to the centreline over the whole riparian zone with 50 m gaps between plots. From each plot, area per habitat type, number of *M. germanica* per age class and dynamic floodplain width (mean of the two plot boundaries) were extracted and used for 'Fitted Linear Regression Models' with R package 'stats 3.4.1' (R Development Core Team 2017) in R (version 3.4.1).

An additional statistical analysis was conducted to investigate the correlation between *M. germanica* occurrence and number of regression happened at each *M. germanica* location, considering the total area per number of regression and study area as weigh factor.

The maximum age of the colonised habitat of *M. germanica* in 2017 was estimated by tracking back each pixel (pixel size 2 x 2 m) in a raster stack, where *M. germanica* with age class three occurred in 2017. Age was determined as soon as habitat type changed to water, forest or artificial areas at each pixel, under the assumption that *M. germanica* can only colonise when water, forest and no habitat first turns to gravel bank or open vegetation. Therefore, as soon as a site turned to an unsuitable habitat type in an image, means that this site must be younger than this image. To incorporate *M. germanica* occurring in forest in 2017, forest areas with *M. germanica* were analysed separately. For those *M. germanica*, forest was not defined as unsuitable habitat.

3 Results

3.1 Habitat dynamics

Habitat composition

Habitat composition changed within each study area (**Figure 7**, maps in Appendix 9 - 11). But not all habitat types showed the same magnitude fluctuations within the 41 years. The trajectory of all study areas developed in the direction of late successional stages, proportion of primary vegetation, shrub open and patchy (summarised as open vegetation) decreased between 1973 and 2014 by 7.8 to 13.2 %. In **Table 6** percentage of habitat cover per year and study area are listed. Statistical analysis revealed a significant trend to less open and more closed vegetation (**Table 7, Figure 4** and **Table 8, Figure 5**), whereby the study areas interacted with area of closed vegetation. Rhäzüns showed the lowest correlation.

Table 6. *Percentage of habitat cover per year and study area.*

CAUMA	**1973**	**1984**	**1990**	**1997**	**2008**	**2014**	**Mean**	**STDEV**
Water/Gravel	49.38	44.41	50.29	44.05	45.39	42.97	**46.08**	*3.02*
Primary veg./Shrub open	8.93	6.64	3.79	3.84	3.58	1.85	**4.77**	*2.55*
Shrub patchy	4.98	4.57	5.77	1.56	2.62	3.01	**3.75**	*1.60*
Shrub close/Forest	29.19	38.24	29.56	40.34	42.40	44.90	**37.44**	*6.62*
No Habitat	7.52	6.14	10.59	10.20	6.01	7.27	**7.95**	*1.99*

RHÄZÜNS	**1973**	**1985**	**1990**	**1999**	**2008**	**2014**	**Mean**	**STDEV**
Water/Gravel	49.49	44.00	48.47	43.39	44.01	42.01	**45.23**	*3.01*
Primary veg./Shrub open	4.99	3.58	2.24	3.00	5.43	6.41	**4.28**	*1.59*
Shrub patchy	14.42	2.74	3.75	3.99	6.93	5.18	**6.17**	*4.29*
Shrub close/Forest	29.33	45.24	42.22	47.10	41.42	43.10	**41.40**	*6.27*
No Habitat	1.77	4.44	3.32	2.52	2.21	3.30	**2.93**	*0.96*

ZIZERS-MASTRILS	**1973**	**1985**	**1990**	**1997**	**2008**	**2014**	**Mean**	**STDEV**
Water/Gravel	67.21	74.62	81.92	66.43	56.09	61.37	**67.94**	*9.23*
Primary veg./Shrub open	5.26	1.19	0.66	5.14	8.88	3.28	**4.07**	*3.04*
Shrub patchy	12.76	2.53	3.17	10.45	6.03	1.55	**6.08**	*4.59*
Shrub close/Forest	10.99	20.66	14.04	17.98	26.23	30.66	**20.09**	*7.40*
No Habitat	3.77	1.01	0.21	0.00	2.77	3.14	**1.82**	*1.61*

Variations between years were similar between study areas except for “Shrub patch” in Cauma and “Water/Gravel” in Zizers-Mastrils (**Table 6**). The largest standard deviation could be found in the habitat type “Shrub dense/forest”. Over all habitat types, the largest variation could be found in Zizers-Mastrils. In 1973, 17.9 % of the total area were open vegetation, the maximum proportion within the observation period. Eleven years later open vegetation was reduced to a minimum of 3.7 %.

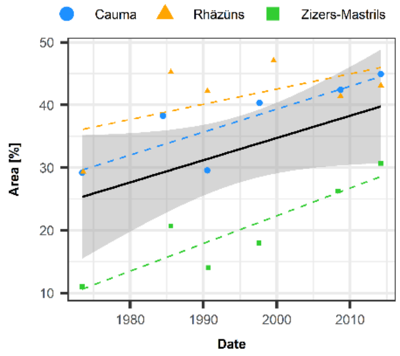


Table 7. *Linear Regression Model of percentage of closed vegetation (closed shrub/forest) area and date of aerial photograph.*

	Df	SS	MS	F value	Pr(>F)	
Date	1	430	430	7.943	*0.014*	*
Date:Study area	2	1043	521	9.637	*0.002*	**
Residuals	14	758	54			

Figure 4. *Area of **closed vegetation** (closed shrub/forest) per aerial photograph. Coloured dashed lines represnt regression (lm) per study area. Black line shows regression (lm) for all study areas.*

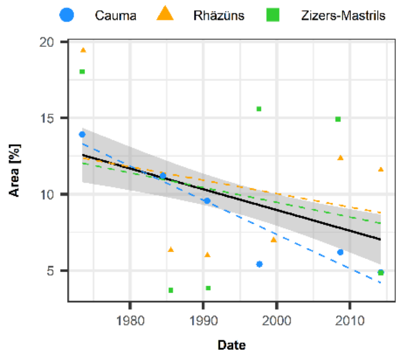


Table 8. *Linear Regression Model of percentage of open vegetation area and date of aerial photograph.*

	Df	SS	MS	F value	Pr(>F)	
Date	1	317	317	15.718	*0.000*	***
Date:Study area	2	118	59	2.931	0.059	.
Residuals	85	1714	20			

Figure 5. *Area of **open vegetation** per aerial photograph. Coloured dashed lines represnt regression (lm) per study area. Black line shows regression (lm) for all study areas.*

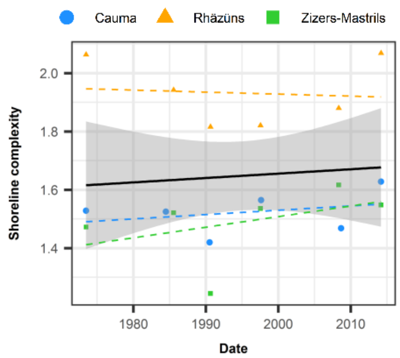


Table 9. *Linear Regression Model of shoreline length per river km and date of aerial photograph.*

	Df	SS	MS	F value	Pr(>F)	
Date	1	0.008	0.008	0.269	*0.612*	
Date:Study area	2	0.495	0.247	8.676	0.004	**
Residuals	14	0.399	0.029			

Figure 6. Shoreline complexity *(Shoreline length per river km) per aerial photograph. Coloured dashed lines represnt regression (lm) per study area. Black line shows regression (lm) for all study areas.*

In contrast to the other two study areas, floodplain Zizers-Mastrils showed large variation in the proportion of water and gravel bank habitat type (Table 6). In 1985 and 1997 a large proportion of the gravel banks were not covered with vegetation.

In the braided reach of Rhäzüns ('natural part'), habitat type abundance fluctuated slightly more than in the regulated part (Appendix 8). But in the regulated part, however, the steady increase in closed vegetation from 25 to 42.1% was substantial. In the regulated part proportion of water was 2.8 % larger than in the 'natural' part. In addition, artificial habitat increased from 1.1 % to 6.7 %.

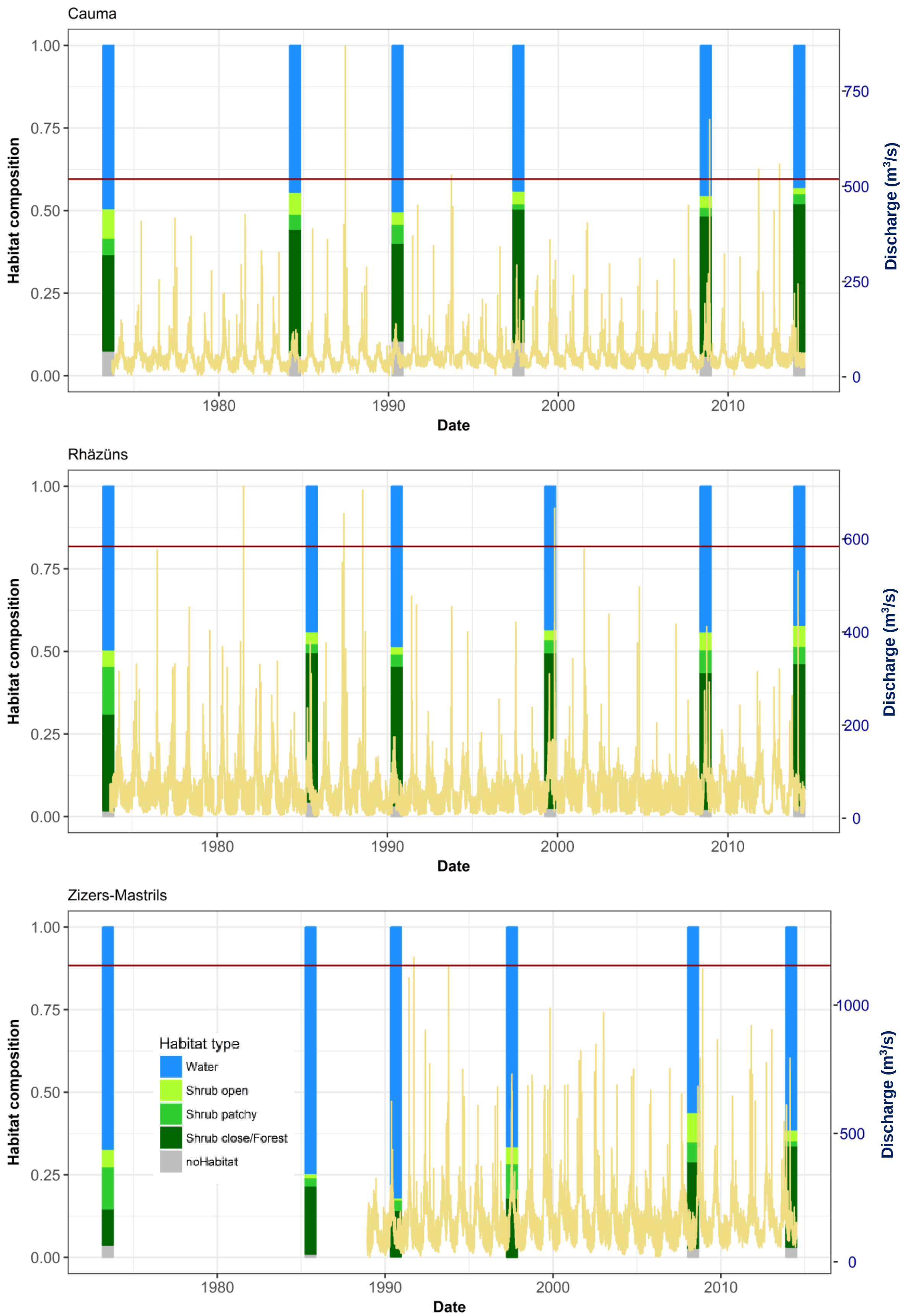


Figure 7. *Proportion of each habitat type per aerial photograph. The yellow lines indicate discharge (daily max.) at the closest measurement station. The red lines indicate discharge with reoccurrence probability of every tenth year.*

Large variation between years and the largest ratio of shoreline length per river kilometre could be detected in the floodplain Rhäzüns (**Figure 6**). Shoreline length to river km was equal in Zizers-Mastrils and Cauma with a mean of 1.49+/- 0.1 and 1.52+/- 0.07. There was an interaction between study area and shoreline length per river km, but no study area showed a trend in one direction (**Table 9** and **Figure 6**).

Habitat changes

The mean proportion of each change type was similar for all study areas (**Table 11**, maps in Appendix 12 - 14). The largest proportion of dynamic area within 41 years could be found in Rhäzüns with 64 %. In the other two study areas, 52 % of the area changed habitat type at least once within 41 years (**Table 10**). Between 65 and 87 % of the study area of each floodplain remained stable between successive images (different length of period interval not considered). Whereby water made up between 57 to 86 % of the stable habitat area. In **Figure 9** the spatial dynamics and in **Figure 10** the proportion of change type per successive aerial photographs of the three study areas are illustrated. In Zizers-Mastrils and in the 'natural' part of Rhäzüns regression and progression patches were evenly distributed along the water course. In Cauma and regulated part of Rhäzüns only a few sites experienced regression.

Table 10. *Percentage of stable and dynamic area within the observation period.*

	Cauma	Rhäzüns	Zizers-Mastrils
Dynamic	51.57	63.53	51.81
Stable - water	27.49	21.41	41.27
Stable - terrestrial	20.94	15.06	6.92

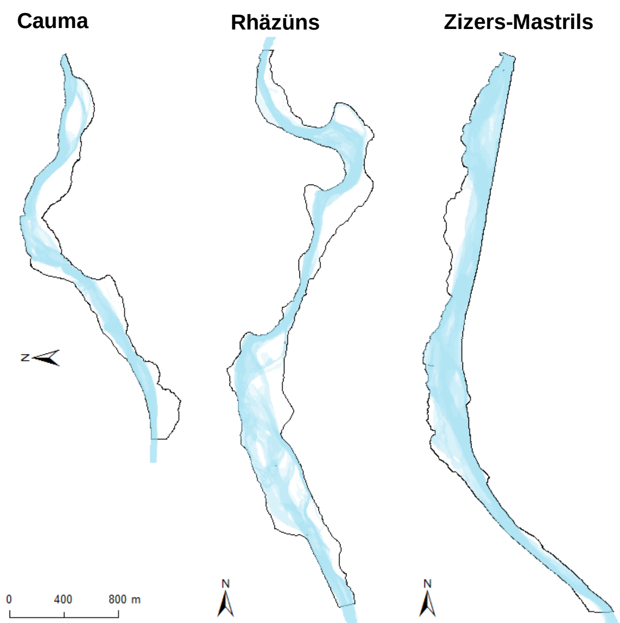


Figure 8. *Water course of all six aerial photographs. The darkness of the colour indicates the frequency of which the water course took this way.*

Table 11. Percentages of changing type between successive aerial photographs. ToHabitat = Change from an artificial area to natural habitat. ToNoHabitat = Change from natural habitat to an artificial area.

CAUMA	1973 - 1984	1984 - 1990	1990 - 1997	1997 - 2008	2008 - 2014	Mean	STDEV
Progression	15.71	4.43	12.69	9.00	8.43	**10.05**	*4.31*
Stable	78.09	71.55	78.19	81.02	87.37	**79.24**	*5.72*
Regression	3.22	17.56	1.00	2.93	2.11	**5.36**	*6.87*
ToNoHabitat	0.80	5.46	3.87	1.43	1.67	**2.65**	*1.95*
ToHabitat	2.18	1.01	4.25	5.62	0.41	**2.70**	*2.20*

RHÄZÜNS	1973 - 1985	1985 - 1990	1990 - 1999	1999 - 2008	2008 - 2014	Mean	STDEV
Progression	23.64	5.75	12.99	13.89	13.21	**13.90**	*6.37*
Stable	64.97	82.63	81.12	72.04	79.03	**75.96**	*7.36*
Regression	6.16	9.20	4.31	12.84	6.48	**7.80**	*3.31*
ToNoHabitat	3.95	0.65	0.39	0.46	1.18	**1.33**	*1.50*
ToHabitat	1.28	1.77	1.19	0.77	0.09	**1.02**	*0.63*

ZIZERS-MASTRILS	1973 - 1985	1985 - 1990	1990 - 1997	1997 - 2008	2008 - 2014	Mean	STDEV
Progression	13.73	2.03	21.16	21.84	10.34	**13.82**	*8.21*
Stable	71.87	86.37	76.63	70.63	80.47	**77.20**	*6.46*
Regression	10.55	10.45	2.00	4.77	7.65	**7.08**	*3.70*
ToNoHabitat	0.54	0.18	0.00	2.77	0.96	**0.89**	*1.11*
ToHabitat	3.31	0.98	0.21	0.00	0.58	**1.01**	*1.33*

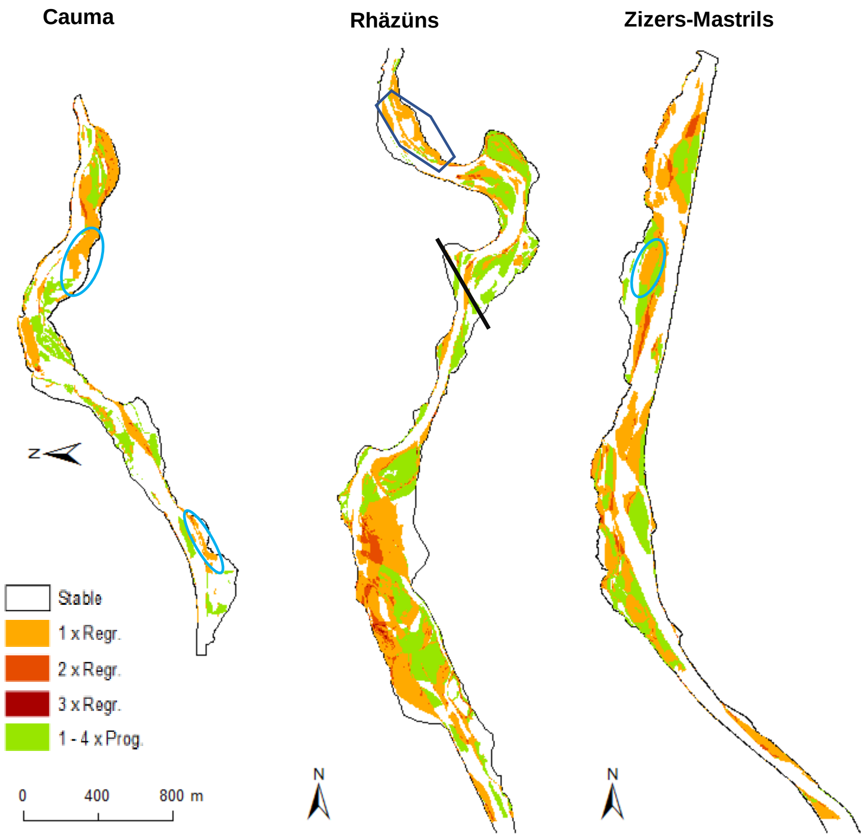


***Figure 9.** Dynamics of the study areas. The figure shows all areas where regression (Regr.) occurred and the areas where only progression (Prog.) took place. Black line illustrates the motorway bridge built between 1975 and 1985. The light blue frame shows regression due to human invention. The dark blue frame indicates the revitalized area, conducted between 2008 and 2014.*

Over the whole observation period, each study area showed a different fluctuation for each change type (**Figure 10**). But mean proportion of area with regression, stable and progression was similar for Rhäzüns and Zizers-Mastrils. In contrast, in Cauma occurred less progression and regression between successive images (**Table 11**). In general, the proportional area of regression exceeded the area with progression only in the time period 1984/1985 to 1990.

'Natural' and regulated parts of Rhäzüns responded differently to flood events (Appendix 8). Because proportion of regression was constant in the regulated part (STDEV: 2 %) but in the 'natural' part, area fluctuated strongly (STDEV: 6.5 %). In the regulated part, results show similar variation (STDEV: 2.6 %) for progression, when excluding the time period 1973 to 1985 with 20 % progression.

Statistical analysis with a 'Fitted linear regression model' revealed that percentage of stable area was negatively correlated with number of days between successive aerial photographs and that there was

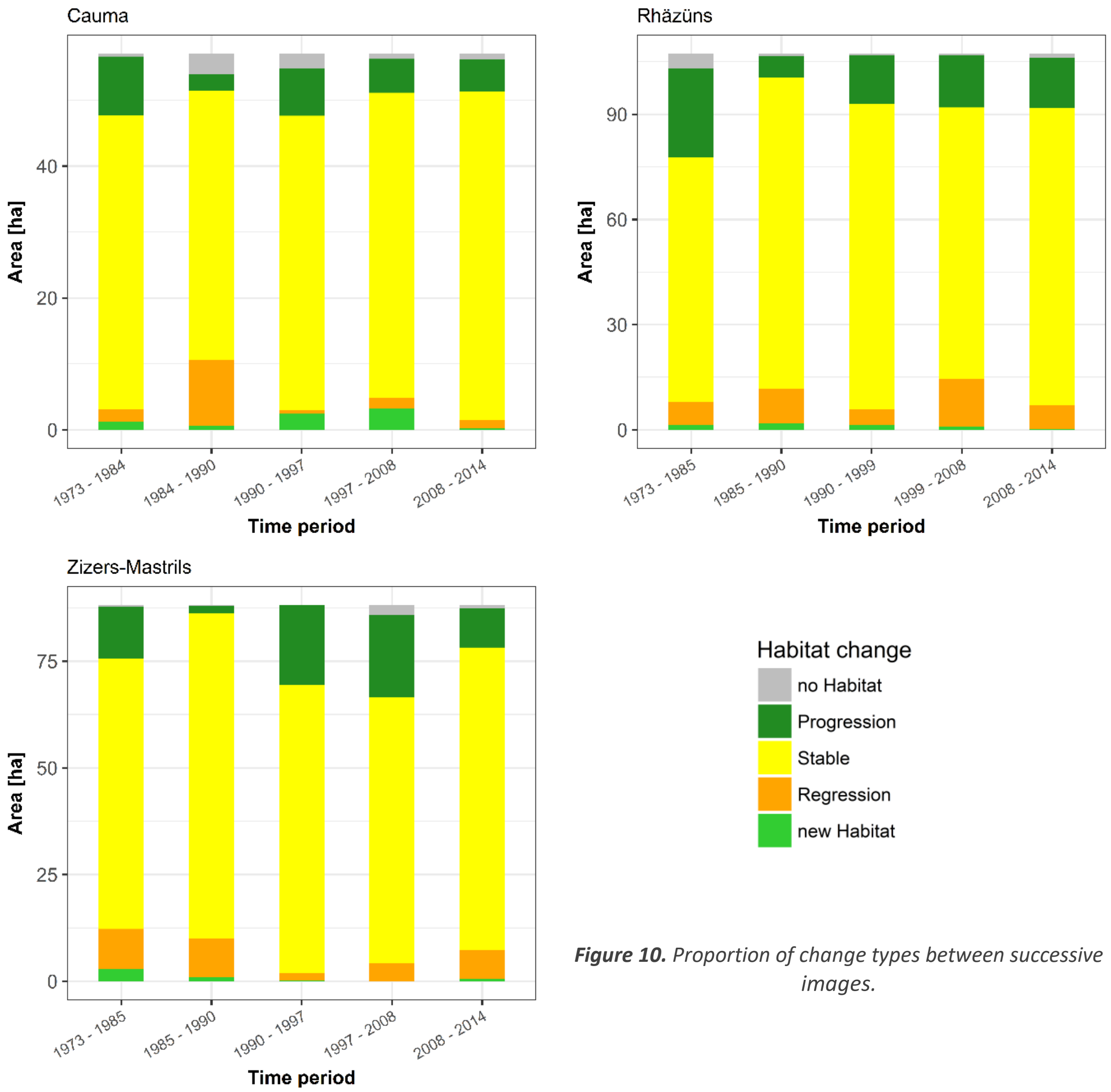


Figure 10. *Proportion of change types between successive images.*

no significant difference between study areas (**Table 12** and **Figure 11**). In contrast, areas with progression increased with time length between successive aerial photographs (**Table 13** and **Figure 12**). Both analyses showed a lower correlation for Cauma than for the other two study areas. Area with regression did not correlate with time interval length (**Table 14** and **Figure 13**). But, time interval length had an impact on number of days with a discharge of $HQ \geq 1$ (water discharge reoccurrence probabilities of every year or less frequent) occurred, whereby correlation strength differed between study areas (**Table 15** and **Figure 14**). Areas, where regression occurred, did not correlate with number of days with a discharge of $HQ \geq 1$ (**Table 16** and **Figure 15**). There was a not significant trend to more stable area in the data (**Table 17** and **Figure 16**) and a weak tendency to less area with regression within 41 years in Cauma and Zizers-Mastrils (**Table 18** and **Figure 17**).

Table 12. Linear Regression Model of percentage of stable area and length of time interval.

	Df	SS	MS	F value	Pr(>F)	
Nr of Days	1	211	211	8.466	*0.014*	*
Nr of Days:Study area	2	57	28	1.144	0.354	
Residuals	11	274	25			

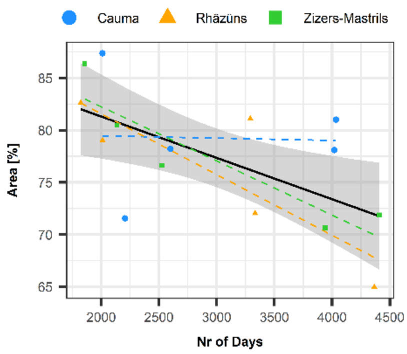


Figure 11. Stable area versus number of days between successive aerial photograph. Coloured dashed lines represent regression (lm) per study area. Black line shows regression (lm) for all study areas.

Table 13. Linear Regression Model of percentage of area with progression and length of time interval.

	Df	SS	MS	F value	Pr(>F)	
Nr of Days	1	211.729	211.729	8.224	*0.015*	*
Nr of Days:Study area	2	59.613	29.806	1.158	0.350	
Residuals	11	283.217	25.747			

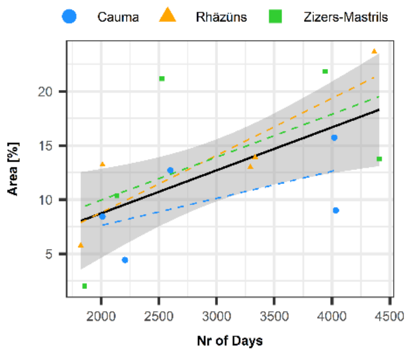


Figure 12. Area with progression versus number of days between successive aerial photograph. Coloured dashed lines represent regression (lm) per study area. Black line shows regression (lm) for all study areas.

Table 14. Linear Regression Model of percentage of area with regression and length of time interval.

	Df	SS	MS	F value	Pr(>F)
Nr of Days	1	8	8	0.336	0.574
Nr of Days:Study area	2	23	12	0.466	0.639
Residuals	11	272	25		

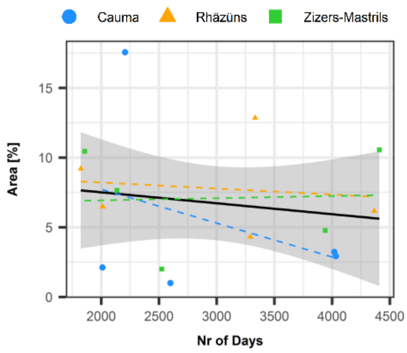


Figure 13. Area with regression versus number of days between successive aerial photograph. Coloured dashed lines represent regression (lm) per study area. Black line shows regression (lm) for all study areas.

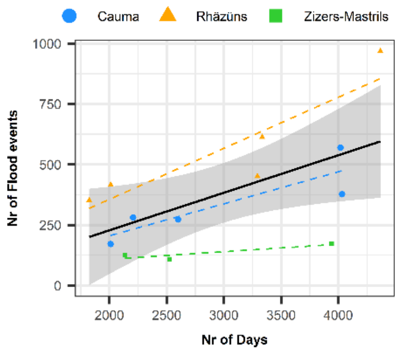


Table 15. *Linear Regression Model of number of days with a discharge of HQ ≥ 1 and length of time interval.*

	Df	SS	MS	F value	Pr(>F)	
Nr of Days	1	243407	243407	29.571	*0.000*	***
Nr of Days:Study area	2	372455	186227	22.624	*0.000*	***
Residuals	9	74082	8231			

Figure 14. *Number of days with a discharge of HQ ≥ 1 versus number of days between successive aerial photograph. Coloured dashed lines represent regression (lm) per study area. Black line shows regression (lm) for all study areas.*

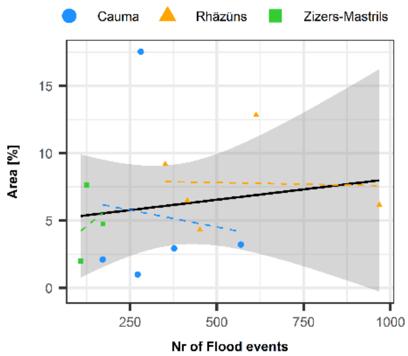


Table 16. *Linear Regression Model of area with regression and number of days with a discharge of HQ ≥ 1.*

	Df	SS	MS	F value	Pr(>F)
Nr of HQ ≥ 1	1	7	7	0.24	0.639
Nr of HQ ≥ 1:Study area	2	15	8	0.27	0.766
Residuals	9	249	28		

Figure 15. *Area with regression versus number of days with a discharge of HQ ≥ 1. Coloured dashed lines represent regression (lm) per study area. Black line shows regression (lm) for all study areas.*

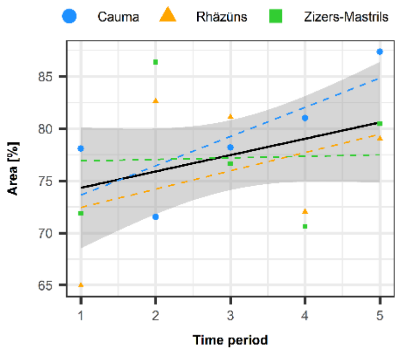


Table 17. *Linear Regression Model of stable area and time period.*

	Df	SS	MS	F value	Pr(>F)
Time period	1	73.730	73.733	1.901	0.195
Time period:Study area	2	41.620	20.811	0.537	0.599
Residuals	11	426.620	38.783		

Figure 16. *Stable area versus time period. Coloured dashed lines represent regression (lm) per study area. Black line shows regression (lm) for all study areas.*

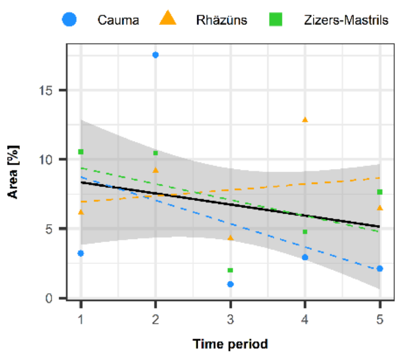


Table 18. *Linear Regression Model of area with regression and time period.*

	Df	SS	MS	F value	Pr(>F)
Time period	1	19	19	0.837	0.380
Time period:Study area	2	30	15	0.656	0.538
Residuals	11	254	23		

Figure 17. *Area with regression versus time period. Coloured dashed lines represent regression (lm) per study area. Black line shows regression (lm) for all study areas.*

3.2 Spatiotemporal distribution of *Myricaria germanica*

Population size and distribution

Number of *Myricaria germanica* was reduced by about 50 % in Cauma in 2017 (829 individuals), compared to 1973 (between 1’483 – 1’833 individuals). From 1973 to 2007 the number of *M. germanica* increased in Zizers-Mastrils but decreased again by more than 50 % until 2017, in contrast to the floodplain Rhäzüns (**Figure 18**). The number of *M. germanica* individuals was equal in 1973 and 2007 (between 3’206 and 7’265, respectively 4’886 individuals) in Rhäzüns but increased until spring 2017 (11’123 individuals).

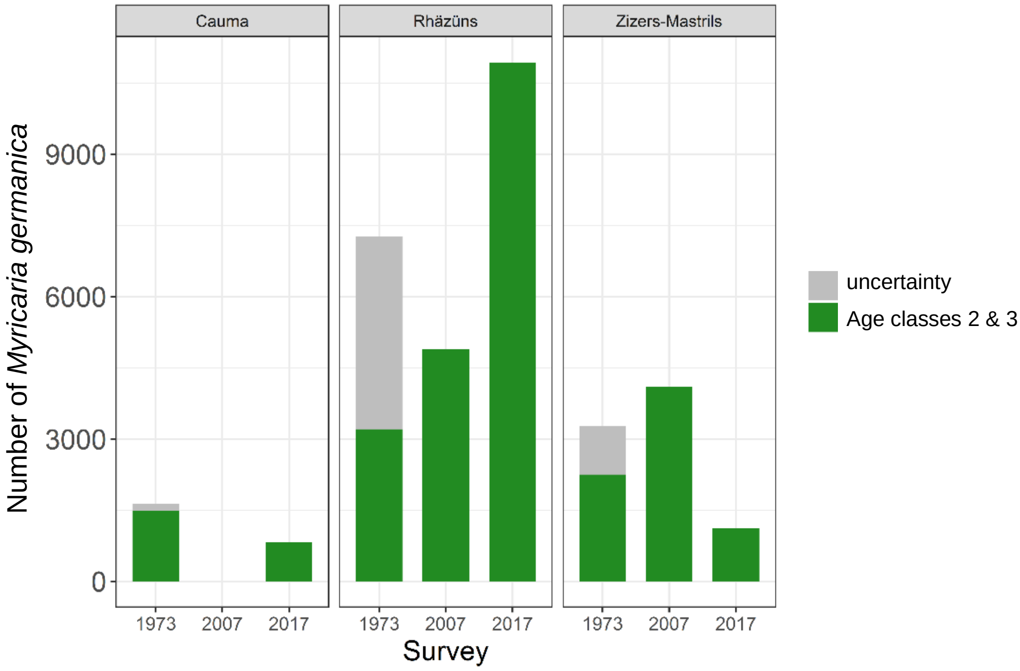


Figure 18. *Number of Myricaria germanica of age classes 2 & 3 (2: young, non-flowering, 20<40 cm; 3: >40cm, adult, flowering) counted within the study areas in two (Cauma) respectively three surveys (Rhäzüns and Zizers-Mastrils). For 1973, no exact number of individuals is known, therefore the grey bar indicates the range of uncertainty.*

In Cauma and Zizers-Mastrils, the number of *M. germanica* sites was stable, respectively decreased slightly (**Figure 19**). In 2017, *M. germanica* occurred at more locations (24 sites) than in the other two surveys in Rhäzünser (1973: 18 sites and 2007: 13 sites). Number of sites with juvenile plants increased between 1973 and 2017 in Rhäzüns and Zizers-Mastrils, by contrast in Cauma the number of sites declined (**Figure 20**). Distribution areas of *M. germanica* in 2017 was reduced compared to the other surveys in all study areas (**Figure 22** for Rhäzüns, for distribution map for Cauma and Zizers-Mastrils see Appendix 16 and 17). Within the study perimeter of Rhäzüns, on the last gravel bank upstream, the number of adult plants declined from nine individuals in 2007 to three plants ten years later.

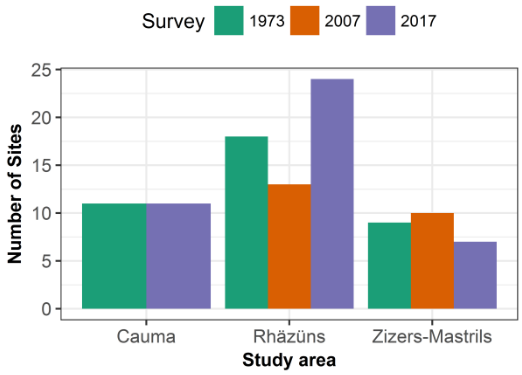


Figure 19. *Number of sites where Myricaria germanica (age class 2 - 3) occurred in two respectively three surveys.*

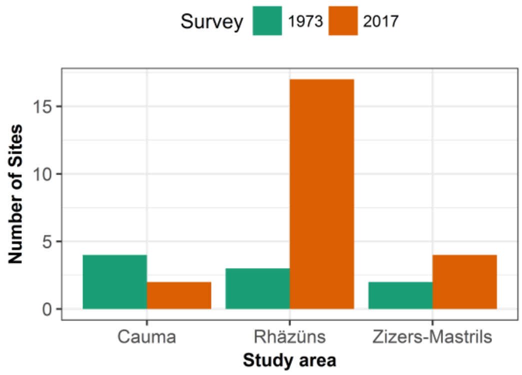


Figure 20. *Number of locations with juvenile plants.*

And, downstream on the last gravel bank number of adult plants decreased from ten to eight individuals, whereby the eight plants were growing in the revitalised reach.

All juvenile (age class 1) and young (age class 2) *M. germanica* individuals grew in primary vegetation or open shrub (Figure 21). Between 3 and 43 % of adult individuals (age class 3) were found in closed shrub vegetation or forest, but most often they occurred in open shrub vegetation.

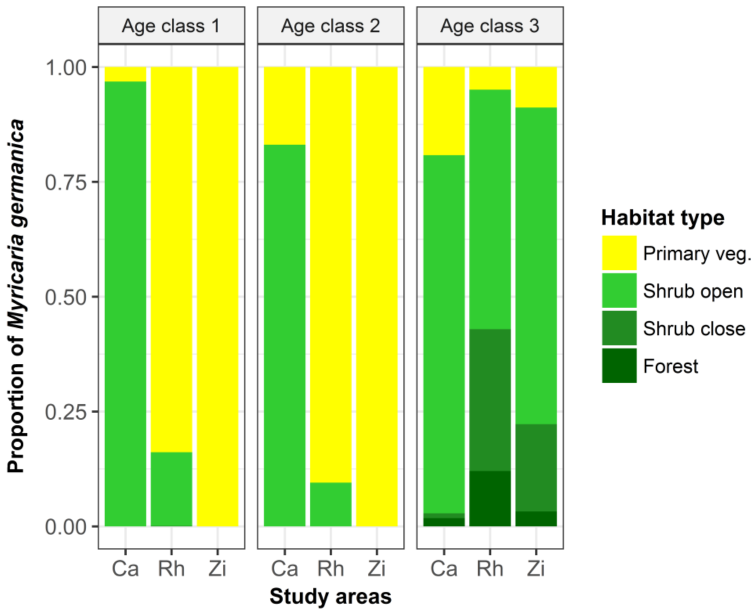


Figure 21. *Proportion of Myricaria germanica individuals per vegetation type. Ca = Cauma; Rh = Rhäzüns; Zi = Zizers-Mastrils.*

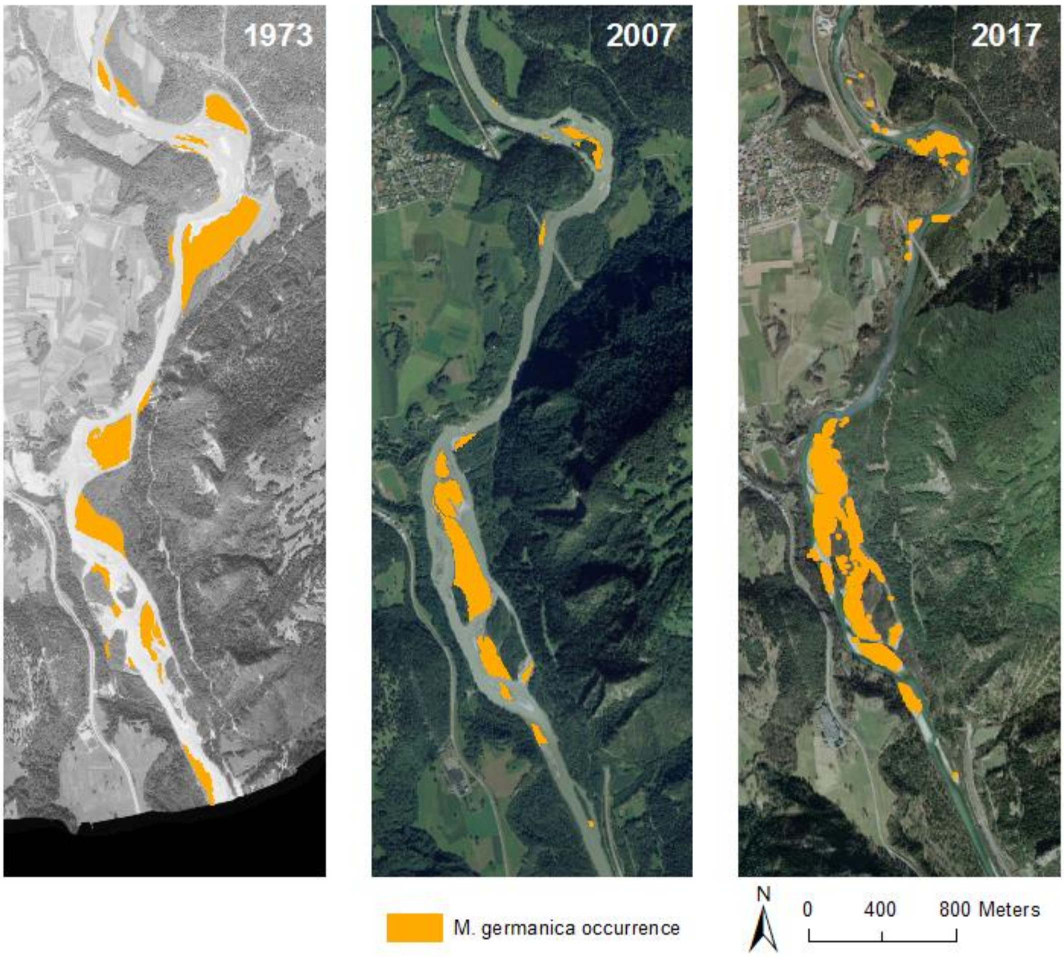


Figure 22. *Orthophotos of Rhäzüns with M. germanica occurrence of three surveys (Endress 1975, Kolly 2007, Wiedmer 2017). Source: Aerial images black/white © 1973 swisstopo (5704000000) and Swissimage © 2008 & 2014 swisstopo (5704000000).*

Myricaria germanica occurrence in relation to floodplain width

The wider the dynamic area of a floodplain the more *Myricaria germanica* of age class 2 and 3 occurred (**Table 19**). In addition, statistical analyses revealed interactions between study area and floodplain width, and between floodplain width and open vegetation. In contrast to Rhäzüns and Cauma, Zizers-Mastrils showed a slight negatively correlation between *M. germanica* occurrence and width (**Figure 23**).

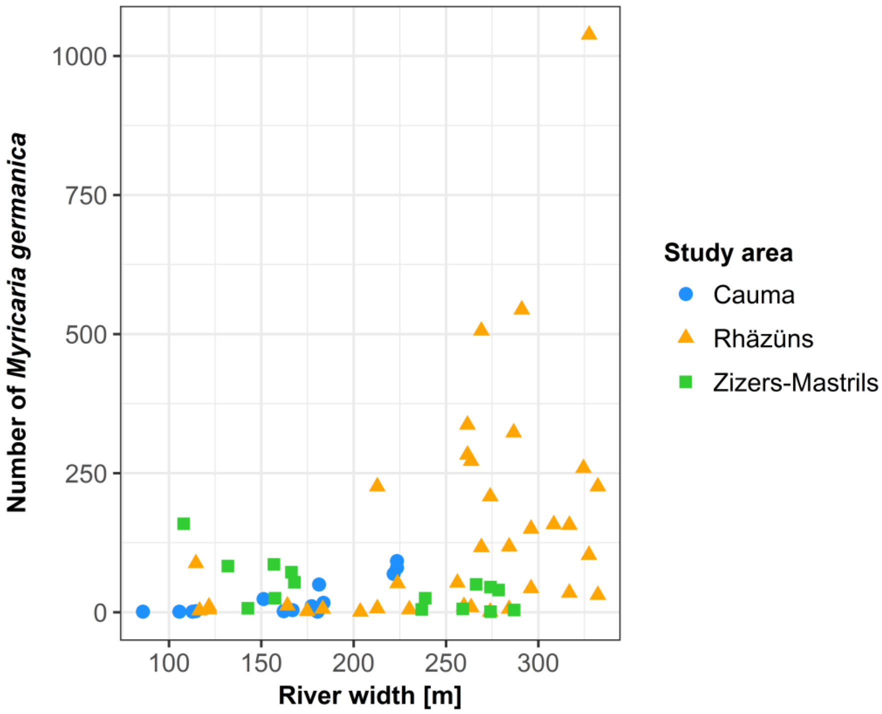


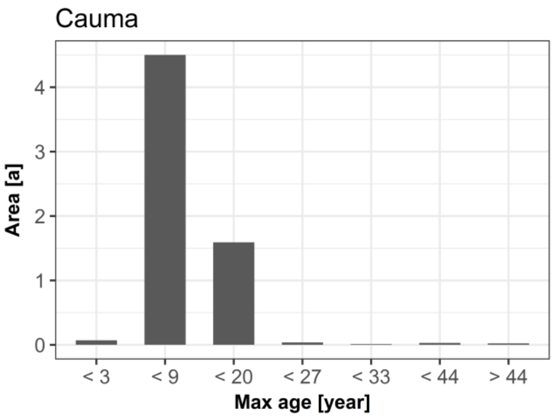
Figure 23. *Correlation between number of Myricaria germanica (age class 2 and 3) and width of dynamic area.*

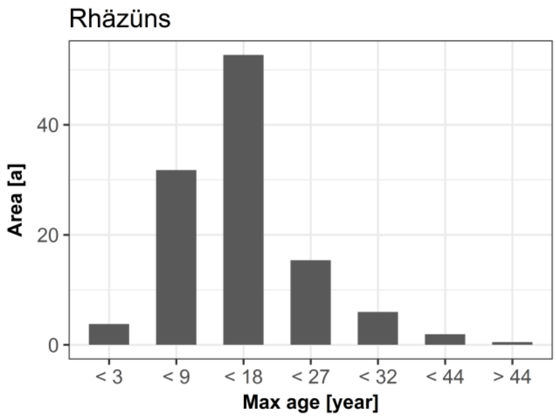
Table 19. *Fitting linear model of number of Myricaria germanica (Age class 2 and 3) versus width of dynamic area and percent of open vegetation (shrub open and shrub patchy).*

	Df	SS	SM	F value	Pr(>F)	
Width	1	440542	440542	54.764	*0.000*	***
Open Veg.	1	140138	140138	17.421	*0.000*	***
Width:Open Veg.	1	412568	412568	51.286	*0.000*	***
Width:Study area	2	65714	32857	4.084	*0.019*	*
Open Veg.:Study area	2	21511	10756	1.337	*0.266*	
Residuals	129	1037732	8044			

Age of *Myricaria germanica* locations

Sites where *Myricaria germanica* occurred in 2017 had different ages. **Figure 24** shows that most of the locations where *M. germanica* occurred in spring 2017 were younger than 20 years. Because in 1997 (Cauma and Zizers-Mastrils), respectively 1999 (Rhäzüns), there was water, forest or artificial areas at these locations. In all study areas, only a very small proportion of *M. germanica* sites could be older than 32 years (**Figure 24**). Today, a few plants were standing on gravel banks where Endress already found *M. germanica* in 1972-1974.





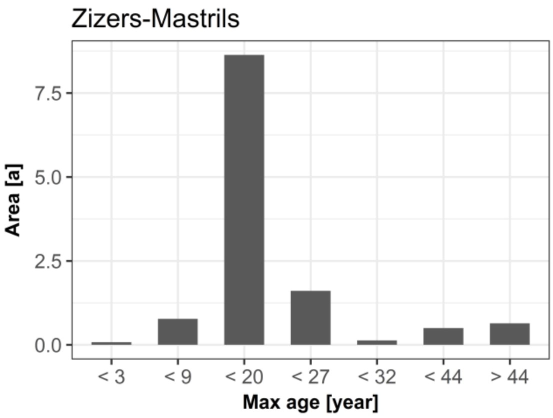


Figure 24. *Age distribution of location where Myricaria germanica occurred in spring 2017.*

Locations where *M. germanica* occurred in 2017 did not correlate with the dynamics of the location (number of regression), but there was an interaction between number of regression and study areas (**Table 20**).

Table 20. *Fitting linear model of location of Myricaria germanica (Age class 3) versus number of regression steps with total number of pixels per regression number as weights.*

	Df	SS	MS	F value	Pr(>F)	
Nr. of regression	1	900019	900019	4.672	0.074	.
Nr. of reg.:Study area	2	2074161	1037081	5.384	*0.046*	*
Residuals	6	1155766	192628			

4 Discussion

4.1 Habitat dynamics

Water regulation, artificial bed-load balance and bank stabilisation are factors that are known to have negative impacts on the habitat heterogeneity and successional trajectories of river ecosystem (Ward & Stanford 1995). Truncated sediment transport can result in channel degradation and lowering of the water-table (Ward & Stanford 1995). The reduction of flood peaks results in a reduction of frequency, extent and duration of floodplain inundation. In addition, it can reduce channel migration. Anthropogenic impacts that reduce fluvial dynamics generally accelerate territorialisation and reinforce the positive feedback that leads to channel stabilisation due to riparian post-pioneer forest within fluvial corridors (Bravard 1989; Magilligan & McDowell 1997).

In this study, I investigated the habitat dynamics and the directional change of habitat types of three natural to semi-natural floodplains, all affected by alternated discharge and bed-load balance. For this purpose, I analysed six historical aerial photographs per study area over four decades. Time intervals were not equal between all successive photographs and area with progression correlates with length of time interval, but the statistics show that there was no correlation between length of time interval and area with regression. Thus, no standardisation to an equal time length was conducted. This imprecision must be considered when interpreting the results.

In addition, change detection between two aerial photographs reflected only the last changes and the dominant processes, many underlying processers were overlooked. In addition, for a strong power in statistical analyses more study areas and more aerial photographs in an equal time interval must be considered. In this study, I chose the simple linear regression model for statistical analyses, even though a linear relationship can not always be assumed, and data was not entirely normal distributed. But it was still a good model for detecting trends in my data. Due to lack of replicates and a slight deviation of residuals from normal distribution, trends may be overestimated.

Vegetation succession

This study shows that more than half of the study perimeter of each floodplain changed habitat type at least once in the observation period and that there was a tend to late successional stages. However, closed vegetation abundance varied most in all study areas. Furthermore, the ratio of regression, progression and stable areas fluctuated largely over time. Between all time periods, except for 1984/85 to 1990, area with progression exceeded area with regression. In addition, there was a trend to more stable area in the data. Area with regression did not correlate with number of days with HQ $\geq$ 1 that occurred between aerial photographs.

The three floodplains differ in their length, width, discharge rate and degree of human impact. Differences between study areas were also reflected in the number of days with HQ $\geq$ 1 per time interval. The missing correlation between number of days with HQ $\geq$ 1 and area with regression indicates that flow rates had largely different erosion capacity on the floodplains. In other studies of braided rivers, the degree of habitat changes was mostly determined by flood magnitude (Van Der Nat et al. 2003), duration, and recurrence intervals of floods and rates of vegetation succession (Whited et al. 2007).

Methodical reasons could explain some of the large fluctuation I found in closely occurring vegetation. Different time intervals between successive aerial photographs and the correlation between progression and length of time interval could have led to these fluctuations. In addition, the positional inaccuracy in classification of closed shrub/forest polygons due to tilting effect and shadow of high vegetation, which is worse than for the other habitat types, could further add to the fluctuation that I found. The final contributor to the large fluctuation is biological rather than methodological and is likely because it takes longer for closed vegetation to regenerate after a large flood event than for the other habitat types.

In Rhäzüns the enlargement of the closed vegetation area occurred after the building of a highway bridge and the levees downstream of the bridge, next to the highway. Today, one bridge pier is standing in the water and two bridge piers in the riparian zone. This study shows that succession and stable area dominated floodplain downstream of the bridge since 1985. In contrast, the 'natural' part showed no obvious trend to more closed vegetation and areas where regression occurred were also spread over the whole reach. Therefore, I assume that, the levees and bridge pier reduced dynamic processes in the regulated part of Rhäzüns.

In Cauma and above Zizers-Mastrils a large amount of gravel was extracted until 1993 (mean 36'000 m^3/year) and 1972 (mean 83'000 m^3/year) (Hunziker, Zarn & Partner AG 2014). In those floodplains, late successional stages may increase due to lowering of the riverbed because of sediment deficit and dammed discharge, resulting in disconnecting of floodplain habitat from river dynamics. As soon as succession proceeds, channels get stabilised (Hereford 1993), due to positive biogeomorphic feedback of the plants (Naiman & Décamps 1997). This feature also explains why in Cauma less regression occurred between successive aerial photographs and why regression was restricted to a few sites. Today, the dynamic area is strongly reduced compared to 1973.

I found the largest shifts in habitat composition in the semi-natural floodplain Zizers-Mastrils. Large fluctuations in water/gravel area, in contrast to Cauma and Rhäzünser floodplain, can mainly be explained by changes in gravel bank area without vegetation. A possible reason for these shifts are the secured embankments along the whole right shore line, which reduced floodplain area and increased the water level. During a large flood event, water cannot spread over a large area and therefore has a strong force to erode vegetation.

Negative impact of gravel deficit and dammed discharge are emphasised when looking at the historical images before construction of reservoir and intensified gravel extraction (Hunziker, Zarn & Partner AG 2014) from 1939/1940 and 1956 (Swisstopo, https://map.geo.admin.ch/; Aerial Images swisstopo b/w). They show a significantly larger proportion of gravel bank free of vegetation and open vegetation compared to the investigated images, and that underlines the trend to late successional stages. The impact of human inventions on the three floodplains are clearly visible in the three study areas.

River morphology

Shoreline is an important ecotone for interactions between water and terrestrial habitats. Large shore-line lengths per river kilometre ratio increases habitat complexity. Shoreline length ratio was significantly larger in Rhäzüns than in the other two study areas. Because Rhäzüns is much wider in the upper part, it has more space for braiding compared to the other two study areas. This result is also reflected by the investigation of the different watercourses over 41 years. Cauma and Zizers-Mastrils have much less space for braiding, they showed a lower variation in watercourse between the six analysed aerial photographs than Rhäzüns. These low dynamics can be explained by the fact that the two floodplains in some part are restricted in their width by cliffs and levees, and some gravel banks are disconnected from the river and therefore additionally stabilised by forest.

Shifting mosaic steady state

An equilibrium between sediment accumulation and sediment erosion characterises naturally braided rivers (Tockner et al. 2006). Due to this fundamental process attribute of unregulated river ecosystems, the coarse composition and abundance of habitat elements in a natural floodplain seem to remain relatively constant over ecological periods (Stanford et al. 2005). Overall, the results of this study show that the relative habitat composition changes were slightly larger than in other studies of braided rivers over a period of more than 40 years (Whited et al. 2007; Zanoni et al. 2008); and a trend to late succes-sional vegetation stages and less regression. These features suggest a deviation from the concept of shifting mosaic steady state. Even the upper part of Rhäzüns, which is characterised by a wide braided floodplain, showed large fluctuations in habitat composition. But the fact that hydrological disturbances occurred along the whole study area in the 'natural' part of Rhäzüns and Zizers-Mastrils, supports the concept of shifting habitat mosaics for these floodplains.

Doering at al. (2012) also detected deviation from the concept of shifting mosaic steady state in an alpine floodplain after human intervention (water abstraction and levee construction). Their study shows the sensitivity of the habitat composition of floodplains to human action, what coincides with this study.

The application of the concept of "Shifting mosaic steady state" is relatively new and therefore no measurement scale exists. Furthermore, the rate of fluctuation is sensitive to length of observation period and time interval, number and choice of images (e.g. short after a flood event), and habitat classification accuracy. Thus, this study is a case study and comparisons with other studies must take these factors into consideration.

4.2 *Myricaria germanica* dynamics

In this study, I investigated changes in distribution and population size of the *Myricaria germanica* over 44 years in three floodplains, based on three, respectively two field surveys and six habitat composition maps per floodplain.

The number of surveys evaluated in this study was small for analyses of population dynamics. Furthermore, habitat composition maps can only provide an approximation of population state. Due to the high dynamic habitat, large population fluctuation must be expected. Periodic plant surveys over a large time would be needed to detect population trajectories. Nevertheless, this study can give a good impression on the degrees of population fluctuation and population conditions.

Suitable habitat

Analysis of habitat composition implies that over the whole observation period suitable *Myricaria germanica* habitat (primary vegetation to shrub patchy) was available. Nevertheless, habitat type abundance fluctuated, and large parts of the floodplain underwent regression within 41 years. The high dynamics of the study areas are also reflected in the age of the *M. germanica* sites. Although there were few overlaps between growing sites in 1973 and 2017, almost all location could not be occupied during the whole study period, due to habitat changes. Flood events between three to 20 years ago created habitat areas, and these are where most *M. germanica* plants occur today. In Rhäzüns, distribution curve of age of *M. germanica* location was nearly normally distributed, which means that many different events created *M. germanica* habitat that are found today and that we can thus expect different population ages. In comparison, Zizers-Mastrils and Cauma flood events in only one, respectively two time periods, were responsible for the formation of suitable habitat. Differences in age distribution of *M. germanica* locations between study areas can be explained by variations in the occurrence of large flood events and the degree of floodplain complexity.

A statistical analysis reveals that there was no correlation between the "number of regressions" for 41 years and *M. germanica* occurrence. This analysis implies that *M. germanica* individuals did not occur more often at locations with more disturbance in the past, which could be detected with these aerial photographs. A reason for that could be the low resolution of dynamic areas, which can be detected with time intervals of five to twelve years. Because, Gostner et al.(2017) evaluated a returning interval of seven years for flood events which eroded banks with *M. germanica*.

Population size & Plant distribution

Plant distribution along the floodplains changed from 1973 until 2017. Today, some edge gravel banks of the floodplains were not colonised with *M. germanica* anymore or the number of plants declined. Furthermore, the centres of distribution declined in Zizers-Mastrils and Cauma. In contrast, in Rhäzüns population size and number of occupied sites increased slightly between 1973 and 2007. While, the other two floodplains showed a decline in number of individuals in 2017. In Zizers-Mastrils the number of sites was also reduced. Additionally, this study found a positive effect of floodplain width on adult and young plant (age class 2 and 3) occurrences.

Beside a general change to late successional stages, I hypothesise that significant flood events were responsible for the current *M. germanica* distribution. In Zizers-Mastrils, it is likely that population was strongly reduced due to a large flood event of HQ >150 in 1987. As shown in the habitat composition maps, forest decreased by 6.5 % and gravel increased between 1985 and 1990. A strong reduction of forest indicates that a large part of the open vegetation (and consequently *M. germanica* habitat) must have eroded during the flood. In addition, a large flood event (HQ ~30) in 2016 is likely responsible for the reduction in number of *M. germanica* between 2007 and 2017. In Cauma the reduction can be explained by the decline of open vegetation area but may also be due to the lack of reproduction in the edges of the floodplain.

Sitzia et al. (2016) investigated *M. germanica* along a 30 km river stretch over a time period of six years. They found also correlations between *M. germanica* occurrence and river width. These findings support the possible explanation that Cauma and Zizers-Mastrils floodplain show a reduction of *M. germanica* population size due to reduced channel width and therefore reduced riparian zone and higher vulnerability to flood events. Therefore, also edge populations are more vulnerable to extinction, because they often occur in narrow river stretches

A similar observation of increase of large *M. germanica* population size was made by Werner (2016). He investigated ten populations in Valais CH over 20 years. During this time, only the two largest populations increased, one along the Rhone in a nine kilometres revitalised river section and another in a natural habitat at the front of a melting glacier. The river section along Rhone with a large *M. germanica* population is characterised by high complexity and river width up to 300 m. In contrast to this study the population along Rhone could also expand along the floodplain up- and downstream, because of a continuous riparian zone. The fact that the riparian plants often grow near water channels (Gostner et al. 2017), supports the assumption that high floodplain complexity can lead to a higher number of individuals.

This investigation shows that *M. germanica* population dynamics and distribution differ between study areas. The hypothesis that population size and colonised sites are reduced can only be confirmed for Zizers-Mastrils, in Cauma only population size declined. Floodplain size, river width together with floodplain complexity are likely the reasons why Rhäzüns has a large population size and positive population development. Due to these attributes, the population is also less vulnerable to oscillations in population size in contrast to the other two populations.

Future of *Myricaria germanica* populations

In this study, reproduction of *Myricaria germanica* worked in all study areas in primary and open shrub vegetation, but in Zizers-Mastrils and Cauma juvenile and young plants were restricted to a few sites. Additionally, in another survey along a river reach of Lech, only a small number of young plants could be detected (Barth 2015). Due to the narrow germination niche (Bill 2000), it is likely that the species cannot germinate every year. However, successful reproduction, at least occasionally, is important for sustainable plant populations. The reduction of area with open vegetation over the years, unsuitable moisture conditions (missing ground water connection and precipitation) and frequent mechanical disturbance likely led to a decline of suitable recolonisation habitat. Gravel banks at the edges of the study areas have especially poor conditions. These gravel banks were in the narrow part of the rivers and therefore are exposed to more frequent and stronger flooding events.

Beside suitable germination conditions, connectivity between populations is important for persistence of *M. germanica*. All three study areas are channelised up- and downstream, and as a result suitable habitat for *M. germanica* is rare along these rivers. According to the Swiss National data base Info Flora (www.infoflora.ch 2017), *M. germanica* went extinct upstream of Rhäzüns. Between Rhäzüns and Zizers-Mastrils no observations were recorded. Only upstream of Cauma are records from 2014 and 2016.

Four population models can be distinguished for terrestrial and aquatic species along rivers: isolated, spatially structured populations, metapopulation and continuous populations (Pollux et al. 2008). A population genetic study of *M. germanica* by Werth & Scheidegger (2014) revealed, that the remaining population along the Alpine Rhine form a metapopulation. They could detect historical geneflow between the remaining populations. But seed input from outside of the study areas occurs probably rarely, when the dispersal kernel of *M. germanica* is taken in to account. Fink et al. 2017 calculated a dispersal kernel for *M. germanica* based on field and experimental data collected along the river of

Sense. The probability curve is characterised by a polynomic function, where most of the seeds falling next to the mother shrub and only small proportion reaching more than 25 m (leptokurtic curve).

For the persistence of the riparian plant in the catchment of the Alpine Rhine, the three floodplains are of great importance due to the rarity of suitable habitat along the three rivers. The size and complexity of Rhäzüns, the habitat dynamics, the distribution of *Myricaria germanica* along the whole floodplain and the family structure with all age classes along the section suggest that *M. germanica* is not immediately threated in this study area. Populations in Zizers-Mastrils floodplain and Cauma are more vulnerable to large flood events, and especially because of their location close to the main stream, and the concentration of *M. germanica* on a few gravel banks. Additionally, a part of the current population is threated due to continuing plant succession to closed forest. For the future we have to continue to expect large population fluctuations in these two floodplains.

5 Conclusion

The habitat composition of the three floodplains of national importance studied here and populations of *Myricaria germanica* fluctuated strikingly over the study period. All study areas showed a trend to late successional stages. Despite of gravel extraction, alternated discharge and river regulation *M. germanica* could persist in all three sites, whereby populations in Cauma and Zizers-Mastrils declined until 2017. In the complex and dynamic floodplain of Rhäzüns, the riparian plant was spread over the whole floodplain. Whereby in Cauma and Zizers-Mastrils *M. germanica* was concentrated to a few gravel banks and, due to the lower floodplain complexity, the shrub species was much more exposed to large flood events and more sensitive to population fluctuation compared to Rhäzüns.

The three study areas are among the last remaining floodplains along the Alpine Rhine, 'Hinterrhein' and 'Vorderrhein', and therefore these sites are of great importance for the preservation of the German Tamarisk in the catchment of Alpine Rhine. For conservation of these populations it is important that areas of suitable habitat do not decline, and populations do not continue to experience erosion at the edges. Therefore, maintenances should focus on a natural bed load balance and discharge, so that it is possible to reconnect gravel banks again and allow recolonisation. In addition, stepping stone habitat between the study areas could further support the metapopulation system.

Since floodplains showed advanced succession compare to 1973, it is important to further investigate the dynamics of the floodplains. Open questions are: 1) whether closed shrub vegetation and forest further increase or if it will even out, and 2) what the main factors for this directional change are and how gravel banks can be reconnected. By consulting digital elevation models, it would be possible to analyse gravel bank movements and inundation frequency of gravel banks. To learn more about population dynamics of *M. germanica* populations investigated in this study should be surveyed again in a few years and compared with the data presented here. In addition, the precise survey of *M. germanica* in this study can now be used for analyses of metapopulation structure within floodplains.

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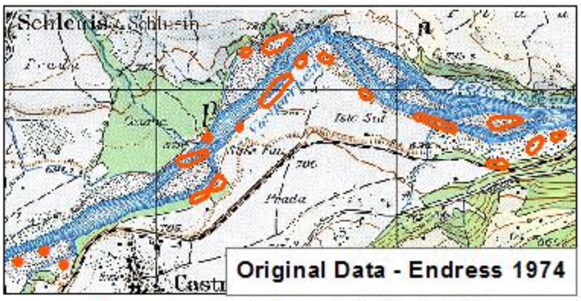
7 List of tables

8 List of figures

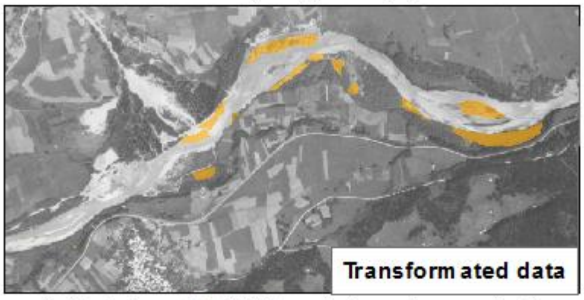
Appendix

Appendix 1 Historical records – Data transformation (Examples)

Cauma

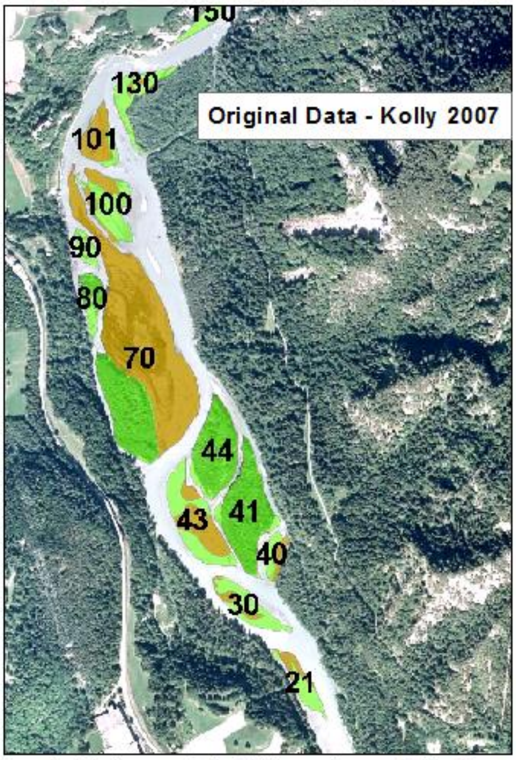


Map source: Landeskarte der Schweiz 1966
1:50'000 (LK50) (swisstopo)



Aerial photograph: Luftbilder swisstopo schwarzweiss ©
1973 swisstopo (5704000000)

Rhäzüns



Aerial photograph: Luftbilder swisstopo farbig ©
2005 swisstopo (5704000000)

Aerial photograph: Luftbilder swisstopo farbig ©
2008 swisstopo (5704000000)

Appendix 2 On-site inspection permit

Amt für Natur und Umwelt
Uffizi per la natira e l'ambient
Ufficio per la natura e l'ambiente

- 2. MRZ. 2017

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3. März 2017
2017-24
AV-2017-70 La

AMTSVERFÜGUNG

Bewilligung für das Sammeln von Pflanzen in Schutzgebieten zu wissenschaftlichen Zwecken

Mit Schreiben vom 1. Februar 2017 und ergänzenden Projektangaben vom 6. Februar 2017 ersucht Prof. Dr. Christoph Scheidegger, Projektleiter an der Eidg. Forschungsanstalt für Wald, Schnee und Landschaft (WSL), um eine Bewilligung für das Betreten von Schutzgebieten (Auen) und das Sammeln von Pflanzenbelegen der Deutschen Tamariske. Das Gesuch steht im Zusammenhang mit Studien zur Populationsdynamik der Deutschen Tamariske am Rhein. In den Auengebieten Cauma, Rhäzünser Rheinauen und Rheinauen Zizers-Mastrils sollen die Pflanzenpopulationen und Bodenstandorteigenschaften erfasst und zur Charakterisierung der Populationen Pflanzenmaterial gesammelt werden. Die Mengen sind gering und für die Pflanzen problemlos.

Die Deutsche Tamariske ist in Graubünden zwar nicht geschützt, aber nach der roten Liste verletzlich und aufgrund der Standortansprüche in Auen generell schützenswert. Diesem Umstand soll Rechnung getragen werden, indem die Pflanzenbestände und Standorteigenschaften weitgehend mit Bild- und Kartenauswertungen erfasst werden. Dazu ist jedoch eine Begehung der Pflanzenstandorte in den Auen erforderlich. Dabei ist es wichtig das Brutgeschäft von Flussuferläufer und Flussregenpfeifer, als sensible und seltene Zeigerarten für diesen Lebensraum, nicht zu stören.

Gestützt auf Art. 22 Abs. 1 des Natur- und Heimatschutzgesetzes vom 1. Juli 1966 (NHG; SR 451) und Art. 21 Abs. 2 des Gesetzes über den Natur- und Heimatschutz im Kanton Graubünden vom 19.Oktober 2010 (Kantonales Natur- und Heimatschutzgesetz, KNHG; BR 496.000) wonach die zuständige kantonale Behörde das Sammeln geschützter Arten und das Sammeln in Schutzgebieten zu wissenschaftlichen Zwecken bewilligen kann,

wird verfügt:

1. Herr Prof. Dr. Christoph Scheidegger, WSL Birmensdorf, und den Projektbeteiligten Dr. Sabine Fink, Andrea Wiedmer und Walter Florian wird die Bewilligung erteilt, im Rahmen des Gesuches zur Erforschung der Deutschen Tamariske die Auen Cauma, Rhäzünser Rheinauen und Rheinauen Zizers-Mastrils zu begehen sowie die nötigen Belege für die Charakterisierung der Populationen zu sammeln.

2. Die Bewilligung ist zum Schutz der seltenen Vogelarten Flussuferläufer und Flussregenpfeifer an die Bedingung geknüpft die Auen während der Brutzeit vom 1. Mai bis 15. Juli nicht zu betreten, Störungen in der übrigen Zeit so gering wie möglich zu halten und sich sofort zurückziehen beim Vernehmen von Warnrufen der Vögel oder bei Sichtung aufgeschreckter Tiere. Dies gilt insbesondere für die Zeit vom 1. April bis 1. Mai.

3. Die Bewilligung gilt für das Jahr 2017.

4. Gegen diesen Entscheid kann innert 30 Tagen seit der Mitteilung Verwaltungsbeschwerde an das Erziehungs-, Kultur- und Umweltschutzdepartement, Quaderstrasse

Erziehungs-, Kultur- und Umweltschutzdepartement
Departament d'educaziun, cultura e protecziun da l'ambient
Dipartimento dell'educazione, cultura e protezione dell'ambiente

17, 7001 Chur, erhoben werden. Die angefochtene Verfügung und allfällige Beweismittel sind beizulegen.

5. **Mitteilung an:**
   - Prof. Dr. Christoph Scheidegger, Biodiversität und Naturschutzbiologie, Eidg. Forschungsanstalt WSL, Zürcherstrasse 111, 8903 Birmensdorf
   - Amt für Jagd und Fischerei, Loestrasse 14, intern

Abteilung Natur und Landschaft
Der Leiter

Andreas Cabalzar

Appendix 3 Field protocol

Protocol for singel plants and dense M. germanica stands

Date:		Study area:		Editors:	
Time:		Altitude:	Accurency:	1. Coordinate:	

Bank No.:	

	Pop	Point (max 2m)	Polygon	Size [cm] MIN	Size [cm] MAX	Age class	Steril/Feril	Count	Competition	Habitat type		Notes
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												
23												
24												
25												
26												
27												
28												
29												
30												
31												
32												
33												
34												
35												

Age classes:
[1] juvenil, up to ca. 20 cm, little branched (Take a sediment sample from the first plant of the gravel bank)
[2] 21 - 60 cm, few lignify branches, Mg from a seed
[3] 61 - 300cm, a lot basal branched
[4] > 1m very old individuals with a lot of dead branches
[5] dead Mg individuals

Bank No.: Given in advance, based on aerial photo, for orientation
Point/Polygon: Waypoint number given by GPS
Point: All plants within 2m around the Waypoint
Polygon: Around dense stands or even dispersed Mg

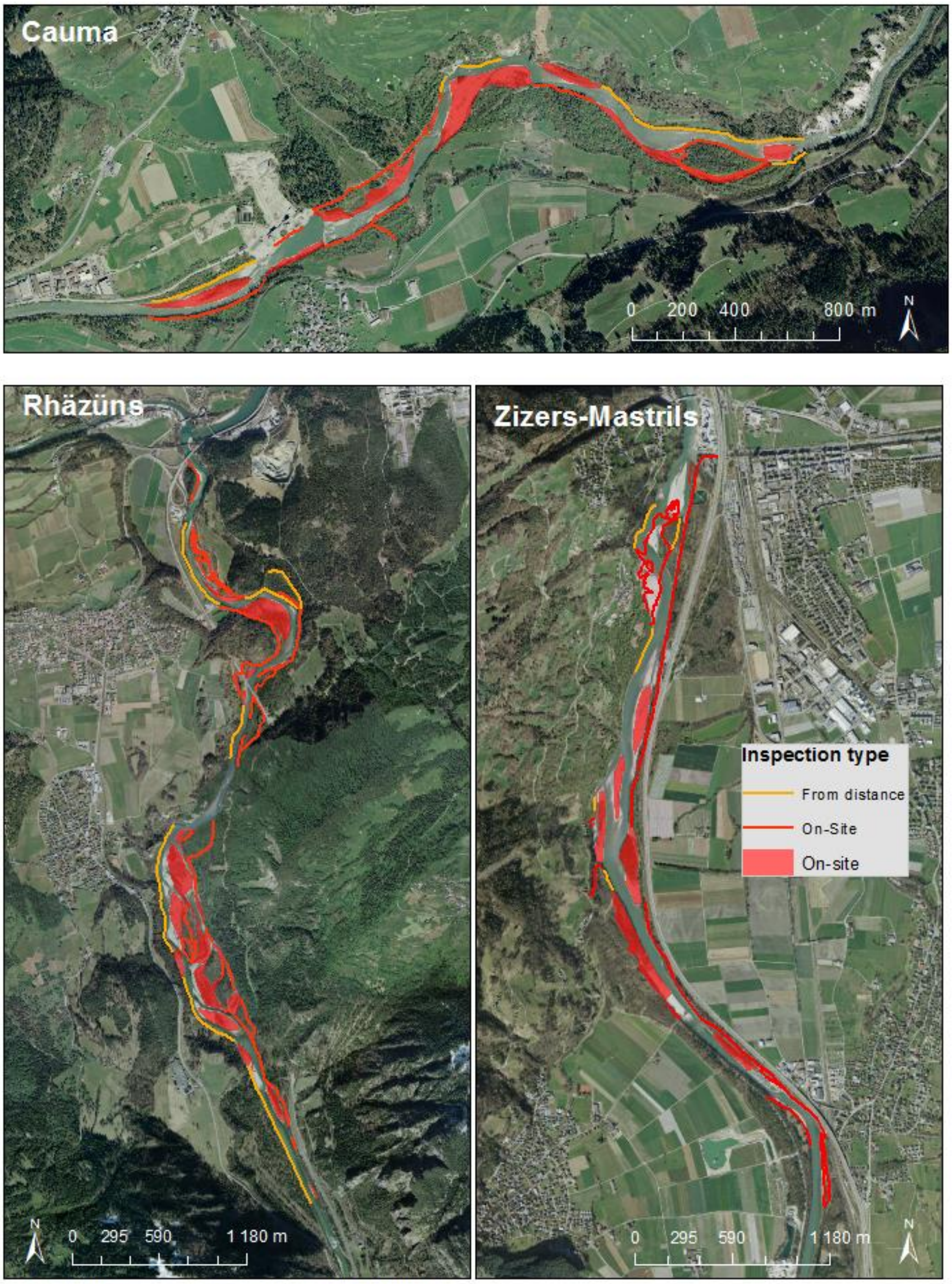
Habitat type and mean height
Primary vegatation [P]: mainly herbaceous plants, Mg possible
Shrub vegetation [S], dense [d], open [o]: shrub +/- 6 m, dominant species: Salix, Mg, Hippophae rhamnoides
Floodplain forest [F]: trees dominate, characteristic species: Salix alba, Alnus incana, Alnus glutinosa, Fraxinus excelsior, Quercus
Mark gravel banks without vegetation

Competition within 1 m:
[0] no competitors
[1] 1 or more plants smaler than Mg
[2] 1 - 2 plants bigger than Mg
[3] 3 or more bigger than Mg

Steril/Fertil
S = Steril **F** = Fertil
? = Unsure **FF** = Strong flowering, more than 10 inflorescences

Salix seedlings
Sand linse where are Salix seedlings (>20cm) but no Mg
Size of area in m2

Appendix 4 On-site inspection maps



Source: Swissimage © 2014 swisstopo (5704000000)

Appendix 5 Detailed information about aerial photographs

Image	Image Nr / Name	Flight data	Scale	Film type	Orthophoto	GCP	RMSE	Pixel
ca_1973	19731830028192	26.06.1973	1:20900	bw	A. Wiedmer	8	2.9	0.25
ca_1984	19849990112502	27.06.1984	1:23900	bw	A. Wiedmer	8	1.3	0.25
ca_1990	wbs_t0_ortho_2_100513_29_1990	13.07.1990		bw	C. Ginzler, WSL			0.5
ca_1997	19971840024533	25.08.1997	1:26100	bw	Swisstopo			0.5
ca_2008	swissimage_ads40_03_level_2_25cm_fj_2008_1194-43	09.09.2008		color	Swisstopo			0.5
ca_2008	swissimage_ads40_03_level_2_25cm_fj_2008_1194-44	09.09.2008		color	Swisstopo			0.5
ca_2014	swissimage_DOP25_LV03_1194-43_2014_1_14	13.03.2014, 17.04.2014		color	Swisstopo			0.25
ca_2014	swissimage_DOP25_LV03_1194-44_2014_1_14	13.03.2014, 17.04.2014		color	Swisstopo			0.25
rh_1973	19731860029330	09.08.1973	1:27500	bw	A. Wiedmer	9	2.5	0.25
rh_1985	wbs_t0_ortho_2_100513_27_1985	23.07.1985		bw	C. Ginzler, WSL			0.5
rh_1990	19901830024022	13.07.1990	1:23500	bw	A. Wiedmer	8	1.76	0.25
rh_1990	19901860024215	20.07.1990	1:22900	bw	A. Wiedmer	8	1.5	0.25
rh_1999	19991840041737	25.07.1999	1:26000	color	A. Wiedmer	10	1.16	0.25
rh_2008	swissimage_ads40_03_level_2_25cm_fj_2008_1195-14	09.09.2008		color	Swisstopo			0.5
rh_2008	swissimage_ads40_03_level_2_25cm_fj_2008_1195-23	09.09.2008		color	Swisstopo			0.5
rh_2008	swissimage_ads40_03_level_2_25cm_fj_2008_1195-32	09.09.2008		color	Swisstopo			0.5
rh_2008	swissimage_ads40_03_level_2_25cm_fj_2008_1195-34	09.09.2008		color	Swisstopo			0.5
rh_2008	swissimage_ads40_03_level_2_25cm_fj_2008_1195-41	09.09.2008		color	Swisstopo			0.5
rh_2008	swissimage_ads40_03_level_2_25cm_fj_2008_1195-43	09.09.2008		color	Swisstopo			0.5

Image	Image Nr / Name	Flight data	Scale	Film type	Orthophoto	GCP	RMSE	Pixel
rh_2014	swissimage_DOP25_LV03_1195-14_2014_1_14	13. 03.2014, 06.06.2014, 17.04.2014		color	Swisstopo			0.25
rh_2014	swissimage_DOP25_LV03_1195-23_2014_1_14	13. 03.2014, 06.06.2014, 17.04.2014		color	Swisstopo			0.25
rh_2014	swissimage_DOP25_LV03_1195-32_2014_1_14	13. 03.2014, 06.06.2014, 17.04.2014		color	Swisstopo			0.25
rh_2014	swissimage_DOP25_LV03_1195-34_2014_1_14	13. 03.2014, 06.06.2014, 17.04.2014		color	Swisstopo			0.25
rh_2014	swissimage_DOP25_LV03_1195-41_2014_1_14	13. 03.2014, 06.06.2014, 17.04.2014		color	Swisstopo			0.25
rh_2014	swissimage_DOP25_LV03_1195-43_2014_1_14	13. 03.2014, 06.06.2014, 17.04.2014		color	Swisstopo			0.25
rh_2014	swissimage_DOP25_LV03_1215-12_2014_1_13	13. 03.2014, 06.06.2014, 17.04.2014		color	Swisstopo			0.25
rh_2014	swissimage_DOP25_LV03_1215-21_2014_1_13	13. 03.2014, 06.06.2014, 17.04.2014		color	Swisstopo			0.25
zi_1973	19739990168133	26.06.1973	1:22200	bw	A. Wiedmer	9	1.6	0.25
zi_1985	19852040023540	23.07.1985	1:26100	bw	A. Wiedmer	9	1.6	0.25
zi_1990	19902010014948	23.08.1990	1:22200	bw	A. Wiedmer	9	1.72	0.25
zi_1997	19972040033446	22.07.1997	1:25500	bw	Swisstopo			0.5
zi_2008	swissimage_ads40_03_level_2_25cm_fj_2008_1175-22	06.05.2008		color	Swisstopo			0.25
zi_2008	swissimage_ads40_03_level_2_25cm_fj_2008_1175-24	06.05.2008		color	Swisstopo			0.25
zi_2008	swissimage_ads40_03_level_2_25cm_fj_2008_1175-42	06.05.2008		color	Swisstopo			0.25
zi_2008	swissimage_ads40_03_level_2_25cm_fj_2008_1176-11	06.05.2008		color	Swisstopo			0.25
zi_2008	swissimage_ads40_03_level_2_25cm_fj_2008_1176-13	06.05.2008		color	Swisstopo			0.25
zi_2008	swissimage_ads40_03_level_2_25cm_fj_2008_1176-31	06.05.2008		color	Swisstopo			0.25
zi_2014	swissimage_DOP25_LV03_1175-22_2014_1_14	12.03.2014		color	Swisstopo			0.25
zi_2014	swissimage_DOP25_LV03_1175-24_2014_1_14	12.03.2014		color	Swisstopo			0.25
zi_2014	swissimage_DOP25_LV03_1175-42_2014_1_14	12.03.2014		color	Swisstopo			0.25
zi_2014	swissimage_DOP25_LV03_1176-11_2014_1_14	12.03.2014		color	Swisstopo			0.25
zi_2014	swissimage_DOP25_LV03_1176-13_2014_1_14	12.03.2014		color	Swisstopo			0.25
zi_2014	swissimage_DOP25_LV03_1176-31_2014_1_14	12.03.2014		color	Swisstopo			0.25

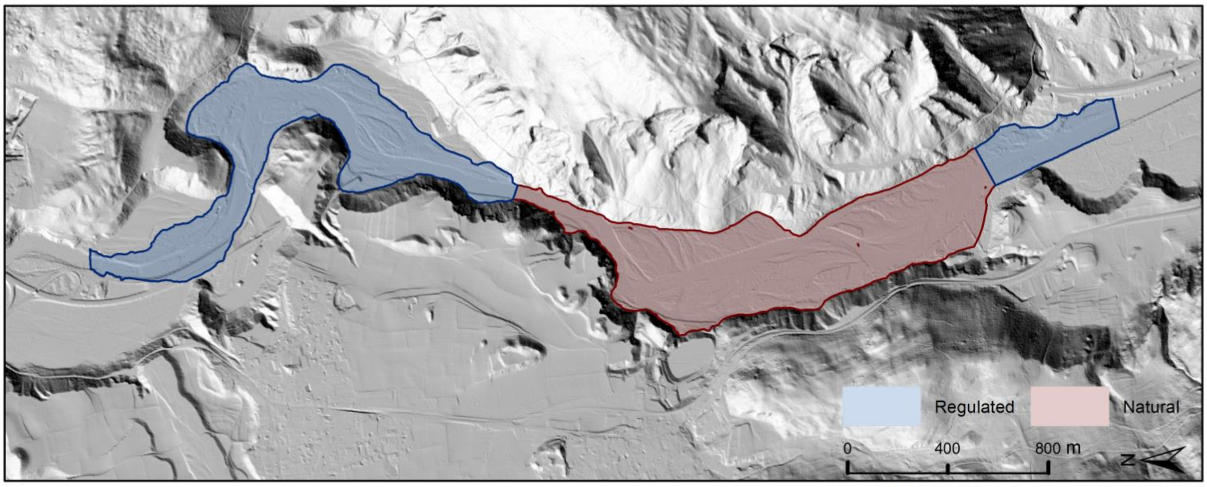
Appendix 6 Habitat classification key - for black/white aerial photographs

Habitat type	Tone	Color	Size	Texture	Pattern	Shadow
Water	Bright to dark	Blue – green, riffles white, low water -> green to grey	Large patches, elongated shape, coherent area	Even flow fine, riffles coarse	Riffles	No
Gravel bank without vegetation	Brightest tone	White – grey, wet sand darker grey, often wet gravel banks greenish	Different shapes and sizes	Fine to coarse	Wet – dry sand patterns	No
Primary vegetation – Open shrub	Dark and bright	Green to brown on light to dark grey ground	Different shapes and sizes	Small patches	Pattern of primary veg. and single shrub plants, cover ratio < 35 %	Negligible
Shrub patchy	Dark and bright	Green to brown on light to dark grey ground	Different shapes and sizes	Large patches	Group of shrub plants with gaps between, groups, cover ratio 35 – 94 %	Small shadow
Closed shrub	Dark	Green to brown	Different shapes and sizes	Less rough than forest	Small shrub crowns visi-ble, smaller than tree crowns, cover ratio > 95 %	Small shadow
Forest	Darkest tone	Dark green conifers, lighter green hardwood	Different shapes and sizes	Rough	Single tree crowns visible	Large shadow
Agriculture	Dark	Green to brown	Different shapes and sizes	Less rough than closed shrub	Parallel management traces visible	No
Gravel extraction	Bright, similar to Gravel banks	White – grey, wet sand darker grey, often wet gravel banks greenish	Different shapes and sizes	Rougher than Gravel banks	Lanes, artificial ponds, artificial squared structures	No
Bank protection - rocks	Bright	White – grey	Elongated shape	Rough	Squared stones visible	No
Rocks	Bright, similar to gravel bank	White – grey with green - brown	Different shapes and sizes	Smooth	No	No
Roads	Bright, similar to gravel banks	Grey - brown	Elongated shape, > 3 m wide	Smooth	No	No

Appendix 7 Raster extent setting in R

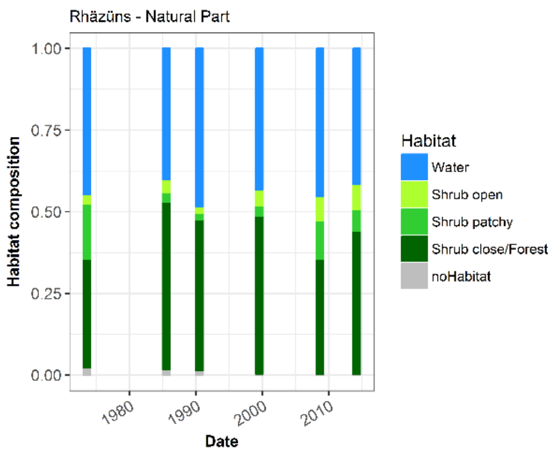
```
# CAUMA

Ca.grid.r <- raster(ncol= 6028, nrow= 2367, xmn=735912.5,
      xmx=738926.5, ymn=182074.8, ymx=183258.3) # res = 0.5 m

crs(Ca.grid.r) <- "+init=epsg:21781"


# RHÄZÜNS

Rh.grid.r <- raster(ncol=2781, nrow= 12111, xmn=749967.4,
      xmx=751357.9, ymn=181722.9, ymx=187778.8) # res = 0.5 m

crs(Rh.grid.r) <- "+init=epsg:21781"


# ZIZERS-MASTRILS

Zi.grid.r <- raster(ncol= 2982, nrow= 9501, xmn=760016.6,
      xmx=761507.5, ymn=199430.6, ymx=204181) # res = 0.5 m

crs(Zi.grid.r) <- "+init=epsg:21781"
```

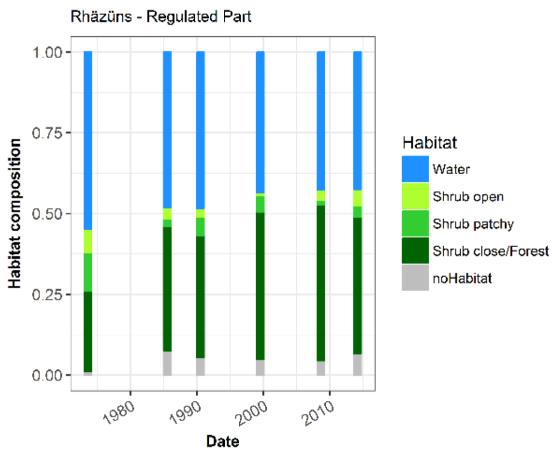
Appendix 8 Results Rhäzüns – Divided into regulated and natural floodplain areas



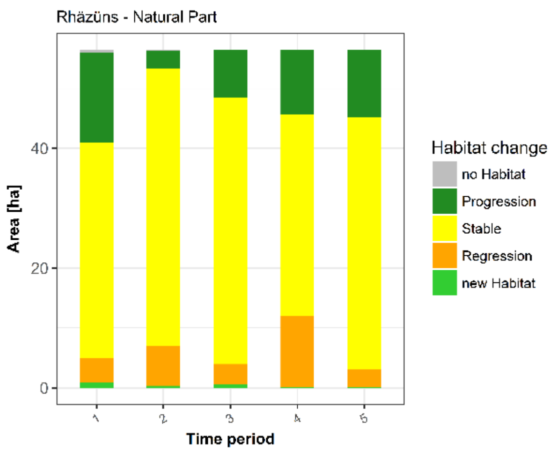
Source: swissALTI3D © 2014 swisstopo (5704000000)

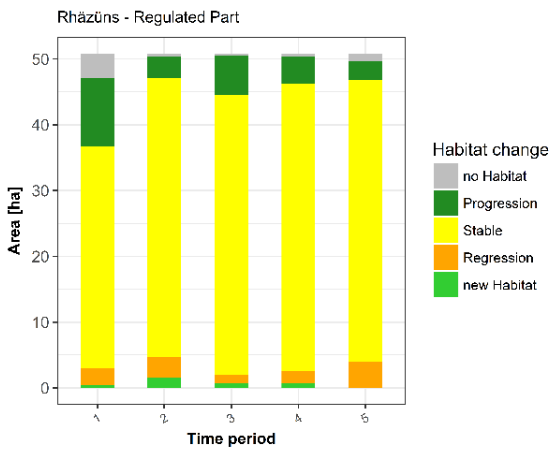
Habitat composition





Habitat changes





Habitat composition (in percent)

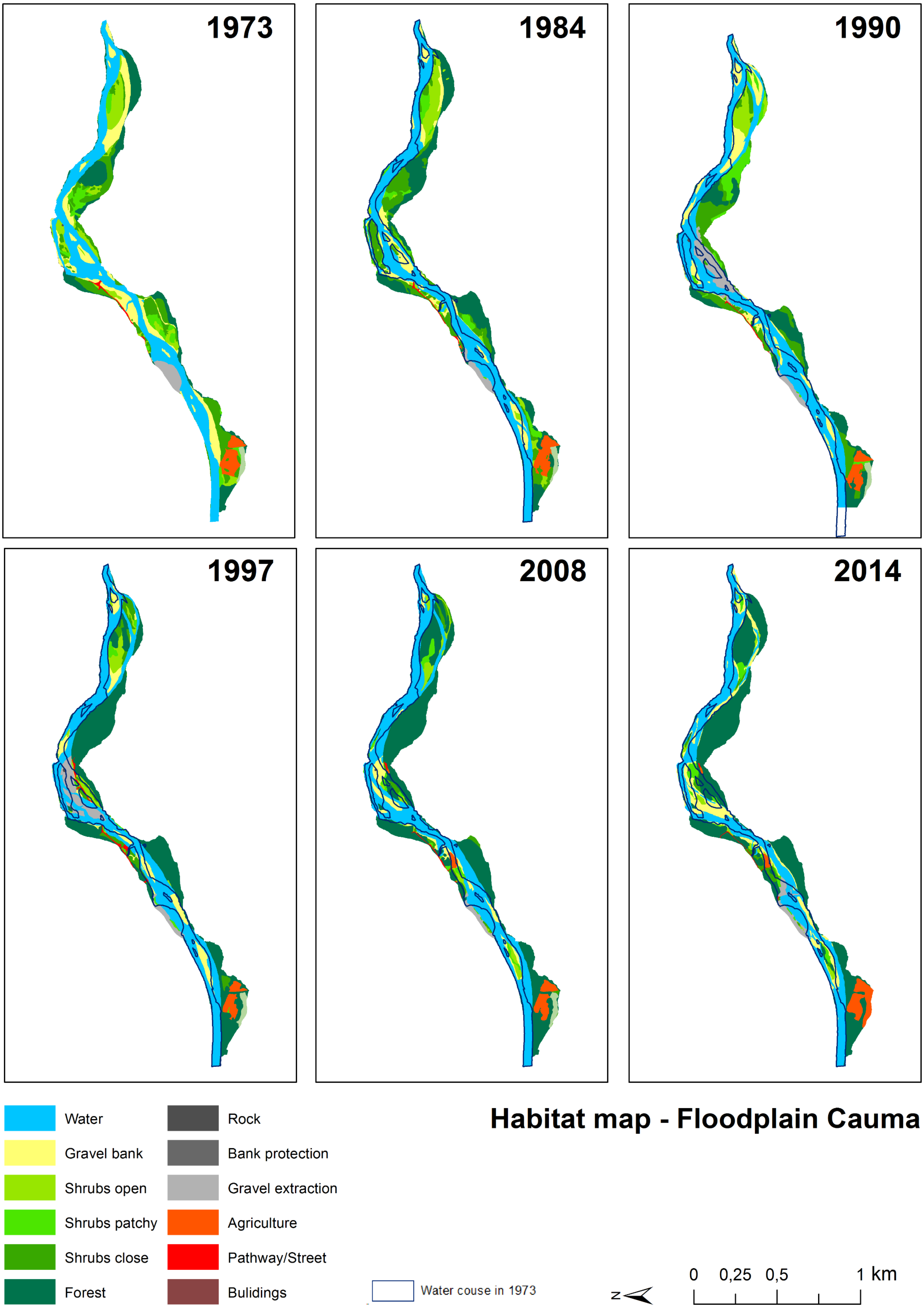
RHÄZÜNS - Natural Part	1973	1985	1990	1999	2008	2014	Mean	STDEV
Water/Gravel	44.71	40.18	48.56	43.21	45.20	41.58	**43.91**	*2.96*
Primary veg./Shrub open	2.99	3.83	1.77	5.01	7.50	7.68	**4.80**	*2.41*
Shrub patchy	16.79	3.02	2.08	3.01	11.90	6.66	**7.24**	*5.93*
Shrub close/Forest	33.19	51.30	46.24	48.40	35.25	43.86	**43.04**	*7.29*
No Habitat	2.32	1.67	1.35	0.38	0.14	0.23	**1.01**	*0.90*

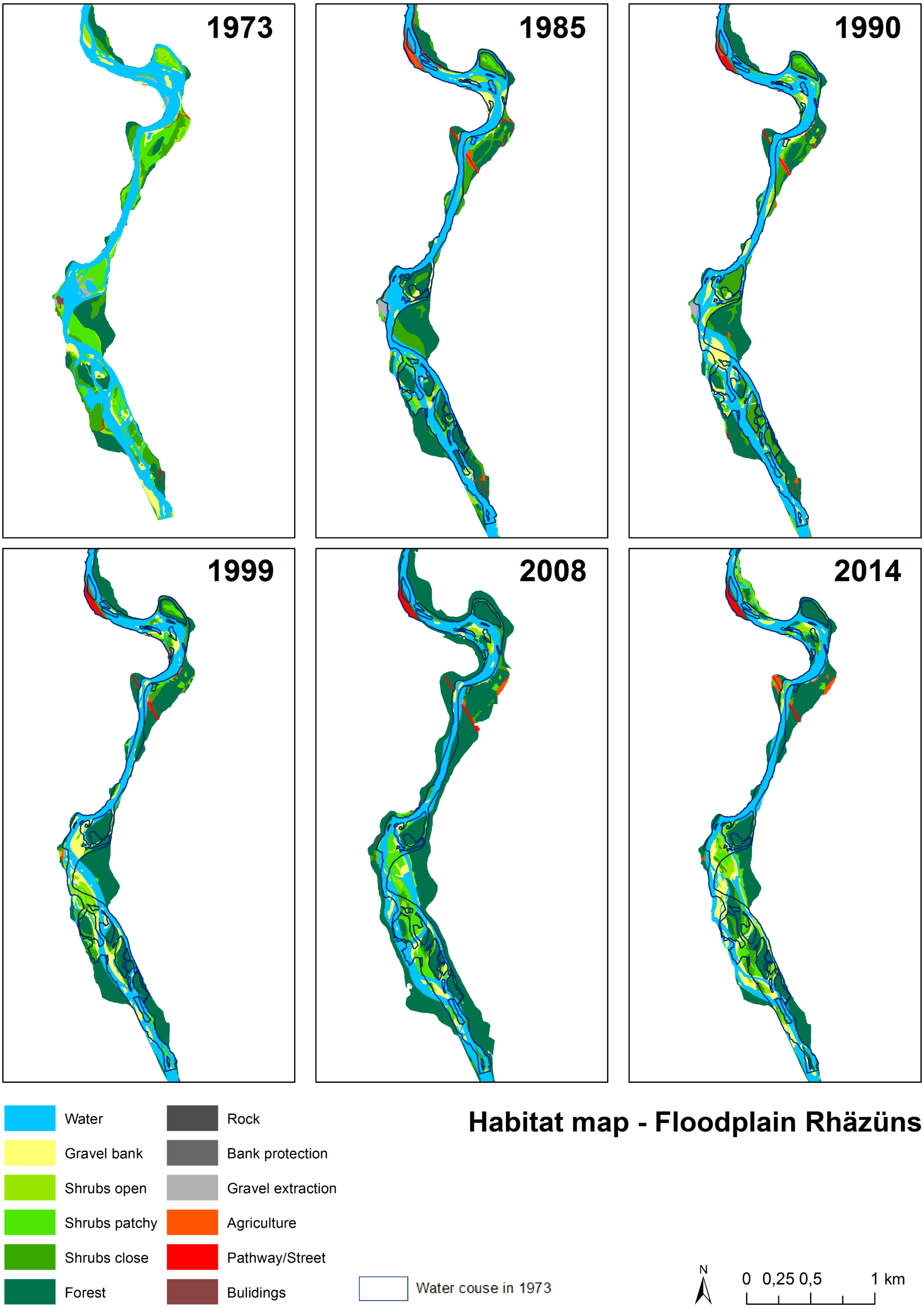
RHÄZÜNS - Regulated Part	1973	1985	1990	1999	2008	2014	Mean	STDEV
Water/Gravel	54.80	48.24	48.38	43.59	42.68	42.50	**46.70**	*4.78*
Primary veg./Shrub open	7.22	3.31	2.75	0.78	3.14	5.00	**3.70**	*2.19*
Shrub patchy	11.79	2.43	5.60	5.08	1.41	3.53	**4.97**	*3.69*
Shrub close/Forest	25.03	38.50	37.75	45.65	48.27	42.26	**39.58**	*8.19*
No Habitat	1.15	7.52	5.51	4.90	4.51	6.71	**5.05**	*2.22*

Habitat changes (in percent)

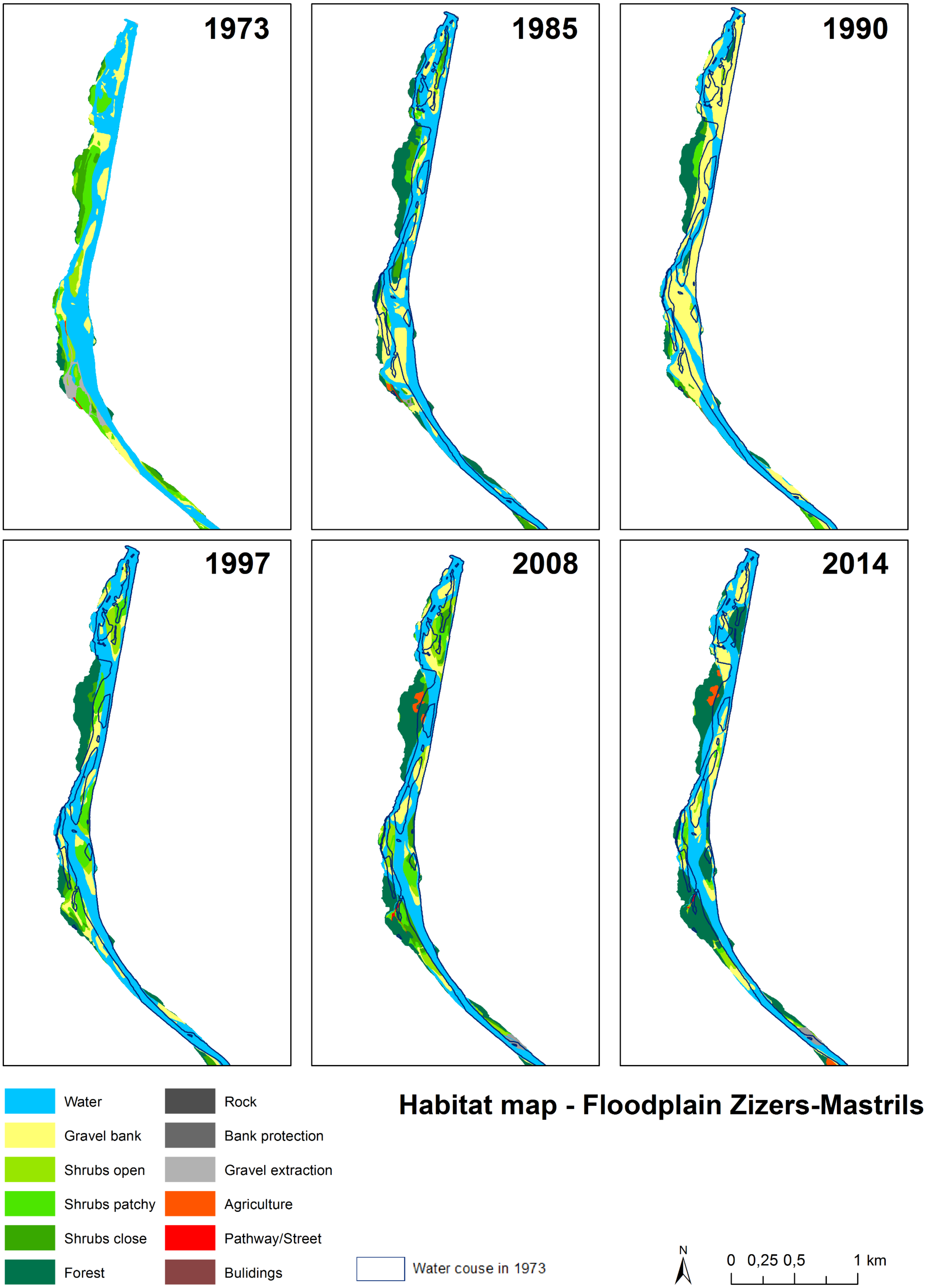
RHÄZÜNS - Natural Part	1973 - 1985	1985 - 1990	1990 - 1999	1999 - 2008	2008 - 2014	Mean	STDEV
Progression	26.54	5.23	14.26	19.16	19.94	**17.03**	*7.91*
Stable	63.70	82.03	78.70	59.48	74.42	**71.67**	*9.70*
Regression	7.19	11.84	6.00	21.04	5.36	**10.29**	*6.52*
ToNoHabitat	0.95	0.29	0.04	0.04	0.18	**0.30**	*0.38*
ToHabitat	1.61	0.61	1.00	0.28	0.10	**0.72**	*0.61*

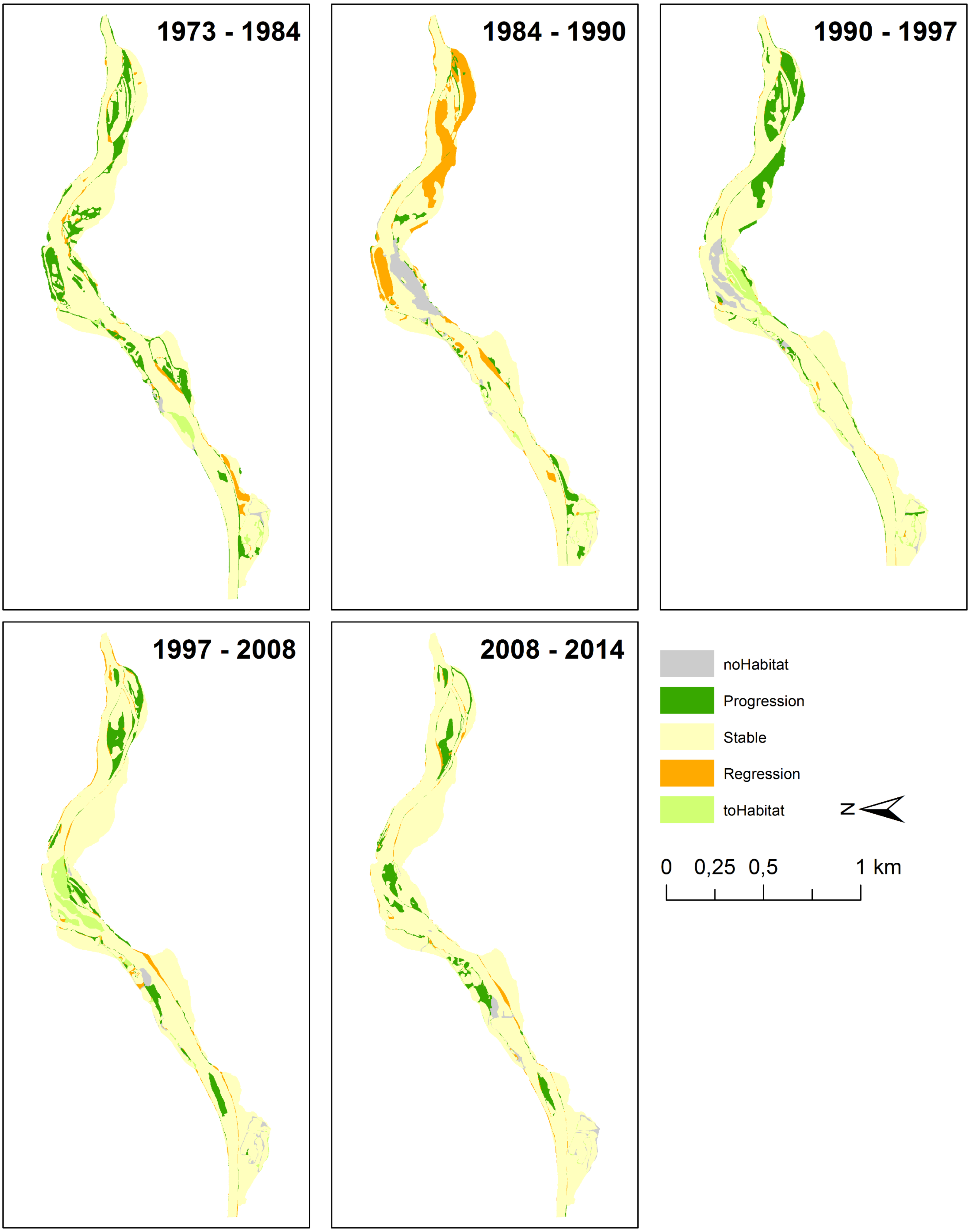
RHÄZÜNS - Regulated Part	1973 - 1985	1985 - 1990	1990 - 1999	1999 - 2008	2008 - 2014	Mean	STDEV
Progression	20.41	6.34	11.58	8.05	5.74	**10.42**	*6.03*
Stable	66.38	83.31	83.79	85.98	84.15	**80.72**	*8.08*
Regression	5.02	6.26	2.43	3.73	7.73	**5.03**	*2.07*
ToNoHabitat	7.28	1.05	0.79	0.92	2.29	**2.47**	*2.76*
ToHabitat	0.91	3.05	1.40	1.32	0.09	**1.35**	*1.08*


1973
1984
1990
1997
2008
2014
Water
Gravel bank
Shrubs open
Shrubs patchy
Shrubs close
Forest
Rock
Bank protection
Gravel extraction
Agriculture
Pathway/Street
Bulidings
Water couse in 1973
Habitat map - Floodplain Cauma
N
0 0,25 0,5 1 km

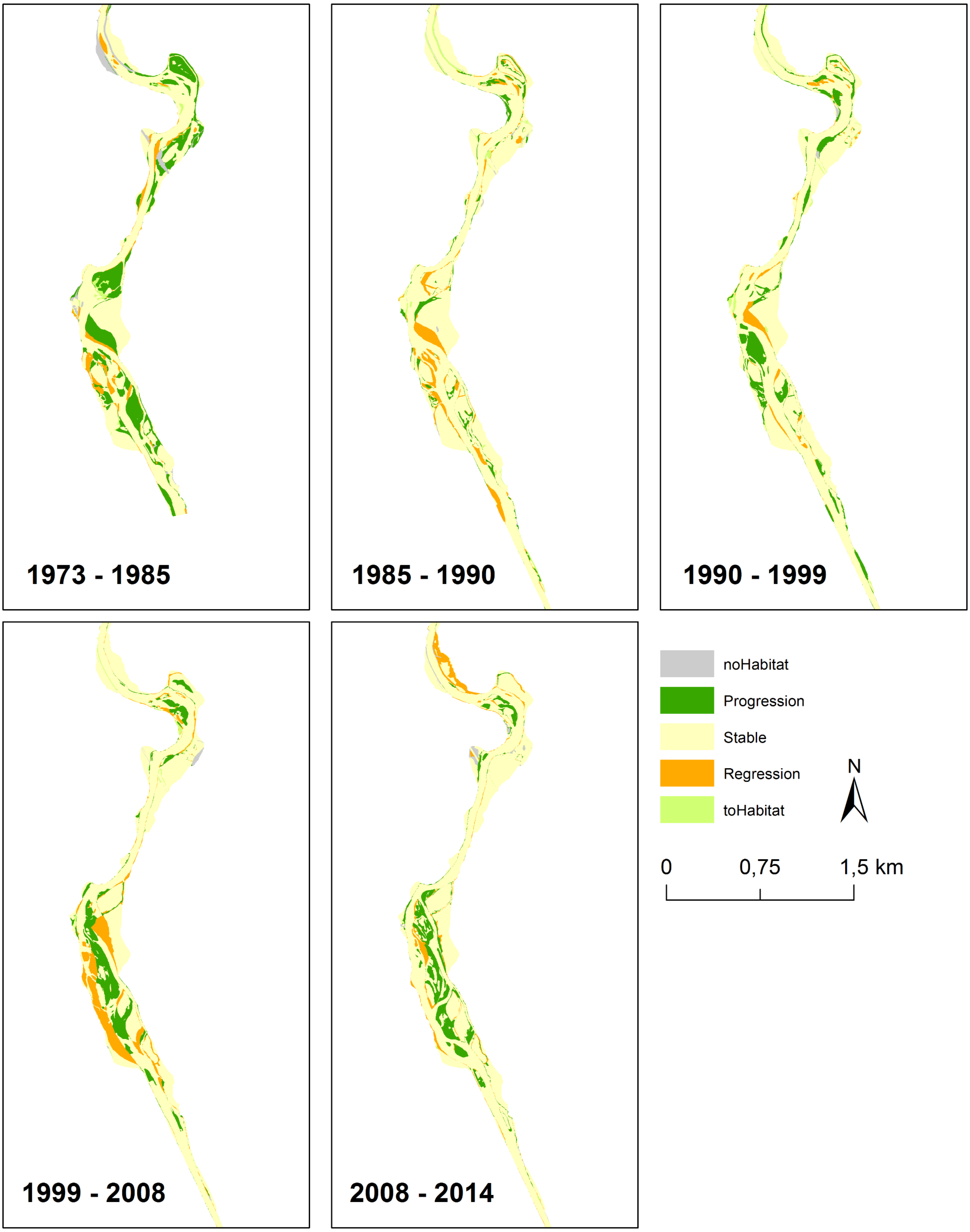


Habitat map - Floodplain Rhäzüns

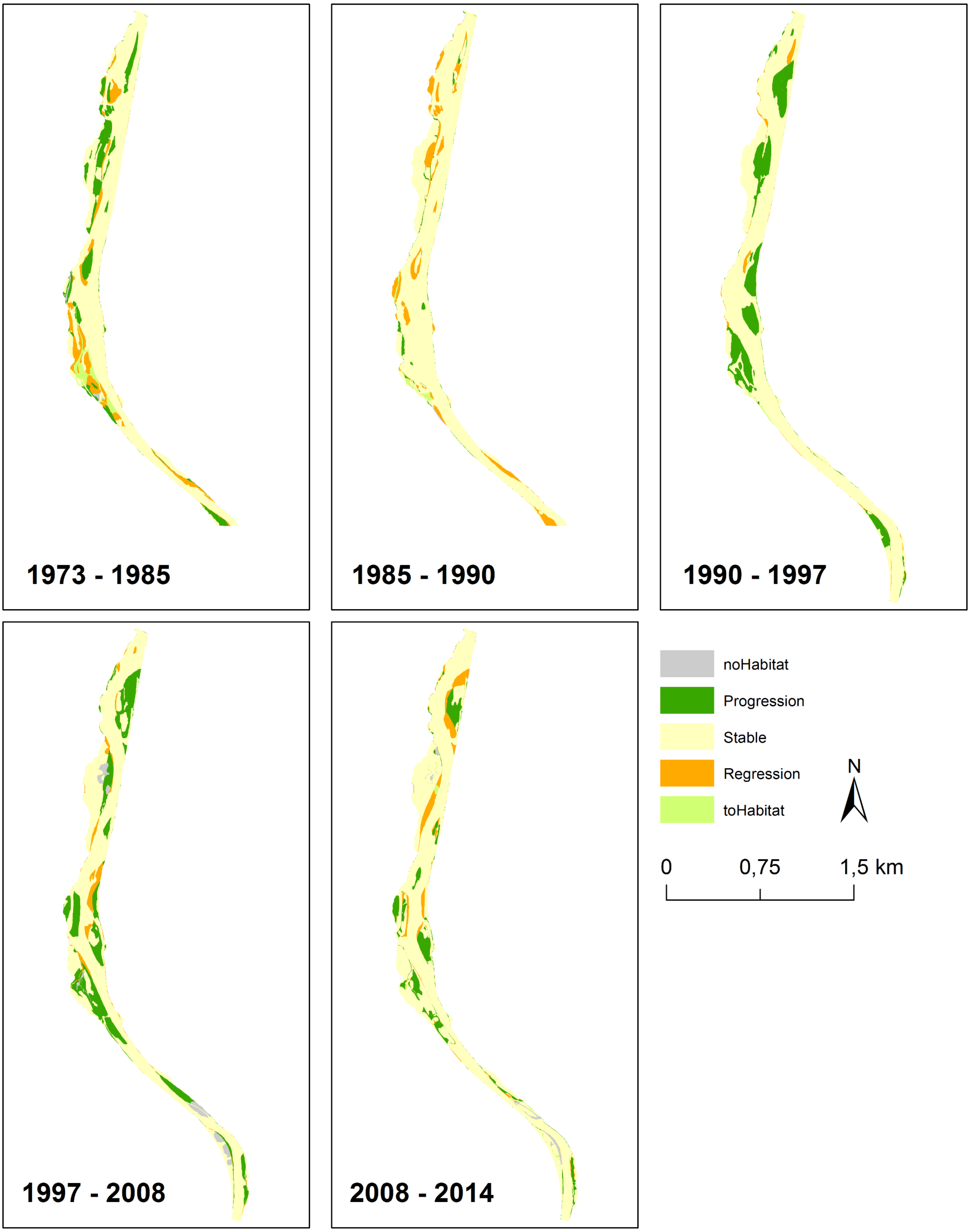

1973
1985
1990
1997
2008
2014
Water
Gravel bank
Shrubs open
Shrubs patchy
Shrubs close
Forest
Rock
Bank protection
Gravel extraction
Agriculture
Pathway/Street
Bulidings
Habitat map - Floodplain Zizers-Mastrils
Water couse in 1973
N
0 0,25 0,5 1 km



Habitat change map - Floodplain Cauma



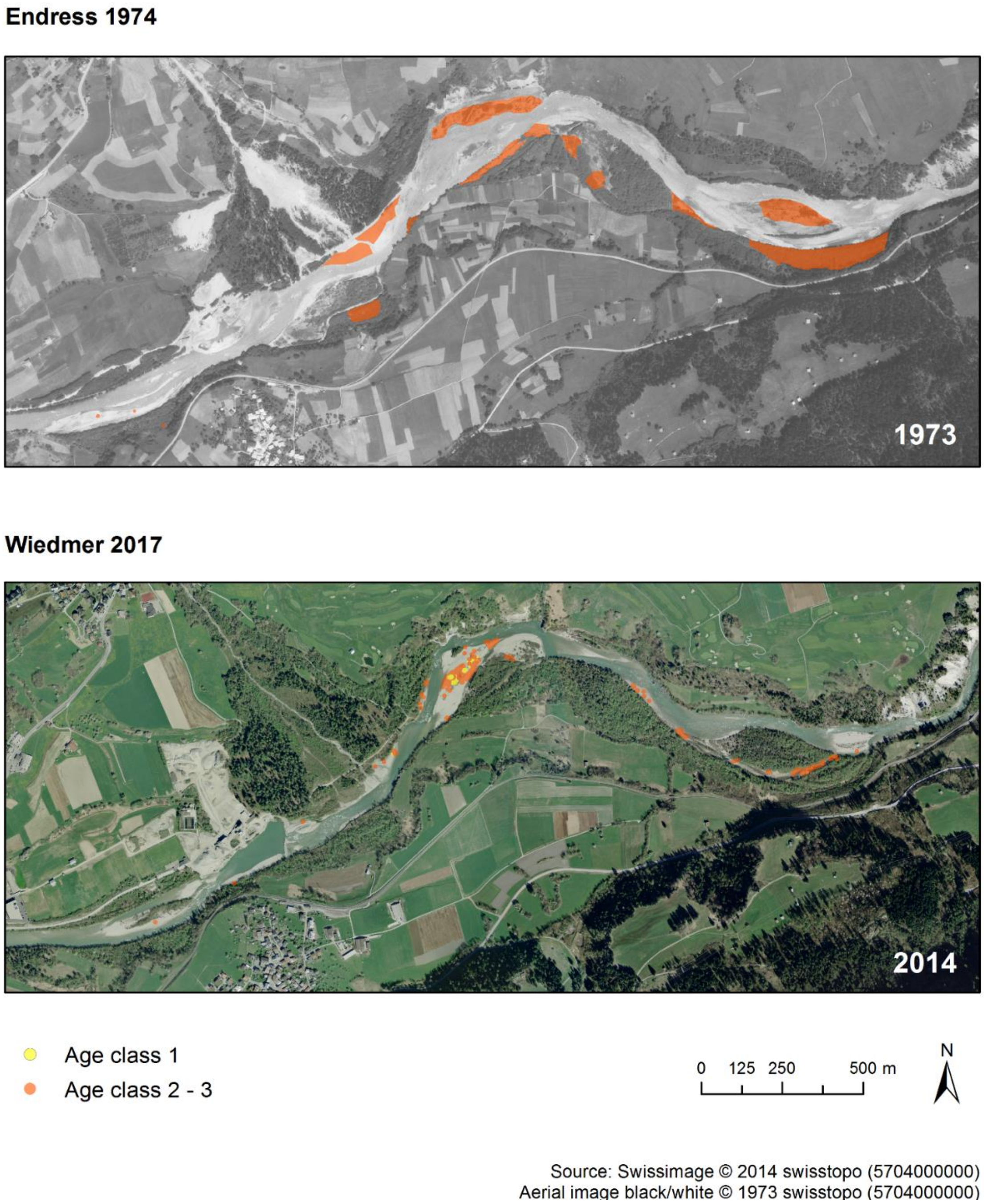
Habitat change map - Floodplain Rhäzüns



Habitat change map - Floodplain Zizers-Mastrils

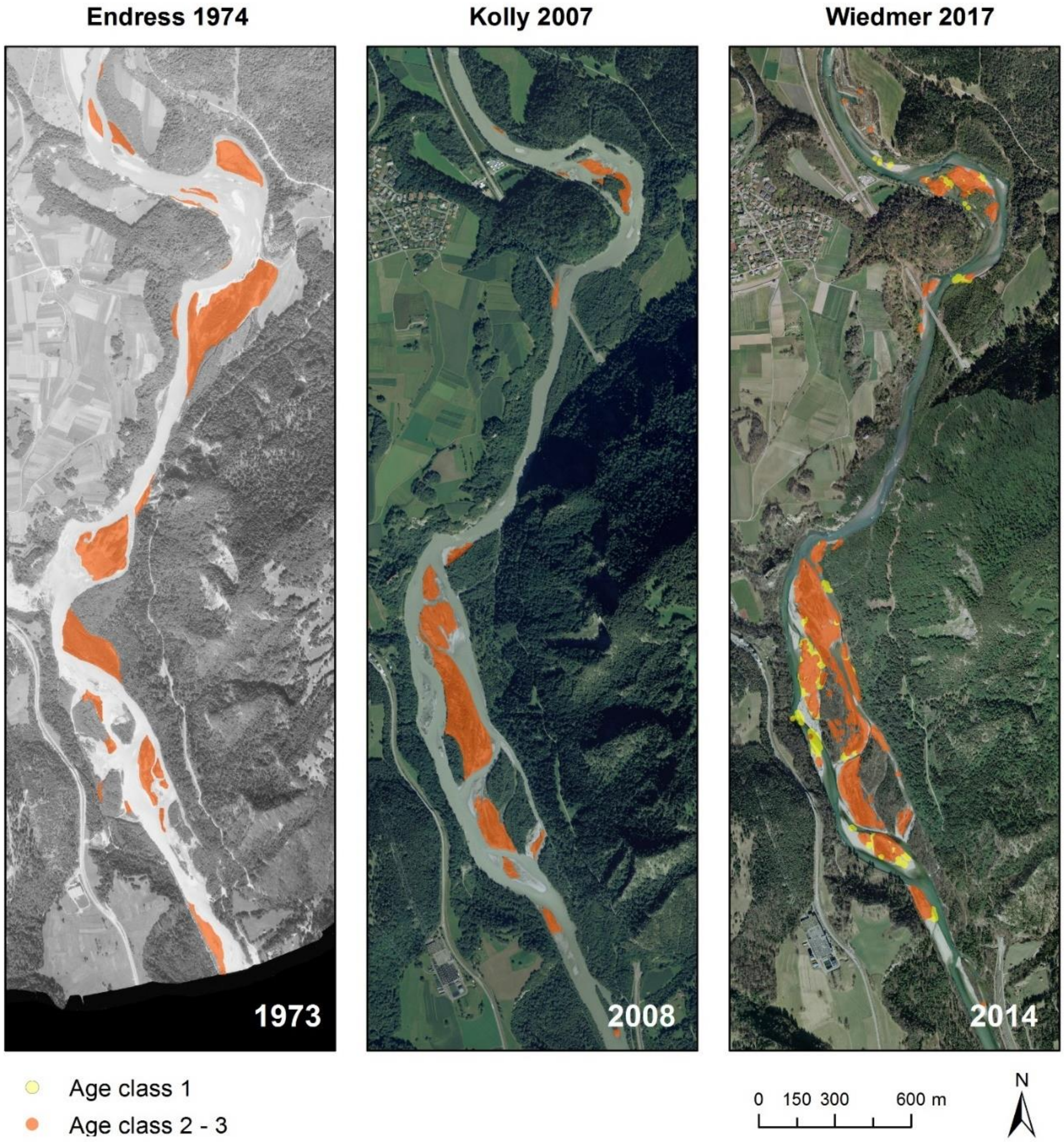
Appendix 15 *Myricaria germanica* distribution maps – Cauma

Orthophotos of Cauma with *M. germanica* occurrence of two surveys (Endress 1974 & Wiedmer 2017). Locations of juvenile plants (age class 1) unknown in 1974.



Appendix 16 *Myricaria germanica* distribution maps – Rhäzüns

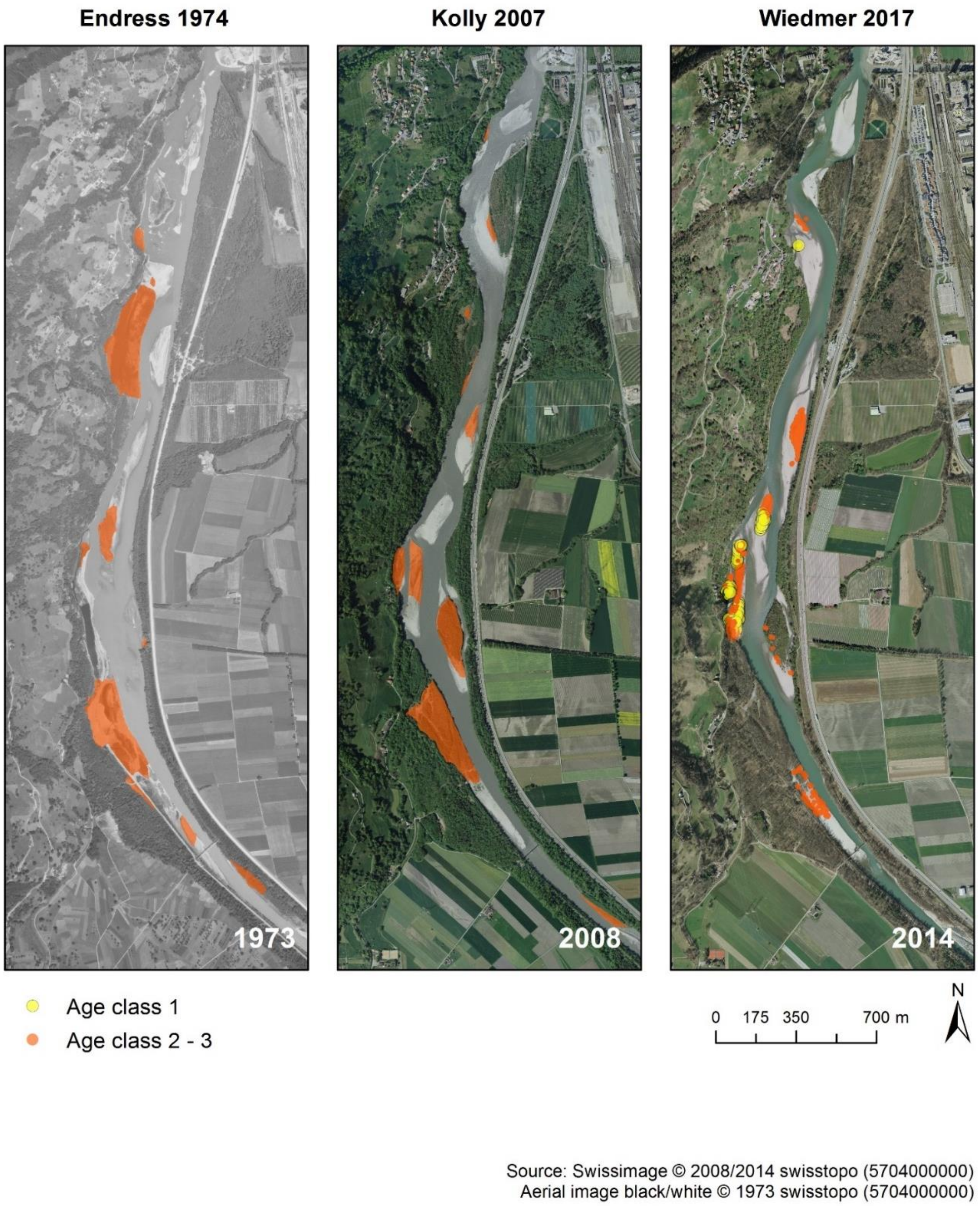
Orthophotos of Rhäzüns with *M. germanica* occurrence of three surveys (Endress 1974, Kolly 2007 & Wiedmer 2017). Locations of juvenile plants (age class 1) unknown in 1974 and 2007.



Source: Swissimage © 2008/2014 swisstopo (5704000000)
Aerial image black/white © 1973 swisstopo (5704000000)

Appendix 17 *Myricaria germanica* distribution maps – Zizers-Mastrils

Orthophotos of Zizers-Mastrils with *M. germanica* occurrence of three surveys (Endress 1974, Kolly 2007 & Wiedmer 2017). Locations of juvenile plants (age class 1) unknown in 1974 and 2007.



Appendix 18 Raw data – Habitat composition

Year	Date	Study area	Habitat type	Percentage	Year	Date	Study area	Habitat type	Percentage
1973	26.06.1973	Cauma	1	49.38	1999	25.07.1999	Rhäzüns	1	43.39
1973	26.06.1973	Cauma	2	8.93	1999	25.07.1999	Rhäzüns	2	3.00
1973	26.06.1973	Cauma	3	4.98	1999	25.07.1999	Rhäzüns	3	3.99
1973	26.06.1973	Cauma	4	29.19	1999	25.07.1999	Rhäzüns	4	47.10
1973	26.06.1973	Cauma	5	7.52	1999	25.07.1999	Rhäzüns	5	2.52
1984	27.06.1984	Cauma	1	44.41	2008	09.09.2008	Rhäzüns	1	44.01
1984	27.06.1984	Cauma	2	6.64	2008	09.09.2008	Rhäzüns	2	5.43
1984	27.06.1984	Cauma	3	4.57	2008	09.09.2008	Rhäzüns	3	6.93
1984	27.06.1984	Cauma	4	38.24	2008	09.09.2008	Rhäzüns	4	41.42
1984	27.06.1984	Cauma	5	6.14	2008	09.09.2008	Rhäzüns	5	2.21
1990	13.07.1990	Cauma	1	50.29	2014	13.03.2014	Rhäzüns	1	42.01
1990	13.07.1990	Cauma	2	3.79	2014	13.03.2014	Rhäzüns	2	6.41
1990	13.07.1990	Cauma	3	5.77	2014	13.03.2014	Rhäzüns	3	5.18
1990	13.07.1990	Cauma	4	29.56	2014	13.03.2014	Rhäzüns	4	43.10
1990	13.07.1990	Cauma	5	10.59	2014	13.03.2014	Rhäzüns	5	3.30
1997	25.08.1997	Cauma	1	44.05	1973	26.06.1973	Zizers-Mastrils	1	67.21
1997	25.08.1997	Cauma	2	3.84	1973	26.06.1973	Zizers-Mastrils	2	5.26
1997	25.08.1997	Cauma	3	1.56	1973	26.06.1973	Zizers-Mastrils	3	12.76
1997	25.08.1997	Cauma	4	40.34	1973	26.06.1973	Zizers-Mastrils	4	10.99
1997	25.08.1997	Cauma	5	10.20	1973	26.06.1973	Zizers-Mastrils	5	3.77
2008	09.09.2008	Cauma	1	45.39	1985	23.07.1985	Zizers-Mastrils	1	74.62
2008	09.09.2008	Cauma	2	3.58	1985	23.07.1985	Zizers-Mastrils	2	1.19
2008	09.09.2008	Cauma	3	2.62	1985	23.07.1985	Zizers-Mastrils	3	2.53
2008	09.09.2008	Cauma	4	42.40	1985	23.07.1985	Zizers-Mastrils	4	20.66
2008	09.09.2008	Cauma	5	6.01	1985	23.07.1985	Zizers-Mastrils	5	1.01
2014	13.03.2014	Cauma	1	42.97	1990	23.08.1990	Zizers-Mastrils	1	81.92
2014	13.03.2014	Cauma	2	1.85	1990	23.08.1990	Zizers-Mastrils	2	0.66
2014	13.03.2014	Cauma	3	3.01	1990	23.08.1990	Zizers-Mastrils	3	3.17
2014	13.03.2014	Cauma	4	44.90	1990	23.08.1990	Zizers-Mastrils	4	14.04
2014	13.03.2014	Cauma	5	7.27	1990	23.08.1990	Zizers-Mastrils	5	0.21
1973	09.08.1973	Rhäzüns	1	49.49	1997	22.07.1997	Zizers-Mastrils	1	66.43
1973	09.08.1973	Rhäzüns	2	4.99	1997	22.07.1997	Zizers-Mastrils	2	5.14
1973	09.08.1973	Rhäzüns	3	14.42	1997	22.07.1997	Zizers-Mastrils	3	10.45
1973	09.08.1973	Rhäzüns	4	29.33	1997	22.07.1997	Zizers-Mastrils	4	17.98
1973	09.08.1973	Rhäzüns	5	1.77	1997	22.07.1997	Zizers-Mastrils	5	0.00
1985	23.07.1985	Rhäzüns	1	44.00	2008	06.05.2008	Zizers-Mastrils	1	56.09
1985	23.07.1985	Rhäzüns	2	3.58	2008	06.05.2008	Zizers-Mastrils	2	8.88
1985	23.07.1985	Rhäzüns	3	2.74	2008	06.05.2008	Zizers-Mastrils	3	6.03
1985	23.07.1985	Rhäzüns	4	45.24	2008	06.05.2008	Zizers-Mastrils	4	26.23
1985	23.07.1985	Rhäzüns	5	4.44	2008	06.05.2008	Zizers-Mastrils	5	2.77
1990	20.07.1990	Rhäzüns	1	48.47	2014	12.03.2014	Zizers-Mastrils	1	61.37
1990	20.07.1990	Rhäzüns	2	2.24	2014	12.03.2014	Zizers-Mastrils	2	3.28
1990	20.07.1990	Rhäzüns	3	3.75	2014	12.03.2014	Zizers-Mastrils	3	1.55
1990	20.07.1990	Rhäzüns	4	42.22	2014	12.03.2014	Zizers-Mastrils	4	30.66
1990	20.07.1990	Rhäzüns	5	3.32	2014	12.03.2014	Zizers-Mastrils	5	3.14

Appendix 19 Raw data - Shoreline length

Date	Study area	Shoreline length [km]	Shoreline length per river km
26.06.1973	Cauma	9.959	1.528
27.06.1984	Cauma	9.938	1.525
13.07.1990	Cauma	9.254	1.420
25.08.1997	Cauma	10.197	1.564
09.09.2008	Cauma	9.570	1.468
13.03.2014	Cauma	10.612	1.628
26.06.1973	Rhäzüns	20.043	2.063
23.07.1985	Rhäzüns	18.866	1.942
23.08.1990	Rhäzüns	17.639	1.816
22.07.1997	Rhäzüns	17.684	1.820
06.05.2008	Rhäzüns	18.261	1.880
13.03.2014	Rhäzüns	20.093	2.068
26.06.1973	Zizers-Mastrils	13.545	1.472
23.07.1985	Zizers-Mastrils	13.997	1.521
23.08.1990	Zizers-Mastrils	11.450	1.245
22.07.1997	Zizers-Mastrils	14.130	1.536
06.05.2008	Zizers-Mastrils	14.873	1.617
12.03.2014	Zizers-Mastrils	14.244	1.548

Appendix 20 Raw data – Habitat changes

Period Nr	Period	Study area	Change	Ratio	Nr of HQ ≥ 1	Nr of HQ ≥ 2	HQ1	HQ2	HQ5	HQ10	Time period length [days]
1	1973-1984	Cauma	1	78.092	569	10	559	10	0	0	4019
1	1973-1984	Cauma	2	7.487	569	10	559	10	0	0	4019
1	1973-1984	Cauma	3	8.221	569	10	559	10	0	0	4019
1	1973-1984	Cauma	4	1.583	569	10	559	10	0	0	4019
1	1973-1984	Cauma	5	1.641	569	10	559	10	0	0	4019
1	1973-1984	Cauma	6	2.179	569	10	559	10	0	0	4019
1	1973-1984	Cauma	7	0.797	569	10	559	10	0	0	4019
2	1984-1990	Cauma	1	71.545	281	5	276	3	0	2	2207
2	1984-1990	Cauma	2	0.840	281	5	276	3	0	2	2207
2	1984-1990	Cauma	3	3.588	281	5	276	3	0	2	2207
2	1984-1990	Cauma	4	10.771	281	5	276	3	0	2	2207
2	1984-1990	Cauma	5	6.784	281	5	276	3	0	2	2207
2	1984-1990	Cauma	6	1.011	281	5	276	3	0	2	2207
2	1984-1990	Cauma	7	5.460	281	5	276	3	0	2	2207
3	1990-1997	Cauma	1	78.195	272	12	260	8	3	1	2600
3	1990-1997	Cauma	2	4.682	272	12	260	8	3	1	2600
3	1990-1997	Cauma	3	8.005	272	12	260	8	3	1	2600
3	1990-1997	Cauma	4	0.859	272	12	260	8	3	1	2600
3	1990-1997	Cauma	5	0.139	272	12	260	8	3	1	2600
3	1990-1997	Cauma	6	4.252	272	12	260	8	3	1	2600
3	1990-1997	Cauma	7	3.868	272	12	260	8	3	1	2600
4	1997-2008	Cauma	1	81.017	377	11	366	9	1	1	4033
4	1997-2008	Cauma	2	4.989	377	11	366	9	1	1	4033
4	1997-2008	Cauma	3	4.010	377	11	366	9	1	1	4033
4	1997-2008	Cauma	4	2.588	377	11	366	9	1	1	4033
4	1997-2008	Cauma	5	0.343	377	11	366	9	1	1	4033
4	1997-2008	Cauma	6	5.622	377	11	366	9	1	1	4033
4	1997-2008	Cauma	7	1.430	377	11	366	9	1	1	4033
5	2008-2014	Cauma	1	87.374	171	8	163	5	1	2	2011
5	2008-2014	Cauma	2	3.431	171	8	163	5	1	2	2011
5	2008-2014	Cauma	3	5.001	171	8	163	5	1	2	2011
5	2008-2014	Cauma	4	1.942	171	8	163	5	1	2	2011
5	2008-2014	Cauma	5	0.169	171	8	163	5	1	2	2011
5	2008-2014	Cauma	6	0.413	171	8	163	5	1	2	2011
5	2008-2014	Cauma	7	1.670	171	8	163	5	1	2	2011

Period Nr	Period	Study area	Change	Ratio	Nr of HQ ≥ 1	Nr of HQ ≥ 2	HQ1	HQ2	HQ5	HQ10	Time period length [days]
1	1973-1985	Rhäzüns	1	64.967	968	9	959	7	1	1	4366
1	1973-1985	Rhäzüns	2	9.225	968	9	959	7	1	1	4366
1	1973-1985	Rhäzüns	3	14.414	968	9	959	7	1	1	4366
1	1973-1985	Rhäzüns	4	5.363	968	9	959	7	1	1	4366
1	1973-1985	Rhäzüns	5	0.800	968	9	959	7	1	1	4366
1	1973-1985	Rhäzüns	6	1.279	968	9	959	7	1	1	4366
1	1973-1985	Rhäzüns	7	3.951	968	9	959	7	1	1	4366
2	1985-1990	Rhäzüns	1	82.632	351	12	339	8	1	3	1823
2	1985-1990	Rhäzüns	2	3.878	351	12	339	8	1	3	1823
2	1985-1990	Rhäzüns	3	1.876	351	12	339	8	1	3	1823
2	1985-1990	Rhäzüns	4	8.151	351	12	339	8	1	3	1823
2	1985-1990	Rhäzüns	5	1.046	351	12	339	8	1	3	1823
2	1985-1990	Rhäzüns	6	1.768	351	12	339	8	1	3	1823
2	1985-1990	Rhäzüns	7	0.648	351	12	339	8	1	3	1823
3	1990-1999	Rhäzüns	1	81.116	451	10	441	10	0	0	3292
3	1990-1999	Rhäzüns	2	9.096	451	10	441	10	0	0	3292
3	1990-1999	Rhäzüns	3	3.892	451	10	441	10	0	0	3292
3	1990-1999	Rhäzüns	4	3.905	451	10	441	10	0	0	3292
3	1990-1999	Rhäzüns	5	0.405	451	10	441	10	0	0	3292
3	1990-1999	Rhäzüns	6	1.192	451	10	441	10	0	0	3292
3	1990-1999	Rhäzüns	7	0.393	451	10	441	10	0	0	3292
4	1999-2008	Rhäzüns	1	72.039	613	9	604	7	1	1	3334
4	1999-2008	Rhäzüns	2	10.378	613	9	604	7	1	1	3334
4	1999-2008	Rhäzüns	3	3.513	613	9	604	7	1	1	3334
4	1999-2008	Rhäzüns	4	10.912	613	9	604	7	1	1	3334
4	1999-2008	Rhäzüns	5	1.928	613	9	604	7	1	1	3334
4	1999-2008	Rhäzüns	6	0.770	613	9	604	7	1	1	3334
4	1999-2008	Rhäzüns	7	0.461	613	9	604	7	1	1	3334
5	2008-2014	Rhäzüns	1	79.033	415	2	413	1	1	0	2011
5	2008-2014	Rhäzüns	2	5.599	415	2	413	1	1	0	2011
5	2008-2014	Rhäzüns	3	7.615	415	2	413	1	1	0	2011
5	2008-2014	Rhäzüns	4	3.712	415	2	413	1	1	0	2011
5	2008-2014	Rhäzüns	5	2.768	415	2	413	1	1	0	2011
5	2008-2014	Rhäzüns	6	0.093	415	2	413	1	1	0	2011
5	2008-2014	Rhäzüns	7	1.179	415	2	413	1	1	0	2011

Period Nr	Period	Study area	Change	Ratio	Nr of HQ ≥ 1	Nr of HQ ≥ 2	HQ1	HQ2	HQ5	HQ10	Time period length [days]
1	1973 - 1985	Zizers-Mastrils	1	71.872	0	0	0	0	0	0	4410
1	1973 - 1985	Zizers-Mastrils	2	5.730	0	0	0	0	0	0	4410
1	1973 - 1985	Zizers-Mastrils	3	7.999	0	0	0	0	0	0	4410
1	1973 - 1985	Zizers-Mastrils	4	10.523	0	0	0	0	0	0	4410
1	1973 - 1985	Zizers-Mastrils	5	0.029	0	0	0	0	0	0	4410
1	1973 - 1985	Zizers-Mastrils	6	3.305	0	0	0	0	0	0	4410
1	1973 - 1985	Zizers-Mastrils	7	0.541	0	0	0	0	0	0	4410
2	1985 - 1990	Zizers-Mastrils	1	86.372	10	0	10	0	0	0	1857
2	1985 - 1990	Zizers-Mastrils	2	1.678	10	0	10	0	0	0	1857
2	1985 - 1990	Zizers-Mastrils	3	0.348	10	0	10	0	0	0	1857
2	1985 - 1990	Zizers-Mastrils	4	8.354	10	0	10	0	0	0	1857
2	1985 - 1990	Zizers-Mastrils	5	2.092	10	0	10	0	0	0	1857
2	1985 - 1990	Zizers-Mastrils	6	0.979	10	0	10	0	0	0	1857
2	1985 - 1990	Zizers-Mastrils	7	0.178	10	0	10	0	0	0	1857
3	1990 - 1997	Zizers-Mastrils	1	76.630	108	9	99	5	3	1	2525
3	1990 - 1997	Zizers-Mastrils	2	17.547	108	9	99	5	3	1	2525
3	1990 - 1997	Zizers-Mastrils	3	3.617	108	9	99	5	3	1	2525
3	1990 - 1997	Zizers-Mastrils	4	1.975	108	9	99	5	3	1	2525
3	1990 - 1997	Zizers-Mastrils	5	0.025	108	9	99	5	3	1	2525
3	1990 - 1997	Zizers-Mastrils	6	0.206	108	9	99	5	3	1	2525
4	1997 - 2008	Zizers-Mastrils	1	70.630	172	5	167	5	0	0	3941
4	1997 - 2008	Zizers-Mastrils	2	13.457	172	5	167	5	0	0	3941
4	1997 - 2008	Zizers-Mastrils	3	8.380	172	5	167	5	0	0	3941
4	1997 - 2008	Zizers-Mastrils	4	4.482	172	5	167	5	0	0	3941
4	1997 - 2008	Zizers-Mastrils	5	0.286	172	5	167	5	0	0	3941
4	1997 - 2008	Zizers-Mastrils	7	2.766	172	5	167	5	0	0	3941
5	2008 - 2014	Zizers-Mastrils	1	80.472	125	4	121	3	1	0	2136
5	2008 - 2014	Zizers-Mastrils	2	2.125	125	4	121	3	1	0	2136
5	2008 - 2014	Zizers-Mastrils	3	8.212	125	4	121	3	1	0	2136
5	2008 - 2014	Zizers-Mastrils	4	7.563	125	4	121	3	1	0	2136
5	2008 - 2014	Zizers-Mastrils	5	0.082	125	4	121	3	1	0	2136
5	2008 - 2014	Zizers-Mastrils	6	0.584	125	4	121	3	1	0	2136
5	2008 - 2014	Zizers-Mastrils	7	0.961	125	4	121	3	1	0	2136

Appendix 21 Raw data – Spatiotemporal distrubution of *Myricaria germanica*

Study area	Survey	Age class	Count
Cauma	Endress	2 -3	1483
Cauma	Endress	uncertainty	150
Cauma	Wiedmer	1	190
Cauma	Wiedmer	2	266
Cauma	Wiedmer	3	563
Rhäzüns	Endress	2 - 3	3206
Rhäzüns	Endress	uncertainty	4059
Rhäzüns	Kolly	3	4886
Rhäzüns	Wiedmer	1	102509
Rhäzüns	Wiedmer	2	1031
Rhäzüns	Wiedmer	3	9893
Zizers-Mastrils	Endress	2 - 3	2249
Zizers-Mastrils	Endress	uncertainty	1031
Zizers-Mastrils	Kolly	3	4096
Zizers-Mastrils	Wiedmer	1	2355
Zizers-Mastrils	Wiedmer	2	29
Zizers-Mastrils	Wiedmer	3	1088

Survey: Wiedmer 2017

Sites with all age classes

Study area	Survey	Sites
Cauma	Endress	11
Cauma	Wiedmer	11
Rhäzüns	Endress	18
Rhäzüns	Kolly	13
Rhäzüns	Wiedmer	24
Zizers-Mastrils	Endress	9
Zizers-Mastrils	Kolly	10
Zizers-Mastrils	Wiedmer	7

Sites with juvenil plants

Study area	Survey	Sites
Cauma	Endress	4
Cauma	Wiedmer	2
Rhäzüns	Endress	3
Rhäzüns	Wiedmer	17
Zizers-Mastrils	Endress	2
Zizers-Mastrils	Wiedmer	4

Surveys: Endress 1972 - 1974; Kolly 2007; Wiedmer 2017

Study area	Age class	Habitat type	Count
Zizers-Mastrils	1	P	2355
Zizers-Mastrils	2	P	29
Zizers-Mastrils	3	F	35
Zizers-Mastrils	3	P	96
Zizers-Mastrils	3	S_d	207
Zizers-Mastrils	3	S_o	750
Rhäzüns	1	P	85182
Rhäzüns	1	P	800
Rhäzüns	1	S_d	100
Rhäzüns	1	S_o	16427
Rhäzüns	2	P	932
Rhäzüns	2	S_o	98
Rhäzüns	3	F	1359
Rhäzüns	3	P	556
Rhäzüns	3	S_d	3490
Rhäzüns	3	S_o	5890
Cauma	1	P	6
Cauma	1	S_o	184
Cauma	2	P	45
Cauma	2	S_o	221
Cauma	3	F	10
Cauma	3	P	108
Cauma	3	S_d	6
Cauma	3	S_o	439

Survey: Wiedmer 2017

Appendix 22 Raw data - Gravel bank age distribution of *Myricaria germanica* sites

Study area	Nr Aerial photo	Age	Area [m^2]
Cauma	1	< 3	7.0
Cauma	2	< 9	450.3
Cauma	3	< 20	159.3
Cauma	4	< 27	3.8
Cauma	5	< 33	1.3
Cauma	6	< 44	3.0
Cauma	7	> 44	2.3
Rhäzüns	1	< 3	377.5
Rhäzüns	2	< 9	3176.0
Rhäzüns	3	< 18	5270.0
Rhäzüns	4	< 27	1537.0
Rhäzüns	5	< 32	598.5
Rhäzüns	6	< 44	192.8
Rhäzüns	7	> 44	49.8
Zizers-Mastrils	1	< 3	7.8
Zizers-Mastrils	2	< 9	77.5
Zizers-Mastrils	3	< 20	863.5
Zizers-Mastrils	4	< 27	161.0
Zizers-Mastrils	5	< 32	13.3
Zizers-Mastrils	6	< 44	50.0
Zizers-Mastrils	7	> 44	64.3

Study area	Nr of Regression	Colonised area [%]
Cauma	0	0.120
Cauma	1	0.085
Cauma	2	0.003
Rhäzüns	0	0.555
Rhäzüns	1	2.063
Rhäzüns	2	1.288
Rhäzüns	3	0.392
Zizers-Mastrils	0	0.100
Zizers-Mastrils	1	0.241
Zizers-Mastrils	2	0.066

Appendix 23 Personal declaration

Personal declaration:

I hereby declare that the submitted thesis is the result of my own, independent, work. All external sources are explicitly acknowledged in the thesis.

Date | Signature

17 January 2018 --------------------- --