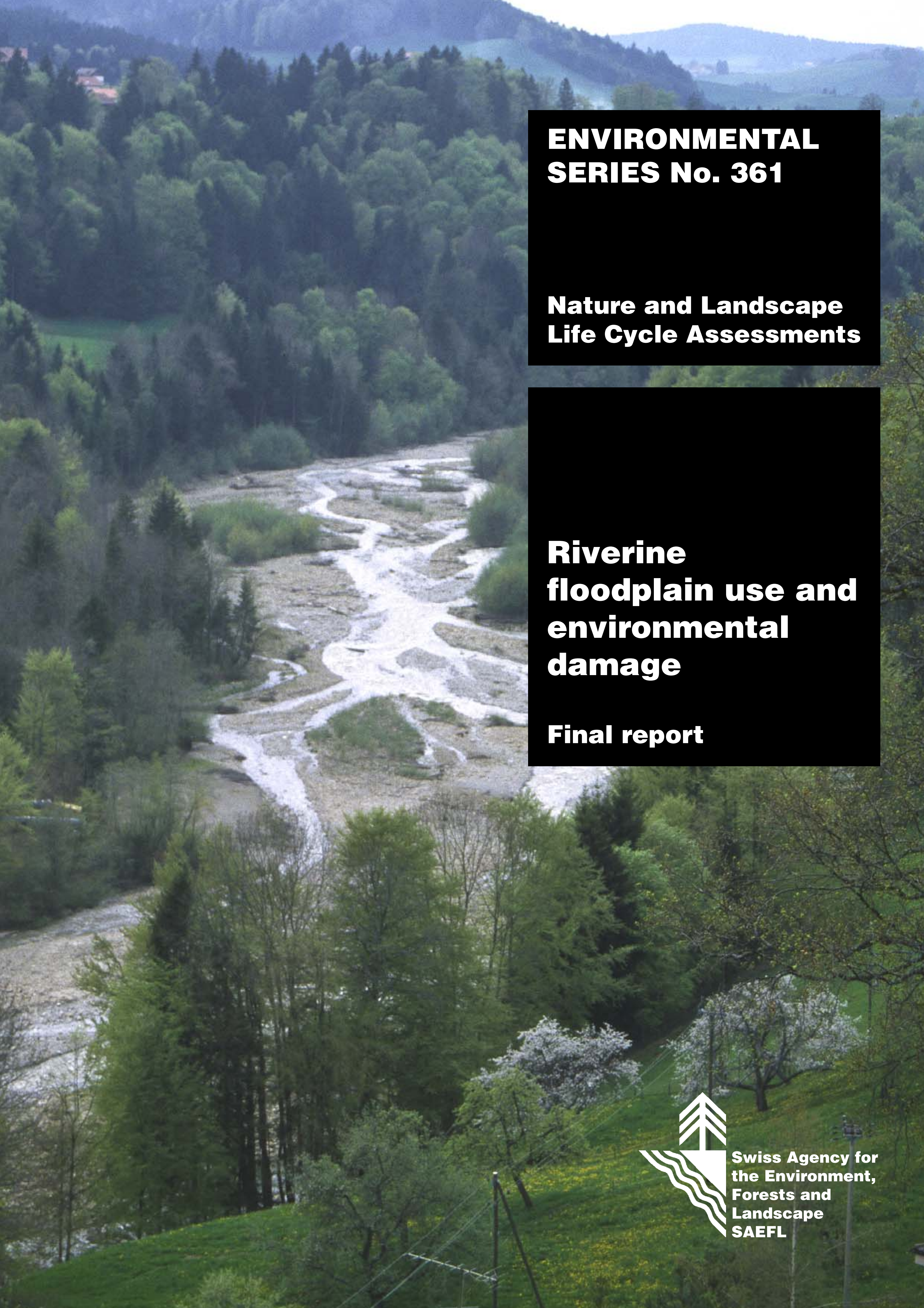

ENVIRONMENTAL SERIES No. 361

Nature and Landscape
Life Cycle Assessments

Riverine floodplain use and environmental damage

Final report

Swiss Agency for the Environment, Forests and Landscape
SAEFL

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Table of contents

Abstracts

E

Keywords:
floodplains, historical floodplains in Switzerland, species endangerment, biodiversity damage, land use, ecobalance, LCA

Since 1850, floodplains of Swiss rivers have been reduced to such a great extent that efforts are now made to restore such areas. In this study, an analysis of historical maps leads to an estimate of a 90% loss of pristine floodplains (chapter 2). Chapter 3 states that 153 species of vascular plants are now endangered as a consequence of floodplain reductions in Switzerland. The calculations of chapter 4 support a claim for additional 30'000 hectares of active floodplains for the purpose of limiting the biodiversity loss. In chapter 5 a method is developed determining for LCA purposes the damage of current land use inside of historical floodplains.

D

Stichwörter:
Auengebiete, historische Auenflächen, Artengefährdung, Biodiversitäts-Schaden aus Landnutzung, Ökobilanz

Die Auengebiete der Schweizer Flüsse sind seit 1850 so stark reduziert worden, dass heute Regenerationen angestrebt werden. Durch Analyse historischer Landkarten wird hier die seinerzeitige Auenfläche und deren zwischenzeitliche Abnahme um 90% ermittelt (Kapitel 2). Kapitel 3 zeigt die dadurch bewirkte Gefährdung von 153 Gefässpflanzen. Geprüft wird, wie gross die Auengebiete der Schweiz sein müssten, um den Artenrückgang zu beschränken; als Ergebnis wird in Kapitel 4 ein erforderlicher Zuwachs von 30'000 Hektaren aktiver Auenfläche ermittelt. In Kapitel 5 wird eine Methode entwickelt, um für die Ökobilanzierung den Schaden aus derzeitiger Intensivnutzung ehemaliger Auengebiete quantitativ zu bestimmen

F

Mots-clés:
zones alluviales, zones alluviales historiques, menace des espèces, dommage causés à la biodiversité par l'utilisation du sol, écobilans

Depuis 1850, les zones alluviales de Suisse ont été réduites à tel point qu'il faut maintenant les régénérer. L'analyse des cartes historiques a permis de constater un recul de 90% de la surface totale des zones alluviales (chapitre 2). Le chapitre 3 montre que 153 plantes vasculaires (fougères et plantes à fleurs) sont menacées par ce recul. Des calculs indiquent que 30'000 hectares de nouvelles zones alluviales seraient nécessaires pour limiter la diminution de la diversité biologique (chapitre 4). Le chapitre 5 présente une méthode permettant de déterminer quantitativement les dommages causés à la biodiversité par l'utilisation intensive d'anciennes zones alluviales, information utile pour l'établissement d'écobilans.

I

Parole chiave:
zone golenali, superfici golenali storiche, minaccia delle specie, danni causati alla biodiversità in seguito all'utilizzazione del suolo, ecobilancio

Dal 1850 le zone golenali dei fiumi svizzeri sono state ridotte al punto tale che oggi si rendono necessari provvedimenti per la loro rigenerazione. L'analisi delle carte geografiche storiche ha evidenziato una riduzione fino al 90% dell'originaria superficie golenale (capitolo 2). Il capitolo 3 mostra che 153 piante vascolari sono minacciate da questa riduzione. Lo studio calcola inoltre che la superficie golenale attiva necessaria per limitare la diminuzione delle specie dovrebbe ammontare a 30'000 ettari (capitolo 4). Il capitolo 5 presenta un metodo per la determinazione quantitativa ai fini dell'dei danni causati dall'attuale utilizzazione intensiva di vecchie zone golenali.

Foreword

The plains originally formed by the rivers are at the centre of human interest. For one, they have proved to be particularly suitable for housing development, road building and agriculture, so that technical means have long been used to establish these uses and protect them from further flooding. For another, their value as a habitat for animals in the wild is unique. The last floodplain areas to have largely kept their natural character are now protected under federal legislation. Furthermore, a movement has started in recent years under the heading ‘more room for rivers’ to provide wider expanses for rivers now constrained to flow in narrow channels. The declared object is to reduce the high-water peaks that endanger the areas further downstream, and to create attractive leisure areas. The reinstatement of areas subject to periodic flooding will at the same time make an important contribution to the protection of animal and plant species at risk.

From the point of view of species protection, all endeavours to renature river courses are to be welcomed. Of fundamental interest is the question as to how great the area in which rivers may freely choose their course must be for the hazard to indigenous species to be substantially reduced. Data are necessary to enable an objective assessment of this to be made.

The present study provides quantitative data on the decline in Swiss floodplains since the mid 19th century and on the threat to the vascular plants depending on them. Based on this, the extent of floodplain areas necessary to largely eliminate this threat is determined. The study also provides a basis for the life cycle assessment of land use in potential floodplain areas. It may therefore be used as a building block for establishing a sustainable scheme of land use for the former floodplain areas.

Swiss Agency for the Environment,
Forests and Landscape

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Substances, soils, biotechnology	*Nature*

1 Introduction: Significant influences on intracontinental surface waters

As a glance at the map of Europe shows, intracontinental surface waters (meaning surface waters other than oceans) account for a quantitatively insignificant part of the land area of continental Europe; expressed as a proportion, it is in the region of a few percent only. If periodically flooded land, i.e. land covered by water on an annual cycle or every few years, is classified as surface water along with the area permanently under water, the ratio of surface water to total surface area of Europe increases slightly but still remains in the region of a few percent. Periodically flooded areas of land adjoining rivers and lakes, known as floodplains, are prime sites for human settlement, which is why in the course of the modern era engineering measures have been undertaken to protect them from flooding and returning to wetlands, after which they have become hotspots of human activity. In the economically highly developed and densely settled countries of Europe, historical floodplain areas have therefore largely been transformed (by bank reinforcement, dike construction, straightening, infilling, riverbed lowering) into "potential" floodplain areas – which, by virtue of their natural features, could continue to be floodplains, but no longer are today – and new uses have been found for the land thus secured from floodwater (construction of settlements, roads and port facilities, agricultural use). This applies particularly to the lowlands flooded periodically by watercourses, the riverine floodplains.

Floodplains in general and riverine floodplains in particular, where water flows and sediment transport make for higher diversity, are also sites with high concentrations of animal and plant life. The effects of periodic and episodic flooding result in the constant recreation of new amphibian habitats for numerous species: wet, damp and dry sites, open and vegetation-covered sites, humus-rich and humus-poor sites, acidic and non-acidic sites, nutrient-poor and nutrient-rich sites. Moreover the network of watercourses effectively interconnects all these sites, enhancing their already high biological value as habitats for animals and plants. Hence it is no surprise that, for instance, of Switzerland's total of 2696 vascular plant species (LANDOLT, 1991, pp.74–127) no fewer than 1050 species occur in present-day floodplain areas (ROULIER, 2002), although the geographical extent of such sites has diminished so drastically that practically all true floodplain-specialist plants must be classified as endangered. High numbers of species and the limited extent of sites mean that the species density of vascular plants (the number of species per unit area) is disproportionately greater on floodplain sites than elsewhere in the country. In view of the crucial role of vascular plants in supporting the entire realm of non-human life, it can be assumed that the floodplains are also a key element for safeguarding the survival of animal and plant species of every other kind.

For this reason, the present study deals with change in the area of riverine floodplains since the mid-19th century (Chapter 2) and the identifiable impacts of this on the diversity of vascular plant species (Chapter 3). In addition it creates a body of baseline data for nationwide planning of floodplain regeneration. This specifies and gives supporting evidence for the minimum area of riverine floodplains required to mitigate the risk of extinction of floodplain-specialist species in Switzerland (Chapter 4). Furthermore it helps to determine the extent to which current land use in the potential floodplain area for building or agriculture is responsible for the endangerment of species (Chapter 5).

This study concentrates on the quantitative aspect, i.e. the decline in area of floodplains with the capacity to take up the floodwater of Swiss watercourses during periodic and episodic flooding. This approach is adopted because under the conditions currently prevailing in Switzerland, constraints of space are probably the critical factor for the deterioration of habitat conditions for wild animals and plants in floodplain areas. Where no space exists for habitats, even qualitative habitat improvement measures such as higher water purity or an end to drainage schemes will not succeed in reversing the endangerment to species which can currently be observed.

Nonetheless it should be mentioned at this point that the biological value of floodplain land can be degraded by a host of human impacts in addition to river engineering measures which restrict the area of the floodplain. Factors to be mentioned in particular are:

- Chemical pollution of water with fertilizers and ecotoxic substances from discharged wastewater and run-off from agricultural land
- Alteration of water temperature by discharges of heated industrial and domestic wastewater, but also by heat extraction in association with heat pump systems
- Changes in rates of flow as a consequence of dike construction, water extraction and redirection of watercourses via lakes
- Decrease in bed-load transport due to river engineering works, dike construction, watercourse redirection and gravel extraction
- Human use of the floodplain area for leisure pursuits including fishing

Section 4.1 sets out that in the Swiss context, the impacts described above are currently on a scale which can be redressed through sufficient expansion of the area of floodable land, following which a gradual recovery in the species inventory can be expected to occur. For plants, this recovery can be expected to largely happen spontaneously through natural processes, as flowing water creates new site conditions for colonization by natural dispersal mechanisms. It deserves note that this kind of "landscape management" to conserve species diversity, unlike agriculture, does not necessitate financial subsidy of the land. Spontaneous restoration does, however, take time and particularly where species have disappeared from large parts of their former range, success may be limited. Hence it is of interest to establish the extent to which additional measures can promote the spontaneous regeneration of land recently allowed to revert to riverine floodplains (MIDDLETON, 1998).

2 Watercourse areas and their loss

The area of Switzerland's riverine floodplains has greatly diminished since the beginning of the industrial age. We suspect that this decline is substantially responsible for the endangered status of a large number of species. In this chapter we attempt to quantify the scale of this decline. To this end a procedure was developed to allow us to determine spatial loss by studying and applying certain techniques to various maps.

To assess the changes to riverine floodplains, it is also important to know their present and their historical extent. In this chapter, therefore, we estimate the current area of Switzerland's riverine floodplains, primarily on the basis of spatial statistical data and an inventory of floodplains. From these, the historic area of Switzerland's riverine floodplains can also be deduced.

2.1 Determining the loss of Switzerland's riverine floodplains: Procedure

2.1.1 Definition of riverine floodplains

Our definition of a *riverine floodplain* is an area of land which is flooded during periodic or episodic flooding of watercourses. The actual river bed which is normally covered with water is treated as a sub-set of this area, because in a natural or near-natural floodplain, water and land merge into one another to such an extent that they are almost impossible to separate. Streams are only included if they are located inside the area affected by flooding. Furthermore the land must have some degree of near-natural status to be considered a *present-day* riverine floodplain, since the purpose of this definition is to determine the geographical area which still offers suitable conditions for species specialized on watercourse sites, including periodically flooded areas. Intensively used agricultural sites on the fringe of the area affected by flooding are not therefore viewed as elements of present-day riverine floodplains. The *historical* extent of the riverine floodplain describes its area at a time when the course of the river was still largely natural, i.e. not corrected to any substantial degree by engineering interventions (dikes, bank reinforcements, earth tipping, sills, lowering of the river bed) and had a flow regime that was not noticeably modified by river engineering measures such as impoundments or diversions. Areas of land which once fell within the historical extent of riverine floodplains, but no longer form a part of present-day riverine floodplains, we will call *potential* riverine floodplains. The area of potential riverine floodplains is equivalent to the *loss* of riverine floodplain land area calculated as per Section 2.2, i.e. the *difference* in area arrived at by deducting the area of present-day floodplains from historical riverine floodplains.

2.1.2 Determining a reference period

The Romans were already capable of radical interventions to influence watercourses. Today Roman walled dams and aqueducts of imposing size can still be seen, for instance in the Spanish region of Extremadura. River engineering measures of that kind came somewhat later to Switzerland. In the Middle Ages, simple flood protection measures were carried out along with construction works for the purpose of harnessing water power, e.g. for flour mills or sawmills. Industrialization brought a further wave of changes to riverine landscapes in connection with the expansion in water power use for factory operations. It would thus be necessary to go back many centuries to find Swiss inland watercourses in their completely natural state.

On the other hand it may safely be assumed that anthropogenic changes to watercourses and their flooding zones were so limited in scope until around the middle of the 19th century that at least on a national scale they would not have caused any substantial reduction in species abundance in the vicinity of watercourses and their floodplains. Because the decline and extinction of a species in a region is a process which can be drawn out over many decades, however, it is almost impossible to pinpoint the precise moment when the level of reduction in natural floodplain land was on the brink of causing a noticeable decline in species diversity. All the same, there are clear comments from experts indicating the period at which changes to floodplain areas had not yet begun to cause significant decline in species diversity:

- (LANDOLT, 1991, p. 11): "The peak of habitat and species diversity in our country was seen in the pre-industrial cultural landscape with broad-scale, extensively-managed areas of land. In contrast the second half of the 19th century brought a series of developments which constrained diversity: exploitation of bodies of water and peatlands as energy sources, mechanical processing, seed cleaning, mineral fertilizer production. The first major drainage and river correction projects occur during this period."
- (HAIDVOGL & EBERSTALLER, 1997, p.5): "Overall the waters of the 19th century cultural landscape thus exhibited extremely diverse habitats and structures, resulting from the effects of the flood cycle, and corresponding biotic conditions."
- (KUHN & AMIET, 1988a, p.1): "In the brief course of a century, drastic changes became apparent. Today they force us to do some serious thinking because as a consequence of engineering works and hydropower use, the majority of riverbanks and watercourses have already been altered and partially or wholly divorced from the natural function they perform within the landscape."
- (GERBER, 1967, p.6): "Until 1848 there was no Confederacy capable of action. Thus in the 18th and the first half of the 19th centuries only two projects of any major significance were brought to fruition: The correction of the Kander which transported enough sediment to pose a threat to Thun and beyond that the Aare valley as far as Bern … likewise the Linth correction, which was planned amid the greatest political difficulties at the time of the old Confederacy, and carried out thanks to the extraordinary dedication of conscientious men in Helvetica Switzerland."

We assume on the basis of these comments that the condition of Swiss watercourses and their floodplain areas in about the mid-19th century, while no longer completely natural, was still near-natural enough that, had they remained in that condition through to the present day, no substantial negative impacts on the diversity of flora and fauna would have resulted. The mid-19th century is accordingly adopted here as a reference period for determining the "historical" extent of floodplains. As will become apparent, in the case of Switzerland, suitable cartographic material for nationwide assessment of the extent of floodplains only dates from around the post-1870 period, so we will take the situation documented in these maps as a guide to the situation in the "mid-19th century".

2.1.3 Method for determining riverine floodplain area loss per sheet of the 1:25'000 National Map of Switzerland

To determine the loss of Switzerland's riverine floodplains the following method was developed. It is essentially based on analysis of the 1:25'000 National Map of Switzerland (BUNDESAMT FÜR LANDESTOPOGRAPHIE, 1952-), and of historical and geological maps. For each sheet of the 1:25'000 National Map of Switzerland work to determine the loss of Switzerland's riverine floodplains was carried out according to the following principles:

Step 1: Selection of 'identified river sections'

With reference to the 1:200'000 Geological General Map of Switzerland (SCHWEIZERISCHE GEOLOGISCHE KOMMISSION, 1942–1964) we sought to identify all sections of watercourses with riverine floodplains which originally extended over a significant area (known in the remainder of this work as *identified sections of watercourses*): These are likely to exist wherever Holocene alluvial layers are marked, and were not subsequently covered by encroaching rivulet or dry-valley talus cones, landslides and rockfalls. In the 1:200'000 Geological General Map of Switzerland these are the areas coloured white but not otherwise marked with symbols for the deposits mentioned above. Various examples indicate that certain fluvioglacial and interglacial gravel beds, shaded pink, may also qualify as riverine floodplain areas and must therefore be investigated further. Our working assumption in this instance is that the fluvial deposits in these locations were too small to have been represented with an appropriate marking. To verify the selection of sites, a comparison was made with the alluvial woodland distribution map produced by Rudolf Siegrist in the year 1913 for his dissertation (SIEGRIST, 1913), and in which all intact or preserved alluvial woodland areas of significant size in Switzerland were marked with a dotted line.

Step 2: Estimate of historical floodplain areas in each identified river section

The *identified sections of watercourses* were studied on the corresponding first editions of the Siegfried Map (EIDGENÖSSISCHES STABSBUREAU, 1870–1926) with the aim of assessing the perimeter and area of the *historic* riverine floodplains. The Siegfried Map is the earliest cartographic work available which covers the whole of Switzerland with a scale of 1:25'000 or 1:50'000. Most of the first editions of the Siegfried Map were published between 1870 and 1889 – which is 100–120 years before the work of (LANDOLT, 1991) – so we consider it justifiable to take the situation documented in these maps as a guide to the situation in the "mid-19th century" (reference period). In cases where first editions of the Siegfried Map were published only after 1889, the *identified sections of watercourses* – if shown – were studied on the Cantonal topographic survey maps used as a basis for the Dufour Maps (DUFOUR, 1864–1867, ESCHMANN, 1851–1856, MICHAELIS, E. H. 1991, WILD, J. 1990). The Dufour Map itself could not be used because it is only available in 1:100'000 format which does not give sufficient definition. On these historic maps the riverine floodplains of the *identified sections of watercourses* were marked. These "historic" riverine floodplains comprise:

- All areas bounded by the outermost side-channels of the river (including the area covered by water) which proceed from the main river channel and flow back into it further down the valley. Spring-fed streams are not included in principle because they are fed from groundwater. However they are taken into account when their source is situated very close to the actual course of the river.

- Areas outside of the outermost side-channels of the river, provided these are marked with the symbols for sand or broadleaved forest.
- Areas outside of the outermost side-channels of the river, provided that the incline and cross-fall of the land on the one hand and the historical settlement structure and infrastructure on the other hand give grounds to suspect periodic flooding. In the latter case, the boundaries of the flooded areas are delineated by lateral dikes, settlements, railway lines parallel to the river and roads parallel to the river with presumed dike function. With a judicious degree of caution, areas of land were also included in the floodplain area on the basis of suitably indicative field names ("Grien", "Werd", "Au").
- Land which is still part of the present-day floodplain.

The floodplains do not include:
- Marshland outside of the riparian alluvial woodland, if there is reason to believe that this has not arisen through river-dynamic processes but as a result of other factors such as groundwater flow, top water or siltation of former lakes.
- Areas which are only influenced by a small watercourse of local origin which is unlikely to have transported any significant amount of sediment.

Step 3: Estimate of existing floodplain areas in each identified river section

On the 1:25'000 National Map of Switzerland (BUNDESAMT FÜR LANDESTOPOGRAPHIE, 1952-) we additionally marked the present-day riverine floodplains associated with all the identified sections of watercourses. These riverine floodplains comprise:
- Blue-coloured areas of watercourses (channels) including banks of gravel and sediment as well as unused, unwooded islets in the river channel
- Area up to the first dike including the inside of the dike (if present) but excluding intensively used agricultural land on the fringe of the flooding zone.
- "Proposed floodplain sites" (cf. Section 2.3.5 below)

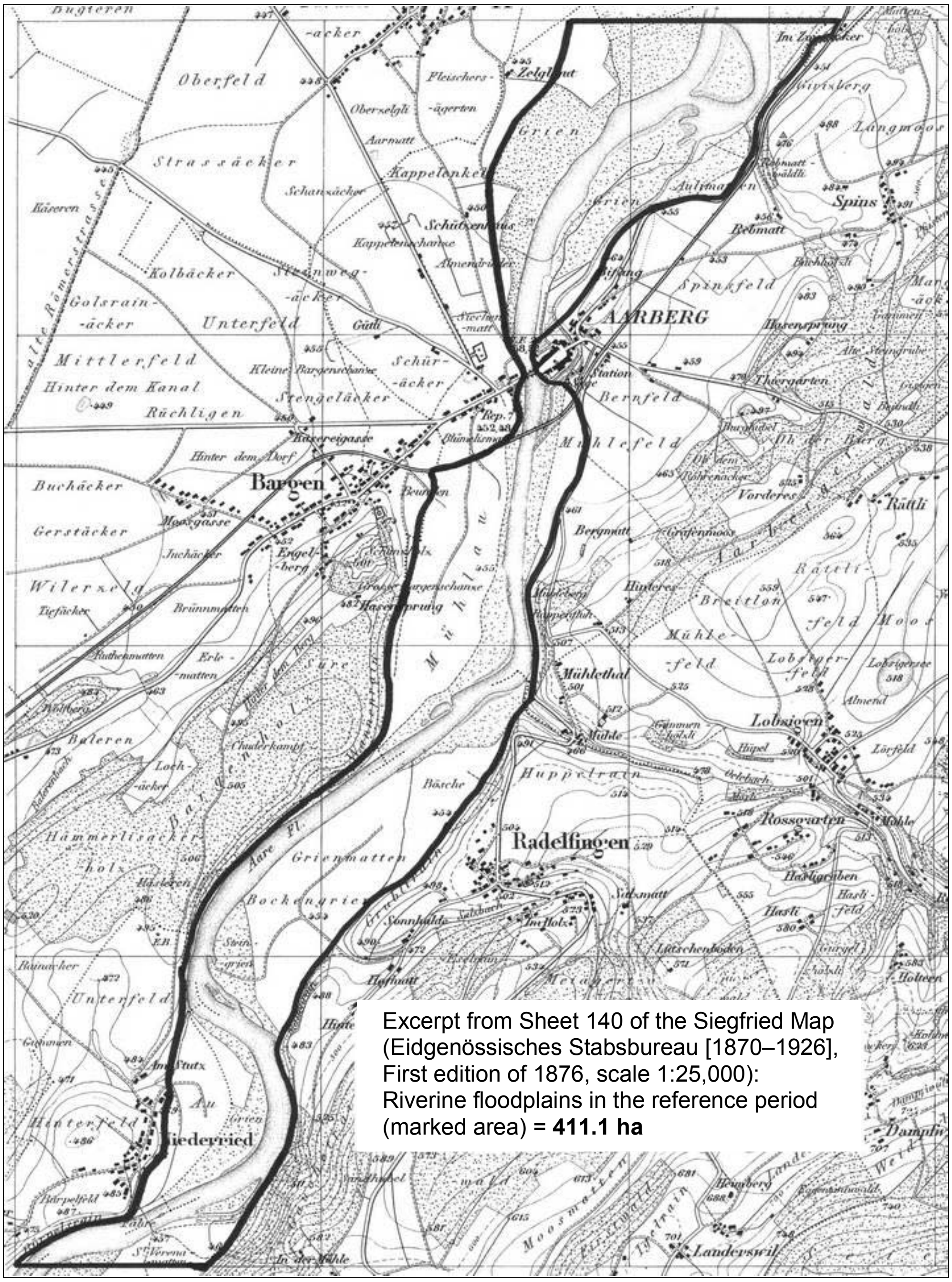
Step 4: Differences between historical and present-day river surface areas

Where there were differences between the historic riverine floodplains and the present-day riverine floodplains of the *identified sections of watercourses*, these *differences* were recorded as follows:
- The *historic* riverine floodplains in the reference period were traced onto transparent paper and then measured using a planimeter (on this, cf. example fig. 2-1). Since the Siegried Map (EIDGENÖSSISCHES STABSBUREAU, 1870–1926) is not available in digital form and the effort involved in scanning all the necessary sheets would have been disproportionately great, we decided not to use GIS. The authors have retained their tracings and working notes.
- The *present-day* riverine floodplains were measured directly from the 1:25'000 National Map of Switzerland (BUNDESAMT FÜR LANDESTOPOGRAPHIE, 1952-) (estimated mean breadth multiplied by length of section as measured with planimeter) or on a to-scale copy of the "proposed floodplain sites" associated with that section, using a planimeter (where the whole site did not fall within the map sheet studied as part of the sample, in which case the officially stated area could be used). In the example of the *identified section of watercourse* in fig. 2-1 the present-day riverine floodplains according to sheet 1146 "Lyss" of the 1:25'000 National Map of Switzerland amount to 122.1 ha (areas without "proposed site" 49: 80.3 ha, part of "proposed site" 49: 41.8 ha).

- For each *identified section of watercourse*, the difference was calculated between the area of historic riverine floodplains in the reference period, and that of present-day riverine floodplains. In the example of the *identified section of watercourse* in fig. 2-1 this difference amounts to 411.1 ha – 122.1 ha = 289.0 ha.

Step 5:
Summation of the historical/present-day differences in area on each national grid sheet of scale 1:25 000

Next the total of these differences across all the *identified sections of watercourses* was calculated to quantify riverine floodplain area loss for the relevant sheet of the 1:25'000 National Map of Switzerland.



Excerpt from Sheet 140 of the Siegfried Map (Eidgenössisches Stabsbureau [1870–1926], First edition of 1876, scale 1:25,000): Riverine floodplains in the reference period (marked area) = **411.1 ha**

Fig. 2-1:
Example of delineation of the historic riverine floodplain areas for an *identified section of watercourse* in the reference period

2.1.4 Sampling technique

The process described above was not applied to the entire area of Switzerland because time resources were limited. Instead a sampling technique was developed based on sheets of the 1:25'000 National Map of Switzerland (BUNDESAMT FÜR LANDESTOPOGRAPHIE, 1952-) which permitted extrapolation to the whole area of Switzerland:

- The 249 sheets of the 1:25'000 National Map of Switzerland were arranged in ascending order according to their sheet numbers and numbered from 1 to 249 in sequence (sheet 1011 was allocated the number 1, sheet 1374 was allocated the number 249).
- Excel was used to generate 10'000 random numbers between 1 and 249.
- Beginning with the first random number, all random numbers were checked in ascending order to see if the same value had already been generated. If so, the random number in question was deleted. By this method we finally obtained the numbers 1 to 249 in a random sequence.
- The numbers 1 to 249 were then replaced with the corresponding sheet numbers. The first 12 sheet numbers were allocated to the first sample of 12 sheets, the next 12 sheet numbers to the second 12-sheet sample, and so on. After 20 12-sheet samples had been obtained, 9 spare sheet numbers remained (cf. Annex A1).

After dealing with each 12-sheet sample, riverine floodplain area loss was extrapolated in linear fashion for the map sheets studied, applying the factor “Swiss territory / Swiss territorial area of all sheets studied”. The measurements for the area of Swiss territory on map sheets which included parts of other countries were taken from an internal Swiss Federal Office of Topography list which was sent to us on 21.8.2001 by e-mail. Each subsequent 12-sheet sample was tackled until the extrapolated figure for area loss, obtained on the basis of all the 12-sheet samples processed so far, had stabilized.

This technique has the advantage that the same procedure could be used to increase the sample size or even to study the whole body of 249 maps, if greater precision were required and if additional resources were available. A complete study of all map sheets during this project would have overstretched the project's financial resources.

2.2 Determining riverine floodplain area loss in Switzerland: Results

2.2.1 Loss of riverine floodplain area per map sheet analysed

The loss of riverine floodplain area for each analysed sheet of the 1:25'000 National Map of Switzerland (BUNDESAMT FÜR LANDESTOPOGRAPHIE, 1952-) is recorded in tab. 2-21 to 2-4. The rationale for calling a halt after four 12-sheet samples can be found in Section 2.2.2.

Fig. 2-2 illustrates that the loss of riverine floodplain area found for the analysed sheets of the 1:25'000 National Map of Switzerland varies greatly. On the majority of sheets it amounts to between 0 and 800 hectares. However the sum of losses in floodplain area for all the sheets analysed is significantly influenced by peak values of up to 2700 ha which only occur in isolation. This raises the question of the accuracy of any extrapolation from the areas analysed to the entire area of Switzerland. This question is the subject of Section 2.2.3.

Tab. 2-1: Riverine floodplain area loss for the analysed sheets of the 1:25'000 National Map of Switzerland (BUNDESAMT FÜR LANDESTOPOGRAPHIE, 1952-) from the first 12-sheet sample

Sheet	Area within Swiss territory (km²)	Riverine floodplain area loss (ha)
1091	210.0	1861.4
1096	65.0	288.4
1113	210.0	243.8
1132	210.0	655.9
1146	210.0	948.9
1155	195.0	392.7
1197	210.0	174.2
1230	210.0	0.0
1241	193.1	0.0
1250	210.0	278.5
1273	210.0	600.3
1274	193.1	43.0
Total	2326.3	5487.0

Tab. 2-2: Riverine floodplain area loss for the analysed sheets of the 1:25'000 National Map of Switzerland (BUNDESAMT FÜR LANDESTOPOGRAPHIE, 1952-) from the second 12-sheet sample

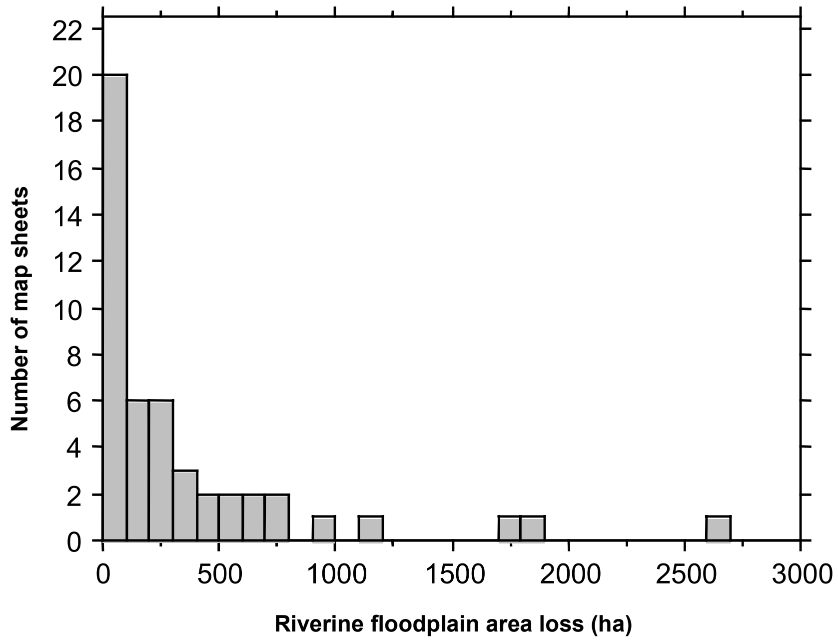
Sheet	Area within Swiss territory (km²)	Riverine floodplain area loss (ha)
1157	40.0	0.0
1162	63.8	20.1
1171	210.0	133.3
1189	210.0	0.0
1193	210.0	39.6
1195	210.0	368.8
1211	210.0	0.0
1213	210.0	214.4
1231	210.0	93.8
1298	111.3	87.9
1300	103.1	195.3
1306	210.0	1783.3
Total	1998.1	2936.4

Tab. 2-3: Riverine floodplain area loss for the analysed sheets of the 1:25'000 National Map of Switzerland (BUNDESAMT FÜR LANDESTOPOGRAPHIE, 1952-) from the third 12-sheet sample

Sheet	Area within Swiss territory (km²)	Riverine floodplain area loss (ha)
1050	101.3	709.3
1051	133.1	540.1
1065	88.1	0.0
1110	210.0	195.9
1116	8.1	15.4
1134	210.0	246.5
1152	210.0	534.8
1218	210.0	163.4
1219	168.8	0.0
1232	210.0	45.5
1249	210.0	0.0
1313	210.0	2679.7
Total	1969.4	5130.5

Tab. 2-4: Riverine floodplain area loss for the analysed sheets of the 1:25'000 National Map of Switzerland (BUNDESAMT FÜR LANDESTOPOGRAPHIE, 1952-) from the fourth 12-sheet sample

Sheet	Area within Swiss territory (km²)	Riverine floodplain area loss (ha)
1070	210.0	419.3
1107	210.0	751.9
1115	188.1	322.8
1167	210.0	480.9
1173	210.0	204.8
1188	210.0	32.1
1191	210.0	144.6
1221	135.0	18.3
1223	210.0	0.0
1235	210.0	43.7
1244	210.0	0.0
1287	210.0	1142.7
Total	2423.1	3561.0



Distribution of riverine floodplain area loss over the analysed sheets of the 1:25'000 National Map of Switzerland (BUNDESAMT FÜR LANDESTOPOGRAPHIE, 1952-)

2.2.2 Projecting riverine floodplain area loss for the whole of Switzerland

After completing the analysis of each 12-sheet sample, riverine floodplain area loss was extrapolated in linear fashion to the whole area of Switzerland (41'293 km^2 (BUNDESAMT FÜR STATISTIK, 2002) (cf. tab. 2-5) and presented graphically (cf. fig. 2-3).

Tab. 2-5: Riverine floodplain area loss obtained from the analysed sheets of the 1:25'000 National Map of Switzerland (BUNDESAMT FÜR LANDESTOPOGRAPHIE, 1952-) after processing one, two, three and four 12-sheet samples, and extrapolation to the whole of Switzerland

Sample size (number of groups of 12)	Area of samples within Swiss territory (km²)	From map-sheet samples analysed	Extrapolated to the area of Switzerland
1	2'326	5'487	97'400
1 and 2	4'324	8'423	80'435
1, 2 and 3	6'294	13'554	88'927
1, 2, 3 and 4	8'717	17'115	**81'076**

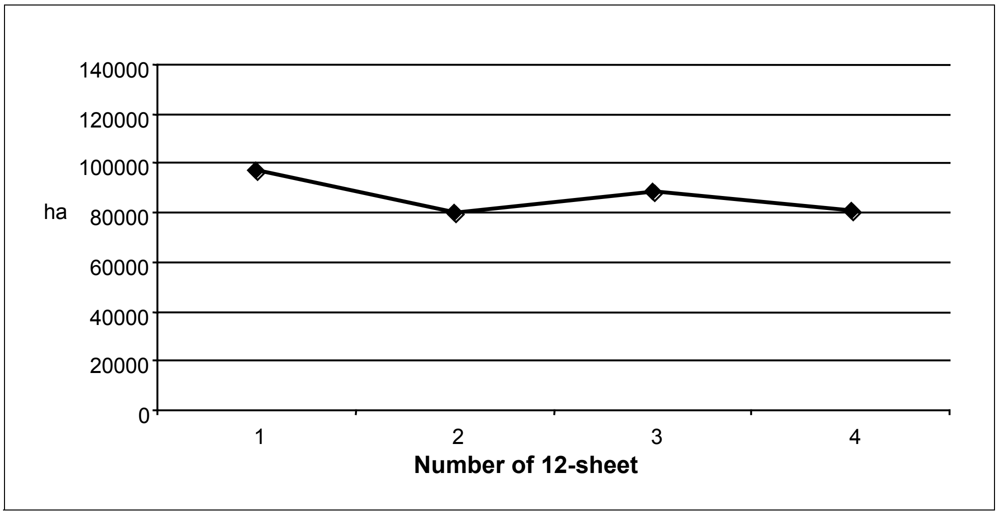


Fig. 2-3:
Results of extrapolating the loss of riverine floodplain area to the area of Switzerland, in association with the number of 12-sheet samples processed

Since the overall results after the incorporation of the third 12-sheet sample, and again after the fourth, no longer varied greatly, and statistical considerations led us to believe that greater accuracy could only be obtained at much greater length (cf. Section 2.2.3 and Annex 2.3), the decision was taken not to pursue work on the fifth 12-sheet sample. The value projected following the fourth 12-sheet sample will be represented by $\bar{y}_s$ from this point, and amounts to 81'076 ha. The Swiss territorial area of the four 12-sheet samples analysed amounts to 8717 km^2 or 21.1% of the area of Switzerland.

2.2.3 Accuracy of results

To calculate a confidence interval for riverine floodplain area loss established on the basis of the four 12-sheet samples (from this point referred to simply as the sample) depends on the assumption of *equivalence* of elements. In our case, this would require each of the 249 sheets of the 1:25'000 National Map of Switzerland (BUNDESAMT FÜR LANDESTOPOGRAPHIE, 1952-) to comprise an equal amount of Swiss territorial land area. Otherwise projecting the loss of riverine floodplain area obtained from every sheet to the total area of Switzerland would result in excessive weighting of sheets comprising a smaller proportion of Swiss territory. However since 103 of the 210 km^2 sheets contain an area of non-Swiss territory of one size or another, this precondition is not met, i.e. sheets with a proportion of non-Swiss territory would carry excessive weight. In order to obtain *approximately* equivalent elements, the sheets with a proportion of non-Swiss territory were *combined* as follows:

- The 103 sheets including some non-Swiss territory were arranged in the sequence in which they were (originally!) drawn (cf. Annex A 1).
- These were subdivided into two groups: One group consisting of the first 15 sheets including some non-Swiss territory (comprising the sample) (cf. Annex A 2.1) and one group consisting of the remaining 88 sheets with some non-Swiss territory which were not part of the sample (cf. Annex A 2.2).
- In each group the sheets were taken in sequence and assembled into combinations of sheets covering as close to 210 km^2 as possible, but never a greater area; i.e. the first sheet was taken and combined with the second sheet provided that this did not result

in a combined Swiss territorial area in excess of 210 km^2. Depending on whether this combination was possible, the third sheet was then combined provided that this did not result in a combined Swiss territorial area in excess of 210 km^2. This process was repeated until the final sheet was reached. This produced the first set of combined sheets. Next these combined sheets were removed from the list and the process was repeated, starting from the first of the remaining sheets, for as long as it took to make combinations of all the sheets. Thus the 15 original sheets of the sample with some non-Swiss territory were combined down to 10 new sheets and the 88 original sheets with some non-Swiss territory which were not part of the sample were combined to form 46 new sheets; i.e. the sample was reduced from 48 to 33+10=43 elements and the population was reduced from 249 to 146+46+10=202 elements.

Besides meeting the condition of equivalence of elements, the size of the sample should also be determined from the outset. However since we chose a sequential procedure here for practical reasons and since the equivalence of elements is only approximately ensured, the results obtained from the following calculations can only be seen as good approximations.

The variance of the arithmetical mean of a sample is generally (HULLIGER, 2000, p.11):

$$\mathrm{Var}(\bar{y}_S) = (1 - n/N)\frac{1}{n}D^2 \qquad [2.1]$$

N is the size of the population, n is the size of the total sample, D^2 is the variance of the population. Since the latter is unknown it is estimated from the variance of the sample d^2. We use the asterisk to indicate that the value in question refers to the population including the combined map sheets:

$$\mathrm{Var}(\bar{y}_S{*}) = (1 - n{*}/N{*})\frac{1}{n{*}}d^{*2} \qquad [2.2]$$

$N*$ is 202, $n*$ 43, d^{*2} as per Annex 2.3 is 12'248'833'224 ha^2.

Since the size of the total sample is relatively large, the central limit theorem applies and an approximate 95% confidence interval $\bar{y}_s{*} \pm 1.96\sqrt{\mathrm{Var}(\bar{y}_s{*})}$ can be calculated. The relevant values are compiled in tab. 2-6.

Tab. 2-6: Mean value $\bar{y}_s{*}$ with 95% confidence interval (absolute and percentage); mean value $\bar{y}_s$ for comparison

$\bar{y}_s{*}$	80'756 ha
$\bar{y}_s$	81'076 ha
Confidence interval – absolute	± 29'349 ha
Confidence interval – percentage	± 36%

The mean values $\bar{y}_s$ and $\bar{y}_s{}^*$ are not identical since the combined map sheets do not generally cover exactly, but only approximately, 210 km^2 of Swiss territory. However since the discrepancy is less than 1%, the confidence interval can safely be applied to $\bar{y}_s$. The result given in Section 2.2.2 can now be stated with a 95% confidence interval (cf. tab. 2-7).

Tab. 2-7: Riverine floodplain area loss with 95% confidence interval

	Area of riverine floodplains, reference period
Mean value $\bar{y}_s$	81'076 ha
Upper limit 95% confidence interval	81'076 ha + 29'349 ha = 110'425 ha
Lower limit 95% confidence interval	81'076 ha – 29'349 ha = 51'727 ha

As we already had reason to believe based on how riverine floodplain area loss was distributed over the analysed sheets of the 1:25'000 National Map of Switzerland (BUNDESAMT FÜR LANDESTOPOGRAPHIE, 1952-) (cf. fig. 2-6), the limits of the 95% confidence interval leave relatively wide latitude. Annex A 3 therefore provides an assessment of the additional effort that would be required to improve the accuracy of the overall results.

2.3 Calculating the present-day area of riverine floodplains in Switzerland

In the interests of greater precision, and contrary to the above use of spot checks to determine the *decline* of floodplain areas in Switzerland, we shall now use countrywide data to determine their *present status*.

2.3.1 Spatial statistics

The present-day area of riverine floodplains in Switzerland as a whole (cf. definition in Section 2.1.1) can be subdivided into the following categories::

- Alluvial plains subject to periodic or episodic flooding by watercourses, including banks of gravel and sediment as well as unused, unwooded islets in the river channel
- Embanked areas of river bed created by engineering measures
- The inside of flood dikes, since these are normally relatively near-natural areas
- Other land, either unwooded (nutrient-poor grassland) or wooded (lower and upper riparian woodland) subject to periodic or episodic flooding

In Swiss spatial statistics the geographical area outlined above (albeit with the missing elements listed below) corresponds to the land use class “Watercourses”, consisting of the basic categories (92) Watercourses, (93) Flood control works, (69) River embankments (BUNDESAMT FÜR STATISTIK, 1992). These account for a total area of 31'732 ha (BUNDESAMT FÜR STATISTIK, 2002).

In addition the following areas not included in this aggregate must be taken into account (BUNDESAMT FÜR STATISTIK, 1992, p. 137–153):

a) Watercourses less than 6 metres in breadth in the wooded zone (forest) (cf. Section 2.3.2)
b) Watercourses beneath the tree crowns of field trees or shrubs (cf. Section 2.3.2)
c) Watercourses under reedbeds (cf. Section 2.3.3)
d) Gravel extraction sites in watercourses (cf. Section 2.3.3)
e) Oxbows and stream storage lakes, if these are marked as lakes in the 1:25'000 National Map of Switzerland (BUNDESAMT FÜR LANDESTOPOGRAPHIE, 1952-) (cf. Section 2.3.4)
f) Unwooded floodplain (cf. Section 2.3.5)
g) Alluvial woodlands (cf. Section 2.3.5)

In the following sections we will estimate the areas of categories a) to g).

2.3.2 Watercourses less than 6 metres in breadth in the wooded zone and beneath the tree crowns of field trees or shrubs

The Swiss Federal Office for Water and Geology undertook a GIS calculation of the total length of watercourses in Switzerland based on the 1:25'000 National Map of Switzerland and informed us on 6.2.2002 by e-mail that the result was 82'955 km. We made the assumption that watercourses less than 6 metres in breadth account for 90% of this length, and that the mean breadth of these watercourses is 2 metres. The plausibility of the magnitude of our estimate that 10% (or around 8300 km of the length) of stretches of river are more than 6m in breadth can be evaluated with reference to the fact that the total length of Switzerland's 10 longest rivers, added together, is only 1756 km (UMWELTSTAT, 2002, Table T2.2.1.2). Furthermore we assumed that these watercourses were evenly distributed over areas a) plus b) and the remaining area of Switzerland. Areas a) plus b) consist of the main categories of forest (comprising basic categories 10–15) and sites covered in woody plants (comprising basic categories 17–19) (BUNDESAMT FÜR STATISTIK, 1992) and make up 30.8% of the area of Switzerland (BUNDESAMT FÜR STATISTIK, 2002). This produces an estimated additional area for a) plus b) of 82'955 km * 90% * 2 m * 30.8% = 4'600 ha.

2.3.3 Watercourses under reedbeds and gravel extraction sites in watercourses

Die Flächen c) und d) dürften von geringfügiger Grösse sein. Denn Kiesentnahmen sind heute in den Schweizer Flüssen nur noch in geringem Mass möglich und gestattet, weil der natürliche Geschiebetransport durch flussbauliche Massnahmen verringert ist und Kiesentnahmen demzufolge zu unerwünschten Sohlenabsenkungen führen würden. Weiter sind die Fliessgeschwindigkeiten in den Schweizer Flüsse so hoch, dass eine Röhrichtbildung nur an vergleichsweise wenigen Stellen möglich ist. Deshalb wird hier die Ausdehnung der Flächen c) und d) näherungsweise auf 0 ha geschätzt.

2.3.4 Oxbows and stream storage lakes marked as lakes on the 1:25'000 National Map of Switzerland

Stream storage lakes marked on the 1:25'000 National Map of Switzerland (BUNDESAMT FÜR LANDESTOPOGRAPHIE, 1952-) as lakes (e.g. Wohlensee) are impounding reservoirs, and are therefore considered as lakes rather than as watercourses. Therefore under our definition they do not qualify as riverine floodplains and are not taken into consideration. It can be assumed that oxbows marked as lakes on the 1:25'000 National Map of Switzerland do not account for an area of any significant size. Therefore areas e) are omitted.

2.3.5 Alluvial woodlands and unwooded floodplains

For calculating the floodplain areas f) and g) the Federal Inventory of Alluvial Zones of National Importance can serve as a foundation. It needs to be borne in mind that the inventory of alluvial zones is not exhaustive, however. It contains only individual sites which exceed 2 ha and satisfy strict requirements as to natural status. Moreover it is possible that in the case of certain sites, Cantons may have resisted inclusion in the inventory of floodplains due to strict conservation regulations. The alluvial zone of the Rhine south of Landquart, for example, is conspicuous by its absence from the inventory. Therefore for the present work, the qualifying factor is not which areas were finally included in the inventory of floodplains, but which areas were *proposed* at any time for inclusion in the inventory of floodplains. The sum of all these proposed areas is determined as follows:

\+ Total area of sites in the 1988 plan for the survey (KUHN & AMIET, 1988b)
\+ Total area of new sites in the 1993 revised alluvial inventory (sites 216–229) (BUWAL, 1993)
\+ Total area of alpine alluvial plains from the first supplement (15 of the total 70 proposed sites) (BUWAL, 1999)
\- Area of proposed site in the 1988 plan for the survey (KUHN & AMIET, 1988b), later proposed as an alpine alluvial plain in the course of the first supplement (site 215) (BUWAL 1999)
\+ Total area of proposed sites from the second supplement (97 sites) (THIELEN et al., 2001)
\- Total area of proposed sites from the 1988 plan for the survey (KUHN & AMIET, 1988b), which were proposed again in the second supplement (sites 22, 25, 64) (THIELEN et al., 2001)
\+ Total additional area from enlargement of the perimeter of various sites in the second supplement (THIELEN et al., 2001)

From the proposal for the first supplement (BUWAL, 1999) only the areas of the alpine alluvial plains are taken into account. The glacial foreland sites are omitted because they do not meet our definition of a riverine floodplain. However there are sites (106, 126, 136, 137, 143) which overlap with these 55 glacial foreland sites. These were retained because they were proposed on the basis of their fluvial rather than their glacial characteristics.

The total area of all floodplain sites proposed at one time or another is 15'328 ha. However we must take into account that their area also includes associated watercourse areas, which are already counted in the spatial statistics, as well as some non-floodplain areas. With the exception of the alpine alluvial plains in the proposal for the first supplement to the alluvial inventory (BUWAL, 1999) and the perimeter enlargements, however, some partial areas (upper and lower riparian woodlands, unwooded floodplain, vegetation-free land, areas of water, non-floodplain land) have been omitted in each category. Thus it is possible to subtract from this area the area of any water and any non-floodplain zone. In doing so, the area of the alpine alluvial plains and the perimeter enlargements is assumed to consist of 15.4% water, in line with the mean figure for the other areas.

The result is an additional area of 11'803 ha for f) and g).

2.3.6 Present-day area of riverine floodplains in Switzerlan

The present-day area of riverine floodplains in Switzerland is the sum of the areas listed in Sections 2.3.1 to 2.3.5:

31'732 ha (spatial statistics) + 4'600 ha (watercourses less than 6 metres in breadth in the wooded zone and beneath the tree crowns of field trees and shrubs) + 11'803 ha (alluvial woodlands and unwooded floodplains) = 48'135 ha.

2.4 Calculating the area of riverine floodplains in the reference period

The area of riverine floodplains in the reference period is the sum of the area of present-day riverine floodplains and the decrease in area of riverine floodplains. The area of riverine floodplains in the reference period, so obtained, is shown in tab. 2-8.

Tab. 2-8: Calculating the area of riverine floodplains in the reference period

	Riverine floodplains – reference period
Mean value	81'076 ha + 48'135 ha = 129'211 ha
Upper limit 95% confidence interval	110'425 ha + 48'135 ha = 158'560 ha
Lower limit 95% confidence interval	51'727 ha + 48'135 ha = 99'862 ha

By placing the riverine floodplain area loss in relation to the estimated area of riverine floodplains in the reference period, an estimated relative loss of riverine floodplain areas is obtained (cf. tab. 2-9). This amounts to a little over 60%. Using the 95% confidence interval values, results of 50 to 70% are obtained.

Tab. 2-9: Estimated relative riverine floodplain area loss

	Relative riverine floodplain area loss
Mean value	81'076 ha / 129'211 ha = 62.7%
Upper limit 95% confidence interval	110'425 ha / 158'560 ha = 69.6%
Lower limit 95% confidence interval	51'727 ha / 99'862 ha = 51.8%

To verify the figures in tab. 2-8, in the following section we intend to gain an idea of the conceivable maximum area of riverine floodplains in the reference period. A suitable method is to take measurements of the maximum potential riverine floodplain areas from a topographical or geological point of view, from soil maps or geological maps.

The 1:500'000 Soil Map, sheet 7a** of the Atlas of Switzerland (IMHOF, 1965–1978), contains data on soil units which could have supported natural growth of floodplain vegetation at some time or another: Fluvisols in the Mittelland region up to 700 m, sandy acidic braunerde in Valais and Ticino, raw fluvisols ('Roh-Fluvisol') in central Alpine valleys up to 1500 m, and gley. The total area of these four soil units within Switzerland is stated in the text accompanying the atlas sheet as 1990 km^2 or 199'000 ha. This total does not include the surface area of watercourses in Switzerland, which are also by definition part of the riverine floodplain area. As an estimated value for the surface area of these watercourses, we can take the present-day area of the land-use class “Watercourses” (BUNDESAMT FÜR STATISTIK, 1992) from the Swiss spatial statistics, which is around 32'000 ha (BUNDESAMT FÜR STATISTIK, 2002). This gives a conceivable maximum figure for the historic extent of riverine floodplains in Switzerland of around 230'000 ha. The upper limit of 158'560 ha according to tab. 2-8 is significantly lower than this maximum value.

In addition the Swiss Federal Office for Water and Geology undertook a GIS calculation of the extent of alluvial plains in Switzerland based on the 1:500'000 Geological Map of Switzerland (SCHWEIZERISCHE GEOLOGISCHE KOMMISSION, 1980) and informed us on 20.7.2001 by e-mail that the result was approx. 290'000 ha. The Swiss Federal Office for Water and Geology also confirmed by e-mail on 30.8.2001 that the following areas of Switzerland were included:

- Recent alluvial layers, i.e. valley bottoms formed from river sediment since the ice age, also subsuming a small proportion of Würm glacial deposits (coloured white on the geological maps).
- The surface waters of the relevant rivers
- Peat layers in the valley plains (marked with brown horizontal dashes on the map)
- Reedbed/marshland areas in the valley plains (marked with black horizontal dashes on the map)
- Flatter, lower part of talus cones projecting from the sloping valley sides into the valley plains (marked with black, trumpet-like fans of dashes or small dots on the map)
- Settlement and transportation areas which have grown up on sites of the above types.

However, the following areas were not included:

- Rockfall sites in the valley bottoms (marked with black dots on the map)
- Steep root zones of talus cones projecting from the sloping valley sides into the valley plains
- Lake areas adjoining the valley bottoms such as Lake Constance, Lake Zurich, etcc.

Since this site classification includes obvious non-floodplain areas (peat layers, marsh areas not associated with watercourses) as well as watercourses within alluvial plains, its 290'000 ha area may safely be assumed, even without the addition of areas of water-courses outside alluvial plains, to represent a maximum value for the historic extent of riverine floodplains. Here, there is no doubt that the maximum limit is very broadly framed. It comes as no surprise that the upper limit according to tab. 2-8 is substantially lower than this broadly framed maximum limit.

From the above analyses of the 1:500'000 Soil Map of Switzerland (IMHOF, 1965–1978) and the 1:500'000 Geological Map of Switzerland (SCHWEIZERISCHE GEOLOGISCHE KOMMISSION, 1980) it accordingly emerges that the extent of Switzerland's riverine floodplains in the historical reference period was less than 230'000 – 290'000 hectares. Thus there is no way that the relative loss of riverine floodplain area determined in tab. 2-9 could exceed a theoretical limit of around 80% (cf. tab. 2-10). The extent of historic riverine floodplains was certainly somewhat lower than this limit because geological maps and soil maps provide evidence of where such floodplains have existed at any time in the period from the end of the last ice age to the present day. Of course, at no point in history would all these floodplain areas have existed simultaneously. To take one example: In the case of the St. Gallen Rhine valley, the breadth of the sedimentary layers closest to the surface, deposited by the Alpine Rhine on three sites (Lustenau, Diepoldsau, Mäder), as taken from transverse geological profiles (HAIDVOGL & EBERSTALLER, 1997, p.12, fig. 4.3), was compared with the estimated breadth of the floodplain shown on the Eschmann Map (ESCHMANN, 1851–1856) dating from the mid-19th century. In these cases it became apparent that the breadth of the floodplain according to transverse geological profiles was many times greater than the breadth that could be read from the Eschmann Map (ESCHMANN, 1851–1856). This is explained by the fact that over the course of millennia, the Alpine Rhine has repeatedly altered its course within the transverse profile of the Rhine valley and left behind sedimentary traces all over the valley. With this in mind, any documentation of the situation of the river and its floodplains in the 19th century is no more than a momentary snapshot.

Tab. 2-10: Conceivable maximum area of riverine floodplains in the reference period and their loss

	1:500'000 Soil Map	1:500'000 Geological Map
Riverine floodplains in the reference period	**230'000 ha**	**290'000 ha**
Loss of riverine floodplains – absolute	230'000 ha – 48'135 ha = **181'865 ha**	290'000 ha – 48'135 ha = **241'865 ha**
Loss of riverine floodplains – relative	181'865 ha / 230'000 ha = **79.1%**	241'865 ha / 290'000 ha = **83.4%**

For comparison: (KUHN & AMIET, 1988a, p. 20) estimated loss at 90%, taking the natural state as the departure point. This estimate is above the conceivable maximum value determined in tab. 2-10 and hence it must be too high. The estimate becomes realistic, however, if it should refer to the decrease in the *land* area of riverine floodplains:

We estimated the relative loss of *land* area of riverine floodplains (not including the areas drawn in blue on the 1:25'000 National Map of Switzerland (BUNDESAMT FÜR LANDESTOPOGRAPHIE, 1952-)), relying for the sake of simplicity on the assumption that the area of water has remained constant. For this purpose the loss of riverine floodplain area was placed in relation to the sum of the decrease in area of riverine floodplains plus the area of present-day riverine floodplains excluding water area (11'803 ha, cf. Section 2.3.5). This produced results of between 80 and 90% (cf. tab. 2-11).

Tab. 2-11: Estimated relative loss of *land* areas of riverine floodplains

	Relative loss of riverine floodplain area not including areas of water
Mean value	81'076 ha / (81'076 ha + 11'803 ha) = 87.3%
Upper limit 95% confidence interval	110'425 ha / (110'425 ha + 11'803 ha) = 90.3%
Lower limit 95% confidence interval	51'727 ha / (51'727 ha + 11'803 ha) = 81.4%

In order to evaluate the importance of riverine floodplains for species diversity and to compare them with other types of site, we determined the area of present-day and historic riverine floodplains as a proportion of the area of Switzerland. This proportion has dropped from just over 3 percent to just over 1 percent (cf. tab. 2-12).

Tab. 2-12: Estimated proportion of riverine floodplains today and in the reference period

	Riverine floodplain area as a proportion of the area of Switzerland Today	**Riverine floodplain area as a proportion of the area of Switzerland Reference period**
Mean value	48'135 ha / 41'293 km² = 1.2%	129'211 ha / 41'293 km² = 3.1%
Upper limit 95% confidence interval	-	158'560 ha / 41'293 km² = 3.8%
Lower limit 95% confidence interval	-	99'862 ha / 41'293 km² = 2.4%

3 Recognized impacts on non-human life attributable to riverine floodplain area loss

3.1 Expressing impacts on non-human life

It is commonly accepted that negative impacts on non-human life are expressed as a reduction in biological diversity in man's natural environment, as effected by the damaging cause. In the UNEP Convention on Biological Diversity, as adopted in Rio de Janeiro on June 5, 1992, the UN Member States recognize the importance of biological diversity; Article 2 of the Convention specifies that there are three levels of biological diversity (*syn*. biodiversity), i.e. "diversity within species, between species and of ecosystems" (RIO, 1992). In common language usage

- the diversity *within* species is equivalent to "genetic diversity",
- the diversity *between* species is equivalent to "species diversity",
- the diversity of *ecosystems* is equivalent to "ecosystem diversity".

In order to be able to assess, monitor, and establish the causes of negative impacts on non-human life it would be desirable to record the extent of the three above-mentioned diversities at a global scale and at different points in time. However, at least for the time being this is not possible as the diversity of non-human life, even though it is declining, is still so great that it is impossible to record and monitor in its entirety. According to (UNEP, 2000, p.16) the number of known and described species in the five kingdoms – plants, fungi, animals, algae/protozoa, and bacteria – amounts to 1.75 million and it is estimated that the earth's biosphere hosts approximately 14 million species including those not yet discovered. The knowledge on the species present is thus quite incomplete. However, the incompleteness of current knowledge on genetic diversity within each species and on the diversity of the ecosystems hosting species is much greater still.

Therefore, at present it is only possible to provide a quantitative assessment of the state and development of biodiversity by selecting a sub-section of non-human life as a representative part of the whole. The characteristics of this sub-section should be that on the one hand there is sufficient knowledge on this sub-section and that on the other hand one can assume that the development in this sub-section is representative of the unknown whole. In practice, there is a tendency to representatively assess changes in biodiversity by limiting the assessment to species diversity (UNEP, 2000, p.12), which usually necessitates a focus on a selected subset of species. In the field of ecotoxicology species sets are chosen to examine the effects of toxic emissions. These species sets characterize as representative as possible a cross-section of the entire taxonomic system of non-human life (SETAC, 2002, Chapter 6). In contrast, where the impact of land use on biodiversity is examined a focus on species diversity in vascular plants is discernable (SETAC, 2002, Chapter 2).

This study is concerned with land uses in potential riverine floodplains which prevent the impact of natural watercourse dynamics on the watercourses' potential floodplains. The impact of such land uses on biodiversity will thus be assessed using species diversity in vascular plants, as has been done in similar land use studies. Apart from the fact that such an approach is routinely used, the following arguments can be made for the use of vascular plants (comprising flowering plants and ferns) as representatives of non-human life in its entirety:

- Globally vascular plants are known and have been described to a very large extent; a similar degree of scientific recording can only be asserted for vertebrates (UNEP, 2000, p. 16, 34).
- Within a defined perimeter vascular plants are relatively easily located since – other than animals – they are stationary; this means that geographical information on the presence of vascular plants is relatively reliable and complete. Furthermore, the relationship between the characteristics of a site and the presence of vascular plants on this site is closer than for animals since plants are stationary except for the seed stage.
- In certain regions the presence of vascular plants has been relatively well documented not only for the present but also for points in time in the past. There is thus a possibility of relating changes in the plants' occurrences over time to changes in causal factors.
- In the terrestrial area vascular plants take a central role as transmitters of solar energy to the other species. A decline in the diversity of vascular plants thus translates into a decline in the diversity of other species which depend on the plants for food or shelter.
- Furthermore there is evidence that species diversity in vascular plants in an area correlates clearly with the species diversity of a number of other taxonomic groups in the same area (DUELLI & OBRIST, 1998).

Numerical data on species diversity always relate to a certain point in time and to a certain spatial area, such as for example the entire Earth's surface, the territory of a country, or a smaller defined area.

In order to quantitatively assess the species diversity of vascular plants in a defined area a record of the species occurring in this area is made at a certain point in time, and it is established whether the recorded frequency of the presence of a species points to the species being endangered. An internationally recognized system of threat categories is available to this end (IUCN, 2001).

The degree of biodiversity in vascular plants in an area can thus be expressed as the sum total of the species occurring in the area, grouped by threat categories. This aggregation of species poses the question as to whether species may be added up without a weighting being assigned to them, or whether apart from the threat category there are "important" or "less important" species of vascular plants. In the literature this question is normally not explicitly posed or answered. However, it would appear to be normal practice to present the degree of biodiversity by accumulating the species present either as a sum total or grouped by threat category; see for example (UNEP, 2000; LANDOLT, 1991). This unweighted adding up of the species present would appear to be an expression of the opinion that the species have an intrinsic value which is independent of the value assigned to a species by society at a certain point in time.

On account of the considerations outlined above, for the purposes of this study the quantitative extent of biodiversity will be expressed as the sum of species of vascular plants present in a defined area at a defined point in time. Therefore, it is an expression of a negative impact on non-human life in this defined area if the total species count, taking threat categories into consideration, has declined as compared to an earlier similar count.

3.2 Loss of riverine floodplain area as a cause of threat to species of vascular plants

There are many reasons for the threat to species of vascular plants in Switzerland; these causes of threats have primarily come into effect within the past 100 years (LANDOLT, 1991, p.14). From today's perspective LANDOLT (1991, p.15–19) cites the following as important causes:

- Stabilization of slopes and regulation of rivers and lakes as protection against natural hazards
- Land use for building
- Impact on watercourses from energy generation plants
- Air and water pollution
- Rationalization in farming and forestry

In this study we are especially interested in the question of how far the decline in riverine floodplains in Switzerland during the past 150 years must be identified as a cause of the currently observed endangerment of species of vascular plants. However, there is often not a single reason for the observed threat to an individual species but two or more causes can act in combination. The question of the causes of the threat to floodplain-dependent vascular plant species will be discussed in more detail in Section 4.1.

3.3 Procedure for determining the species of vascular plants which are primarily threatened by riverine floodplain area loss

The species of vascular plants which are primarily threatened as a result of the loss of riverine floodplain area were determined in three steps:

- In Step 1 the plant communities dependent on floodplain sites were identified.
- In Step 2 the threatened vascular plants associated with these plant communities in Switzerland were identified.
- In Step 3 an additional assessment was made for each of these threatened vascular plant species in order to determine whether floodplain area loss can be taken as the primary cause of threat.

For Step 1 the schematic description of the vegetation of Central Europe by (KUHN, 1987) was used which specifically notes the alliances containing associations which occur in riverine floodplains and are largely absent from other natural landscapes. For these the relevant habitats were identified in (DELARZE et al., 1999). As per the definition of riverine floodplains (cf. Section 2.1.1) the actual river bed is also considered part of the riverine floodplains. Therefore the habitats of watercourses and associated standing waters given by (DELARZE et al., 1999) were also considered. In this context no differentiation was made between riverine floodplains and lake floodplains, as the loss of riverine floodplain area has also led to a loss of area of floodplains of standing waters. Natural rivers are characterized by a variety of flow speeds in their sphere of influence: while flow speeds reach a maximum at the centre of the main channel, the flow speed can slow down to near-zero velocity for long periods in the side channels, thus creating lake-like conditions.

For Step 2 the connection between species and habitats outlined by (DELARZE et al., 1999) was utilized. This publication contains an alphabetic list of 3214 plant species (of which 2610 are vascular plants) (DELARZE et al., 1999, p. 381–401), which is not only cross-referenced with the number coded habitats in which these species occur but where the species which are endangered in Switzerland are also marked with an asterisk. From this "Delarze list" all the vascular plant species were systematically extracted which are marked with an asterisk and for which also at least one of the listed habitat number codes denotes a floodplain habitat within the meaning of Step 1. This initial selection resulted in a list of 172 species which was subsequently refined in a step-by-step process using the following criteria:

- Elimination of species which are not currently considered endangered even though they carry an asterisk in Delarze's list: The information used to assess the threat status was the latest list of endangered ferns and flowering plants in Switzerland (ZDSF, 2002), in conjunction with the IUCN red list categories (IUCN, 2001). Those species with IUCN status LC (Least Concern), DD (Data Deficient), NE (not evaluated) and species not listed were eliminated from the list. The eight species thus eliminated are given in Annex A 4.1 and A 4.2 of the present study.
- Elimination of species which are not considered a part of the Swiss flora, since specialist botanic literature (HESS et al., 1976–1980; LAUBER & WAGNER, 2001) describes them as "adventitious" species, i.e. species which were brought in from other countries in more recent times or which are garden escapes. Other than species which have entered the country centuries ago or even earlier and which have become naturalized in Switzerland, these "newly adventitious" species may not be able to survive in the wild in the long term given the biogeographical conditions of Switzerland. Hence their "endangerment" may actually be a sign of a natural selection process which is not due to anthropogenic causes. On the basis of this criterion seven species were eliminated which are given in Annex A 4.3.
- Elimination of species which according to (DELARZE et al., 1999) occur not only in floodplain habitats but also in other habitats which are available in sufficient quantities in Switzerland both at present and in the foreseeable future, which indicates that their endangerment must be due to causes other than the loss of riverine floodplain areas. On the basis of this criterion four species were eliminated which are given in Annex A 4.4.

As the result of this step-by-step evaluation of the initial list a total of 153 vascular plant species remain which are part of the Swiss flora, are also endangered, and the endangerment of which can primarily be ascribed to riverine floodplain area loss. These species are given in the table in Annex A 4.5t.

In Step 3, using specialist literature (HESS et al., 1976–1980; LAUBER UND WAGNER, 2001; OBERDORFER, 2001), the 153 species of the "shortlist" in Annex A 4.5 were divided into three sub-groups with different levels of dependency on floodplain habitats:

- Floodplain-dependent species in the strict sense: These species are exclusively dependent on riverine floodplains for their survival. The 32 such species are marked with the code A in the list in Annex A 4.5.
- Partially floodplain-dependent species, i.e. species which also occur in some habitats outside of floodplains but which in Switzerland primarily depend on sufficiently large and intact riverine floodplains for their survival. The 19 such species are marked with the code B in the list in Annex A 4.5.
- Species the survival of which could be assured by the provision of sufficiently large and intact riverine floodplains but also by the maintenance of the traditional farming landscape as a substitute habitat. These species also occur in landscape elements such as fallow lands, furrows in tillage land, on tracks and track margins, in copses, woodland margins, ditches, traditionally managed meadows mown for animal bedding, and spring vegetation. However, for the purposes of this study we work on the assumption that in view of the pressure towards agricultural modernization these elements of the cultural landscape can not be maintained or recreated at a sufficient scale and hence the safeguarding of these species is in practical terms dependent on opportunities for reactivation in the area of riverine floodplains. This sub-group contains 102 species which are not marked with code A or B in the list in Annex A 4.5.

We consider it reasonable to view all three sub-groups, i.e. all 153 species contained in the list in Annex 4.5, as floodplain-dependent in the sense that elimination of this endangerment can practically only be achieved by an approximation of the situation of the riverine floodplain areas to the situation which prevailed around the mid-19th century.

The breakdown of these species according to the various floodplain-dependent habitat types is given in Annex A 4.6. Vascular plant species which occur in two floodplain-dependent habitat types were counted as 0.5 species for each of the two types. Annex A 4.7 shows the breakdown of these 153 vascular plant species dependent on water-courses, according to IUCN, 2001 threat categories.

The list by (DELARZE et al., 1999) gives a total of 546 vascular plant species (threatened and non-threatened species) for which at least one of the habitat type number codes indicates a floodplain habitat within the meaning of Step 1. However, we are also aware of the list by (ROULIER, 2002) which gives 1056 vascular plant species (threatened and non-threatened species) *occurring* in floodplains. We assume that the procedure described above did indeed yield a complete list of vascular plant species threatened by riverine floodplain area loss, i.e. that where individual species amongst the more than 500 additional vascular plant species contained in the list by (ROULIER, 2002) are threatened, this threat can not be ascribed to riverine floodplain area loss or that there is a sufficient reserve of other habitat types.

4 Extent of riverine floodplains required in Switzerland from a species diversity perspective

Today, it is widely acknowledged that the narrowing and channelization of watercourses in Switzerland has gone too far and that additional floodplains should be created, not least in order to reduce dangerous flood peaks. Individual projects are currently being planned or implemented for several rivers. This chapter examines the question of the total area required for such river widening schemes, if the aim is a reduction of the threat to species that depend on riverine floodplains: What percentage of the potential riverine floodplain area, i.e. the riverine floodplain area that existed one and a half centuries ago and has since disappeared, should be renaturalized to achieve this aim?

4.1 Dependency of species diversity on the extent of riverine floodplains in Switzerland

In Chapters 2 and 3, the loss of riverine floodplain areas in Switzerland since the middle of the 19th century was estimated and put into context with the number of vascular plant species that are today classified as endangered (threat categories EX, EW, RE, CR, EN, VU, NT) and at the same time depend on riverine floodplains as a habitat. It was assumed that practically no such risk existed around 1850.

However, the question of whether there is indeed a causal interrelationship between the declining spatial extent of habitats and the increasing threat to plant species within these habitats requires further examination: After all, while the threat to floodplain-dependent species identified in Chapter 3 arose during the same period as the loss of riverine floodplain areas identified in Chapter 2, the latter may not necessarily be the cause of the former. If the existence of a causal connection can be demonstrated, it would be interesting to establish the precise form of this interrelationship. These questions are examined in more detail below.

Biologists have been examining the interrelationship between the extent and structure of habitats on the one hand and biodiversity on the other hand for decades. These interrelationships have been presented extensively with reference to the original biological literature in (BROGGI U. SCHLEGEL, 1989, p.48–65), for example, so that we will refrain from repeating them here in detail.

We will concentrate on some findings that are important for the current study:

- Isolated habitats with small areas ("islands") contain fewer species than interconnected habitats with large areas. The long-term preservation of a species requires a species-specific minimum population, which in turn requires an associated minimum size of the available habitat. This means that the probability of extinction reaches a critical level for more and more species, if the habitat becomes smaller and smaller. The more isolated a habitat, the less this extinction can be compensated through immigration, so that the number of species in smaller and at the same time relatively isolated "islands" is small.
- An increased probability of extinction of a species does not mean that the species will die out in the short term as soon as the probability of extinction increases due to changes in causative factors. The effective extinction of a species is expected to occur with a time lag, i.e. once an increased probability of extinction has existed over

several years or decades. A decline in population and/or shrinking of the range of a species may be observed as intermediate stages.

- In this context, “islands” are not only areas of land surrounded by water on all sides, but in a wider sense also relatively natural habitats surrounded by intensively used areas that are hostile to many species, e.g. settlement areas and farmland. In this sense, natural or near-natural riverine floodplains can therefore be seen as “islands” that are surrounded by strongly anthropogenic land. The number of species is greater if the floodplain area is larger.
- If the distance between several “islands” is not too great, so that a certain connection between them is still possible for a large number of species (e.g. through seed transport, migration of individuals etc.), these individual “islands” can approximately be considered as a single “overall island”. For the floodplain areas of Switzerland, this type of aggregation is particularly appropriate for contiguous river systems: The total area of floodplains can then be seen as relevant for the total number of species living in them.
- Habitats with a diverse structure (“mosaic”) contain more species than homogeneous habitats. This is because the more the environmental conditions vary from location to location, the more species will find precisely the right conditions for them. This is particularly true for stenoecious species (i.e. those that can only survive within a narrow, species-specific range of environmental parameters). While the areas intensely utilized by humans are generally homogenized (i.e. uniformly drained, uniformly planted, uniformly levelled, etc.), the natural heterogeneity of near-natural “islands” increases with the size of the island, which is an additional reason for the increasing number of species. For floodplain areas this means that another reason for the number of species increasing with increasing area is that the dynamics of the watercourse can create more heterogeneous habitats. Examples are gravel areas that may be in a sunny or shaded position, flooded frequently or less frequently, based on alkaline or acidic rocks, covered by snow for longer or shorter periods, etc.

From the findings of biological research summarized above, it appears plausible that the currently observed threat to floodplain-dependent vascular plant species in Switzerland is indeed a *result* of the loss of Swiss floodplain areas over the last one and a half centuries: *Because* the total area of riverine floodplains was drastically reduced during the last 150 years, many species are today classified as endangered. There is therefore a causal relationship between the findings of Chapters 2 and 3 of this report.

However, this does not mean that there are no other reasons for the observed threat to species. The observed threat to stenoecious vascular plant species living in riverine floodplain areas may *also* have been influenced by other significant causes, as listed in the introductory Chapter 1 of this report. Regarding the question of additional causes of the threat to floodplain-dependent species, the following statements can be made for the conditions in Switzerland:

- Chemical pollution of the air and of watercourses no doubt has an influence on the threat to species living in riverine floodplains. While originally floodplains were rather low-nutrient sites, the quantity of nutrients available to plants in floodplain areas has increased, particularly through nitrogen in the air, and through nitrogen and phosphorus in the water. This contributed to the threat to plant species that can only compete in low-nutrient locations.

Meanwhile, water pollution control measures have significantly reduced these "conventional" types of water pollution (with the exception of nitrogen content) towards the end of the 20th century, as confirmed by continuous monitoring of the associated quality parameters as part of the Swiss federal river monitoring and survey programme (known by its German acronym NADUF) (BUWAL, 2000). While the conditions for fish and other water animals are possibly increasingly affected by "non-conventional" water pollution, e.g. hormones, drugs and other substances that are effective in low quantities, it can be assumed that chemical water pollution is not a significant threat to vascular floodplain plants. This hypothesis can be supported by comparing the NADUF results for rivers with mainly natural loads (Inn-Martinsbruck, Ticino-Riazzino, Rhine-Diepoldsau, Rhone-ports-de-Scex) and rivers with intensive agriculture and high population densities in their catchment areas (BUWAL, 2000, p. 225, fig. 6): Since around 1990, the total phosphorus and TOC (Total Organic Carbon) pollution of rivers characterized strongly by anthropogenic activities has fluctuated approximately within the statistical range of rivers with mainly natural loads, while for total nitrogen and DOC (Dissolved Organic Carbon) the former are roughly three times more polluted than the latter. Overall, the anthropogenic loads are therefore not very far outside the frame of natural background loads. Furthermore, the influence on vascular floodplain plants through anthropogenic loads in the water is all the lower, since the majority of these vascular plant species only come into immediate contact with surface waters during flood events (see Table A 4.6), i.e. only on occasions when the anthropogenic nutrient concentrations of the water are already reduced due to high precipitation or a high proportion of melt water.

- In terms of the transport of nitrogen from the air into floodplain areas it can be assumed that total Swiss NOx emissions have increased drastically since 1950, reached a maximum around 1985, and in 2000 were still approximately three times as high as 1950 levels, with the increase compared with 1950 mainly due to motor vehicle traffic (BUWAL, 1997, p.70). It therefore comes as no surprise that average annual NO_x values exceed the ambient load limit value of 30 micrograms/m^3 particularly in towns and along busy roads, while levels away from busy roads are significantly below the limit value (BUWAL, 1992). Since a significant proportion of the remaining floodplain areas is located at sufficient distance from urban agglomerations and busy roads, it can be assumed that NO_x emission levels, which have been elevated since 1950 and are still high, did not lead to significantly increased nitrogen levels and the associated threat to species in most floodplain areas.

In summary, it can be assumed that the chemical pollutant load from surface waters and from the air in the remaining floodplain areas *is not a significant cause for the observed loss of vascular plants*.

- As a result of general climate change and of anthropogenic discharges, the temperature of Swiss rivers is increasing (BUWAL, 1997, p.50; UMWELTSTAT, 2002, Table T2.3.4.2). But this too is unlikely to affect vascular plants living in the floodplains, because the majority of them live outside continuously flooded areas, and the water temperature therefore is not a location factor for them.
- The quantitative change in the discharge conditions of the rivers has reached a significant level within the context of water abstraction; particularly in the mountains, many rivers have practically been shut off, with associated consequences on

life within the actual aquatic areas. However, the size of flooding events does not appear to have decreased: According to data for the 10 largest rivers in Switzerland, only for 2 rivers (Ticino and Rhone) did the largest discharge quantities (measured in m^3/s) originate from the time before 1950 (UMWELTSTAT, 2002, Table T2.2.1.2). Notwithstanding the significant interventions in the flow of the water it can be assumed that the formative power of the rivers is still available for maintaining active floodplain areas (and therefore the biological quality of the floodplains), as long as the rivers have the necessary space available for flooding. Recently carried out renaturalization schemes in former floodplain areas associated with Swiss rivers appear to confirm this.

- Apart from the flow of water, the sediment transport of the rivers is an important element for maintaining the biological quality of floodplain areas. Sediment transport has been changed significantly through the construction of dams, river diversions through lakes and other river engineering measures. Recent flooding events show that many rivers today still carry sufficient sediment for creating new sediment layers in floodplain areas, thus maintaining the biological quality of the floodplain, provided the watercourse is not prevented from accessing the potential floodplain areas. A visible sign are the gravel beds of the Alpine Rhine, the Moesa or the Rhone that are moving downstream. In contrast, the sediment transport of the Aare from Thun to the Emme was reduced by corrective measures for the Kander and Jura rivers and is regarded to be insufficient for suitable floodplain dynamics.
- The direct human influence on floodplain areas through leisure activities is significant, at least during times of pleasant summer weather, manifesting itself by vegetation being trampled and animals being scared away. No data about the threat to floodplain-dependent vascular plants through direct human influence appear to be available. On the other hand, there is no evidence for the hypothesis that tearing out or trampling are significant causes of the observable threat to vascular plants.

The facts described above seem to suggest that it is primarily the *quantitative* loss in active riverine floodplains during the last one and a half centuries that led to the threat to the floodplain-independent vascular plant species demonstrated in Chapter 3 of this study, rather than the qualitative deterioration of the floodplains through the above-mentioned interventions. This statement is further supported by the subsequently carried out checks of the species listed in Annex A 4.5 for endangered species, for which one of the above-mentioned causes would be known as a cause of the threat among experts. The loss of riverine floodplain areas and the threat to the floodplain-dependent vascular plants have therefore not only occurred during the same 150-year period, but the former process was indeed the cause of the second. On the other hand, the causal connection may be less clear for animals that live in the water itself and therefore respond more sensitively to its properties.

The establishment of the causal connection means that for a step by step elimination of the current threat to floodplain-dependent vascular plants it would essentially be sufficient to once again provide access for Swiss rivers to part of the historical floodplains by reversing previous engineering measures and by abandoning the utilization of the land within these areas. The formative power of rivers would then basically be adequate for a return to active and biologically high-quality floodplain areas during periodic and episodic flooding events. “Landscaping” support for the natural areas would not be required, in contrast to some types of near-natural areas outside the floodplains. The only measure that should be considered would be the initial propagation of nearly extinct vascular plants through the supply of seeds.

Now that the argument for the causal connection between the loss of Swiss riverine floodplain areas and the threat to the diversity of vascular plant species has been set out, it would be useful to *quantify* this interrelationship.

We can now say that at the present extent A_g = 48'000 ha of the Swiss riverine floodplains (Section 2.3.6), a total of S_g = 153 vascular plant species (Section 3.3) are endangered, while at extent A_h = 129'000 ha of these floodplain areas during the historic reference period one and a half centuries ago (Sector 2.4), the threat to species can be assumed to be practically zero. Since we assume that, provided the lost floodplain areas are renaturalized soon, the vascular plants currently under threat will not become irreversibly extinct, but would once again grow to stable populations, we can state that, with 100% renaturalization of the historical floodplain areas (A_h = 129'000 ha) the threat to a total of S_g = 153 species would be completely eliminated. But how would the number of species under threat develop if only 20% or 30% of the lost floodplain areas were to be reactivated and no longer utilized?

The simplest assumption would be to postulate a *linear* relationship between the increase in reactivated floodplain areas and the number of species that would no longer be threatened. This would mean that with a reactivation of, for example, N% of the lost floodplain areas (A_h – A_g) = 81'000 ha, for an equivalent proportion of N% of the currently endangered vascular plants S_g = 153 species, the threat would gradually disappear as a result of the re-establishment of the species due to immigration, germination of existing viable seeds, and expansion of remnant populations.

The studies by (KÖLLNER, 2001, p.182–191) indicate that, based on empirical results, the relationship between the number of vascular plant species and the proportion of a certain land-use type of a total regional area can indeed be assumed to be approximately linear, as long as the boundaries near 100% and 0% are not included.

If, however, the whole process is considered, both the general *plausibility* and the *results of biological research* indicate a *non-linear* relationship between the extent of suitable habitats and the number of species.

It is *plausible* that extending an initially small habitat type in a first step by, say, 10% would trigger a larger growth in species than a second or third step of the same size: Starting from a very small area, the first additional 10'000 hectares of floodplain area "yield" more than the second or following increases of further 10'000 hectares. Similar to economic processes, the general rule of diminishing returns is likely to apply.

This is also supported by an important result of biological research: It is postulated that the equation

$$S = a*A^b \qquad [4.1]$$

applies to the relationship of habitat extent and number of species. This equation states that the number of species S is proportional to the power of b of a habitat area A. Since b is a positive number and varies within the range <1, this means that the increase in S becomes smaller if the area A is enlarged in constant steps. The parameter a indicates how many species occur within an area of size 1; it therefore initially depends on the unit (km^2, hectares,...) in which the area A is expressed.

Since the first presentation of this equation (ARRHENIUS, 1921), discussions have ensued among biologists about its relevance and applicability. Particularly notable within the context of these discussions are the empirical verifications (CONNOR & MCCOY, 1979) of the equation compared with alternative approaches, which have confirmed the suitability of the Arrhenius equation for modelling the species/area dependency.

Notwithstanding the mathematically precise formulation, the Arrhenius equation does not claim to represent an exact law of nature. Rather, it is a summary model of the expected relationship between habitat area and number of species. That it can only yield summary information can already be gleaned from the fact that no accurate parameters are specified for the shape, the internal structure or the boundary features of area A and its adjacent areas, and for the counting method and the temporal development of the number of species within area A. Accordingly, the area/species characteristics can be modified within a wide range through appropriate selection of parameters a and b within the Arrhenius equation. Since a and b have to be positive, and moreover b<1, the Arrhenius equation limits the possible area/species characteristics only insofar as the number of species S = 0 if A = 0, and the increase in the number of species becomes smaller and smaller with increasing positive A. Justifiable "calibrations" of the Arrhenius equation could be realized in empirical research by determining for certain species to be counted (birds, vascular plants, etc.) the effective extent of a large number of individual areas of a characteristic habitat type (broadleaved forest, fen, etc.) and the number of species found within them. From this, "empirical" values for a and b could be determined, which would lead to an Arrhenius curve that matched the empirical results.

If vascular plants and Central European conditions are considered for the number of species S, and if A is expressed in hectares, based on the above-mentioned studies additional information for determining parameters a and b of the Arrhenius equation can be derived. The parameter a then expresses the number of species that can be expected within an area of 1 hectare. A large number of empirical studies on the occurrence of vascular plant species was evaluated in (KÖLLNER, 2001, p.72–76). The findings (number of species S found together with the associated area) are compiled in (KÖLLNER, 2001, fig. 7-5, p. 77). The corresponding diagram is presented in fig. 4-1 below.

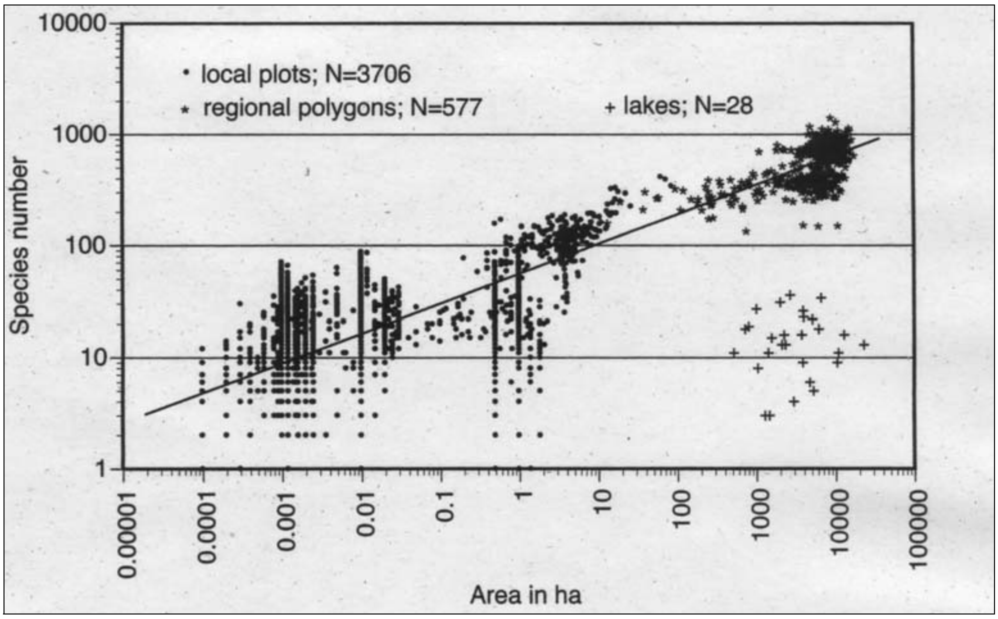


Fig. 4-1:
Presentation of empirical numbers of vascular plant species depending on the size of the area examined in hectares (a total of around 4000 areas were considered). Both the number of species and the area sizes are shown on a logarithmic scale. After (KÖLLNER, 2001).

The diagram shows that the number of species found within an area of, for example, 1 hectare, predominantly ranges between 10 and 100, with extreme values ranging between 2 and approximately 150 species. Based on this information, a value between 10 and 100 can be used for parameter a of the Arrhenius equation; the higher value applies to species-rich areas. The diagram from Köllner also shows that the empirical studies indicate a larger number of species for larger areas, with the logarithm of the number of species showing a linear relationship with the logarithm of the extent of the area, albeit with significant scattering. As already mentioned, this large scatter in the number of species found within study areas of identical size is mainly due to the fact that there are species-rich (e.g. meadows on which little fertilizer is used) and species-poor (e.g. farmland) area types. The cases indicated by the + sign in fig. 4-1 are lake areas that are extremely species-poor in terms of vascular plants and therefore fall outside the framework of land areas.

The regression line shown in the diagram corresponds to the Arrhenius equation $S = a*A^b$, which in logarithmic form $\ln(S) = \ln(a) + b*\ln(A)$ is linear. The coefficient of determination R^2 for this regression line with the parameters a = 60 species and b = 0.2 was calculated by Köllner as 0.64; this means that the Arrhenius equation represented by the line cannot fully explain the empirically determined pairs of values (number of species/extent of study area), but can nevertheless explain them to a significant degree. Deviations of these pairs of values from the regression line are expected to depend mainly on the type of land use of the respective study area, i.e. a relatively high number of species with low-impact use (low-nutrient meadows, woods with natural regeneration, etc.) and a relatively low number of species with strongly non-natural use (farmland, compact man-made structures, etc.).

While Köllner's analyses require further refinement, the following statements about the number of vascular plants species under Central European conditions appear justifiable at this stage:

- The number of species S depends on the reference area A hectares], with equation $S = a*A^b$ being applicable as a rough approximation.
- The value of b in the above Arrhenius equation is approximately within the range 0.1 to 0.4 (KÖLLNER, 2001, p. 68, p.77/78).
- The value of a, i.e. the number of species expected within 1 hectare, is approximately between 10 and 100 species. The number of species is generally higher in near-natural, non-intensively used area types, and lower in area types which are highly non-natural, used with high impacts, and strongly homogenized.
- Area A does not have to be contiguous; it may consist of several similar individual areas that are located within a contiguous region and are not completely isolated by regions of different types situated between the study areas.
- However, for the current study it is important to note that the above-mentioned numbers are based on *effectively found* species (endangered and non-endangered species), and not on the number of species that would be expected to be found in future after long-term exposure to the causes of threat.

4.2 A concrete proposal: The required recovery of riverine floodplains for reducing the threat to floodplain-dependent vascular plant species in Switzerland

We assume that the number of currently endangered species S_g of floodplain-dependent vascular plants would gradually become non-endangered, if the riverine floodplain areas that were lost over the last one and a half centuries ($A_h – A_g$) were fully renaturalized in the foreseeable future. “In the foreseeable future” means that the floodplain area would be released for watercourse dynamics to take place soon enough so that remnant populations or viable seeds would still exist and enable gradual spreading of the endangered species, including the species currently classified as “extinct”.

However, full renaturalization of the riverine floodplain areas to the conditions found during the middle of the 19th century is not a realistic target, since in many places extensive settlements have emerged within these potential floodplain areas, for example in the Limmat valley between Zurich and Wettingen, or in the Rhine valley upstream from Lake Constance. Partial renaturalization appears to be possible, since the potential floodplain areas still contain large agricultural areas, for which abandoning the current utilization could even be politically desirable in view of the efforts to reduce the production surplus of Swiss agriculture. It should be stressed that abandonment of agricultural utilization in riverine floodplains would not entail expensive management measures, as is the case in the non-floodplain areas of the Swiss Mittelland region if the aim is to avoid large-scale afforestation.

What quantitative target would be appropriate for returning to river dynamics parts of the riverine floodplain areas that were lost since the middle of the 19th century through river engineering and subsequent melioration measures, thereby releasing them for renaturalization? If a non-linear relationship between the number of species and habitat area is assumed for the purpose of the Arrhenius equation, the first steps of any floodplain renaturalization are particularly beneficial, i.e. a first step for riverine floodplain restoration can make a greater contribution to reducing the threat to species than subsequent steps of similar scope. Based on this premise, the following aims for partial renaturalization of the historical floodplain areas are rationally justifiable:

- One could aim for eliminating the current threat to the majority of the currently endangered species S_g, e.g. 80% of S_g. Due to the non-linearity of the area/species characteristics this target would be achieved with a renaturalization rate below $0.8*(A_h–A_g)$. One could therefore imagine that the population of 0.8*153, i.e. approximately 120 currently endangered floodplain-dependent species could be secured, if perhaps only a third of the potential floodplain areas (i.e. areas lost during the last one and a half centuries) were again left to river dynamics.
- An alternative target would be to renaturalize potential floodplain areas only up to the point where the reduction of the threat to species is still larger is than the percentage increase in effective floodplain area. Up to this point, the renaturalization could be called "efficient". Due to the above-mentioned non-linearity, for the first 10% of regenerated area a removal of the threat for more than 10% of the currently endangered species is to be expected, with the ratio of threat removal decreasing during subsequent renaturalization steps of similar scope. One could therefore determine an efficiency limit, above which the threat removal would be less than 10%, if a further 10% of $(A_h–A_g)$ were left to river dynamics.

For assessing these possible target alternatives, tab. 4-1 shows area/species characteristics that can be justified based on the above considerations and on existing data.

Tab. 4-1: F Area/species characteristics according to Arrhenius for riverine floodplains with different parameters a and b and different reference areas (total renaturalized floodplain area or total renaturalized floodplain area minus proportion of continuously submersed area)

Riverine floodplain areas in Switzerland							
Floodplain area		**Case a=160.65 and b=0.1595**			**Case a=100 and b=0.188**		
Hectares	% of increase	A exp(b)	No. species S	% of increase	A exp(b)	No. species S	% of increase
48135	0	5.58	896.88		7.59	759.11	
56243	10	5.72	919.42	14.74	7.82	781.65	14.56
64350	20	5.85	939.39	27.79	8.02	801.69	27.50
72458	30	5.96	957.34	39.52	8.20	819.78	39.18
80565	40	6.06	973.67	50.20	8.36	836.29	49.84
88673	50	6.15	988.67	60.00	8.52	851.50	59.67
96781	60	6.24	1002.57	69.09	8.66	865.62	68.79
104888	70	6.32	1015.52	77.55	8.79	878.81	77.31
112996	80	6.40	1027.65	85.48	8.91	891.20	85.31
121103	90	6.47	1039.07	92.94	9.03	902.89	92.85
129211	100	6.54	1049.86	100.00	9.14	913.95	100.00
Total increase in species			152.99			154.85	
Floodplain area water excluded		**Case a=439.78 and b=0.0763**					
Hectares	% of increase	A exp(b)	No. species S	% of increase			
11803	0	2.05	899.72				
19911	10	2.13	936.36	23.88			
28018	20	2.19	961.10	40.00			
36126	30	2.23	979.93	52.27			
44233	40	2.26	995.19	62.21			
52341	50	2.29	1008.06	70.60			
60449	60	2.32	1019.21	77.86			
68556	70	2.34	1029.05	84.27			
76664	80	2.36	1037.87	90.02			
84771	90	2.38	1045.86	95.23			
92879	100	2.39	1053.18	100.00			
Total increase in species			153.46				

The upper part of tab. 4-1 shows floodplain areas which, based on the current area (A_g = 48'135 ha; first line), increase in constants steps in subsequent rows up to the state (A_h = 129'211 ha) as it prevailed in the reference period in the middle of the 19th century. The top of the central part of the table shows the number of species to be expected according to the Arrhenius equation, using the parameter values of a=160.65 and b=0.1595 that were pre-calculated using the following boundary conditions, namely

- that today a total of 1050 vascular plant species occur in Swiss riverine floodplains covering 48'135 ha, including endangered species (ROULIER, 2002),
- that today 153 species occurring in Swiss riverine floodplains are classified as endangered (Section 3.3), whose threat would be removed if the riverine floodplains were to be extended to 129'211 ha,
- that consequently today 1050–153 = 897 of vascular plant species occurring in Swiss riverine floodplains could be regarded as "stable", while 153 species would

require an expansion of the riverine floodplain area from 48'135 ha to 129'211 ha to ensure their long-term survival .

Under these boundary conditions, the above-mentioned values for parameters a and b can be calculated by solving 2 Arrhenius equations as follows:

$$\ln(897) = \ln(a) + b * \ln(48'135) \quad [4.2]$$
$$\ln(1050) = \ln(a) + b * \ln(129'211)$$

These equations show that for a floodplain area of 48 135 ha (including the river bed), only 897 species of vascular plant would survive in the long term, whereas for an area of 129 211 ha, a total of 1050 species could be protected (this figure includes the 153 species presently at risk).

The parameters a and b obtained from the equations may now be used to predict the number of vascular plant species that could be safeguarded in the long term (i.e. would no longer be at risk), including those protected by renaturing potential floodplain areas:

The central part of tab. 4-1 above indicates that, with increasing extension of the floodplain area, the number of species expected to be "stable" gradually increases from 897 to 1050. Note the development of the threat reduction: A first renaturalization step of 10% ($A_h - A_g$) = 8108 ha would remove the threat for 14.74% of 153 species, or around 23 species. In contrast, the last renaturalization step of again 8108 ha would remove the threat for only (100–92.94) % of 153 species, or around 10 species. From the tabular values one can conclude the following:

- The first target variant of "saving 80% of endangered species" would be achieved if around 70% of lost floodplain areas were renaturalized.
- The second target variant, i.e. "renaturalize as long as the percentage of threat reduction is greater than the percentage growth in area" would be achieved if approximately 40% of the lost floodplain areas were renaturalized.

A value of 160.65 for parameter a, resulting from the solution of equations [4.2], is rather high: It corresponds to 160 species per 1 ha of reference area, which is in the top range of the empirical data listed in fig. 4-1. One could carry out a sensitivity analysis to assess whether the above conclusions would change significantly if the boundary conditions were changed.

Firstly, in view of the empirical data listed in fig. 4-1, one could reduce parameter a to 100. From equations [4.2], this would result in a value of 0.188 for parameter b, with a resulting number of species that would reasonably be within the boundary conditions with floodplain areas of 48'000 ha or 129'000 ha respectively. This situation is shown in the top right section of fig. 4-1. The figures show that the above conclusions with regard to the first and the second target variants remain practically unchanged.

Secondly, one could assume that only few vascular plant species occur in the continuously submerged areas of the riverine floodplains, and that it is predominantly the intermittently flooded areas that are relevant for the threat to vascular plants. According to Section 2.3.6, one could roughly estimate the current floodplain area, less permanent surface water area, to be 11'803 ha, and assume that one and a half centuries ago this area was 11'803+81'076 ha = 92'879 ha according to Section 2.4. This situation is shown in the lower part of tab. 4-1, with the Arrhenius parameters a and b again having been calculated according to equations [4.2], but this time with appropriately modified area values. With 439 species, parameter a now has a value that can no longer be justified based on empirical experience – according to latest studies as part of the Swiss biodiversity monitoring programme (BDM) the hitherto largest number of vascular plant species found per 1 km^2, i.e. per 100 ha, was 365 species (NZZ, 2002). This leads to the conclusion that parameter a, representing the number of species per 1 ha, is very unlikely to assume the high value of 439. If one ignores this flaw, the lower part of tab. 4-1 shows that, as expected, the reduction in the threat is significantly larger during a first floodplain enlargement by 8108 ha, i.e. the threat is eliminated for approximately 24% of 153 species or around 36 species. The conclusions with regard to the two target variants lead to somewhat lower requirements for the renaturalization of riverine floodplains. However, the overall picture is not significantly different compared with the situations listed in tab. 4-1 above.

This leads to the conclusions and an answer to the question raised in this Section about the renaturalization target for Swiss riverine floodplain areas:

- The target of removing the threat for 80% of the currently endangered floodplain-dependent vascular plant appears unrealistic in view of the large floodplain area of around 60'000 ha that would have to be renaturalized, which would be in conflict with the present state of the settlement and transport infrastructure within the potential riverine floodplain areas.
- A more realistic target would be to concentrate regeneration efforts on the "efficient" parts of the historical Swiss riverine floodplains. Based on the above analysis this means that approximately 40% of the lost floodplain areas ($A_h - A_g$), or around 32'000 hectares of land currently mainly used as farmland should be reverted back into active floodplain areas through the correction of river engineering measures and the abandonment of utilization. These 32'000 hectares represent some 3% of the current agricultural land (excluding alpine agricultural land) in Switzerland (UMWELTSTAT, 2002, Table T2.2.2.2). If, therefore, agricultural production in Switzerland is to be reduced to some extent within the framework of a world market-oriented agricultural policy in Switzerland, it would make sense to initially abandon the utilization of those 32'000 hectares of potential floodplain area that were active riverine floodplains one and a half centuries ago and could become floodplains again due to their special topographic features.

5 Model for determining the environmental impact of land use in floodplain areas

Chapter 4 determined on the basis of the findings gained in Chapters 2 and 3 how many hectares of the floodplains lost since the mid-19th century would need to be re-instated to functioning floodplain areas if the currently observed endangerment of vascular plant species (taken as representatives of non-human life in its entirety) in floodplain areas is to be reduced effectively.

The present chapter now examines the complementary issue of what extent of endangerment to vascular plant species (as representatives of non-human life in its entirety) can be allocated as the impact of a certain land use within the perimeter of potential floodplain areas, assuming that the present utilization of these potential floodplain areas persists. Put in concrete terms: To what extent are vascular plants endangered if, in the Magadino plain, 100 square metres of potential floodplain area are to be used as arable land in the current year? This question has particular importance in life-cycle assessment (LCA). The aim of LCA is to inventorize the emissions, resource consumption and land appropriation associated with a specific industrial/economic process (this phase of LCA is known as the "life-cycle inventory analysis") and then, building upon the findings of this inventory, to assess the adverse effects (impacts) of these exchanges between the anthroposphere and ecosphere (this LCA phase is termed "life-cycle impact assessment"). The state of the art of modern LCA methodology is set out in a fundamental form in (SETAC, 2002) and in a similar, more application-focussed form in e.g. (GOEDKOOP, 1999). This methodology, with a focus on land use, is presented briefly in the following Sections 5.1 and 5.2. Its application to the specific case of land use in floodplains is then pursued in Section 5.3.

5.1 Using LCA to determine the environmental impacts of land use

When an industrial/economic process, e.g. wheat production, electricity production or road transport, appropriates a land area A for a certain duration t, then, during this period, other uses on the same land and in the wider region are generally hampered or rendered impossible. This hampering or rendering impossible also extends to the availability of the land area in question as habitat for fauna and flora, and as a spatial element for vital natural processes such as hydrological cycles or climate regulation. This is because the human use of a land area is frequently accompanied by a reduction in the ecological quality of that area: The more intensive human use is, the more circumstances are constrained for fauna and flora, and the lower the functional value of the area is in terms of natural processes. This adverse effect of human land use upon the natural environment can be quantified by means of suitable indicators. The diversity of vascular plant species is frequently taken in practice as an indicator. This indicator is believed to represent fairly well the overall impairment of biodiversity. (Additional indicators may become necessary where there is a need to identify the impairment of the natural environment caused by human land use in a more differentiated fashion.)

Use of a certain area of A hectares generally causes not only an adverse ecological effect upon precisely this area A, but also an additional effect upon a wider region of which A is a part. If, for instance, a previously near-natural area A is covered completely in asphalt and used as a car parking plot, then species diversity not only changes within A but also in the surroundings of A. We therefore speak of a local effect (within A) and a regional effect (affecting a wider region of which area A is a part).

If we now wish to draw up an LCA for the production of 60 kg cereal grain within the spatial frame of a region of (for instance) 10'000 hectares, and if an area of arable land A=0.01 ha is required for this over the period of one year, the impact upon species diversity arising as a result of this intensive use of the land can be expressed as the decline in the number of species of vascular plants compared to a near-natural reference use. On the utilized area A itself (local effect) the loss of species is then typically large and comes into effect swiftly, for the arable field is kept free of undesired species by mechanical or chemical means. Within the frame of the entire region, a loss of species is also to be expected (regional effect), but the extent of this is much smaller and it only reaches its full level with a time lag of decades. Moreover, an observable degree of species loss across the whole region is only to be expected when the aggregate of intensively utilized areas within the region has reached the scale of several percent of the territory of the region; nonetheless, a fraction of this species loss can be allocated to the small arable area of A=0.01 ha under consideration. (For the sake of completeness, it may be noted that when first arable farming plots are inserted within a previously entirely natural landscape, regional species diversity would not decline but would rather rise, as this would create “islands” with novel boundary conditions; this case, however, is not currently representative of the conditions prevailing in Switzerland.)

If empirical data is available on species numbers for arable land use and near-natural land use, such as have been collated and evaluated by (KÖLLNER, 2001), then the local and regional damage to species diversity resulting from pressures placed upon land resources to produce 60 kg of grain can be determined quantitatively. What is the purpose of such calculations? The advantage of such an analysis is, within an LCA context, that the damage to species diversity resulting from land use can then be added to other sources of damage to species diversity such as emissions and natural resource consumption. This simplifies the results of an LCA and makes it easier to interpret. It can then be ascertained, for instance, whether from an environmental perspective the production of textile fibres is done best through agricultural production or, alternatively, through synthesis from fossil resources.

It is important to note that human land use can take two different forms. One is that the area under consideration is used in the same basic manner as it was prior to the use under consideration: In our example, the 60 kg grain would be produced on a land area A which had previously already been intensively utilized arable land. This form of use is termed land occupation. It could also be, though, that a forest stood previously on the required area A = 0.01 ha, so that prior to planting the cereals the soil would need to be deforested and levelled. Such a fundamental modification to the properties of the land is termed land transformation.

Both land transformation and land occupation can generate a damaging effect upon nature. If a near-natural forest is converted to arable land through *land transformation*, then after a future abandonment of all uses it would need a great number of years until the forces of nature have “healed” the damage and a state has been reached that, while not equal, can be considered equivalent to the original level of ecological quality: The long-lived damaging effect of land transformation from near-natural forest to arable land is evident. If, land transformation having already taken place, the land thus made arable is used to produce grain for one year in the form of *land occupation*, then this "healing" process is delayed by 1 additional year, because spontaneous renaturalization is prevented throughout this year by continuous measures such as weed control and fertilization: Land occupation, too, thus generates a damaging effect, for the duration of the relatively less natural state is extended by the duration of occupation. It would thus be incorrect to negate that a damaging environmental effect occurs when cereals are produced on land previously already used for arable production, arguing that the land is in the same quality state before and after such use. This would be the same error as to claim that an emission of 1 tonne of a gaseous pollutant during a certain year is harmless, arguing that the same quantity has already been emitted in each of the previous years.

The above deliberations are visualized in fig. 5-1 at the end of Section 5.2. The values used there are taken from the example calculated in the following Section 5.2.

5.2 Quantitative determination of species diversity damage for a calculated example

Building upon the above principles and using the empirical data reported in (KÖLLNER, 2001) we now continue the above example by calculating the level of damage to species diversity that occurs when, in the Swiss Mittelland region, an area A of 0.01 ha is first *transformed* into arable land from average near-natural land and is then *occupied* for a period of 1 year to produce the required 60 kg of grain. This damage is expressed as the drop in the number of vascular plant species within the area A = 0.01 hectares (local damage) and the drop in a region surrounding the area A, for which, for reasons of the specific data material processed in (KÖLLNER, 2001), a mean extent of 8600 hectares is assumed (regional damage). An underlying assumption of these calculations is that this loss in species number is taken to be temporary. This means that here and in the following, the analysis is based on the notion that at some point all human use ceases (fallow), whereupon the number of species spontaneously begins to rise again gradually, and finally reaches levels comparable to those of the original state. To ease comprehension, we first calculate the damage resulting from land occupation, and only then the damage resulting from the land transformation which precedes occupation.

Local damage resulting from land occupation:

On an area of A = 0.01 hectares, according to (KÖLLNER, 2001, p. 87/88) in the Swiss Mittelland region on average near-natural land the occurrence of about 40 vascular plant species is to be expected (reference use). Only about 10 species occur on conventionally managed arable land. With these data, the local damage to species diversity resulting from the occupation of 0.01 ha during 1 year can be expressed as (40–10) species on 0.01 ha over 1 year, or 30 species * 0.01 ha * 1 year. Damage thus has the dimension [species number * reference area * time].

Regional damage resulting from land occupation:

The determination of regional damage to species diversity is more complicated and is based on the following conceptual steps:

- The mean size of a Swiss region (termed "polygon" in the EDV-Flora-1.0 botanical data bank) figures about 8600 ha if the polygons above the tree line and the lakes are excluded (KÖLLNER, 2001, p. 90). On average, about 600 vascular plant species occur in such a polygon (cf. fig. 4-1, cases marked with an asterisk *).
- Using regression analysis of the data for several hundred polygons, Köllner has found that, in such polygons, the number of species that have disappeared during the last decades is on average higher by 0.4% if the present area proportion of intensive agricultural use is higher by 1% (KÖLLNER, 2001, p. 106, 114, 190).
- Based on this, the following causal connection is assumed: Over the longer term, the number of species in such a polygon of 8600 ha will drop on average by 0.4% of the roughly 600 species, i.e. by about 2.5 species, if the area under intensive agricultural management is enlarged by 1%, i.e. by 86 hectares (cf. KÖLLNER, 2001, p. 104/105). This reduction by 2.5 species per additional percentage point of agricultural area is to be understood as a point of equilibrium within a dynamic process of species impoverishment that will be reached at some time after a long period of growth of the proportion under intensive agricultural management by 1% within the polygon. (This connection of course only applies to a certain range in the proximity of the present proportion of agricultural area within the polygon, and not in the proximity of the boundary cases of 0% agricultural area or 100% agricultural area).
- If we now consider the arable plot of 0.01 ha taken in our example, then we can allocate to this small fraction of the polygon as a generator of damage a fraction of 0.01[ha]/86[ha] of the "absent" 2.5 species of the entire 8600 ha polygon. This allocation is based on the model concept that the state of "absence" of 2.5*0.01/86 species is prolonged by 1 further year if cereal production (land occupation) on the 0.01 ha is maintained for the period of 1 year.
- The regional damage attributable to the occupation of A = 0.01 ha thus equals the fraction 0.01/86 of 2.5 species on 8600 hectares over 1 year, or 2.5*(0.01/86) species * 8600 ha * 1 year = 0.00029 species*8600 ha* 1 year. In the uppermost graph in fig. 5-1, the product (0.00029 species * 1 year) is represented by the narrow, high rectangle. This graph further shows that the full species loss of 0.00029 species is only reached after 60 years of occupation. However, this does not mean that the damaging effect of the first year of land occupation is much smaller than that of the sixtieth year. There is a time lag between regional species loss and the causal land occupation. The regional level of damage shown in the graph for e.g. the year 60 is effectively the summation of delayed damage contributions from all occupations of the previous 60 years. From year 61 onwards, a dynamic equilibrium develops between the declining effect of earlier occupations and the growing effect of later occupations. After the year 90, a part of the shaded area in the graph is still an after-effect of land occupation that took place before the year 90. The conclusion is that the curve of damage presented in the uppermost graph of fig. 5-1 is not in contradiction to an allocation of the full level of species loss of 0.00029 species to each of the years of occupation. (However, this calculation does produce a damage differential represented in fig. 5-1 by the area between the dashed horizontal line and the curve rising from zero. This surplus is taken into consideration below when the level of damage to species diversity allocatable to land transformation is determined.

Total damage resulting from land occupation:

We assume that the loss of 1 species on a reference area of 10 hectares can be considered equivalent to a loss of 10 species on 1 hectare, for the damage to species diversity is greater if a species is lost over a large reference area (such as the whole of Europe or the whole of Switzerland) than if it only disappears from a smaller reference area (e.g. the canton of Wallis) but remains in other areas. Under this precondition, the levels of local and regional damage calculated above can be summated to a total damage resulting from land occupation as follows:

$$
\begin{array}{llll}
\text{Total damage} & = \text{local damage} & + \text{regional damage} & [5.1] \\
 & = 30 \text{ spec.} * 0.01 \text{ ha} * 1 \text{ year} & + 0.00029 \text{ apec.} * 8600 \text{ ha} * 1 \text{ year} & \\
 & = 0.3 & + 2.49 & \\
 & = 2.79 & [\text{species} * \text{ha} * \text{years}] &
\end{array}
$$

Thus, in our example, the regional damage, as far as the number of species is concerned, is much smaller than the local damage within the immediate confines of the arable plot A of 0.01 hectares, but this smaller species loss extends across the much larger regional area of 8600 hectares. Thus, once the overall area to which the damage applies is included in the calculation, with the above figures the level of regional damage is about eight times that of the local damage. Proceeding from the data reported in (KÖLLNER, 2001), this ratio between local and regional damage depends upon the type of use of the area A. In the case of land use for settlements or for extensive grazing, a different ratio between local and regional damage would result than for the example of cereal farming calculated here. Nonetheless, for other types of use, too, area-weighted regional damage would also predominate.

Local damage resulting from land transformation:

What damage to biodiversity results from land *transformation*? This is not a matter of the area A=0.01 ha being used for a further year as arable land, but a matter of converting an *additional* area A=0.01 ha to arable land, proceeding from a prior state of a near-natural reference use of this plot.

We may initially state that in the case of land *transformation* on 0.01 ha the number of species "lost" at *local* level is equal to the number lost in the case of the occupation of 0.01 ha, because the reference use serving to determine species loss can be taken to be the same for both use types. What is different, however, is the *duration* of the damage. If land *occupation* has a duration of 1 year, then the calculated damage to species diversity only arises during 1 additional year. In contrast, the *transformation* of near-natural land to arable land causes damage that persists over many years. This is because the loss of species caused by transformation is only mitigated by spontaneously arising new species diversity in a process of renaturalization that typically needs several decades. The new diversity of species is certainly not identical to the original diversity. However, after a sufficient duration of renaturalization it can generally be considered equivalent to the original species diversity.

The local-level damage to species diversity resulting from transformation proceeds as shown by the graph in the middle of fig. 5-1. Transformation damage is the damage that would arise if, after transformation took place in year 1, instead of the 89 years of occupation shown in the graph there was no further use at all and the land area A = 0.01 ha was left immediately to spontaneous renaturalization. For this case of "pure" transformation, the middle graph would consist entirely of the diagonally shaded area under the curve, with the only difference that this would be shifted by 89 years to the left, for if there were no occupation whatsoever the renaturalization process of area A would commence immediately after the transformation process in year 1. Based on the renaturalization duration of 3 decades assumed in the middle graph we thus arrive at the following:

Local damage due to land transformation = 30 species * 0.01 ha * 30 years * ½
= 4.5 [species * ha * years]

The factor 0.5 expresses the circumstance that the diagonally shaded area approximates a triangle.

Regional damage resulting from land transformation:

Even if on the area A = 0.01 ha a "pure" transformation of land were carried out without any subsequent occupation, this process would have an impact upon species loss across the entire region. This is because immediately after and in the initial period following land transformation the state of the local plot A in terms of local species loss would be roughly as unfavourable as the initial part of the curve in the middle graph in fig. 5-1. Accordingly, an effect of the unfavourable state of area A upon the surrounding region would commence. As, however, local species loss on the area A would already start to drop significantly after a few years in the case of "pure" transformation, the *growth* of the unfavourable influence upon the region would also start to drop substantially after a few years. In fig. 5-1 this means that in the case of "pure" transformation without any subsequent occupation the rise in regional species loss would be less strong than in the uppermost graph. Already after 3 decades, due to full renaturalization of the local plot A, there would be no new unfavourable influence upon the region at all. The species loss curve in the uppermost graph would then only be influenced by the time-delayed effects of local species loss on plot A during the first 3 decades. This means that in the case of "pure" transformation without any subsequent occupation of plot A the level of damage would be much lower than indicated in the uppermost graph of fig. 5-1: The maximum level of species loss would remain far below 0.00029 species, and regional species loss would fall back to zero much earlier than in year 180.

However, at present no empirical data are available that would permit determination of the development over time of the regional species loss curve in the case of pure transformation. Therefore, by proxy, an approximate calculation of the regional damage to species diversity resulting from transformation is carried out as follows: The diagonally shaded area under the curve of local species loss shown in the middle graph of fig. 5-1, which represents the driving cause of regional species loss resulting from transformation, is converted, as an approximation, into a rectangle of equal area. This expresses a constant species loss of 30 species over 0.5 * 30 years. In terms of the local damage that it causes, land transformation is thus equated to land occupation over 15 years. We can now ask how great the regional damage to species diversity would be if this were driven by a loss of 30 species on the local plot A = 0.01 ha over 15 years. This question has already been answered within the context of equations [5.1]. We thus take as approximation to regional damage resulting from transformation in analogy to [5.1]:

Regional damage due to land transformation = 0.00029 spec. * 8600 ha * 15 years
= 37.4 [spec. * ha * years]

This proxy calculation *does not* state that the regional level of species loss caused by the transformation process figures 0.00029 species over 15 years. This would be in contradiction to the discussion presented above. This calculation rather determines a product (species loss * years) that *does not represent the form* of the unknown regional species loss curve in the case of pure land transformation, but rather provides an estimate of its *integral*. With a view to the uppermost graph in fig. 5-1 it can be stated that the calculated estimate of regional damage to species diversity resulting from land transformation corresponds to that damage which cannot be allocated to land occupation, namely the horizontally shaded area under the curve, minus the area between the unbroken line and the dashed line over the period from year 1 to year 60. This latter area represents the damage allocated above to land occupation during the years 1 to 60, although in this time interval the loss of species, as shown in the species loss curve, had not yet reached the level of 0.00029. This surplus must now be subtracted from the horizontally shaded area. The entire damage allocatable to land occupation and land transformation then corresponds precisely to the integral under the species loss curve of the uppermost graph in fig. 5-1.

We can now determine numerically the entire damage attributable to land transformation.

Total damage resulting from land transformation:

Total damage	= local damage	+ regional damage [5.2]
	=30 spec.*0.01 ha*30 years*½	+0.00029 spec.*8600 ha*15 years
	=4.5	+37.4
	=41.9	[species*ha*years]

The damage resulting from land transformation is thus as large as the damage resulting from 15 years of land occupation.

The following fig. 5-1 illustrates the above discussion in order to aid comprehension, showing the development over time of the causes of damage (land transformation and subsequent land occupation, bottom graph), and the extent and proposed allocation of the resultant local and regional damage (middle and uppermost graph) to these causes of damage. Damage has the dimension [species * ha * years]. The graphs only show species number and time. To determine the level of damage, the product of these two needs to be multiplied by the reference area (0.01 ha for local damage and 8600 ha for regional damage).

In conclusion, it is important to note once more that in the approach taken by this study damage to species diversity is assumed to be reversible. This does not mean, however, that the regenerative capacity of nature recreates the same state after cessation of the damaging land use on the plot that prevailed before the human intervention. If, for instance, a reed swamp is filled, covered in humus and used as arable land, then after abandonment of all use a reed swamp of the original kind will scarcely emerge again. Nonetheless, the forces of nature will modify the topographies, moisture conditions, soil structures etc. that human agency has created. In time, a new diversity of species will emerge that, in a first approximation, can at some time be considered equivalent to the original diversity of species. The time needed for this renaturalization process will vary depending upon the type of land transformation that has occurred.

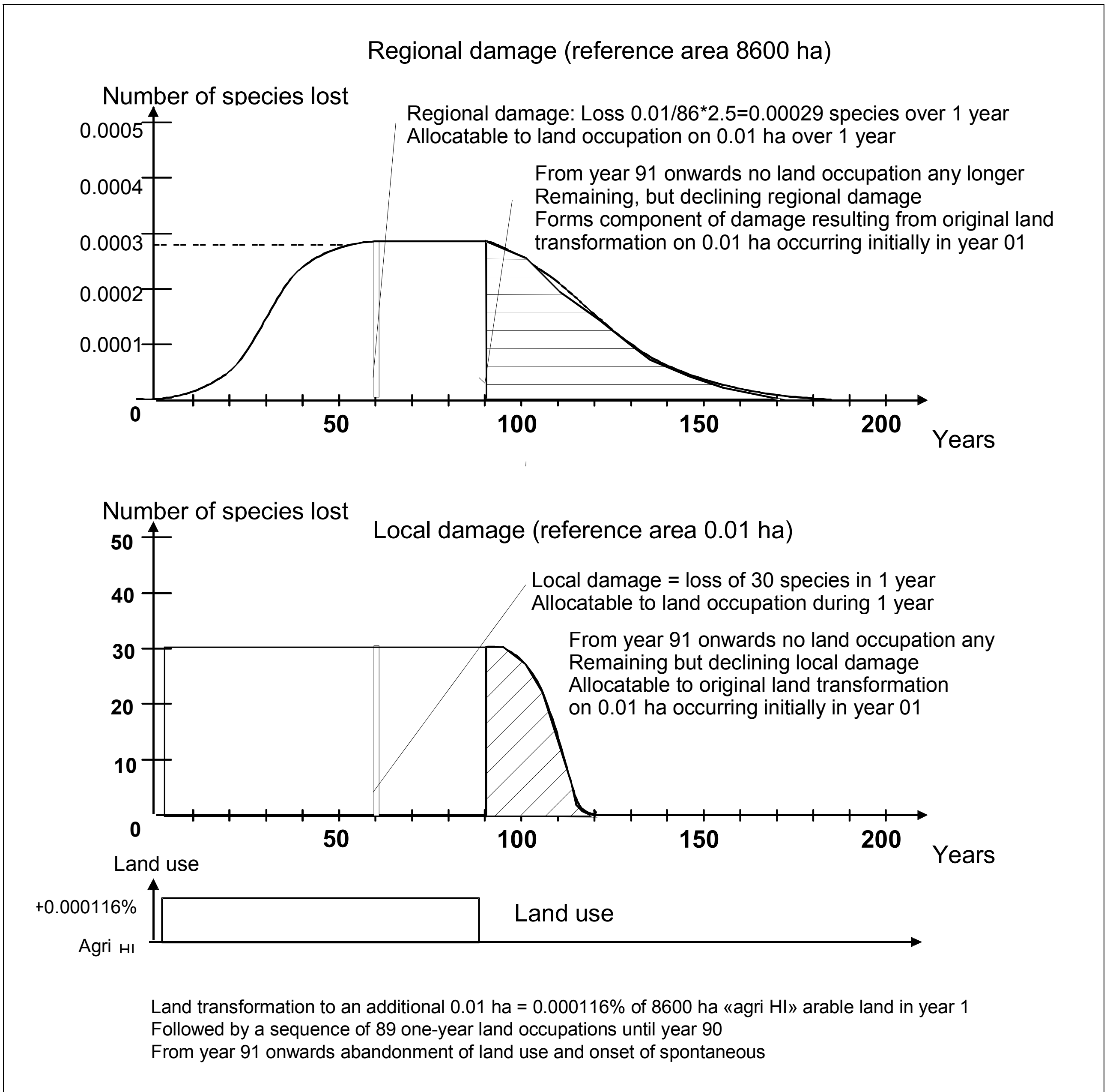


Fig. 5-1: Local and regional species loss resulting from use of 0.01 ha as arable land in the Swiss Mittelland region, and their allocation to land transformation/occupation.

5.3 Environmental damage attributable to land use in potential riverine floodplain areas

Section 5.2 has shown how an LCA of land occupation and land transformation can be carried out if the land areas are assumed to be “near-natural” under the average conditions prevailing in the Swiss Mittelland region as a reference state. Section 5.3 now addresses the question of how damage to species diversity can be identified if a plot of land is used for arable farming *within the perimeter of potential riverine floodplains*, i.e. within areas that were floodplains at some former time. A special treatment of land use within potential riverine floodplain areas is justified because such areas potentially harbour a particularly large and endangered inventory of species, and because it is impossible to modify the topography of a country such that a destroyed floodplain area of a river is recreated somewhere on the map as a substitute site. In contrast, other near-natural habitat sites such as those of forests, meadows or pastures are not tied so closely to a given topography.

For land use within potential riverine floodplain areas, the prime issue is one of land occupation, as Swiss law currently prohibits any substantial transformation of land from active riverine floodplains to utilizable land. In contrast, large parts of potential riverine floodplain areas continue to be used as agricultural or settlement areas (wastewater treatment facilities!) in the form of land occupation.

Such a use within the perimeter of potential floodplain areas necessitates the continuation of flood control engineering measures and supplementary land management measures for the area in question. This means that, despite the natural topography being suited, the river continues to be prevented from exercising its capacity to shape this area dynamically. This prevents the continuous creation of a broad array of diverse habitats in the wake of flooding, sediment deposition, erosion etc., and the animal and plant species dependent upon these habitats cannot flourish.

How can the findings of Chapters 2 and 3 now be used to quantify the damage to species diversity resulting from land occupation in potential riverine floodplains? To this end, we need to answer 2 questions:

- How can we determine whether a utilized area in question is located within the perimeter of a potential riverine floodplain?
- Which parameter values for the local and regional damage resulting from land occupation in the form of arable use are to be inserted in equations [5.1] if the utilized area in question is indeed located within this perimeter?

The first question – whether a utilized area in question is a part of a potential riverine floodplain – can be answered on a case-by-case basis using the criteria stated in Section 2.1.3. Moreover, using the stated criteria, the concrete boundaries of floodplain areas have been mapped cartographically within the context of the present study for about one-fifth of all 1:25'000 sheets of the 1:25'000 National Map of Switzerland (BUNDESAMT FÜR LANDESTOPOGRAPHIE, 1952-) (cf. fig. 2-1).

What, now, is the level of damage to species diversity if in the Swiss Mittelland region 0.01 ha of potential riverine floodplain area is occupied for 1 year as arable land? In the following, we apply the procedure developed in Section 5.2 to express this damage in terms of a decline in the number of vascular plant species within the plot A = 0.01 hectares (local damage) as well as within the region surrounding plot A (regional damage)).

Local damage resulting from land occupation in potential riverine floodplain areas:

To apply equations [5.1] we now need to know how many species of vascular plants are to be expected on 100 m^2 of a "representative" active riverine floodplain. Here the problem immediately arises that active riverine floodplains are characterized by a small-scale mix of diverse habitat units, while conventional species surveys refer to individual habitat units. For instance, (BUWAL, 1993) states species numbers of (highly species-rich) habitat units such as the following:

- Willow scrub and woodland edge communities on upland sites (110 species)
- Rosemary willow (Salix elaeagnos) – sea buckthorn (Hippophaë rhamnoides) riverine floodplain scrub (178 species)
- Open rosemary willow scrub with dryness indicator species (210 species)

The number of species in a reference area of 100 m^2 of course depends upon whether it contains only a single habitat type or patches of more than a single habitat type. In the absence of better information, we use the data presented in fig. 4-1, according to which at most 80–90 species were found in the case of highly species-rich conditions in surveys of 0.01 ha survey areas. As a rough approximation, we assume in the following that there are about 80 species of vascular plants in a riverine floodplain area of 100 m^2 of an average degree of activity. With this preliminary assumption, equations [5.1] provide the following result:

Local damage resulting from 0.01 ha land occupation by arable use over 1 year in a floodplain area = (80–10) species on 0.01 hectares over 1 year, or 70 species * 0.01 ha * 1 year.

Regional damage resulting from land occupation in potential riverine floodplain areas:

Here, in turn, the same logical operations are to be carried out as in Section 5.2 .

- We consider first of all the entire historical riverine floodplain area of Switzerland. This amounts to 129'211 ha, consisting of 48'135 ha present-day and 81'076 ha potential floodplain areas (Section 2.4). We term this the "region".
- According to (ROULIER, 2002) 1050 species of vascular plant occur in the present floodplain areas. We have found that 153 of these species are endangered as long as only 48'135 ha of the historical floodplain areas are now floodplain areas of more or less good quality (Section 3.3). We further assume that the number of species reported by Roulier does not change significantly if we consider not only the present floodplain areas but the entire historical floodplain areas of 129'211 ha in their present forms of use. This is because, in the 81'078 ha now used for agriculture and settlements, mainly only species occur that are also present in floodplain areas and will therefore already be included in Roulier's count. We conclude from tab. 4-1 that in a first step of growth of floodplain areas with active ecosystem functions from 48'135 ha to 56'243 ha (i.e. + 8108 ha) the number of endangered plant species can be expected to drop by some 15% of the 153 species currently endangered, i.e. by about 23 species. The inverse argument is that maintaining (occupying) 0.01 ha arable land within potential floodplains stands in the way of a reduction of the number of endangered plant species by 23*0.01/8'108 or 0.000028 species. The occupation of

0.01 ha for a period of one year for arable use in floodplain areas thus makes impossible this reduction in endangerment. We can therefore allocate with good reason to this land occupation a level of damage amounting to the loss of 0.000028 species across the entire reference area of 129'211 ha over one year. For if the land occupation were to cease permanently and the river were to regain its active role in shaping the landscape, then species richness would re-emerge in the course of time, in that the currently endangered species (which will thus presumably disappear with a certain time lag) would reproduce again to form sufficiently large populations.

Regional damage thus amounts to

= 0.000028 species * 129'211 ha * 1 year
= 3.62 [species * ha * years].

Total damage resulting from land occupation in potential riverine floodplain areas:

Total damage	= local damage	+ regional damage [5.3]
	= 0.7	+3.62 [species * ha * year]
	= 4.32	[species * ha * year]

As in the calculations set out in Section 5.2, this total damage to species diversity is characterized mainly by the regional damage component. Moreover, comparison with Section 5.2 shows that the total damage resulting from land occupation for arable farming is, in the case that potential floodplain areas are occupied, about one and a half times more than if average land in the Swiss Mittelland region is occupied (4.32 instead of 2.79 [species*hectare*year).

At first sight, this additional damage in the case that floodplain land is occupied is not all that striking – intuitively, one would rather have expected that the occupation of 0.01 ha in floodplain areas might produce ten times the damage to species diversity compared to occupation of “average” land. However, an important additional factor yet needs to be taken into consideration in this comparison. If a species is endangered throughout the entire potential riverine floodplain area of Switzerland of 129'211 ha, then according to the discussion presented in Chapter 3 it is also endangered throughout the whole of Switzerland, i.e. on an area of 4'129'300 ha, for the survival of such species depends essentially upon floodplain areas which are not to be found outside of the 129'211 ha within Swiss territory. In contrast, the endangerment of a species in a single 8600 ha polygon as set out in the calculations in Section 5.2 generally does not yet mean that the species in question is also endangered in the other several hundred polygons of Switzerland. For most habitat units occur in several or many of the some 600 polygons that make up Switzerland. To assess the damage to species diversity at the national level it is therefore reasonable to multiply the damage resulting from land occupation within potential floodplain areas obtained from equations [5.3] with the factor obtained by dividing the overall area of Switzerland by the total floodplain area of Switzerland, i.e. 4'129'300 ha divided by 129'211 ha, which equals 32.0 .

This then leads to the conclusion that in Switzerland the occupation of land within the perimeter of potential riverine floodplain areas is about 50 times more harmful to species diversity than the occupation of an area of equal size somewhere in the Swiss Mittelland region that has “average” characteristics.

Finally, note that the procedures for including land use in existing life cycle assessments are still at an early stage. This is likely to change in future, since it is now recognised in scientific circles that the decline in natural diversity is mainly attributable to the impact of land use (and not so much to other environmental factors). However, it is not expected in the foreseeable future that the performance and availability of life cycle assessments for production processes with land demand will lead to consumers dispensing with products and services based in potential floodplain areas, nor to a progressive retreat from these areas and their final renaturing. In the short term therefore, efforts should be directed to safeguarding sufficiently large areas in existing floodplains by implementing the criteria given in Chapter 4.

Annex

A1 Random sequence of sheets of the 1:25'000 National Map of Switzerland, and their assignment to 12-sheet samples

Sample	Sheet number of the 1:25'000 National Map of Switzerland
1	1113, 1197, 1273, 1132, 1274, 1146, 1155, 1096, 1091, 1250, 1230, 1241
2	1298, 1231, 1195, 1300, 1193, 1189, 1211, 1171, 1213, 1157, 1162, 1306
3	1232, 1313, 1116, 1219, 1249, 1218, 1134, 1050, 1065, 1051, 1152, 1110
4	1287, 1167, 1188, 1173, 1221, 1223, 1191, 1107, 1070, 1235, 1244, 1115
5	1284, 1199, 1094, 1304, 1186, 1263, 1245, 1075, 1053, 1226, 1185, 1373
6	1133, 1106, 1275, 1344, 1352, 1151, 1011, 1239b, 1258, 1095, 1168, 1159
7	1130, 1093, 1254, 1346, 1256, 1031, 1264, 1253, 1087, 1234, 1237, 1247
8	1111, 1280, 1209, 1052, 1049, 1126, 1333, 1124, 1236, 1072, 1222, 1265
9	1334, 1067, 1349, 1240, 1203, 1183, 1291, 1090, 1294, 1123, 1332, 1327
10	1163, 1069, 1150, 1169, 1276, 1012, 1175, 1199b, 1238, 1210, 1309, 1184
11	1252, 1194, 1212, 1326, 1033, 1176, 1286, 1170, 1217, 1149, 1187, 1071
12	1214, 1246, 1281, 1154, 1324, 1296, 1208, 1047, 1055, 1224, 1308, 1178
13	1112, 1207, 1347, 1242, 1262, 1166, 1289, 1177, 1085, 1345, 1190, 1285
14	1172, 1205, 1227, 1076, 1182, 1219b, 1035, 1064, 1092, 1233, 1270, 1374
15	1348, 1271, 1144, 1243, 1366, 1196, 1293, 1198, 1325, 1215, 1068, 1290
16	1229, 1267, 1261, 1066, 1206, 1153, 1239, 1192, 1135, 1228, 1114, 1127
17	1251, 1109, 1307, 1054, 1073, 1305, 1145, 1125, 1201, 1165, 1179, 1277
18	1312, 1301, 1225, 1131, 1257, 1148, 1314, 1048, 1353, 1288, 1365, 1255
19	1034, 1328, 1269, 1311, 1084, 1266, 1089, 1268, 1108, 1104, 1204, 1292
20	1136, 1260, 1128, 1278, 1216, 1129, 1032, 1105, 1248, 1147, 1164, 1143
Remaining	1074, 1056, 1329, 1088, 1086, 1272, 1156, 1202, 1174

A2 Estimation of a confidence interval for the loss of riverine floodplain area in Switzerland

A 2.1 Combinations of map sheets with a proportion of non-Swiss territory belonging to the sample

Combination	Sheets of the 1:25'000 National Map of Switzerland belonging to the combination
K 1	1116, 1274
K 2	1155
K 3	1096, 1298
K 4	1241
K 5	1157, 1162, 1300
K 6	1219
K 7	1050, 1065
K 8	1051
K 9	1221
K 10	1115

A 2.2 Combinations of map sheets with a proportion of non-Swiss territory not belonging to the sample

Combination	Sheets of the 1:25'000 National Map of Switzerland belonging to the combination
K 11	1035, 1056, 1136, 1219b, 1240, 1263, 1280, 1284, 1344, 1352
K 12	1123, 1159, 1199, 1199b
K 13	1304, 1334
K 14	1011, 1178, 1239b, 1275, 1373
K 15	1012, 1049, 1064, 1258, 1332, 1349
K 16	1254
K 17	1346
K 18	1031, 1047
K 19	1264, 1374
K 20	1333, 1366
K 21	1033, 1124
K 22	1066, 1067
K 23	1262, 1291
K 24	1201, 1294
K 25	1163, 1260
K 26	1276
K 27	1238, 1296
K 28	1309
K 29	1076, 1281, 1290
K 30	1182, 1324
K 31	1034, 1048, 1055
K 32	1311, 1347
K 33	1289
K 34	1084, 1177
K 35	1085
K 36	1345
K 37	1104, 1270
K 38	1348
K 39	1271
K 40	1198
K 41	1068
K 42	1261
K 43	1239
K 44	1135
K 45	1179, 1301
K 46	1277
K 47	1314, 1365
K 48	1353
K 49	1255
K 50	1278
K 51	1032
K 52	1105
K 53	1143, 1329
K 54	1086
K 55	1156
K 56	1202

A 2.3 Determination of the mean and variance of the sample comprising the population of combined sheets

Sheet	Swiss territory (km^2)	Loss (ha)	Extrapolation (ha)
1091	210.0	1'861.4	366'011
1113	210.0	243.8	47'937
1132	210.0	655.9	128'966
1146	210.0	948.9	186'585
1197	210.0	174.2	34'263
1230	210.0	0.0	0
1250	210.0	278.5	54'755
1273	210.0	600.3	118'035
1171	210.0	133.3	26'208
1189	210.0	0.0	0
1193	210.0	39.6	7'787
1195	210.0	368.8	72'524
1211	210.0	0.0	0
1213	210.0	214.4	42'152
1231	210.0	93.8	18'454
1306	210.0	1'783.3	350'652
1110	210.0	195.9	38'521
1134	210.0	246.5	48'462
1152	210.0	534.8	105'164
1218	210.0	163.4	32'124
1232	210.0	45.5	8'947
1249	210.0	0.0	0
1313	210.0	2'679.7	526'916
1070	210.0	419.3	82'451
1107	210.0	751.9	147'839
1167	210.0	480.9	94'566
1173	210.0	204.8	40'267
1188	210.0	32.1	6'305
1191	210.0	144.6	28'429
1223	210.0	0.0	0
1235	210.0	43.7	8'593
1244	210.0	0.0	0
1287	210.0	1'142.7	224'691
K 1	201.3	58.4	11'987
K 2	195.0	392.7	83'159
K 3	176.3	376.2	88'146
K 4	193.1	0.0	0
K 5	206.9	215.4	42'990
K 6	168.8	0.0	0
K 7	189.4	709.3	154'661
K 8	133.1	540.1	167'535
K 9	135.0	18.3	5'594
K 10	188.1	322.8	70'852
Mean			**80'756**
Variance (ha^2)			**12'248'833'224**

A3 Estimation of the effort for improving the accuracy of the overall result

A simple general estimation of the sample size n_0 required for achieving a variance of V for the sample mean is provided by (HULLIGER 2000, p.13):

$$n_0 = \frac{D^2}{V}\,. \qquad \text{[A.1]}$$

Estimation of the variance of the population D^2 via the variance of the sample d^2, taking account of the finiteness correction, leads to

$$n^*/(1 - n^*/N^*) = \frac{d^{*2}}{V^*}\,. \qquad \text{[A.2]}$$

Once again, we use the asterisk to indicate that the value in question refers to the population including the combined map sheets. The percentage deviation of the upper limit of the 95% confidence interval $VI(\%)^*$ from the mean value $\bar{y}_s^*$ is estimated with

$$VI(\%)^* = \frac{196\sqrt{V^*}}{\bar{y}_s^*}\,. \qquad \text{[A.3]}$$

This results in the relationship

$$VI(\%)^* = 196\frac{d^*}{\bar{y}_s^*}\sqrt{\frac{N^* - n^*}{N^* n^*}} \qquad \text{[A.4]}$$

fig. A-1 shows the percentage deviation of the upper limit of the 95% confidence interval $VI(\%)^*$ from the mean value $\bar{y}_s^*$ as a function of n^*. d^* and $\bar{y}_s^*$ were estimated from the sample (cf. Section A 2.3). The arrows show the value of around 36% reached according to tab. 2-7 with n^* of 43. It can be seen that a significant reduction of the 95% confidence interval could only be achieved with relatively large effort. If the aim was to reduce this, for example, from currently around ± 36% to 20% of the mean value $\bar{y}_s^*$, it is estimated that an *additional* six 12-sheet samples – i.e. 50% *more* than hitherto – would have to be processed.

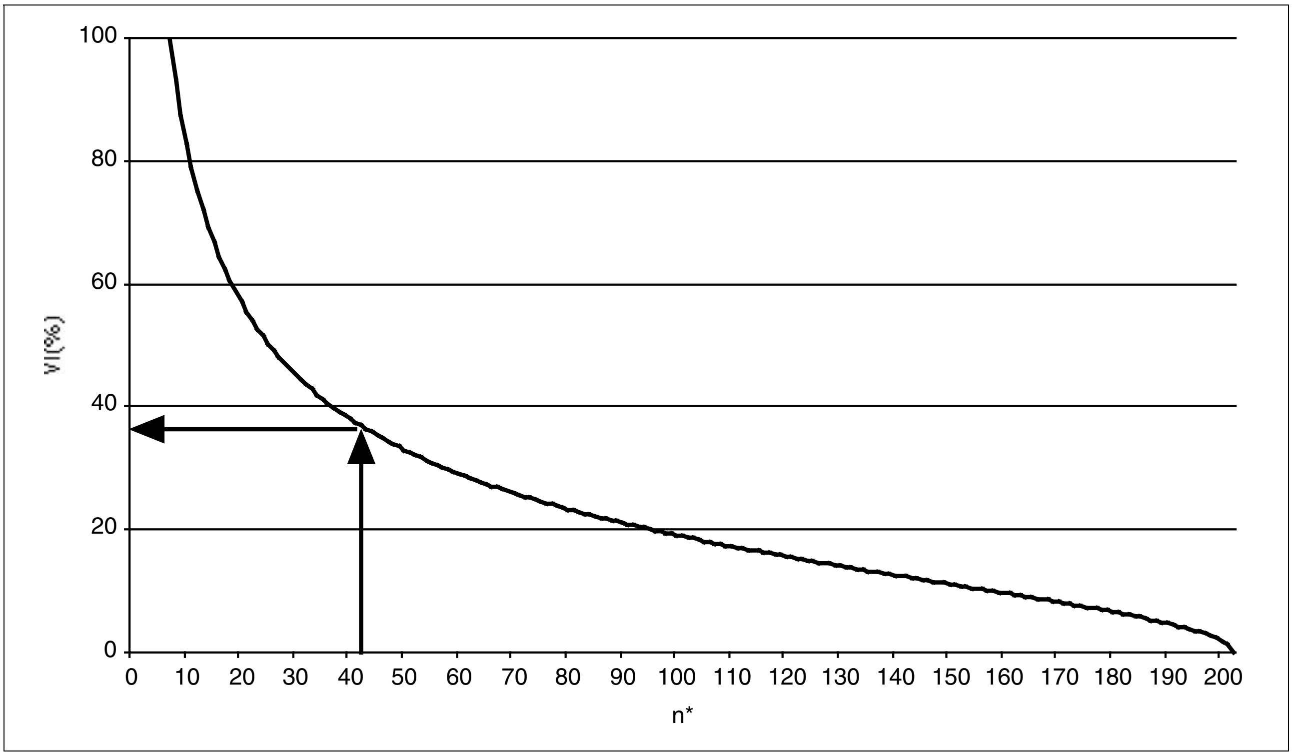


Fig. A-1: Percentage deviation of the upper limit of the 95% confidence interval $VI(\%)^*$ from the mean value $\overline{y}_s{}^*$ as a function of n^*; d^* und $\overline{y}_s{}^*$ were estimated from the sample

A4 Determination of vascular plant species endangered by riverine floodplain area loss

A 4.1 List of vascular plant species no longer contained in the new Red List

Name of species	Notes
Agrostis verticillata	Only occurred adventitiously and extremely rarely in Switzerland, and is no longer included in the new Red List
Azola filiculoides	Does not occur in Switzerland
Berula erecta f. submersa	Is considered to be a taxon included in Berula erecta L. according to synonym index
Leonurus marrubiastrum	Only occurred adventitiously and extremely rarely in Switzerland, and is no longer included in the new Red List
Najas marima var. Intermedia	Is considered to be a taxon included in Najas marina L. according to synonym index
Potamogeton compressus	Only occurred adventitiously and extremely rarely in Switzerland, and is no longer included in the new Red List

A 4.2 List of vascular plant species not classified as threatened by IUCN

Name of species	Code number	IUCN status in Switzerland
Berula erecta (Huds.) Coville	59500	LC
Brassica nigra (L.) W. D. J. Koch	64500	DD

A 4.3 List of vascular plant species that can not be considered a component of Swiss flora

Name of species	Notes
Anthriscus cerefolium (L.) Hoffm.	Herb
Arabis scabra All.	Chasmophytic/scree species (occurs in the canton of Geneva)
Aristolochia rotunda L.	Mediterranean plant (occurs in the cantons of Ticino and Grisons)
Glaucium flavum Crantz	Species of marine drift line (salt)
Hymenolobus procumbens (L.) Nutt.	Species of marine drift line (salt)
Salix alpina Scop.	Not in Switzerland
Vallisneria spiralis L.	Tropical aquarium plant

A 4.4 List of vascular plant species with floodplain-dependent and non-floodplain-dependent habitats (Numbers of habitat units according to [DELARZE et al., 1999)

Name of species	Floodplain-dependent habitat	Non-floodplain-dependent habitat
Aethionema saxatile (L.) R. Br.	3.2.1	3.3.1.5
Calamagrostis canescens (F. H. Wigg.) Roth	2.1.2.2	5.3.7, 6.1.1
Odontites vernus subsp. serotinus Corb.	7.1.1	4.5.3
Parietaria officinalis L.	5.1.5	6.3.9

A 4.5 List of vascular plant species endangered by riverine floodplain loss

Name of species	Number	Code	IUCN status in Switz.
Agropyron pungens (Pers.) Roem. & Schult.	8000		NT
Alisma gramineum Lej.	21700	B	EN
Alisma lanceolatum With.	21800		VU
Allium scorodoprasum L.	24300	A	VU
Alopecurus aequalis Sobol.	25500		VU
Alopecurus geniculatus L.	25700		VU
Anagallis minima (L.) E. H. L. Krause	30000		EN
Anthriscus caucalis M. Bieb.	35600		VU
Apium nodiflorum (L.) Lag.	38500	A	CR
Apium repens (Jacq.) Lag.	38600	A	CR
Aremonia agrimonoides (L.) DC.	43200		NT
Aristolochia clematitis L.	44600	A	VU
Berteroa incana (L.) DC.	59400	A	NT
Bidens cernua L.	60800		EN
Bidens radiata Thuill.	61200		CR
Blackstonia acuminata (W. D. J. Koch & Ziz) Domin	62300		EN
Blackstonia perfoliata (L.) Huds.	62400		VU
Bolboschoenus maritimus (L.) Palla	62900		EN
Bryonia alba L.	67500	A	CR
Callitriche obtusangula Le Gall	73200	A	CR
Carex atrofusca Schkuhr	83600	A	VU
Carex bicolor All.	83900	A	NT
Carex bohemica Schreb.	84000	A	CR
Carex buxbaumii Wahlenb.	84500		EN
Carex dioica L.	86200		NT
Carex maritima Gunnerus	89900	A	VU
Carex microglochin Wahlenb.	90200	A	VU
Carex otrubae Podp.	91400	B	VU
Carex pseudocyperus L.	92900		VU
Carex vaginata Tausch	95100	A	EN
Carpesium cernuum L.	96800		CR
Catabrosa aquatica (L.) P. Beauv.	97300	A	VU
Centaurium pulchellum (Sw.) Druce	101300		VU
Ceratophyllum submersum L.	105600		EN
Chenopodium ficifolium Sm.	108900		NT
Chenopodium glaucum L.	109100		NT
Chondrilla chondrilloides (Ard.) H. Karst.	110300	A	EN
Cicuta virosa L.	113300	A	EN
Corrigiola litoralis L.	120900	A	CR
Crepis foetida L.	123600		VU
Crepis setosa Haller f.	125200		VU
Cucubalus baccifer L.	126700	A	VU

Name of species	Number	Code	IUCN status in Switz.
Cyperus flavescens L.	129700	B	VU
Cyperus fuscus L.	129800	B	VU
Cyperus longus L.	130000	B	EN
Cyperus michelianus (L.) Delile	130100	B	RE
Cyperus rotundus L.	130200	B	RE
Cyperus serotinus Rottb.	130300	B	RE
Dactylorhiza cruenta (O. F. Müll.) Soó	132100		VU
Dactylorhiza lapponica (Hartm.) Soó	132500		NT
Dipsacus pilosus L.	139400		VU
Draba muralis L.	141200		VU
Eleocharis ovata (Roth) Roem. & Schult.	145600		EN
Euphorbia palustris L.	160800		VU
Fumaria capreolata L.	174800		VU
Galium rubioides L.	180000	A	CR
Geranium divaricatum Ehrh.	187300	B	EN
Geranium palustre L.	187900	A	NT
Glyceria declinata Bréb.	191400		EN
Gnaphalium luteoalbum L.	192300		VU
Gnaphalium uliginosum L.	192700		NT
Gypsophila muralis L.	193600		EN
Holoschoenus romanus (L.) Fritsch	207000		CR
Hottonia palustris L.	208600		EN
Hydrocharis morsus-ranae L.	209300	B	EN
Illecebrum verticillatum L.	213400		RE
Inula britannica L.	214000		EN
Inula helvetica Weber	214500	A	VU
Isolepis setacea (L.) R. Br.	216300		VU
Juncus ambiguus Guss.	217900	B	CR
Juncus arcticus Willd.	218000	A	VU
Juncus capitatus Weigel	218400		CR
Juncus castaneus Sm.	218500	B	EN
Juncus sphaerocarpus Nees	219500		CR
Juncus tenageia L. f.	219900		CR
Kobresia simpliciuscula (Wahlenb.) Mack.	222700	B	NT
Leersia oryzoides (L.) Sw.	231800	A	EN
Lemna gibba L.	232200		RE
Lemna minuta Humb. & al.	232410	B	EN
Lemna trisulca L.	232500		NT
Leontodon saxatilis Lam.	234200		NT
Leucojum aestivum L.	237000		VU
Limosella aquatica L.	238700		EN
Lindernia procumbens (Krock.) Philcox	240400		RE
Liparis loeselii (L.) Rich.	241800		VU
Ludwigia palustris (L.) Elliott	245300		CR

Name of species	Number	Code	IUCN status in Switz.
Lythrum hyssopifolia L.	251900		CR
Lythrum portula (L.) D. A. Webb	252000		EN
Malaxis monophyllos (L.) Sw.	252600	A	VU
Mentha pulegium L.	258300		EN
Mentha suaveolens Ehrh.	258600		VU
Montia fontana subsp. chondrosperma (Fenzl) Walters	264300		RE
Myosurus minimus L.	267400		CR
Myriophyllum alterniflorum DC.	267600		EN
Najas flexilis (Willd.) Rostk. & W. L. E. Schmidt	268200		RE
Najas marina L.	268400		VU
Najas minor All.	268500		EN
Nasturtium microphyllum (Boenn.) Rchb.	269800	A	EN
Nuphar pumila (Timm) DC.	272400		EN
Oenanthe aquatica (L.) Poir.	273600		EN
Orchis palustris Jacq.	281300		VU
Ornithogalum nutans L.	283200		VU
Pinguicula grandiflora Lam. s.str.	304400		EN
Pisum sativum subsp. elatius (M. Bieb.) Asch. & Graebn.	306900		EN
Polygonum lapathifolium subsp. danubiale (A. Kern.) O. Schwarz	315200	A	CR
Potamogeton acutifolius Link	318000		CR
Potamogeton gramineus L.	318900		EN
Potamogeton helveticus (G. Fisch.) W. Koch	319000	A	EN
Potamogeton nodosus Poir.	319300	A	VU
Potamogeton obtusifolius Mert. & W. D. J. Koch	319500		CR
Potamogeton plantagineus Roem. & Schult.	319900		EN
Potamogeton praelongus Wulfen	320100		EN
Potamogeton trichoides Cham. & Schltdl.	320400		CR
Potenzilla supina L.	324800		EN
Ranunculus peltatus Schrank	340000		EN
Ranunculus rionii Lagger	341100	A	CR
Ranunculus sardous Crantz	341200		CR
Ranunculus sceleratus L.	341500		VU
Rumex aquaticus L.	359600	A	EN
Rumex hydrolapathum Huds.	360000		EN
Rumex maritimus L.	360200		CR
Sagina apetala Ard. s.str.	361500		VU
Sagina apetala subsp. erecta F. Herm.	361600		NT
Sagina nodosa (L.) Fenzl	362100		VU
Sagina subulata (Sw.) C. Presl	362400		EN
Samolus valerandi L.	368500		CR
Schoenoplectus mucronatus (L.) Palla	378300		EN
Schoenoplectus supinus (L.) Palla	378600		CR
Schoenoplectus tabernaemontani (C. C. Gmel.) Palla	378700		VU

Name of species	Number	Code	IUCN status in Switz.
Scrophularia auriculata L.	381800		CR
Senecio erraticus Bertol.	388300		EN
Sison amomum L.	398100		CR
Sisymbrium strictissimum L.	398800		VU
Sonchus palustris L.	402000	B	RE
Sparganium emersum Rehmann	403000	B	VU
Sparganium erectum subsp. microcarpum (Neuman) Domin	403300		EN
Sparganium erectum subsp. neglectum (Beeby) K. Richt.	403400		EN
Spergularia segetalis (L.) Don	404800		RE
Spiranthes aestivalis (Poir.) Rich.	405000		VU
Spirodela polyrhiza (L.) Schleid.	405200		NT
Stratiotes aloides L.	409700		VU
Teucrium scordium L.	415200		EN
Thalictrum flavum L.	415800		VU
Thalictrum morisonii C. C. Gmel.	416400	A	EN
Trapa natans L.	423500		CR
Trifolium fragiferum L.	425400		VU
Typha minima Hoppe	432300	A	EN
Utricularia vulgaris L.	434200		VU
Valeriana pratensis Dierb.	436000	B	EN
Veronica acinifolia L.	440100		CR
Veronica anagalloides Guss.	440600	B	CR
Veronica catenata Pennell	441300	B	EN
Zannichellia palustris L.	455700		VU

A 4.6 Habitat types dependent upon watercourses, and number of associated endangered vascular plant species

Habitat types	Number of endangered species
1 Waters	**29**
1.1.2 Potamion	12
1.1.3 Lemnion	7
1.1.4 Nymphaeion	4
1.2.1 Ranunculion fluitantis	4.5
1.2.2 Fontinalidion antipyreticae	1.5
2 Vegetation of banks and wetlands	**87**
2.1.2.2 Phalaridion	12
2.1.4 Glycero-Sparganion	6
2.2.3 Caricion davallianae	8
2.2.5 Caricion bicolori-atrofuscae	9
2.3.3 Filipendulion	7
2.5.1 Nanocyperion	35
2.5.2 Bidention	10
3 Glaciers, rock, scree and talus	**1**
3.2.1.1 Epilobion fleischeri	1
5 Herbaceous ecotones, tall herb communities, scrub	**14**
5.1.3 Convolvulion	3
5.1.5 Aegopodium + Alliarion	9
5.3.2 Berberidion	2
5.3.6 Salicion elaeagni	0
5.3.8 Salicenion waldsteinianae	0
6 Forests	**4**
6.1.2 Salicion albae	1
6.1.4 Fraxinion	3
7 Ruderal sites	**16**
7.1.1 Agropyro-Rumicion	13
7.1.6 Dauca-Melilotion	3
8 Plantings, arable fields, crops	**2**
8.2.3.1 Polygono-Chenopodion	2
Total vascular plant species	**153**

A 4.7 Distribution among IUCN (2001) threat categories of vascular plant species dependent upon floodplain sites

IUCN status in Switzerland	Number of species
EX (Extinct – ausgestorben)	0
EW (Extinct in the Wild – in der Natur ausgestorben)	0
RE (Regionally Extinct – regional, bzw. in der Schweiz, ausgestorben)	10
CR (Critically Endangered – vom Aussterben bedroht)	31
EN (Endangered – stark gefährdet)	49
VU (Vulnerable – verletzlich)	48
NT (Near Threatend – potenziell gefährdet)	15
Total vascular plant species	**153**

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