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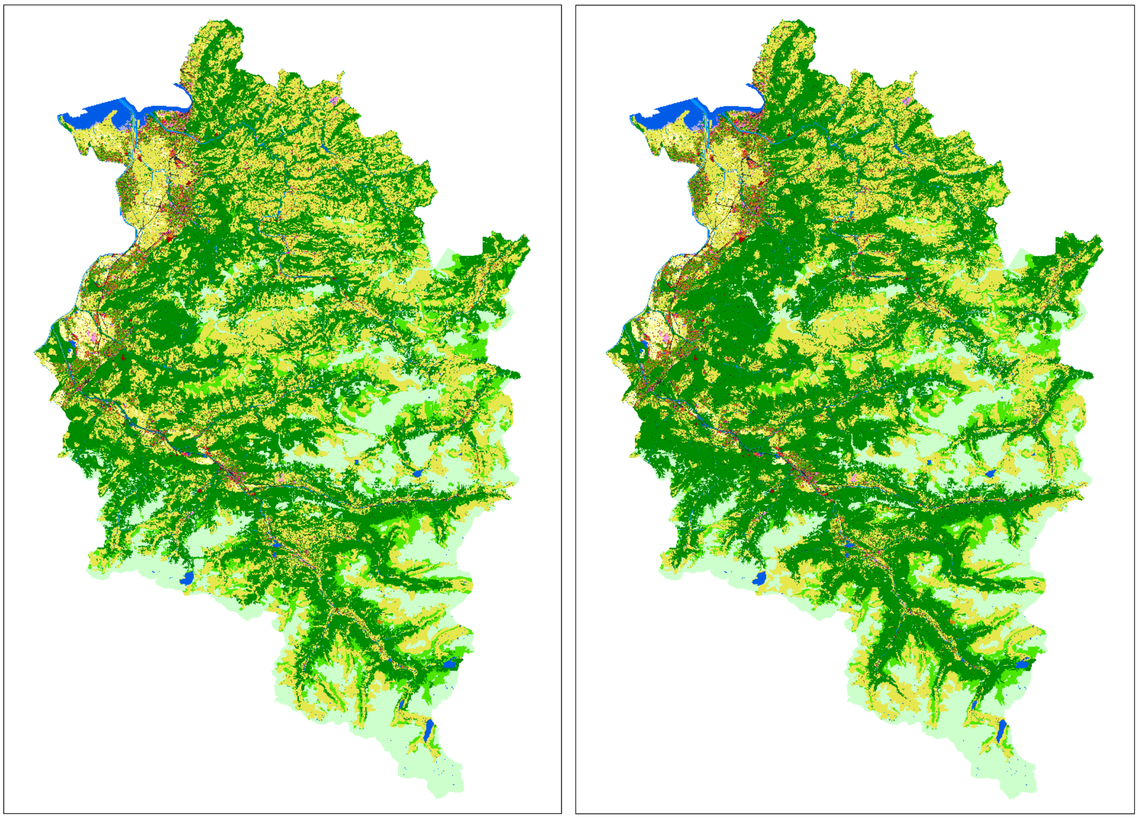
Master thesis

The effects of land use change on ecosystem services in a mountainous region



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Cover pictures: land use map of the study area Vorarlberg, Austria from 2016 (left hand side) and a potential land use map for 2050 based on a future land use scenario (right hand side)

Abstract

This Master thesis presents an example of a regional-scale assessment of three ecosystem services (flood protection, nearby recreation and biodiversity) which could facilitate incorporation of ecosystem services into policy making. The assessment included mapping of service supply and demand in the region of Vorarlberg, Austria based on a land use map. Respective indicators as proxies for each service were determined. For the mapping of biodiversity the InVEST habitat quality model was applied. The assessment aimed at identifying potential discrepancies between supply and demand of the individual services but also at analysing potential synergies or conflicts between the different services. Additionally, two future land use scenarios were used to analyse potential consequences of land change on ecosystem service supply and demand and service interactions. Since the study area is characterised as a mountainous region, the ecosystem services were also analysed in terms of their altitudinal distribution.

The assessment identified high supply of flood protection, nearby recreation and biodiversity in mid-elevation areas with a peak around 1200 m a.s.l. and low supply at low (< 600 m a.s.l.) and high (> 2000 m a.s.l.) elevations. Thereby, nearby recreation showed higher spatial variability of supply than flood protection and biodiversity. Demand for flood protection and nearby recreation plus habitat degradation was high in low elevation areas with a peak around 500 to 600 m a.s.l. and gradually decreasing with increasing elevation. Where highest demand for a service concurred with low supply (in particular in the densely-populated Rhine valley) supply might not be able to meet demand. However, these discrepancies would have to be quantified in a more local-scale assessment. 6.5% of the total area of Vorarlberg was found to provide high supply of all the three services assessed, whereas 1.3% of the total area was identified as potential conflict area between biodiversity and nearby recreation. Comparison with the distribution of different land use types across Vorarlberg revealed a clear correlation of service supply and synergistic areas with forest areas and correlation of service demand, habitat degradation and conflict areas with human-dominated land use types including built-up and agricultural areas. The future assessment projected increases in both supply and demand of flood protection and nearby recreation but with supply increasing more than demand. Hence, pressure on these services was predicted to decrease over the total area of Vorarlberg. In contrast, habitat degradation was projected to increase more than biodiversity supply, meaning that pressure on species and habitats would increase under the two scenarios of land change.

In conclusion, the assessment indicated that certain land use types, in particular forests and built-up areas highly impact supply and demand of ecosystem services. The here presented approach for mapping of ecosystem services could facilitate to take potential consequences of land change on ecosystem services into account in policy making and support decision-making concerning issues of spatial planning or nature conservation.

Keywords: ecosystem services, land use change, mapping service supply & demand,
future land use scenarios, service interactions

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1. Introduction

Ecosystem services are commonly defined as “the benefits humans obtain from ecosystems”, which are derived from ecosystem functions (Costanza et al., 1997; Millenium Ecosystem Assessment (MA), 2005a). In contrast, ecosystem functions is a term used to describe the basic structures and processes of natural ecosystems and is distinguished from the human centred definition of ecosystem services (Costanza et al., 1997). Ecosystem services provide a variety of different benefits. They are usually divided into three or four categories, respectively. The Common International Classification of Ecosystem Services (CICES) differentiates the three categories “provisioning services” (e.g. food, fresh water, construction materials or medicinal plants), “regulating services” (e.g. pollination, climate regulation, maintenance of air quality or moderation of extreme events) and “cultural services” (e.g. recreation, spiritual experiences or aesthetic appreciation) whereas The Economics of Ecosystems and Biodiversity (TEEB) and the MA both defined a fourth category which is “supporting services” (Haines-Young and Potschin, 2018; MA, 2005a; TEEB, 2010). However, TEEB and the MA do not consider the same services as being supportive services. TEEB (2010) specifies lifecycle maintenance and gene pool protection as supporting services while the MA (2005a) includes services such as nutrient cycling, soil formation or primary production.

1.1. Problem statement

The MA carried out between 2001 and 2005 has identified drastic changes in the Earth’s ecosystems induced by human activities. These changes have caused the degradation of approximately 60% of the examined services provided by ecosystems (MA, 2005b). The synthesis report states that human attempts to make use of ecosystem services have substantially fostered human well-being and economic development over the past decades. However, these activities were accompanied by significant impairment of ecosystem integrity. Furthermore, activities to increase the supply of one ecosystem service often lead to decreasing supply of other ecosystem services. Hence, ecosystem services are associated with certain trade-offs (MA, 2005b; TEEB, 2010). For example, increasing the production of food by expanding agricultural areas at the expense of forest areas could lead to decreases in timber production.

The main drivers which lead to a degradation of ecosystems and consequently reduced provision of ecosystem services are habitat and climate change, overexploitation, invasive alien species and pollution, particularly through nitrogen and phosphorus. Habitat change mainly occurs in the form of land use change or physical modification of aquatic systems (MA, 2005b; Maes et al., 2014). Land use change has been one of the most important drivers of change in terrestrial ecosystems (Burkhard et al., 2010; Helfenstein and Kienast, 2014). Processes of particular relevance are the conversion of natural landscapes to cropland (MA, 2005b) or built-up areas (Jaeger and Schwick, 2014) The underlying processes influencing these drivers are population development, economic growth and technological change (Erhard et al., 2017) plus socio-political and cultural factors (MA, 2005b).

Since humans depend on well-functioning ecosystems and their services (Costanza, 2016) ecosystem degradation might have significant negative impacts on the well-being of future generations. The MA (2005b) emphasises the need to address these findings by changing current policies, institutions and practices. In order to be able to develop effective policies for the management of ecosystems there needs to be a solid basis for decision-making. In recent years, the concept of ecosystem services has become increasingly popular in the field of ecosystem management (Burkhard et al., 2013; Seppelt et al., 2011). It is considered as a useful tool to incorporate natural capital into a decision-making process and therefore, allows better accounting for the value of an ecosystem. Finally, this could provide incentives to preserve ecosystems and their services (Costanza et al., 1997; Daily et al., 2009).

An inherent characteristic of ecosystems which makes sustainable management very difficult is their complexity. Human understanding of the structures and processes of ecosystems is highly limited. Different levels within one ecosystem as well as different ecosystems are interconnected and influence one another. This might have effects on various temporal and spatial scales (Christensen et al., 1996). Accordingly, it is important to consider that the provision of ecosystem services is not homogenous in space and time either (Fisher et al., 2009). As ecosystem services are defined as the benefits humans obtain from an ecosystem (Costanza et al., 1997) it is crucial to consider where and when the demand for these services occurs (Paetzold et al., 2010; Syrbe and Walz, 2012). Just as the provision of ecosystem services varies in space and time does the demand. Furthermore, the demand for an ecosystem service might occur elsewhere than the service is actually provided.
In order to address these problematic aspects it is important to assess not only the supply but also the demand for ecosystem services in a spatially explicit way (Cowling et al., 2008; Kroll et al., 2011; Van Jaarsveld et al., 2005). Still, the demand is often neglected in ecosystem service assessments (Burkhard et al., 2012). A key tool to assess ecosystem services spatially are maps. Maps allow the communication of complex spatial information and can help to facilitate practical implementation of the ecosystem service concept (Burkhard and Maes, 2017). In fact, mapping of ecosystem services is a widely applied practice and many different approaches have been developed (Burkhard et al., 2009; Kienast et al., 2009; Willemen et al., 2015).

1.2. State of the art of ecosystem service mapping

This section provides an overview about the current state of the art of ecosystem service mapping. Spatial assessments of ecosystem services have been applied to a broad range of topics at various spatial scales (see Burkhard et al., 2012; Maes et al., 2012a; Willemen et al., 2015). Some studies also made use of scenarios to assess future development of ecosystem services. On a global scale, the MA (2005a) has developed four scenarios for global development (globalisation vs. regionalisation and proactive vs. reactive ecosystem management) to describe possible states of the world's ecosystems and their services in the year 2050. Thereby, land use change has been an important driver characterising the different scenarios. On the scale of the EU, Stürck and Verburg (2017) used different land-change scenarios in the European Union (EU) to analyse the supply of ecosystem services in 2040. Also on the continental scale of Europe Kienast et al. (2009) performed a sensitivity analysis of different landscape functions under four future land use change scenarios. On a regional scale, Zhang et al. (2017) analysed the effects of land use change on the supply of ecosystem services in the agglomeration of Beijing, China. Specifically, they simulated urban expansion from 2013 to 2040 and assessed its impacts on different ecosystem services. Also on a regional scale, Huber et al. (2017) looked at the future potential of renewable energies under land use change in Switzerland, albeit the current debate whether renewable energies should be considered as ecosystem services (see Burkhard et al., 2012; De Groot et al., 2002; Haines-Young and Potschin, 2018). Other studies (e.g. Feng et al., 2017; Gimona and van der Horst, 2007; Han and Dong, 2017; Lin et al., 2018; Maes et al., 2012b) focused not only on mapping ecosystem services but on analysing potential trade-offs and synergies between the different services.

The capacity of an ecosystem to supply ecosystem services is influenced by its properties. These properties include the type of ecosystem, its spatial arrangement (well-connected or not), productivity (nutrient-rich or nutrient-poor systems) and condition (healthy or degraded) and they are the basis for mapping ecosystem services (Maes et al., 2016a). The measures to delineate ecosystem properties depend on the quality of the input data, i.e., their spatial and temporal resolution in relation to the specific ecosystem service of interest (Helfenstein and Kienast, 2014). In many cases, data need to be spatially and temporally highly resolved and such data is scarce (Maes et al., 2012a). Therefore, proxy indicators such as land cover data are used (Maes et al., 2016a). The natural land cover as well as anthropogenic land use directly influence an ecosystem's capacity to supply a service (Burkhard et al., 2012; Crossman et al., 2013a). A prominent tool to link such proxies for ecosystem properties with ecosystem services are look-up tables. Look-up tables are a common, straightforward approach to map ecosystem services (Burkhard and Maes, 2017; Kienast and Helfenstein, 2016). They express whether or to what degree a specific land cover type supports the supply of different ecosystem services (Kienast et al., 2009). Seppelt et al. (2011) found in their review of 153 studies about ecosystem services that two thirds of the studies made use of look-up tables. Only the minority of studies used simulation models. Burkhard et al. (2009) developed an extensive matrix linking 29 ecosystem services with 44 land cover types and assessed the capacity of each land cover type to provide these services. Kienast et al. (2009) generated a similar matrix but with binary links between ecosystem services and land cover type, expressing whether a land cover type supports a certain service or not. If available, additional information can be included following a tiered approach, usually including three tiers (Burkhard and Maes, 2017; Grêt-Regamey et al., 2015; Kienast and Helfenstein, 2016; Maes et al., 2014). Tier 1 basically follows the approach described above, linking ecosystem services and land cover data (Maes et al., 2016a). Examples of case studies which applied a tier 1 approach are Burkhard et al. (2009) and Burkhard et al. (2012) performed for the region of Leipzig-Halle in Germany, Vihervaara et al. (2010) conducted in Finnish Lapland, Brenner et al. (2010) who assessed ecosystem services in the region of Catalonia in Spain or the study by Goldenberg et al. (2017) conducted in the Stockholm region, Sweden. Tier 2 adds more detail including data from other indicators than land cover. These data can be gained from expert interviews, literature reviews or statistical data of the case study area (Maes et al., 2016a). Different studies have compiled potential tier 2 indicators for the supply of ecosystem services (e.g. De Groot et al., 2010; Egoh et al., 2012; Maes et al., 2016b; Müller et al., 2016). Examples using a tier 2 approach are Peña et al. (2015) performed in northern Spain, Weyland and Laterra (2014) conducted in Argentina, Posthumus et al. (2010) applied in Nottinghamshire, England or Villamagna et al. (2014) conducted in Virginia and North Carolina in the USA. Finally, tier 3 is the most detailed, but also a very time- and data-intensive mapping procedure, since it includes modelling of biophysical processes (Maes et al., 2016a). A typical example would be the use of hydrological models to model flood regulation potential as applied by Stürck et al. (2014) for the EU or by Nedkov and Burkhard (2012) for the Etropole municipality in Bulgaria. The appropriate tier for a specific case should be chosen according to the goal of the mapping exercise and the data availability (Grêt-Regamey et al., 2017).

Because of the increasing application of the ecosystem service concept many different tools have been developed to quantify and map ecosystem services (Maes et al., 2016a). Bagstad et al. (2013) did a comparative assessment of various tools which range from simple spreadsheets to complex software. Today, the most commonly used software tools are InVEST (Integrated Tool to Value Ecosystem Services and Trade-offs), ARIES (Artificial Intelligence for Ecosystem Services), SolVES (Social Values for Ecosystem Services) and GUMBO (Global Unified Metamodel of the Biosphere; Maes et al., 2016a). The rapid development of different approaches and tools has led to a high diversity of tools that can be used to model and map ecosystem services (Crossman, 2017). Assessing their respective use and limitations is seen as a major challenge for the practical implementation of the ecosystem service concept in policy making (Crossman et al., 2013b; Maes et al., 2016a).

1.3. Aim and research questions

This Master thesis aims at applying the ecosystem service concept on a regional scale for incorporation into a decision-making process. The objective is to analyse how supply and demand of three ecosystem services (flood protection, nearby recreation, biodiversity) may develop between 2016 and 2050 in Vorarlberg, Austria as a function of land change. Two land change scenarios developed in the project

"High Resolution Flood Risk Assessment for Climate Change Adaptation with a Coupled Modelling Approach" (HiFlow-CMA; http://www.alp-s.at/cms/en/water/current-projects/hiflow/) were used. The project is part of the Austrian Climate Research Programme (funded by the Austrian Climate and Energy Fund) and aims at analysing future flood risk in Vorarlberg based on changes in climate, hydrology and socio-economy. A first scenario was a trend scenario representing a business-as-usual development relying on linear projections of observed past land changes into the future. A second scenario represented an extreme pressure scenario of land change with strong urbanisation in the lowland and land abandonment at higher elevations.

I focused on three ecosystem services from different categories. The first service, which is also the focus of the HiFlow-CMA project, is flood protection. This service is commonly classified as a regulating service (Haines-Young and Potschin, 2018; MA, 2005a; TEEB, 2010). The second service is nearby recreation, which is classified as a cultural ecosystem service (Haines-Young and Potschin, 2018; MA, 2005a; TEEB, 2010). The third ecosystem service considered is biodiversity. Although there is some controversy over how to classify biodiversity within the range of ecosystem services. CICES on the one hand does not consider biodiversity as an ecosystem service per se but does indirectly include different biodiversity services into other ecosystem services. For example, CICES specifies "maintaining nursery populations and habitats" as a regulation and maintenance service or the symbolic and spiritual value of species as a cultural ecosystem service (Haines-Young and Potschin, 2018). TEEB on the other hand distinguishes an additional category of ecosystem services called "habitat or supportive services" (TEEB, 2010). In this category TEEB includes "habitats for species" and "maintenance of genetic diversity" representing the different aspects of biodiversity which are "diversity within species, between species and of ecosystems" (Secretariat of the Convention on Biological Diversity (CBD), 2010; p. 15). In spite of the controversy over its classification biodiversity is undisputedly the basis for the provision of all ecosystem services (MA, 2005a).

Four research questions were specified to be tackled in the course of this Master thesis.

1. Which indicators are appropriate to represent and map the three ecosystem services flood protection, nearby recreation and biodiversity in the region of Vorarlberg?
2. What is the current spatial distribution of supply and demand of the three ecosystem services?
3. What is the future supply and demand of the three ecosystem services under two different scenarios for land change (business-as-usual and pressure scenario)?
4. What are the interactions between the different ecosystem services? Are there any conflicts or synergies?

This Master thesis will provide an example on how land use scenarios can be used to map supply and demand of ecosystem services on a regional scale to assess likely consequences of land change for ecosystem services. By including the demand, these maps can point out possible shortfalls of ecosystem service provision and thereby indicate the need for policy action. Furthermore, my assessment helps to identify areas of particular importance in terms of ecosystem service provision. This information can be used to support decision making in the context of conservation policy and spatial planning.

2. Materials and method

2.1. Study area

The state of Vorarlberg covers an area of 2’601 km^2 and is located in the most western part of Austria at the border to Switzerland and Lichtenstein. Around 383’000 people live in the area, indicating that Vorarlberg has a high population density compared to the rest of Austria. The population density is particularly high in the Rhine valley where 2/3 of all people are living. Vorarlberg is a mountainous region characterised by a diverse landscape. The elevation ranges from 369 m to 3312 m a.s.l. (Amt der Vorarlberger Landesregierung - Landespressestelle, 2016). Currently, forests (36%) and meadows and pastures (31%) are the dominating land use types. Built-up areas cover 1% of the area (Fig. 1).

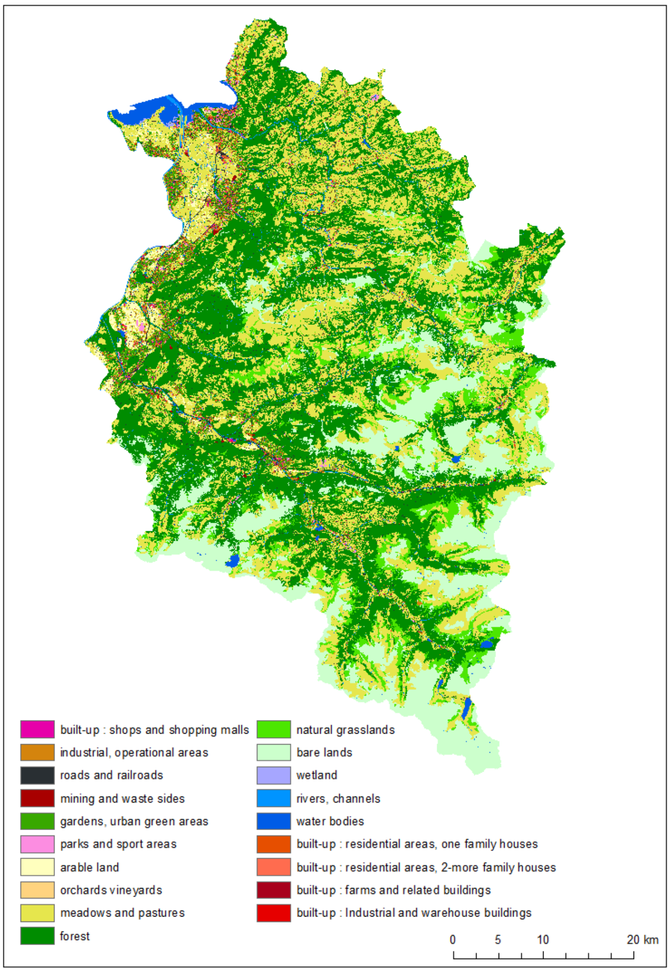

Fig. 1: Land use map of Vorarlberg 2016.

2.2. Scenarios of land change

To identify the plausible future land change in the area of Vorarlberg future scenarios of land change developed as part of the HiFlow-CMA project were used. Five scenario maps were developed as an output of various statistical data, stakeholder’s assessments and previous scenario-based projects (e.g. “ÖROK-Prognosen”; Hanika, 2010). The scenario maps have the same land use nomenclature structure and spatial resolution (10 metres) as the current land-use map. From the five scenarios “trend” and “competition” were selected for the assessment of the future state of the ecosystem services. The “trend” scenario represents the more conservative business-as-usual development, whereas the “competition” scenarios represents the more extreme development. It is characterised by a focus on strong economy and growth in population and tourism. It describes increasing pressure on built-up area, especially in cities and growth of social disparities. However, not all of the land use types included in the map were actually modelled to change in the future. Roads and railroads, mining and waste sites, parks and sport areas, orchards and vineyards, bare lands, wetlands, river, channels and water bodies are assumed to be stable.

Regarding the remaining land use types both of the land use scenarios for 2050 projected an increase in forest area (trend scenario: +8.9%, competition scenario: +12.8%) and decreases in the area of meadows and pastures (trend scenario: -6.6%, competition scenario: -13.7%) and natural grasslands (trend scenario: -22.8%, competition scenario: -11.6%). Built-up area as well as gardens and urban green areas were projected to increase in both scenarios. The trend scenario predicted an increases of 10.5% for residential areas, 17.9% for farms and related buildings, 18.3% for industrial and warehouse buildings, 9.7% for industrial and operational areas, 8.9% for shopping areas and 6.4% for gardens and urban green areas. The competition scenario predicted changes in a similar range but with more significant changes in residential areas (+18.2%). Instead, the increase in industrial and warehouse buildings was projected to be less intense (+7.5%) in comparison to the trend scenario. The trend scenario projected an increase in the area of arable land (+6.1%) whereas the competition scenario projected a slight decrease (-1.9%; Fig. 2).

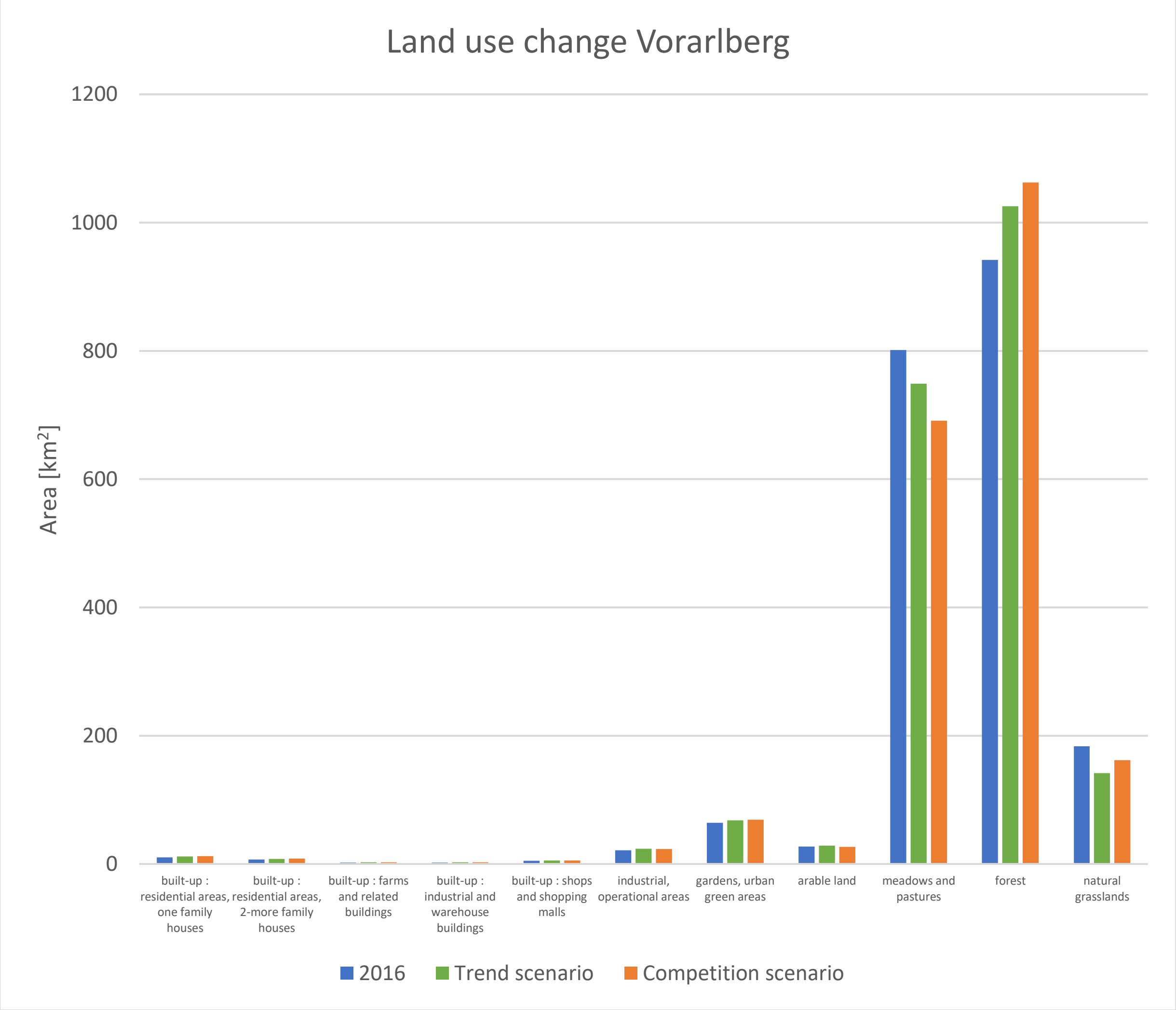

Fig. 2: projected change of different land use types in Vorarlberg from 2016 to 2050 under consideration of two future land use scenarios.

2.3. Selection of indicators for supply and demand of ecosystem services

It is important to state the definitions applied for the different terms used in the context of ecosystem services to avoid any misconceptions (Villamagna et al., 2013; Wolff et al., 2015). There are three main aspects of ecosystem services distinguished in literature (Bukvareva et al., 2017). First, there is the potential service provision by ecosystems irrespective of whether people use the services or not. This aspect will be referred to as "supply" as in Tallis et al. (2012). The second aspect is to what degree a service is actually used or consumed by humans in a particular area within a given time period. This will be referred to as "flow" as in Burkhard et al. (2014). However, the flow of ecosystem services will not be assessed in this thesis. The third aspect is "the amount of a service required or desired by society" (Villamagna et al., 2013; p. 116), here called "demand".

In order to be able to assess an ecosystem's capacity to provide certain services it is necessary to define an indicator or a set of indicators for each service of interest. The same applies to the demand for these services. The indicator selection for the three services considered here was based on an extensive literature research. I took 49 studies into account to identify suitable indicators for the region of Vorarlberg (list of the assessed indicators in appendix A1). To determine the suitability of each potential indicator a set of criteria was adapted from Kandziora et al. (2013), Heink et al. (2016) and Albert et al. (2016a). The indicators should fulfil as many of the following criteria as possible, whereby criteria 1-4 were mandatory. Based on the selected indicators (Table 1) the ecosystem services of interest were assessed using ArcGIS (detailed ArcGIS procedure in appendix A2).

1) **Clear and comprehensible representation of the object of indication**: the selected indicators should serve as suitable, adequately specific representation of the ecosystem service of interest.
2) **Allow ecosystem services to be mapped**: indicators should provide spatially explicit information which allows for them to be mapped.
3) **Distinction between indicators for supply, flow and demand of ecosystem services**: supply indicators should actually indicate the capacity of an ecosystem to provide a certain service. One should not use indicators representing the flow of a service as a proxy for supply because flow is highly influenced by demand. Changes in a supply indicator should reflect changes in the ecosystem's capacity rather than changes in the demand. Furthermore, flow indicators should not be used as indicators for demand because flow is likewise influenced by supply and actual demand might in fact be higher or lower.
4) **Indicators address local context**: as the thesis considers a relatively small geographical area it is important to choose indicators which are relevant for the study area. Some indicators which work fine for a certain area might be irrelevant for Vorarlberg or one could miss a crucial indicator by not considering the local context. Besides the ecological and geographical context, the social, political and institutional context is of high importance.
5) **High degree of data availability**: for the sake of practicability one should choose indicators with input data that is already available or easy to collect.
6) **Relevant cause-effect relations**: as land use change is the pressure of interest in this thesis, the indicators should be adequately sensitive to changes in land use and land use change should actually be the cause of changes in the indicator. Here, it depends not only on whether an indicator would be sensitive to changes in land use but also on whether the future land use scenarios actually model changes in a certain indicator.
7) **Adequate spatial and temporal scales**: indicators should be chosen according to the spatial and temporal level of the study. The spatial resolution should be fine enough to show local differences within Vorarlberg. Concerning the temporal scale the indicators should allow to make projections up to the year 2050.
8) **Policy relevance and direct relations to management actions**: the indicators should have a relation to management actions so policy makers can react on potential changes by targeting the respective indicators.

Table 1: Selection of indicators for the different ecosystem services and their fulfilment of the defined criteria.

Ecosystem service	**Indicator(s)**	**Criteria fulfilled (partly fulfilled)**	**Tier level**
Flood protection (supply)	Land use	1,2,3,4,5,6,7,(8)	1
Flood protection (demand)	Land use	1,2,3,4,5,6,7,(8)	2
	Inundation areas	1,2,3,4,5,6,7	
Nearby recreation (supply)	Shores of brooks and rivers	1,2,3,4,5	1
	Lake shores	1,2,3,4,5	
	Wetland area	1,2,3,4,5	
	Forest area	1,2,3,4,5,6,7,(8)	
	Variety of land use types	1,2,3,4,5,(6),(7)	
	Hills	1,2,3,4,5	
	Settlement area	1,2,3,4,5,6,7,(8)	
	Hiking trails	1,2,3,4,5,8	
	Bike trails	1,2,3,4,5,8	
	Roads	1,2,3,4,5,(8)	
Nearby recreation (demand)	Distance to settlement areas	1,2,3,4,5,6,(7)	2
	Number of inhabitants per municipality	1,2,3,4,5,6,(7)	
Biodiversity (supply)	Land use	1,2,3,4,5,6,7,(8)	1
	Threat sources	1,2,3,4,(6),(8)	

2.4. Flood protection

According to the international disaster database EM-DAT which is maintained by the Centre for Research on the Epidemiology of Disasters (CRED), floods are the most frequent and costliest natural hazard in Europe (European Environmental Agency (EEA), 2010). Floods also affect Austria (Penna and Borga, 2013). The flood event of August 2005 for example caused economic losses of 620 million Euros in Austria (EEA, 2010). Economic costs caused by floods are projected to grow due to increased exposure (Jongman et al., 2012) and increases in frequency and magnitude of precipitation events induced by climate change (Kundzewicz et al., 2006). Therefore, flood protection measures are of increasing importance. Investing in the natural flood regulation capacity of ecosystems has gained interest as alternative to structural flood mitigation measures such as dams and dikes (Stürck et al., 2014) which are often associated with negative effects on biodiversity (Lytle and Poff, 2004). Ecosystems can mitigate flood hazards by reducing the runoff of a precipitation event. Thereby vegetation and the surface texture are critical factors (Maes et al., 2017; Rabe et al., 2016). In the absence of surface texture data, I used land use data as a proxy.

2.4.1. Supply

Supply of flood protection was assessed using a tier 1 approach. The study by Burkhard et al. (2009) served as a guideline to develop the respective look-up tables. A value was assigned to each land use type according to its flood regulation capacity. The capacity was transferred to a scale from 0 to 5 where 0 means “no relevant capacity” and 5 indicates “very high relevant capacity”.

For each of the land use types present on the land use map of Vorarlberg the equivalent from the study of Burkhard et al. (2009) with the respective supply value was determined (Table 2). In some cases (e.g. forest) it was appropriate to choose a combination of different land use types. If these land use types differed in their supply value the mean value was taken for the assessment. Because land use types with high and very high flood regulation capacity such as “salt marshes”, “beaches, dunes and sand plains”, “intertidal flats” or “coastal lagoons” are not present in Vorarlberg, there were no supply values of 4 or 5. The maximum value was 3 which represents medium relevant capacity. The supply values were assigned to each 10m x 10m grid cell of the land use map based on its land use category.

2.4.2. Demand

In a recent study, Burkhard et al. (2012) developed a procedure to assess the demand for a specific ecosystem service analogous to the supply assessment. As for supplies, demand values ranged from 0 to 5 for the different land use types. The resulting demand values for flood protection and their corresponding land use types are shown in Table 2. As for supply, if there were different suitable land use types, the mean demand values were calculated. The demand values were attributed to the same 10m x 10m grid cells of the land use map as used for supply. Burkhard et al. (2012) did not attribute a demand value of 3 to any of the land use types, therefore there was no demand value of 3 in Vorarlberg either.

As a result, maps indicating the sensitivity of different land use types to floods were obtained. These maps were complemented with data on inundation areas in Vorarlberg (similar to Syrbe and Walz, 2012; Bubeck et al., 2011). Hence, the assessment of flood protection demand was based on a tier 2 approach. Floods with a recurring period of 100 years were taken into account for the assessment. The final demand was determined as the sensitivity of all the infrastructure and agricultural area situated in the respective inundation areas. This means, only areas which are actually at risk of being flooded were considered as areas with relevant demand.

Table 2: Flood protection supply and demand values of the land use types present in Vorarlberg plus their equivalent in the studies of Burkhard et al. (2009) and Burkhard et al. (2012), respectively.

Land use type Vorarlberg	**Equivalent in Burkhard et al. (2009)/ Burkhard et al. (2012)**	**Supply value**	**Demand value**
Built-up: residential areas, one family houses	“Continuous urban fabric” + “Discontinuous urban fabric”	0	5
Built-up: residential areas, 2-more family houses; hotels and pensions s	“Continuous urban fabric” + “Discontinuous urban fabric”	0	5
Built-up: farms and related buildings	“Industrial or commercial units”	0	4
Built-up: industrial and warehouse buildings	“Industrial or commercial units”	0	4
Built-up: “Freifläche Sondergebiet”, shops and shopping malls	“Industrial or commercial units”	0	4
Industrial, operational areas	“Industrial or commercial units”	0	4
Roads and railroads	“Road and rail networks”	0	4
Mining and waste sites	“Mineral extraction sites” + “Dump sites”	0	2
Gardens, urban green areas	“Green urban areas”	0	0
Parks, sport areas	“Sport and leisure facilities”	0	0
Arable land	“Non-irrigated arable land” + ”Annual and permanent crops”+ “Agriculture & natural vegetation”	1	1
Orchards, vineyards	“Vineyards” + “Fruit trees and berries”	1	0
Meadows, pastures	“Pastures”	1	1
Forest	“Broad-leaved forest” + “Coniferous forest” + “Mixed forest”	3	0
Natural grassland, Alps	“Natural grassland”	1	0
Bare lands	“Bare rock”	1	0
Wetland	“Moors and heathland” +”Inland marshes”	3	0
Rivers, channels	“Water courses”	2	0
Water bodies	“Water bodies”	2	0

2.5. Nearby recreation

Various studies point out the importance of green spaces for human well-being (Matsuoka and Kaplan, 2008). Both urban and natural green spaces help to reduce stress, preventing mental and physical illnesses and generally improve mood states (Björk et al., 2008; Hartig et al., 2003; Tsunetsugu et al., 2013; Tyrväinen et al., 2014). Therefore, the recreational quality in the surroundings of residential areas plays an essential role in the well-being of residents. Nearby recreation means the day-to-day recreational activity of residents excluding touristic aspects. Typical for nearby recreation, people seek for recreation close to their residential home. Preferably, the recreational area should be reachable in 10 to 15 minutes on foot (Buchecker et al., 2013; Kienast et al., 2012). Assuming a mean walking speed of 4-5 km per hour, people could cover about 1000m in this time period (Bohannon, 1997). To strictly focus on nearby recreation, both supply and demand were only assessed in a range of 1000m around settlement areas. This approach assumes that people can walk without hindrance directly to the recreation area, which might not be true in every case, for example because there are no trails or because people have to cross settlement area first. In such a case people might not reach the 1000m boundary in 15 minutes. But as demand is assumed to decrease with increasing distance from settlement areas anyway, this simplification seems to be appropriate.

2.5.1. Supply

The supply of nearby recreation in Vorarlberg was assessed using different landscape elements which are considered as being relevant in this respect based on a literature review. On the one hand side, these are natural elements which are generally seen as attractive for recreational activities. On the other hand, these are infrastructural elements which provide opportunity to perform recreational activities and allow for better experience of the natural elements. Furthermore, roads are considered as a landscape element reducing the recreational potential in the surrounding area. These different elements were then specified as indicators (Table 3). The indicators were individually assessed for 1 ha grid cells on the land use map for 2016. The obtained values were then reclassified on a scale of 0 to 10 to ensure comparability of the different indicators. The highest grid cell value was attributed a 10 for each indicator. The reclassification continued in equal intervals downward to 0. One must consider that the resulting supply value is not an absolute value which can be compared to other areas than Vorarlberg. The reclassification is based on the maximum value of a specific element which is actually present in Vorarlberg, hence the maximum value might be completely different in another area.

Finally, the reclassified indicator values were summed up to a total recreational value for each grid cell. Thereby, the indicators were weighted according to a procedure developed by Buchecker et al. (2013). For indicators which are considered as particularly relevant for the recreational potential of a landscape the indicator value was multiplied by a weighting factor of 2. For roads which are considered as an indicator reducing the recreational potential a weighting factor of -1 was applied. All the other indicators were treated as being of normal relevance and weighted by a factor 1.

Because some of the landscape elements exclude each other the maximum value possible does not correspond to the sum of all the different indicator values with the respective weighting factors. For example, a 1 ha grid cell cannot have the maximum value of forest area and variety of land use types simultaneously. The possible maximum would be a final supply value of 100.

Table 3: Selection of indicators used to assess the supply of nearby recreation in Vorarlberg (based on Kienast et al., 2012; Peña et al., 2015; Schröter et al., 2014a; Szücs et al., 2015; Willemen et al., 2008). Individual weighting of the indicators based on Buchecker et al. (2013).

Indicator	**Description**	**Weighting factor**
Shores of brooks and rivers	Length of brook and river shores in m per 1 ha cell	2
Lake shores	Length of lake shores in m per 1 ha cell	2
Wetland area	Number of 10m x 10m pixels covered with wetland per 1 ha cell	1
Forest area	Number of 10m x 10m pixels covered with forest per 1 ha cell	1
Variety of land use types	Number of land use types per 1 ha cell	1
Hills	Type of elevation in 1 ha cell	1
Settlement area	Number of 10m x 10m pixels covered with settlement per 1 ha cell	1
Hiking trails	Length of hiking trails in m per 1 ha cell	2
Bike trails	Length of bike trails in m per 1 ha cell	2
Roads	Length of major roads in m per 1 ha cell	-1

2.5.2. Demand

Demand for nearby recreation was determined by two factors. First, distance from settlement area and second, the number of people living in the catchment area. These two factors were then combined to a final demand value for each of the 1 ha grid cells used for the assessment of supply.

The assessment was based on the assumption that the closer to settlement area the higher the demand for recreation. This was represented by four zones with increasing distance from settlement area (Table 4). The boundaries of the zones were set at 100m, 300m, 500m and 1000m.

In addition to distance, number of inhabitants[1] was taken in to account as a factor influencing demand for nearby recreation (Amt der Vorarlberger Landesregierung - Landesstelle für Statistik, 2017). Therefore, each municipality was categorised as either small, medium or big according to its number of inhabitants. Consequently, the demand was derived with big municipalities showing high demand and small municipalities showing low demand (Table 5).

The two factors were eventually multiplied to determine the final demand value of each 1 ha grid cell. Hence, the maximum demand value was 12 and was present in the immediate surrounding of municipalities with more than 10’000 inhabitants.

Table 4: Demand for nearby recreation as a function of distance from settlement area.

Distance from settlement area	**Demand**	**Demand value 1**
0m - 100m	very high	4
100m - 300m	high	3
300m - 500m	medium	2
500m - 1000m	low	1

Table 5: Demand for nearby recreation as a function of inhabitants per municipality.

Number of inhabitants	**Demand**	**Demand value 2**
≤ 1000 inhabitants (small)	low	1
1001 – 10’000 inhabitants (medium)	medium	2
> 10’000 inhabitants (big)	high	3

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[1] Only people with primary residence in Vorarlberg considered for the assessment

2.6. Biodiversity

Biodiversity has an essential supportive role for the provision of all ecosystem services. First, indirectly because biodiversity contributes the living elements of ecosystems in the form of plants, animals and microorganisms which compose an ecosystem. This in turn, determines which services an ecosystem can provide. Second, biodiversity directly provides ecosystem services in the form of goods such as food, construction materials or genetic resources (MA, 2005a). Still, the classification of biodiversity within the concept of ecosystem services is contested. TEEB (2010) on the one hand specified a separate category of supportive services which includes different biodiversity services in addition to provisioning, regulating and cultural services. CICES on the other hand, includes these biodiversity services in the latter three categories and does not know a separate category (Haines-Young and Potschin, 2018). Finally, the MA (2005b) does not consider biodiversity as an ecosystem service per se, but as the essential basis for the provision of all ecosystem services. In the case of biodiversity the assessment will be limited to the supply since it is not reasonable to quantify demand for biodiversity (see 4.2).

2.6.1. Supply

To assess regional biodiversity in Vorarlberg the habitat quality model of InVEST[2] was applied. InVEST models habitat quality as a proxy for biodiversity. This is based on the assumption that changes in habitat quality are representative for changes on the different levels of biological diversity which would be genetic, species or ecosystem changes (CBD, 2010). It is assumed that areas with higher habitat quality better support biodiversity and that decreases in habitat quality correlate with decline in biodiversity (Sharp et al., 2016). Habitat quality was chosen over other existing biodiversity indicators because it does not require any information about numbers or spatial distribution of species (Terrado et al., 2016). In addition, it is based on land use data which is the driver of interest of the present assessment.

Running the habitat quality model required information on land use, habitat requirements and threat sources potentially degrading a habitat type[3]. The basis for the model is a land use map indicating the different land use types present in the area of interest. Furthermore, the user needs to specify how suitable each land use type is as a habitat and how sensitive it is to degradation. In addition to the land use map there are individual maps required for each threat considered, indicating where the sources of the threat are located. Moreover, one had to define the relative impact of each threat and its effective distance (Sharp et al., 2016). The habitat quality was assessed for 10m x 10m grid cells. The habitat quality model generated two output maps. One indicating the habitat quality of the area of interest and the second one showing the degree of habitat degradation.

Species considered

In the InVEST user guide it is emphasised that the model is only suitable to predict habitat quality for specific species or species groups (Sharp et al., 2016). However, biodiversity as an ecosystem service is characterised by the interaction of many different species. In the scope of this Master thesis it would not be feasible to model habitat quality for all relevant species groups separately. Therefore, habitat quality was assessed on a general biodiversity level, meaning not for a specific species or species group. The habitat suitability values aim to represent suitability for all kinds of species. Hence, high habitat suitability indicates that a high number of different species would choose this land use type as habitat. In this case the final habitat quality value can serve as an indicator for species diversity.

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[2] InVEST version 3.4.2

[3] Additionally, it required specification of the half-saturation constant k, which was kept at the default level of 0.5

Still, one should not ignore the fact that the habitat quality hotspots might be very different when focusing on other species. To exemplify how habitat quality might differ when considering species with other habitat requirements two additional assessments were performed. One for species which prefer open grassland as their habitat and species who live in settlement areas. Hence, habitat suitability values had to be defined for each of the assessments separately (Table 8).

Threats to biodiversity

Austria's most recent national report within the Convention on Biodiversity (Tiefenbach et al., 2014) was used to determine the threats relevant for Vorarlberg. Again data availability and spatial explicitness were of crucial importance to decide whether a threat was included in the assessment or not. This is the reason why other very important threats such as climate change or invasive species were not considered in this case. The three threat sources which were included to model habitat quality with InVEST are "urbanisation", "agriculture" and "roads and railroads" (Table 6). Habitat loss due to general land use changes is already incorporated in the habitat quality model of InVEST, hence this was not considered as a specific threat source. The spatial representation of the threats "urbanisation" and "agriculture" was extracted out of the current land use map. "Roads & railroads" included communal roads, higher level roads and railroads. Table 7 specifies the characteristics of these threats.

Table 6: Description of the three selected threat sources for the InVEST habitat quality model.

Threat source	Description of threat	Spatial representation
Urbanisation	Urban areas and their ongoing expansion are seen as a major cause of habitat degradation, habitat loss and species endangerment (Czech et al., 2000). Not only, urbanisation directly replaces natural areas (Czech et al., 2000) it also changes the local biophysical environment including temperature, wind, nutrient concentration, light conditions etc. (CBD, 2012).	Any type of built-up area and sealed area (excluding roads and railroads to avoid double counting)
Agriculture	Agriculture is associated with various factors contributing to habitat degradation. This includes pollution by pesticides, soil erosion, nutrient loading, particularly of nitrogen and phosphorus, intensive livestock grazing, change of the hydrological regime by irrigation etc. (Czech et al., 2000; CBD, 2006).	Land use type "arable land"
Roads & railroads	Roads and railroads contribute to species endangerment through automobiles overrunning crossing animals. Road and railroad construction and maintenance are associated with frequent disturbances and the use of chemicals such as salt which contribute to habitat degradation (Czech et al., 2000). Furthermore, roads and railroads cause fragmentation of habitats. Fragmentation leads to decreased patch size, isolation of populations and increase of patch perimeter to area ratio. The latter increases the habitat's exposition to negative effects from neighbouring areas, so called edge-effects (Coyner, 2008; Marcantonio et al., 2013).	Communal roads, higher level roads and railroads

Table 7: Characteristics of threat sources required for the InVEST habitat quality model based on Polasky et al. (2011), Sallustio et al. (2017) and Terrado et al. (2016).

Threat	Maximum distance [km]	Relative impact	Decay
Urbanisation	4	0.9	exponential
Agriculture	3	0.7	exponential
Roads & railroads	2	0.7	exponential

The threat characteristics were considered as equal for the general biodiversity assessment and the two species group assessments. This is the reason why degradation was the same for all of the three assessments.

Data on biodiversity threats and habitats

The values of habitat suitability and their sensitivity to the different biodiversity threats (Table 8) as well as the threat data (Table 7) were determined based on published studies which applied the habitat quality model of InVEST (Polasky et al., 2011; Sallustio et al., 2017; Terrado et al., 2016).

Table 8: Habitat suitability and sensitivity data required for the InVEST habitat quality model adapted from on Polasky et al. (2011), Sallustio et al. (2017) and Terrado et al. (2016).

Land use type	**Habitat suitability**			**Sensitivity to threats**		
	General biodiversity	*Grassland species*	*Settlement areas*	*Urbanisation*	*Agriculture*	*Roads & railroads*
Built-up: residential areas, one family houses	0.1	0.1	0.5	0	0	0
Built-up: residential areas, 2-more family houses; hotels and pensions	0.1	0.1	0.5	0	0	0
Built-up: farms and related buildings	0.1	0.1	0.6	0	0	0
Built-up: industrial and warehouse buildings	0.1	0.1	0.1	0	0	0
Built-up: “Freifläche Sondergebiet”, shops and shopping malls	0.1	0.1	0.1	0	0	0
Industrial, operational areas	0.1	0.1	0.1	0	0	0
Roads and railroads	0.1	0.1	0.1	0	0	0
Mining and waste sites	0.1	0.1	0.1	0	0	0
Gardens and urban green areas	0.4	0.4	0.9	0.3	0.2	0.3
Parks and sport areas	0.4	0.4	0.6	0.3	0.2	0.3
Arable land	0.3	0.3	0.3	0.6	0	0.5
Orchards and vineyards	0.5	0.5	0.6	0.6	0.2	0.5
Meadows and pastures	0.5	0.9	0.3	0.6	0.2	0.5
Forest	0.9	0.2	0.3	0.8	0.7	0.7
Natural grassland, Alps	0.8	0.9	0.3	0.7	0.7	0.6
Bare lands	0.3	0.3	0.3	0.3	0.3	0.3
Wetland	0.9	0.4	0.3	0.8	0.7	0.7
Rivers and channels	0.6	0.1	0.1	0.5	0.5	0.4
Water bodies	0.6	0.1	0.1	0.5	0.5	0.4

2.7. Future development of supply and demand

In general, the future assessment of supply and demand followed the same procedure as described above for the current assessment. Instead of the land use map of 2016 the future land use maps based on the land use scenarios “trend” and ”competition” were used. The future land use maps were used to regenerate the required input data where projections were available. For nearby recreation supply the indicators “forest area”, “variety of land use types” and “settlement area” could be generated based on the projections for 2050. For the biodiversity assessment the threat sources “urbanisation” and “agriculture” could be regenerated for 2050. Regarding input data additional to land use data projections for 2050 were available only for the population numbers, which were required for the assessment of recreation demand. The projections were developed by the Österreichische Raumordnungkonferenz (ÖROK) and predict a population increase of 6.6% in Vorarlberg (Hanika, 2010). This increase was assumed to be distributed equally over the different municipalities. Based on these projections the municipalities were again categorised as either small, medium or big. Other additional input data which was data on inundation areas for the assessment of flood protection demand and data on habitat suitability, sensitivity to threats and threat characteristics for the biodiversity assessment was assumed to be stable over time.

2.8. Spatial and temporal analysis of ecosystem service supply and demand

In a final step, supply and demand of flood protection, nearby recreation and biodiversity were compared in 2016 as well as in the two future scenarios to identify areas where supply does not meet the respective demand. Furthermore, the potential future development of all the three services was analysed to determine where supply and demand might increase or decrease, respectively. To compare the 2016 values with the projected 2050 values the different maps of supply and demand for each service were subtracted from each other. Thus, increases or decreases in supply or demand could be easily identified.

As Vorarlberg is a mountainous region, it was of interest how supply and demand were distributed spatially across different elevational ranges. Frank and Burkhard (2017) state that elevation has a significant effect on the provision of ecosystem services. Therefore, the area of Vorarlberg was divided into 100m elevation strata. Supply and demand of each ecosystem service were subsequently assessed for each stratum separately using the zonal statistics tool of ArcGIS.

Flood protection

In the case of flood protection, supply and demand were compared by subtracting the supply value from the demand value in each 10m x 10m grid cell to get a delta value (Burkhard et al., 2012). This was possible because the same 0 to 5 scale was applied for both supply and demand. Wherever the difference between supply and demand was negative, demand exceeded supply, indicating an undersupply. Where the difference was zero or positive, supply met or exceeded demand, respectively.

Nearby recreation

In the case of nearby recreation, supply and demand could not be compared in the same way as flood protection because the values were assessed using different scales, making it difficult to compare supply and demand. Hence, it was not possible to subtract supply values from demand values and calculate a delta value. Anyhow, the supply value in each of the demand zones around settlement areas was of special interest to see whether areas of high demand coincide with areas of high supply. Again, the zonal statistics tool of ArcGIS was applied for the analysis. As a result tables listing the mean supply value of each demand zone were obtained.

Biodiversity

Since the biodiversity assessment was limited to the assessment of supply, a comparison with demand was omitted. Instead, the output maps for supply were compared qualitatively.

Spatial trade-offs and synergies among ecosystem services

Conflict areas or areas of special value were identified in order to derive policy-relevant statements. More precisely, the following areas were identified:

- Areas of high value for both humans and biodiversity (high[4] supply of nearby recreation and flood protection and high habitat quality) to see which areas are of particular relevance in terms of ecosystem service provision.
- Areas of high pressure on biodiversity (high demand for nearby recreation and/or unmet demand for flood protection and high habitat quality) to see where high demand for ecosystem services from society might have negative impacts on biodiversity.

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[4] As high supply or high demand the top 25% of the respective values were considered (top quartile)

3. Results

3.1. Current state and future development of ecosystem services

To answer research questions 2 and 3 the results of the ecosystem services assessment for 2016 and the two future scenarios “trend” and ”competition” will be presented for each of the services of interest.

3.1.1. Flood protection

The assessment of flood protection in Vorarlberg showed that most areas provided flood protection at least to some degree (Fig. 4). Only few areas (6.7% of the total area) where the land use was dominated by built-up area did not provide any flood protection. However, the degree of flood protection was rather low, with no areas providing high or very high supply. The mean supply value was 1.68 (Table 9). In contrast, there were only very few areas (1.2% of the total area) with demand for flood protection (Fig. 5). The most sensitive land use types to flood damages encompassed all categories related to infrastructure (built-up areas, roads and railroads), located predominantly at lower elevations. Land types with low sensitivity to floods included agriculturally used open-land areas (arable land, meadows and pastures) and mining and waste sites. The remaining land types were not sensitive to flood events. Where these sensitive land use types coincided with statistical inundation areas, demand for flood protection was identified (Fig. 5). The mean demand value was 0.0176, thus considerably lower than the mean supply value (Table 9), indicating that total demand for flood protection across the region of Vorarlberg was low.
Calculating the differences between supply and demand for flood protection revealed that supply met demand almost everywhere (99.8% of the total area; Fig. 6). Because of the lack of supply values of 4 and 5, not the full range of delta values from -5 to 5 was obtained. The maximum positive delta value was 3. Due to the specific combinations of demand and supply values for each land use type there was no delta value of -3 and -1 either. On an area of 5.01 km^2 (0.19% of total area) demand exceeded the supply for flood events with a recurring period of 100 years (Fig. 6). These areas were all located at low elevations. The mean delta value was 1.67, so there was almost no difference to the mean supply value (Table 9).

Concerning the future development both land use scenarios projected an increase of areas providing no flood protection (trend scenario: +5.4%, competition scenario: +6.4%). These areas are still primarily located at low elevations. However, more areas will provide medium supply and less areas low supply (Fig. 3). The projected mean supply values increased by 3.6% for the trend scenario and by 5.3% for the competition scenario (Table 9). On the demand side, the total area of demand was projected to slightly decrease (trend scenario: -0.6 km^2, competition scenario: -1.3 km^2), but areas of high (trend scenario: +7.7%, competition scenario: +6.3%) and very high demand (trend scenario: +16.9%, competition scenario: +29.7%) were projected to grow substantially. The trend scenarios projected a mean demand value of 0.0179 and the competition a mean value of 0.0177. Finally, both scenarios projected an increase of areas with demand exceeding supply. The trend scenario predicted a total area with negative delta values of 5.45 km^2 (+8.8%) and the competition scenario an area of 5.46 km^2 (+9.0%). Although the area of negative delta values was predicted to increase, in most of the grid cells delta values are increasing (Fig. 8 &Fig. 9). The projected mean delta values were 1.72 for the trend scenario and 1.76 for the competition scenario, so again almost as high as mean supply values.
Differences in the predictions of the two scenarios were only minimal and spatially widely distributed (Fig. 10). However, it is surprising that the trend scenario projected a higher increase in demand than

the competition scenario since the latter is characterised by urbanisation and assumed higher increases in built-up area (+15.8% vs. +11.6%), which is sensitive to floods. However, these increases seem to occur in areas outside inundation zones.

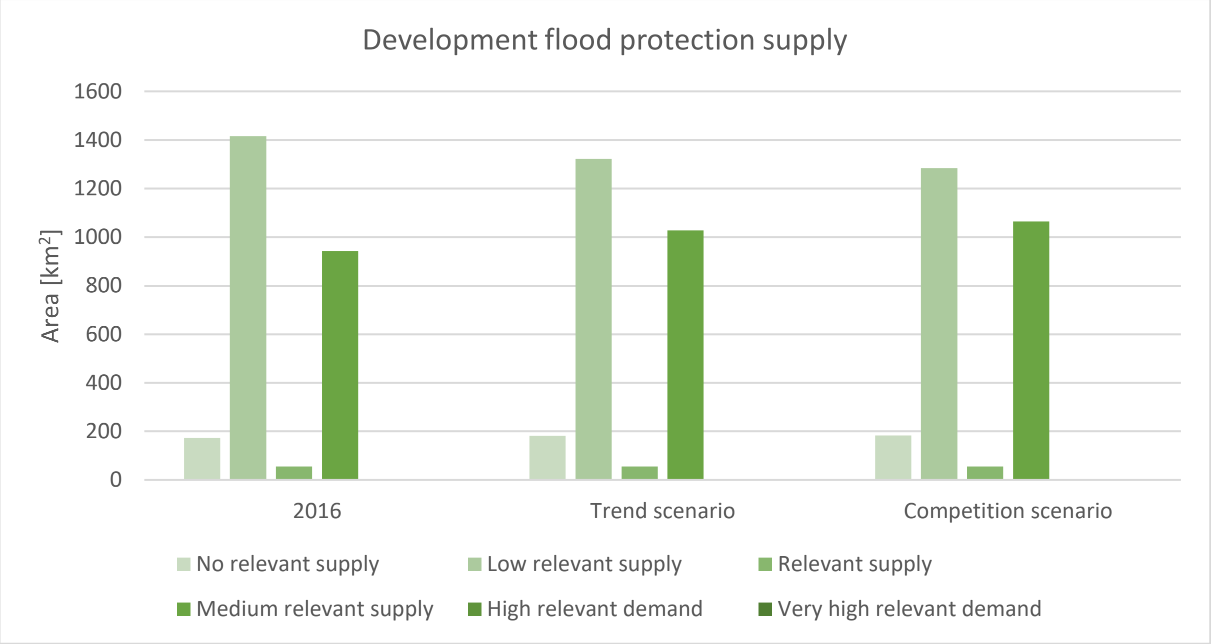

Fig. 3: Development of flood protection supply in Vorarlberg for two future scenarios (trend & competition). Categorisation based on Burkhard et al. (2009).

Table 9: Mean supply, demand and delta values and their respective ranges for flood protection in Vorarlberg for 2016 and two future scenarios (trend & competition). The number in brackets indicates the percentage of change relative to the 2016 value.

	2016	**2050 (Trend scenario)**	**2050 (Competition scenario)**
Mean supply value [Range]	1.68 [0 - 3]	1.75 (+3.6%) [0 - 3]	1.77 (+5.3%) [0 - 3]
Mean demand value [Range]	0.0176 [0 - 5]	0.0179 (+1.7%) [0 - 5]	0.0177 (+0.6%) [0 - 5]
Mean delta value [Range]	1.67 [-5 - 3]	1.72 (+3.6%) [-5 - 3]	1.76 (+5.3%) [-5 - 3]

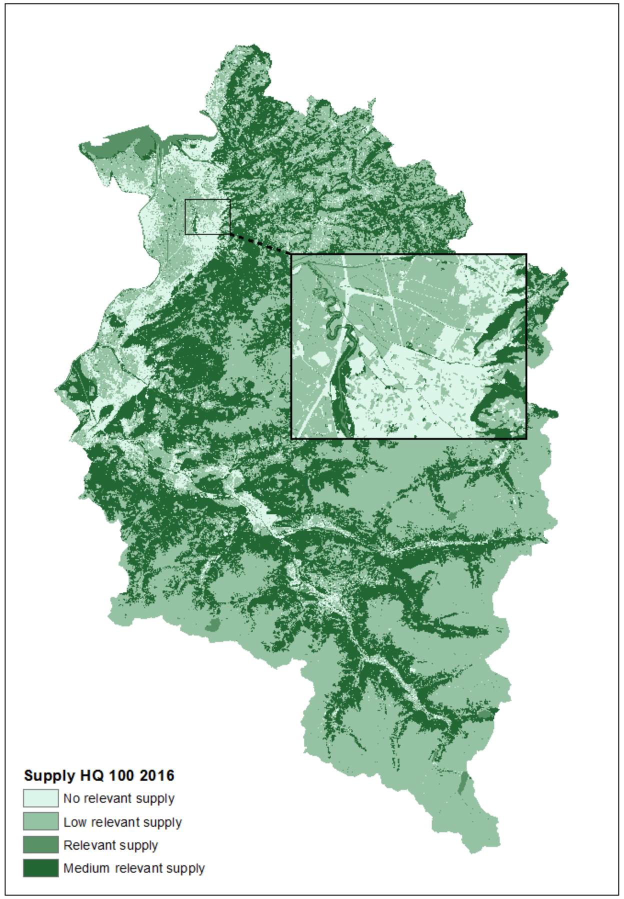

Fig. 4: Supply of flood protection in Vorarlberg 2016.

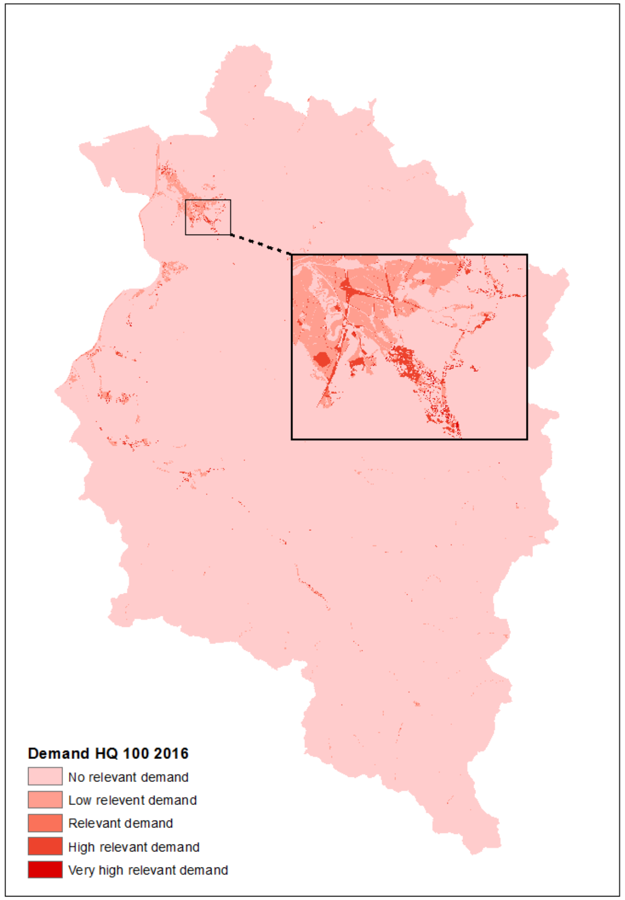

Fig. 5: Demand for flood protection in Vorarlberg 2016 for 100-year floods.

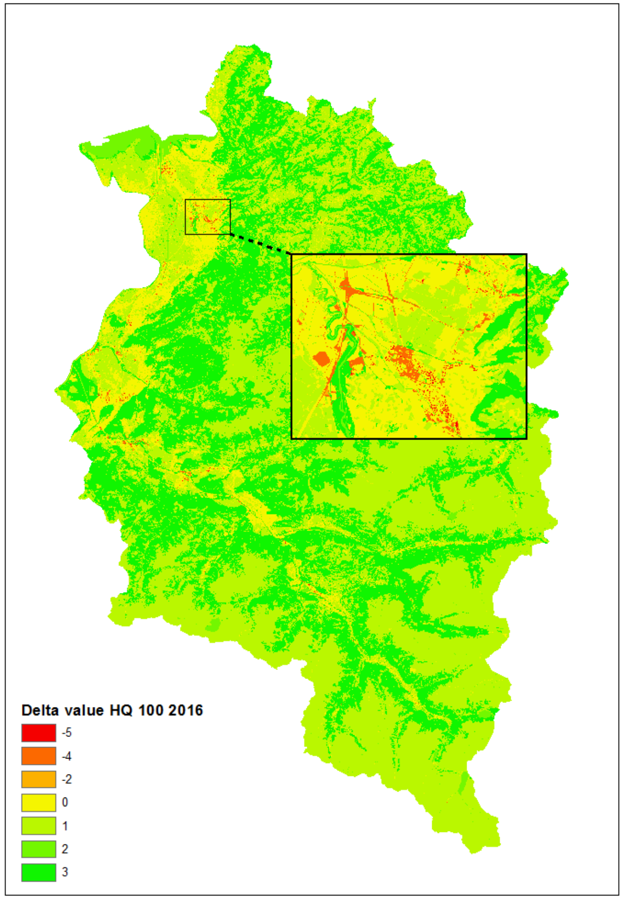

Fig. 6: Delta values of flood protection in Vorarlberg 2016 for 100-year floods.

Setting these results in relation to elevation showed that the mean differences were never negative on any of the 100 m elevation strata for 2016 and both future scenarios (Fig. 7). This means that in total supply could offset demand in each elevation stratum and undersupply occurred only locally. The analysis highlights the fact that demand for flood protection dominates at low elevation areas, peaking at 500 m a.s.l. Above 800 m a.s.l. demand values became insignificantly low. On the contrary, mean supply values were greater at higher elevation areas with a peak at 1300 m a.s.l. in 2016 and 1200 m a.s.l. in 2050. However, in areas above 2000 m a.s.l. supply values became low again, eventually decreasing to the value 1.

Generally, the future projections showed a distribution of values very similar to 2016. However, mean supply and delta values were projected to be higher in 2050 according to both scenarios, with the competition scenario predicting the highest values. Projected demand values were almost identical to 2016.

Fig. 7: Mean supply, demand and delta values of flood protection as a function of elevation for 2016 and two future scenarios (trend & competition) plus the respective minimum and maximum values. Minimum and maximum values were identical across all elevation strata for 2016 and both future scenarios. Maximum delta values interfere with maximum supply values and minimum demand values interfere with minimum supply values, hence not all the lines are visible.

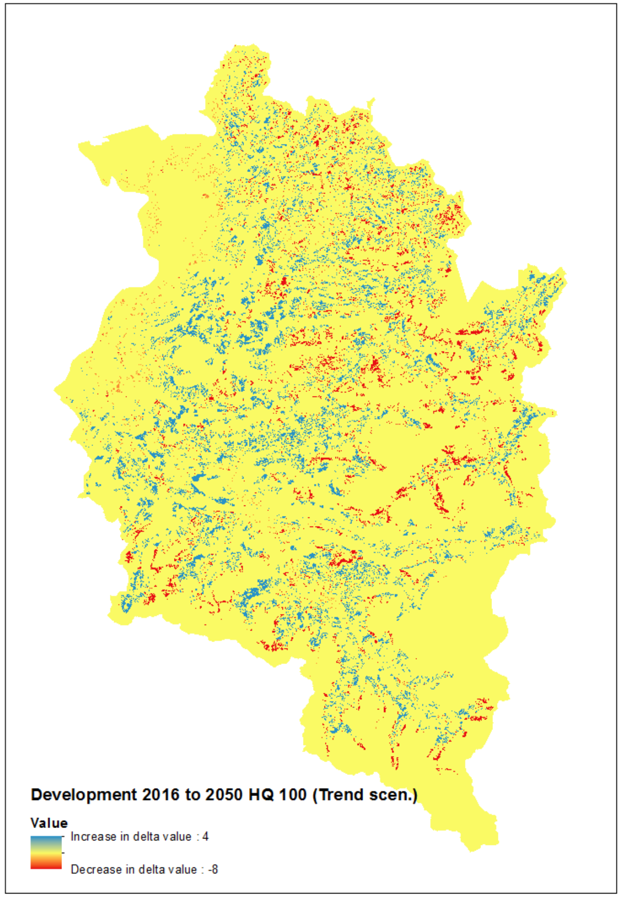

Fig. 8: Development of delta values between supply and demand of flood protection in Vorarlberg from 2016 to 2050 according to the trend scenario.

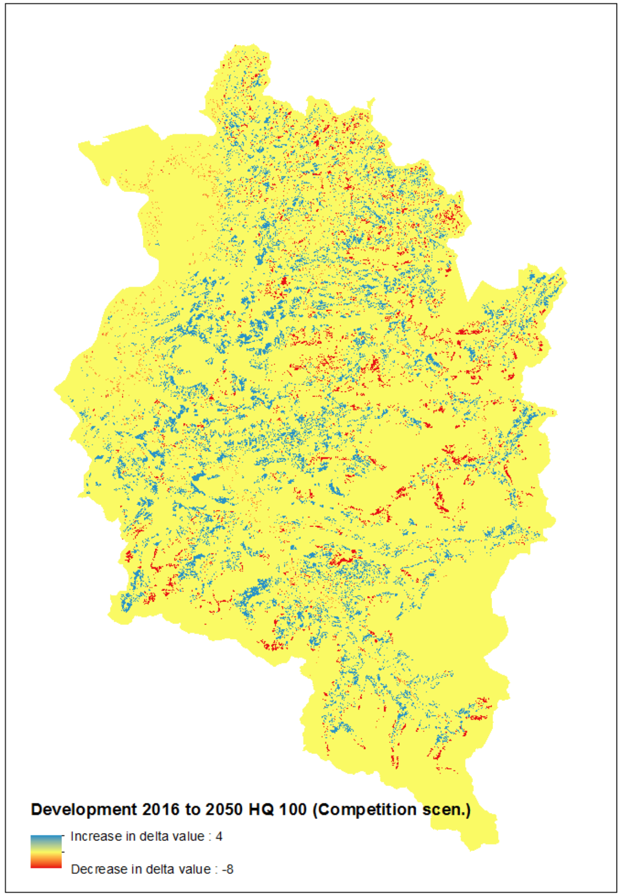

Fig. 9: Development of delta values between supply and demand of flood protection in Vorarlberg from 2016 to 2050 according to the competition scenario.

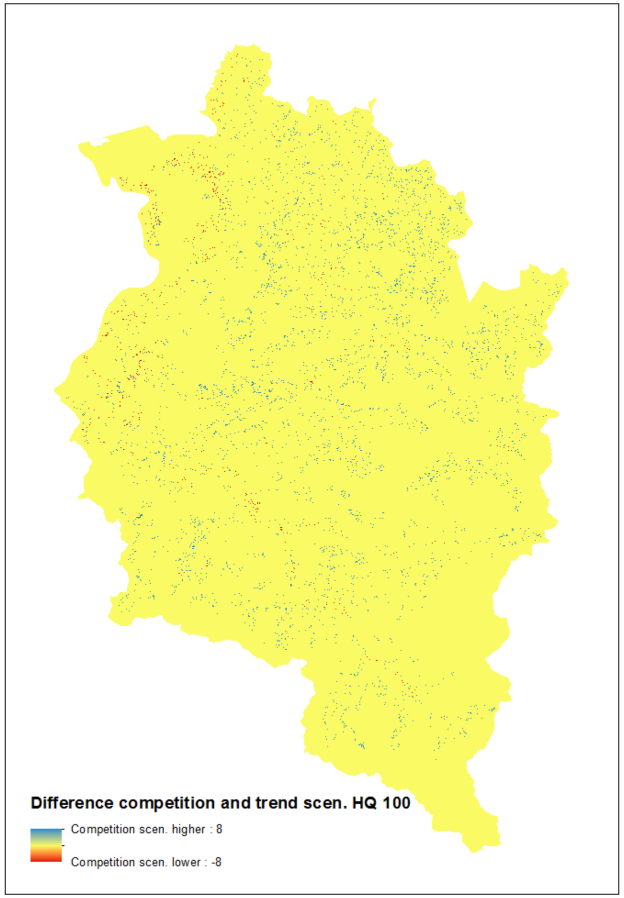

Fig. 10: Differences in the projections of delta values for Vorarlberg 2050 between the trend scenario and the competition scenario.

3.1.2. Nearby recreation

The assessment of nearby recreation showed a high spatial variability of recreational supply (Fig. 11). However, there was a distinct pattern with high supply values often following linear elements such as brooks or rivers. Low supply values were primarily located in lowland areas with dense road networks and a lot of agricultural areas. But not only in lowland areas, but also in higher elevation areas supply values were low because of missing landscape variety and attractive elements such as forest. The maximum supply value was 46 and the mean value of supply all over the assessed area of Vorarlberg was 12.08 (Table 10). There were also areas with negative supply values because of high disturbance levels through roads (minimum value: -4).

Regarding recreational demand there were obvious hotspots around municipalities with high population numbers for example Dornbirn, Feldkirch or Bregenz (Fig. 12). These hotspots were located in lowland areas. At the same time, there were areas with very low demand for recreation because they are less populated, such as the Grosses Walsertal in the centre of Vorarlberg. In 28% of the area there was no demand for nearby recreation since the distance from settlement areas was greater than 1000m. The mean demand value was 3.40 (Table 10). The zonal statistics assessment of supply per demand zone revealed that mean supply values were the highest (13.4 in 2016) in areas with demand value 3 and slightly lower (12.2 in 2016) in areas with maximum demand (Fig. 13). Hence, residents of large municipalities might have to cover longer distances in order to satisfy their recreational demand.

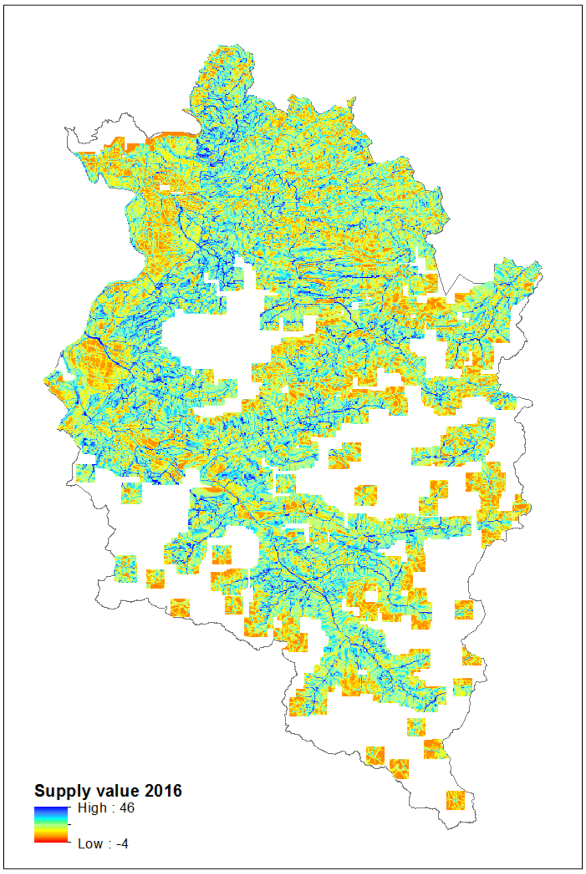

Fig. 11: Supply value of nearby recreation in Vorarlberg 2016.

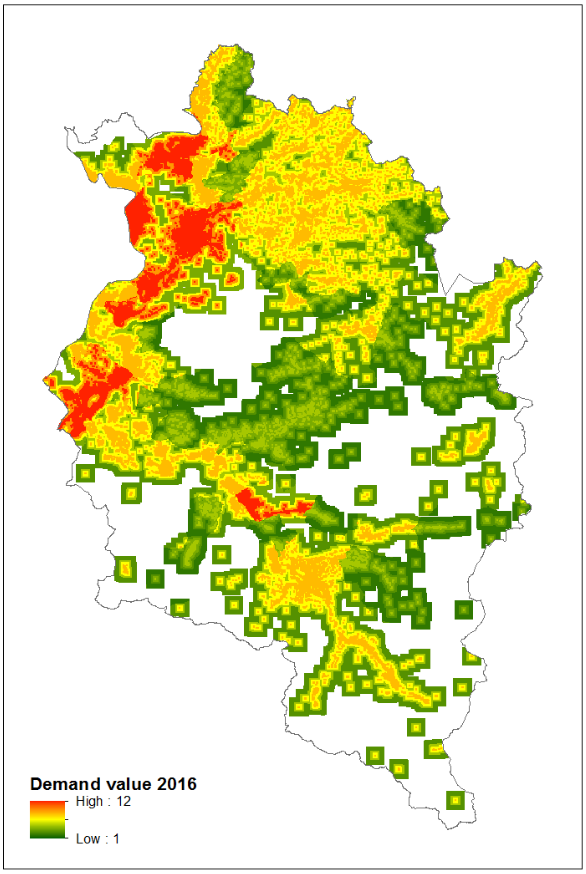

Fig. 12: Demand value for nearby recreation in Vorarlberg 2016.

The future assessment of recreation supply projected an increase of supply for both land change scenarios. For both scenarios, the maximum and mean supply values were predicted to be higher in 2050 than 2016 (Table 10). The trend scenario projected the mean value to increase by 3.0% whereas the competition scenario projected an increase of 11.6%. This considerable difference between the projections of the two scenarios is probably due to the fact that settlement areas, which were considered as positive elements for nearby recreation, are expected to expand significantly more in the competition scenario than in the trend scenario. The mean supply values per demand area were projected to increase for both scenarios (Fig. 13). In terms of spatial development the biggest changes in service supply were expected to occur in forested areas. Hardly any changes were projected for the Rhine valley. Differences in projections between trend and competition scenario were only marginal (Fig. 15 &Fig. 16).

Future demand for nearby recreation is expected to slightly increase (+1.2% for both scenarios). In particular, there are two municipalities where demand was projected to grow because population numbers increase so they are classified as medium rather than small municipalities (Innerbraz and Schoppernau). Other than that, there are only minimal changes in demand. Again, there were almost no differences in projections of the trend scenario and the competition scenario (Fig. 17 &Fig. 18).

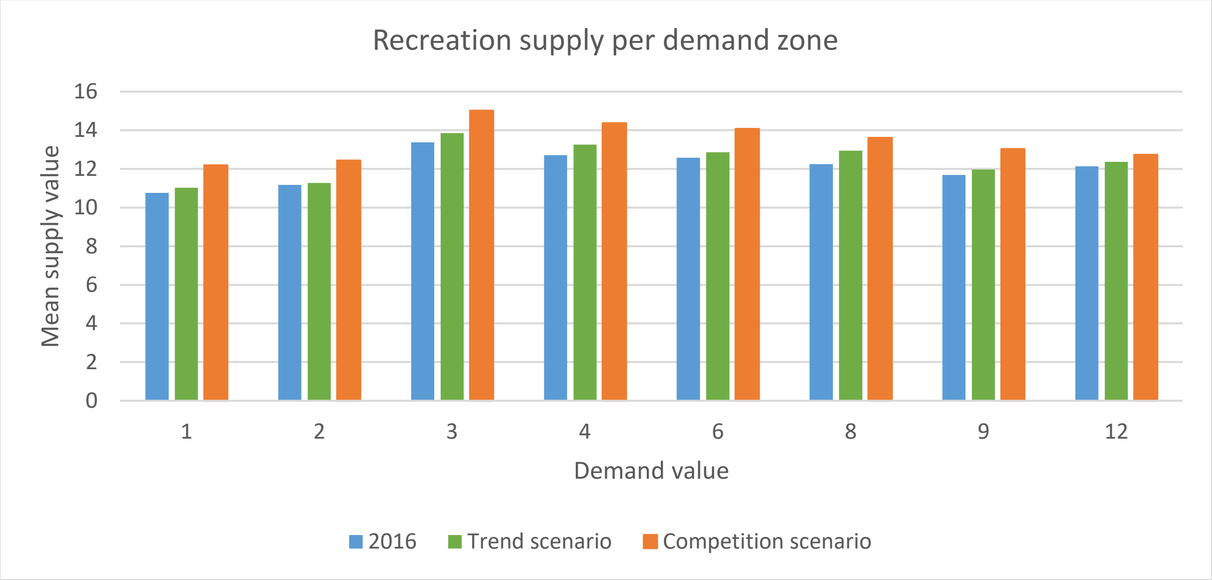

Fig. 13: Mean supply value of nearby recreation in Vorarlberg per demand area in a distance of 1000 m around municipalities.

Table 10: Mean supply and demand values and their respective ranges for nearby recreation in Vorarlberg for 2016 and two future scenarios (trend & competition). The number in brackets indicates the percentage of change relative to the 2016 value.

	2016	**2050 (Trend scenario)**	**2050 (Competition scenario)**
Mean supply value	12.08	12.44 (+3.0%)	13.48 (+11.6%)
[Range]	[-4 - 46]	[-4 - 48]	[-3 - 48]
Mean demand value	3.400	3.440 (+1.2%)	3.441 (+1.2%)
[Range]	[0 - 12]	[0 - 12]	[0 - 12]

The analysis of nearby recreation in dependence of elevation revealed a distinct pattern for mean supply and demand values. While mean supply values reached their maximum at around 1000 m a.s.l. in 2016 and 1200 m a.s.l. in 2050 mean demand values peaked at 500 m a.s.l, so at significantly lower elevation. Above 3000 m a.s.l. there was no more supply or demand of nearby recreation at all because there were no more settlements (Fig. 14). Maximum supply and demand values showed a similar tendency with decreasing maximum values as elevation increased. However, supply showed an unexpected course above 2600 m a.s.l. with again increasing mean values. There were only very few areas with relevance for nearby recreation above this level because of the low population density, so mean values were determined by a small number of grid cells. Therefore, this values might be less representative than supply values in lower-elevation areas.

Minimum supply values were mainly close to 0 or below. Negative supply values were identified primarily in areas below 1200 m a.s.l. and again around 1800 m a.s.l. Minimum demand values were 0 across all elevation strata.

Generally, minimum and maximum values of both supply and demand predicted by the future scenarios were very similar to 2016. Mean future supply values were projected to be higher than 2016, especially above 800 m a.s.l. Future projections of mean demand values were only slightly higher than 2016 values.

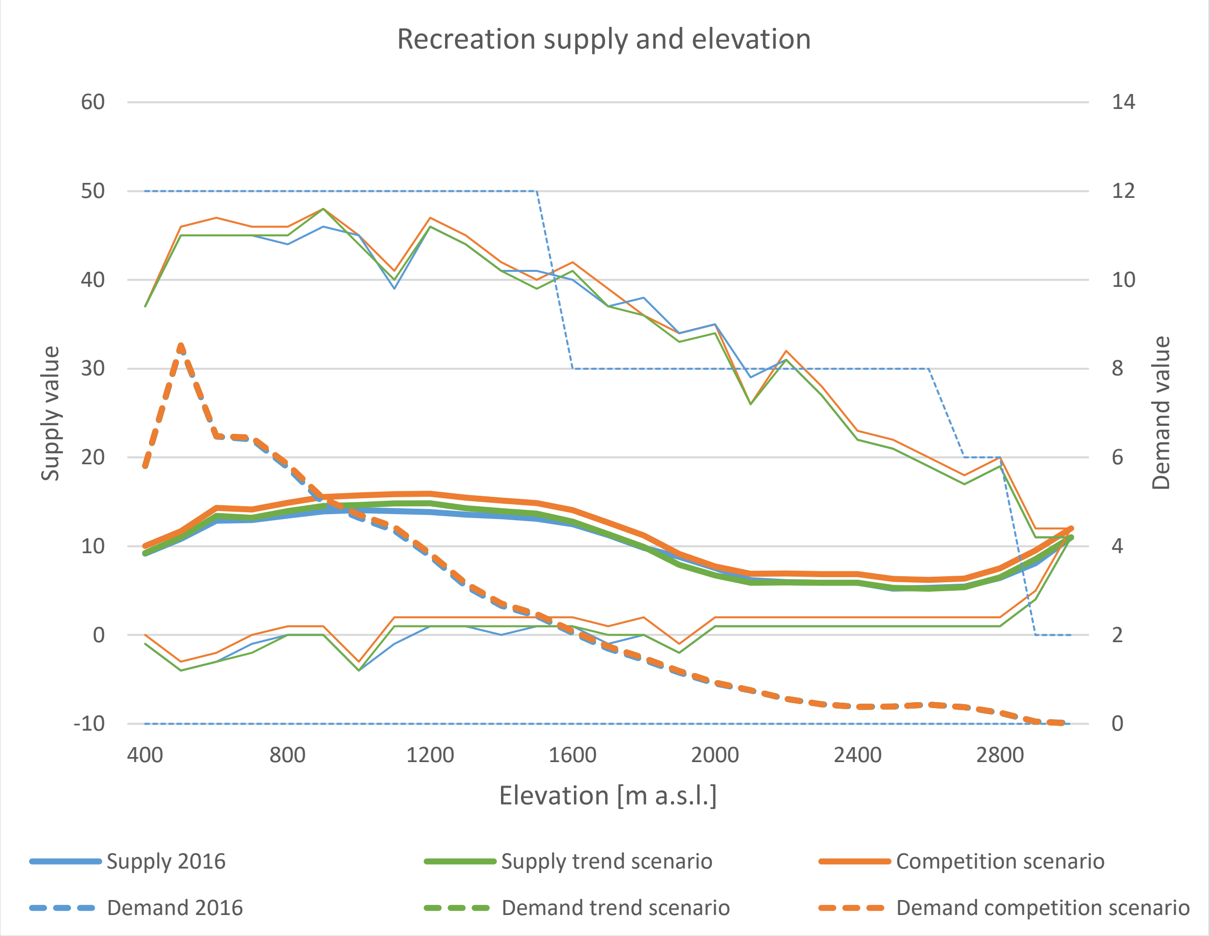

Fig. 14: Supply and demand of nearby recreation for 2016 and two future scenarios (trend & competition) as a function of elevation. Thick lines indicate the mean value and thin lines the minimum and maximum value, respectively.

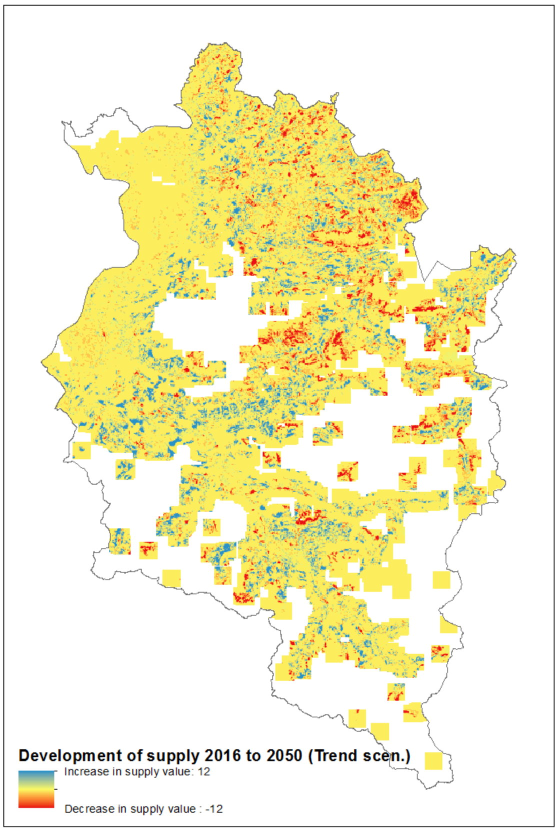

Fig. 15: Development of supply for nearby recreation in Vorarlberg from 2016 to 2050 according to the trend scenario.

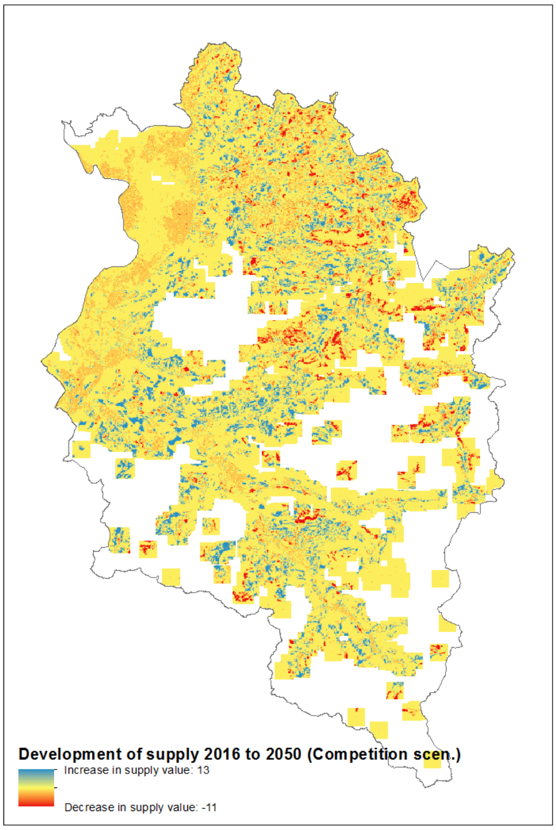

Fig. 16: Development of supply of nearby recreation in Vorarlberg from 2016 to 2050 according to the competition scenario.

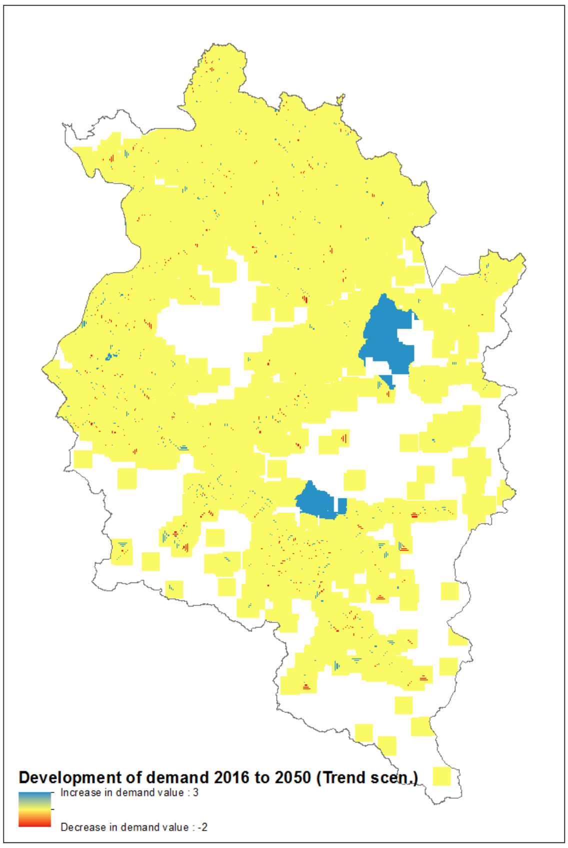

Fig. 17: Development of demand for nearby recreation in Vorarlberg from 2016 to 2050 according to the trend scenario.

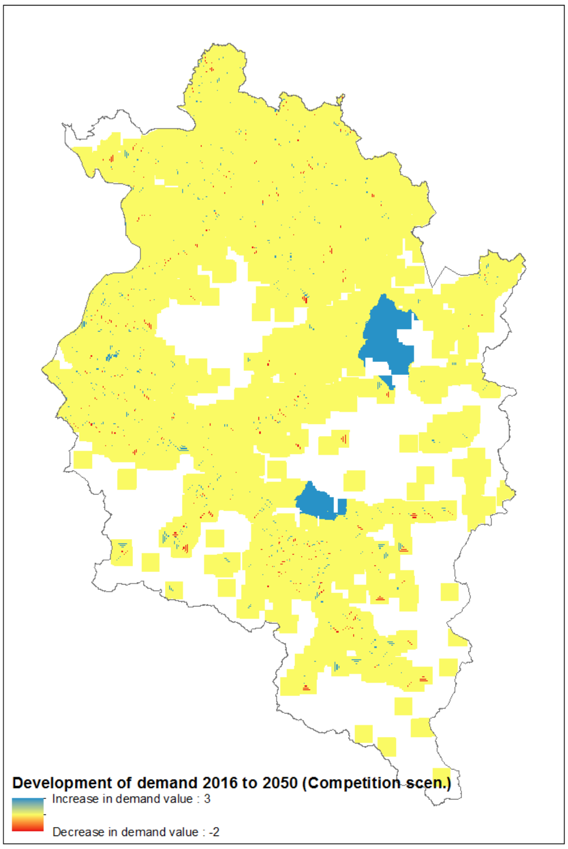

Fig. 18: Development of demand for nearby recreation in Vorarlberg from 2016 to 2050 according to the competition scenario.

3.1.3. Biodiversity

The assessment of biodiversity using the InVEST habitat quality model revealed that results differ a lot depending on the species group considered. For the general biodiversity assessment where forests together with wetlands were considered as the land use type with the highest habitat suitability, habitat quality hotspots were evidently located in forested areas (Fig. 19). Areas with low habitat quality were located primarily in the settlement and agricultural areas. The value distribution showed that most grid cells were only minimally degraded with a peak around the initial habitat suitability value and only a few grid cells with lower habitat quality (Fig. 23).

For species who prefer open grassland as their habitat the habitat quality hotspots were either in higher elevation areas or on meadows and pastures in the lowlands (Fig. 20). Forest areas were of rather low habitat quality for these species. And for settlement species the habitat quality hotspot were obviously located in the gardens and urban green areas of settlement areas (Fig. 21). For this species group habitat quality was particularly low in industrial areas or on roads and railroads.

The habitat degradation map showed a clear pattern (Fig. 22). Degradation was the highest in the Rhine valley and was decreasing with increasing distance from the valley. However, the degradation sources themselves such as roads and buildings were not considered as degraded. Hence, they stood out as non-degraded elements within areas of high degradation.

The future assessment of Vorarlberg projected a slight increase of habitat quality for both scenarios (Table 11). The trend scenario predicted an increase of mean habitat quality of 1.1% and the competition scenario an increase of 2.5%. Minimum and maximum habitat quality values were expected to remain constant. The distribution of habitat quality values was almost identical to 2016 (Fig. 23).

However, habitat degradation was expected to increase as well, 5.9% in case of the trend scenario and 6.5% in case of the competition scenario. Furthermore, maximum degradation values were projected to be higher than 2016 (trend scenario: +7.3%, competition scenario: +4.9%).

Table 11: Mean habitat quality and degradation values and their respective ranges for general biodiversity in Vorarlberg for 2016 and two future scenarios (trend & competition). The number in brackets indicates the percentage of change relative to the 2016 value.

	2016	**2050 (Trend scenario)**	**2050 (Competition scenario)**
Mean habitat quality	0.617	0.624 (+1.1%)	0.632 (+2.5%)
[Range]	[0.100 - 0.899]	[0.100 - 0.899]	[0.100 - 0.899]
Mean habitat degradation	0.00707	0.00749 (+5.9%)	0.00753 (+6.5%)
[Range]	[0 - 0.02947]	[0 - 0.03162]	[0 - 0.03090]

Regarding the spatial development the main increases in habitat quality were expected to occur in forested areas. The main decreases in quality were projected to happen in higher elevation areas or close to settlement areas. The differences between the projections of the two scenarios were not pronounced. The changes were expected to occur in the same areas and in the same directions with negative changes being slightly more extensive in the trend scenario (Fig. 25 &Fig. 26). Habitat degradation was expected to further increase especially in and around the Rhine valley (Fig. 27 &Fig. 28).

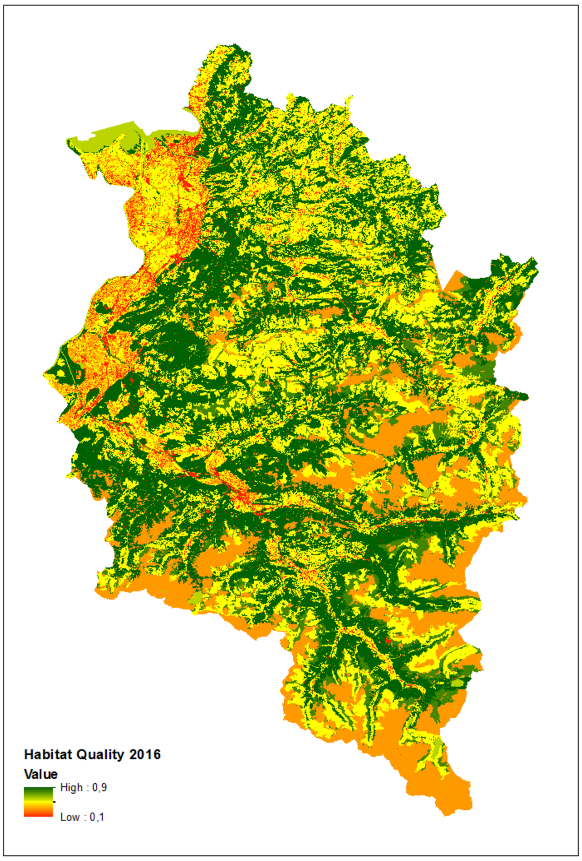

Fig. 19: Habitat quality in Vorarlberg 2016 for biodiversity in general.

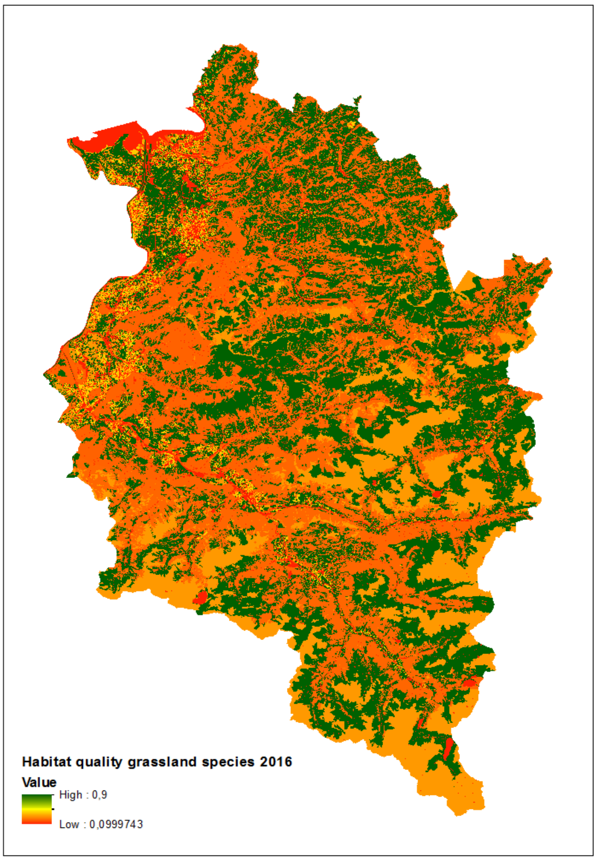

Fig. 20: Habitat quality in Vorarlberg 2016 for grassland species.

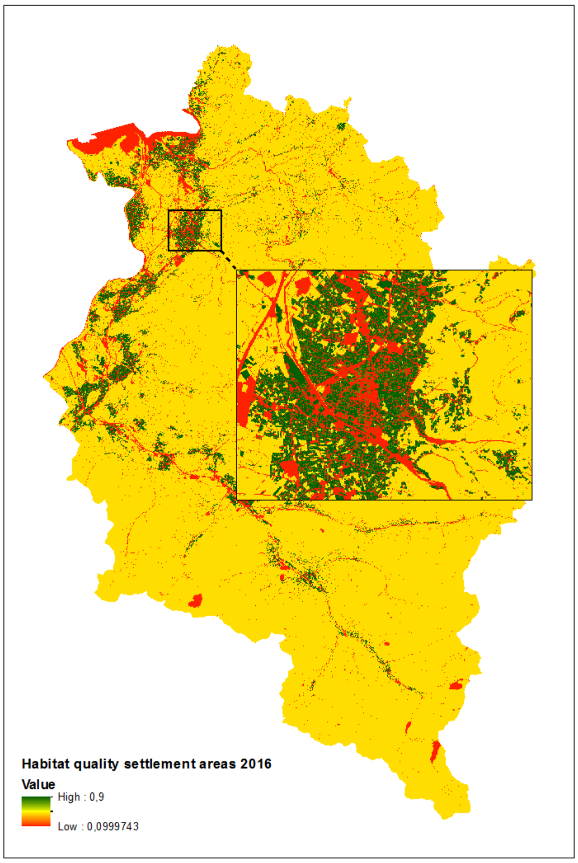

Fig. 21: Habitat quality in Vorarlberg 2016 for settlement species.

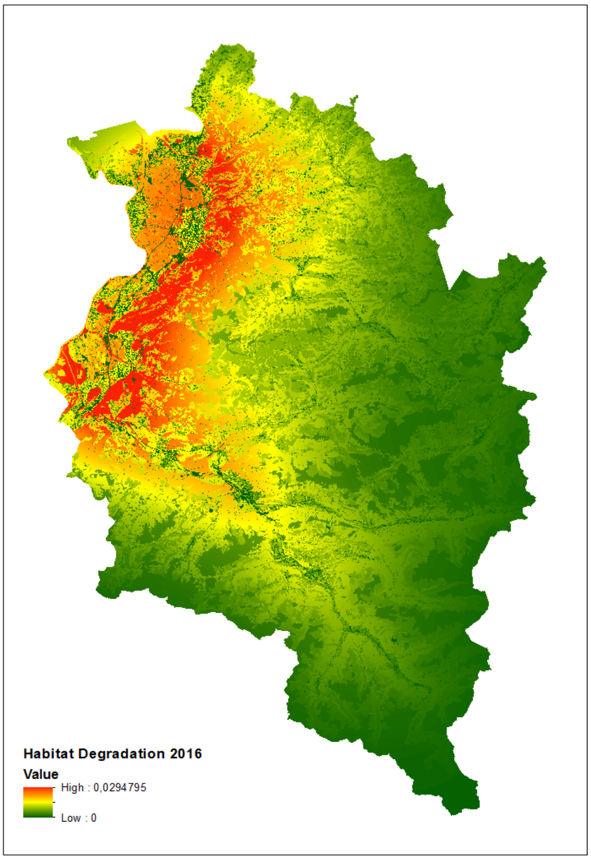

Fig. 22: Habitat degradation in Vorarlberg 2016 based on the degradation sources “urbanisation”, “agriculture” and “roads and railroads”.

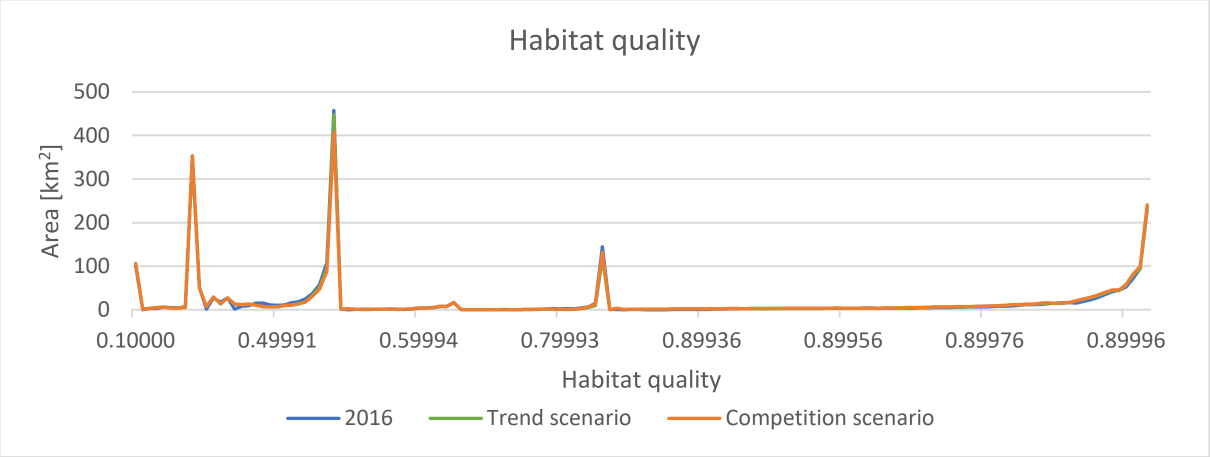

Fig. 23: Distribution of habitat quality values in Vorarlberg for 2016 and two future scenarios (trend & competition).

The analysis of habitat quality and degradation in dependence of elevation showed that the peak of mean habitat quality was located at 1300 m a.s.l. in 2016 and at around 1200 m a.s.l. in 2050 (Fig. 24). From there it was decreasing to a mean value of 0.3 at 2600 m a.s.l. and above. Maximum habitat quality values of 0.9 were identified across all elevation strata until 2300 m a.s.l. in 2050 and 2400 m a.s.l. in 2016, respectively. Above this level, maximum quality decreased rapidly. Minimum mean habitat quality was identified at 500 m a.s.l. Minimum habitat quality never fell below 0.1.
Mean habitat degradation in contrast, was highest at 600 m a.s.l. and from there gradually decreasing to almost 0 at 3300 m a.s.l. Maximum degradation values showed a similar distribution as the mean values but about 3-4 times as high. Minimum degradation values of 0 were identified across all elevation strata, meaning that also in low elevation areas there existed un-degraded habitats.

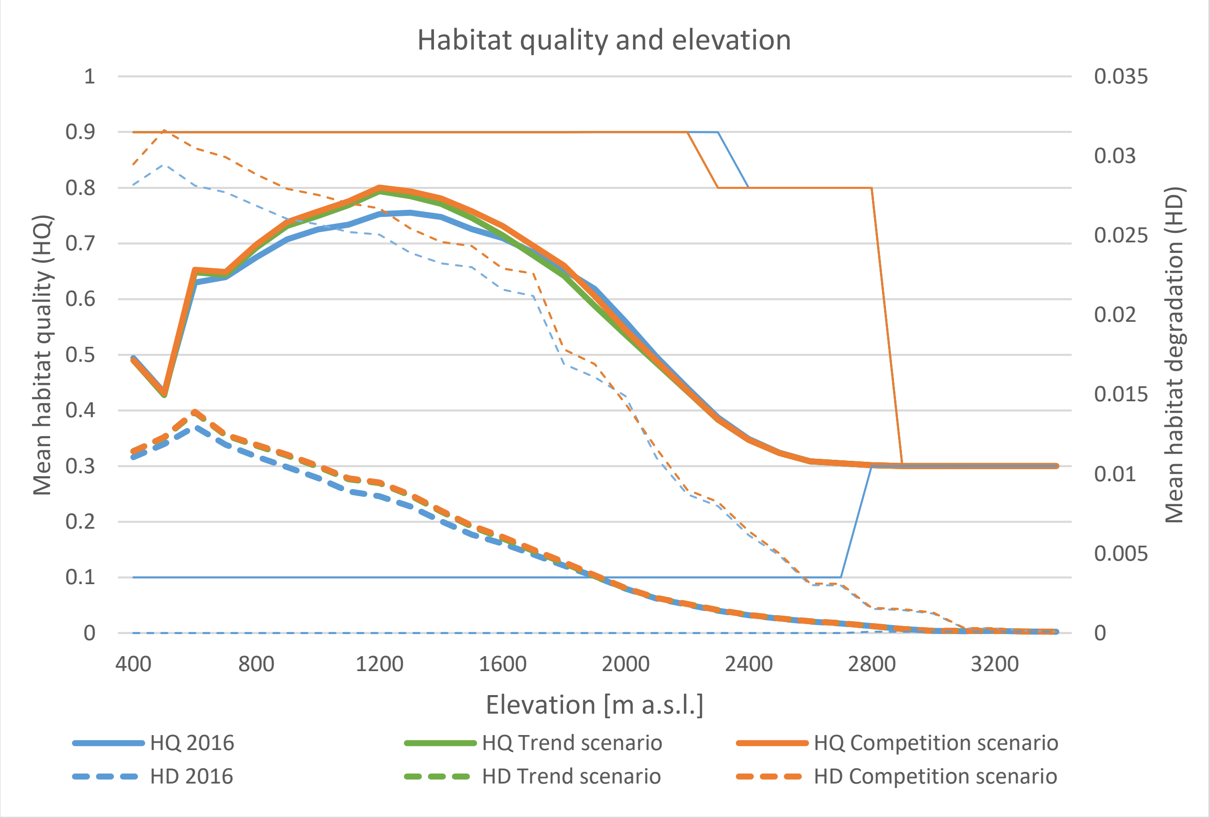

Fig. 24: Habitat quality (HQ; solid lines) and habitat degradation (HD; dashed lines) for 2016 and two future scenarios (trend & competition) as a function of elevation plus the respective minimum and maximum values.

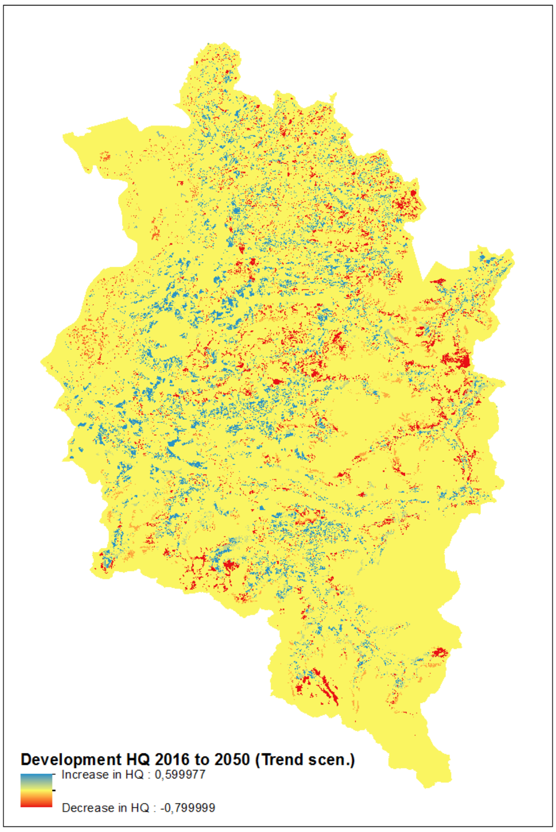

Fig. 25: Development of habitat quality (HQ) in Vorarlberg from 2016 to 2050 according to the trend scenario.

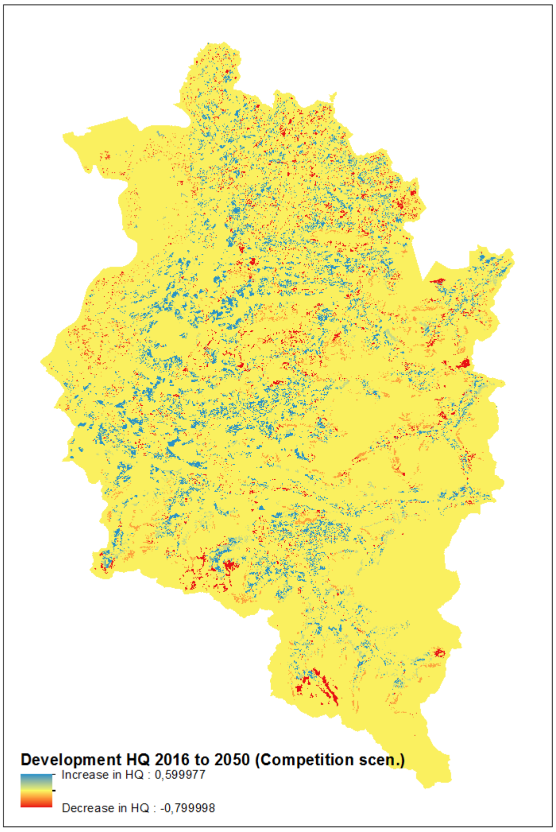

Fig. 26: Development of habitat quality (HQ) in Vorarlberg from 2016 to 2050 according to the competition scenario.

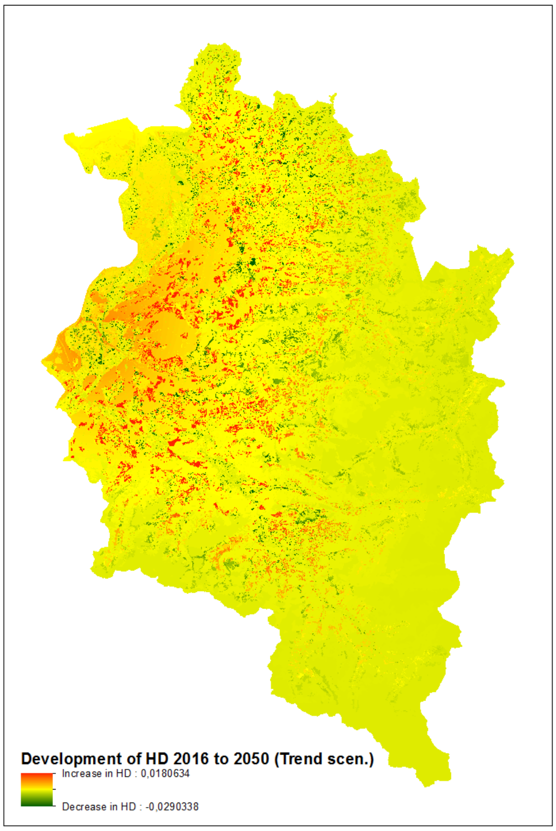

Fig. 27: Development of habitat degradation (HD) in Vorarlberg from 2016 to 2050 according to the trend scenario.

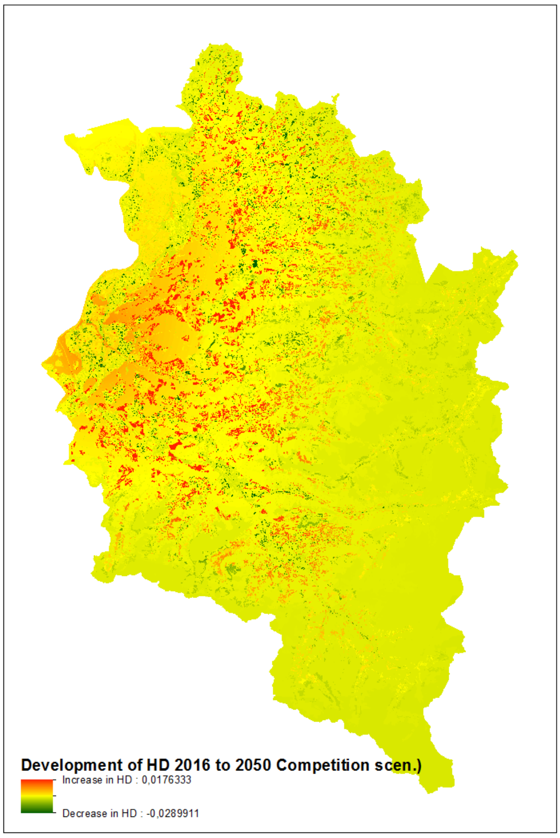

Fig. 28: Development of habitat degradation (HD) in Vorarlberg from 2016 to 2050 according to the competition scenario.

3.2. Interactions between ecosystem services

The objective of the final research question was to identify areas of potential conflicts or synergies between the different ecosystem services. First, areas of high value for humans and high value for biodiversity were assessed, meaning high supply of nearby recreation and flood protection in combination with areas of high habitat quality. The results showed that a large area of Vorarlberg was important for the provision of all the three ecosystem services considered. In 2016, 170.5 km^2 provided high supply of nearby recreation, flood protection and biodiversity which equals 6.5% of total area of Vorarlberg (Fig. 30). According to the trend scenario it would be 183 km^2 in 2050 which is an increase of 7.3%. The competition scenario predicted 178 km^2 for 2050 which is an increase of 4.4% compared to 2016 (Table 12; Fig. 31 &Fig. 32).

Regarding potential conflict areas the assessment revealed that there were no areas where high demand for nearby recreation and unmet demand for flood protection concur with areas of high habitat quality. However, there were areas where high recreation demand and high habitat quality concurred which might still lead to a high pressure on biodiversity in these areas. In 2016 this was the case on 33.4 km^2 which is 1.3% of the total area of Vorarlberg (Fig. 33). The trend scenario projected an increase of the conflict area between recreation and biodiversity of 26.6% to 42. 7 km^2 and the competition scenario projected a slightly lower increase with 24.2% to 41.9 km^2 (Table 12; Fig. 34 Fig. 35).

It is surprising that the trend scenario predicted higher increases for both types of area even though it assumed lower increases of the individual services than the competition scenario. Apparently, the increases must occur at slightly different locations so there was more overlap between the individual service areas.

Synergistic areas between flood protection, nearby recreation and biodiversity were identified only scarcely in areas below 600 m a.s.l. (Fig. 29). They were primarily located between 600 m a.s.l. and 1600 m a.s.l. with a peak at 1000 m a.s.l. in 2016 and 1200 m a.s.l. in 2050. Above 2200 m a.s.l. no more synergies between the three services were identified. The future scenarios predicted more synergistic areas across most elevation strata. But below 900 m a.s.l. and above 1700 m a.s.l. 2016 values were higher than the projected 2050 values. Below 1600 m a.s.l. the trend scenario predicted higher values than the competition scenario. Above this level the competition scenario projected slightly more synergistic areas.

Potential conflict areas between demand for nearby recreation and high habitat quality reached a pronounced peak at 600 m a.s.l. and were then decreasing to 0 at 1900 m a.s.l. and above. Below 700 m a.s.l. 2016 values were almost identical to the projected future values. From there on above the future scenarios predicted more potential conflict areas than 2016.

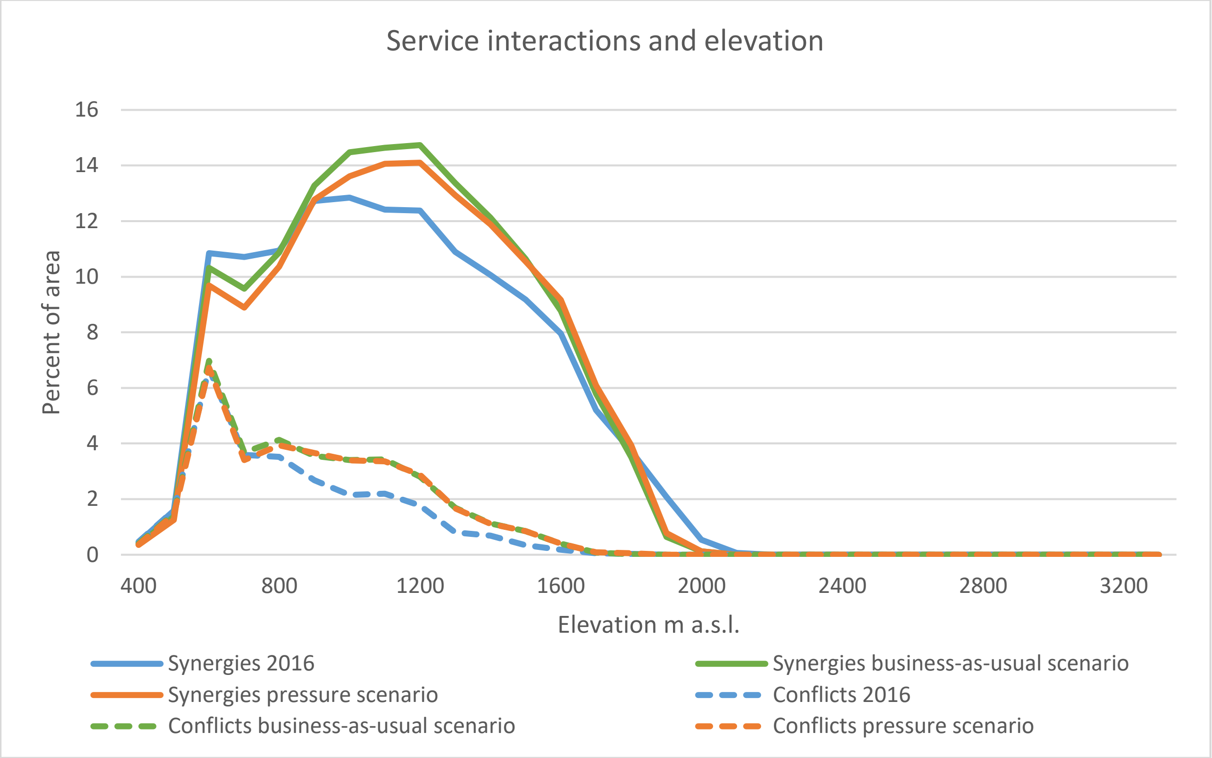

Fig. 29: Distribution of synergistic areas (solid lines) and conflict areas (dashed lines) for 2016 and two future scenarios (trend & competition) as a function of elevation. Synergies occurred where the provision of all of the three services considered was high (top quartile of supply values). Conflict areas occurred where high demand for nearby recreation concurred with high habitat quality (top quartile of supply values).

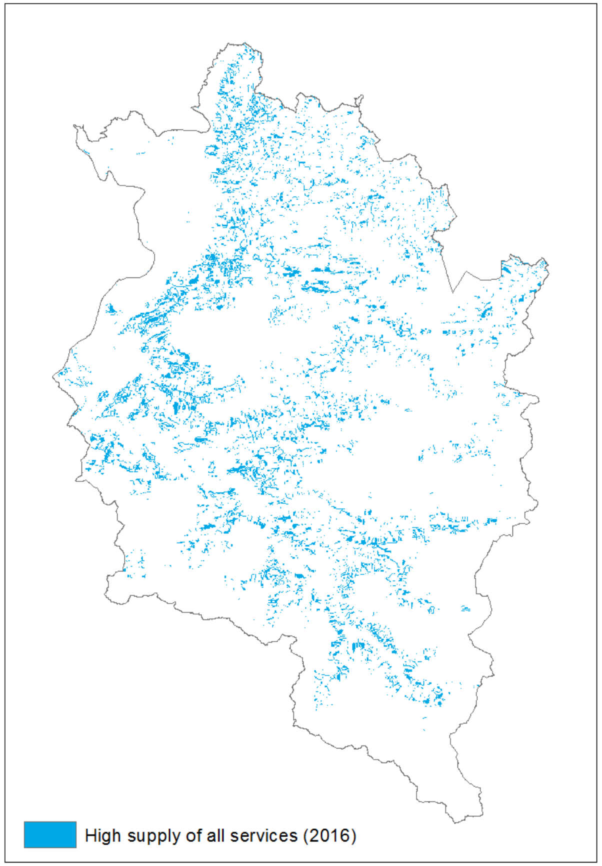

Fig. 30: Areas within Vorarlberg which provide high supply of nearby recreation, flood protection and biodiversity in 2016.

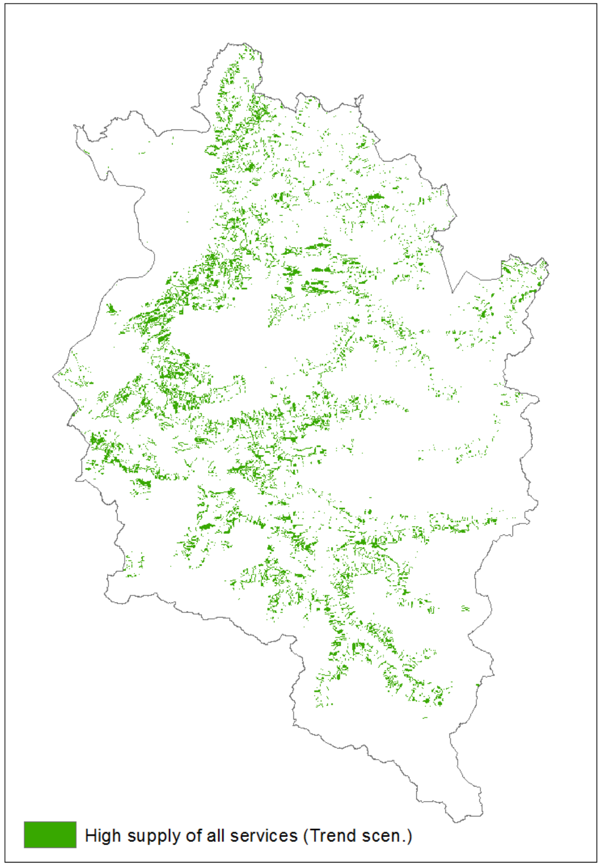

Fig. 31: Areas within Vorarlberg which provide high supply of nearby recreation, flood protection and biodiversity in 2050 according to the trend scenario.

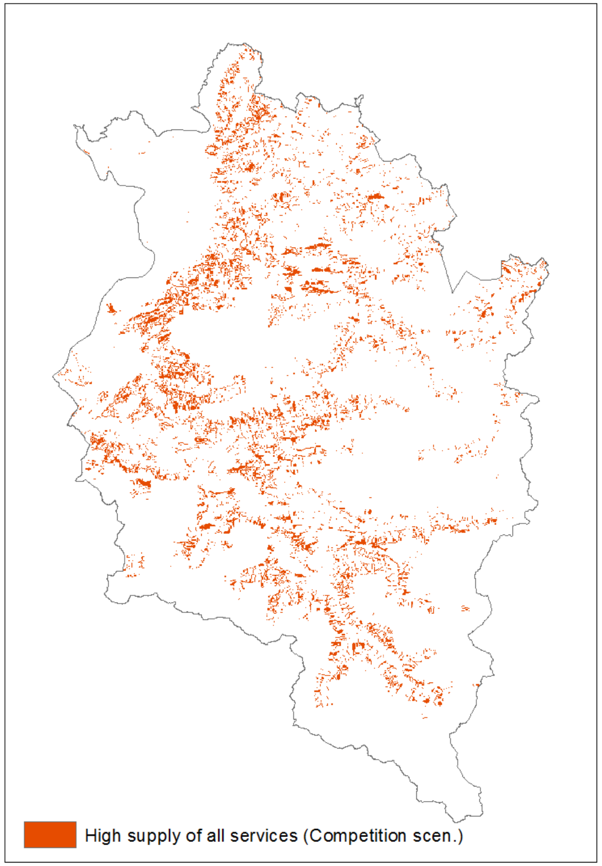

Fig. 32: Areas within Vorarlberg which provide high supply of nearby recreation, flood protection and biodiversity in 2050 according to the competition scenario.

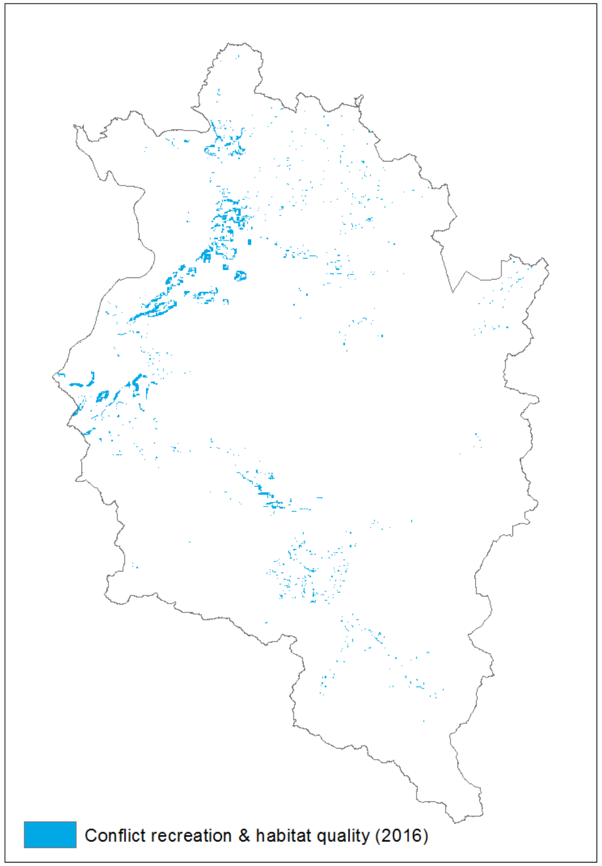

Fig. 33: Area of potential conflict within Vorarlberg between nearby recreation and biodiversity in 2016.

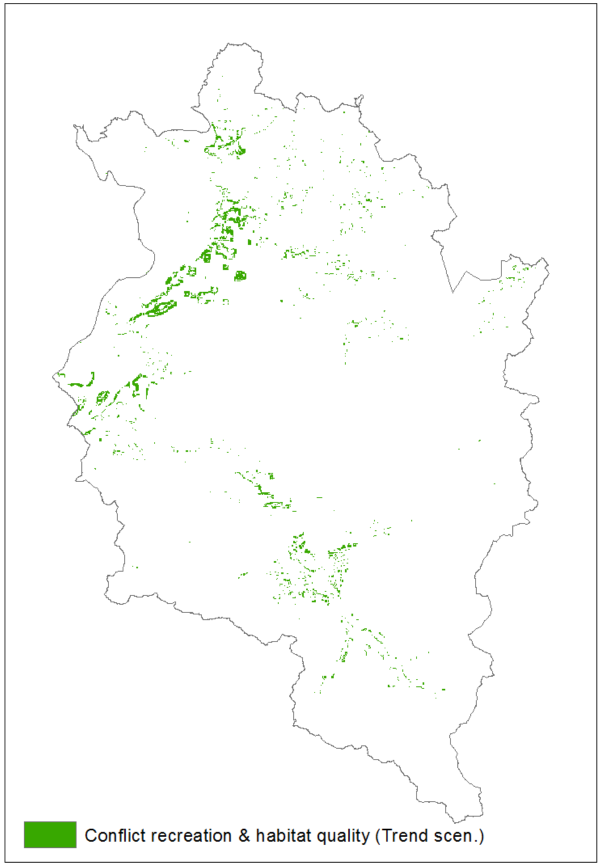

Fig. 34: Area of potential conflict within Vorarlberg between nearby recreation and biodiversity in 2050 according to the trend scenario.

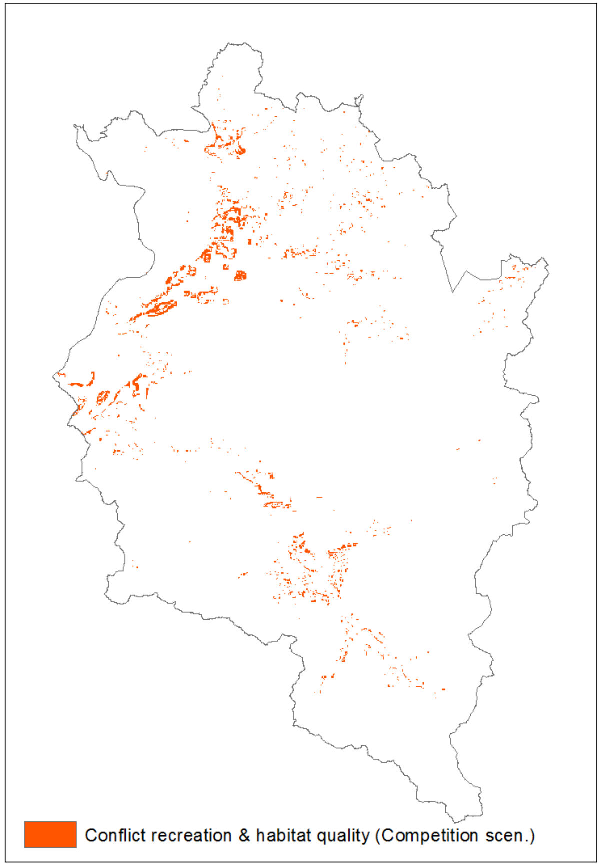

Fig. 35: Area of potential conflict within Vorarlberg between nearby recreation and biodiversity in 2050 according to the competition scenario.

Table 12: Area with synergies and conflicts between the different ecosystem services in Vorarlberg for 2016 and two future scenarios (trend & competition) plus the expected change in percent.

	2016	2050 (Trend scenario)	2050 (Competition scenario)
Synergistic areas	170.5 km^2	183 km^2 +7.3%	178 km^2 +4.4%
Conflict areas	33.4 km^2	42.7 km^2 +26.6%	41.9 km^2 +24.2%

Looking at the altitudinal distribution of different land use types (Fig. 36), I found a clear correlation between the distribution of forest and the distribution of synergistic service areas (Fig. 29). Forest peaked around 1200 m a.s.l. just as synergistic areas did and the decrease of synergistic areas above 2000 m a.s.l. corresponded to the treeline. Hence, forest areas seemed to concur with hotspots of service provision. Indeed, 97.5% of the synergistic areas are covered with forest. This fact highlights the importance of forests for the synergistic provision of ecosystem services in Vorarlberg.

The same applies to the individual services (compare Fig. 7, Fig. 14 & Fig. 23 to Fig. 36) indicating that forest areas are also essential for the individual supply of flood protection, nearby recreation and biodiversity in Vorarlberg.

Conflict areas between recreation and biodiversity, habitat degradation as well as demand areas for the individual services showed correlation with built-up area and agricultural areas since all of them peaked around 500 m a.s.l. and were decreasing with increasing elevation. This indicates, that the distribution of human infrastructure and agricultural production sites directly affects the distribution of demand for flood protection, nearby recreation and habitat degradation in Vorarlberg.

The projected increases in forest areas and built-up areas by the future land use scenarios also explain the expected increases in service supply and demand for 2050.

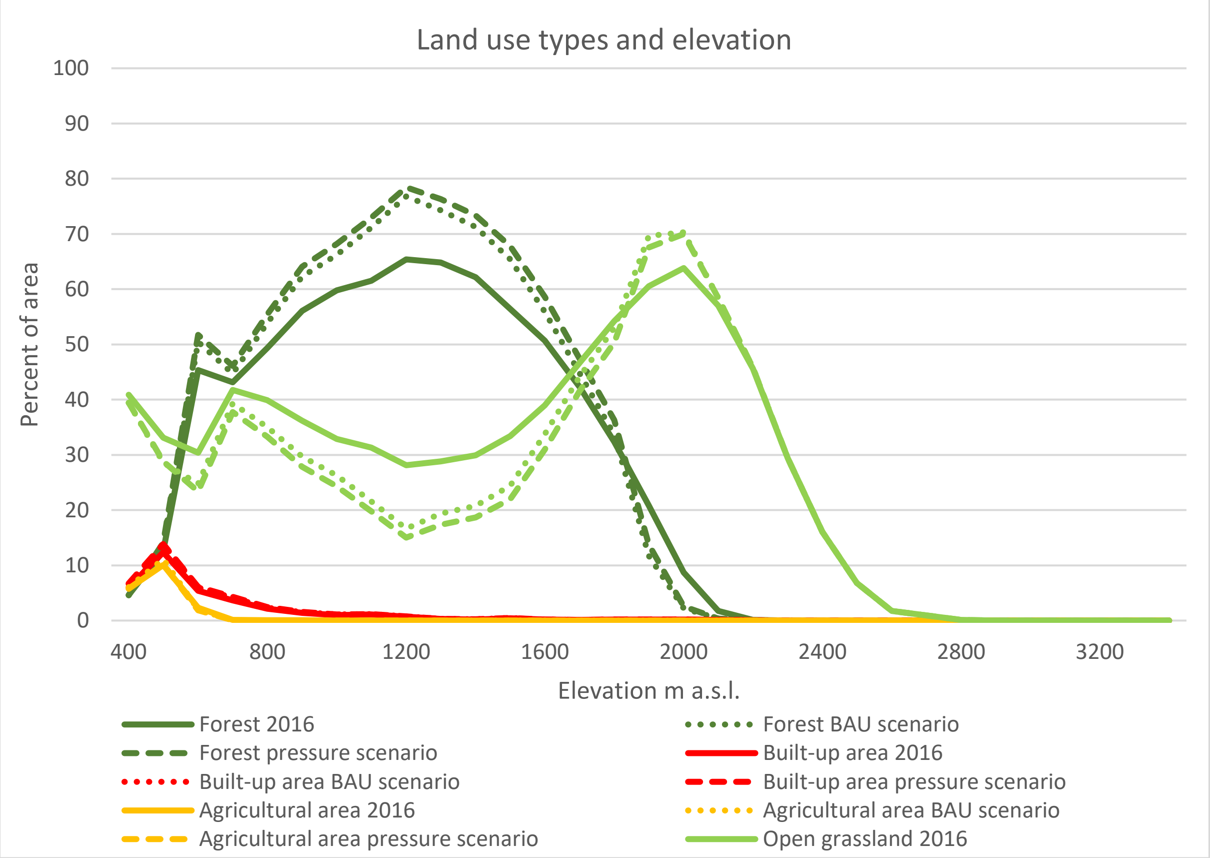

Fig. 36: Distribution of different land use types in Vorarlberg as a function of elevation for 2016 and two future scenarios (trend (TS), dotted line & competition (CS), dashed line)

4. Discussion

4.1. Discussion and interpretation of results

The goal of this Master thesis was to map ecosystem services in Vorarlberg based on a land use map of 2016 and two future land use scenarios in order to gain insights about the effect of land use on ecosystem services and their potential future development. The assessment included mapping of supply and demand of three ecosystem services to identify areas where service supply does not meet its respective demand, areas which are important for the provision of all services and areas of potential conflict between the different services. The selected services should be of high relevance for the region of Vorarlberg and cover a wide range of benefits for society. The gained information should then help to support policy making in spatial planning and conservation issues.

The assessment found correlations between forest areas and supply of the three services both individually and synergistically and correlations between built-up and agricultural areas and demand for the two services considered, habitat degradation and potential conflict areas. Mismatches between supply and demand were not prevalent. The future land use scenarios predicted moderate increases in supply and demand for all the services considered and in synergistic areas plus high increases in conflict areas (Table 13).

In the following section these findings will be compared to the results described in scientific literature and discussed in terms of their significance.

Table 13: Mean values of supply and demand for the different ecosystem services as well as synergistic and conflict areas for 2016 and two future scenarios (trend & competition) plus the expected change in percent.

	2016	2050 (Trend scenario)	2050 (Competition scenario)
Flood protection supply	1.68	1.75 +3.6%	1.77 +5.3%
Flood protection demand	0.0176	0.0179 +1.7%	0.0177 +0.6%
Nearby recreation supply	12.08	12.44 +3.0%	13.48 +11.6%
Nearby recreation demand	3.400	3.440 +1.2%	3.441 +1.2%
Biodiversity supply	0.617	0.624 +1.1%	0.632 +2.5%
Synergistic areas	170.5 km^2	183 km^2 +7.3%	178 km^2 +4.4%
Conflict areas	33.4 km^2	42.7 km^2 +26.6%	41.9 km^2 +24.2%

Indicators for mapping of ecosystem services

Mapping ecosystem services as a way to assess their supply and demand is a common, widely applied approach in scientific literature (see (Burkhard et al., 2012; Maes et al., 2012a; Willemen et al., 2015)). During the process of studying different case studies in order to find suitable indicators as proxies for the ecosystem services of interest in this Master thesis, an immense number and diversity of indicators was identified (for list of indicators see appendix A1). Most of the indicators represented service supply and less indicators were found for the assessment of demand. Most indicators were ineligible for the present assessment either because they did not represent the respective service sufficiently clear and specific or because the necessary data was not available for Vorarlberg. However, many indicators were excluded because of an unclear distinction between supply, flow and demand. Kandziora et al. (2013), for example, proposed to quantify the supply of recreation as a cultural ecosystem service through the indicators “turnover from tourism” or “number of visitors or facilities”. Similarly, Layke et al. (2012) listed “number of tourists visiting for nature and/or rural tourism” as potential indicator for recreation. I consider these as indicators for the actual use of a service i.e. ecosystem service flow and not supply.

In the case of flood protection many indicators found in literature would have served as suitable indicators for supply and would have been probably more accurate than the eventually chosen look-up table approach proposed by Burkhard et al. (2009). Examples are the hydric significance indicator developed by Šatalová and Kenderessy (2017) or the water retention index proposed by Maes et al. (2017). Still, they had to be excluded because they required a lot of input data which was not available for the whole region of Vorarlberg, for example soil data. For flood protection demand “built-up area within floodplains” as proposed by Syrbe and Walz (2012) was chosen as indicator, since most indicators found in literature were based on a similar aspect, covering potential damage by floods.

Concerning nearby recreation supply I found many different types of indicators in literature. They encompassed aspects such as naturalness or diversity of landscapes, specific landscape attributes such as water bodies, mountain summits or trees, recreational elements including built infrastructure and fishing or hunting spots. Accordingly, I decided that there was not one single indicator to adequately represent recreational potential and selected a set of indicators based on Buchecker et al. (2013). Demand indicators for nearby recreation were primarily based on statistical data on visitor rates or people’s stated preferences via local surveys. As both was not available for Vorarlberg, potential users of nearby recreation was chosen as indicator instead. This was expressed by the number of residents living in the catchment area of nearby recreation areas (based on Buchecker et al., 2013).

In the case of biodiversity most indicators required detailed information on species presence and abundance. Habitat quality was chosen as an indicator to mimic biodiversity in the absence of biological monitoring data for Vorarlberg. The InVEST habitat quality model (Sharp et al., 2016) served as a tool to assess this indicator.

Considering the number and diversity of indicators it important to check which indicators are suitable for the area of interest and the aim of each assessment to be performed.

Effect of land use on ecosystem services and further implications

Although flood protection, nearby recreation and biodiversity are classified as different service types (Haines-Young and Potschin, 2018; MA, 2005a; TEEB, 2010) the assessment found some similarities between the spatial distribution of the three services. Generally, service supply of the three services was low for low (< 600 m a.s.l.) and for high (> 2000m a.s.l.) elevation areas. Maximum supply for all three ecosystem services was identified between 1000 m a.s.l. and 1300 m a.s.l. This was correlated with the distribution of forest areas.

In contrast, demand for the two services considered was high for low elevation areas (maximum around 500 m a.s.l.) and became very low at higher elevations. Same applied to the distribution of habitat degradation. This showed correlations with the distribution of built-up and agricultural areas.

The observation, that the spatial distribution of supply is driven by forest areas is in agreement with findings from other studies. Bastian et al. (2012) investigated the effect of forested areas among other, on ecosystem services in an urban region. They detected a positive effect of forested areas on the supply of all the assessed services which were climate regulation, carbon sequestration and recreation. Brandt et al. (2014) found that forestes provided the highest diversity of ecosystem services within their study area. They concluded that conditions for supplying ecosystem services and biodiversity were most suitable on forest areas among all the land use types considered. Han and Dong (2017) identified high supply of sediment retention, carbon sequestration and habitat quality provided by forests. According to Lin et al. (2017) forests provide high levels of carbon storage, habitat quality, soil retention, and water yield. Also, Burkhard et al. (2012) attributed very high supply values to forest areas for all regulating and cultural ecosystem services and most provisioning services. The MA (2005b) identified deforestation as an important driver reducing the supply of various ecosystem services globally, including climate regulation and disease control.

The results of these studies indicate that forest areas are not only essential for the provision of flood protection, nearby recreation and biodiversity in Vorarlberg but also in other regions of the world and for the provision of even more ecosystem services. Considering the ongoing deforestation in some parts of the world, especially the tropics (Food and Agriculture Organisation (FAO), 2016), this might cause decreases in the provision of various services. Since several of the studies mentioned above pointed out the important role of forests in carbon sequestration and climate regulation and since both of these services have effects on a global scale (meaning their benefits are not bound to the location of service provision; Costanza, 2008), the negative impact of deforestation might be of global relevance, especially in the light of climate change. In turn, expansion of forest areas as projected for Vorarlberg and other regions of the world (FAO, 2016) would increase the provision of ecosystem services and might have positive effects on a global scale as well.

The fact, that built-up area together with agricultural area were the determining land uses types for the distribution of service demand is in line with the definition of ecosystem services. The definition “the benefits humans obtain from ecosystems” (Costanza et al., 1997; MA, 2005a) already implied that demand will occur where humans are living. Accordingly, Burkhard et al. (2012) attributed high demand values for almost all ecosystem services to the different types of built-up area and other anthropocentric land uses. Furthermore, the degradation of habitats was determined by the distribution of built-up areas including roads and railroads and agricultural areas, since these land use types were considered as threat sources (based on Polasky et al., 2011; Sallustio et al., 2017; Terrado et al., 2016). Sallustio et al. (2017) being the only study found which worked with the InVEST habitat quality model and actually presented the results of habitat degradation, identified a similar distribution of habitat degradation as in Vorarlberg with highest degradation in urban areas.

Already in 2014, 54% of the world’s population was living in urban areas. This proportion is expected to rise to 66% in 2050 (United Nations, 2015). Considering the relevance of built-up area in the distribution of service demand and habitat degradation, this drastic increase would entail growing demand for ecosystem services and increasing habitat degradation in and around urban areas worldwide. Especially in the case of regulating and cultural ecosystem services this might lead to severe shortages in supply since most services of these categories cannot be imported from other locations as easily as provisioning services (Villamagna et al., 2013) and settlement areas are found to be generally low in service provision.

Projections of future development of ecosystem services

Since only a small number of studies assessing future ecosystem service supply covering the region of Vorarlberg was found and none of these considered service demand it is difficult to set the result of the present assessment in comparison. The MA (2005b) assessed future supply of provisioning, regulating and cultural services on a global scale. The “global orchestration” scenario, which assumed high economic growth just as the competition scenario in this Master thesis, predicted water regulation supply in 2050 to remain at the same level as in 2000 for industrial countries. For recreation supply it projected a decrease in industrial countries. Regarding other services the global orchestration scenario predicted increases for provisioning services such as food, fuel and fresh water, decreases for biochemicals and pharmaceuticals, pollination and cultural diversity. The other services were expected to remain at the level of 2000. Thus, the results of the present assessment are not in line with the MA (2005b). However, comparison is hardly possible because of the difference in spatial scale. Stürck and Verburg (2017) who focused on multifunctionality of ecosystem services in Europe predicted slight increases in multifunctionality for 2040. This corresponds to the findings of the present assessment but there is no information about the development of individual services. Same applies to Kienast et al. (2009) who found that most regions within Europe can maintain the supply of the ecosystem services considered in future, but did not specify the development of individual services. Zhang et al. (2017) who performed a regional assessment but focused on an entirely different geographical area (Beijing-Tianjin-Hebei urban agglomeration in China) projected all of the assessed services including water retention which is closely linked to flood protection (Nedkov and Burkhard, 2012) to decrease until 2040. Specifically on the service of biodiversity the Global Biodiversity Outlook (CBD, 2010) predicted continuing high levels of species extinction and loss of habitats worldwide. This contradicts the projections of the present assessment based on the InVEST habitat quality model.

The comparison of the results from the assessment of Vorarlberg and these other assessments highlights the fact that it is difficult to generalise future projections for ecosystem services. Differences in scale and geographical location impede to transfer the results of one study area directly to another. Therefore, it is important to specifically assess future service supply based on the most important drivers of change in the area of interest.

Policy implications

The spatial distribution between supply and demand is fairly balanced in the region of Vorarlberg. Accordingly, there is no need for immediate policy action in most areas. Still, the assessment identified some areas which require closer attention. Based on the findings of the present assessment some general recommendations for future decision making processes can be derived.

In the case of flood protection there were some areas (5.01 km^2) where supply could not offset demand located within the inundation zones of lowland areas. For these areas I would recommend to assess flood risk in more detail, including the vulnerability of affected buildings and people living there. Where necessary, potential measures to increase flood protection should then be considered. Furthermore, future projections predicted the area of demand exceeding supply to increase (trend scenario: +8.8%, competition scenario: +9.0%). This potential development has to be taken into account in spatial planning and should be prevented. Construction of new infrastructure should occur outside of inundation areas whenever possible. If this is not feasible, the vulnerability of the infrastructure should be minimised. Additionally, land use policies should attempt to maintain flood protection supply.

In case of nearby recreation potential shortfalls would be expected to occur in the Rhine valley where population density is very high (Amt der Vorarlberger Landesregierung - Landespressestelle, 2016) and recreational potential was found to be relatively low. Although, based on the present assessment, potential shortfalls of supply were not expected to increase since demand was growing more slowly than supply (trend scenario: +1.2% vs. +3.0% & competition scenario: +1.2% vs. +11.6%), spatial planning should pay special attention to the development in these areas. It should make sure that recreational supply is not further decreasing in these areas. If necessary the recreational potential could be enhanced by establishing additional recreational elements within zones of highest demand such as parks and urban green areas.

Even though biodiversity is expected to increase (trend scenario: +1.1% & competition scenario: +2.5%) based on the projected land use changes, habitat degradation is assumed to grow as well. This has to be kept in mind when looking at the habitat quality projections. The habitat quality model can serve as a tool to keep track of habitat quality and degradation in Vorarlberg and to prevent the loss of high quality habitats and further degradation of habitats. In the context of biodiversity, the drastic increases of conflict areas between high quality habitats and high demand for nearby recreation projected for the future (trend scenario: +26.6% & competition scenario: +24.2%) are of particular relevance. Recreation seems to exert more pressure on high quality habitats in future. Considering this fact in conservation management could help to prevent negative impacts on biodiversity by informing people about the value of biodiversity in the respective areas or establishing conservation areas where appropriate.

Special attention should also be paid to synergistic areas of service supply. They are of particular importance as they provide high levels of all services. In Vorarlberg an area of 170.5 km^2 was considered as synergistic, providing high supply of flood protection, nearby recreation and biodiversity. Other studies confirm that there are synergistic effects between different ecosystem services. For example between soil erosion control and carbon sequestration (Feng et al., 2017), biodiversity, visual amenity and recreation (Gimona and van der Horst, 2007), carbon storage and habitat quality (Han and Dong, 2017), net primary production, wind prevention and sand fixation, and water retention (Li and Wang, 2018). Lin et al. (2018) who assessed correlations between 8 ecosystem services found that out of the 28 possible service pairs 20 pairs are positively correlated. On the European scale Maes et al. (2012b) found positive correlations between biodiversity and the aggregated supply of 10 ecosystem services. This results suggest that the synergistic areas in Vorarlberg might provide high supply of even more services. In any case, areas which provide high levels of more than one service are worth to be considered as potential conservation areas. Establishing conservation areas at these locations would help to maintain ecosystem service supply at high levels very efficiently, since several services are addressed at once. At the moment, only 8.6% of the synergistic areas in Vorarlberg are under protection.

4.2. Critical points and limitations

There are several critical points about the ecosystem service assessment performed in the course of this Master thesis which require attention. This should support the interpretation of the results and facilitate further application of ecosystem service mapping. In the following section these critical points which might as well limit the significance of the results will be discussed. The limitations can be attributed either to the data basis or the here applied methods for the assessment of the individual services. Subsequently, the selection of ecosystem services for the present assessment will be discussed. Conclusively, some critical points about the separate assessment of ecosystem service supply and demand and the ecosystem service concept in general will be mentioned.

Limitations due to data availability

First, there are some limitations due to the available data which affect the quality of all ecosystem services assessed. Although the land use map of Vorarlberg with grid cell size of 10m x 10m is exceptionally small-scale the number of land use classes depicted is rather low. The classification has a strong focus on built-up area with 8 out of 19 land use classes being different types of built-up area. However, regarding the natural land use classes the classification is less detailed. For example, there is no differentiation of forest types or different types of arable land, although this might be relevant to assess an ecosystem's capacity to provide certain services accurately. Furthermore, the future land use scenarios are based on even less land use classes because future development is modelled for 11 land use classes only. For some land use types it is unlikely that they will change within the scope of the projection such as water bodies. For other land use types which are assumed to be stable until 2050 it is more likely that they will change such as roads or orchards and vineyards. However, the projection period of 34 years from 2016 to 2050 is too long in order to make accurate projections.

Method-specific limitations

Second, the methods applied for the assessment of the different ecosystem services reduce the quality of the individual assessments. Starting with flood protection, which followed the approach proposed by Burkhard et al. (2012) for the assessment of supply and a combined approach of Burkhard et al. (2012), Syrbe and Walz (2012) and Bubeck et al. (2011) for the assessment of demand, several problems have been identified. Burkhard et al. (2012) developed their approach based on the CORINE land cover data of the EU. This classification system includes 44 land cover classes with a spatial resolution of 25 ha. Since the Vorarlberger land use data distinguishes only 19 land use classes and has an even higher spatial resolution some of the accuracy gets lost when adopting the approach. In any case, the deduction of flood protection capacity from land use data is a drastic simplification. Several studies which assessed flood protection capacities point out the diverse factors determining the capacity in addition to land cover (e.g. Chan et al., 2006; Nedkov and Burkhard, 2012; Šatalová and Kenderessy, 2017; Stürck et al., 2014). However, very limited data availability on these factors in Vorarlberg, especially soil characteristics, did not allow for such an in-depth assessment.

In regards of demand the inclusion of local inundation areas provides a more detailed picture of the situation in Vorarlberg than only considering land use would have. By incorporating the financial value of the infrastructure located within inundation areas, the results would be even more accurately representing demand for flood protection.

Continuing with the assessment of nearby recreation supply it has to be mentioned that the approach proposed by Buchecker et al. (2013) and Kienast et al. (2012) which served as a guideline was actually developed for peri-urban areas, meaning medium sized cities of 10’000-100’000 inhabitants. In the region of Vorarlberg 86 out of 96 municipalities have less than 10’000 inhabitants (Amt der Vorarlberger Landesregierung - Landesstelle für Statistik, 2017). The present assessment is based on the assumption that people’s recreational preferences in these municipalities can be captured through the same landscape elements as in peri-urban areas. However, this would have to be confirmed by empirical research. At least in terms of the indicator selection there seems to be a general support for their relevance as several studies propose the same or very similar indicators (Peña et al., 2015; Schröter et al., 2014a; Szücs et al., 2015; Willemen et al., 2008). In any case, cultural ecosystem services are difficult to assess and questionnaires or observations are the best way to increase accuracy (Kandziora et al., 2013; Kienast et al., 2012; Layke et al., 2012). The procedure developed by Buchecker et al. (2013) and Kienast et al. (2012) is considered as a valid alternative to estimate the recreational potential of an ecosystem where time for an extensive survey is lacking.

Demand for nearby recreation was assessed in a more general way distributed evenly within the defined zones around residential areas. It is considered as not feasible to model the exact distribution of demand without collecting empirical data. Furthermore, it is possible that demand does relocate quickly for example due to excessive demand at one place. Demand for recreation is not bound to a specific place but can adapt according to supply (Costanza, 2008; Villamagna et al., 2013). This makes specific future projections of distribution of demand even more difficult. Hence, I decided to focus on the total demand for nearby recreation within the different zones.

In case of the habitat quality model of InVEST which served as a proxy for the biodiversity assessment there are some limitations due to the model’s specifics and due to the data basis. Sharp et al. (2016) mention the following limitations and simplifications in the model’s user guide. First, all threats in the model are considered as additive, although the total impact of multiple threats might be greater than the sum of the individual threats. Second, defining the area of interest sets an artificial boundary in a larger landscape. The surrounding landscape is ignored, hence threat intensity will always be lower at the edges of the area of interest. These limitations have to be considered for the interpretation of the results.

In addition to the model specific limitations, the available data on the different threat sources and habitat characteristics was very limited. The threat data is solely based on land cover because these data was readily available. However, there are no future projections for the threat “roads and railroads”, hence only two of three threats actually change in the future scenarios. For a more profound assessment land cover data could be complemented with data on the intensity of different threat sources, for example how intensive agricultural practices are on arable land. The values for habitat suitability and their sensitivity to threats as well as the threat characteristics are based on studies which considered a different geographical area. Thus, the values might not be representative for the

habitats and threat sources in Vorarlberg. In a further assessment it would be recommended to perform interviews with local experts to get a better basis for the required input values.
The question remains, whether or not the habitat quality value can be seen as a reliable indicator for biodiversity, since Sharp et al. (2016) state that the model should only be used for specific species or groups of species. Other studies applying the habitat quality model and testing its reliability showed that the habitat quality values are significantly correlated to existing biodiversity indicators (Sallustio et al., 2017; Terrado et al., 2016). However, future research might be necessary to confirm the reliability.

Selection of ecosystem services

Concerning the selection of ecosystem services to be assessed in this Master thesis it was important to choose services with a high relevance for Vorarlberg and services which cover a wide range of benefits for society. Therefore, services from different service categories (according to the classifications of Haines-Young and Potschin, 2018; MA, 2005a; TEEB, 2010) were chosen. However, I decided not to consider any provisioning service because of their specific properties. Specifically, supply and demand of provisioning services are less bound to a specific location than most services from other categories (Villamagna et al., 2013). This means that the demand for provisioning services can be met by importing the required goods. Likewise, supply of these goods does not necessarily meet local demand but could be exported to other locations. Hence, it is difficult to determine where the goods are eventually consumed. Since Austria is a highly developed country embedded in global trade systems any over- or undersupply could be balanced easily through exports or imports, respectively. Therefore, provisioning services were not considered as relevant in the context of this Master thesis.
Because of limited time one service of each of the remaining categories was chosen. The selected services aim at representing more than their individual benefits mentioned above. Flood protection as the regulating service represents the issue of natural hazards and dynamic processes which is of high relevance for a mountainous region such as Vorarlberg (Penna and Borga, 2013). Gill and Malamud (2014) found that floods trigger or increase the probability of the occurrence of other natural hazards such as landslides, ground heaves or ground collapses. Penna and Borga (2013) also state that floods, landslides and debris flows often occur jointly. An ecosystem's capacity to reduce the intensity of a flood event could thus decrease the probability of these additional hazards.
Nearby recreation as the cultural service represents the nonmaterial benefits humans obtain from nature. Cultural services are considered as relatively abstract especially in comparison to provisioning services (Mononen et al., 2016; Wei et al., 2017). Furthermore, the different cultural services are closely interlinked and difficult to separate (Posthumus et al., 2010; Swanwick et al., 2007). Focusing on nearby recreation as a more tangible service thus allows at least partly, to account for other cultural services such as aesthetic appreciation or experiential use of nature.
In addition to representing ecological integrity, biodiversity as the supportive service accounts for the intrinsic value of nature which is often criticised to be neglected by the concept of ecosystem services. There is an ongoing debate within environmental ethics about whether the valuation of ecosystem services should be focused on an anthropocentric perspective or a biocentric perspective (Schröter et al., 2014b). Including biodiversity in the present assessment attempts at incorporating both perspectives.

Separate assessment of ecosystem service supply and demand

Finally, there are some critical points to be discussed about the separate assessment of ecosystem service supply and demand. There is controversy over how the assessments should include demand and whether a balance between supply and demand should be created. Burkhard et al. (2012) present a straightforward approach which makes use of a dimensionless 0 to 5 scale for the assessment of both supply and demand of all ecosystem services to create a final balance. Since then, the method has been applied for several case studies (e.g. Burkhard et al., 2015; Goldenberg et al., 2017). Wei et al. (2017) found in their review of 38 studies assessing demand and supply of ecosystem services that 33 of them did identify mismatches between supply and demand using various methods. However, Schröter et al. (2012) and Schröter et al. (2014a) argue that creating balances might not be useful for every ecosystem service and special attention should be paid to this step.

As mentioned above, I decided that in the case of biodiversity it is not reasonable to quantify or localise demand. Biodiversity as a supportive service is of fundamental importance for the provision of all other ecosystem services (MA, 2005a; TEEB, 2010) and thus demand is basically indefinite. Additionally, supportive services are associated with a high risk of double-counting (Boyd and Banzhaf, 2007; Burkhard et al., 2010; Costanza, 2008), in the sense that quantifying demand for both the supportive service and the supported service would lead to double-counting. Because it is unclear who should be considered as the final beneficiary it is recommended not to quantify demand (Schröter et al., 2012). The problem of double-counting has to be taken into account also for the assessment of supply, especially when it comes to economic valuation of service provision (Crossman, 2017; Fisher et al., 2009). As the focus of the present assessment was the localisation of biodiversity hot- and coldspots plus the relative changes of biodiversity in time rather than absolute quantification, it was considered as acceptable to include biodiversity in the assessment.

In the case of nearby recreation demand was assessed, even though only on a coarse spatial scale. Nearby recreation is important for human well-being (Matsuoka and Kaplan, 2008) but it is also a potential stressor for biodiversity (Young et al., 2005). Therefore, demand is seen as a relevant factor to consider in spatial planning and conservation policy. However, I decided not to equalise the scales of supply and demand values which would have been necessary to create the balance. Although, this would have facilitated the comparison, the supply value does not quantify the amount of demand it can offset. Therefore, it would not have been justified to use the same scale (Schröter et al., 2014a) and a qualitative comparison was performed instead.

For flood protection, in contrast, it was considered as important to create the balance between supply and demand. Only the localisation of mismatches between supply and demand allows to determine the need for potential interventions. However, the procedure which was based on the approach of Burkhard et al. (2012) assumes that an ecosystem has to provide supply exactly at the location where demand occurs. Indeed, several studies approve that demand for most regulating ecosystem services needs to be met locally (Costanza, 2008; Nedkov and Burkhard, 2012; Villamagna et al., 2013). All the same, they state that in the case of flood protection it is the physical connection which is relevant and not necessarily in-situ supply. Other studies state that hydrological catchment areas are the spatial unit of particular relevance for flood protection (Goldenberg et al., 2017; Laterra et al., 2012; Walz et al., 2017). Hence, it might be even more important to consider the flood protection supply upstream of the demand area. The comparison of supply and demand values in specific grid cells might distort the actual situation. Furthermore, Schröter et al. (2012) criticise the lack of specification regarding the 0 to 5 value scale applied by Burkhard et al. (2012). Indeed, there is hardly any information on how these values were developed. This makes it difficult to understand how supply compares to demand and if compensation is actually realistic or not. Nevertheless, the here performed straightforward assessment of flood protection supply and demand can serve as a valid basis for further, more detailed assessments where necessary.

In conclusion, demand is seen as a useful tool to inform policy-makers about the state of certain ecosystem services. It allows to put the actual level of supply in relation to a desired or required level. This in turn, facilitates planning of management strategies in order to achieve sustainable use of ecosystem services. However, it is important to evaluate whether it is appropriate to assess the demand of each ecosystem service of interest individually and if so, how to do it properly.

Use and limitations of the ecosystem service concept

The concept of ecosystem services seems to be well-established in scientific literature and is considered as a useful tool to incorporate natural capital into decision-making processes (Costanza et al., 1997; Daily et al., 2009). It has found practical application in conservation projects (see Tallis et al., 2009) or biodiversity strategies, for example in the EU (Maes et al., 2014). Nevertheless, the concept is associated with certain limitations, some of which will be mentioned in the following section.

Scientific understanding of ecosystem functions is still limited. Imperfect understanding of the ecological processes behind ecosystem services impedes accurate assessment of the services (Daily et al., 2009). Furthermore, the quality of service assessments is affected by the available input data (Helfenstein and Kienast, 2014). Insufficient accuracy of ecosystem service assessments as the basis for decision-making might lead to the implementation of inadequate policies (Hauck et al., 2013b; Turner and Daily, 2008). Furthermore, the ecosystem service assessment per se cannot resolve some of the inherent characteristics of ecosystem services which complicate the development of adequate policy measures for their conservation. First, there are trade-offs between certain services (Hauck et al., 2013a; MA, 2005b), second, the beneficiaries of ecosystem services are often different from those who profit from exploitation of natural resources (Turner and Daily, 2008) and third, many ecosystem services are public goods or open access resources (= non-excludable goods; Costanza, 2008). These characteristics remain as challenges of crucial importance to be addressed by institutional and political adaptations. Finally, the ecosystem service concept focuses by definition on ecosystems' benefits for humanity which has been criticised in scientific literature repeatedly (Schröter et al., 2014b) since it neglects the intrinsic value of biodiversity. It is even claimed that the ecosystem service concept would promote a more exploitative human-nature relationship by treating nature as a commodity (Schröter et al., 2014b). This could lead to the negligence of services without obvious benefits for society.

Despite these and potential additional limitations I consider the ecosystem service concept as a valuable tool in ecosystem management. Especially, because it fosters understanding of the links between human well-being and ecosystem services on the one hand and the impacts of human activities on ecosystem services on the other hand. As a well-established concept it can facilitate communication between different stakeholders in the field of ecosystem management (Hauck et al., 2013b). The diversity of practices developed to quantify, map or monetarise ecosystem services (see e.g. Willemen et al., 2015) allows to find an appropriate approach for almost every objective in this context, although this process requires a high level of carefulness.

4.3. Outlook

In addition to addressing the methodological limitations mentioned above there are other ways to enhance the quality of the ecosystem service assessment. In order to obtain a valuable basis for decision-making processes it is important to have realistic scenarios for the future development of ecosystem services. For the present assessment the only driver of change included in the scenario modelling is land use change. Although, the MA (2005b) states that land cover change, together with the application of new technologies, has been the most important driver of change for terrestrial ecosystems in the past decades, it projects the impact of other drivers to increase rapidly. Two drivers with rapidly increasing impact on all types of ecosystems are climate change and pollution, in particular with nitrogen and phosphorous. In contrast, the projected trend of the impact of land cover change is a less rapid increase or a continuation of the current impact levels. In case of temperate forests its impact is even projected to decrease. For future assessments it might be appropriate to include climate change and pollution as additional drivers of change because their impact on ecosystems influences their capacity to provide certain services.

5. Conclusion

The here presented approach of ecosystem service mapping applied at the region of Vorarlberg serves as an example of how ecosystem services could be included in regional policy making in order to maintain their provision for present and future generations.

The assessment found that supply of flood protection, nearby recreation and biodiversity was highest in mid-elevation areas but low in low (< 600 m a.s.l.) and high (> 2000m a.s.l.) elevation areas, which was in clear correlation with the distribution of forest areas. Also, synergistic areas which provide high supply of all the services were identified almost entirely (97.5%) within forests.

Demand for the assessed services as well as habitat degradation were high in low elevation areas (peak around 500 to 600 m a.s.l.), particularly in the densely populated Rhine valley and were decreasing with increasing elevation. This was correlated with the distribution of human-dominated land use types including built-up and agricultural areas. In contrast, service supply was low on these areas.

Assessing the potential future development of the three services based on future land use scenarios revealed that supply is likely to increase which was once more correlated with the projected increases of forest area. Likewise, demand was projected to increase as well since settlement areas are assumed to expand and population numbers are growing.

Neither the assessment of 2016 nor the future assessment identified vast areas of discrepancies between supply and demand. Supply and demand of ecosystem services in Vorarlberg seemed to be fairly balanced. However, there were some locations in the lowlands where demand for flood protection exceeded supply or areas where high demand for nearby recreation concurred with high quality habitats, which might exert pressure on local biodiversity.

In conclusion, the here presented procedure for ecosystem service mapping is considered as suitable for a basic assessment of flood protection, nearby recreation and biodiversity on a regional scale. Based on readily available land use data, it can support decision-making concerning issues of spatial planning or nature conservation. The specific selection of the three services plus the analysis of their interactions allows to derive information additional to the information gained from individual service assessments. Hence, policy measures can be more efficient than by addressing each service individually.

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Appendix

A1: List of indicators for mapping of ecosystem services

The following lists include the indicators found in scientific literature to assess ecosystem services, the geographical area of their application within the respective study and whether the indicator was selected for the assessment or, if not, the reason why it was excluded from further consideration. There are separate lists for flood protection supply, flood protection demand, nearby recreation supply, nearby recreation demand and biodiversity. Within the lists similar indicators are grouped into indicator categories or indicator groups, respectively. However, this is no official categorisation, but based on the thematic diversity of the here assessed indicators.

Criteria required for an indicator to be considered for the assessment of Vorarlberg:

1) **Clear and comprehensible representation of the object of indication**: the selected indicators should serve as suitable, adequately specific representation for the ecosystem service of interest.
2) **Allow ecosystem services to be mapped**: indicators should provide spatially explicit information which allows for them to be mapped.
3) **Distinction between indicators for supply, flow and demand of ecosystem services**: supply indicators should actually indicate the capacity of an ecosystem to provide a certain service. One should not use indicators representing the flow of a service as a proxy for supply because flow is highly influenced by demand. Changes in a supply indicator should reflect changes in the ecosystem's capacity rather than changes in the demand. Furthermore, flow indicators should not be used as indicators for demand because flow is likewise influenced by supply and demand might in fact be higher or lower. In any case, it is important to distinguish these terms and categorise the indicators accordingly (For definitions: see below).
4) **Address local context**: as the thesis considers a relatively small geographical area it is important to choose indicators which are relevant for the study area. Some indicators which work fine for a certain area might be irrelevant for Vorarlberg or one could miss a crucial indicator by not considering the local context. Besides the ecological and geographical context, the social, political and institutional context is of high importance.

Other reasons for the exclusion of an indicator:

- **Lack of data**: the required input data for the indicator is not available for the region of Vorarlberg
- **More specific indicator selected**: the indicator would be qualified for the assessment of Vorarlberg, but a more specific indicator was selected
- **Similar indicator selected**: the indicator would be qualified for the assessment of Vorarlberg, but a similar indicator was selected instead

Flood protection – supply

Table a: Indicators for flood protection supply found in literature.

Indicator category	Indicator	Selected for assessment of Vorarlberg	Reason for exclusion (unfulfilled criteria)	Reference	Application area
Land cover	Land cover	x		Burkhard et al. (2009)	Halle-Leipzig region, Germany
				Vihervaara et al. (2010)	Forest Lapland, Finland
				Goldenberg et al. (2017)	Stockholm region, Sweden
Natural barriers	Wetland areas		Criterion 3	Kandziora et al. (2013)	–
	Area proportion of vegetation in floodplains		Criterion 3	Rabe et al. (2016)	Germany
	Area proportion of water bodies in floodplains		Criterion 3	Rabe et al. (2016)	Germany
	Area of wetlands in flood risk zones		Criterion 3	Maes et al. (2016b)	EU
Floodplain areas	Floodplain areas		Criterion 3	Maes et al. (2016b)	EU
	Proportion of area flooded annually		Criterion 3	Posthumus et al. (2010)	Beckingham Marshes, England
	100-y-flood inundation areas		Criterion 3	Albert et al. (2016b)	Mardorf, Germany
Water storage capacity	Storage capacity		Lack of data	De Groot et al. (2010)	–
				Layke et al. (2012)	Global MA & sub-global MA
				Posthumus et al. (2010)	Beckingham Marshes, England
				Burkhard et al. (2014)	–
				Maes et al. (2011)	EU
				Nedkov and Burkhard (2012)	Etropole municipality, Bulgaria
Water retention capacity	Retention capacity of floodplains		Lack of data	Albert et al. (2016a)	Germany
	Holding capacity of wetlands		Lack of data	Laterra et al. (2012)	Pampa, Argentina
	Holding capacity of rivers & lakes		Lack of data	Maes et al. (2014)	EU
	Holding capacity of wetland soils		Lack of data	Maes et al. (2014)	EU
Soil infiltration	Infiltration capacity		Lack of data	Maes et al. (2011)	EU
	Infiltration rate		Lack of data	Clec'h et al. (2016)	Pará state, Brazil
Status of waterbodies & wetlands	Conservation status of rivers, lakes, wetlands		Criterion 1	Maes et al. (2014)	EU
	Condition of water bodies		Criterion 1	Helfenstein and Kienast (2014)	Switzerland
Modelling/Composed indices	STREAM Catchment types Catchment zones Precipitation types		Lack of data	Stürck et al. (2014)	EU

	Crop factor Water holding capacity			
	AGWA/KINEROS Interception Infiltration Surface runoff Erosion	Lack of data	Nedkov and Burkhard (2012)	Etropole municipality, Bulgaria
	MARXAN Percent vegetation cover Percent agricultural cover Flow distance from 100-y-floodplain Percent vegetation cover within riparian zone	Lack of data	Chan et al. (2006)	Central Coast ecoregion California
	Hydric significance indicator Amount of precipitation Slope Soil type Ground transmissivity Current land use Forest ecological status	Lack of data	Šatalová and Kenderessy (2017)	Poprad river basin, Slovakia
	Water retention index Leaf area index of vegetation Surface water Bodies Water holding capacity of soil Relative bedrock permeability Slope Surface imperviousness	Lack of data	Maes et al. (2017)	EU
Actual Performance	Number of prevented flood hazards [n/year]	Criterion 3	Kandziora et al. (2013)	–
	Total number of floods mitigated	Criterion 3	Maes et al. (2011)	EU

Flood protection – demand

Table b: Indicators for flood protection demand found in literature.

Indicator category	Indicator	Selected for assessment of Vorarlberg	Reason for exclusion (unfulfilled criteria)	Reference	Application area
Land cover	Land cover		More specific indicator selected	Burkhard et al. (2012)	Halle-Leipzig region, Germany
				Goldenberg et al. (2017)	Stockholm region, Sweden
Risk areas	Built area within floodplain	x		Syrbe and Walz (2012)	Saxony, Germany
	Number of flood hazards and fatalities		Criterion 3	Burkhard et al. (2014)	–
	Vulnerability		Similar indicator selected	Nedkov and Burkhard (2012)	Etropole municipality, Bulgaria
	Damage costs		Criterion 3	Burkhard et al. (2014)	–
Damage modelling	Estimated damage per upstream area		Lack of data	Stürck et al. (2014)	EU
	Rhine Atlas Model (RAM) Land use data Inundation data		Similar indicator selected	Bubeck et al. (2011)	Rhine catchment

Recreation – supply

Table c: Indicators for recreation supply[5] found in literature.

Indicator category	Indicator group	Indicator(s)	Selected for assessment of Vorarlberg	Reason for exclusion (unfulfilled criteria)	Reference	Application area
Land cover	Land cover type	Land cover		More specific indicators selected	Burkhard et al. (2009)	Halle-Leipzig region, Germany
					Vihervaara et al. (2010)	Forest Lapland, Finland
					Brenner et al. (2010)	Catalan coastal zone, Spain
					Nahuelhual et al. (2013)	Ancud municipality, Chile
	Vegetation	Lushness of vegetation		Criterion 1	Weyland and Laterra (2014)	Argentina
		Heterogeneity of vegetation		Lack of data	Weyland and Laterra (2014)	Argentina
		Percent tree cover		Similar indicator selected	Weyland and Laterra (2014)	Argentina
		Forested area	x		Raudsepp-Hearne et al. (2010)	Quebec, Canada
					Kienast et al. (2012) Buchecker et al. (2013)	4 regional case studies in Switzerland
Specific landscape attributes	Presence of water bodies	Length of river & lake shores	x		Kienast et al. (2012) Buchecker et al. (2013)	4 regional case studies in Switzerland
		Coastlines		Criterion 4	Maes et al. (2011)	EU
		River, streams, lakes and shores coast density		Similar indicator selected	Weyland and Laterra (2014)	Argentina
		Number of streams, water bodies		Similar indicator selected	Szücs et al. (2015)	Göttingen, Germany
		Presence of rivers, water bodies, coastline related to recreation in viewshed		Similar indicator selected	Peña et al. (2015)	Basque Country, Spain
		Distance from coast		Criterion 4	Paracchini et al. (2014)	EU

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[5] The literature review of studies assessing recreation supply includes studies which do not focus on nearby recreation. Therefore, many of the indicators are excluded because they are not considered as relevant for the assessment of nearby recreation (Reason for exclusion: criterion 1)

		Coastline included in protected areas		Criterion 4	Paracchini et al. (2014)	EU
	Prevalence of green linear elements	Length of hedgerows or tree lines		Lack of data	Van Zanten et al. (2016)	Winterswijk, Netherlands Märkische Schweiz, Germany
	Specific positive habitat components	Abundance of dragonflies Spatial distribution of dragonflies Noticeability of dragonflies		Criterion 4	Richards et al. (2015)	Fishlake wetland, UK
		Large native trees		Criterion 4	Nahuelhual et al. (2013)	Ancud municipality, Chile
					Szücs et al. (2015)	Göttingen, Germany
		Existence of fruit trees		Criterion 4	Szücs et al. (2015)	Göttingen, Germany
		Wetlands	x		Kienast et al. (2012) Buchecker et al. (2013)	4 regional case studies in Switzerland
	Sites of geological interest	Sites of geological interest with high or low recreational value		Criterion 1	Peña et al. (2015)	Basque Country, Spain
	Summits/vista	Presence of mountain summits	x		Peña et al. (2015)	Basque Country, Spain
					Kienast et al. (2012) Buchecker et al. (2013)	4 regional case studies in Switzerland
		Number of view axes, panoramas		Similar indicator selected	Szücs et al. (2015)	Göttingen, Germany
		Paths leading to viewpoint		Similar indicator selected	Buchecker et al. (2013)	Switzerland
	Roughness/steepness	Roughness of reliefs		Criterion 1	Weyland and Laterra (2014)	Argentina
		Number of steep minor roads/trails		Criterion 1	Kienast et al. (2012)	4 regional case studies in Switzerland
Naturalness	Hemeroby	Hemeroby		Lack of data	Paracchini et al. (2014)	EU
					Maes et al. (2011)	EU
	Natural land cover	Natural land cover		Lack of data	Peña et al. (2015)	Basque Country, Spain
					Chan et al. (2006)	Central Coast ecoregion California
					Albert et al. (2016a)	Germany
	Natural areas	Natural areas		Lack of data	Willemen et al. (2008)	Gelderse Vallei region, Netherlands
Diversity	Diversity of land use	Diversity of land uses	x		Kienast et al. (2012) Buchecker et al. (2013)	4 regional case studies in Switzerland

					Willemen et al. (2008)	Gelderse Vallei region, Netherlands
		Diversity of agricultural land use		Lack of data	Van Zanten et al. (2016)	Winterswijk, Netherlands Märkische Schweiz, Germany
	Diversity of landscapes	Diversity of landscapes		Similar indicator selected	Peña et al. (2015)	Basque Country, Spain
					Szücs et al. (2015)	Göttingen, Germany
					Albert et al. (2016a)	Germany
Protection	Natural protected areas	Natural protected areas		Criterion 1	Paracchini et al. (2014)	EU
					Peña et al. (2015)	Basque Country, Spain
					Maes et al. (2011)	EU
	Accessibility of protected areas	Area proportion of settlements in catchment area of protected areas		Criterion 1	Rabe et al. (2016)	Germany
Recreational elements	Hiking	Length of hiking trails	x		Kienast et al. (2012) Buchecker et al. (2013)	4 regional case studies in Switzerland
		Density of hiking paths		Similar indicator selected	Schröter et al. (2014a)	Telemark, Norway
	Cycling	Local road network for cycling	x		Willemen et al. (2008)	Gelderse Vallei region, Netherlands
	Hunting	Deer kills		Criterion 1	Raudsepp-Hearne et al. (2010)	Quebec, Canada
	Bird watching	Natural capabilities of bird-watching		Criterion 1	Bukvareva et al. (2017)	Russia
	Recreational fishing	Area of water bodies Game-fish species richness Water quality Forested riparian areas Boating access sites Fishing spots Fish stocking		Criterion 1	Villamagna et al. (2014)	Virginia & North Carolina, USA
		Natural capabilities of fishing		Criterion 1	Bukvareva et al. (2017)	Russia
	Bathing	Area proportion of settlements in catchment area of bathing water		Criterion 1	Rabe et al. (2016)	Germany
		Quality of bathing water		Criterion 1	Maes et al. (2011)	EU
					Paracchini et al. (2014)	EU
		Swimming locations		Criterion 1	Willemen et al. (2008)	Gelderse Vallei region, Netherlands

	Infrastructure	Information tables, marked trails, benches		Lack of data	Szücs et al. (2015)	Göttingen, Germany
		Natural and constructed infrastructures to guide or be enjoyed by visitors		Criterion 1	Peña et al. (2015)	Basque Country, Spain
		Number of hotels, restaurants, hiking paths, parking lots		Criterion 1	Kandziora et al. (2013)	–
		Objects such as fountains, monuments, ruins		Lack of data	Buchecker et al. (2013)	Switzerland
	Urban recreation	Public areas for recreation		Criterion 1	Rabe et al. (2016)	Germany
		Green spaces in urban areas		Criterion 1	Albert et al. (2016a)	Germany
Convenience	Pleasant climate	Pleasant climate		Criterion 1	Bukvareva et al. (2017)	Russia
		Mean annual temperature & annual thermal amplitude		Criterion 1	Weyland and Laterra (2014)	Argentina
	Accessibility	Accessibility of urban green areas		Criterion 1	Albert et al. (2016a)	Germany
		Level of public access		Similar indicator selected	Chan et al. (2006)	Central Coast ecoregion California
		Density of roads & paths		Similar indicator selected	Nahuelhual et al. (2013)	Ancud municipality, Chile
					Peña et al. (2015)	Basque Country, Spain
		Proximity to major roads		Similar indicator selected	Chan et al. (2006)	Central Coast ecoregion California
					Willemen et al. (2008)	Gelderse Vallei region, Netherlands
	Distance	Distance from residence	x		Kienast et al. (2012) Buchecker et al. (2013)	4 regional case studies in Switzerland
		Distance to tourism services		Criterion 1	Nahuelhual et al. (2013)	Ancud municipality, Chile
		Distance to population centres		Similar indicator selected	Chan et al. (2006)	Central Coast ecoregion California
	Settlement areas nearby	Settlement area	x		Kienast et al. (2012) Buchecker et al. (2013)	4 regional case studies in Switzerland
Actual use	Economic value	Turnover from tourism		Criterion 3	Kandziora et al. (2013)	–
		Financial value of recreation		Criterion 3	Layke et al. (2012)	Global MA & sub-global MAs
	Number of people	Park visitations		Criterion 3	Brandt et al. (2014)	Pacific Northwest, USA

		Number of tourists visiting for nature and/or rural tourism		Criterion 3	Layke et al. (2012)	Global MA & sub-global MAs
		Number of recreational anglers and hunters		Criterion 3	Layke et al. (2012)	Global MA & sub-global MAs
		Number of visitors per facility (e.g. hotels, restaurants, parking lots)		Criterion 3	Kandziora et al. (2013)	–
		Photo user days		Criterion 3	Wood et al. (2013)	–
					Sharp et al. (2016)	–
Disturbances	Disturbing elements	Abundance of debris Spatial distribution of debris Noticeability of debris		Criterion 4	Richards et al. (2015)	Fishlake wetland, UK
		Number and visibility of disturbing elements		Similar indicator selected	Szücs et al. (2015)	Göttingen, Germany
		Industrial elements		Criterion 4	Willemen et al. (2008)	Gelderse Vallei region, Netherlands
		Bare soil cover		Criterion 4	Weyland and Laterra (2014)	Argentina
		Crop area		Criterion 4	Weyland and Laterra (2014)	Argentina
	Noise	Distance to highways		Similar indicator selected	Willemen et al. (2008)	Gelderse Vallei region, Netherlands
		Presence of major roads	x		Buchecker et al. (2013)	Switzerland
	Smell disturbance	Distance to intensive livestock farms		Criterion 4	Willemen et al. (2008)	Gelderse Vallei region, Netherlands

Recreation – demand

Table d: Indicators for recreation demand[6] found in literature.

Indicator category	Indicator	Selected for assessment of Vorarlberg	Reason for exclusion (unfulfilled criteria)	Reference	Application area
Stated preferences	People's plans and expectations		Lack of data	Burkhard et al. (2014)	–
	Social preferences of different ecosystems and landscapes for recreation		Lack of data	Peña et al. (2015)	Basque Country, Spain
				Tratalos et al. (2016)	UK
	Public preference for specific positive and negative habitat components		Lack of data	Richards et al. (2015)	Fishlake wetland, UK
Economic demand	Number of tourists in nature that is necessary for regional business		Criterion 1	Bukvareva et al. (2017)	Russia
Land cover	Land cover		More specific indicator selected	Burkhard et al. (2012)	Halle-Leipzig region, Germany
Potential users	Share of population employed in service sector		Criterion 1	Wolff et al. (2017)	Global
	Possibility to participate in outdoor recreation activities (GDP per capita)		Criterion 1	Wolff et al. (2017)	Global
	Potential user indicator (Inhabitants per municipality, tourist overnight stays, number of cabins)		Criterion 1	Schröter et al. (2014a)	Telemark, Norway
	Number of residents in catchment area	x		Buchecker et al. (2013)	Switzerland
Actual use	Number of fishing licenses		Criterion 3	Villamagna et al. (2014)	Virginia & North Carolina, USA
	Touristic lodging units		Criterion 3	Syrbe and Walz (2012)	–
	Number of facility visitors		Criterion 3	Burkhard et al. (2014)	–
	Number of visitors		Criterion 3	Maes et al. (2014)	EU
				Bukvareva et al. (2017)	Russia
Infrastructure	Built tourism & transport infrastructure		Criterion 1	Bukvareva et al. (2017)	Russia
Financial flow	Turnover from tourism		Criterion 1	Burkhard et al. (2014)	–

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[6] The literature review of studies assessing recreation demand includes studies which do not focus on nearby recreation. Therefore, many of the indicators are excluded because they are not considered as relevant for the assessment of nearby recreation (Reason for exclusion: criterion 1)

Biodiversity – supply

Table e: Indicators for biodiversity supply found in literature.

Indicator category	Indicator	Selected for assessment of Vorarlberg	Reason for exclusion (unfulfilled criteria)	Reference	Application area
Protection	Protected areas		Criterion 1	Maes et al. (2012b)	EU
				Helfenstein and Kienast (2014)	Switzerland
	Number of protected species		Criterion 1	Burkhard et al. (2012)	–
	Number of protected habitats		Criterion 1	Burkhard et al. (2012)	–
Species diversity	Simpson diversity index		Lack of data	Brandt et al. (2014)	Pacific Northwest, USA
				Kandziora et al. (2013)	–
	Shannon-Wiener index		Lack of data	Maes et al. (2012b)	EU
				Kandziora et al. (2013)	–
	Mean species abundance		Lack of data	Maes et al. (2012b)	EU
	Biodiversity index Number of moths, birds, bees, fruit flies, spiders, ants, soil macrofauna, termites, earthworms, small, medium and high plants		Lack of data	Clec'h et al. (2016)	Pará state, Brazil
	Species number		Lack of data	Helfenstein and Kienast (2014)	Switzerland
	Biodiversity Intactness Indicator		Lack of data	Scholes and Biggs (2005)	South Africa
Genetic diversity	Variety of crops and animals		Criterion 1	Helfenstein and Kienast (2014)	Switzerland
Specific species	Number of endangered or rare species		Criterion 1	Burkhard et al. (2012)	–
	Presence or absence of indicator species		Criterion 1	Burkhard et al. (2012)	–
				Kandziora et al. (2013)	–
	Number of endemic species		Criterion 1	De Groot et al. (2010)	–
	Number of endangered species		Criterion 1	Helfenstein and Kienast (2014)	Switzerland
	Number of invasive species		Criterion 1	Helfenstein and Kienast (2014)	Switzerland
Quality of habitats	Abiotic habitat components' heterogeneity indices		Criterion 1	Kandziora et al. (2013)	–
	Minimum critical size		Criterion 1	De Groot et al. (2010)	–

	InVEST Habitat Quality Habitat suitability of land use types Impact of relevant threat sources	x		Sharp et al. (2016)	–
Habitat diversity	Diversity of habitats		Criterion 1	Kandziora et al. (2013)	–
Rare or endangered habitats	Number of endangered or rare habitats		Criterion 1	Burkhard et al. (2012)	–
Habitat connectivity	Fragmentation		Criterion 1	Helfenstein and Kienast (2014)	Switzerland
				Overmars et al. (2014)	EU
	Proximity index		Criterion 1	Stürck and Verburg (2017)	EU
Disturbances	Negative influences on habitat quality Pollutants, nitrogen deposition, climate change, eutrophication		Criterion 1	Helfenstein and Kienast (2014)	Switzerland
	Negative influences on habitat quality Disturbances, harvesting, toxic pollutants, trampling, nitrogen input		Criterion 1	Overmars et al. (2014)	EU

A2: ArcGIS procedure of ecosystem service mapping (Model Builder), ArcMap 10.5.1s

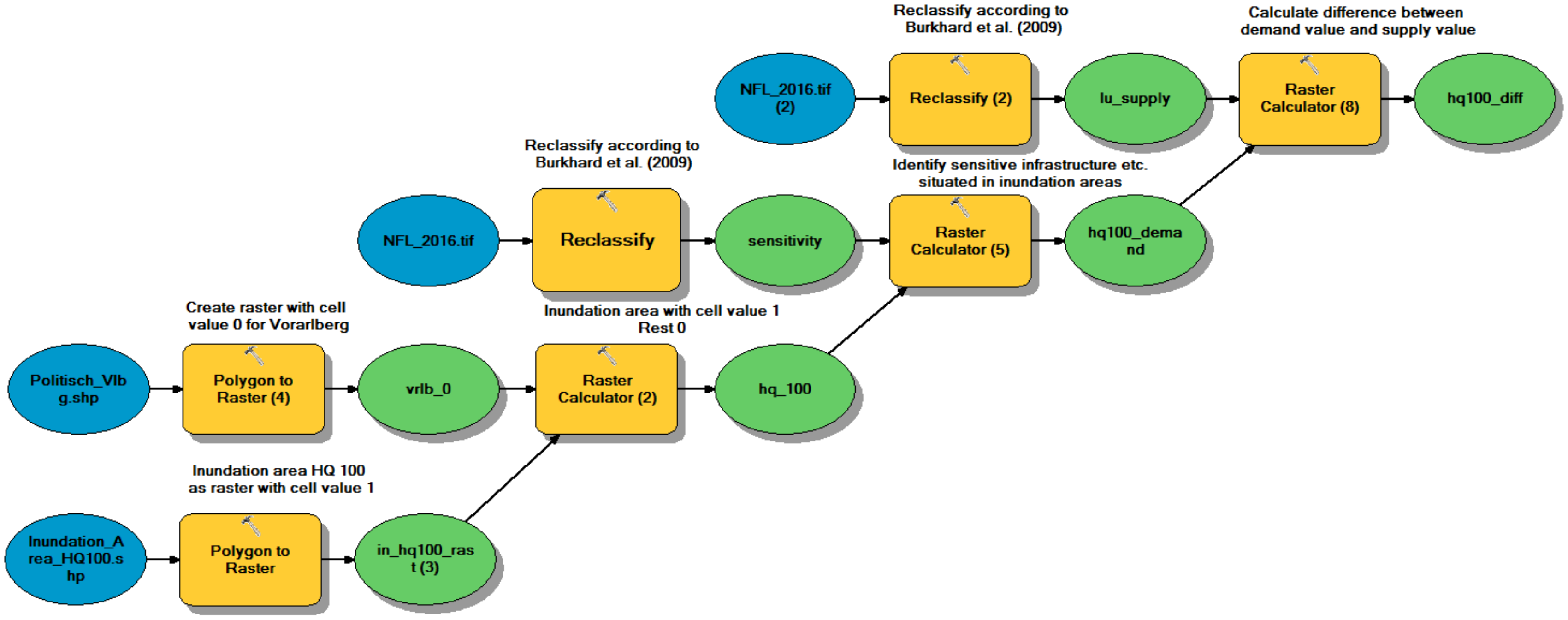

Fig. a: ArcGIS procedure to assess supply, demand and delta value of flood protection for 2016. The assessment for 2050 followed the same procedure with the respective future land use scenarios instead of NFL_2016.

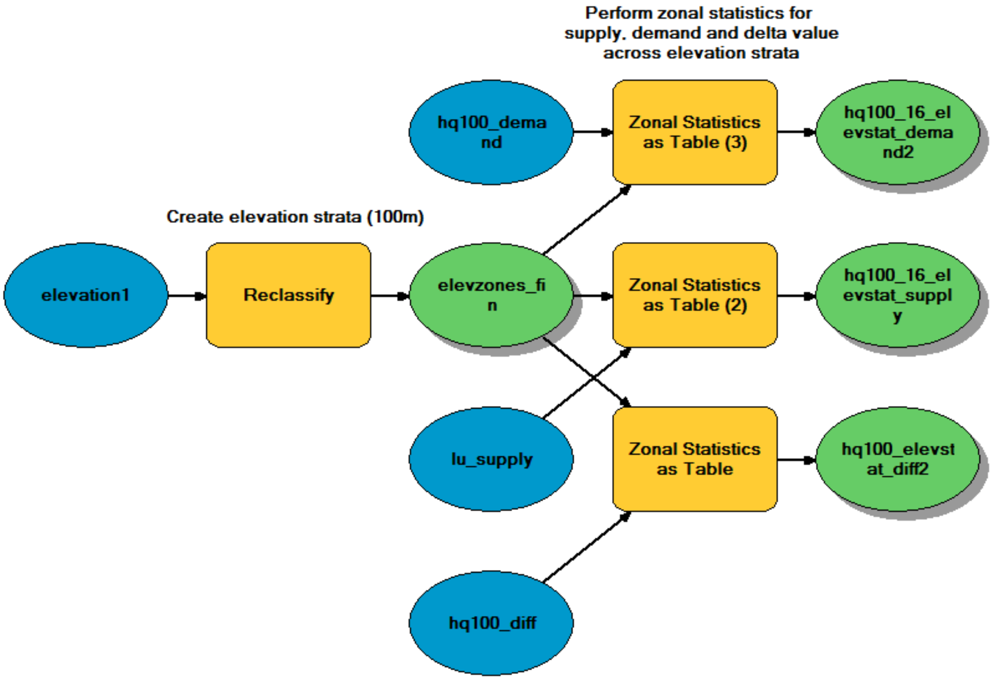

Fig. b: ArcGIS procedure to analyse flood protection supply, demand and delta values as a function of elevation for 2016. The assessment for 2050 followed the same procedure with the respective scenario values instead.

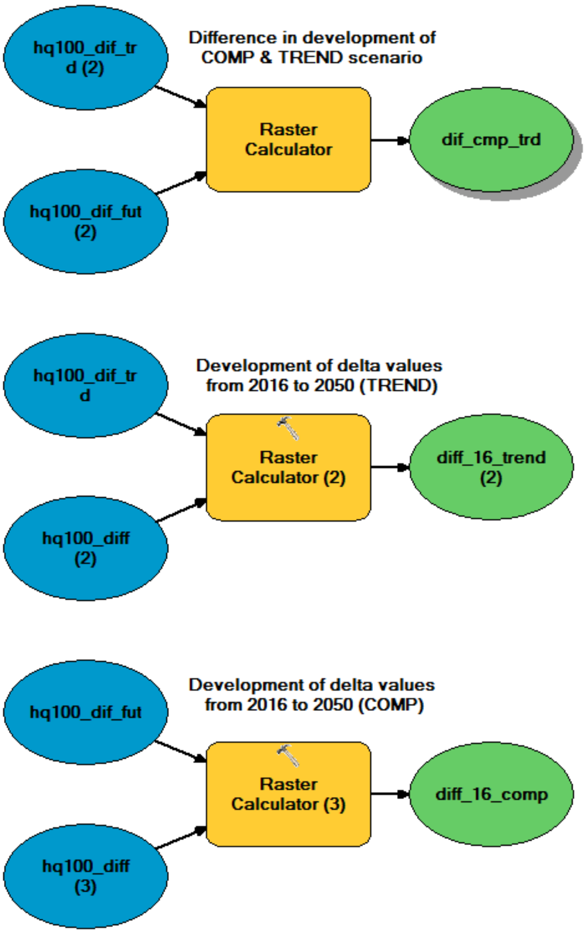

Fig. c: ArcGIS procedure to analyse development of flood protection delta values from 2016 to 2050 and to analyse differences between the projections of the two future land use scenarios.

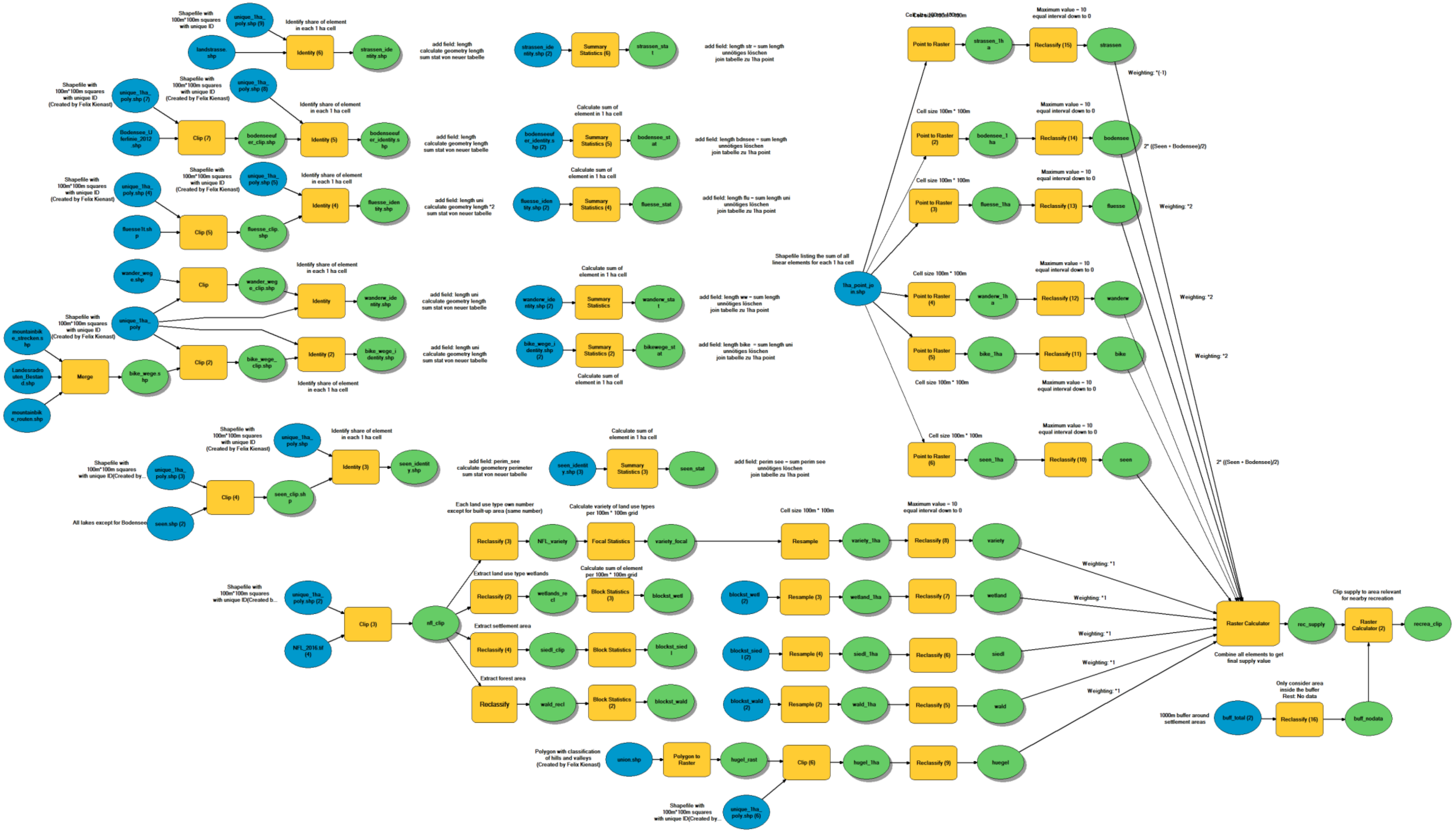

Fig. d: ArcGIS procedure to assess nearby recreation supply for 2016. The assessment of 2050 followed the same procedure with the respective scenario inputs instead.

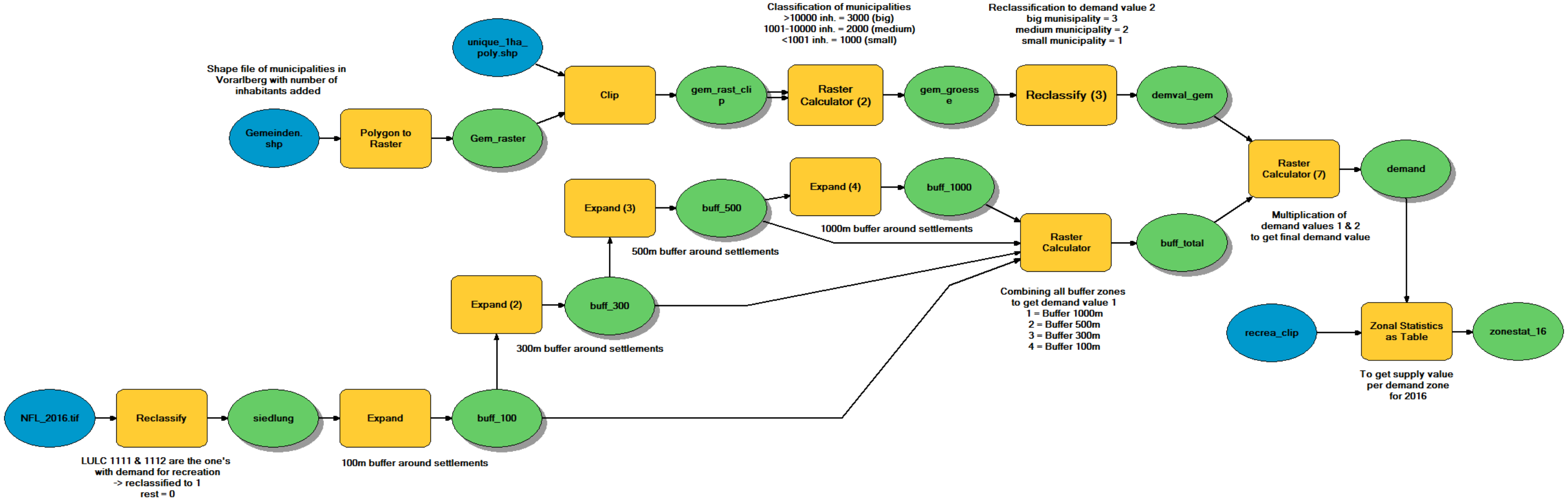

Fig. e: ArcGIS procedure to assess demand for nearby recreation for 2016. The assessment of 2050 followed the same procedure with the respective scenario inputs instead.

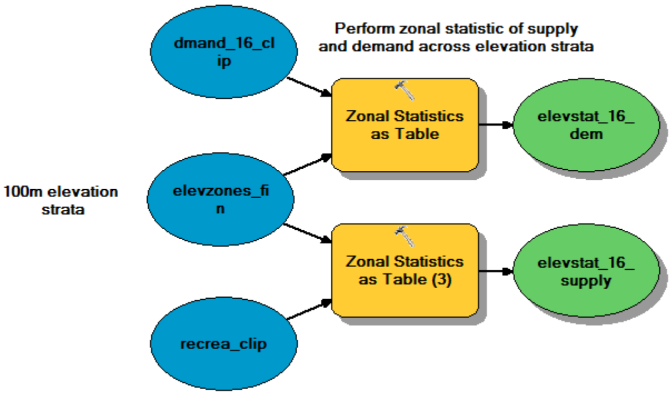

Fig. f: ArcGIS procedure to analyse nearby recreation supply and demand values as a function of elevation for 2016. The assessment for 2050 followed the same procedure with the respective scenario values instead.

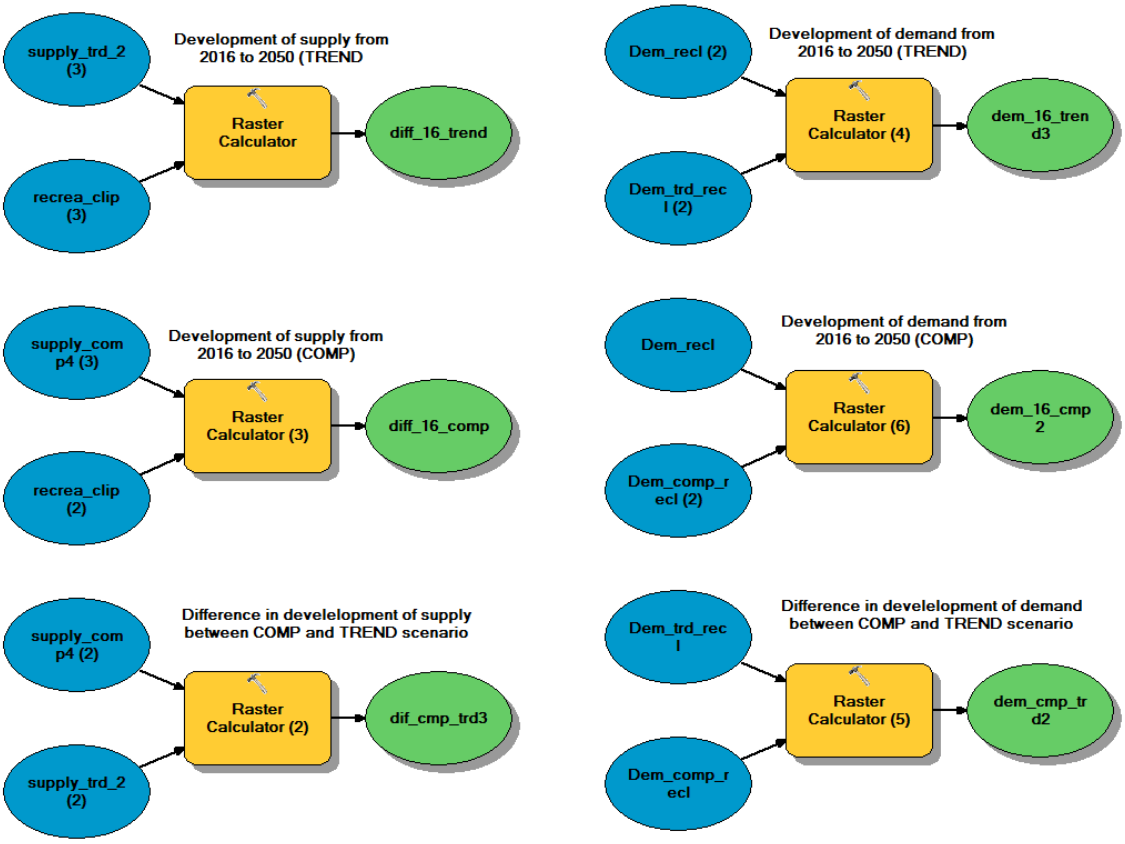

Fig. g: ArcGIS procedure to analyse development of nearby recreation supply and demand from 2016 to 2050 and to analyse differences between the projections of the two future land use scenarios.

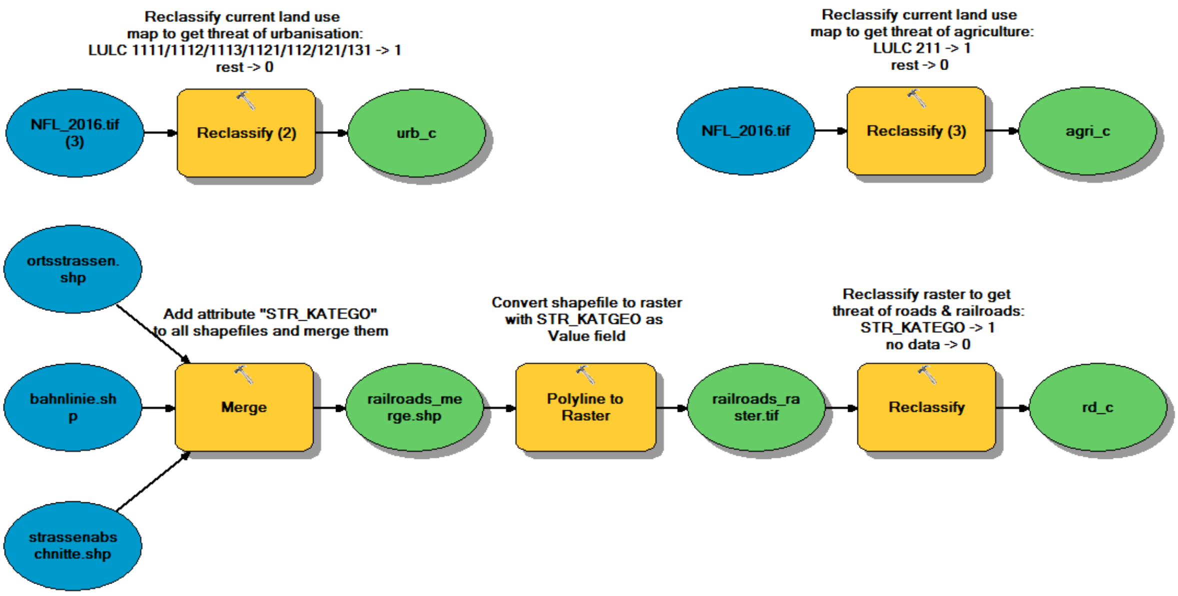

Fig. h: ArcGIS procedure to generate the maps of the threat sources urbanisation, agriculture and roads & railroads for the assessment of biodiversity 2016. The maps for 2050 were generated following the same procedure with the respective land use scenario instead of NFL_2016.

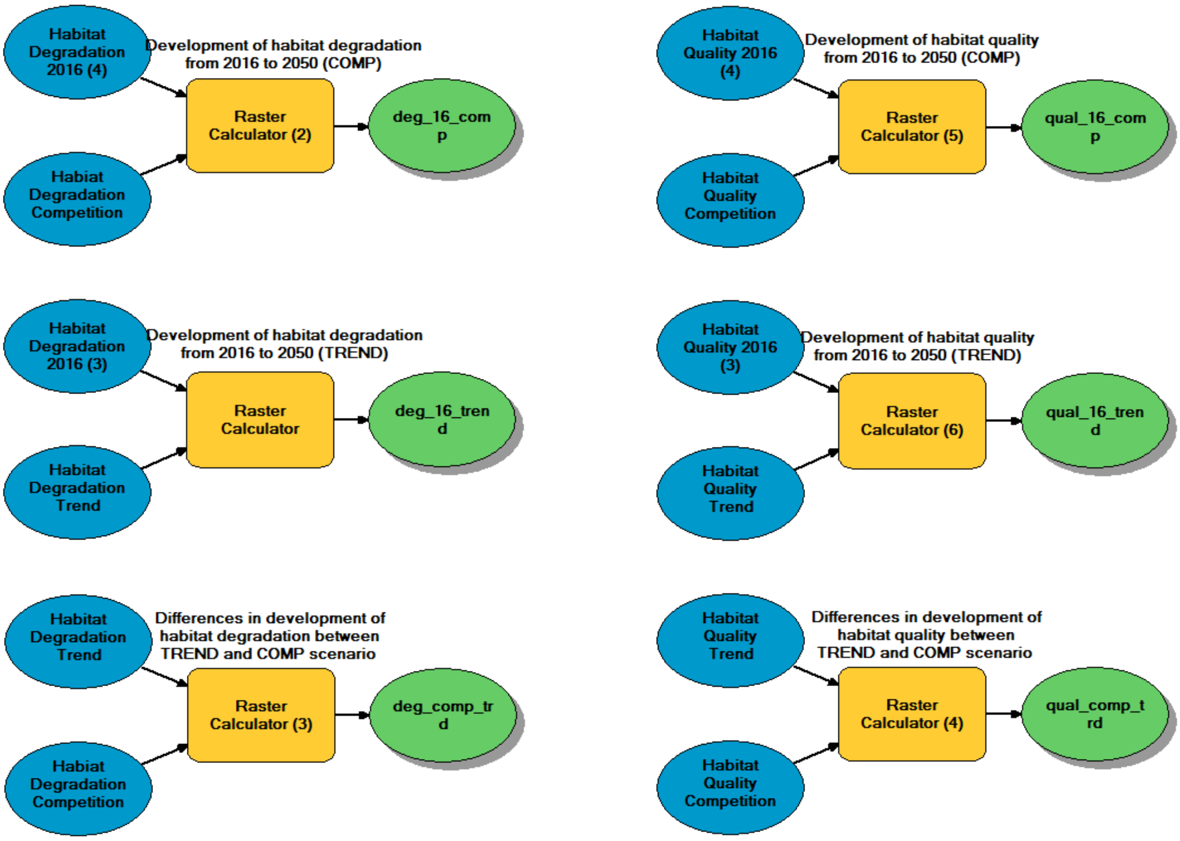

Fig. i: ArcGIS procedure to analyse development of habitat quality and habitat degradation from 2016 to 2050 and to analyse differences between the projections of the two future land use scenarios.

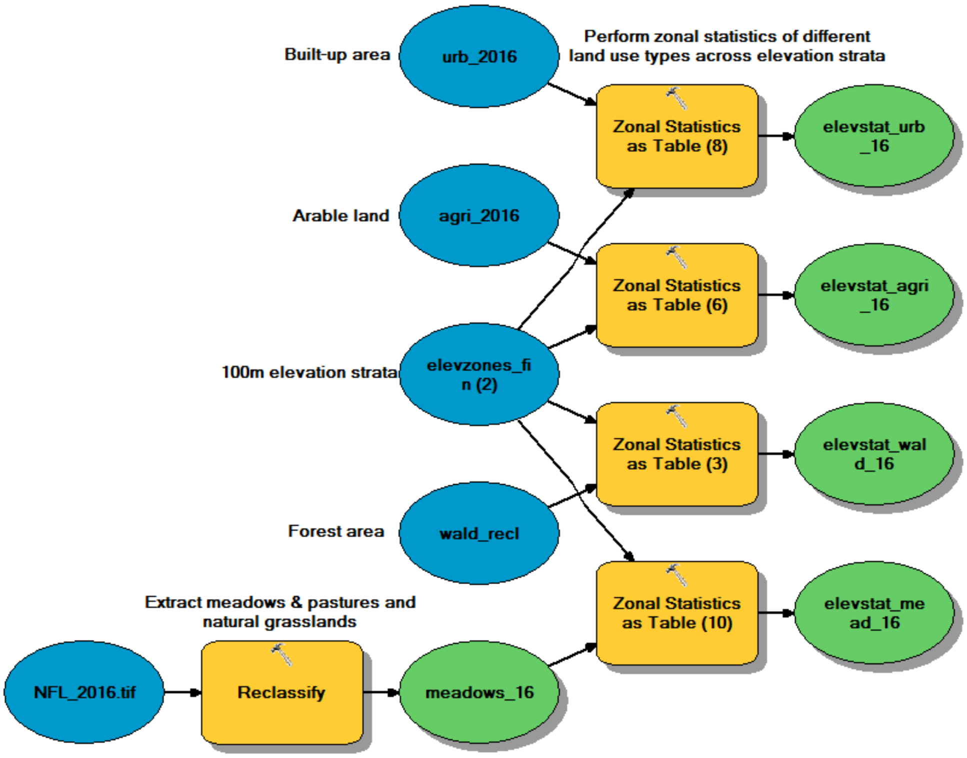

Fig. j: ArcGIS procedure to analyse distribution of different land use types (built-up, arable land, forest and open grass lands) as a function of elevation for 2016. The analysis for 2050 followed the same procedure with the respective scenario inputs instead.

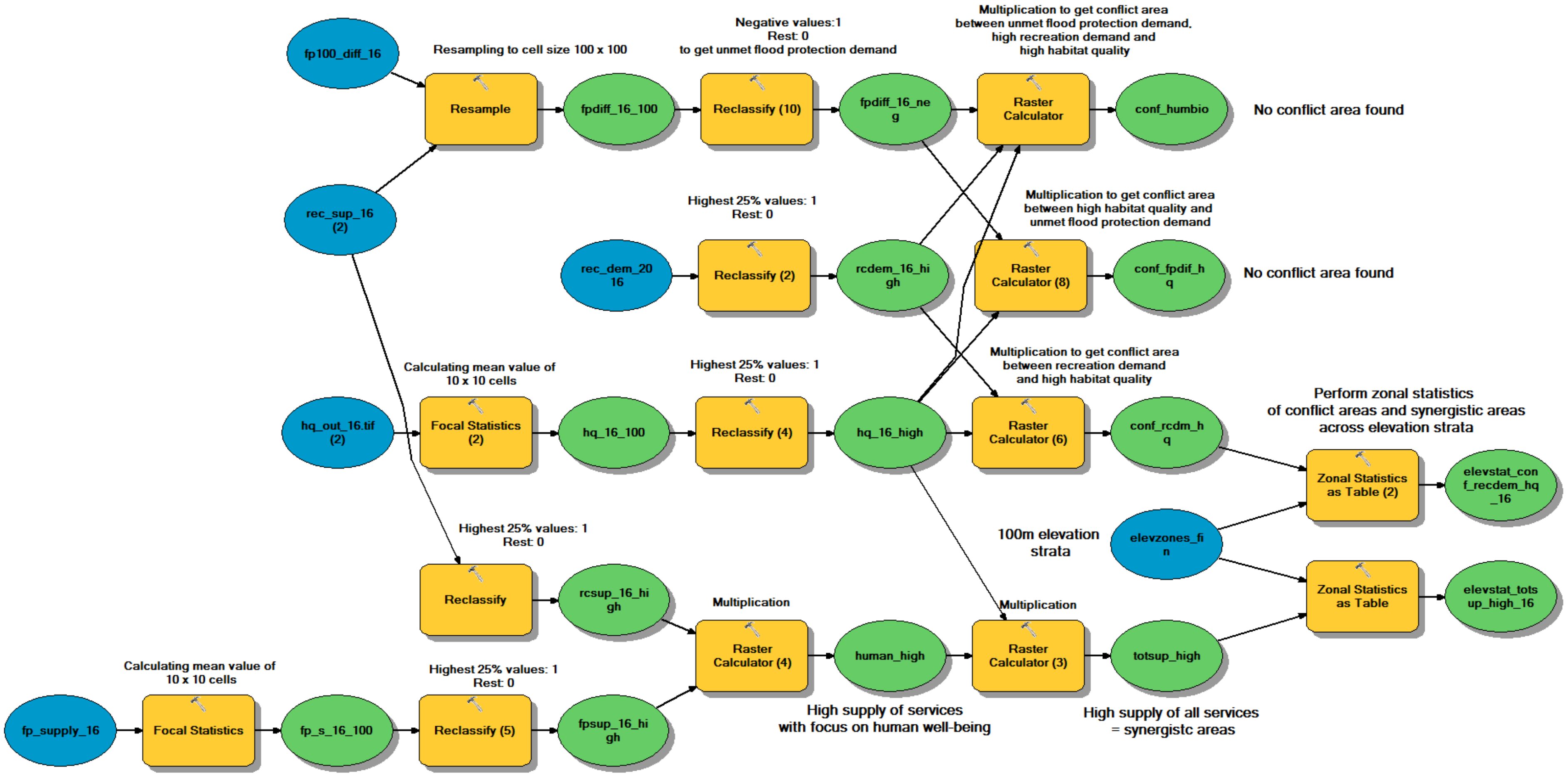

Fig. k: ArcGIS procedure to identify conflict and synergistic areas between flood protection, nearby recreation and biodiversity and to analyse the distribution of these areas as a function of elevation for 2016. The assessment for 2050 followed the same procedure with the respective scenario values instead.

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Eigenständigkeitserklärung

Die unterzeichnete Eigenständigkeitserklärung ist Bestandteil jeder während des Studiums verfassten Semester-, Bachelor- und Master-Arbeit oder anderen Abschlussarbeit (auch der jeweils elektronischen Version).

Die Dozentinnen und Dozenten können auch für andere bei ihnen verfasste schriftliche Arbeiten eine Eigenständigkeitserklärung verlangen.

Ich bestätige, die vorliegende Arbeit selbständig und in eigenen Worten verfasst zu haben. Davon ausgenommen sind sprachliche und inhaltliche Korrekturvorschläge durch die Betreuer und Betreuerinnen der Arbeit.

Titel der Arbeit (in Druckschrift):

The effects of land use change on ecosystem services in a mountainous region

Verfasst von (in Druckschrift):
Bei Gruppenarbeiten sind die Namen aller Verfasserinnen und Verfasser erforderlich.

Name(n):	**Vorname(n):**
Sauter	Isabel

Ich bestätige mit meiner Unterschrift:
- Ich habe keine im Merkblatt „Zitier-Knigge" beschriebene Form des Plagiats begangen.
- Ich habe alle Methoden, Daten und Arbeitsabläufe wahrheitsgetreu dokumentiert.
- Ich habe keine Daten manipuliert.
- Ich habe alle Personen erwähnt, welche die Arbeit wesentlich unterstützt haben.

Ich nehme zur Kenntnis, dass die Arbeit mit elektronischen Hilfsmitteln auf Plagiate überprüft werden kann.

Ort, Datum	**Unterschrift(en)**
Uhwiesen, 09.04.2018	I. Sauter

Bei Gruppenarbeiten sind die Namen aller Verfasserinnen und Verfasser erforderlich. Durch die Unterschriften bürgen sie gemeinsam für den gesamten Inhalt dieser schriftlichen Arbeit.