The impact of land use- and climate change on the managed eco-geomorphic balance in the Alps

Inauguraldissertation

Zur Erlangung der Würde eines Doktors der Philosophie

vorgelegt der

Philosophisch-Naturwissenschaftlichen Fakultät der

Universität Basel

von

Chatrina Caviezel

aus Cinuos-chel (Schweiz)

Basel, 2015

Originaldokument gespeichert auf dem Dokumentenserver der Universität Basel
edoc.unibas.ch

Dieses Werk ist unter dem Vertrag „Creative Commons Namensnennung-Keine kommerzielle Nutzung-Keine Bearbeitung 3.0 Schweiz" (CC BY-NC-ND 3.0 CH) lizenziert.
Die vollständige Lizenz kann unter
creativecommons.org/licenses/by-nc-nd/3.0/ch/
eingesehen werden.

Genehmigt durch die Philosophisch Naturwissenschaftliche Fakultät

auf Antrag von

Prof. Dr. Nikolaus Kuhn
(Universität Basel)
Fakultätsverantwortlicher / Dissertationsleiter

PD Dr. Margreth Keiler
(Universität Bern)
Korreferentin

Basel, den 17.02.2015

Prof. Dr. Jörg Schibler
Dekan

creative commons

Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0)

You are free to:

Share — copy and redistribute the material in any medium or format.

Under the following terms:

Attribution — You must give appropriate credit, provide a link to the license, and indicate if changes were made. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use

Non Commercial — You may not use the material for commercial purposes.

No Derivatives — If you remix, transform, or build upon the material, you may not distribute the modified material.

No additional restrictions — You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits

Notices:

You do not have to comply with the license for elements of the material in the public domain or where your use is permitted by an applicable exception or limitation

No warranties are given. The license may not give you all of the permissions necessary for your intended use. For example, other rights such as publicity, privacy, or moral rights may limit how you use the material

Source: http://creativecommons.org/licenses/by-nc-nd/4.0/ Date : 23.03.2015

Summary

During the last decades, agricultural development in European mountain regions has caused considerable changes in land use intensity and management and as a consequence, in land cover (Brugger et al. 1984; MacDonald et al., 2000; Bätzing, 2005). The changing economic conditions for mountain farmers are causing a trend towards intensification of centrally located areas where farm machines can be used, whereas remote areas unsuitable for mechanization of farming experience a marginalization. Additionally, future climate scenarios predict a reduction in summer average rainfall accompanied by an increase in short, but potentially devastating heavy rainfall events (Beniston, 2006). Mountain ecosystems are fragile and highly sensitive to environmental alteration like land use or climate change (Steinwidder et al., 2011). The "managed eco-geomorphic balance" in mountain landscapes depends on physical site factors, ecological patterns controlled by organisms, the human impact and on geomorphologic processes. Soils are at the interface of the spheres forming the landscape, and represent a crucial parameter in alpine ecosystem services providing water (Meusburger and Alewell, 2008; Sutter, 2009), nutrients (Sutter, 2009), substrate and habitat for flora and fauna (MacDonald et al., 2000). Soil and slope stability are limited due to low soil depth and soil formation rates. In addition, the steep slope angles are associated to large erosion and mass wasting rates (Alewell and Bebi, 2011). In awareness of the vulnerability to land degradation and due to the dependence on fertile soil resources, alpine landscapes have been actively managed for about 5000 years to ensure ecosystem services for subsistence farming (Bätzing, 2005). During the last decades, several studies report an increase of soil degradation processes in the Alpine region (Tappeiner and Cernusca, 1993; Dommermuth, 1995; Newesely et al., 2000; Tasser et al., 2003; Meusburger and Alewell, 2008, 2014). Considering the limited soil depth (Alewell and Bebi, 2011) and soil formation rate in Alpine regions (Sutter, 2009; Alewell and Bebi, 2011), an assessment of the effect of land use and climate change on the managed eco-geomorphic balance is essential to prevent soil loss and to promote a sustainable development of the Alpine region.

In order to determine the effects of land use and climate change on the managed eco-geomorphic balance, a reconstruction of the environmental history is needed, including the history of land use, mass wasting, and climate. Understanding the past interactions of land use, climate change and soil degradation processes can support the assessment of future risks of land degradation processes and is essential for directed measures to prevent the loss of soil resources. The Ursern Valley in the central Alps of Switzerland offers an ideal opportunity for studying the history of land degradation in the 20th century. Land tenure lies largely with the Korporation Ursern, owning 90% of the agricultural area in the valley (Wunderli, 2011). The Korporation Ursern stores detailed reports on pastures condition and mass wasting events reaching back to 1900. Further on, the reports provide information on extreme weather events, land use intensity and land use management, which can be analyzed in the context of the mass wasting history. In addition, the study area experienced an increase in land degradation since the 1950s. According to Meusburger and Alewell (2008), the eroded area in the Ursern Valley nearly doubled between 1959 and 2004. Thus, a distinct research on the managed eco-geomorphic balance and its controlling factors is necessary.

The first study, published in Die Erde, (Caviezel et al., 2010), aimed at determining the applicability of historical data for the purpose of detecting triggering factors for mass wasting processes and at reconstructing mass wasting and land use history. Based on a pre-analysis of the reports, a checklist for the qualitative and semi-quantitative document analysis of classifiable parameters with relevance for mass wasting processes and land-use management was developed. The analysis of historical data showed, that mass wasting events are not distributed uniformly in time and space. A concentration of mass wasting events was found on geological sensitive areas of the Mesozoic layer shortly after the abandonment of use restrictions.

In order to distinguish between the effect of land use intensity and the change in rainfall characteristics on the increased surface degradation, a second study, published in Geoöko (Caviezel and Kuhn, 2012), was performed. Reported mass wasting events recorded in the historical archives were set in context to rainfall data of the “Swiss Meteo” station in Andermatt. The analysis of rainfall data allowed defining a threshold magnitude for triggering mass wasting events. Extreme rainfall events can therefore be considered as trigger for mass wasting events. However, the frequency analysis of rainfall events above the threshold magnitude and of mass wasting events revealed that the period of highest mass wasting frequency does not correlate with the period of highest frequency of potentially triggering rainfall events. Thus, land use change has affected the susceptibility of landscape towards mass wasting processes as shown by the increased frequency of mass

wasting events that coincides with significant changes in land use and the abolishment of use restrictions.

A third study prepared for publication (Caviezel et al., 2015, in prep.), concentrated on the quantification of land abandonment. In the Unteralptal, a side valley of the main Ursерntal, landscape characteristics show considerable changes primarily by the heterogeneous encroachment of green alder (*Alnus viridis*) and Alpine rose (*Rhododendron ferrugineum*) on former pasture areas. The area encroached by shrubs was analyzed using a series of air photographs. The results showed an increase of green alder cover of 63% between 1959 and 2007. The study also illustrated an interesting effect of the way land cover change is calculated in mountain areas. Assuming the conventional planimetric view, the area covered by shrubs increased by 72.8 ha, while the true area generated values of 86.7 ha. The latter difference is of particular importance when assessing issues such as net primary production or nutrient turnover in a biogeochemical context. Additionally, the analysis of the topographic and geomorphic landform characteristics of newly encroached areas since 1959 shows that green alder shrubs colonize noticeably areas with less geomorphic activity, more gentle slopes and south aspect, showing that the habitat spectrum of green alder is much wider than assumed. Thus, the previous green alder cover was mostly controlled by the former intensive land use on the adjacent areas

A final study in the Unteralptal, published in Earth Surface Processes and Landforms (Caviezel et al., 2014), was performed in order to assess the effects of land abandonment and shrub encroachment on soil stability. Along a chronosequence of shrub encroachment, identified by air photograph analysis, an index for soil stability was generated based on measuring shear resistance, penetration resistance, soil bulk density and rooting density. Soil properties, relevant for soil erosion caused by water runoff and mass movement, show two signals of change towards a greater erosion risk: i) a decreasing shear and penetration resistance after 15 years of shrub encroachment and ii) an increasing porosity, associated with an increase in infiltration capacity, after 40-90 years of shrub encroachment. The increased porosity decreases the stability of the less compacted soil potentially leading to greater rates of soil creeping; the increased infiltration capacity reduces soil erosion by running water. The complex interaction between soil and changing vegetation reveals that neither a general association of land cover with surface processes nor a single soil parameter are sufficient to assess the impact of land use change on slope stability.

The four studies in the central Alps showed that both, land use intensification as well as land abandonment, have a remarkable effect on the managed eco-geomorphic balance, and thus, on soil stability. Land use intensification on pastures, especially on slopes that are prone to mass wasting due to their geology, increases the frequency of solitary high

magnitude landslide events. High magnitude rainfall events affected the managed eco-geomorphic balance predominantly in connection with the mentioned land use intensification. This result shows that the effect of land use change has a high relevance for the managed eco-geomorphic balance in Alpine regions comparable to the effect of climate change. Land abandonment changes surface processes towards continuous soil creeping processes of loose soil prone to liquefaction. Beside climate change, it is therefore necessary to consider the changes in soil properties and vegetation composition as well as their interaction with land use, to understand the current and future change in the managed eco-geomorphic balance.

Zusammenfassung

Seit der zweiten Hälfte des 20. Jahrhunderts führt der Strukturwandel zu Veränderungen in der Nutzungsintensität und den Unterhaltsmassnahmen in der alpinen Landwirtschaft. Strukturschwache, schwer erreichbare Gebiete, wie beispielsweise abgelegene Alpweiden, werden extensiviert oder brachgelegt, wohingegen in lagegünstigen Gebieten die Landwirtschaft intensiviert wird (Brugger et al. 1984; MacDonald et al., 2000; Bätzing, 2005). Dadurch verändert sich auch das Landschaftsbild der Alpen. Zudem weisen Klimaszenarien auf eine Verringerung von Sommerniederschlägen hin, welche jedoch mit einer Zunahme von verheerenden Starkniederschlägen einhergeht (Beniston, 2006). Das alpine Ökosystem befindet sich in einem fragilen Gleichgewicht und reagiert sehr sensibel auf Änderungen der Landnutzung und der klimatischen Bedingungen (Steinwidder et al., 2011). In Abhängigkeit der Interaktion zwischen den natürlichen Standortfaktoren, den ökologischen Begebenheiten, welche durch Organismen beeinflusst sind, dem anthropogenen Einfluss sowie den geomorphologischen Prozessen hat sich ein „aktiv gestaltetes öko-geomorphologisches Gleichgewicht“ in der alpinen Landschaft gebildet. Landnutzungs- und Klimaänderungen führen jedoch zu ökologischen Folgeerscheinungen wie Veränderungen der Vegetationszusammensetzung, der Bodenproduktivität oder des Bodenwasserhaushalts. Böden stellen dabei die Schnittstelle landschaftsformender Prozesse dar und sind ausschlaggebend für verschiedene alpine Ökosystemdienstleitungen wie die Wasserversorgung (Meusburger und Alewell, 2008; Sutter, 2009), die Nährstoffversorgung (Sutter, 2009), das Vorhandensein von Substrat und als Lebensraum für Flora und Fauna (MacDonald et al., 2000). Die Ressource Boden wie auch die Bodenstabilität in den Alpen ist aufgrund der geringen Bodenmächtigkeit sowie der geringen Bodenbildungsrate begrenzt. Zudem weisen die steilen Hänge auf eine natürlich hohe Verwundbarkeit alpiner Böden gegenüber Bodenerosion und Massenbewegungsprozessen hin (Alewell und Bebi, 2011). In Abhängigkeit der Ressource Boden und im Bewusstsein, dass diese Ressource natürlicherweise durch Massenbewegungsprozesse gefährdet ist, wurde der Naturraum der Alpen während 5000

Jahren durch eine flächenhafte, dezentrale und an die den natürlichen Gegebenheiten angepasste Nutzung bewirtschaftet. Durch die aktive Bewirtschaftung wurden die Ökosystemdienstleistungen und die Subsistenzwirtschaft erhalten. Verschiedene Untersuchungen aus dem Alpenraum zeigen jedoch, dass Massenbewegungsprozesse in den letzten Jahrzehnten stark zugenommen haben (Tappeiner und Cernusca, 1993; Dommermuth, 1995; Newesely et al., 2000; Tasser et al., 2003; Meusburger und Alewell, 2008, 2014). In Anbetracht der geringen Mächtigkeit und Bildungsraten alpiner Böden (Alewell und Bebi, 2011; Sutter, 2009), ist es daher von grosser Bedeutung, die Auswirkungen von Landnutzungs- und Klimaänderungen auf das aktiv gestaltete öko-geomorphologische Gleichgewicht der Alpen abschätzen zu können, um auch zukünftig eine nachhaltige Nutzung zu gewährleisten.

Im Rahmen dieser Doktorarbeit werden die Auswirkungen der Nutzungsintensivierung wie auch die Folgen der Nutzungsaufgabe und veränderter Niederschlagsmuster auf die Bodenstabilität in den Alpen untersucht. Um zwischen den Auswirkungen der Landnutzungsänderungen und der Veränderungen der klimatischen Bedingungen auf die Bodenerosion unterscheiden zu können, ist es notwendig, sowohl die Nutzungsgeschichte, die Klimageschichte, wie auch die Geschichte von Massenbewegungsprozessen zu rekonstruieren. Das Verständnis des Zusammenwirkens von Landnutzungs- und Klimaänderungen sowie von Massenbewegungsprozessen in der Vergangenheit, kann bei der Abschätzung zukünftiger Risiken für die Ressource Boden helfen und ist notwendig, um gezielte Massnahmen gegen den Verlust der Ressource Boden einzuleiten.

Das Urserntal in der Zentralschweiz bietet eine einzigartige Möglichkeit, die Geschichte von Massenbewegungen zu rekonstruieren. Die Landnutzung im Urserntal ist stark mit der Korporation Ursern verbunden, welche 90% der landwirtschaftlich genutzten Fläche besitzt und alljährlich Inspektoren beauftragt, die Nutzungsintensität, die Fronarbeiten, sowie die Art und Lokalität von Massenbewegungsprozessen auf den Wiesen und Weiden des Urserntals festzuhalten. Daher ist die Nutzungsgeschichte des Urserntals in jährlichen „Alpinspektionsberichten“ seit dem Beginn des 20. Jahrhunderts im regionalen Archiv in Andermatt dokumentiert. Zudem wurde im Urserntal in einer Studie eine beinahe Verdoppelung der von Bodenerosion betroffenen Flächen zwischen 1959 und 2004 festgestellt (Meusburger und Alewell, 2008). Eine differenzierte Untersuchung der Auswirkungen von Landnutzungs- und Klimaänderungen auf das aktiv gestaltete öko-geomorphologische Gleichgewicht der Alpen und dessen kontrollierende Faktoren ist daher notwendig.

Die erste Untersuchung mit dem Ziel die historischen Quellen auf ihre Verwendbarkeit zur Rekonstruktion der Massenbewegungen und der beteiligten Prozesse zu prüfen und die

Geschichte der Massenbewegungen zu rekonstruieren, wurde in der Zeitschrift „Die Erde“ veröffentlicht (Caviezel et al., 2010). Aus einer Voruntersuchung der Alpinspektionsberichte wurde ein Raster für die qualitative und semi-quantitative Dokumentenanalyse anhand von klassifizierbaren, relevanten Auswahlparametern für Massenbewegungsprozesse und die Landnutzungsgeschichte, erstellt. Die Untersuchung zeigt einerseits, dass sich die historischen Quellen dazu eignen, die auslösenden Faktoren für Massenbewegungsprozesse qualitativ zu identifizieren, andererseits zeigt die Untersuchung auch, dass sich die Massenbewegungsprozesse räumlich und zeitlich konzentrieren. Eine Häufung der Prozesse wurde in den geomorphologisch sensiblen Bereichen der Freiberge kurz nach der Aufhebung der Nutzungsbeschränkungen gefunden.

Eine weitere Untersuchung, welche in der Zeitschrift „Geoöko“ (Caviezel und Kuhn, 2012) veröffentlich wurde, befasst sich mit der Unterscheidung zwischen den Auswirkungen von Landnutzungsänderungen und der Veränderung von Niederschlagsmustern auf Massenbewegungsprozesse. Dabei wurden die Niederschlagsdaten von „Meteo Schweiz“ der Station Andermatt analysiert und mit den in den Alpinspektionsberichten erwähnten Massenbewegungsprozessen in Bezug gesetzt. Dadurch konnte ein Niederschlagsschwellenwert für das Auslösen von Massenbewegungsprozessen identifiziert werden. Die Frequenzanalyse der Niederschlagsereignisse über dem ermittelten Schwellenwert und der Massenbewegungsprozesse zeigt jedoch, dass die Periode mit der höchsten Frequenz von potentiell auslösenden Niederschlagsereignissen nicht mit der Periode der höchsten Frequenz von Massenbewegungen übereinstimmt. Die Zunahme der Niederschlagsereignisse mit hoher Magnitude kann daher zwar als auslösender Faktor für Massenbewegungsprozesse betrachtet werden, allerdings hat der Wandel in der Landnutzung die Verwundbarkeit der Landschaft gegenüber Massenbewegungsprozessen und Landdegradierung ebenfalls so stark beeinflusst. Dies zeigt die Tatsache, dass die Zunahme in der Häufigkeit von Massenbewegungsprozessen mit drastischen Änderungen in der Landnutzung zusammenfällt.

In einer dritten Untersuchung, welche zur Veröffentlichung vorbereitet wird (Caviezel et al., 2015, in prep.), wurde in einem Seitental des Urserntals, dem Unteralptal, die Verbuschung der Weideflächen seit 1959 analysiert. Das Unteralptal zeigt eine augenfällige Verbuschung mit Grünerlen (*Alnus viridis*) und Alpenrosen (*Rhododendron ferrugineum*), welche mittels der Analyse von Luftbildern quantifiziert wurde. Die Verbuschung ehemaliger Weideflächen dient als Indikator für die Aufgabe der Landnutzung. Das mit Grünerlen verbuschte Gebiet im Unteralptal hat seit 1959 um 63% zugenommen. Dabei konnte aufgezeigt werden, dass bei der Quantifizierung von Flächen in Bergregionen der Ansatz der herkömmlichen planimetrischen Berechnung nicht ausreichend ist. Die verbuschte Fläche nimmt nach dem planimetrischen Ansatz um 72.8 ha zu, wird Fläche jedoch oberflächengetreu berechnet,

nimmt das neu verbuschte Gebiet eine Fläche von 86.7 ha ein. Diese Unterschiede sind vor allem im biochemischen Kontext bei Berechnungen der Nettoprimärproduktion und des Nährstoffumsatzes von Bedeutung. Zudem zeigt die Analyse der seit 1959 verbuschten Flächen hinsichtlich ihrer topographischen Eigenschaften und der ihnen zugeordneten Landformen, dass sich die Grünerlen zusehends auf geomorphologische weniger aktive Bereiche wie auch auf Bereiche geringerer Hangneigung und südlicher Ausrichtung ausdehnen. Dies zeigt, dass die Grünerle ein viel breiteres Standortspektrum hat als bisher vermutet wurde und dass die Ausbreitung der Grünerle vorwiegend durch die Landnutzung kontrolliert wird.

Die letzte Untersuchung, welche in der Zeitschrift „Earth Surface Processes and Landforms" veröffentlicht wurde (Caviezel et al., 2014), widmet sich den Auswirkungen der Nutzungsaufgabe und der Verbuschung auf die Bodenstabilität. Dabei wurden entlang einer Chronosequenz von Grünerlen (*Alnus viridis)*, welche auf der Basis einer Luftbildanalyse ermittelt wurde, der Scherwiderstand, der Eindringwiderstand, die Bodendichte, sowie die Durchwurzelung als Index für die Bodenstabilität gemessen. Die Bodeneigenschaften, welche für die Bodenerosion durch Oberflächenabfluss sowie für Massenbewegungsprozesse relevant sind, deuten in zweierlei Hinsicht auf ein erhöhtes Erosionsrisiko hin: i) Die Ergebnisse zeigen bereits nach 15-jähriger Verbuschung eine signifikante Verminderung des Scher- und Eindringwidertandes, ii) eine Verringerung der Bodendichte und damit einhergehend eine Zunahme der Infiltrationskapazität zwischen 40- und 90-jähriger Verbuschung. Die Veränderungen implizieren eine Veränderung der Erosionsprozesse. Einerseits wird durch die Verbuschung die Bodenerosion durch Oberflächenabfluss verringert, da der Boden eine erhöhte Infiltrationskapazität aufweist. Zudem wird das Abgleiten ganzer Bodenschollen durch die Wurzeln der Grünerle verhindert. Andererseits zeigen die geringen Scherwiderstände und die erhöhte potentielle Wassersättigung der Böden jedoch eine Tendenz zu erhöhten Kriechprozessen. Die Komplexität der Prozesse zwischen der Veränderung der Vegetation und den Bodeneigenschaften zeigt, dass keine allgemeingültige Aussage über die Landnutzungsaufgabe und der damit einhergehenden Veränderung der Bodenbedeckung und die Bodenstabilität gemacht werden kann. Zudem können die Auswirkungen der Landnutzungsaufgabe auf die Bodenstabilität nicht anhand der Veränderung eines einzelnen Bodenparameters abgeschätzt werden.

Die vier Untersuchungen im Urserntal zeigen, dass sowohl die Intensivierung wie auch die Aufgabe der Landnutzung, das aktiv gestaltete öko-geomorphologische Gleichgewicht und damit die Bodenstabilität, stark beeinflussen. Vor allem in geomorphologisch empfindlichen Bereichen erhöht die Intensivierung der Landnutzung durch eine intensive Beweidung die Frequenz von Erdrutschereignissen. Extreme Niederschlagsereignisse führten vor allem in

Verbindung mit der Nutzungsintensivierung besonders häufig zu Erdrutschereignissen. Dies zeigt, dass der Veränderung der Landnutzung eine besondere Bedeutung hinsichtlich der Stabilität alpiner Böden zukommt, welche der Bedeutung der veränderten klimatischen Bedingungen zumindest gleichkommt. Auch die Aufgabe der Landnutzung kann die Stabilität alpiner Böden verändern und aufgrund der erhöhten Wassersättigung zu kontinuierlichem Bodenkriechen der losen Bodenpartikel führen. Daher ist es wichtig, neben der Veränderung der klimatischen Bedingungen auch die Veränderung der Bodeneigenschaften, der Vegetationszusammensetzung wie auch deren Wechselbeziehungen mit Landnutzungsänderungen zu verstehen um aktuelle und zukünftige Veränderungen des aktiv gestalteten öko-geomorphologischen Gleichgewichts alpiner Regionen zu verstehen.

Content

Chapter 3

Chapter 4

Chapter 5

Chapter 6

Chapter 7

List of Figures

List of Tables

List of Photos

Chapter 1

1 Introduction

1.1 Man-made cultural landscapes in the Alps

In the European Alps, traditional agricultural cultivation forms have generated unique landscapes and habitats of high ecological value (Gellrich and Zimmermann, 2007). For large parts, agriculture in alpine areas is a land of man-made meadows and pastures (Tasser et al., 2011), developed by clearance and by suitably adapted utilization. Only the traditional low intensive use of grazing and mowing adapted to natural site factors (Bätzing, 2005; Strijker, 2005; Soliva et al., 2008) and the work intensive maintenance practices (MacDonald et al., 2000) guaranteed sustainable productivity in these areas. The long lasting traditional land use created a man-made cultural landscape that was kept in an artificial balance with natural degradation processes, affecting the fertile soil layer, by active management. At one time, alpine pasture farming was inevitable to keep the artificially developed ecosystem in balance and thus sustain productivity (Dommermuth, 1995). During the last decades, an increase of soil loss is reported in several studies for many areas of the Alps (Dommermuth, 1995; Newesely et al., 2000; Meusburger and Alewell, 2008). As most of the triggering factors for mass wasting events such as geology and slope are quasi static and do not change over the time period of some decades, the recent increase of events leading to soil loss must be driven by dynamic factors like anthropogenic influence such as land use or climate change.

1.2 Land use change and the managed eco-geomorphic balance

During the last century, agricultural structures in the Alps changed induced by political, economic and social changes (Flury et al., 2013). Due to high production costs, farming in mountain regions became disadvantaged in a globalized market (Streifeneder et al., 2007b). This caused a polarization in land use intensity (Tappeiner et al., 1998; Bätzing, 2005). On more accessible areas near valleys, intensity of use increased steadily, implying

for example the use of fertilizer (Bätzing, 2005) or an increase of cutting per year (MacDonald et al., 2000; Bätzing, 2005; Maurer et al., 2006; Niedrist et al., 2008; Tasser et al., 2011). On the other hand, marginal areas experienced land abandonment and traditional farming practices were abolished (Bätzing, 2005; Tasser et al., 2011). Former hay meadows were converted to grazing pasture land and remote pasture land fell into disuse (Bätzing, 2005).

The changes in land use have a strong effect on the artificially developed and managed ecosystem balance of wide areas and carry the risk of an increase of soil degradation processes, as reported in several studies (Tappeiner and Cernusca, 1993; Dommermuth, 1995; Newesely et al., 2000; Meusburger and Alewell, 2008; Tasser et al., 2003). According to Renschler et al., (2007), ecosystem and geomorphic processes are mutually dependent. Changes in land use dramatically alter land cover and ecosystems and, as a consequence, are subjected to affect geomorphic activity (Renschler et al., 2007). This leads to the conceptual term “managed eco-geomorphic balance” including the active management of landscapes, the interaction of ecological patterns controlled by organisms, the physical site factors and the geomorphic processes, driven by physical site factors and ecosystem properties. Soils are at the interface of the spheres forming the landscape, and represent a crucial parameter in alpine ecosystems providing water (Meusburger and Alewell, 2008; Sutter, 2009), nutrients (Sutter, 2009), substrate and habitat for flora and fauna (MacDonald et al., 2000). As soil depth, vegetation period (Alewell and Bebi, 2011) and soil formation rates (Sutter, 2009; Alewell and Bebi, 2011) decrease with altitude, the artificial “managed” balance is crucial to preserve the ecological functions of the mountain environment. The current risk of land degradation in the Alps, documented in several studies (Tappeiner and Cernusca, 1993; Dommermuth, 1995; Newesely et al., 2000; Meusburger and Alewell, 2008; Tasser et al., 2003), gives evidence for a change in the managed eco-geomorphic balance. Changes in land use practices and intensity have been shown to affect many above- and belowground soil properties, contributing to the managed eco-geomorphic balance, and affect soil and slope stability by various processes. Land use intensification by intensive mowing and the use of machines and fertilizer, for example, cause soil compaction and changes in vegetation composition towards species with lower rooting depth (Von Wyl, 1987; Schmidlin, 2008; Bosshard et al., 2010). Further, intensive grazing with heavier cattle (Bätzing, 2005) leads to trampling, terracing, soil compaction, soil injuries and missing plant cover. The mentioned changes in above- and belowground soil properties affect the managed eco-geomorphic balance as they lead to a decrease of soil anchoring by diverse rooting, a decrease of infiltration capacity and an increase of runoff. Thus, land use change can be expected to have substantial effects on the managed eco-geomorphic balance (Alewell and Bebi, 2011) associated with risks for sustainable ecosystem services.

The traditional low intensity farming with grazing and mowing aimed at maintaining the productivity on the largest possible area and influenced surface processes by traditional cultivating methods, as for example drainage measures, debris collection and mowing on steep areas. Depending on the type, the management and the intensity of land use, a high diversity of landscapes and vegetation communities developed (Tasser and Tappeiner, 2002). According to Spiegelberger et al. (2006), species and habitat diversity shows to be of main importance to preserve ecosystem services such as prevention of soil loss or the maintenance of hydrological cycles.

The effect of land use change on the managed eco-geomorphic balance in alpine mountains depends on both human disturbance and protection. Today, approximately one third (31.4%) of the European alpine area with an extent of 190600 km^2 is still used for agricultural purposes and thus also contributes to the maintenance of a diversified cultural landscape in the Alps (Streifeneder, 2010). However, in large parts of the Italian, French and the Slovene Alps, as well as in the Swiss Alps, the significance of the agricultural sector is in sharp decline (Tasser et al., 2011). Therefore, both land use intensification and abandonment are landscape shaping processes in alpine areas.

Land abandonment changes the vegetation composition and reduces plant density and species diversity (Fischer and Wipf, 2002; Anthelme et al., 2003; Dullinger et al., 2003; Niedrist et al., 2008). According to Spiegelberger et al. (2006), species diversity shows to be of main importance to preserve ecosystem services such as prevention of soil loss, maintenance of hydrological cycles or ecosystem goods, like tourism and recreation. On average, land use has been abandoned on 20% of the agricultural land of the Alps between 1980 and 2000, in some regions even on 70% of the former used areas (MacDonald et al., 2000; Tappeiner, 2003). Therefore, understanding the consequences of land abandonment seems to be essential for alpine ecology. Abandoned land will be exposed to natural processes of succession. Generally, an established perennial vegetation cover improves the mechanical anchoring of the soil and the regulation of the soil water budget and hampers therefore runoff generation and erosion. However, the changing vegetation composition in the course of succession affects many above- and belowground properties like root density, diversity and geometry (Tasser et al., 2003), soil structure, pore volume, acidity (Caviezel et al., 2014), and evapotranspiration rates (Körner et al., 1978), which can enhance or hamper soil degradation processes.

Thus, interaction between vegetation and soil properties can vary and reduce or enhance stability, depending on former land use, species composition and time after abandonment. Therefore, the spatial and temporal identification of such areas is essential for estimating the impact of land abandonment on the former managed eco-geomorphic balance. As

abandoned areas lost their economic relevance, the knowledge on land use history and the soil degradation processes of these areas is limited. By using proxies, as for example the chronologic encroachment by shrubs, land use abandonment can be reconstructed.

1.3 Climate change and the eco-geomorphic managed balance

Changes in the Alps have not been limited to land use alone. Several studies point to the vulnerability of hillslope processes to climate change (Beniston, 2003; Keiler et al., 2010; Beniston et al., 2011). Average temperature in the Alps increased by 2 °C during the 20th century (Beniston et al., 2011), inducing substantial changes in the length of the growing season (Beniston et al., 2003), site specific vegetation composition (Gottfried et al., 1998; Theurillat and Guisan, 2001; Dirnböck et al., 2003) and the upwards shifting of specific vegetation compositions (Pauli et al., 1996; Walther et al., 2005). A significant increase of intense rainfall event between 1901 and 1994 was found for winter and autumn for northern Switzerland and at least a positive trend was observed for almost all climate stations of the Swiss Alps by Frei and Schär (2001). According to the IPCC, the frequency and intensity of such heavy precipitation events over land will likely increase on average in the near term (Kirtman et al., 2013). Future scenarios foresee that mean and extreme precipitation values may undergo a seasonal shift with more spring and autumn heavy precipitation events than at present and fewer in summer (Beniston, 2006; Stoffel et al., 2014). As vegetation during autumn and spring is sparse, the increase of autumn and spring rainfall on the northern ridge of the Alps (Beniston, 2006) can result in an increase of erosion, as interception and evapotranspiration are limited and surface runoff as well as infiltration increase. This leads to an increase of shallow landslides induced by excess load and positive water pore pressure and soil erosion due to surface runoff. The effect can be enhanced, if heavy rainfall events coincide with spring snow melt (Fuhrer et al., 2006).

As function of shifts in both temperature and precipitation, climate change affects soil stability indirectly by the alteration of snow cover and snow processes. According to Beniston (2003), long term average climatic conditions during the 20th century have favored a longer snow season at high elevations above 2000 m a.s.l. in the Swiss Alps. Below 1500 m a.s.l., snow cover duration changed towards lower snow accumulation and earlier snow melting (Beniston, 1997). The thicker snow pack at higher altitudes results in greater runoff rates from snow melt in spring. In addition, the aforementioned increased precipitation in spring and autumn will less often fall as snow in lower altitudes. This results in an increase of runoff and landslide risk. During the last decades, several extreme rainfall events led to severe soil damage in the Alps (Rebetez et al., 1997; Beniston, 2006; Meusburger, 2010).

Another important proxy for changes in snow dynamics is the frequency of avalanches, which is regarded as potential risk factor for landslides (Meusburger et al 2008).

Meusburger et al. (2008) conclude that, due to the absence of tension fissures, avalanches do not directly trigger landslides, but rather occur at the same place, as stability of snow cover and stability of soils are controlled by similar environmental conditions(Meusburger and Alewell, 2008).

1.4 Aims and outline of the thesis

The ongoing changes of land use and climate and the vulnerability of the managed eco-geomorphic balance of alpine soils, gives evidence for a better understanding of the current processes affecting the stability of alpine soils. The aim of this PhD thesis is to determine to which extent land use and climate change affect the managed eco-geomorphic balance using historical data. In a first step, the trends of soil degradation processes are examined for the study site in central Switzerland. However, it is difficult to distinguish between the effect of climate and land use change, especially if historical data is limited. The identification of triggering factors for land degradation events requires a high temporal resolution of mass wasting history and climate data as well as additional information on land use. In order to identify areas that experienced land abandonment and to assess the effect of land abandonment on the land degradation processes, proxies for land abandonment, as for example the encroachment of shrubs, are needed. Thus, the following research questions stimulated this PhD thesis.

1. Is it possible to link the spatial and temporal appearance of mass wasting events in the Urserntal to changes in land use practices or climate change, or both?
2. Is shrub encroachment a suitable proxy for land abandonment in the Urserntal?
3. How does land abandonment affect the previously managed eco-geomorphic balance?

The content of the present PhD thesis is summarized in Figure 1.1 and structured as follows: An overview on agricultural structures and rural development in the European and particularly in the Swiss Alps since the 1960s is provided in chapter 2. A focus is thereby given on farm and land abandonment, the Swiss agricultural policies having an important impact on Swiss mountain agriculture, and on the ecological effects of land use change. The study site and its agricultural history and structures are introduced in chapter 3. In addition, subchapter 3.3 discusses whether the chosen study site, the Urserntal, acts as representative for the current development in other alpine regions. A detailed description on the physical geography of the study site is given in the journal contributions, sections 4.2, 5.2, 6.2 and 7.2. The first research question is addressed in the chapters 4 and 5. Chapter 4 focuses on the analysis of historical reports concerning their applicability to study mass wasting history and concerning the spatial and temporal occurrence of mass wasting events. With the focus on the differentiation of land use and climate change as triggering

factor of mass wasting events, the study presented in chapter 5 analyzed meteorological data in order to identify the influence of changing rainfall magnitude on the managed eco-geomorphic balance. The results of the two studies allow distinguishing between the effects of changing rainfall characteristics and intensification of land use on land degradation processes. The study presented in chapter 6 addresses the second research question. In order to identify areas that experienced an abandonment of land use, a chronosequence of shrub encroachment was established, by the identification of step wise shrub encroachment, using air photographs of different age. Analyzing the topographic and geomorphologic properties of the areas that experience an encroachment of shrubs in the Unteralptal, a side valley of the main Ursental, the encroachment of shrub could be related to the change in land use. The effect of land abandonment on the previously managed eco-geomorphic balance of hillslopes, in particular the surface process domain is addressed in chapter 7. Thereby, measurements of soil stability indices along the chronosequence were performed in order to estimate and characterize the previously managed eco-geomorphic balance after abandonment. The synthesis in chapter 8 summarizes the results of the presented studies attempting to answer the major research questions that were raised in the introduction and evaluate the impact of land use and climate change on the managed eco-geomorphic balance in alpine regions.

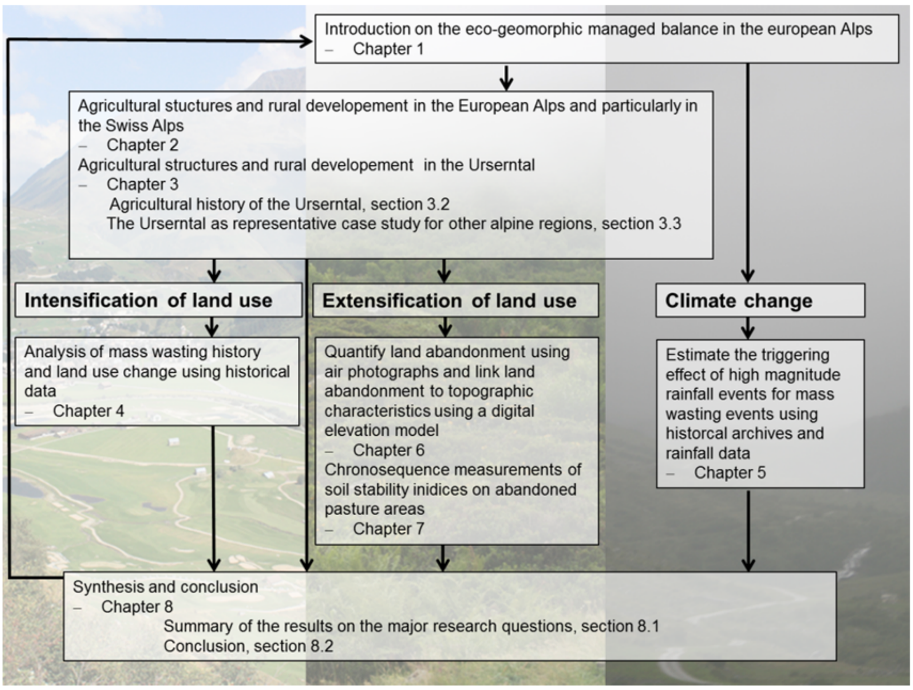


Figure 1.1: Main sections and outline of the PhD thesis.

Chapter 2

2 Agricultural structures and rural development in the European Alps and particularly in the Swiss Alps

2.1 Introduction

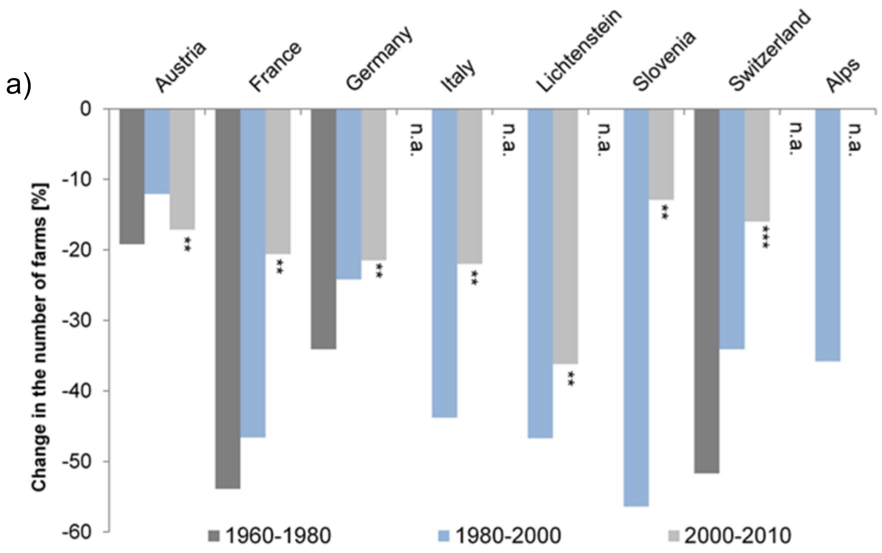
The following chapter gives an introduction to the history of alpine agriculture, the social and structural changes that took place during the 20th century, and their impact on alpine ecology. The main focus is on Swiss alpine agriculture, whereby developments are compared to other countries of the alpine arc. In order to understand the motivation behind the changes in land use, it is necessary to know how social, structural and economic changes affected alpine agriculture during the last century. An overview is given in section 2.2. Besides social and economic circumstances, changes in land use practices depend on agro-political factors. Thus, the continuation of traditional agricultural practices depends heavily on direct support from the government (Strijker, 2005). According to Tappeiner (2003), farmers' decisions are heavily influenced by market support, direct payments, agro-environmental policies and environmental legislation. Therefore, an overview on Swiss agriculture policies and their effects on land use practices is given in section 2.3. As land use change has an enormous impact on land cover, chapter 2.4 focuses on the quantification of the utilized agricultural area, in the following named "agricultural area" in Switzerland and the quantification of land abandonment and forest regrowth. Section 2.5 gives an overview on the effects of land use change on alpine ecology. This is essential for estimating the effects of land use change on the managed eco-geomorphic balance.

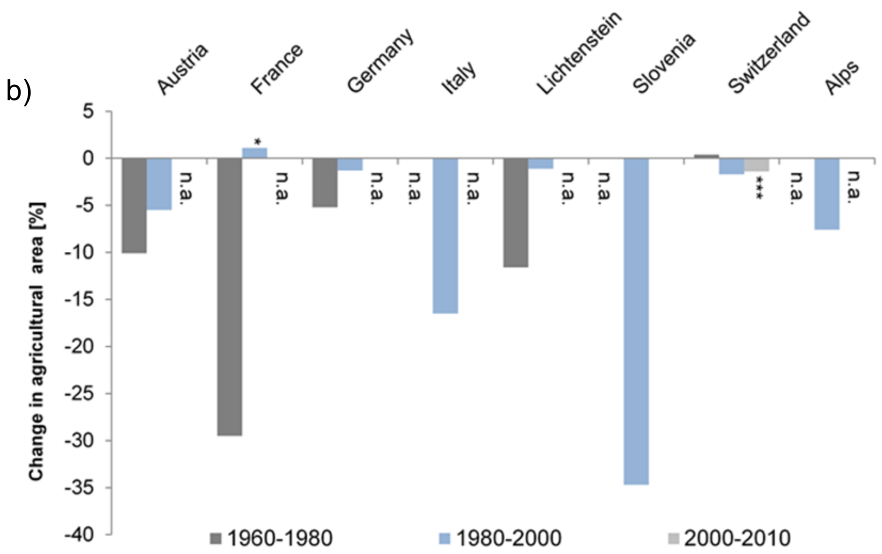
2.2 Polarization in land use

Until the middle of the 19th century, the economy in the European Alps was based on subsistence farming. Due to the diverse combinations of altitude, aspect and slope, mountain farmers were forced to adapt as well as possible to the natural environment, and developed a large diversity in production practices (Walther, 1986). Alongside with the

active management of landscape in mountain agriculture lasting for thousands of years, semi-natural ecosystems of high diversity developed (Maurer et al., 2006; Niedrist et al., 2008). In Switzerland for example, grasslands below the current timberline are mostly man-made as forest was cleared to obtain pasture areas, which harbor up to three times more species than the former forest (Niedrist et al., 2008). Due to the long term and low intensity farming in the form of livestock farming and traditional cultivating methods combined with maintenance measures to ensure soil stability, the ecology of mountain regions is characterized by a particularly sensitive human-environment relationship maintained in an artificial stability by diverse traditional techniques and practices.

From the 1850s onwards, political, economic and social changes accelerated the structural development in mountain areas, initiated by the development of industry in the middle of the 19th century and development of tourism later on (Anthelme et al., 2001; Flury et al., 2013). In most alpine areas, the portion of the population employed in agriculture sank from 70% at the beginning of the 20th century to 10% in the late 1970s (Flury et al., 2013). In the Alps, the trend of farm abandonment was especially strong between the two world wars and again from the beginning of the 1950s (Niedrist et al., 2008). During the second half of the 20th century, production changed from self-sufficiency towards a production for the market (MacDonald et al., 2000; Tasser et al., 2011). Farmers encountered global competition, which they could not withstand due to the limited but labor intensive productivity of the steep and climatically unfavorable areas, where the use of machinery is unsuitable and the growing season is shortened. The inability to modernize land use (Mather and Fairbairn, 2000) and the restrictiveness to livestock and grassland farming (Hoffmann et al., 2010) led to the successive abandonment of marginal land with low yields (Tasser et al., 2011). Additionally, the income differences between farm and non-farm employment have been identified as driver for land abandonment (Surber, 1973; Mather and Fairbairn, 2000). The retirement of the farmer followed by the unwillingness of the heirs to take over on their parents' farm is also reported as reason for farm abandonment (Wunderli, 2011). Comparable data concerning agriculture in alpine countries are available since 1960 and have been harmonized by a recent PhD thesis (Streifeneder, 2009). Figure 2.1 a/b summarizes data published in (Streifeneder et al., 2007a, 2007b; Streifeneder, 2009; Flury et al., 2013), and data from the Swiss Federal Statistical Office (BfS, 2011).





* The positive change is due to the consideration of previously unregistered cooperatively-owned alpine pastures in the survey
** 2000-2007
***2000-2010 BfS

Figure 2.1 a): Changes in the number of farms and b) changes in agricultural areas for the alpine areas of the European countries between1960 and 2010.

As remaining farms absorbed parts of the abandoned areas of retired farmers (Streifeneder, 2009), the average size of farms within the Alpine arc increased between 1980 and 2000 by 43.7%, varying between 17.6% in Austria and 127% in Lichtenstein (Streifeneder et al., 2007a). The average size of farms in Swiss mountain agriculture increased as shown in Figure 2.2. Meanwhile, the total number of mountain farms decreased by 44% between 1980 and 2010 from 43192 farms to 24322 farms (BfS, 2013b).

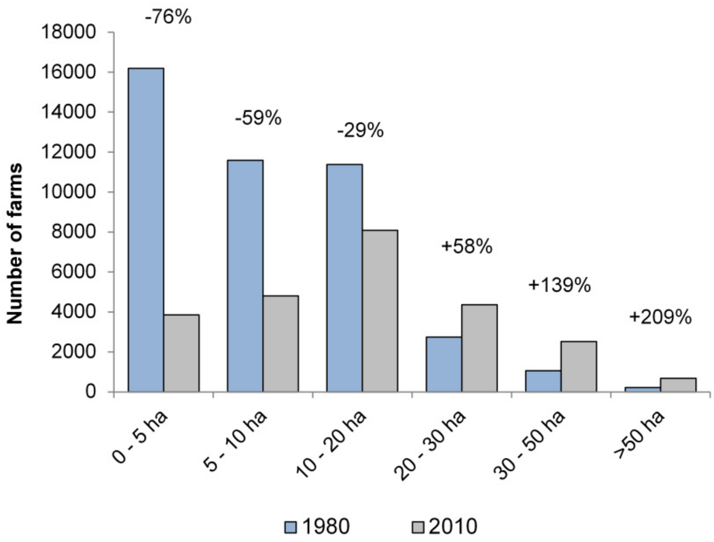


Figure 2.2: Changes in farm size in Swiss mountain agriculture between 1980 and 2010 (BfS, 2013b)

With the increasing size of farms, hours of work per area decreased, leading to a labor-extensive form of farming concentrating on areas which are easily accessible and which can be cultivated using machines and resulting in an intensification of land use on these areas (Flury et al., 2013). The intensification requires the use of machines and fertilizer on mown areas (Bätzing, 2005) and an increase of cutting per year. On pastures, intensification often involves more and heavier grazing animals, but can also implicate the cessation of shepherding and lead to uncontrolled grazing.

The structural changes in mountain agriculture lead to the abandonment of former used agricultural land, mostly hay meadows and pastures. The economic value and productivity of agricultural land depends on altitude, slope and aspect, but also on the costs of managing land, which depend on accessibility and appropriate machinery (Gellrich et al., 2007a; Tappeiner et al., 2008). Therefore, marginal areas that supplied small yield at high costs ceased to be viable under the changing economic conditions (Gellrich et al., 2007a). This procedure is also known as agricultural “marginalization” and is characterized by a gradually reduction of land use intensity (Baldock, 1996; Gellrich et al., 2007b). Thereby, marginalization can imply a total cessation of mown meadows, the conversion from mown meadows to pasture areas or the total abandonment of the pastures, implying a successional decrease of use intensity on marginal areas (Surber, 1973; MacDonald et al., 2000). In Switzerland, agricultural land abandonment has been observed for more than 150 years (Mather and Fairbairn, 2000). During this time period, the forested area has increased by 30-50% (Brändli, 2010). Mather and Fairbairn (2000) even refer to an approximate doubling of the forested area. The largest part of reforested area is attributed to natural forest re-growth on former pasture areas or unproductive abandoned agricultural land

(Surber, 1973; Walther, 1986; Mather and Fairbairn, 2000; Gellrich et al., 2007a; Brändli, 2010). Mac Donald et al. (2000) conclude that there was a clear drop in the utilization of alpine pastures and unfavorable agricultural areas as shown by the ongoing increase in reforestation. Figure 2.3 explains the mechanisms of polarization in land use.

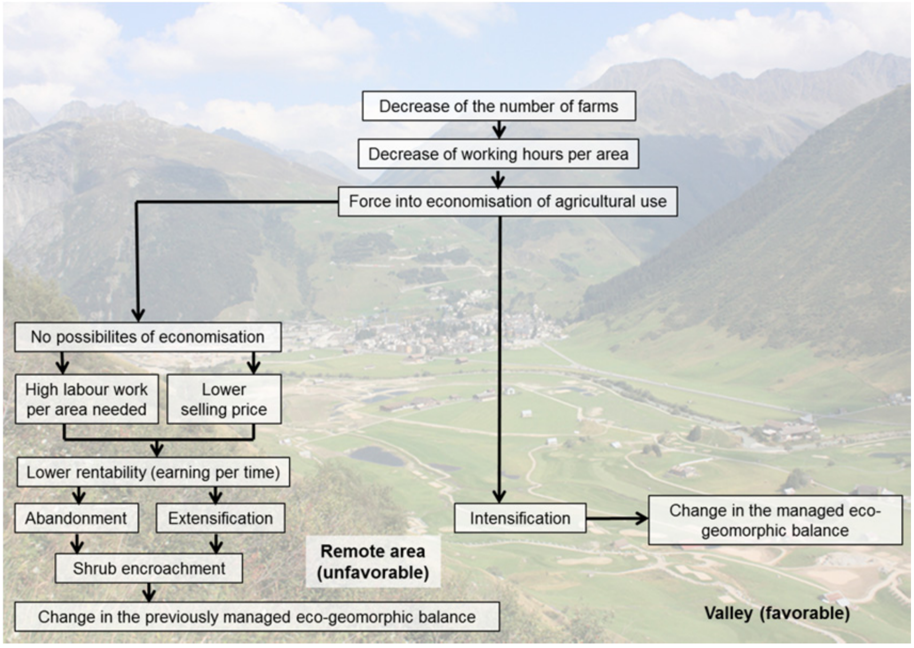


Figure 2.3: The mechanisms of polarization in land use (adapted from Ruef and Stettler, 2004). The background photograph shows the main Urserntal, central Switzerland, with its remote former wild haying areas to the left.

2.3 Swiss agricultural policy and its effect on land use change in the mountain areas of the Swiss Alps

2.3.1 Swiss agricultural policy and agricultural protection from 1851 to 1992

In Switzerland, agricultural policy has a strong influence on agricultural development. This subsection gives a short overview on the beginning of agricultural policy and the most important interventions protecting the Swiss agriculture. Already in 1851, agricultural associations were supported without a legal base (Baumann and Moser, 2012). In 1884, the Swiss federal government issued a resolution claiming the promotion of the agricultural sector (Bundesbeschluss zur Förderung der Landwirtschaft) (Bosshard et al., 2010). The first agricultural legislation was enacted in 1892 (Rieder and Phan-huy, 1994). This legislation gave a legal base for the agricultural subsidies. With the First World War, the Swiss government introduced provisions to raise the production of cereals and potatoes as the degree of self-sufficiency reached only 20% (Rieder and Phan-huy, 1994). In the course of the world economic crisis, the federal government built up a protected agriculture system by price and sales guarantees. During the Second World War, the Swiss agriculture was

pushed by the government to build autonomous food resources by the promotion of fertilizer, machinery and forage imports (Bosshard et al., 2010). The second agricultural legislation introduced in 1951 stated in Article 2 that the specific living- and production conditions in mountain agriculture should be taken into account in Swiss agricultural policy (Rieder and Phan-huy, 1994). The main incentive was to reduce income disparities between lowland and mountain farmers to maintain decentralized settlements and to preserve agricultural land in case of disturbed supply. Essential instruments of the Swiss government were restrictions of imports (*e.g.* import quotas), promotion of exports (*e.g.* subsidies), internal organization of the market by price guides and guarantees of purchase, structural improvements by investment loans as well as regional and social compensation payments (Tappeiner, 2003). The most important decrees to promote minimal cultivation of land in regions with unfavorable production conditions include the purchase guarantee for alpine cattle (1962), subsidies for cattle farming in mountain areas (1974) and direct income payments for farmers using summer alpine pastures (1979) (Rieder and Phan-huy, 1994). The concentration on price policies, where agricultural output was subsidized in order to support agricultural incomes, led to intensification, overproduction and ecological pressures as well as to the introduction of production quotas (Bosshard et al., 2010). According to Bosshard et al. (2010), the ecological impact of agricultural policies in Switzerland was even higher than in most of the industrialized countries and led to eutrophication, soil compaction, soil erosion, loss of biodiversity and loss of cultural landscapes.

2.3.2 Paradigm shift in Swiss agricultural policy

A fundamental change of agricultural policies started in the 1990s. The most important adaptions in agricultural policy are summarized in the following. Due to the almost total saturation of the markets with agricultural products, new requirements in ecology and the increasing international integration, a reorganization of agricultural policy started in 1993. The reform program introduced supplementary and ecological direct payments and a reduction in the price of milk, meat and cereals. In 1996, a large majority of the Swiss population approved a new agricultural Act in Federal Constitution. Based on the constitutional article, the old agricultural law dating from 1951 was replaced and a new agricultural law came into force on January 1, 1999, building the legal base for several decrees in agricultural policy that were brought together in the adoptions called AP 2002, AP 2007 and AP2011. According to the Swiss Federal Office for Agriculture (2009) the reforms in agricultural policy are based on a “multifunctional agricultural sector “pursuing a “socially acceptable” and “market oriented” production policy and the conservation of natural resources (Swiss Confederation, 1999, Art.104; Swiss Federal Office for Agriculture, 2009). The revisions in the agricultural law led to a restriction of the traditional price supports like the abolition of a guaranteed milk price (Tappeiner, 2003) and to a

differentiation of subsidies into so called direct payments consisting of base payments and ecological payments. Base payments include payments per hectare, supplemented by slope payments for land management on slopes between 19 and 35%, and base payments per livestock unit (Stöcklin et al., 2007). Ecological payments for an extensive use, including for example payments for summer alpine pasture, organic farming or water pollution protection, accounted for only 20% of the direct payments (Bosshard et al., 2010). Thereby, payments for summer alpine pastures, accounting for 35% of the agricultural area in Switzerland (Bosshard et al., 2010) and 53% of the agricultural area in the Alps (Stöcklin et al., 2007), amount to only 4% of the total subsidies in agriculture (Bosshard et al., 2010). In consequence, 80% of the direct payments are not linked to ecological achievements (Bosshard et al., 2010). According to Baur (2006), this fostered the intensive use of favorable pastures and meadows. Bosshard et al. (2010) state that the discrepant proportion between base payments and ecological payments led to missing incentives for maintenance measures on alpine pastures.

2.3.3 Recent agricultural policy and its effect on mountain agriculture

In 2009, even before the AP 2011 was enacted, the Swiss Parliament decided that there was room for improvement and that the direct payments system should be basically modified. The Swiss Federal council was asked to formulate a law for revised direct payments system (Lanz, 2012), which was enacted in January 2014 (Verordnung über die Direktzahlungen an die Landwirtschaft (Direktzahlungsverordnung, DZV). The so-called AP2014/17 (Swiss Federal Council, 2013) pursues a new agricultural policy. Its aim is to shift livestock subsidies (encouraging more intensive livestock farming) to subsidies for ensuring food supplies, which would be dependent on the acreage of land used, priority being given to grazing animals on grassland with minimum herd sizes (Lanz, 2012). The introduction of subsidies for the alpine farming and the use of alpine pastures, which rise to CHF 124M per year (Dudda, 2012), should promote grassland farming in mountain areas. However, the mentioned subsidies will replace the payment for animals kept under disadvantageous production conditions (TEP) and the payment for roughage consuming animal unit (RVGE) (Huber et al., 2012). This means that CHF 89M of subsidies paid for animals, which potentially spend the summer on alpine pastures, will be cancelled (Dudda, 2012). According to modelled scenarios by Swiss Agroscope (Flury et al., 2012), the change in agricultural policy will lead to a substantial decrease of livestock units on summer pastures by 2017 compared to 2011 (Table 2.1). Even though subsidies for traditional extensive use of alpine summer pasturing will increase by the introduction of area related subsidies, the number of livestock units grazing the area will potentially decrease. Thus, the future consequences for alpine pastures and the related ecological consequences of land use change cannot be foreseen. According to Flury et al. (2012), the new agricultural policy

will not stop the further polarization in mountain farming and will not be able to guarantee the low extensive use of marginal areas.

Table 2.1: Modelled change in livestock by 2017 for either pursuing AP 2011 or for introducing AP 2014/17. Changes refer to livestock in 2011 (adapted from Flury et al., 2012). Mountain zones II-IV refer to the Swiss legislation on agricultural zones, where the agricultural area is classified according to vegetation period, topography and transport connection (Landwirtschaftliche Zonen-Verordnung) (Swiss Federal Council, 1998)

	Persuing AP 2011			Introducing AP2014/17		
	Mountain zone II	Mountain zone III	Mountain zone IV	Mountain zone II	Mountain zone III	Mountain zone IV
Change of livestock in mountain farming [% livestock units]	-2.8	-5.8	-4.9	-11.9	-19.8	-20.9
Change of sheep and goat livestock in mountain farms [% livestock units]	-7.7	n.a	n.a	-30.5	-31.6	-34.8
Change of livestock units on summer alpine pastures [% livestock units]	-4.6	-6	-4.8	-6.4	-11.7	-15.4

2.4 Change in land cover induced by the polarization in land use

The polarization of land use towards an intensified use of near, favorable, areas and the marginalization and abandonment of remote areas has considerable and manifold effect on land cover and on mountain ecosystems including changes in soil and slope stability (Tappeiner and Cernusca, 1993; Dommermuth, 1995; Cernusca et al., 1999; MacDonald et al., 2000; Newesely et al., 2000; Tasser et al., 2003; Meusburger and Alewell, 2008) and hydrological cycles (Alewell and Bebi, 2011). The polarization in land use is also of socio-economic relevance with regards to natural hazards (MacDonald et al., 2000; Tasser et al., 2003), the generation of touristic value (Hunziker and Kienast, 1999; Tasser et al., 2011), as well as loss of traditional cultivation forms (MacDonald et al., 2000). Several studies use forest and shrub regrowth as indicator for land abandonment and there is an overall agreement that the abandonment of pastures and meadows is the main driving factor for forest and shrub regrowth (Bebi and Baur, 2002; Gehrig-Fasel et al., 2007; Gellrich et al., 2007a; Gellrich and Zimmermann, 2007; Pellissier et al., 2013; Tasser and Tappeiner, 2002). The increase in forest and shrub covered area is reported in a wide range of regional studies throughout the whole Alpine arc (Anthelme et al., 2003; Gehrig-Fasel et al., 2007; Gellrich et al., 2007a; Camacho et al., 2008; Cocca et al., 2012; Huber and Frehner, 2013; Pellissier et al., 2013). There is an overall agreement that the abandonment of pastures and meadows is the main driving factor for forest regrowth. Thereby, shrub encroachment on abandoned agricultural land and the related consequences for the environment are an issue of great concern (Newesely et al., 2000; Anthelme et al., 2001, 2007; Gamper et al., 2007; Huber and Frehner, 2013). According to Baur et al. (2007), grazing areas decreased by 600

km^2 (9%) between the observation period of the alpine statistic of 1891/1911 and the alpine cadaster of 1954/1982. Between the observation period of 1979/85 and 2004/09, the area of alpine summer pastures in Switzerland decreased by a further 295 km^2 (Schubarth and Weibel, 2013). Between 1985 and 2009, the extent of the agricultural land in Switzerland decreased by 5.4% (Schubarth and Weibel, 2013). The decrease of agricultural area varies for the biogeographic regions of Switzerland and is shown in Figure 2.4. The former use of the area is shown in Figure 2.5, the transformation the area experienced in Figure 2.6 (Schubarth and Weibel, 2013)

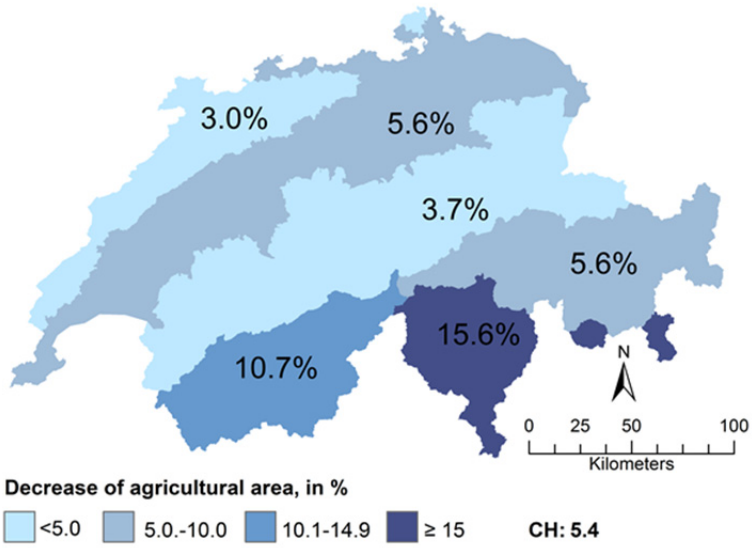


Figure 2.4: Decrease of agricultural area between 1985 and 2009 for the biogeographic regions of Switzerland (adapted from Schubarth and Weibel, 2013).

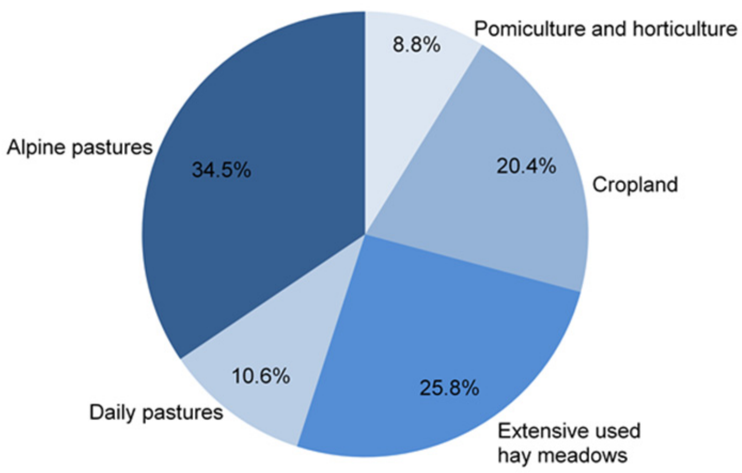


Figure 2.5: Former use of agricultural area (adapted from Schubarth and Weibel, 2013).

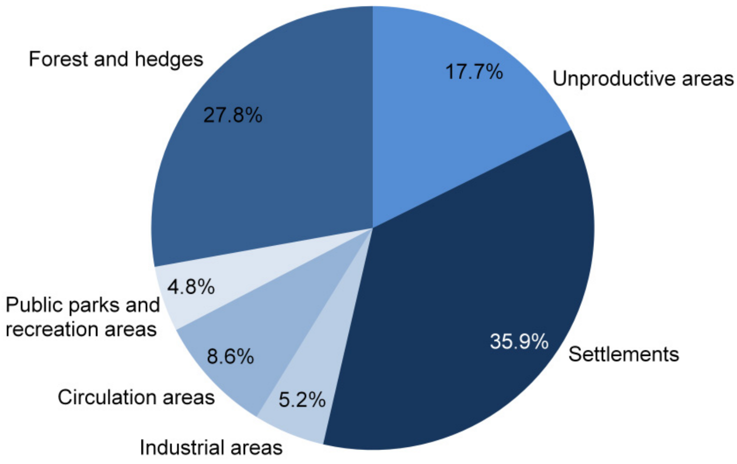


Figure 2.6: Land cover change on former agricultural area (adapted from Schubarth and Weibel, 2013).

Between the observation periods of 1983/85 and 2009/11, the forested area in Switzerland increased by 1304 km^2, including 174 km^2 of shrub woodland (WSL, 2012a, 2012b, 2012c, 2012d). Almost the total of the new forested area (97.5%) lies within the Swiss Alpine region (Brändli, 2010). In the central Alps of Switzerland, green alder, an early successional species, is a major component of the increasing subalpine shrub woodland. Due to their strong colonization ability and high seed production (Farmer et al., 1985), green alder shrubs, naturally restricted to steep, north facing subalpine well drained slopes, take advantage of current land disuse and spread on abandoned subalpine pastures (Wiedmer and Senn-Irlet, 2006) and on more gentle slopes (Didier and Brun, 1997).

2.5 Ecological significance of land use change in the Alps

2.5.1 Intensification on meadows and pastures

The yield and therefore the economic value of pastures and meadows depends on use intensity, type of use, the time between two cuttings and improvement measurements like fertilization, drainage or debris collection. As soils constitute the production resource for alpine agriculture, its careful management is crucial for preventing soil erosion leading to the loss of nutrients and maintaining water storage capacity (Zischg et al., 2011). The intensification of land use on the easily accessible areas has several effects on ecological parameters affecting soil and slope stability, which are summarized in Figure 2.7. Intensification on mown areas implies the use of fertilizer (Bätzing, 2005) and an increase of cutting per year. The time for plant cover to recuperate decreases by cutting more often and implies a decrease of sward building grasses and soil shear resistance (Bosshard et al., 2010). The use of fertilizer reduces species diversity and therefore the variety of roots

(Maurer et al., 2006; Spiegelberger et al., 2006; Schmidlin, 2008). Further on, the rooting depth decreases with fertilization (Bosshard et al., 2010). Von Wyl (1987) showed that the shear resistance of fertilized meadows decreases and enhances the risk for shallow landslides. Moreover, intensification by the use of machines can lead to soil compaction and injuries on the grass sward especially if machines are used during wet weather periods. Thereby, runoff as well as the risk for landslides increases. Intensification on pastures often involves more and heavier grazing animals, leading to greater soil compaction and cattle trails, which can enhance soil erosion due to injuries on the grass sward and increased runoff (Rickli and Bucher, 2003; Bosshard et al., 2010; Zischg et al., 2011). Herding control of large herds is mostly performed by fences, leading to a high heterogeneity in grazing intensity as animals concentrate on preferred areas. This results in soil compaction, trampling and rupture of the grass layer (Zischg et al., 2011). Rickli et al. (2008) observed in different case studies in the Swiss Alps that the frequency of landslides after torrential rainfall events is higher on alpine pastures than on extensive mown areas, which were cut once a year. The conversion of former extensively used hay meadows into pastures leads to grazing on inappropriate steep slopes and can therefore enhance soil erosion (Zischg et al., 2011). However, according to Zischg et al. (2011), it is not possible to quantify the effect of grazing on slope stability. Further on, the effect on slope processes and stability depends on the natural site factors and the former land use.

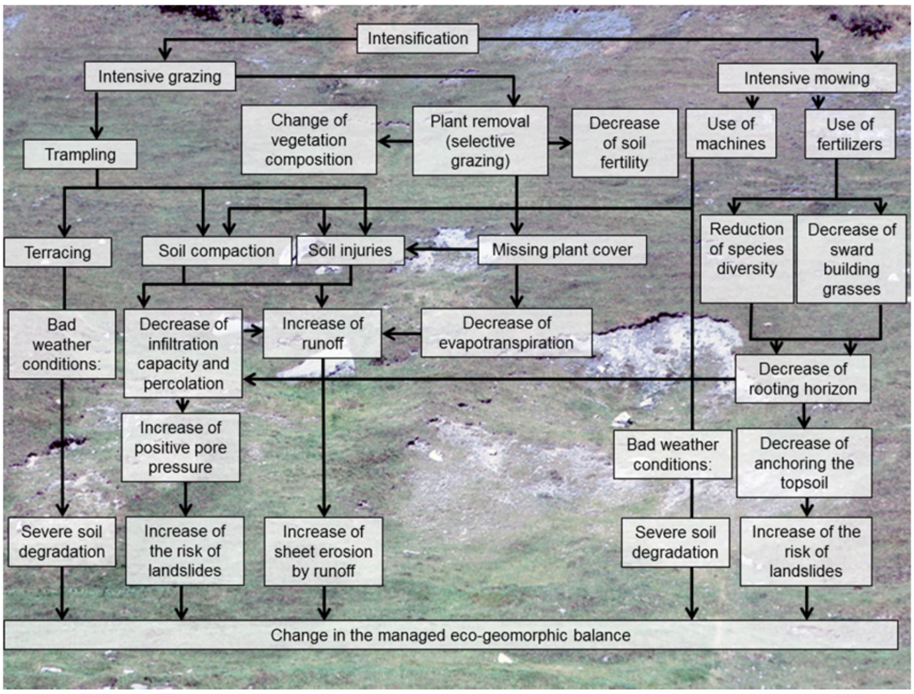


Figure 2.7: Ecological effects of intensified land use and their impact on the managed eco-geomorphic balance. The background photograph shows soil injuries due to intensive grazing on the “Freiberge” in the Urserntal, central Switzerland.

2.5.2 Abandonment of meadows and pastures

While the effects of intensified land use on soil stability are well documented and shown in several studies (Schauer, 1975; Dommermuth, 1995; Rickli and Bucher, 2003; Tasser et al., 2003; Meusburger and Alewell, 2008), there is a considerable uncertainty about the effects of land abandonment on soil stability. The brief review of the literature on the effects of land abandonment on slope processes and stability in Alpine regions will illustrate the complex interaction between the factors controlling previously managed eco-geomorphic balance and is summarized in Figure 2.8.

Abandoned land will be exposed to natural processes of succession and tend to revert to former climax vegetation prevailing prior to land use activities (Tappeiner and Cernusca, 1993). In the course of succession, the changing vegetation composition affects many above- and belowground ecological properties. Vegetation succession alters soil properties like root density, diversity and geometry, soil structure, pore volume, organic carbon content (Bebi and Baur, 2002; Tasser et al., 2003; Gamper et al., 2007; Bolliger et al., 2008; Tappeiner et al., 2008), as well as bulk density, and shear resistance which potentially affect soil and slope stability. Further on, vegetation succession can lead to an increase of evapotranspiration (Körner et al., 1978) and infiltration capacity (Zischg et al., 2011), and therefore to a decrease of runoff and sheet erosion. Generally, a change from grazing to forest would suggest a stabilization of soil as coarse tree and shrub roots have a higher ability to penetrate rock fragments (Morgan and Rickson, 2011) and to anchor the topsoil to the underlying bedrock (Rickli and Graf, 2009) compared to grass roots. Even though root biomass and depth increase with succession as shrub roots have a higher ability to penetrate down to the bedrock than grass roots, soil stability does not necessarily increase as species- and root diversity, and thus density and geometry, decrease (Tasser et al., 2003). Tasser et al. (2003) concluded that long abandoned areas which are densely covered with shrubs or *Alnus viridis* bushes tend to be more prone to landslides, *i.e.* sliding clods in topsoils. Thus, the complexity of interacting processes and sensitivity of mountain areas requires research on the maintenance of sustainable land use.

Further on, the abandonment of land results in the abandonment of maintenance practices like drainage measurements and debris collection. The deterioration of drainage systems leads to an increase of the risk to landslides through an overload of soil weight (Gall, 1985). The abandonment of mowing and grazing as well as the renouncement of collecting debris enhances snow gliding, where the whole snow cover moves downslope along the surface of the soil. Thereby, sites which were not mown or grazed offer ideal gliding conditions for the snow, as the long grass forms downward directed mats. If snow cover moves downslope along the surface, stones and vegetation frozen in the snow pack can be torn off the

surface and lead to injuries on the grass sward. Snow gliding can even uproot stronger plants like dwarf shrubs and herbs that are frozen in the snowpack. The injuries on the grass sward and the missing plant cover can enhance erosion processes (Newesely et al., 2000). According to Meusburger et al. (2013), snow gliding is a key process impacting soil erosion pattern as the increase of snow gliding distances correlates with an increase of winter soil erosion, except on green alder areas. According to Tasser et al. (2001), snow gliding distances after abandonment increase until established Alpine rose associations build a closed cover after about 40 years of land abandonment.

Beside the direct impact of land use abandonment on the previously managed eco-geomorphic balance, the abandonment of land use is mostly accompanied by an intensification of use on the more favorable areas leading to ecological effects shown in the preceding section. Furthermore, the conversion of abandoned land back into agricultural use is economically unfeasible.

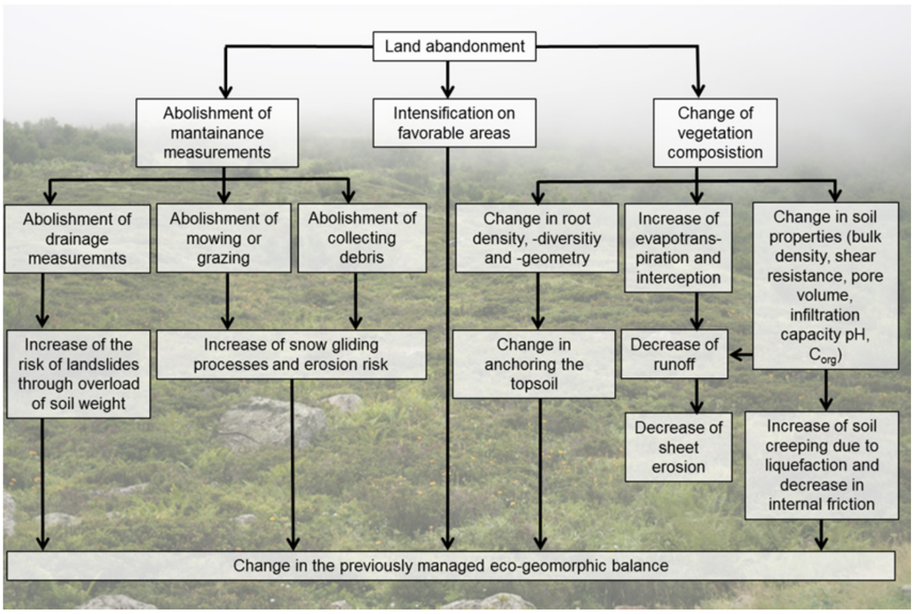


Figure 2.8: Ecological effects of land use extensification and abandonment and their impact on the previously managed eco-geomorphic balance. The background photograph shows a former pasture area in the Unteralptal, central Switzerland, overgrown by green alder after land abandonment.

Chapter 3

3 Study site

3.1 Introduction

The Urserntal in central Switzerland comprises a total area of 17509 ha; therefrom 6590 ha are in agricultural use (BfS, 2013a). Most of the agricultural area (90%) belongs to the Korporation Ursern, a cooperation of associated citizens under public law, *i.e.* communal land (Wunderli, 2011). Figure 3.1 shows the current land cover and the land cover change in the Urserntal. Detailed information on the physical geography of the Urserntal and its side valleys, especially the Unteralptal, is given in the journals contributions in sections 4.2, 5.2, 6.2 and 7.2.

Land tenure lies largely with the Korporation Ursern and is documented in the regional archive in Andermatt. Since 1900, the council of the Korporation Ursern has commissioned farmers to oversee the pasture areas and write a detailed report on their condition for the cooperation. The reports contain information about land-use intensity and maintenance practices as well as information about type and location of mass wasting processes on the pasture areas. The study area experienced an increase in land degradation since the 1950s. According to Meusburger and Alewell (2008), the eroded area in the Urserntal increased by 92% between 1959 and 2004. Further on, dense shrub cover in the Urserntal increased for 32% since 1965 (Wiedmer and Senn-Irlet, 2006). The historical data offer an annual temporal resolution and fill significant information gaps between data sources such as aerial photographs taken only ones in a decade. Additionally, the archive provides a wide range of information on the changes in land use and pasture management associated with the structural changes in Swiss agriculture during the 20th century. Section 3.2 gives an overview on the agricultural history of the Urserntal. Section 3.3 discusses whether the Urserntal acts as representative for the current development in other Alpine regions.

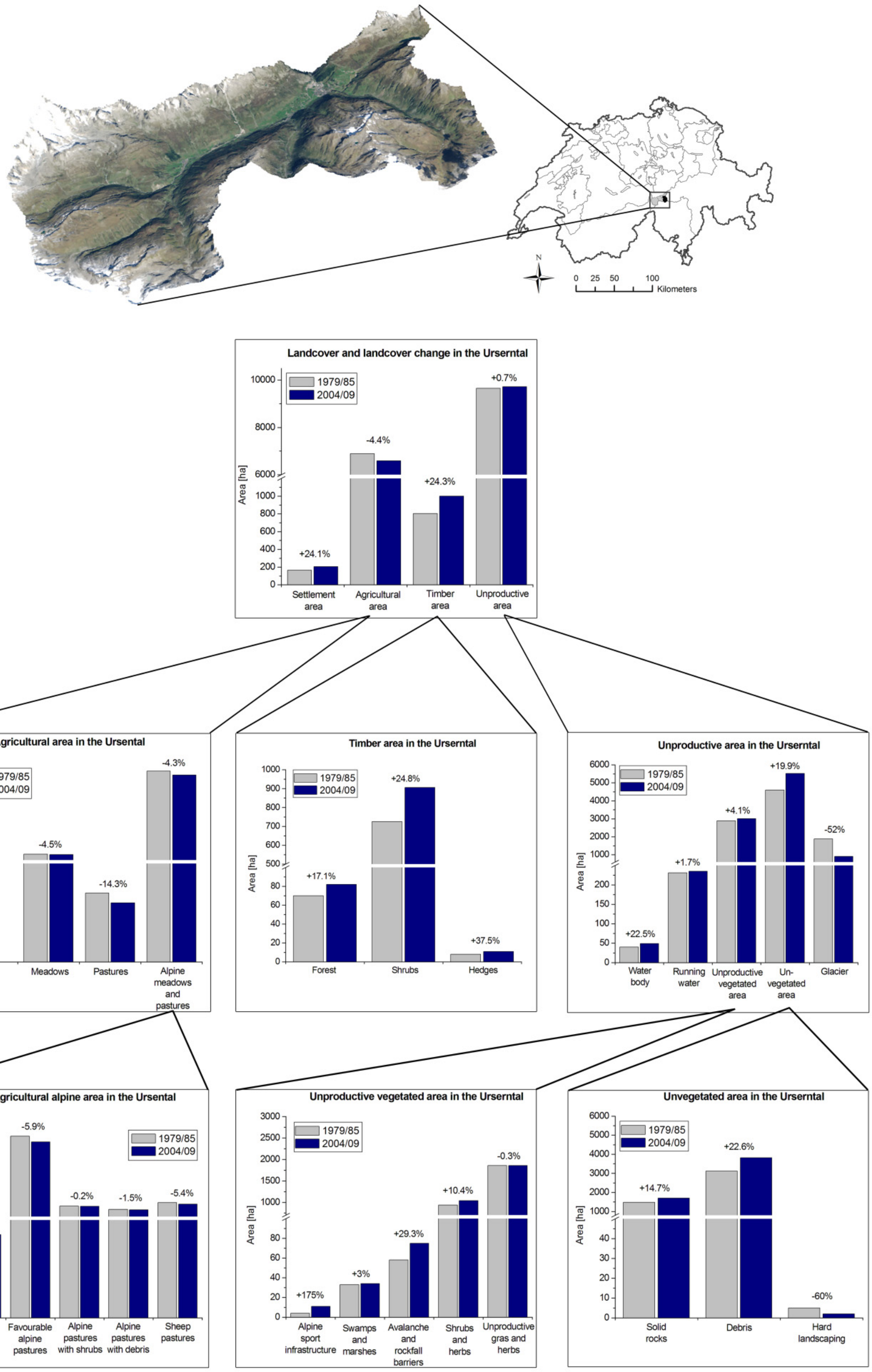


Figure 3.1: Land cover and its change in the Urserntal between 1979/85 and 2004/09 (BfS, 2013a)

3.2 Agricultural history of the Urserntal

In the Urserntal, traditional alpine farming reaches back for centuries and the cooperative pasture use in the valley began in the 13th century (Rebsamen, 1919). Nowadays, the Ursern Valley is characterized by extended pastures mainly belonging to the cooperative. Since 1905, when farming in the Urserntal was of low intensity with traditionally high proportion of small farms, the number of farms in the study site decreased by 84% (BfS, 2007). The development of farm numbers and farming area is illustrated in Figure 3.2. Even between 1975 and 2012, the number of farms decreased by 57%, thereby the number of farmers decreased by 62% (BfS, 2013b). Nowadays, 72% of the farmers are part time farmers (BfS, 2013b). In 2004, employment in the agricultural sector reached only 5.7%, thereby 40% of farmers are part time farmers (Hürlimann et al., 2004). The agricultural sector contributed to only 1.7% of the regional sales (Hürlimann et al., 2004), whereby 39% of agricultural income derives from governmental subsidies (Hürlimann et al., 2004). Farmers of the valley explain farm abandonment in “oral history interviews” performed by Wunderli (2011) with missing available labor force and the orientation of the following generation towards non-farming employment. With the decrease of farm numbers, farm sizes in the Urserntal increased as shown in Figure 3.3 from 1939 to 2007 (Wunderli, 2011). Due to the unviability and the missing workforce, the trend of increasing farm sizes was accompanied by the abandonment of several labor intensive tasks, like mowing the wild hay, meaning the haying on communal land that is even too steep for grazing, or the collection of firewood in the 1940s and 1950s (Wunderli, 2011). Agricultural area decreased by 20% between 1955 and 2007 (BfS, 2007), as illustrated in Figure 3.2. Despite the decline in farming activities, the communal land is of great economic importance in the Urserntal. Over the summer, local livestock (*i.e.* cattle, sheep and goats from the three municipalities Andermatt, Hospental and Realp to which the alpine pastures belong) and non-local livestock (from regions outside these municipalities) graze on the alpine pastures. Summer pasture area is not considered as agricultural land in the federal statistic data. According to the pasture maps stored in the archive of the Korporation Ursern, sheep pasture area nearly doubled, as the former cattle pasture area on the extended terraces was replaced by sheep pasture area. As a result, the cattle pasture area decreased by 39%. Meanwhile, the number of cattle on summer pasture areas increased from 1149 cattle in 1955 to 1482 in 2005, and the number of small cattle experienced a fivefold increase from 1500 to 7500 small cattle, thereby the reports do not distinguish between goat and sheep until 1975 as shown in Figure 3.3. However, farmers point out the dramatic decrease of goat number in the “oral history interviews” performed by Wunderli (2011).

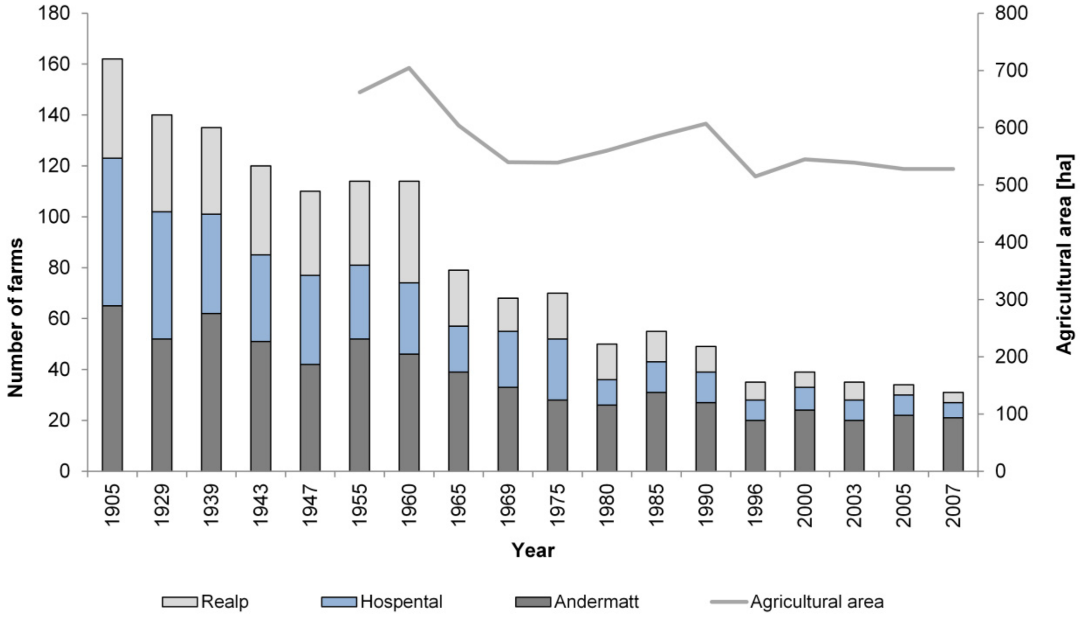


Figure 3.2: Development of the number of farms between 1905 and 2007 and the agricultural area in the Urserntal between 1955 and 2007 (BfS, 2007).

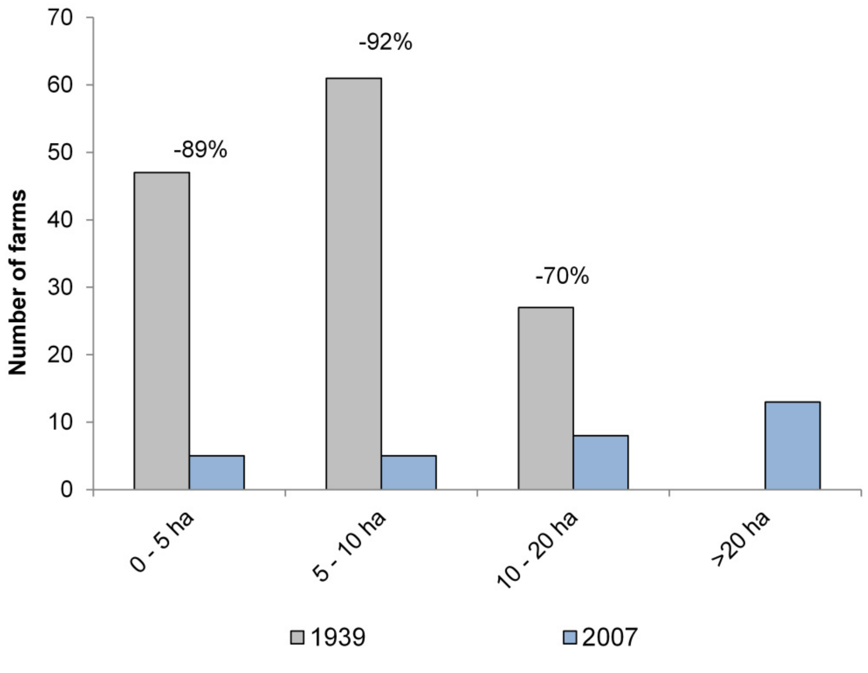


Figure 3.3: Changes in farm size between 1939 and 2007 (adapted from Wunderli, 2011).

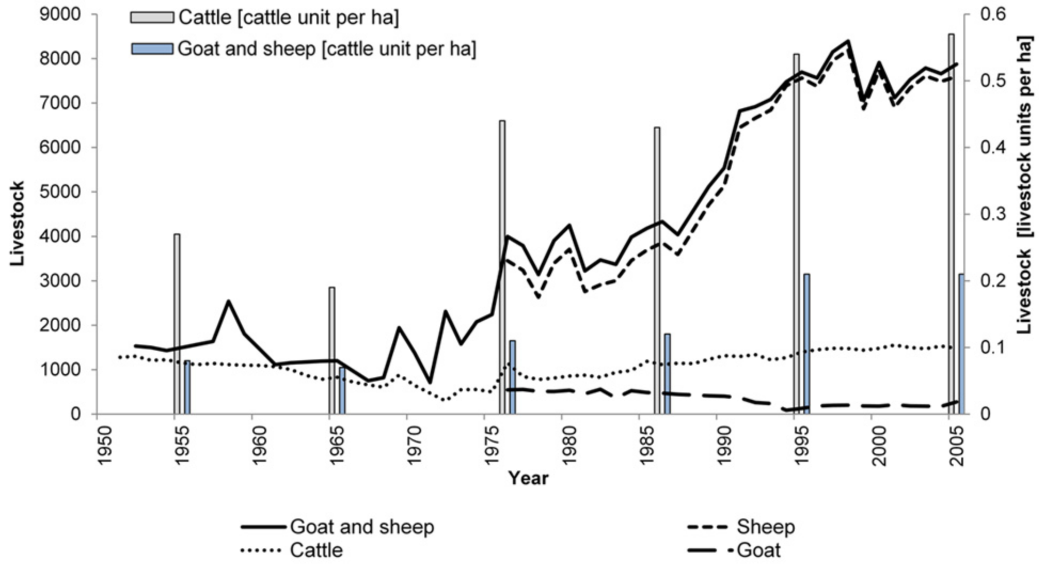


Figure 3.4: Development of livestock and livestock density on summer alpine pastures in the Urserntal between 1955 and 2005 (Archive from the Korporation Ursern, n.d.).

3.3 Land use change in the Urserntal as representative for the current development in other Alpine regions

The communal land and the well-documented land management practices in the Urserntal offer an opportunity to study the managed eco-geomorphic balance in the Alps. However, the question remains whether the Urserntal constitutes an accurate representation for studying the effects of land use and climate change on the managed eco-geomorphic balance in the Alps. In order to answer this question, the agricultural development in the Urserntal is compared to the development in other Alpine regions following the approach of a “classification of characteristic agrarian structure regions in the Alps” performed by Tappeiner (2003). Tappeiner (2003) classifies the Alpine regions based on a selection of 76 variables. Thereby, agricultural structure is presented by 57 indicators (*e.g.* agricultural density, increase and decrease of livestock, part time farming), socio-economic condition by 12 indicators (*e.g*. population density, employment in agriculture, tourism intensity) and natural conditions by 7 indicators (*e.g*. climatic type, mean annual precipitation, geology, hill slope erosion). According to the mentioned approach, the Urserntal is characterized as “structured full time farming region with a tendency to intensification” (in the following referred to as class 6). Class 6 comprises regions with high farm abandonment but negligible land abandonment and an increase of livestock units (Tappeiner, 2003). The term “structured full time farming region” implies a well performing, competitive agriculture with high acceptance and moderate structural changes. However, agrarian history of the Urserntal shows the overall tendencies in alpine agriculture, summarized in section 3.2. Additionally, although the study region has been classified as region with a marginal

decrease of agriculture (Tappeiner, 2003), the study in the Unteralptal revealed an increase of either closed or open green alder cover of 63% between 1959 and 2007. The unequal perception may be caused by a different time period of observation or by the different interpretation of agricultural land, where pasture area is possibly not included.

The Urserntal is not considered as a region that is highly affected by land use change like for example the regions of the Piedmont and the Savoy with land abandon rates of 72% (Tappeiner, 2003) or the region of the northern ridge of the Swiss Alps with high intensive cattle production on large farms (Tappeiner, 2003). However, the clear exposure of the managed eco-geomorphic balance towards degradation processes as shown by Meusburger and Alewell (2008), the fundamental change in land use practices (Caviezel et al., 2010) and the apparent increase of shrub cover on former pasture areas (Wiedmer and Senn-Irlet, 2006) leads to the conclusion that the managed eco-geomorphic balance in the Urserntal is affected by either land use or climate change and that the valley provides an accurate study region, albeit that the effect in other Alpine regions is even more pronounced.

Chapter 4

4 Land use intensification and its effect on managed eco-geomorphic balance

This study reconstructs the mass wasting history in the Urserntal and relates periods of increased mass wasting frequency to changes in land use practices. The study was published in die Erde as:

Caviezel, C., Kuhn N. J., Meusburger K. 2010. Applicability of Alp Inspection Reports for the Reconstruction of Land-Use and Mass Wasting History in the Ursern Valley, Switzerland. Die Erde, v. 141, 1-16.

DIE ERDE **141** 2010 (4)	Landscape Ecology and Beyond	pp. 1-16

• *Mass wasting history – Mountain environment – Agriculture archives*

Chatrina Caviezel, Nikolaus J. Kuhn and **Katrin Meusburger**

Applicability of Alp Inspection Reports for the Reconstruction of Land-Use and Mass Wasting History in the Ursern Valley, Switzerland

Die Eignung von Alpinspektionsberichten für die Rekonstruierung von Landnutzung und Landdegradierungsprozessen im Urserntal, Schweiz

With 6 Figures, 6 Tables and 1 Photo

Changes in land use and climate can increase landscape susceptibility for mass wasting. This study illustrates a method aimed at reconstructing landscape susceptibility for mass wasting in the Ursern Valley, Switzerland, based on an analysis of alp inspection reports of the years 1950-2000. The yearly reports were written by farmers commissioned to supervise pasture use and condition on the communal land. The analysis offers the possibility to reconstruct mass wasting history, its patterns in time and space as well as its determining factors. Preliminary results show that mass wasting frequency increased since 1970 and that the recorded events are not distributed uniformly in time and space, but concentrated on geologically sensitive slopes which experienced an increase in grazing intensity.

1. Introduction

Alpine grasslands have been used by humans for about 5000 years (*Bätzing* 2005). In order to ensure food resources, great efforts have been made to maintain soil and slope stability. In the past 30 years, changing economic conditions like the reduction of protective tariffs and the liberalisation of agricultural markets have promoted competition in global agriculture. Farming in mountain regions is disadvantaged in such a globalised market because of higher production costs (*Streifeneder* and *Ruffini* 2007), leading to the abandonment of pastures. The Swiss government tries to prevent land abandonment in mountain regions by subsidies consisting of base payments for farmers in mountain regions and further rewards for best practice management and extensive use (*Flury* et al. 2005). Nonetheless, the number of farms decreased by 40 % between 1985 and 2008 (BfS 2009). At the same time, the land area managed and maintained by one single farm increased steadily (BfS 2009). Easily accessible production sites with high productivity experi-

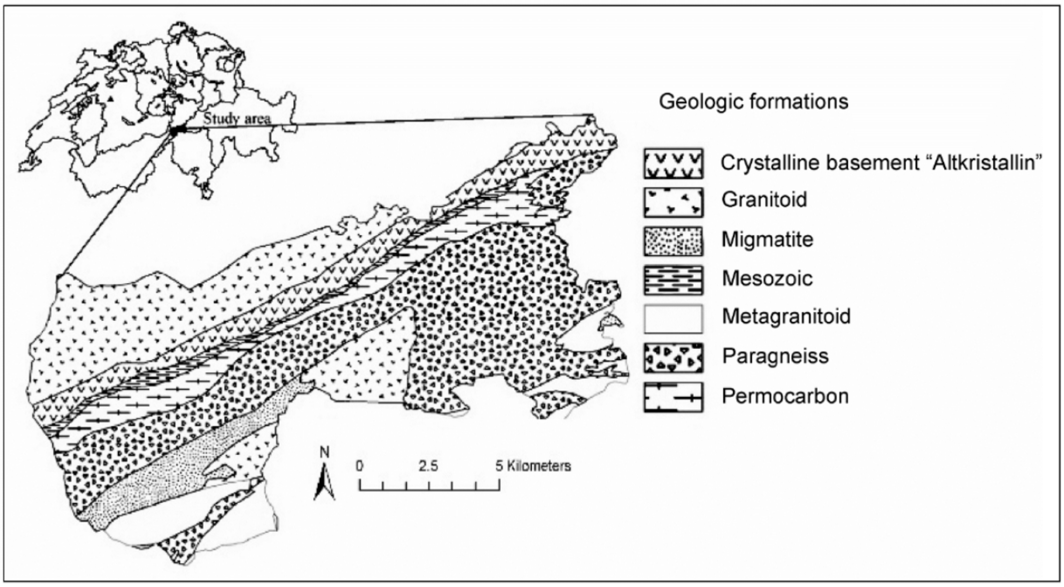


Fig. 1 Geological formations of the Ursern Valley (Source: *Labhart* 1999) / *Geologische Karte des Urserntals*

enced an intensification while remote areas with high production costs became marginalised (*Bätzing* 2005). Environmental impacts of these changes in land use affect soil stability (*Newesely* et al. 2000; *Tasser* et al. 2003), biodiversity and habitat quality (*Tasser* and *Tappeiner* 2002) and cause a loss of traditional cultivation forms (*MacDonald* et al. 2000) as well as at least a perceived decline of aesthetic landscape value (*Hunziker* and *Kienast* 1999).

Our study area, the Ursern valley in central Switzerland, experienced considerable changes in land degradation since the 1950s. By generating a time-series inventory map of landslides based on seven air photograph series from different years starting in 1959, *Meusburger* and *Alewell* (2008) found that the eroded area in the Ursern Valley nearly doubled between 1959 and 2004 (increase of 92 %).

The detailed reconstruction of land degradation in the Ursern Valley requires a higher temporal resolution of information than provided by air photograph interpretation to cover both rapid changes in land use and stocking intensity as well as the effects of individual high-magnitude rainfall events triggering mass wasting events. The Ursern Valley offers a good opportunity for studying the history of land degradation in the 20th century. Land tenure lies largely with the *Korporation Ursern,* a cooperation of associated citizens under public law owning most of the pasture areas. Since 1900, the council of the *Korporation Ursern* has commissioned farmers to oversee the pasture areas and write a detailed report on their condition for the cooperation. The reports contain information about land-use intensity and maintenance practices as well as information about type and location of mass wasting processes on the pastures area. They are stored in the archives of the *Korporation* in Andermatt. This study aims at examining the use of the alp inspection reports to reconstruct mass wasting history. By analysing the alp inspection reports, the gap in mass wasting history can be closed because of their greater tem-

poral resolution. In addition, alp inspection reports provide information about changes in land use management which can be analysed in the context of the mass wasting history.

It is assumed that alp inspection reports or similar sources can be found in other regions, as different alp associations still stipulate the inspection of the pasture in its regulations (for example Klosters, Serneus). *Raetzo-Brülhart* (1997) mentions reports of the '*Société fribourgeoise d'économie alpestre*' as a source to detect mass wasting in the Gurnigelflysch. National inspections were also held between 1894 and 1914 and from 1962 to 1988.

2. Site Description

The Ursern Valley is a glaciated u-shaped valley in Kanton Uri, Switzerland. The study area consists of the main Ursern Valley and the side valleys of Wittenwassern, Unteralp, Mutten, Furka, Gotthard and Oberalp and covers an area of 17,924 ha (BfS 2008). Elevation ranges from 1442 m a.s.l. to 3200 m a.s.l. The whole study area is drained by the river Reuss and its tributaries.

Geologically, the Ursern Valley is part of the Ursern zone, a sediment zone between the gneiss massif of the Gotthard in the south and the granite basement massif of the Aare in the north (*Kägi* 1973; *Fig. 1*). The main valley corresponds to the geological fault line that separates the gneiss massif of the Gotthard system to the south from the granite massif and the pre-existing basement (named "*Altkristallin*" by *Labhart* 1999) of the Aare system in the north. Intermediate vertically dipping layers along the fault line consist of Permocarbonic and Mesozoic sediments (*Labhart* 1999). During the Permocarbon it was sandy-clayey sediments that were deposited, followed by different materials from the Trias (sandstone, rauhwacke and dolomite), Lias (dark clay-marl and marl) and Dogger (clays, marl and limestone) during the Mesozoic. In the orogeny process the material underwent metamorphosis to greenschist (*Angehrn* 1996; *Kägi* 1973). Weathering of the calcareous material produced marls that are prone to landslides. The

Tab. 1 Main land cover types in the Ursern Valley / *Landschaftstypen im Urserntal*

Land cover type	**Proportion of total area (%)**	**Plant communities**
Alpine grassland with dwarf shrubs	59	*Calluna vulgaris, Rhododendron ferrugineum, Juniperus sibirica*
Debris	21	Grassland with more than 70 % boulders
Bare rock	10	
Glacier	5	
Shrubs	4	*Alnus viridis, Sorbus aucuparia*
Urban and forest	1	
Total	100	

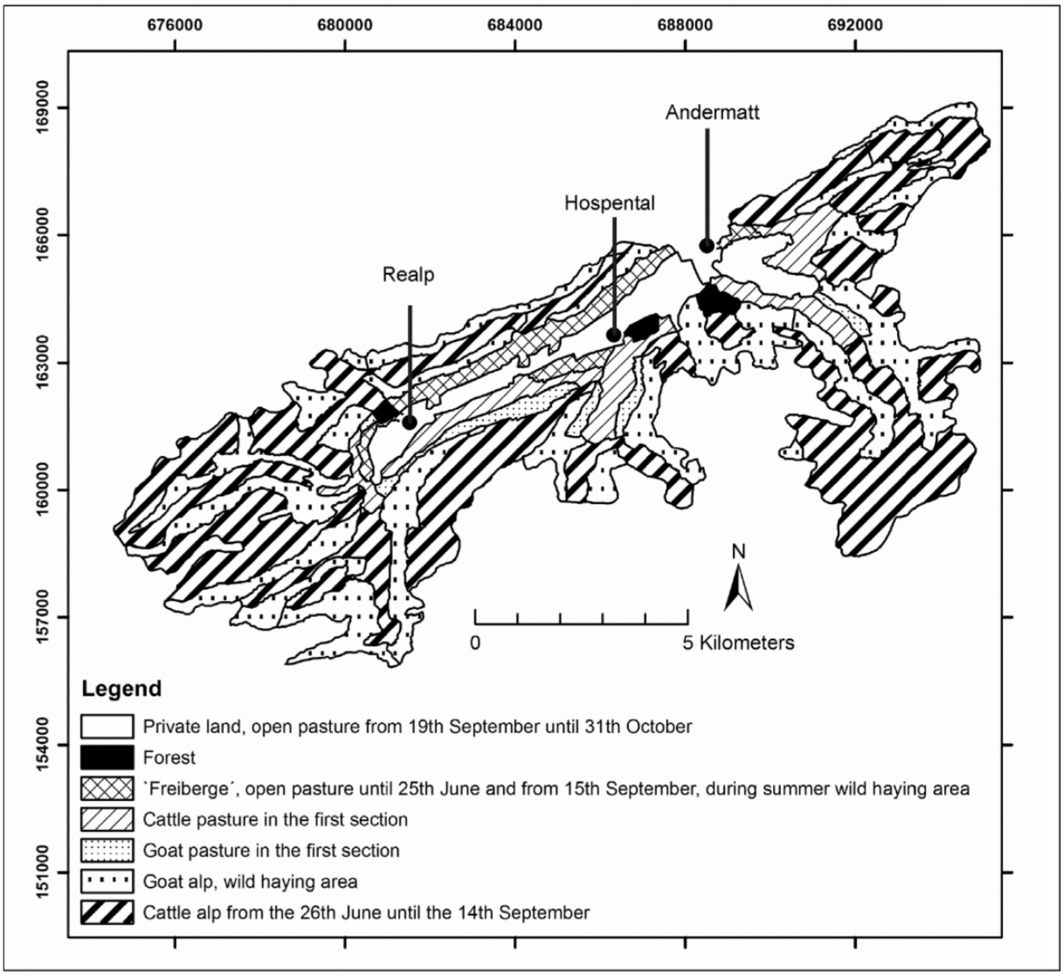


Fig. 2 Map with restriction rules for the pasture areas of the Ursern Valley (after *Oechslin* 1935). Numbers given refer to the Swiss grid. / *Karte der Nutzungsregeln für die Weidegebiete des Urserntals* (nach *Oechslin* 1935). *Angaben in Schweizer Landeskoordinaten*

bottom of the valley and the lower valley slopes consist of Quaternary moraines of mainly siliceous loamy gravel material and talus fans. A detailed geologic and tectonic description of the area is given by *Wyss* (1986).

Podzols and Albic Umbrisols are major soil types in the catchment (IUSS Working Group WRB 2006). Above 2000 m a.s.l. and on steep valley slopes, Leptosols are common, with Rendzic Leptosols on the calcareous substrates. At the valley bottom and lower slopes, predominantly clayey-gleyic Cambisols, Histosols, Fluvisols and Gleysols developed.

The climate in the valley is alpine with an average air temperature of 3.1°C (1901-1961). The temperatures of the last years (1961-2006) show a deviation of +1.5°C compared to the long-term

average (1901-1961) (*Angehrn* 1996). Average annual precipitation at Andermatt's Swiss-Meteo Station is about 1400 mm, about 35 % falling as snow. The valley is snow covered from November to April (*Angehrn* 1996).

The natural alpine vegetation has been strongly modified by agricultural land use (*Kägi* 1973). Deforestation of the valley started in 1100 AD, when the first settlements were established (*Küttel* 1990). Forest clearance was motivated by the need of agricultural land and timber and was practised until the 19th century (*Rebsamen* 1919). Cooperative pasture use began in the 13th century (*Rebsamen* 1919). Nowadays, the Ursern Valley is characterised by extended pastures mainly belonging to the *Korporation*. *Table 1* shows the main land cover types in the Ursern Valley.

2.1 Land-use management in the Ursern Valley in the 19th and 20th century

Pastures for summer grazing dominate the cultural landscape of the Ursern Valley. The private land, mainly situated on the valley floor and adjacent slopes, serves as hay meadow to feed the cattle during the winter. The remaining land consists of common pasture which mainly belongs to the *Korporation Ursern*. Every associated citizen has, as it is written in the *Korporation's* constitution, the right to use every desired pasture of the *Korporation Ursern* (Korporation Ursern 1901/1934). Stocking is not practiced according to production potential, but pastures of nearby farms in the valley are preferred to remote pastures on the higher terraces. To control overgrazing and to preserve the quality of the pastures, land use was traditionally temporally and spatially restricted, which is shown by the restriction rules on the land-use map of 1935 (*Fig. 2*).

With these restrictions pasture condition on the Freiberge and on the pastures in the first section has been preserved in case of summer snowfalls on the higher pasture area. The pasture area of the second section consists of the extended alpine meadows called '*Alp*' where cattle, goats, and sheep stay during the entire summer (*Kägi* 1973). Goat and sheep pastures have traditionally been located on the steeper slopes, cattle pastures on the extended flatter terraces. By rotation of the pastures and herding restrictions, the regeneration of soils and vegetation was assured. These detailed rules show the importance of the maintenance of the pastures which had been achieved traditionally.

2.2 Land degradation in the Ursern Valley

Given its geology and alpine setting, the Ursern Valley is affected by mass wasting. Most common are shallow slides and debris or mud flows. *Meusburger* and *Alewell* (2008) created and analysed a landslide database in which they related landslides to trends in landscape and climate change. By generating a time-series inventory map of landslides based on seven air photograph series of different years starting in 1959, *Meusburger* and *Alewell* (2008) could observe a continuous increase of landslides in the Ursern Valley over time. The photographs have a scale of at least 1:12000 and are available for seven different years: 1959, 1975, 1980, 1986, 1993, 2000, and 2004. A detailed description of the pre-processing and mapping procedure is given in *Meusburger* and *Alewell* (2008). The eroded area nearly doubled between 1959 and 2004 (increase of 92 %) (*Meusburger* and *Alewell* 2008). Catchment characteristics like geology, slope and stream density are quasi-static, hence, their impact on mass wasting does not change over a period of fifty years, and therefore they cannot explain the increase of mass wasting events. Due to the long time span between the individual air photographs, an exact year or date on which the mass wasting events happened cannot be identified and a link to individual triggers is therefore not possible.

Tab. 2 Checklist of attributes related to land use, maintenance measures, weather and mass wasting events. *Nennungen aus den Alpinspektionsberichten mit Relevanz für Landnutzung, Meliorations- (wie in den Alpinspektionsberichten angegeben) aufgelistet.*

Issues		**Attributes / *Eigenschaften***	**Provides information on:**
Local name of the pasture		**Year**	Localisation, time
Stocking number		No. of local cattle / *Anzahl Großvieh*	Use intensity
		No. of external cattle / *Anzahl Fremdvieh*	
		No. of local sheep / *Anzahl Schafe*	
		No. of external sheep / *Anzahl Fremdvieh Schafe*	
		No. of local goats / *Anzahl Ziegen*	
		No. of external / *Anzahl Fremdvieh Ziegen*	
Pasture yields		Low / *gering*	Use intensity
		Adequate / *genügend*	
		Good / *gut*	
		Outstanding / *ausgezeichnet*	
		Not mentioned / *keine Aussage*	
Pasture condition		Affected by debris / *Vergandung durch Geröll*	Use intensity, relative importance of individual pasture
		Affected by shrubs / *Vergandung durch Verbuschung*	
		Overgrazed / *überweidet*	
		Undergrazed / *unterweidet*	
		Animal trails / *Viehtritte*	
		Tension fissures / *Anrissstellen*	
		Wet soils / *vernässter Boden*	
		In good condition / *guter Weidezustand*	
		In bad condition / *schlechter Weidezustand*	
		Not mentioned / *keine Aussage*	
Measures to improve pasture yields		Manuring / *Düngung*	Relative importance of individual pasture
		Collecting debris / *Abschönen*	
		Recultivation / *Ansäen*	
		Mowing / *Mähen*	
		Measures against shrubs / *Bekämpfen der Verbuschung*	
		Not mentioned / *keine Aussage*	
Weather patterns		Beneficial / *günstig*	Weather condition
		Satisfying / *befriedigend*	
		Wet and cold / *kalt und nass*	
		Hot and dry / *heiß und trocken*	
		Not mentioned / *keine Aussage*	
Extreme weather events		Thunderstorm / *Gewitter*	
		Hail / *Hagel*	
		Wet spell / *Regenperiode*	
		Snow fall (summer) / *Schneefall (Sommer)*	
		Not mentioned / *keine Aussage*	

Attributes are listed in English and German (as mentioned in the alp inspection reports). *Aufnahmeraster für maßnahmen, Wetterereignisse und Massenbewegungsprozesse. Nennungen sind in Englisch und Deutsch*

Issues		Attributes / *Eigenschaften*	Provides information on:
Damages to paths		Slipped-off / *abgerutscht*	Indicating further mass wasting
		Blocked / *verschüttet*	
		In bad condition / *in schlechtem Zustand*	
		In good condition / *in gutem Zustand*	
		Not mentioned / *keine Aussage*	
Damages to bridges		Flushed away / *weggespült*	
		Bad condition / *in schlechtem Zustand*	
		Good condition / *in gutem Zustand*	
		Not mentioned / *keine Aussage*	
Infrastructure maintenance		River canalisation / *Kanalisierung des Flussbettes*	Relevance of infrastructure
		Measures on paths / *Meliorationen an Wegen*	
		Measures on bridges / *Meliorationen an Brücken*	
		Not mentioned / *keine Aussage*	
Natural hazards		Flooding / *Überschwemmung*	Indicator for mass wasting processes
		Earth creeping / *Erdbewegung*	
		Landslide / *Erdrutsch, Erdschlipf, Rüfi*	
		Debris/mud flow / *Murgang, Rüfi*	
		Rock fall / *Steinschlag*	
		Avalanche / *Lawine*	
		Bank erosion / *Weideland mitgerissen*	
		Water erosion / *Gräben ausgewaschen*	
		Not mentioned / keine Aussage	
Measures to prevent damages by natural hazards		Cleaning riverbeds / *Reinigen des Flussbettes*	Relative importance of individual pasture, consciousness of natural hazards
		Avalanche barriers / *Lawinenverbauung*	
		Reforestation / *Aufforstung*	
		Other work / *andere Maßnahmen*	
		Not mentioned / *keine Aussage*	
Measures to improve soil stability		Drainage measures / *Entwässerungsmaßnahmen*	Relative importance of individual pasture
		Stick pickets / *Pfähle einschlagen*	
		Retaining walls / *Stützmauern errichten*	
		Deflection rill for debris/mud flow *Ablenkungsgraben für Murgang, Rüfi*	
Conflicts of interest		Military use / *Militär*	Relevance of agriculture
		Tourism / *Tourismus*	
		Railway / *Bahn*	
		Waste deposit / *Mülldeponie*	
		Stone chipping / *Steinbruch, Stollenbau*	
		Not mentioned / *keine Aussage*	

3. Analysis of Alp Inspection Reports

The archives of the Ursern Valley house the *Korporation's* alp inspection reports which go back until the year 1900. The reports, written by farmers that were commissioned to oversee the pasture area, contain information about pasture yields, land use, stocking, weather conditions, maintenance work and natural hazards for every year for the different parts of the valley. The reports were written for the *Korporation* council and were used for decision-making on pasture use and maintenance measures. Accuracy of the alp inspection reports differs depending on the author. Nevertheless, as all authors used the same traditional reporting scheme and structure, there is a continuous account of essential information for reconstructing the mass wasting history.

This study focuses on the reconstruction of mass wasting history and land-use change for the time span 1950-2000. The period was chosen to cover the structural changes in alpine agriculture since the 1960s (*Bätzing* 2005), as well as the increase of mass wasting events between 1959 and 2004 observed by *Meusburger* and *Alewell* (2008). The reports for the years 2001-2010 were only partially filed in the *Korporation's* archives, which is why they have not been included in the analysis. Based on an analysis of the reports from 1934 to 1949, a checklist was developed (*Tab. 2*), in which all comments with relevance for mass wasting processes and land-use management were recorded. This period was chosen in order to have a complete interval of at least 15 years. To reconstruct mass wasting in time and space, the reported events were linked to information on dates and location given in the reports. For further studies, comments about weather events were recorded as well.

Mass wasting processes were classified based on *Summerfield* (1999). Most expressions used by the inspectors could be clearly associated with a

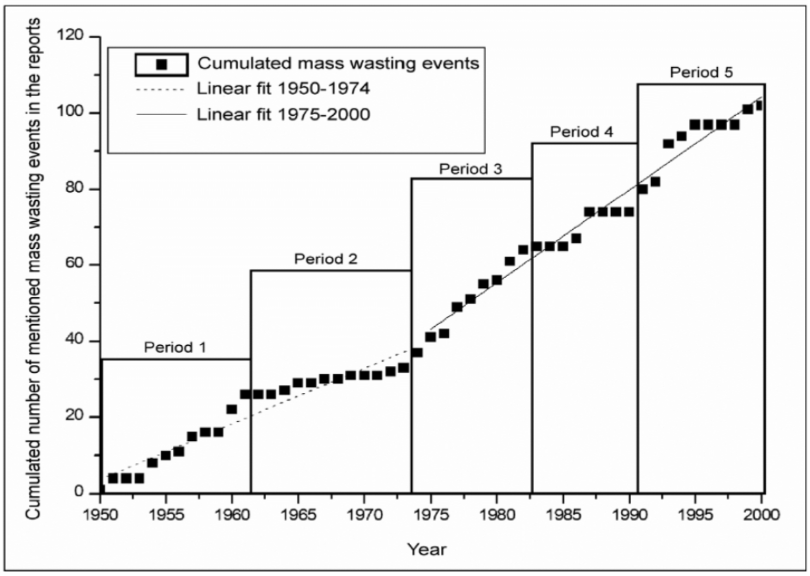


Fig. 3 Cumulative mass wasting events mentioned in the alp inspection reports of the Ursern Valley between 1950 and 2000 / *Kumulierte Anzahl der in den Alpinspektionsberichten genannten Massenbewegungsprozessen im Urserntal zwischen 1950 und 2000*

form, process or activity. However, to clarify the terminology used in the alp inspection reports, two farmers were interviewed about mass wasting processes, changes of land use and management practices within the last decades (TPU 2006). It turned out that in the reports, the term '*rüfi*' was used for either a landslide or a debris/mud flow. Since these two mass wasting features are associated with a specific surface morphology, the topographic maps of Ursern 1231 (Swisstopo 2002b) and Oberalp 1232 (Swisstopo 2002a) were used to differentiate between them. Every '*rüfi*' confined to a river bed was classified as debris/mud flow, while the remaining were considered to be landslides. Besides landslides and debris/mud flows, alp inspection reports mention earth creeping processes, rock falls, soil injuries and animal treads. Notes about pasture destroyed by rivers were considered as bank erosion, notes about gullies on pastures and paths as water erosion. Slipped-off and blocked paths suggest further mass wasting processes than mentioned by name. The number of events was often circumscribed with 'multiple' or 'numerous'. In such cases, two events were registered. Descriptive information about the volume of the mass wasting events is given only exceptionally. Locations were mainly given by local names. Notes about avalanches and flooding were registered as indicators for land degradation, but not considered as mass wasting events. To set stocking numbers in correlation to the pasture area, a series of pasture maps of the years 1935, 1955, 1992 and 2006 (*Russi* 2006) was digitised and geo-referenced.

4. Results

4.1 Mass wasting event history in the Ursern Valley from 1950 to 2000

The frequency of mass wasting events was not uniform between 1950 and 2000 (*Fig. 3*). The following periods can be distinguished based on the frequency and temporal pattern of events:

1: 1950-1961: Medium frequency of regularly occurring mass wasting events (26 events during 12 years, annual average value: 2.10);

2: 1962-1973: Low, but regular frequency (7 events during 12 years, annual average value: 0.58);

3: 1974-1983: High, regular frequency (31 events during 10 years, annual average value: 3.10);

4: 1984-1990: Medium frequency with a concentration of events in 1987 (9 events during 7 years, annual average value: 1.29);

5: 1991-2000: High frequency of events, concentrated on 1991, 1993 and 1999 (28 events during 10 years, annual average value: 2.80).

The number of reported land degradation events was not uniform in space either. *Figure 4* shows the type of mass wasting events on the different pasture areas in the Ursern Valley.

4.2 Changing land-use and management practices in the Ursern Valley

The alp inspection reports illustrate a gradually decreasing relevance of farming (*Fig. 5*) due to the declining economic role of agriculture and the mechanisation of agriculture.

Along with the decreasing number of farmers, the number of cattle decreased, and about 15 % of the remote cattle pastures fell into disuse between 1950 and 2000. Other former cattle grazing areas were converted to sheep pastures. The number of goats decreased dramatically in the whole Kanton Uri (1866: 13,150 goats, *Marti* 1970, in 2005 only 1,770, BfS 2005). As a consequence of these changes in the agricultural land use, several restrictions were no more adhered

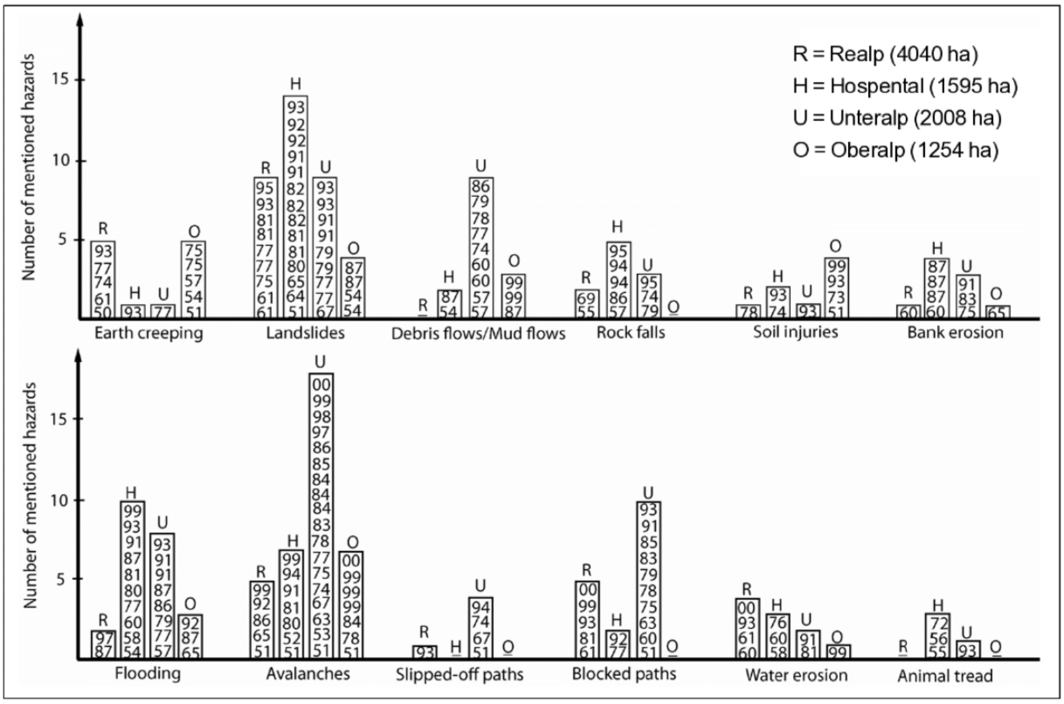


Fig. 4 Land degradation, flooding and avalanches mentioned in the alp inspection reports of the *Korporation Ursern* between 1950 and 2000. The size of the pasture area is given in brackets behind the name of the pasture areas. The numbers refer to the year in which the mentioned event happened. / *In den Alpinspektionsberichten der Korporation Ursern erwähnte Landdegradierungsprozesse, Überschwemmungen und Lawinen zwischen 1950 und 2000. Die Flächen der Weidegebiete sind in Klammern wiedergegeben. Die Zahlen beziehen sich auf die Jahre, in denen die erwähnten Ereignisse stattfanden.*

to in the 1970s. Limits on the Freiberge in the geologically sensitive Mesozoic area were abandoned for the greatest part and the use as pasture during the whole summer was allowed.

The restriction of using the pastures near the farms only with five cattle per farmer and the calves was also abolished. Furthermore, the *Korporation* began to stock the pastures during the summer with an increasing number of animals from outside the valley. These changes in land use and management led to an increase of grazing pressure on the geomorphologically sensitive and unstable Freiberge and on pasture areas near farms (*Photo 1*). Generally, large livestock were kept on the lower steep slopes near the valley bottom, while small livestock pasture areas shifted to the flatter terraces higher up on the valley trough shoulders. At the same time, disadvantageous areas for large herds were avoided which led to a low grazing pressure on remote and small pastures. Unfortunately, the alp inspection reports do not provide continuous individual data for sheep which can enhance soil erosion by their grazing habit (*Maag* et al. 2001) and goats that are known to prevent shrub encroachment. *Table 3* shows the immense increase of the importance of sheep; their number doubled between 1976 and 2005. In addition, in the interviews farmers pointed out the marginalisation of goats.

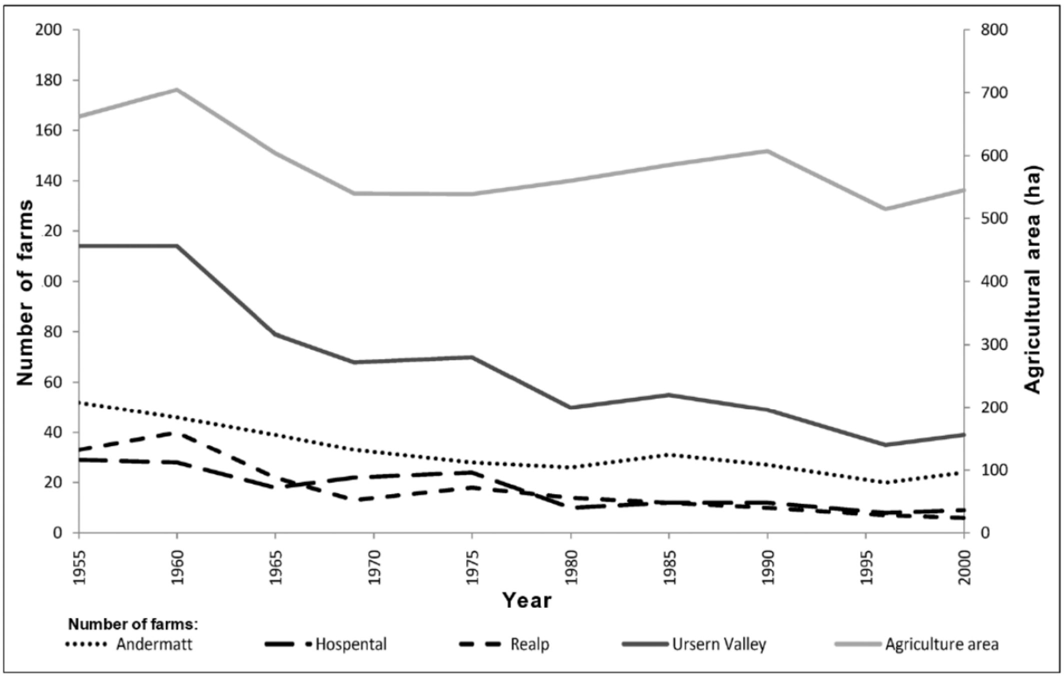


Fig. 5 Number of farms and agricultural area in the Ursern Valley, 1955-2000, with alpine pasture area converted to agricultural area considering stocking numbers and time (BfS 2007a/b). / *Anzahl landwirtschaftlicher Betriebe und landwirtschaftliche Nutzfläche im Urserntal 1955-2000. Die Fläche der Sömmerungsgebiete wurde in Abhängigkeit der Bestockungszahl und der Stoßtage in landwirtschaftliche Nutzfläche umgerechnet (BfS 2007a/b).*

Photo 1 Cow grazing in the Freiberge area between Andermatt and Hospental, with shallow landslide of September 2006
Weidende Kuh in den Freibergen zwischen Andermatt und Hospental mit flachgründiger Rutschung vom September 2006

Tab. 3 Cattle and small livestock (sheep and goats) per area for different years for the whole pasture area of the Ursern Valley. Total pasture area increased due to the use of the Freiberge as pasture since 1975. In addition, sheep pastures on the terraces reach up higher than the former cattle pastures. / *Anzahl an Groß- und Schmalvieh (Schafe und Ziegen) pro Fläche für das gesamte Weidegebiet des Urserntals für ausgewählte Jahre. Die Zunahme des Gesamtweidegebiets ist durch die Weidenutzung der Freiberge ab 1975 zu erklären. Außerdem reichen die Weidegebiete für Schafe auf den Hangterrassen weiter hinauf als die vormaligen Weidegebiete für Großvieh.*

	Number of cattle	Cattle pasture area [ha]	Cattle per ha	Proportion of external cattle [%]	Number of small livestock	Of these: goats	Small livestock pasture area [ha]	Small livestock per ha	Cattle unit[6] per ha	Proportion of external sheep [%]
1955	1149	4265	0.27		1500		3126	0.48	0.08	
1965	831	4265	0.19		1200		3126	0.38	0.07	50[1]
1976	1149	2618	0.44	30[1]	3997	546	6276	0.64	0.11	75[2,3,4]-90[5]
1986	1113	2618	0.43	30[1]	4332	473	6276	0.69	0.12	75[2,3,4]-90[5]
1995	1401	2618	0.54	40[5]-65[3]	7697	131	6276	1.23	0.21	60[4]-90[2,3,5]
2005	1482	2618	0.57		7875	276	6276	1.25	0.21	

[1] For all pasture areas, [2] for the pasture areas of Hospental, [3] for the pasture areas of Realp, [4] for the pasture area of the Unteralp, [5] for the pasture area of the Oberalp, [6] cattle units (*Großvieheinheiten*) are used for assessing grazing intensity and dung production of different animals. 1 cattle unit is equivalent to a 650 kg cow. A sheep older than 1 year, for example, equals 0.17 cattle units (*Großvieheinheit*; BfS 2011)

4.3 Maintenance history

The number of farmers in the Ursern Valley gradually declined (see Section 4.2). As a consequence, time-consuming traditional measures to maintain pasture yields as well as measures to maintain soil stability became impracticable for the few remaining farmers and were initially abandoned. However, more recently, maintenance measures have increased again. Four periods with different frequencies of maintenance work can be identified: Compared to the mentioned numbers of maintenance measures between 1934 and 1949, extracted out of the reports used to develop the checklist, a clear pattern is visible. After 1950, all types of maintenance declined in number. Maintenance of soil stability declined after 1950 and never recovered to a pre-1950 level. By the 1970s, infrastructure maintenance increased again and, between 1983 and 2000, reached a higher level than before 1950 (*Tab. 4*).

5. Discussion

5.1 Applicability of alp inspection reports for the reconstruction of mass wasting

Quantitative data of the landslides mentioned in the alp inspection reports of Hospental and Realp were compared with the data generated from air photographs by *Meusburger* and *Alewell* (2008). The temporal pattern of the mass wasting history based on air photographs corresponds well with the number of landslides mentioned in the alp inspection reports of Hospental and Realp covering the same area (*Fig. 6*).

The most notable difference between the landslides mapped from aerial photograph interpretation and those mentioned in alp inspection reports is their number which is approximately an order of magnitude greater on the aerial photographs than in the alp inspection reports. This

Tab. 4 Periods of maintenance priority and frequency
Zeitabschnitte mit unterschiedlicher Ausprägung der Meliorationsmaßnahmen

Maintenance	1934-1949	1950-1954	1955-1971	1972-1982	1983-2000
Infrastructure	36	12	29	42	58
Pasture yield	38	5	1	15	45
Soil stability	12	1	4	2	5

difference can be explained by the purposes the alp inspection reports were written for. First, remote and unused areas were not inspected by the authors of the reports. Therefore, the area inspected by them is not identical with the area covered by the aerial photographs. Second, the focus on economic damage leads to a further lack of spatial resolution. Landslides which did not cause any damage to pastures, meadows or paths as well as landslides with

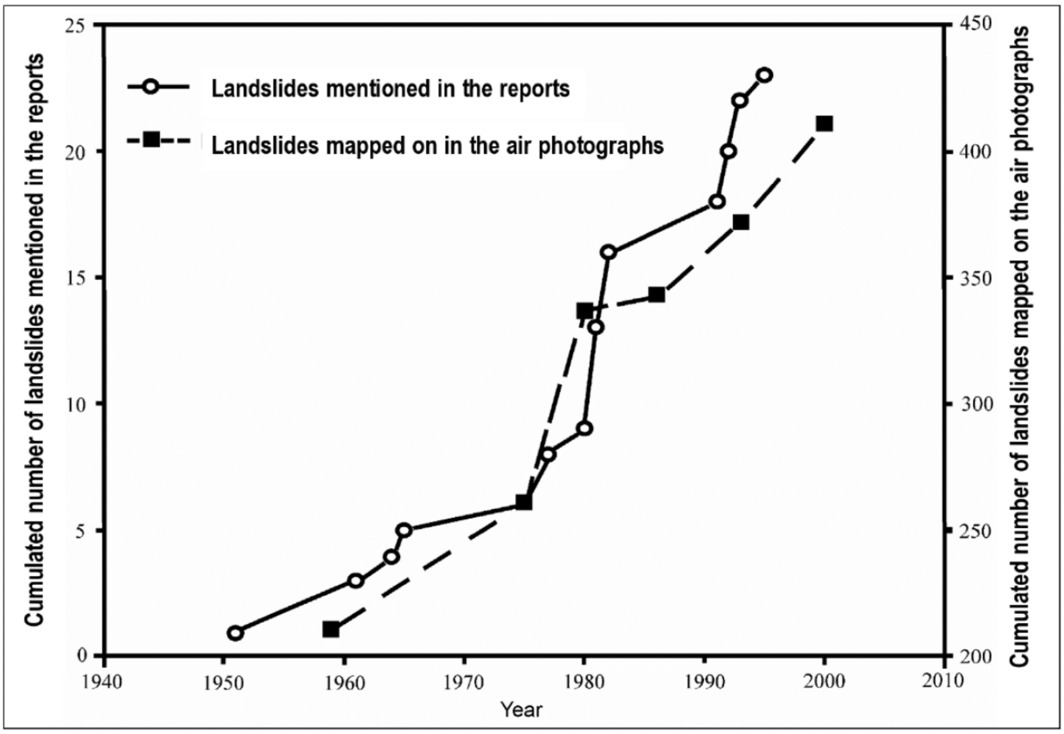


Fig. 6 Comparison of landslide numbers based on either air photograph interpretation or alp inspection reports analysis / *Vergleich der Resultate aus der Luftbildinterpretation mit jenen aus der Analyse der Alpinspektionsberichte*

a negligible effect on a pasture's yield and landslides on abandoned pastures were generally not mentioned in the alp inspection reports. Third, a quantitative assessment of spatial extent, type and damage of mass wasting based on the inspection reports is problematic because of their descriptive nature. The number of landslides in the alp inspection reports is often described as 'numerous' or 'multiple', which is why a correct number of landslides per mentioning in the reports cannot be given. Some information is also given indirectly, e.g. notes of blocked (17) or slipped-off (5) paths suggest that landslides were more frequent than mentioned in the reports. While providing greater temporal resolution than the aerial photographs, the quality of the spatial information in the inspection reports is limited. Therefore, the alp inspection reports provide an inexpensive method to detect periods of increased mass wasting frequency in conjunction with information on land use and management. While lacking spatial resolution, the information is sufficient to formulate hypotheses on the causes and effects of land use and management on land degradation in the Ursern Valley.

5.2 Mass wasting and land use

Despite the increased stocking intensity, no significant correlation between stocking numbers of cattle and sheep on the one hand and the occurrence of landslides on the other hand is observed ($P < 0.05$) in the results of the inspection report analysis. This may be due to the fact that the spatial resolution of the information about stocking numbers is too low in the alp inspection reports. Therefore, a detailed time series of land-use intensity for individual pastures cannot be reconstructed. Several references to undergrazed pastures highlight the different use intensity on the pastures. However, the analysis of spatial patterns of land use and mass wasting shows that the number of reported landslides was not uniformly distributed over the pasture land. The number of landslides in the Freiberge area is comparable to the number of mentioned landslides in the rest of the pasture area (*Tab. 5*), even though the Freiberge area accounts only for 5.25 % of total cooperative grazing land. Landslide frequency in the Freiberge area also shows a marked increase after the use restrictions were abolished in the 1970s.

Tab. 5 Number of mentioned landslides for the pasture area of the Freiberge and for the rest of the pasture area before and after the abolishment of the use restrictions 1975 / *Anzahl erwähnter Erdrutsche für das Gebiet der Freiberge und für das übrige Weidegebiet vor und nach der Aufhebung der Nutzungseinschränkungen 1975*

	Number of mentioned landslides		
	Freiberge	**Rest of pasture area**	**Total**
Before the abolishment of the restrictions 1975	3	9	12
After the abolishment of the restrictions 1975	14	10	24
Total	17	19	36

In the Oberalp area, on the other hand, landslides (4), earth creeping processes (4) and debris/mud flows (3) have been reported as less frequent, even though pastures are occasionally considered as explicitly overgrazed (Alp inspection reports (AIR): Oberalp 1954, 1983, 1984) or well used (AIR Oberalp 1984, 1985, 1987, 1992, 1993, 1996, 1997, 1998). The greater stability of the soil in the Oberalp area may be attributed to the specific characteristics of the gneiss of the '*Tavetscher Zwischenmassiv*' (*Labhart* 1999). Already in 1898, *Nager* had pointed out that landslide and rock fall susceptibility was lower in the Oberalp area because of its geological setting, generating more stable surface conditions than in other parts of the valley (*Nager* 1898). The analysis of the alp inspection reports indicates that not grazing intensity per se but stocking numbers on geologically sensitive areas is positively related to landscape susceptibility to degradation as shown by the increase of mass wasting events in the area of the geologically sensitive Freiberge after the use restrictions were abolished (*Tab. 5*).

5.3 Maintenance practices

Soil and slope maintenance work is essential to limit land degradation by mass wasting in an agricultural mountain landscape. Most notably, the deterioration of drainage systems can significantly increase landslide vulnerability and destabilise the slope (*Cernusca* 1978; *Gall* 1985). Maintenance work in the Ursern Valley shows a pattern of decline between the 1950s and 1980s, with a subsequent increase during the past 25 years (*Tab. 6*).

Comparing the numbers of the measures to maintain soil stability and pasture yields to mass wasting events shows no correlation. However, the connection between land maintenance and mass wasting was made by the inspectors. In the 1980s the inspection reports sporadically mention the negative effect of neglecting measures of land maintenance (AIR Oberalp 1981, 1990, AIR Unteralp 1983). They also point out that landslides in the past had been triggered as a consequence of neglecting measures, like improving soil drainage by striking pickets and digging drainage chan-

Tab. 6 Mass wasting and maintenance measures for the mass wasting periods identified in section 4.1
Zusammenfassung der jährlichen Massenbewegungsraten und Meliorationsraten für die verschiedenen Massenbewegungsperioden aus Abschnitt 4.1

	1950-1961	1962-1973	1974-1983	1984-1990	1991-2000
Average of mass wasting events per year	2.1	0.58	3.1	1.29	2.8
Average of maintenance measures on soil stability per year	0.25	0.18	0.1	0.14	0.3
Average of maintenance measures on pastures per year	0.3	0.3	1.7	2	2.7
Use intensity on geologically sensitive areas	Baseline	Baseline	Increased	Increased	Stable

nels (AIR Hospental 1982, 1981, 1980). These statements in the inspection reports suggest that increased frequencies of mass wasting events and the associated damage in the 1970s raised awareness of the need to re-establish maintenance efforts.

6. Conclusion and Outlook

The alp inspection reports of the *Korporation Ursern* were used as an archive for the reconstruction of land use and mass wasting history of the pasture areas in the Ursern valley between 1950 and 2000. The analysis of the reports showed an overall decline in agricultural use of the pastures in the Ursern Valley. At the same time, land degradation events associated with mass wasting increased, confirming the analysis of aerial photographs by *Meusburger* and *Alewell* (2008). The alp inspection reports show that grazing concentrated on steep slopes near the valley bottom and large continuous pasture areas on flat shoulder slopes, the latter largely used for small cattle. The intensified grazing on the lower slopes close to the valley bottom affected pasture areas which are particularly susceptible to mass wasting due to their geology. These results infer that the increase in mass wasting events and thus land degradation is caused, at least in part, by the changing patterns in land-use intensity. This potential role of land-use change for mass wasting events in the Ursern Valley is an important result because an increase of mass wasting could also be associated with climate change (*North* et al. 2007). The annual resolution of mass wasting frequency offers the possibility for analysing the mass wasting events in relation to rainfall data and enables us to assess the role of climate versus land-use change (*Caviezel* and *Kuhn* 2011).

Our study highlights the benefits of the use of alp inspections for improving the information retrieved from other sources, such as aerial photographs, for studying land degradation in alpine environments. The alp inspection reports offer a greater temporal resolution than maps or photographs and therefore fill significant information gaps. The way the mass wasting events are described in an illustrative manner facilitates the identification of its triggers. The reports also offer a wide range of information on land use and pasture management associated with the changes of agriculture in Switzerland during the 20th century. An additional benefit is that the information is not retrospective and thus uninfluenced by later findings. However, there are also some clear limitations. The spatial coverage of the inspection reports is limited to areas of economic interest. Often the number of mass wasting events is not accurate; therefore correlations between mass wasting frequency, indices of land-use intensity and measures to maintain land quality cannot be established.

The results of our study show that the alp inspection reports can be considered as an inexpensive source to detect periods of increased landscape susceptibility to land degradation. Possibly, similar alp inspection reports could also be found for other alpine valleys in order to provide inexpensive information about land use and mass wasting history in particular and human-environment relationships in general. Further studies could also focus on the analysis of weather events mentioned in the alp inspection reports and mass wasting frequency and thus enable the assessment of the effects of climate and land-use change on landscape susceptibility for land degradation.

Acknowledgements

The authors wish to thank the Korporation Ursern for the supply of alp inspection reports and land-use maps and the Transdisciplinary Project Ursern for the interviews with the farmers. The support of *Martin Schaffner, Rahel Wunderli* and *Christine Alewell* is also gratefully acknowledged.

7. References

Angehrn, P. 1996: Hydrogeologische Grundlagen Urserntal. – Unpublished manuscript. – Altdorf

BfS 2005: Nutztierbestand der Landwirtschaftsbetriebe nach Gemeinden. – Neuchâtel. – Online available at: http://www.ur.ch/dateimanager/lbz05-ur-betriebe-gmde.pdf, 21/01/2008

BfS 2007a: Landwirtschaftliche Produktion bzw. Bodenbenützung in Ursern 1939-2007. Betriebszählungen, Anbaustatistiken. – Elektronische Datenbank des Bundesamts für Statistik BfS

BfS 2007b: Anzahl Landwirtschaftsbetriebe im Urserntal 1939-2007, unterteilt nach Gemeinden. Betriebszählungen, Anbauerhebungen. – Elektronische Datenbank des Bundesamts für Statistik BfS

BfS 2008: Arealstatistik Standard – Gemeindedaten nach 4 Hauptbereichen. – Neuchâtel. – Online available at: www.bfs.admin.ch/bfs/portal/de/index/themen/02/03/blank/data/gemeindedaten.html, 28/04/2010

BfS 2009: Landwirtschaftsbetriebe: Grösse, Fläche, Besitzverhältnisse. Landwirtschaftliche Betriebszählungen, Landwirtschaftliche Betriebsstrukturerhebungen. – Neuchâtel. – Online available at: http://www.bfs.admin.ch/bfs/portal/de/index/themen/07/03/blank/data/01/01.html, 28/04/2011

BfS 2011: Land- und Forstwirtschaft. Statistische Grundlagen Definitionen. – Online available at: http://www.bfs.admin.ch/bfs/portal/de/index/themen/07/11/def.html, 08/03/2011

Bätzing, W. 2005: Die Alpen: Geschichte und Zukunft einer europäischen Kulturlandschaft. – München

Caviezel, C. and *N.J. Kuhn* 2011: Causes of Temporal Variation in Mass Wasting Occurrence in the Ursern Valley, Switzerland (in preparation)

Cernusca, A. 1978: Ökologische Veränderungen im Bereich aufgelassener Almen. Zusammenfassung der Ergebnisse einer interdisziplinären Ökosystemstudie im Gasteiner Tal. – In: *Cernusca, A.* (Hrsg.): Ökologische Analysen von Almflächen im Gasteiner Tal. – MaB-Hochgebirgsprogramm Hohe Tauern **2**. – Innsbruck: 7-16

Cernusca, A., M. Bahn, C. Chemini, W. Graber, R. Siegwolf, U. Tappeiner and *J. Tenhunen* 1998: ECOMONT: A Combined Approach of Field Measurements and Process-Based Modelling for Assessing Effects of Land-Use Changes in Mountain Landscapes. – Ecological Modelling **113** (1-3): 167-178

Flury C., N. Gotsch and *P. Rieder* 2005: Site-Specific and Regionally Optimal Direct Payments for Mountain Agriculture. – Land Use Policy **22** (3): 207-214

Gall, H. 1985: Bodenerosion und Bodenerhaltung im Gebirgsland am besonderen Beispiel Nordtirols. – Kufstein

Hunziker, M. and *F. Kienast* 1999: Potential Impacts of Changing Agricultural Activities on Scenic Beauty – A Prototypical Technique for Automated Rapid Assessment. – Landscape Ecology **14**: 161-176

IPCC 2007: Climate Change: The Physical Science Basis. Summary for Policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). 10th Session of Working Group I of the IPCC. – Paris

IUSS Working Group WRB 2006: World Reference Base for Soil Resources 2006. – World Soil Resources Report **103**. – FAO. – Rome

Kägi, H.U. 1973: Die traditionelle Kulturlandschaft im Urserntal: Beitrag zur alpinen Kulturgeographie. – Zürich

Korporation Ursern 1901/1934: Verordnung betreffend das Sömmern des Viehs auf den Alpen. – Talarchiv Korporation Ursern, Andermatt

Küttel, M. 1990: Zur Vegetationsgeschichte des Gotthardgebietes. – Mitteilungen der Naturforschenden Gesellschaft Luzern **31**: 99-111

Labhart, T.P. 1999: Planbeilage: Geologisch-tektonische Übersichtskarte Aarmassiv, Gotthardmassiv und Tavetscher Zwischenmassiv. – Rotterdam

MacDonald, D., J.R. Crabtree, G. Wiesinger, T. Dax, N. Stamou, P. Fleury, J. Gutierrez Lazpita and *A. Gibon* 2000: Agricultural Abandonment in Mountain Areas of Europe: Environmental Consequences and Policy Response. – Journal of Environmental Management **59** (1): 47-69

Maag, S., J. Nösberger und *A. Lüscher* 2001: Mögliche Folgen einer Bewirtschaftungsaufgabe von Wiesen und Weiden im Berggebiet. Ergebnisse des Kompetentenprojektes D, Polyprojekt Primalp: 1-57 – Online available at: http://www.primalp.ethz.ch/pdf-files/Schlussbericht_Komponentenprojekt_D.pdf, 05/04/2011

Marti, E. 1970: Schweizerischer Alpkataster Kanton Uri. – Bern

Meusburger K. and *C. Alewell* 2008: Impacts of Anthropogenic and Environmental Factors on the Occurrence of Shallow Landslides in an Alpine Catchment (Ursern Valley, Switzerland). – Natural Hazards and Earth System Sciences **8**: 509-520. – Online available at: http://hal.archives-ouvertes.fr/docs/00/29/95/25/PDF/nhess-8-509-2008.pdf, 06/04/2011

Nager C. 1898: Die Alpwirtschaft im Kanton Uri. – Solothurn

Newesely, C., E. Tasser, P. Spadinger and *A. Cernusca* 2000: Effects of Land-Use Changes on Snow Gliding Processes in Alpine Ecosystems. – Basic and Applied Ecology **1**: 61-67

North N., N. Kljun, F. Kasser, J. Heldstab, M. Maibach, J. Reutimann and *M. Guyer* 2007: Klimaänderung in der Schweiz: Indikatoren zu Ursachen, Auswirkungen, Maßnahmen. – Umwelt-Zustand; Klima; 07/**28**. – Bundesamt für Umwelt (Hrsg.). – Bern

Oechslin, M. 1935: Die Markgenossenschaft und die Alpen im Gotthardgebiet. Bericht über den 134. Alpwanderkurs des Schweizerischen Alpwirtschaftlichen Verbands (SAV) durch Alpen der tessinischen Leventina und des Urner Reusstales. – Langnau

Raetzo-Brülhart, H. 1997: Massenbewegungen im Gurnigelflysch und Einfluss der Klimaänderung. – PhD Dissertation, University of Fribourg

Rebsamen, H. 1919: Zur Anthropogeographie der Urner-Alpen. – Wetzikon

Russi, A. 2006: Erhebungen über den Viehauftrieb in Ursern. – Unpublished manuscript. – Talkanzlei Korporation Ursern, Andermatt: 1-2

Streifenede, T. and *F. V. Ruffini* 2007: Selected Aspects of the Agricultural Structure Change in the Alps – A Comparison of Harmonised Agristructural Indicators at Municipality Level within the Alpine Convention Area. – Berichte über Landwirtschaft **85**: 406-440

Summerfield, M.A. 1999: Global Geomorphology: An Introduction to the Study of Landforms. – Harlow

Swisstopo 2002a: Landeskarte der Schweiz 1:25 000, Oberalppass 1232. – Wabern

Swisstopo 2002b: Landeskarte der Schweiz 1:25 000, Ursern 1231. – Wabern

Tasser, E., M. Mader and *U. Tappeiner* 2003: Effects of Land Use in Alpine Grasslands on the Probability of Landslides. – Basic and Applied Ecology **4**: 271-280

Tasser, E. and *U. Tappeiner* 2002: Impact of Land Use Changes on Mountain Vegetation. – Applied Vegetation Science **5**: 173-184

TPU 2006: Transdisziplinäres Projekt Ursern. Forschungsprojekt der Universität Basel unter der Leitung von Prof. Dr. em. Martin Schaffner und Dr. Erika Hiltbrunner. – Unpublished manuscript

Wyss, R. 1986: Die Ursern-Zone – Lithostratigraphie und Tektonik. – Eclogae Geologicae Helvetiae **79**: 731-767

Summary: Applicability of Alp Inspection Reports for the Reconstruction of Land-Use and Mass Wasting History in the Ursern Valley, Switzerland

The Ursern Valley in central Switzerland has experienced considerable changes in land use and management practices since the 1950s. These changes pose a risk to landscape susceptibility for land degradation. Former studies made by air photograph interpretation found that the eroded area in the Ursern Valley nearly doubled between 1959 and 2004 (increased by 92 %, *Meusburger* and *Alewell*, 2008). Analysing alp inspection reports written by farmers which were commissioned to oversee the pasture area and write a report on the pastures' condition, mass wasting and land use history were reconstructed for the time span 1950-2000. Alp inspection reports excel in higher temporal resolution and additional information about land use and maintenance practices compared to air photograph interpretation. Temporal and spatial analysis of the mentioned events show an increase of mass wasting events since the 1970s whereas mass wasting was not uniformly distributed in time and space. The contained information about land-use intensity and maintenance practices shows that land-use intensity can modify mass wasting frequency.

Zusammenfassung: Die Eignung von Alpinspektionsberichten für die Rekonstruierung von Landnutzung und Landdegradierungsprozessen im Urserntal, Schweiz

Die Landwirtschaft in den europäischen Alpen verzeichnet seit den 1950er Jahren tiefgreifende struk-

turelle Veränderungen. Die veränderte Art und Intensität der Nutzung wirkt sich mitunter negativ auf die Stabilität der alpinen Böden aus. Mittels Luftbildinterpretation wurde für das Urserntal (Zentralschweiz) zwischen 1959 und 2004 eine Zunahme der erodierten Fläche um 92 % ermittelt (*Meusburger* und *Alewell* 2008). Dank der Analyse von Alpinspektionsberichten, jährlich verfasst von ausgewählten Landwirten, die bevollmächtigt waren, die Nutzung und den Zustand der Weiden zu beaufsichtigen, konnte die Entwicklung der Nutzung und der Unterhaltsmaßnahmen sowie die jährliche Frequenz von Massenbewegungen rekonstruiert werden. Gegenüber der Luftbildinterpretation zeichnen sich die Alpinspektionsberichte durch eine höhere zeitliche Auflösung sowie durch die zusätzlichen Informationen bezüglich der Landnutzung aus. Die zeitliche und räumliche Analyse zeigt eine Zunahme der Massenbewegungsprozesse seit 1970 sowie eine ungleichmäßige zeitliche und räumliche Verteilung der Massenbewegungsprozesse. Die Rekonstruierung der Landnutzungsgeschichte weist darauf hin, dass eine veränderte Landnutzung die Massenbewegungsfrequenz modifizieren kann.

Résumé: L'applicabilité des rapports d'inspection concernant le pâturage alpestre pour la reconstruction de l'histoire de l'exploitation du terrain et des mouvements de masse dans la Vallée d'Ursern en Suisse

L'agriculture dans les Alpes européennes est soumise à de profonds changements structurels depuis 1950. Ces changements s'expriment dans l'intensification des sites avantageux et dans le recul de l'activité agricole aux sites défavorables ce qui présente un risque pour la stabilité du paysage. La vallée d'Ursern en Suisse centrale illustre bien ce phénomène. Par l'interprétation des photos aériennes, une augmentation de 92 % des surfaces érodées a pu être observée entre 1959 et 2004 (*Meusburger* et *Alewell* 2008). Par l'aide de l'analyse des rapports des agriculteurs qui étaient chargés de surveiller la mise en pâture et la condition du pâturage, nous étions capable à reconstituer l'histoire des mouvements de masse ainsi que le développement annuel de l'exploitation et des mesures de maintenance. Comparé aux résultats obtenus par l'interprétation aérienne l'analyse des rapports se distingue par une résolution temporelle plus détaillée et par des informations précises concernant l'exploitation du terrain. L'analyse temporelle et spatiale rend compte de l'augmentation du nombre des mouvements de masse depuis 1970 et de la distribution spatiale et temporelle asymétrique de ces mouvements de masse. La reconstruction de l'exploitation du terrain et des mesures prises sur la maintenance de la pâture indique que le changement structurel dans l'agriculture peut modifier la fréquence des mouvements de masse.

Lic. phil. geogr. Chatrina Caviezel, Prof. Dr. Nikolaus J. Kuhn, Geographisches Institut, Departement Umweltwissenschaften, Universität Basel, Klingelbergstr. 27, 4056 Basel, Switzerland, c.caviezel@unibas.ch, nikolaus.kuhn@unibas.ch

Dr. Katrin Meusburger, Institut für Umweltgeowissenschaften, Departement Umweltwissenschaften, Universität Basel, Bernoullistr. 30, 4056 Basel, Switzerland, k.meusburger@unibas.ch

Manuscript submitted: 04/01/2010
Accepted for publication: 13/02/2011

Chapter 5

5 Changing rainfall characteristics and its effect on the managed eco-geomorphic balance

This study addresses the question whether it is possible to distinguish between land use change and climate change as triggering factor for land degradation events. The study was published in Geoöko as:

C. Caviezel, N.J. Kuhn (2012): Causes of temporal variation of mass wasting occurrence in the Ursern Valley, Switzerland. Geoöko. v. 33, 89-109.

GEOÖKO	VOLUME/BAND XXXIII, 89 – 109	GÖTTINGEN 2012

CAUSES OF TEMPORAL VARIATIONS IN MASS WASTING OCCURRENCE IN THE URSERN VALLEY, SWITZERLAND

URSACHEN FÜR DAS UNGLEICHMÄSSIGE AUFTRETEN VON LANDDEGRADIERUNGSPROZESSEN IM URSERNTAL, SCHWEIZ

CHATRINA CAVIEZEL & NIKOLAUS J. KUHN

ZUSAMMENFASSUNG

Die mit den strukturellen Veränderungen in der Landwirtschaft einhergehende veränderte Art und Intensität der Nutzung sowie die Zunahme von extremen Niederschlagsereignissen erhöhen die Anfälligkeit alpiner Böden gegenüber Massenbewegungsprozessen und Degradierung. Die Analyse von Alpinspektionsberichten im Urserntal für den Zeitraum von 1950-2000 zeigt eine Zunahme der Ereignisse seit 1970 sowie eine ungleichmässige zeitliche und räumliche Verteilung der Massenbewegungen. Der Vergleich der Landnutzungsgeschichte und der Niederschlagtrends weist darauf hin, dass der Wandel in der Landwirtschaft neben der Zunahme an extremen Regenereignissen die Anfälligkeit gegenüber Landdegradierung und Massenbewegungen seit 1950 erhöht.

Schlüsselworte: Landnutzungswandel, Massenbewegungen, regionale Archive, Klimawandel, Nutzungsregelungen

SUMMARY

Considerable changes in land use and management practices together with an increased frequency of extreme weather events in mountain regions are considered major factors in the susceptibility of landscape to mass wasting in the Alps. An increase in mass wasting events since 1970 as well as uneven spatial and temporal distribution of mass wasting events was found on analysis of alp inspection reports between 1950 and 2000. These were written annually by farmers commissioned to supervise pasture use and report on conditions prevailing on the communal land in the Ursern Valley, Switzerland. To investigate variations in mass wasting frequency, controlling parameters such as climate and grazing patterns and intensity were analysed using the regional archive. The results infer that land use changes and maintenance measures modified the effects of an increasing number of high magnitude rainfall events by changing landscape susceptibility to mass wasting and land degradation since 1950.

Keywords: Land use change; mass wasting; regional archive, climate change, grazing regulations

1 INTRODUCTION

Alpine landscapes in Switzerland are formed by both natural processes and human land use, which started about 5000 years ago (Bätzing, 2005). Therefore, the geomorphology of these landscapes is characterized by a particularly sensitive relationship between humans and the environment. As a consequence, alpine valleys in Switzerland have been subject to human-induced acceleration of land degradation such as landslides, debris/mud flows and water erosion. This degradation was balanced by efforts to maintain surface stability and land productivity. In recent decades, changes in climate (IPCC, 2007) and land use (Bätzing, 2005) started to pose a new risk to this relationship in general and to the stability of alpine soils (Cernusca et al., 1998; Newesely et al., 2000; Rebetez et al., 1997; Tasser et al., 2003). By generating a time-series inventory map of landslides based on a series of seven air photographs starting in 1959, Meusburger and Alewell (2008) found that the area affected by mass wasting in the Ursern Valley in central Switzerland nearly doubled between 1959 and 2004 (increase of 92%). Due to the long time gap between the individual air photographs, an exact year or date when mass wasting happened could not be identified and a link to individual causes is therefore not possible. However, the Ursern Valley still offers a good opportunity to study the history of land degradation in the 20th century. Land tenure in the Ursern Valley lies largely with the *Korporation Ursern*, a cooperative of associated citizens under public law that owns most of the pasture areas. Since 1900, the cooperative has commissioned farmers to oversee the pasture area and write detailed annual reports on its condition. The annual reports contain information on stock numbers, weather conditions, natural hazards and measures to maintain soil stability and pasture yields. Therefore, these reports, stored in the archive of the *Korporation Ursern* in Andermatt, provide greater temporal resolution and further information on land use and weather conditions associated with mass wasting events than air photographs (Caviezel et al., 2010). Historical documents often provide useful data for the assessment of landscape susceptibility to land degradation, with special regard to its triggering and damaging effects. Tropeano and Turconi (2004) compiled a summary of studies that analysed historical data to determine the occurrence of landslides, debris flows, and stream floods in the past.

For the purpose of reconstructing the reasons for the variations in mass wasting history, found in a previous study (Caviezel et al., 2010), alp inspection reports by the *Korporation Ursern* were analysed for the years between 1950 and 2000. Due to the variation in mass wasting frequency, diverse triggering factors for mass wasting were expected. The objective was to determine whether not only the increase in frequency of high magnitude

rainfall events but also the change in land use parameters is responsible for the variation in the frequency of mass wasting processes. In order to distinguish between the effects of structural changes in agriculture and climate change on landscape susceptibility to land degradation in mountain areas, land use patterns and intensity, as well as the maintenance practices applied to maintain pasture yields in the Ursern Valley were analysed. Finally, the results were compared to the meteorological data collected at the SwissMeteo station in Andermatt.

2 SITE DESCRIPTION

The study area consists of the main Ursern Valley and its side valleys of Wittenwassern, Unteralp, Mutten, Furka, Gotthard and Oberalp and covers an area of 17.924 ha (BfS, 2008). The bottom of the main valley is situated at an elevation of 1442 m a.s.l. in Andermatt and 1538 m a.s.l. in Realp. The entire study area is drained by the river Reuss and its tributaries. Slope angle on the U-shaped main valley lies within 22° and 33° (Swisstopo, 2004). Valley side-slopes reach to 2000 m a.s.l.. Above, a more shallow shoulder slope reaches to 2600 m a.s.l. in the western part and 2800 m a.s.l. in the eastern part of the valley (Kägi, 1973). The rugged mountain peaks, which were never glaciated, reach up to 3200 m a.s.l. (Kägi, 1973).

Geologically, the Ursern Valley is part of the Ursern zone, a sediment zone between the gneiss massif of the Gotthard in the south and the granite basement massif of the Aare in the north (Kägi, 1973). The main valley corresponds to the geological fault line, with vertically dipping layers consisting of Permocarbonic and Mesozoic sediments (Labhart, 1999). Throughout the orogenesis, the material was metamorphosed to green schist (Angehrn, 1996; Kägi, 1973). Weathering of the calcareous material produced marls that are prone to landslides. The bottom of the valley and the lower valley slopes consist of Quaternary moraines of mainly siliceous loamy gravel material and talus fans. A detailed geologic and tectonic account of the area is given by Wyss (1986).

The major soil types are Podsols and Albic Umbrisols (WRB, 2006). Above 2000 m a.s.l. and on steep valley slopes, Leptosols are common, with rendzic Leptosols on the calcareous substrates. At the valley bottom and lower slopes, clayey gleyic Cambisols, Histosols, Fluvisols and Gleysols developed predominantly.

The valley has an alpine climate with an average air temperature of 3.1° C (1901-1961). The temperatures of between 1961-2006 show a positive deviation of 1.5° C compared to the long term average (1901-1961) (Angehrn, 1996). The annual precipitation received at the SwissMeteo Station in Andermatt averages 1400 mm, with approximately 35% falling as snow. The valley is snow-covered from November to April (Angehrn, 1996).

Tab.1: *Main land cover types of the Ursern Valley 2004*

Land cover type	Percentage	Plant communities
Alpine grassland with dwarf shrubs	59%	*Calluna vulgaris, Rhododendron ferrugineum, Juniperus sibirica*
Debris	21%	Grassland with more than 70% boulders
Bare rock	10%	
Glacier	5%	
Shrubs	4%	*Alnus viridis, Sorbus aucuparia*
Urban and forest	1%	*Picea abies, Larix decidua*

The natural alpine vegetation has been strongly modified by agricultural land use (Kägi, 1973). Tab.1 shows the main land cover types in the Ursern Valley.

Deforestation of the valley started in 1100 AD, when the first settlements were established (Küttel, 1990). Forest clearance was motivated by the need for agricultural land and timber and was practiced until the 19th century (Rebsamen, 1919). Cooperative pasture use began in the 13th century (Rebsamen, 1919). Nowadays, the Ursern Valley is characterized by extended pastures mainly belonging to the cooperative. Fig.1 shows the pasture area of the Ursern valley in 2006.

3 RESEARCH DESIGN

The archives of the Ursern Valley house the Korporation's annual alp inspection reports since 1900. The reports, written by farmers that were commissioned to observe the pasture area, contain information on pasture yields, land use, stocking, weather conditions, maintenance work and natural hazards. The reports were written every year for the pasture area of the Unteralp and the Oberalp belonging to the community of Andermatt, the pasture area of Realp, and the pasture area of Hospental. A detailed description of the alp inspection reports and the development of the check list used for their analysis (Tab.2) is given in Caviezel et al., (2010). The study period between 1950 and 2000 was chosen for three reasons: first, a structural change in alpine agriculture began in the 1960s (Bätzing, 2005); second, the reconstruction of mass wasting history for 1950-2000 showed a temporal variation in mass wasting occurrence in the Ursern valley (Caviezel et al., 2010); and finally, the inspection reports for the selected period were sufficiently consistent to enable a quantitative analysis (Caviezel et al., 2010). To reconstruct mass wasting in time

and space as well as its triggering causes, the reported events were linked to information on date, location and weather conditions. Based on the deviation from the average of two mass wasting events per year, four periods of different mass wasting frequencies were defined, comparing the mean values by a Mann-Whitney rank sum test using the SPSS statistic package.

The suitability of the alp inspection reports for examining mass wasting history was assessed by comparing the results to an air photograph analysis done by Meusburger and Alewell (2008) (Caviezel et al. 2010). Mass wasting events were then compared to rainfall characteristics in Andermatt during the study period. The study concentrates on mass wasting events triggered by high magnitude rainfall events and does not consider pre-wetting by snowmelt as a triggering factor. Precipitation events during months with an average temperature below 0° C are considered as snowfall and are therefore excluded. This omission appears to be justifiable because only a single landslide is mentioned in conjunction with an extreme snowfall event (Archive of the *Korporation Ursern*; Alp inspection report 1991). Farmers and reports pointed out that landslides and debris/mud flows generally happen during or after high magnitude rainfall events lasting 2-3 days (Caviezel et al., 2010). Therefore, not only daily rainfall totals, but also three-day rainfall totals were compared to mass wasting frequency. A regional threshold for rainfall magnitudes triggering mass wasting was identified in

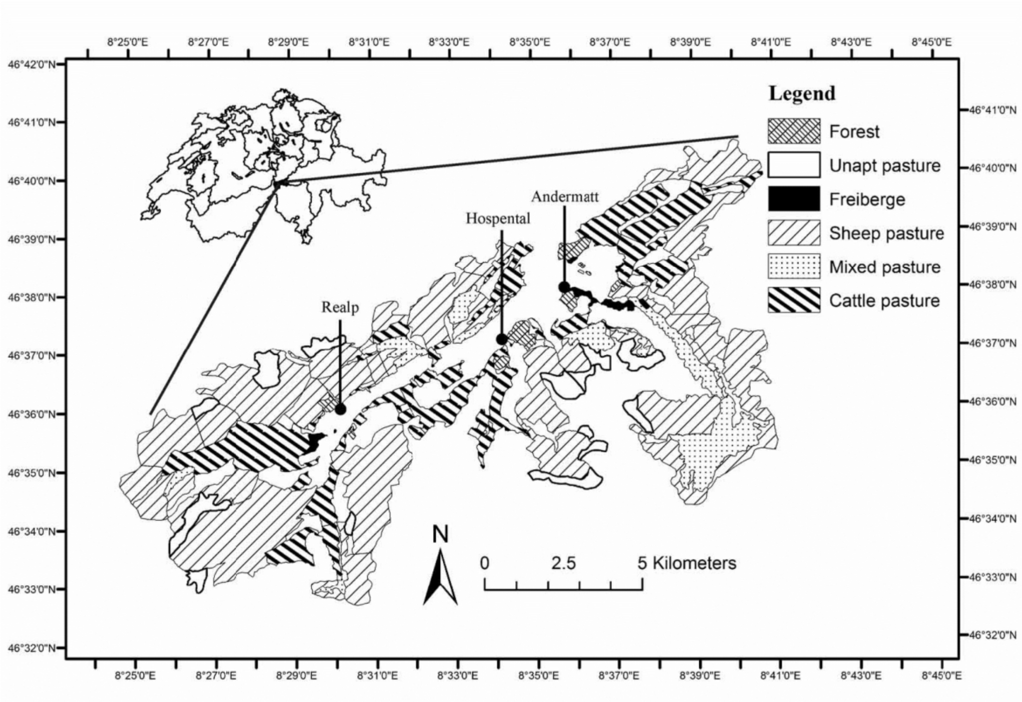


Fig.1: *The Ursern valley and its pasture area in 2006.*

Tab.2: *Checklist of attributes with relevance to land use, maintenance measures, weather and mass wasting events. Attributes are listed in English and German (as mentioned in the reports). Aufnahmeraster für Nennungen aus den Alpinspektionsberichten mit Relevanz für Landnutzung, Meliorationsmassnahmen, Wetterereignisse und Massenbewegungsereignisse. Nennungen sind in Englisch und Deutsch (wie in den Alpinspektionsberichten) aufgelistet.*

Issue		Attributes / Eigenschaften	Provides information on:
Local name of the pasture			Localization
Year			Time
Stock number		No. of local cattle/ Anzahl Grossvieh	Use intensity
		No. of external cattle / Anzahl Fremdvieh	
		No. of local sheep/ Anzahl Schafe	
		No. of external sheep/ Anzahl Fremdvieh Schafe	
		No. of local goats/ Anzahl Ziegen	
		No. of external goats/ Anzahl Fremdvieh Ziegen	
Pasture yields		Low/ gering	Use intensity
		Adequate/ genügend	
		Good/ gut	
		Outstanding/ ausgezeichnet	
		Not mentioned/ keine Aussage	
Pasture condition		Affected by debris/ Vergandung durch Geröll	Use intensity, relevance of pasture
		Affected by shrubs/ Vergandung durch Verbuschung	
		Overgrazed/ überweidet	
		Undergrazed/ unterweidet	
		Animal trails/ Viehtritte	
		Tension fissures/ Anrissstellen	
		Wet soils/ vernässter Boden	
		In good condition/ guter Weidezustand	
		In bad condition/ schlechter Weidezustand	
		Not mentioned/ keine Aussage	
Measures to improve pasture yields		Manuring/ Düngung	Relevance of pasture
		Collecting debris/ Abschönen	
		Recultivation/ Ansäen	
		Mowing/ Mähen	
		Measures against shrubs/ Bekämpfen der Verbuschung	
		Not mentioned/ keine Aussage	
Weather patterns		Beneficial/ günstig	Weather condition
		Satisfying/ befriedigend	
		Wet and cold/ kalt und nass	
		Hot and dry/ heiss und trocken	
		Not mentioned/ keine Aussage	
Extreme weather events		Thunderstorm/ Gewitter	
		Hail/ Hagel	
		Wet spell/ Regenperiode	
		Snow fall (summer)/ Schneefall (Sommer)	
		Not mentioned/ keine Aussage	

Issue		Attributes / Eigenschaften	Provides information on:
Damages to paths		Slipped-off/ abgerutscht	Indicating further mass wasting
		Blocked/ verschüttet	
		In bad condition/ in schlechtem Zustand	
		In good condition/ in gutem Zustand	
		Not mentioned/ keine Aussage	
Damages to bridges		Flushed away/ weggespült	
		In bad condition/ in schlechtem Zustand	
		In good condition/ in gutem Zustand	
		Not mentioned/ keine Aussage	
Infrastructure maintenance		River canalization/ Kanalisierung des Flussbettes	Relevance of infrastructure
		Measures on paths/ Meliorationen an Wegen	
		Measures on bridges/ Meliorationen an Brücken	
		Not mentioned/ keine Aussage	
Natural hazards		Flooding/ Überschwemmung	Indicator for mass wasting processes
		Earth creeping/ Erdbewegung	
		Landslide/ Erdrutsch, Erdschlipf, Rüfi	
		Debris/ mud flow/ Murgang, Rüfi	
		Rock fall/ Steinschlag	
		Avalanche/ Lawine	
		Bank erosion/ Weideland mitgerissen	
		Water erosion/ Gräben ausgewaschen	
		Not mentioned/ keine Aussage	
Measures to prevent damages by natural hazards		Cleaning riverbeds/ Reinigen des Flussbettes	Relevance of pasture, consciousness of natural hazards
		Avalanche barriers/ Lawinenverbauung	
		Reforestation/ Aufforstung	
		Other work/ andere Massnahmen	
		Not mentioned/ keine Aussage	
Measures on soil stability		Drainage measures/ Entwässerungsmassnahmen	Relevance of pasture
		Stick pickets/ Pfähle einschlagen	
		Retaining walls/ Stützmauern errichten	
		Deflection rill for debris/ mud flow/ Ablenkungsgraben für Murgang, Rüfi	
Conflicts of interest		Military use/ Militär	Relevance of agriculture
		Tourism/ Tourismus	
		Railway/ Bahn	
		Waste deposit/ Mülldeponien	
		Stone chipping/ Steinbruch, Stollenbau	
		Not mentioned/ keine Aussage	

this way. Frequency analysis for rainfall events above the defined threshold magnitude was conducted for the respective time periods with different mass wasting frequencies, comparing significant deviation of the mean return interval for the different periods by two tailed t-tests using the SPSS statistic package.

4 RESULTS

4.1 MASS WASTING FREQUENCY IN THE URSERN VALLEY BETWEEN 1950 AND 2000

Mass wasting frequencies reported in the alp inspection reports show a distinct pattern between 1950 and 2000 (Fig.2).

On average, exactly two events were reported every year. Based on the deviation from this average, the following periods with varying mass wasting frequency can be distinguished:

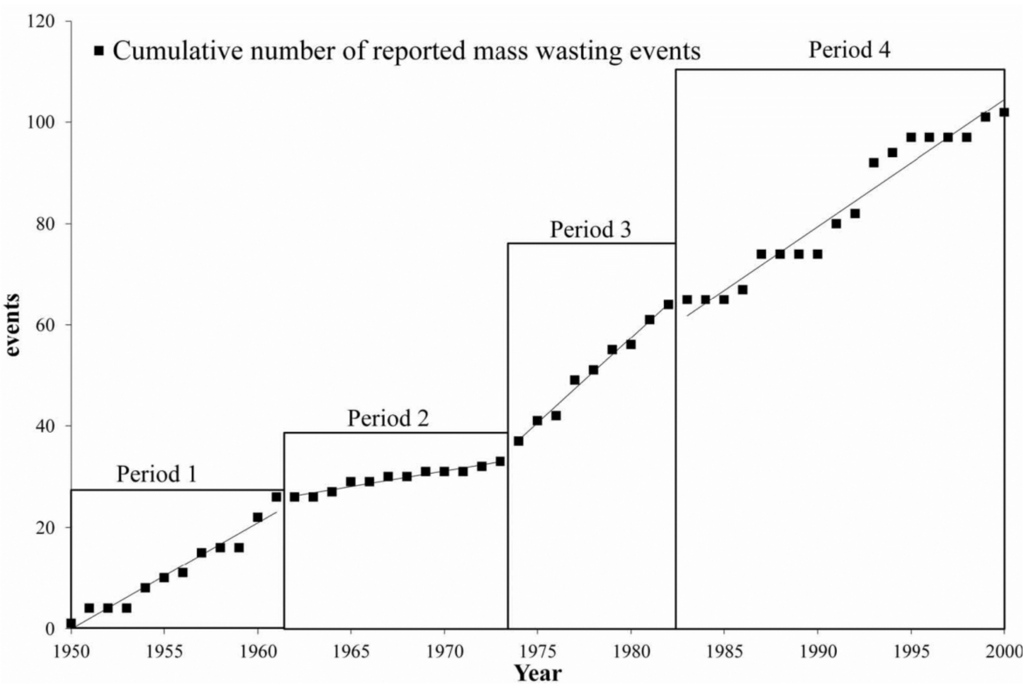


Fig.2: *Cumulative mass wasting events mentioned in the alp inspection reports of the Ursern Valley between 1950 and 2000.*

1950-1961: Medium frequency of regularly occurring mass wasting events (26 events during 12 years, on average 2.16 p.a.).

1962-1973: Low but regular frequency (7 events during 12 years, on average 0.58 p.a.). Mean differs from the pre-period mean by an exact probability of error of 5.2% (Mann-Whitney rank sum test).

1974-1982: High, regular frequency (31 events during 9 years, on average 3.4 p.a.). Mean differs from the pre-period mean by an exact probability of error of 0% (Mann-Whitney rank sum test).

1983-2000: Medium frequency of events, concentrated in 1987, 1991, 1993 and 1999 (38 events during 18 years, on average 2.11 p.a.). Mean differs from the pre-period mean by an exact probability of error of 5.9% (Mann-Whitney rank sum test); it is noteworthy that the span is significantly greater compared to the pre-period span (Moses test probability of error 1.8%)).

4.2 SPATIAL PATTERNS OF MASS WASTING EVENTS IN THE URSERN VALLEY

Analyzing the spatial distribution of landslides, a concentration was found in the area called "Freiberge" (Tab.3). The area of the Freiberge is characterized both by a sensitive geomorphology and by essential changes in land use. The steep terrain, with slide-prone lithology (Meusburger and Alewell 2008), underwent intensified use as a result of abolishment of the

Tab.3: *Number of landslides mentioned for the area of the Freiberge and for the former pasture area before and after the official abolishment of the use restrictions in 1975.*

	Number of mentioned landslides		
	Freiberge	Rest of the pasture area	Total
Before the abolishment of the restrictions 1975	3	9	12
After the abolishment of the restrictions 1975	14	10	24
Total	17	19	36

use restrictions preserving soil and pasture yield, beginning in the early 1970s. The number of reported landslides on the Freiberge is comparable to the number of landslides mentioned for the rest of the pasture, even though the area accounts for only 5.25% of the entire cooperative grazing land. Landslide frequency on the Freiberge further increased after the use restrictions were abolished.

4.3 CHANGES IN LAND USE AND MAINTENANCE PRACTICES IN THE URSERN VALLEY SINCE 1950

The development of land use and management practices in the Ursern Valley corresponds to the agricultural development in the European Alps described in the literature (e.g. Bätzing, 2005; MacDonald et al., 2000; Tasser and Tappeiner, 2002) and can be summarized as follows: the number of farms declined from 114 farms in 1955 to 31 farms in 2007 (BfS, 2007). Grazing restrictions on the geomorphologically sensitive slopes of the Freiberge and on the more easily accessible pasture areas near the farms were officially abolished for most parts in 1975. As a consequence, grazing intensity on these areas increased. The number of cattle increased slightly, the number of goats decreased dramatically and the number of sheep experienced a quintuplication (Caviezel al., 2010). Permanent herding of goats and sheep was continuously replaced by uncontrolled grazing of large sheep herds. Due to the increasing size of the herds, large, continuous pasture areas were preferred by farmers and experienced an increase in grazing intensity, due to the selective grazing of uncontrolled sheep (Transdisziplinäres Projekt Ursern, 2006). Steep areas, formerly mown by hand, were converted to pastures or fell into disuse. Sheep pasture area nearly doubled; replacing former cattle pasture area on the extended terraces by sheep pasture, while cattle pasture area decreased by 39%. An overview of change in grazing patterns for the different pasture areas is given in Tab.4. Fig.3 shows the number of mentioned maintenance activities for the different mass wasting periods. Compared to the mentioned numbers of maintenance measures between 1934 and 1949, when pressure on the land use was greatest (Imsand, 2011), all types of maintenance declined in number after

Tab.4: *Grazing patterns on the pasture areas in the Ursern valley*

Year	Cattle number	Cattle pasture area [ha]	Cattle [ha^{-1}]	Percentage of external cattle [%]	Small livestock number	Small livestock pasture area [ha]	Small livestock [ha^{-1}]	Cattle unit [ha^{-1}]	Percentage of external sheep [%]
1955	1149	4265	0.27		1500	3126	0.48	0.08	
1995	1388	2618	0.53	40[4]-65[2]	8025	6276	1.28	0.22	60[3]-90[1,2,3]

[1] For the pasture areas of Hospental

[2] For the pasture areas of Realp

[3] For the pasture area of the Unteralp

[4] For the pasture area of the Oberalp

1950 (Caviezel, 2008). Subsequently, maintenance activities to improve soil stability remained below the pre-1950 level, but by the 1970s infrastructure maintenance activities increased again and reached a greater number between 1983 and 2000 than before 1950. This shift in maintenance activities highlights the declining relevance of the extent of the total grazing area, but emphasizes the need for easy access to the pastures that were actually used.

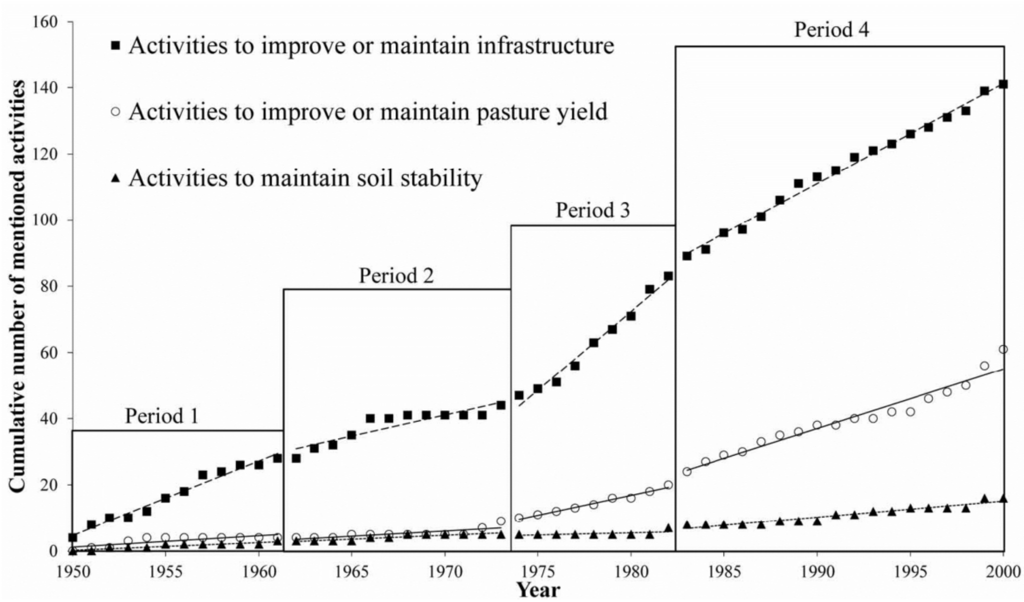


Fig.3: *Maintenance activities for the different mass wasting periods.*

4.4 CORRELATION BETWEEN MASS WASTING EVENTS AND RAINFALL

Mass wasting and rainfall generally correlate, as soil stability is a function of water content (Rebetez et al., 1997), declining when soil becomes overloaded by the weight of water during high magnitude rainfall. Although the number of landslides mentioned by accurate date in the alp inspection reports is lower than expected, six landslides, four debris/mud flows and four flooding events were compared with the climate data of the SwissMeteo Station in Andermatt (Tab.5). Two out of six landsides mentioned by accurate date occurred 2-5 days after prolonged rain events.

Overall, the rainfall data indicate that mass wasting processes occurred when precipitation exceeded 58 mm in one day, 125 mm in three days or if precipitation on consecutive days

Tab.5: *Mass wasting events mentioned by accurate date in comparison to precipitation data. Greatest cumulative precipitation for five days before recorded event is listed, accounting for events that occurred either shortly after the rainfall event or were possibly recorded with several days of delay. All precipitation fell as rainfall except for the event of the December 21st 1991.*

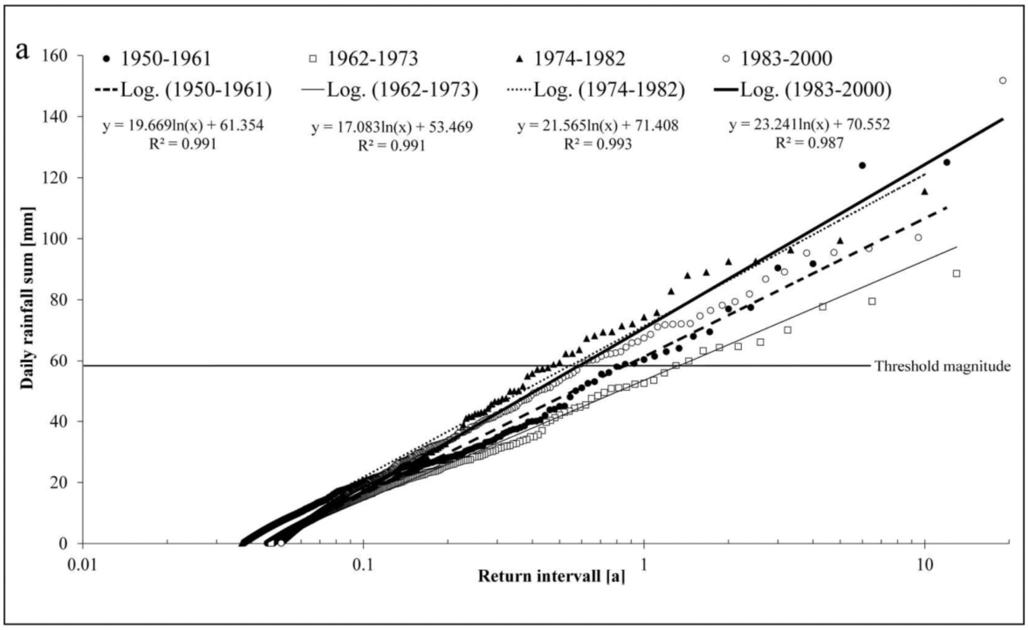
Date	Event	Daily precipitation sum [mm]	Three-day cumulative precipitation [mm]	Highest cumulative precipitation event for five days before the recorded event [mm]
10.11.1951	Landslide	**77.5**	**119**	126
22.08.1954	Debris/ mud flow	4.5	**135**	146.5
13.08.1957	Debris/ mud flow	**58.9**	**95.7**	95.7
19.08.1958	Flooding	**90.4**	92.7	92.7
27.04.1964	Landslide	0	3	**127.1**
30.08.1965	Landslide	0.2	2.2	**131.7**
05.07.1986	Debris/ mud flow	0	0.2	0.2
06.07.1986[1]		38.5	38.5	38.7
24.08.1987	Debris/ mud flow	**151**	191	191
17.06.1991	Flooding/ landslide	53.4	**126.7**	126.7
29.09.1991	Flooding	**86.8**	110.2	171.9
21.12.1991	Landslide	**136.5**	174	208.7
22.09.1993	Landslides	**79.4**	92.8	92.8
24.09.1993	Flooding	**76.5**	204.4	217.8

[1]Debris/mud flow on 05.07.1986 happened during a dry period that ended one day after the event. Possibly the date was not reported accurately.

exceeded 125 mm for five days before the event. While obviously only a very rough estimate, the identified values can still be used to assess the relevance of changes in magnitude-frequency distributions of rainfall on mass wasting frequency in the Ursern Valley.

4.5 RAINFALL MAGNITUDE ANALYSIS FOR ANDERMATT 1950 TO 2000

Return intervals (Fig.4) indicate that rainfall events above the defined threshold magnitude cannot be considered as extreme events, due to their high frequency. In Andermatt, the return interval for a daily rainfall exceeding 58 mm is 1.3 years, for the three-day rainfall events exceeding 125 mm, 0.58 years. Fig.4 shows the return intervals for the daily rainfall events (a) and the three-day rainfall events (b) at the Andermatt station based on the four



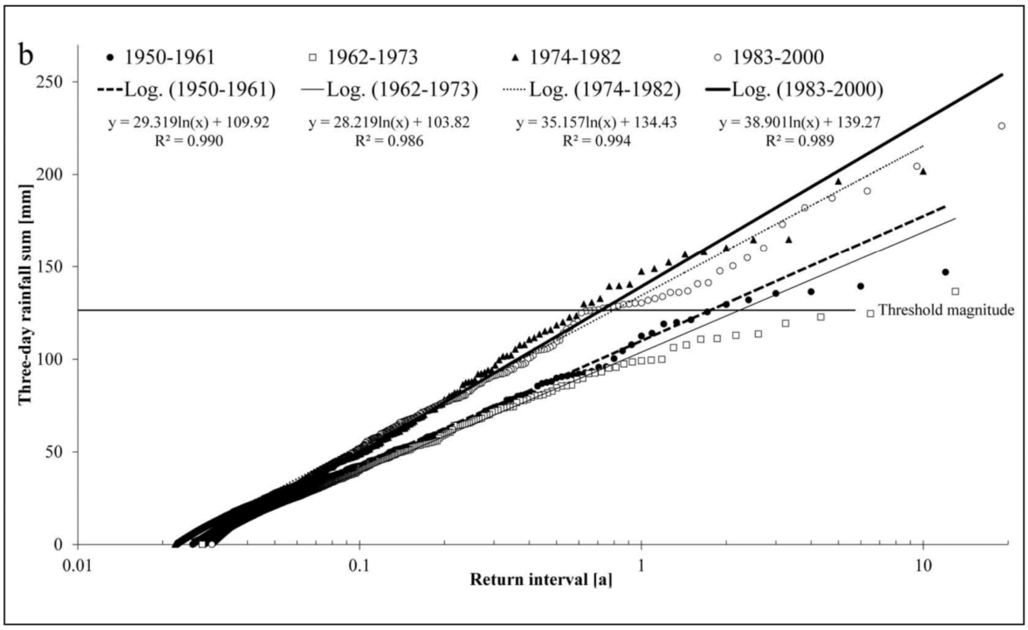


Fig.4a/b: *Return intervals of daily rainfall sum (a) and three-day rainfall sum (b) for the defined mass wasting periods*

mass wasting periods identified above. While the log transformed return intervals above the defined threshold magnitude do not differ significantly for the mass wasting period of 1950-1961 compared to the period 1962-1973 (two-tailed t-test, for daily rainfall sum p = 0.181; for three day rainfall sum p = 0.127), the return intervals during the period 1974-1982 are significantly shorter than during the period 1962-1973 (two-tailed t test, for daily rainfall sum p = 0.006; for three day rainfall sum p = 0.017). The comparison of the periods 1974-1982 to 1983-2000 shows no significant deviation of the return intervals (two-tailed t test, for daily rainfall sum p=0.237; for three day rainfall sum p = 0.974)

The rainfall magnitude-frequency analysis therefore confirms that the number of mass wasting triggering rainfall events increased during the latter part of the study period.

5 DISCUSSION

Generally, landslides and precipitation are related by a threshold function (Guzzetti et al., 1999), as soil strength properties are a function of soil water content. Analyzing the different parameters associated with mass wasting for the identified periods indicates that the frequency of high magnitude rainfall events represents an important controlling factor for mass wasting. Nevertheless, high magnitude rainfall events do not fully explain the changes in frequency of reported mass wasting events in the Ursern Valley (Tab.6). This result has also been described by Meusburger and Alewell (2008), whose correlation coefficients between precipitation characteristics (yearly maximum 1 day-events, –3 day-events and –5 day-events; yearly mean precipitation) and landslides were not significant for the Ursern Valley. In particular, the decline in mass wasting between 1983 and 2000 compared to the preceding period is disproportionally large compared to the only slightly lower frequency of triggering events.

The limited data allow no quantitative assessment of the relationship between rainfall characteristics, mass wasting and the potential effects of land use change. Using a double sum analysis of the annual frequency of landslides and high magnitude rainfall events (Fig.5) generates some further insight into the relevance of climate and land use to mass wasting. Three types of relationships for each mass wasting period can be identified: i) linear fit: correlation between landslide frequency and high magnitude rainfall events, ii) step up: greater frequency of landslide events than of high magnitude rainfall events, iii) step forward: greater frequency of high magnitude rainfall events, but no greater frequency of landslide events (Fig.5).

Mass wasting periods 1, 2 and 3 show a close linear relationship between threshold rainfall magnitude events and mass wasting. It is noteworthy that period 3 has a steeper slope,

which is consistent with the increased number of triggering rainfall events and intensified grazing on sensitive areas (Fig.4). Also Meusburger and Alewell (2009) observed a deviation from statistical susceptibility models analysing landslide events on air photographs for the years 1959 and 2000. The majority of new high susceptibility zones are located within the two land use types, *Freiberge* and Private land (Meusburger and Alewell 2009). Meusburger and Alewell conclude that the most plausible explanation of a local shift in susceptibility zones is the change in land use types between 1955 and 2006 (Meusburger and Alewell 2009). Period 4 shows a marked stepped pattern, with limited reaction of mass wasting events to triggering events. This apparent decline in landscape susceptibility to mass wasting is attributed to the more regular accomplishment of maintenance measures since the late 1980s (Fig.3). Another explanation could be that mass wasting frequency increased dramatically after the revocation of use restrictions in 1975, because of the abundance of colluvial material that was kept in stable condition by grazing restrictions. With increasing grazing pressure, the stored potential energy in the regolith layer was released (Dietrich et al., 1993), leading to more landslides before a new balance between weathering, soil formation and erosion was re-established

Tab.6: *Summary of parameters relevant for mass wasting during periods with different frequencies of mass wasting events.*

	1950-1961	1962-1973	1974-1982	1983-2000
Average of mass wasting events $year^{-1}$	2.16	0.58	**3.44**	2.11
Average of landslide events $year^{-1}$	0.41	0.25	1.66	0.72
Average of 1day rainfall events with more than 58.9 mm $year^{-1}$	1.16	0.75	**2.11**	1.72
Average of 3 day rainfall events with more than 125 mm $year^{-1}$	0.25	0.16	**1**	0.88
Average of maintenance measures on soil stability $year^{-1}$	0.25	0.16	0	0.27
Average of maintenance measures on pastures $year^{-1}$	0.33	0.41	**1.44**	2.5
Average of maintenance measures on infrastructure $year^{-1}$	2.33	1.33	**4.33**	3.22
Use intensity on geologically sensitive areas	baseline	baseline	increased	increased

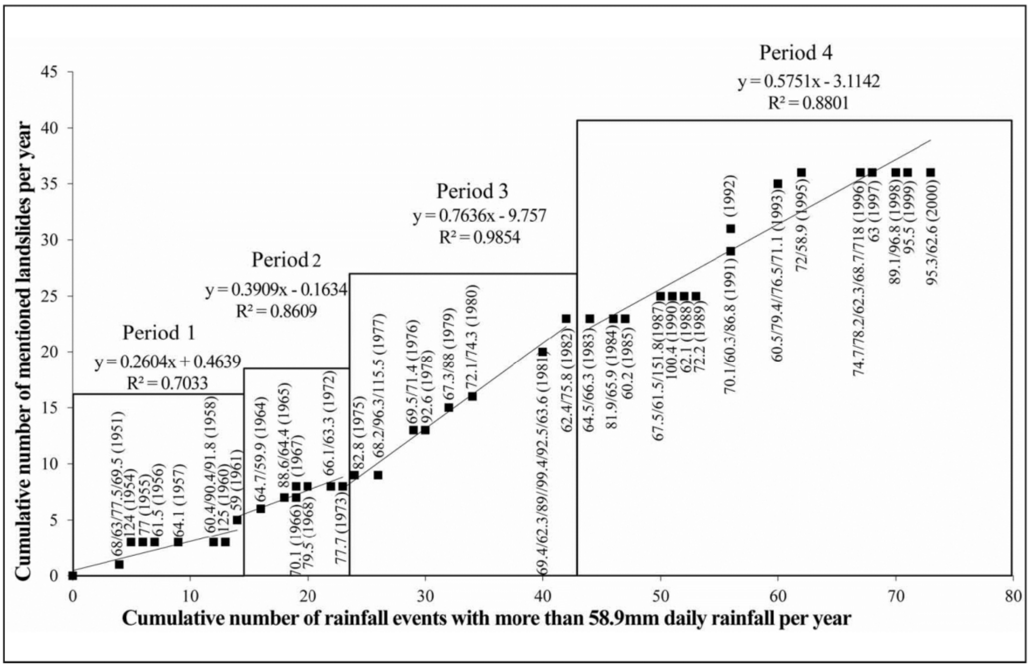


Fig.5: *Double sum of landslide events in relation to rainfall events above the defined threshold magnitude of 58.9 mm per day. Double sum analysis of all mass wasting processes show similar patterns for both threshold magnitude of the 58.9 mm day sum and the 125 mm three day sum.*

under the new grazing and rainfall regime. Overall, the double-sum analysis indicates that not only rainfall characteristics, but also landscape susceptibility to mass wasting changed between 1950 and 2000.

However, despite the apparent relevance of grazing intensity and changes in management practices for land degradation in the Ursern Valley, a significant correlation between stocking number and mass wasting frequency could not be observed (Caviezel 2008, unpublished).

Based on this concept of stored potential energy developed by Dietrich et al., (1993), the magnitude of mass wasting events may also increase on the extended remote areas that were abandoned and covered with shrubs. In the short term, the anchoring of the soil by the roots and the greater evapotranspiration rates may stabilize the slopes and diminish water run-off. However, the long term effects of root stabilization on a regolith remain unclear. This risk requires careful geomorphic study of slope systems on appropriate time scales, especially in the light of the currently debated measures to reduce shrub cover.

6 CONCLUSION AND OUTLOOK

The alp inspection reports of the *Korporation Ursern* were used as an archive for the reconstruction of triggering parameters for mass wasting events on the pasture areas in the Ursern valley between 1950 and 2000. Even though a complete understanding of the temporal variation in mass wasting processes is limited, due to missing knowledge on previous land use, climate and their interaction, which may have long term effects on landscape susceptibility, the reports provide a good overview of the changes in grazing, land management, maintenance practices, mass wasting frequency and extreme weather conditions over the past 60 years. Reported mass wasting events are associated with rain events exceeding 58 mm in one day, or more than 125 mm in three days. The frequency of high magnitude rainfall events appears to be responsible for increased frequencies of mass wasting. The analysis of the alp inspection reports also shows that the risks of land degradation cannot be associated with climate change alone. The concentration of landslides on the Freiberge after grazing restrictions were lifted indicates that the susceptibility of geologically unstable areas to mass wasting is due to intensified grazing. Further changes in the relationship between mass wasting and rainfall magnitude were observed during periods with rather constant land use. This infers that neglecting and re-establishing maintenance measures can affect landscape susceptibility for mass wasting events. Finally, the dynamic geomorphic reaction to changing climate and land use has to be taken into account when assessing mass wasting frequencies.

Climate scenarios for alpine regions foresee an increase in precipitation of 20% during winter, while summer and autumn rainfall will decrease (Beniston, 2006). Reduction in summer average rainfall may be accompanied by an increase in short, but potentially devastating heavy rainfall events (Beniston, 2006). The results indicate that the risk of mass wasting may increase as a consequence of climate change if more precipitation events above the critical threshold for triggering a mass wasting fall as rainfall, especially on saturated ground after snowmelt. However, they also show the significant potential of land management, especially grazing regulations and maintenance, to mitigate the negative effects of climate change on land degradation. In fact, one must question whether climate or land use change poses a greater threat to sustainable agriculture in the Ursern Valley.

This study also illustrates that the alp inspection reports of the *Korporation Ursern* provide a valuable additional source of information to assess the factors contributing to land degradation in an alpine environment. The greatest benefits are the relatively high temporal resolution and the possibility of distinguishing between trends in landscape susceptibility to degradation caused by rainfall or land use as well as land management change. The analysis of inspection reports could therefore be extended in other alpine areas with land tenure and reporting similar to that practised by the *Korporation Ursern*.

ACKNOWLEDGEMENT

The authors wish to thank the *Korporation Ursern* for the supply of the alp inspection reports and land use maps. The support of Martin Schaffner, Rahel Wunderli and Christine Alewell is also gratefully acknowledged.

REFERENCES

ANGEHRN P. (1996): Hydrogeologische Grundlagen - Urserntal. - Altdorf. (Unpublished).

ARCHIVE OF THE KORPORATION URSERN: Alp inspection reports and meeting protocols from 1934-2000. Andermatt. (Unpublished)

BENISTON, M. (2006): Mountain weather and climate: A general overview and a focus on climatic change in the Alps. - Hydrobiologia, v. 562, 3-16.

BFS (2007): Anzahl Landwirtschaftsbetriebe im Urserntal1939-2007, unterteilt nach Gemeinden. Betriebszählungen,Anbauerhebungen. – Elektronische Datenbank des Bundesamts für Statistik

BFS (2008): Arealstatistik Standard – Gemeindedaten nach 4 Hauptbereichen. - Neuchâtel. Bundesamt für Statistik. Available at: www.bfs.admin.ch/bfs/portal/de/index/themen/02/03/blank/data/gemeindedaten.html, 28/04/2010

BÄTZING, W. (2005): Die Alpen : Geschichte und Zukunft einer europäischen Kulturlandschaft. - München: Beck, 431 pp.

CAVIEZEL, C. (2008): Analyse von Alpinspektionsberichten zur Ermittlung von Landdegradierungsprozessen auf Sömmerungsweiden im Urserental von 1950-2000. Master Theses at the Universitiy Basel.1-89. Unpublished. 1-108.

CAVIEZEL, C., KUHN N. J., MEUSBURGER K. (2010): Applicability of alp inspection reports for the reconstruction of land-use and mass wasting history in the Ursern valley, Switzerland. Die Erde, v. 141, 1-16.

CERNUSCA, A., BAHN, M., CHEMINI, C., GRABER, W., SIEGWOLF, R., TAPPEINER, U., TENHUNEN, J. (1998): ECOMONT: A combined approach of field measurements and process-based modelling for assessing effects of land-use changes in mountain landscapes. - Ecological Modelling, v. 113, 167-178.

CERNUSCA, A. (1999): Land-use changes in European mountain ecosystems : ECOMONT - concept and results. - Berlin. Blackwell, 368 pp.

DIETRICH, W. E., REISS, R., HSU, M. L., MONTGOMERY, D. R. (1993): A process-based model for colluvial soil depth and shallow landsliding using digital elevation data. Workshop on Scale Issues. - Hydrological/Environmental Modelling, v. 9, 383-400.

IMSAND K. (2011): Das Archiv der Korporation Ursern in Andermatt – Bewertung zur Analyse des Wirkungsgefüges der Talgemeinschaft in der ersten Hälfte des 20. Jahrhunderts. Master Theses at the Universitiy Basel.1-89. Unpublished.

IPCC (2007): Climate Change: The Physical Science Basis. Summary for Policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). 10th Session of Working Group I of the IPCC. - Paris.

GUZZETTI, F., CARRARA, A., CARDINALI, M., REICHENBACH, P. (1999): Landslide hazard evaluation: a review of current techniques and their application in a multiscale study, Central Italy, Geomorphology, 31, 181-216.

KÄGI, H. U. (1973): Die traditionelle Kulturlandschaft im Urserntal : Beitrag zur alpinen Kulturgeographie. - PhD thesis at University of Zürich, 212.

KÜTTEL, M. (1990): Zur Vegetationsgeschichte des Gotthardgebietes. - Mitteilungen der naturforschenden Gesellschaft Luzern, v. 31, 99-111.

LABHART, T. P. (1999): Planbeilage: Geologisch-tektonische Übersichtskarte Aarmassiv, Gotthardmassiv und Tavetscher Zwischenmassiv 1:200 000. In: Vorerkundung und Prognose des Basistunnels am Gotthard und am Lötschberg : Tagungsband zum Symposium Geologie Alptransit, Zürich, 15.-17. Februar 1999 Löw S., Wyss R., (ed.). - Rotterdam: A.A. Balkema, 404 + 6 Planbeilagen.

MACDONALD, D., CRABTREE, J. R., WIESINGER, G., DAX, T., STAMOU, N., FLEURY, P., LAZPITA, J. G., GIBON, A. (2000): Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response. - Journal of Environmental Management, v. 59, 47-69.

MARTI, E. (1970): Kanton Uri: Schweizerischer Alpkataster: Bern, Abteilung für Landwirtschaft des EVD, 163.

WYSS, R. (1986): Die Ursern-Zone - Lithostatigraphie und Tektonik. - Eclogae Geologicae Helvetiae, v. 79, 731-767.

Eingang des Manuskripts: 20.03.2012
Annahme des Manuskripts: 16.05.2012

Anschriften der Autoren:

Lic phil. geogr. Chatrina Caviezel
C.Caviezel@unibas.ch

Prof. Dr. Nikolaus J. Kuhn
Nikolaus.Kuhn@unibas.ch
University of Basel,
Department of Environmental Sciences
Physical Geography and Environmental Change
Klingelbergstrasse 27
CH - 4056 Basel
C.Caviezel@unibas.ch

Chapter 6

6 Quantification and characterization of abandoned areas in the Unteralptal

This chapter includes an unpublished study on the relation between the topographic characteristic, landforms and shrub encroachment in the Unteralptal in central Switzerland. The study is prepared for publication as:

C.Caviezel, M. Hunziker and N.J. Kuhn (2015): **Green alder (*Alnus viridis*) encroachment in the Unteralptal, central Switzerland: A temporal and spatial analysis.** *in prep*.

Green alder *(Alnus viridis*) encroachment in the Unteralptal, central Switzerland: A temporal and spatial analysis

C.Caviezel, M. Hunziker and N.J. Kuhn

Physical Geography and Environmental Change, Environmental Department, University of Basel, Switzerland

Abstract

In the Swiss Alps, long lasting traditional cultivation forms have shaped and preserved alpine grasslands of high ecological value. The changing economic conditions of mountain farmland are causing a trend towards intensification of favorably and machinable areas, while the remote and unsuitable meadows and pastures experience marginalization and abandonment (Bätzing 2005). The natural forest regrowth and shrub encroachment reflect this decline agricultural use of “marginal” areas.

In the Unteralptal, a side valley of the main Ursern Valley in central Switzerland, landscape characteristics show considerable encroachment of green alder (*Alnus viridis*) on former pasture areas. Green alder encroachment induces several ecosystem changes, as for example soil nitrification and the loss of biodiversity. Further on, established shrub areas are considered as forest, thus, Swiss legislation prohibits its clearance. This study investigates the small scale topographic and geomorphologic controls for shrub encroachment on pastures by analyzing the relationship between “new shrub areas” and their relative abundances on topographic and geomorphologic features. The habitat spectrum of green alder showed to be much wider than assumed. The results indicate that the green alder cover is mostly controlled by land use intensity and that the presence of green alder cover has been relegated to areas that were not suitable for land use in the past. Knowing the areas which presumably encroach by shrubs in the near future helps to concentrate prevention efforts on these areas and to protect alpine grazing areas.

Keywords: land use and land cover change; land abandonment; shrub invasion; alpine pastures; green alder (*Alnus viridis*), relief parameter, landform analysis

6.1 Introduction

6.1.1 Polarization in land use in the European mountain agriculture

In the European Alps, traditional agricultural cultivation has formed and preserved unique landscapes and habitats of high ecological value (Gellrich and Zimmermann, 2007). For broad parts the agricultural alpine area is a land of man-made meadows and pastures (Tasser et al., 2011). During the last century agriculture structures in the Alps changed, induced by political, economic and social changes (Flury et al., 2013). These structural changes caused a polarization of land use intensity (Bätzing, 2005). On the better accessible areas near the villages use intensity increased (MacDonald et al., 2000; Bätzing, 2005; Maurer et al., 2006; Niedrist et al., 2008; Tasser et al., 2011). On the other hand, marginal areas experienced an abandonment of land use and the abolishment of traditional farming practices (Bätzing, 2005; Tasser et al., 2011). Former hay meadows were converted to grazed pasture land, remote pastures land fell into disuse (Bätzing, 2005). Today, both land use intensification and abandonment are landscape shaping processes in alpine areas.

6.1.2 Land abandonment and land cover change

Several studies use forest regrowth and shrub encroachment as indicator for land abandonment and there is an overall agreement that the abandonment of pastures and meadows is the main driving factor for forest regrowth and shrub encroachment (Bebi and Baur, 2002; Tasser and Tappeiner, 2002; Gehrig-Fasel et al., 2007; Gellrich et al., 2007; Gellrich and Zimmermann, 2007; Pellissier et al., 2013). In Switzerland, the land used for agriculture decreased by 5.4% between 1985 and 2009 (Schubarth and Weibel, 2013). In the meantime, forested area in Switzerland increased by 1304 km^2, including 174 km^2 shrub woodland (WSL, 2012a, 2012b, 2012c, 2012d). Almost the total of the new forested area (97.5%) lies within the Swiss Alpine region (Brändli, 2010). In the Alps of Switzerland, green alder (*Alnus viridis*), an early successional species is a major component of the increasing subalpine shrub woodland as 70% of the shrub areas consist of green alder, 20% of dwarf mountain pine (*Pinus mugo*), the remaining 10% consist of hazel and willow species (Brändli, 2010). Due to their strong colonization ability and high seed production (Farmer et al., 1985) green alder shrubs take advantage of the current land disuse and spread on abandoned subalpine pastures (Anthelme et al., 2003; Wiedmer and Senn-Irlet, 2006; Camacho et al., 2008). The ecological requirements of green alder are described as naturally restricted to steep, north-facing, moist slopes and disturbed habitats such as avalanche and debris flow track with high geomorphologic activity and water lines (Schröter, 1908; Richard, 1968; Hörsch, 2003). However, the obvious and wide expansion of green

alder observed in several studies (Wiedmer and Senn-Irlet, 2006; Anthelme et al., 2007; Flury et al., 2013) gives evidence for improving the understanding on the spreading and the ecologic requirements of green alder.

6.1.3 Aim of the study

In order to improve the understanding on the spreading of green alder, a spatial and temporal study on the encroachment of green alder in the Unteralptal in the central Swiss Alps was performed. The study aims at quantifying and describing the area that experienced an encroachment of green alder. The pattern of topography is characterized by geomorphometric measures on the scale of single pixels and single relief parameters like slope angle, slope exposition, elevation and curvature, which can be derived from digital elevation models (DEM). The relation between topography and vegetation composition has been shown in several studies (Barrio et al., 1997; Pinder et al., 1997; Franklin, 1998; Guisan et al., 1998; Hörsch et al., 2002; Hörsch, 2003; Pfeffer et al., 2003). According to Guisan et al. (1998), vegetation and plant distribution can be linked to the physical environment as plant communities and species are in equilibrium with environmental parameters. The rugged topography in mountain environments produces high spatial variability of micro-ecology of habitat sites by varying the spatial distribution of radiation, air and soil temperature or soil water (Hörsch, 2003). In literature the presence of green alder is related to north-facing, steep slopes and moist soil conditions (Schröter, 1908). Thus, the DEM's and its relief derivatives can be used as proxies for habitat conditions and indicate the presence or absence of a specific vegetation composition.

Vegetation associations that can persist on particular ecological site conditions are also controlled by parameters such as surface stability and geomorphic activity (Swanson et al., 1988). According to Renschler (2007), ecosystem and geomorphic processes are mutually dependent. At one hand, landforms reflect the complex interaction between relief parameters, on the other hand, their development is controlled by the frequency of geomorphic processes. Therefore, they alter biotic features and processes (Swanson et al., 1988). Swanson et al. (1988) point out, that the consideration of geomorphic processes and landforms is of a great importance for analyzing ecosystem processes as geomorphic processes and landforms interact with vegetation on various temporal and spatial scales. The ecological requirements of green alder for example are described as naturally restricted disturbed habitats such as avalanche and debris flow track and water lines with high geomorphologic activity (Schröter, 1908; Richard, 1968; Hörsch, 2003).

The apparent increase of green alder on former pasture areas all over the Alpine region gives evidence to question the ecological restriction of green alder. In order to analyze whether green alder encroachment is related to the ecologic requirements mentioned in literature and to describe the habitat conditions of "new" shrub areas, the areas that

experienced an encroachment by green alder since 1959 will be related to topographic parameters and geomorphic landforms. The main aim of the study is to identify proxies that control the encroachment of green alder using different approaches. First, based on the approach of geomorphometric measures on the pixel scale of a DEM2 and second, on the scale of landforms representing specific site conditions.

Thus the main research questions of this study can be summarized as follows:

i) Is the green alder encroachment related to specific geomorphometric measures representing the ecologic requirements as described in literature?

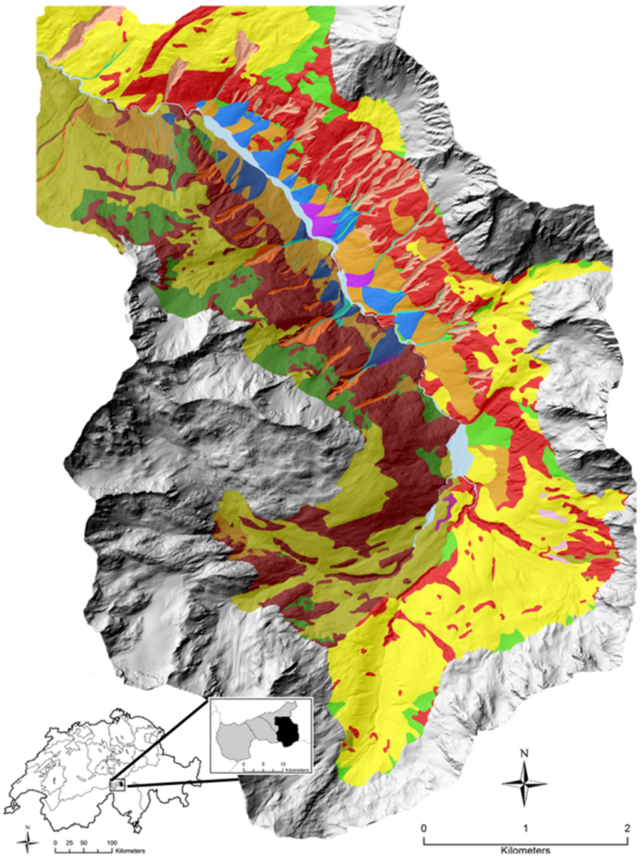
ii) Is the green alder encroachment related to specific landforms representing the ecologic requirements and habitat disturbance as described in literature?

For several reasons, an assessment of green alder encroachment is important. According to Huber and Frehner (2013), green alder associations are preventing the establishment of other species including conifer forests and should therefore not be considered as pioneer forests. Moreover, green alder does not fulfil the protective function of a conifer forest against erosion (Caviezel et al., 2014). Further ecologic effects of the encroachment of green alder include soil acidification (Caviezel et al., 2014) and nitrification (Bühlmann et al., 2014). Swiss forest legislation prohibits the clearing of forests even if they overgrow former pasture land (Swiss Federal Council, 1991) and defines newly colonized areas as forest when the stands reach an age 10-20 years, (Swiss Federal Council, 1992, WaV Art 1c) whereby woodlands are included in the forest definition (Swiss Federal Council, 1991,WaG Art.2, 2010, PSV Anhang 11 Art. 2). In addition, experiences of local farmers in central Switzerland show that clear cutting does neither help turning shrub area into a conifer forest nor does it contribute to the reversion of shrub area into pastures again (Bühlmann et al., 2014). Therefore, the preservation of open pasture land is crucial for future mountain agriculture and the knowledge about the areas that presumably encroach by shrubs in the near future helps to concentrate prevention efforts on these areas. The explicit analysis of areas that experienced an encroachment of green alder can improve the understanding of the controlling factors and provide a further insight in the ecologic requirements of green alder.

6.2 Study site

The Unteralptal, a side valley of the main Urserntal in central Switzerland (46.37°N, 8.38°E), comprises an area of 35 km^2 stretching from the highest point at 2900 m a.s.l. to the mouth of the main Urserntal near the town of Andermatt at 1442 m a.s.l. (Ambühl et al., 2008). Geologically, the Unteralptal is part of the Gotthardmassiv and consists of paragneiss, migmatit and orthogneiss (Ambühl et al., 2008). The climate is alpine with a mean air temperature of 3.4°C and a mean annual rainfall (1961–1990) of 1422 mm per year at the

nearby MeteoSwiss climate station in Andermatt (1442 m a.s.l.). Based on the FAO World Reference Base for soil resources (IUSS Working Group WRB, 2006), the dominant soil types in the catchment are Leptosols on steep valley slopes and Podzdocambisols and Cambisols on lower slopes. The predominant soil texture is silty sand and sandy silt. The previously glaciated valley is about 10 km long and characterized by a rugged terrain. The steep slopes of the U-shaped valley lead to high topographic energy and geomorphic activity resulting in diverse erosional and depositional landforms as shown in Figure 1. The main vegetation types nowadays are alpine grasslands, dwarf-shrubs mostly Alpine rose (*Rhododendron ferrugineum*) and bilberry (*Vaccinium myrtillus*) and shrubs mostly green alder (*Alnus viridis*) with single mountain ashes (*Sorbus aucuparia*).



Orographic left side	True surface area [ha]	Percentage of total study area [ha]
Bedrock	401.8	16.2
Channel	45.7	1.8
Debris cone	1.2	0.1
Debris flow track	9.0	0.4
Moraine deposit	374.9	15.1
Rockfall deposit	117.5	4.7
Talus cone	30.2	1.2
Talus sheet	87.7	3.5
Wetland	2.1	0.1
Orographic right side		
Bedrock	398.7	16.1
Channel	116.8	4.7
Debris cone	10.6	0.4
Debris flow track	9.3	0.4
Moraine deposit	596.2	24.1
Rockfall deposit	80.3	3.2
Talus cone	44.4	1.8
Talus sheet	110.6	4.5
Wetland	3.9	0.2
Valley bottom		
Alluvium	32.8	1.3

Figure 6.1: Study site and landform classification of the Unteralptal, the classification is based on the DEM2 hillshade, the geomorphologic map of the area (1:25000) and the air photographs (Messenzehl et al., 2014); terminology is used according to Ambühl et al. (2008). Further on, landforms have been allocated according to their positioning into orographic left and orographic right areas, as the orographic right side areas are characterized by a better accessibility by the drivable road.

Almost the total of the study area belongs to the Korporation Ursern, a cooperation of associated citizens under public law, *i.e.* communal land. Cooperative pasture use began in

the 13th century. Due to grassland farming for centuries, the current vegetation shows strong anthropogenic influences. According to Rebsamen (1919) and Kägi (1973), there has once been a closed forest in the Urserntal and its side valleys, reaching to the through shoulder. The presence of conifer forest is proofed by documentary evidence, field names connected to forests, as well as by numerous findings of preserved trunks (Kägi, 1973). The forest has been cleared to gain pasture area and for firewood collection and the clearance is dated for 12th and 13th century (Kägi, 1973). Only small conifer forests remained. Traditionally land use in the Urserntal was temporally and spatially restricted to control overgrazing and to preserve the quality of the pastures (Caviezel et al., 2010). The regulations led to a small scaled heterogeneous land use where the type of land use was adapted on natural site factors. The use restrictions were abolished in the beginning of the 1970s and pasture areas were merged to more homogeneous areas. Further observed changes include i) the disappearance of goat pastures as goats lost their importance and thus, their number decreased dramatically, ii) the abandonment of steep areas that are difficult to access and have formerly been mown by hand and iii) the ceasing of firewood collection by the introduction of oil heating (Caviezel et al., 2010).

6.3 Methods

6.3.1 Derivation of landcover and topographic data

6.3.1.1 Land cover classification

Land cover types were identified by visually digitizing the area from air photographs (© Swisstopo). The oldest available air photograph dates back to the year 1959. To calculate land cover change, photographs were chosen with an interval of approximate 20 years, *e.g.* 1959 1979 and 2007. The photographs from 1959 and 1979 are black and white images; the photograph of 2007 is an RGB image. In order to allow local comparison of the area of the different vegetation compositions between different years, the photographs were georeferenced and orthorectified. The geometrical corrections were performed by ENVI software package (ENVI 4.7) using between 15 and 20 ground control points based on the digital topographic map, the digital elevation model (DEM2 and DEM25 above 2000 m a.s.l.) (© Swisstopo) and the camera calibration protocols (© Swisstopo). Root mean square errors of the orthorectification lie between 0.039 and 1.006. The photographs had a scale of 1:25700, 1:19000 and 1:29000, respectively. Pixel resolution lies between 0.62 m for the picture of 1959, 0.24 and 0.28 m for the pictures of 1979 and 0.47 m for the picture of 2007. Due to the differences in illumination, resulting from mountain topography, it was not possible to perform digital image classification based on color differentiation. Problems during the digitalization arose from completely shaded areas where vegetation was not identifiable. Shaded areas were therefore digitized on each air photographs, merged and

excluded for calculating vegetation and vegetation change. However, the high spatial resolution of the aerial photographs made it possible to distinguish between the four vegetation categories: i) green alder (*Alnus viridis*) associations with closed canopy (subsequently called closed *Alnus viridis* associations) (C *AV*), ii) green alder associations with a cover between 20% and 40% (Braun-Blanquet, 1964) (subsequently called open *Alnus viridis* associations) (O *AV*), iii) Alpine rose (*Rhododendron ferrugineum*) and bilberry (*Vaccinium myrtillus*) associations (subsequently called dwarf shrubs associations) (D S) and iv) grassland. As maximum elevation of a single standing green alder shrub was determined at 2390 m a.s.l., calculations for the vegetation categories was reduced to the area below 2400 m a.s.l. reducing the investigation area to approximate 20 km^2. Grassland was calculated as "investigation area" minus "C *AV*-area" minus "O *AV*-area" minus "D S-area" minus "permanent areas" namely lakes, water currents, debris, rocks, streets and shaded areas. Field verification to identify the vegetation composition and to proof the boundaries of the areas digitized by the air photograph interpretation was performed in summer 2010.

6.3.1.2 Area calculation

Conventionally land cover is calculated using planimetric area resulting from the projection of a non flat surface into a 2-dimensional grid. Using the planimetric approach, a square kilometer in a mountainous area does not represent the same amount of surface area as a square kilometer in a flat area (Jenness, 2004). Thus, the planimetric approach is not considered as accurate to quantify land cover change in mountain areas with its rough topography (Zhiming et al., 2012). This technique is based on a moving 3×3 window algorithm and estimates the surface area for each pixel using a triangulation method. Further information on the algorithm is given in Jenness (2004) and Zhiming et al. (2012). Applying the true surface approach for area analysis, the area of the study site below 2400 m a.s.l. increases for 19.6% compared to the planimetric approach. The comparison of the vegetated areas, on which this study addresses, shows an underestimation of closed *Alnus viridis* associations and open *Alnus viridis* associations of about 30% using the planimetric approach compared to the surface calculations (Table 6.1). Due to the fact that the underestimation of shrub areas is higher than the mean underestimation of the planimetric compared to the surface approach, we consider the true surface analysis as evident for vegetation studies in mountain areas with a rough topography. Especially in regard to the calculation of stock flows as for example carbon stocks, an exact quantification of the area is essential, as green alder cover shows an underestimation by one third. Thus, the results presented in this study refer to the surface approach. As some vegetated areas experienced a change opposite to succession, *e.g.* converted from shrub to dwarf shrub or grass, relative and absolute gross vegetation changes in between the vegetation

associations were calculated for 1959 to 2007. Further results on the area affected by vegetation change are presented as net changes for the time periods of 1959 to 1979 and 1979 to 2007.

Table 6.1: Land cover categories analyzed by planimetric and surface analysis for 1959 (below 2400 m a.s.l.).

	Planimetric area [ha]	Surface area [ha]	Underestimation by planimetric analysis [%]
Shadow	117.3	174.1	**48.4**
River bed	21.8	22.2	**1.6**
Road	2.3	2.3	**2.3**
Closed *Alnus viridis* associations (C *AV*)	90.2	118.5	**31.4**
Open *Alnus viridis* associations (O *AV*)	14.0	18.1	**29.1**
Dwarf shrub associations (D S)	21.1	25.3	**19.7**
Grassland	1560.1	1792.8	**14.9**
Lake	3.3	3.3	**0.0**
Rock surface	124.3	193.6	**55.7**
Debris	114.4	125.1	**9.4**
Total	2068.9	2475.3	**19.6**

6.3.1.3 Selection and derivation of primary and secondary relief parameters using DEM data

The pixel based analysis of primary relief parameters of the areas that experienced shrub encroachment provides quantitative information on the environmental site conditions of encroached areas. The analysis of the elevation related to green alder cover increase can be used as proxy for the contribution of climate change to the increase of green alder cover, if green alder cover shows a raise in elevation over time (Pauli et al., 1996). The analysis of the green alder encroachment related to slope angle can point to changes in and use, as the kind and intensity of land use is related to specific slope angles (Surber, 1973; Sutter, 2009). Further, slope angle controls the geomorphic activity (Summerfield, 2002) and can indicate habitat niches of green alder. The analysis of green alder increase related to the slope exposition can be used as proxy for the ecologic requirements of green alder, as green alder are known to be naturally restricted to north-facing slopes (Schröter, 1908). Plan curvature (tangential curvature) indicates areas of convergent and divergent flow, *e.g.* is used as a proxy for ecological requirements of green alder as it indicates soil moisture as well as geomorphic activity. Profile curvature (upwardly curvature) indicates areas of accelerated or slowed flow, and is used as a proxy green alder ecology as it indicates moist depression zones also related to longer snow cover protecting green alder against frost damage in early spring (Richard, 1990), as well as zones of high geomorphic activity indicated by erosion and accumulation zones. In order to perform descriptive analysis of

relief parameters for the areas which experienced shrub encroachment, pixel based classification of primary relief parameters (elevation, slope angle, slope exposition, plan curvature and profile curvature) were extracted from DEM with a resolution of 2 m (DEM2).

Further proxies that were used to indicate ecological site conditions that are expected to control the encroachment of green alder are the secondary relief parameters, like solar radiation and topographic wetness index. According to Richard (1990), the presence of green alder is limited by the water supply during summer. Solar radiation was accumulated for an approximated vegetation period of 15th of May until 15th of October (Schröter, 1908). Computing the topographic wetness index provides information on soil moisture based on slope angle and curvature. The topographic wetness index, indicating the spatial distribution of soil moisture, takes into account all neighboring pixels and distributing the water proportionally to the slope angles for its calculation. Thereby, higher TWI values represent drainage depressions; lower values represent crests and ridges. According to (Richard, 1990), water supply during summer represents the limiting factor for presence of green alder. Table 6.2 provides an overview on the analyzed parameters, their classification, derivation and their relevance for controlling habitat conditions and vegetation distribution. Secondary relief parameters related to areas that encroached by green alder are expected to provide a more accurate understanding of the ecologic requirements, as they take into account several primary relief parameters. Solar radiation for example is computed of elevation, inclination and exposition information. Secondary relief parameters like solar radiation and topographic wetness Index (TWI) were created based on primary relief parameters using ESRI ArcGIS (10.0).

Table 6.2: Analyzed topographic and geomorphic parameters and their relevance for controlling habitat conditions and vegetation distribution.

	Parameter	Computed by	Scale	Classification	Relevance for controlling habitat conditions and vegetation distribution
Primary relief parameter	Slope inclination	First derivate from DEM2	Pixel based (2 m×2 m) In accordance to Dikau (1988), classified as “picorelief” to“microrelief A”	Literature (Sponagel, 2005); land use recommendations (Surber, 1973); geomorphic activity (Summerfield, 2002)	Frequency and intensity of gravitational geomorphic processes; influencing land use activity and intensity
	Elevation	First derivate from DEM2	Pixel based (2 m×2 m) *Do*.	Equal interval	Temperature; solar radiation; snow cover
	Slope aspect	First derivate from DEM2	Pixel based (2 m×2 m) *Do*.	Equal interval	Radiation; temperature; snow cover; influencing land use, the type of land use activity and intensity
	Plan curvature	First derivate from DEM2	Pixel based (2 m×2 m) *Do*.	Defining outlier values and stretched curvatures. Values in between were classifies using geometric intervals	Differentiation between ridges and valleys, frequency and intensity of gravitational geomorphic processes; snow accumulation, soil moisture
	Profile curvature	First derivate from DEM2	Pixel based (2 m×2 m) *Do*.	Defining outlier values and stretched curvatures. Values in between were classifies using geometric intervals	Indication of flow velocity, frequency and intensity of gravitational geomorphic processes, differentiation between erosion and accumulation zones; soil moisture
Secondary relief parameter	Topographic wetness index	Combination of first derivates from DEM2 (distributing water proportionally to the slope angle of neighboring pixels)	Pixel based (2 m×2 m) In accordance to Dikau (1988), classified as “picorelief” to“microrelief A”	Geometric interval	Soil moisture; waterlines and ravines
	Solar radiation	Combination of first derivates from DEM2 (elevation, slope exposition and inclination, topographic shading)	Pixel based (2 m×2 m) *Do*.	Equal interval	Radiation; soil moisture; temperature
Landform classification	Bedrock Channel Debris cone Debris flow track Moraine deposit Rockfall deposit Talus cone Talus sheet Wetland Alluvium	Based on the DEM2 hillshade, the geomorphologic map of the area (1:25000) and the air photographs, ground trothing (Messenzehl et al., 2014)	In accordance to Dikau (1988), classified as “microrelief B” to “mesorelief A”	Visually, based on identifiable landforms from the DEM2 hillshadet; erminology based on Ambühl et al., (2008). Landforms have been allocated according to their positioning, into orographic left and orographic right side of the valley	Frequency and intensity of gravitational geomorphic processes; boundary of specific habitat conditions within a landform (interaction between several relief parameters); influencing land use activity and intensity

6.3.2 Analysis of the correlation between vegetation change, topographic and geomorphic parameters

Pixel based analysis of the net vegetation change related to the primary and secondary relief parameters was performed by cross-tabulating vegetation associations according to the defined classifications of the relief parameter using ArcGIS for the year 1959 and 2007. The differences in vegetation cover of 1959, 1979 and 2007 within the classes show the net vegetation change in the mentioned time period.

On the landform scale descriptive analysis of vegetation change related to classified landforms was performed by cross-tabulating the increase and the decrease of the defined vegetation associations within the landforms for the time periods of 1959 to 1979 and 1979 to 2007. Results presented in this study focus on the net total area that experienced an encroachment by either closed or open green alder associations between 1959 and 2007. As dwarf shrub associations (D S) show a net decrease in the area between 1959 and 2007, pixel based and landform analysis of the areas with dwarf shrub cover analysis are not shown in the results. Results for both relief and landform analysis were calculated as absolute area and as relative increase in the defined class to the vegetated area within the class. The absolute and relative calculations were performed for the total area encroached by green alder by summing the area encroached by closed *Alnus viridis* associations and the area encroached by open *Alnus viridis* associations between 1959, 1979 and 2007.

6.3.3 Assessment of green alder encroachment in the near future

In order to identify the areas which presumably experience an encroachment by green alder in the near future, the following processing was pursued. First, the area on each landform that was covered either by open and closed green alder associations in 2007, was analyzed concerning the zonal statistics of the primary and secondary relief parameters. For each landform, a table containing the mean and standard deviation values for slope angle, slope exposition, plan curvature, profile curvature, elevation, topographic wetness index and solar radiation, was generated for closed and for open *Alnus viridis* associations. In the following, pixels that remained grass areas in 2007 and were lying within all of the generated ranges (mean ± standard deviation) of the relief parameters, were identified by building intersection areas. The grass areas within the intersections were classified to have a high risk for experiencing an encroachment of green alder. For each landform, surface area of the modelled shrub encroachment was calculated by intersecting areas that will encroach by open green alder associations with the areas that presumably encroach by closed green alder associations.

6.4 Results

6.4.1 Quantification of gross and net changes in vegetation associations between 1959 and 2007

Net changes of the different vegetation associations for the whole analyzed time span show that closed *Alnus viridis* associations increased by 43%, and that open *Alnus viridis* associations nearly increased fourfold (Table 6.3). Thereby, the increase rates for open and closed *Alnus viridis* associations show to be higher for the time period of 1959 to 1979 compared to the time period of 1979 and 2007. Dwarf shrub areas show a marginal net decrease. The area in the Unteralptal that experienced an encroachment by either closed or open *Alnus viridis* associations (C *AV* + O *AV)* within 48 years accounts to 86.7 ha corresponding to an increase of 63%.

Table 6.3: Net increase of surface area for the vegetation categories between 1959, 1979 and 2007 (below 2400 m a.s.l.).

	Total vegetated area 1959 [ha]	Change between 1959 and 1979 [ha]	Change between 1959 and 1979 [%]	Total vegetated area 1979 [ha]	Change between 1979 and 2007 [ha]	Change between 1979 and 2007 [%]	Total vegetated area 2007	Change between 1959 and 2007 [ha]	Change between 1959 and 2007 [%]
Closed *Alnus viridis* associations (C *AV*)	**118.5**	30.3	25.6	**148.9**	21.0	14.1	**169.9**	51.4	43.3
Open *Alnus viridis* associations (O *AV*)	**18.1**	22.3	123.3	**40.4**	13.0	32.1	**53.3**	35.3	195.0
Rhododendron ferrugineum and *Vaccinium myrtillus* associations (D S)	**25.3**	1.0	4.0	**26.3**	-4.3	-16.3	**22.0**	-3.3	-12.9
Grassland	**1792.8**	-57.7	-3.2	**1735.1**	-25.5	-1.5	**1709.7**	-83.2	-4.6

Some of the vegetated areas experienced a change opposite to succession, *e.g.* converted from shrub to dwarf shrub or grass. Table 6.4 shows the gross relative and absolute changes between vegetation associations. Most of the area that turned to closed *Alnus viridis* associations (gross increase of 77.86 ha) during the observed period of 48 years consisted previously of grassland (77%), 12% were classified as open *Alnus* viridis associations and 11% as dwarf shrub associations on the air photograph of 1959. Opposite succession vegetation changes, indicating an intensification or a shift in land use, include

8.7 ha that converted from closed *Alnus viridis* associations to open *Alnus viridis* associations, 1.4 ha that converted from closed and open *Alnus viridis* associations to dwarf shrubs, 3.6 ha dwarf shrubs that converted to grass and 5.3 ha open *Alnus viridis* as well as 17.4 ha closed *Alnus viridis* associations that converted to grassland.

Table 6.4: Relative and absolute gross changes between 1959 and 2007 between the vegetation associations of a) closed *Alnus viridis* (C *AV*) associations, b) open *Alnus viridis* (O *AV*) associations, c) *Rhododendron ferrugineum* and *Vaccinium myrtillus* (D S) associations, d) grassland.

Former vegetation association	Proportion of former vegetation associ-ations on "new" C *AV* 2007 [%]	Area of former vegetation associ-ations building "new" C *AV* 2007 [ha]	Proportion of former vegetation associ-ations on "new" O *AV* 2007 [%]	Area of former vegetation associ-ations building "new" O *AV* 2007 [ha]	Proportion of former vegetation associ-ations on "new" D S 2007 [%]	Area of former vegetation associ-ations building "new" D S 2007 [ha]	Proportion of former vegetation associ-ations on "new" grassland 2007 [%]	Area of former vegetation associ-ations building "new" grassland 2007 [ha]
C *AV*	–	–	17	8.7	9	1.1	66	17.4
O *AV*	12	9.3	–	–	3	0.3	20	5.3
D S	11	8.4	8	4.1	–	–	14	3.6
Grass-land	77	60.2	74	36.9	89	11.4	–	–

6.4.2 Analysis of the topographic and geomorphic characteristics of the areas that experienced vegetation changes

6.4.2.1 Pixel based analysis of primary and secondary relief parameters

The results of the pixel based analysis refer to net vegetation changes for the time period of 1959 to 1979 and 1979 to 2007, green alder cover is calculated by summing the area encroached by closed (C *AV*) and open green alder associations (O *AV*). As dwarf shrub associations (D S) show a net decrease in the area, changes for D S associations are not shown in the results. Results are shown as relative and absolute change of green alder surface cover within a class. Information on the analyzed topographic and geomorphic parameters and their relevance for controlling habitat conditions and vegetation distribution can be found in the methods section 6.3.2 and in Table 6.1.The results of the primary relief parameter analysis are summarized in Figure 6.2 (a-e), the results of secondary relief parameter analysis in Figure 6.3 (a-b).

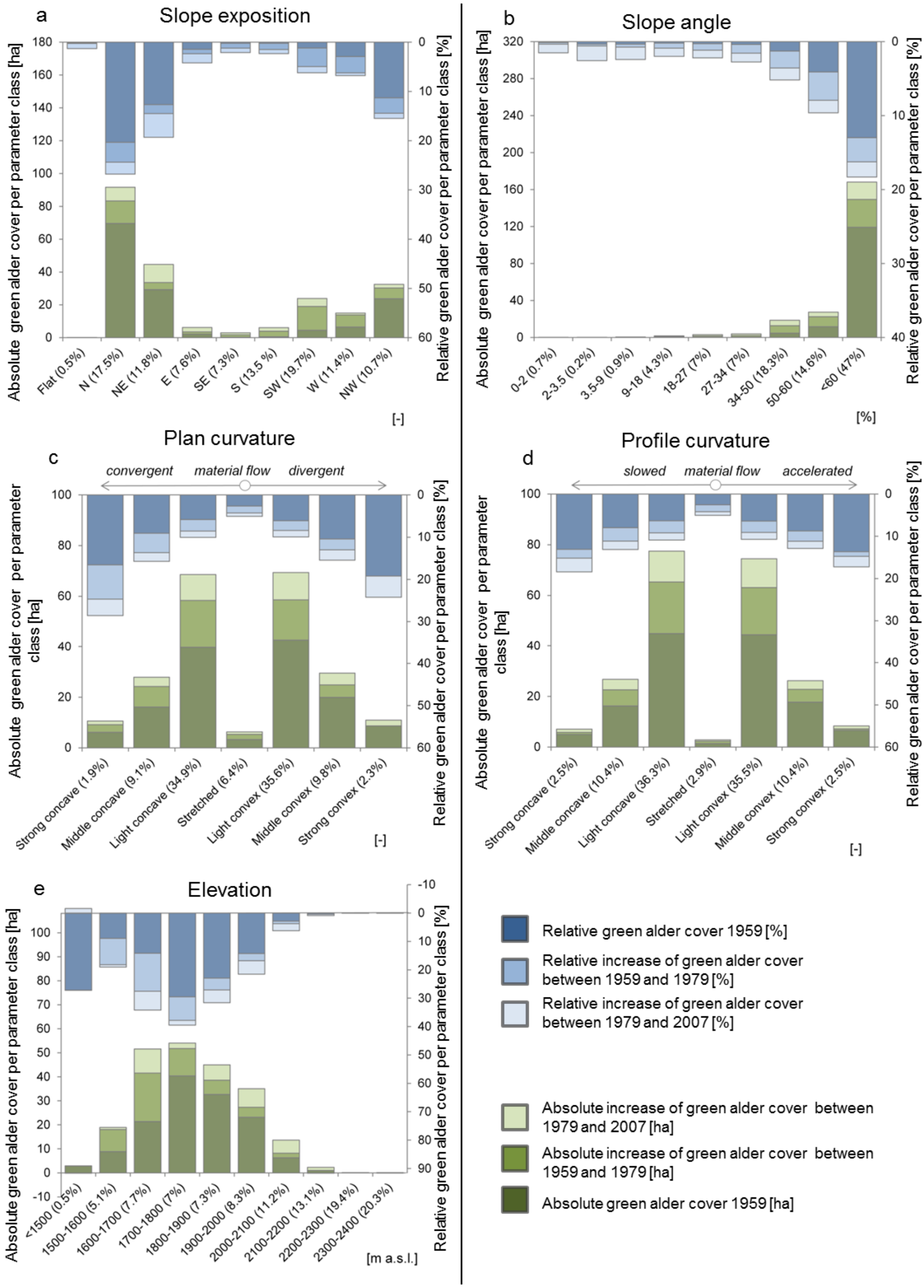


Figure 6.2: Green alder cover and increase per primary relief parameter class. a) Slope exposition, b) slope angle, c) plan curvature, d) profile curvature, e) elevation. Results are shown as absolute area (green) and relative to total vegetated area per defined relief class (blue), calculated for the surface area. The number in brackets indicates the portion of each class to the whole vegetated area in the study area below 2400 m a.s.l.

Slope exposition analysis (Figure 6.2a) shows that green alder cover is highest on north-facing slopes reaching 26.8% of the total vegetated area within the category. Also the increase of green alder cover is highest on north- (6.5%) and northeast-facing slopes (6.6%). However, the increase rates on southwest-facing slopes reach 5%, corresponding to an increase of 19.4 ha. Thus, the absolute increase on southwest-facing slopes is comparable to north- (22 ha) and northeast-facing (15.3 ha) slopes. Even though the proportional increase of green alder cover on south- and southeast- facing areas is low, the area within these classes increased remarkably by 5.5 ha (S), 2.6 ha (SE) between 1959 and 2007. Concerning the analysis of slope angle (Figure 6.2b) a distinct pattern for shrub increase is visible; steep slopes (>60%) show highest proportional (18%) and absolute (168 ha) cover in 2007. However, proportional increase rates between 1959 and 2007 are higher on slopes of 50-60% angle (5.5%, corresponding to 15.7 ha) and also the slope angle class of 27-34% shows remarkable increase rates. For the less steep slopes, one can summarize that increase of green alder cover appears mostly in the time period of 1979 to 2007. Regarding plan curvature (Figure 6.2c), the proportion of green alder cover diminishes the more the area stretches. However, the absolute values for strong curvatures are marginal. Increase rates show an identic pattern than the green alder cover in 1959. The light convex and light concave areas show the highest absolute increase values with 28.8 ha on light concave and 26.7 ha on light convex areas corresponding to an increase of 4.2% and 3.8% respectively. Profile curvature (Figure 6.2d) shows an almost identic pattern like the plan curvature classes for the proportional cover of green alder in 1959 with a decrease of the green alder cover the more the area stretches, but marginal absolute values on strong curvatures. In contrast to the plan curvature classes, increase rates do not correspond to the mentioned pattern as they show comparable proportional increases over all the curvature classes between 1959 and 2007. Highest absolute increase is found on light convex (30 ha) and light concave (32.5 ha) areas. Elevation analysis (Figure 6.2e) shows that green alder cover in 2007 is highest on 1700-1800 m a.s.l. covering 39% of the total vegetated area within the class. Proportional (20%), as well as absolute (30 ha) increase between 1959 and 2007 is highest for 1600-1700 m a.s.l. On areas above 2100 m a.s.l., accounting to 53% to the whole study area, change in green alder cover is marginal, the net absolute increase between 1959 and 2007 accounts to only 0.4 ha.

The analysis of the secondary relief parameters shows the following results. The analysis of total solar radiation during vegetation period (Figure 6.3a) illustrates that solar radiation had a strong influence on the presence of green alder in 1959. Within the categories of 0.2-0.3 $MWhm^{-2}$ and 0.3-0.4 $MWhm^{-2}$, more than half of the area within the mentioned classes was covered by green alder associations. Surprisingly, the analysis of green alder cover change shows a slight decrease (-2 ha) of the green alder cover within the mentioned classes. The most remarkable green alder encroachment between 1959 and 2007 took place on the

categories of 0.4-0.5 $MWhm^{-2}$. Highest proportional increase appeared within the categories of 0.4-0.5 $MWhm^{-2}$ with an increase of 10.3%, highest absolute increase (37 ha) on the class of 0.5-0.6 $MWhm^{-2}$. Concerning the topographic wetness index analysis (Figure 6.3b) only a slight signal in proportional cover over the topographic wetness index classes can be seen, with lowest proportional cover on medium low and intermediate TWI values. Absolute values of green alder cover in 1959, as well as absolute increase shows to be highest on intermediate wetness index classes. However, proportional increase rates between 1959 and 2007 show to be highest on extreme low TWI values, representing crests and ridges, and to decrease the more the TWI value increases indicating moister conditions.

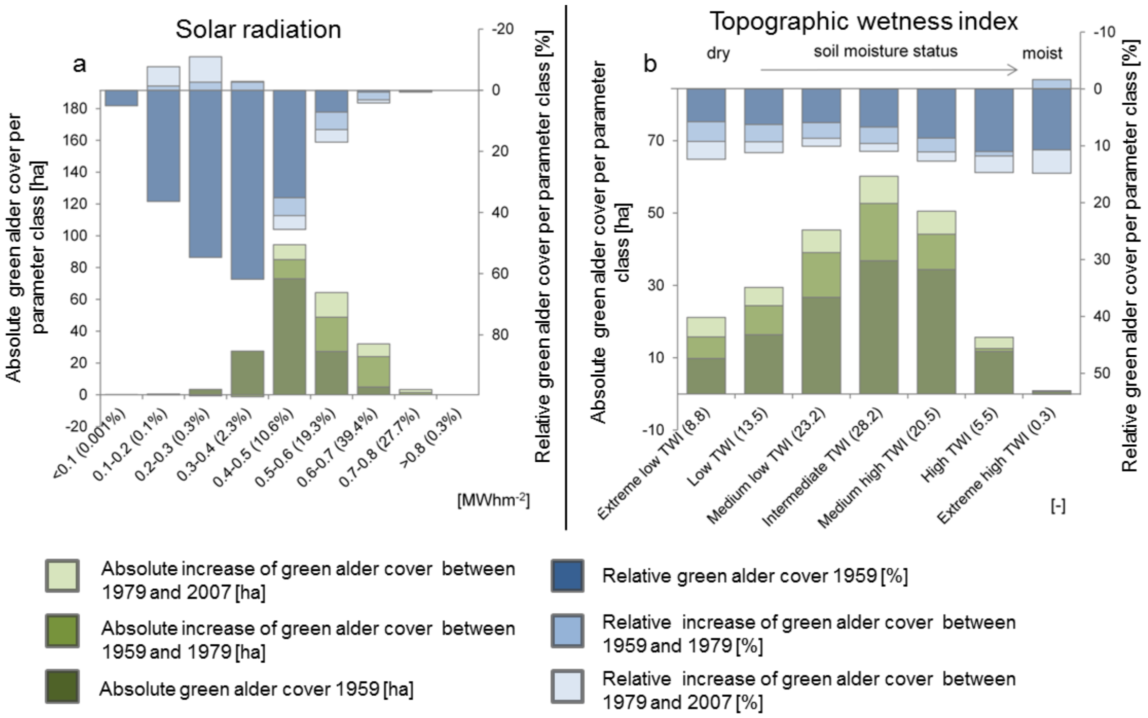


Figure 6.3: Green alder cover and increase per secondary relief parameter class. a) Solar radiation, b) topographic wetness index. Results are shown as absolute area (green) and relative to total vegetated area per defined relief class (blue), calculated for the surface area. The number in brackets indicates the portion of each class to the whole vegetated area in the study area below 2400 m a.s.l.

6.4.3 Landform based analysis

Vegetation change analysis based on landform classification shows a different dynamic for the classified landforms (Figure 6.4). The most apparent result is the difference in the proportion of green alder cover according to the landform orientation in the valley. The proportion of green alder cover within each landform is significantly higher on the orographic left side allocated landforms. In 1959, 124 ha out of 136 ha of green alder grew on left side allocated areas. The analysis shows that channels, debris flow tracks and talus

sheets hold the highest proportion of green alder cover in 1959 as well as in 2007, for both orographic left and right allocated areas.

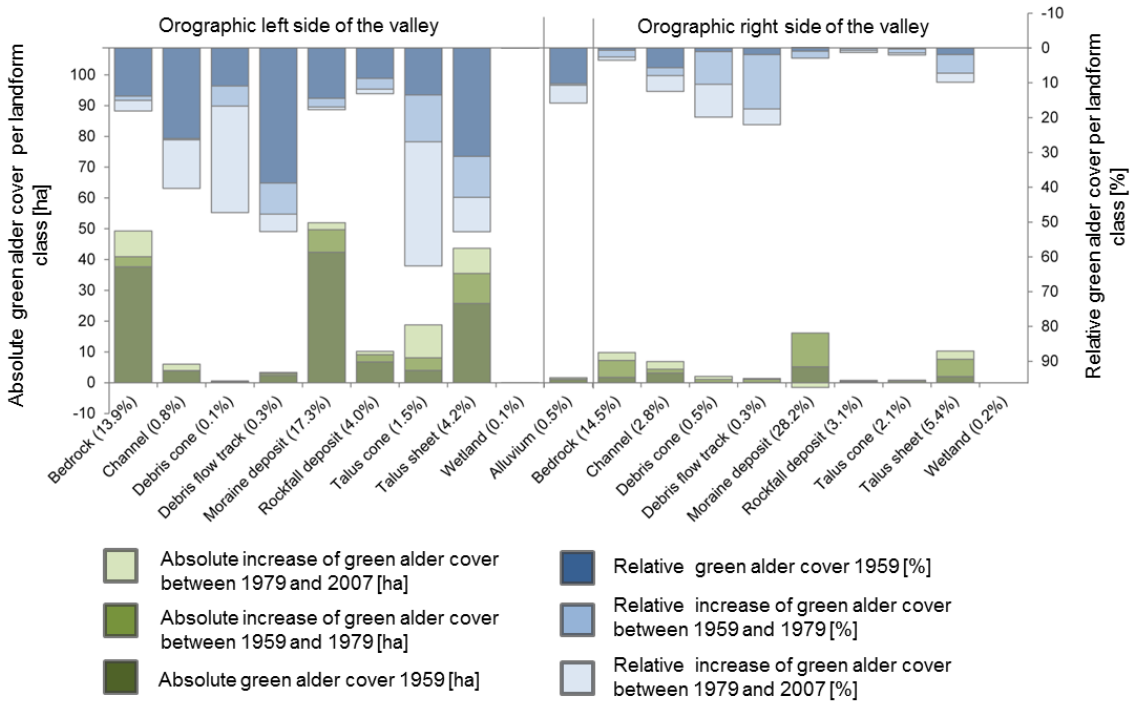


Figure 6.4: Green alder cover and increase per landform class. Results are shown as absolute area (green) and relative to total vegetated area per defined relief class (blue), calculated for the surface area. The number in brackets indicates the portion of each class to the whole vegetated area in the study area below 2400 m a.s.l.

However, proportional cover on the mentioned landform on the orographic right side was almost negligible in 1959 but increased dramatically until 2007. On talus sheets in contrast, the absolute increase of green alder cover reaches 26 ha, corresponding to 30% of the total green alder increase. The proportional cover of green alder within the orographic left talus sheets reaches approximately 53% in 2007, within the right talus sheets only 10.3%. Further on, high absolute increase values are detected on moraine deposits. Moraine deposits show an absolute increase of 19 ha corresponding to 22% of the total green alder increase. In the meantime, the proportional cover within the landforms is still low, reaching 15.4% for orographic left and only 2.6% for right allocated moraine deposits. While the absolute green alder area on the orographic left moraine deposits increased by one quarter, the green alder area on the right allocated moraine deposits experienced a triplication. At last, landforms classified as bedrock show high absolute increase values of 20 ha corresponding to 22% of the total increase. The proportional cover and absolute increase follows the same pattern as on the moraine deposits. Both, the analysis of green alder encroachment based on single relief parameters on the pixel scale, as well as the analysis of green alder encroachment on the scale of landforms, shows that the encroachment of

green alder is not only related to areas that reflect the ecologic requirements of green alder as described in literature.

6.5 Discussion

6.5.1 Evaluation of the contribution of the topographic and geomorphic proxies for controlling green alder encroachment

6.5.1.1 Topographic relief parameters as proxies for controlling green alder encroachment

The ecological requirements of green alder were described by Schröter (1908) as naturally restricted to steep, north-facing moist slopes. The analysis of green alder cover in the Unteralptal on the base of relief parameters revealed that proportional presence of green alder is still highest on extreme steep, north-facing slopes of more than 60% slope angle. However, comparable proportional increase rates for the slope angle class of 34-50% give rise to the assumption that shrub encroachment can be linked to land use extensification as it is recommended that small cattle graze to 60% slope angle and cattle to 50% slope angle (Surber, 1973). Further on, the absolute increase on south-, southwest- and southeast-facing slopes shows that green alder build permanent stands, which are not restricted to north-facing slopes. This result coincides with the outcome of a study on green alder encroachment in the eastern part of Switzerland by Huber and Frehner (2012, 2013). A further parameter contributing to the expansion of shrub area in the Unteralptal could be found in a general upward shift of vegetation associations due to climate change (Pauli et al., 1996; Paulsen and Körner, 2001). However, the analysis showed that climatic induced expansion near the tree line is not of significant importance (Figure 6.2e) compared to the effect of land use extensification. This result is in agreement with former studies concerning forest regrowth in general by Bebi and Baur (2002) and Gehrig-Fasel et al. (2007). Concerning the correlation of the presence of green alder with depression zones as found by Hörsch et al. (2002), the study in the Unteralptal revealed that for 1959 the proportion of green alder cover generally increases the more the pixel curves for both convex and concave curvatures. This implicates that, in this small scaled analysis, the presence of green alder is not bound on depression zones but on zones with high curvature. On plan curvatures, proportional increase shows the same pattern over the categories as vegetation cover on 1959. For profile curvature, the proportional increase is equally distributed over the profile curvature classes. Possibly, the correlation of green alder presence with depression zones should be examined on a wider scale, as the analysis on a 2 m × 2 m level results in a far too detailed roughness of the area. This result also underlines that ecological site conditions cannot be represented by small scaled analysis of single relief parameters alone and that a look at the entirety of a landform is needed.

The analysis of secondary relief parameters, which are expected to reflect ecologic requirements more accurately, as they involve several relief parameters, shows a distinct pattern for the proportional increase of green alder cover over the defined classes. The analysis of green alder cover increase related to solar radiation shows that green alder are spreading on drier areas. Also the analysis of the topographic wetness index on encroached areas revealed a light trend toward higher proportional increase on areas with a lower topographic wetness index, representing drier areas. Boscutti et al. (2013) even refer to a new ecological association of green alder, colonizing disused pastures on moderate slopes together with Alpine rose (*Rhododendrum ferrugineum*) in contrast to the known association in avalanche gullies and moderately steep slopes characterized by perennial herbs understorey. Some authors refer to *Alnus alnobetula ssp. brembana* as a subspecies, with smaller leaves and minor height as being competitive under drier conditions and spreading on former pastures with south-, southwest- and southeast-facing slopes, mostly building transitional populations with *Alnus viridis* (Wettstein, 2001; Landolt, 2010; Senn-Irlet et al., 2012; Huber and Frehner, 2013).

6.5.1.2 Landforms as proxy for geomorphic activity and green alder encroachment

Hörsch et al. (2002) found that the presence of green alder shrubs highly correlate with depression zones along waterlines and on debris flow tracks and is related to their affinity to high soil moisture and to the high geomorphological activity of these areas. The analysis on the base of landforms revealed that the proportional presence of green alder is highest on channels and debris flow tracks. Geomorphic activity on channels and debris flow tracks in the Unteralptal is considered to be high due to the steep slope angle and the reported high frequency of avalanches and debris flows (Coaz, 1881; Kägi, 1973; Caviezel et al., 2010). The proportional increase between 1959 and 2007 was highest on the deposition zones of debris flows, namely debris cones, and on talus cones. In light of the fact that green alder are known to be dominant on disturbed habitats, the high proportional cover on these areas is not surprising. However, a closer look at the absolute values shows that the absolute increase on channels, debris flow tracks, talus cones and debris cones accounts only to 16 ha, explaining only 18.4% of the total green alder increase. Thus, the encroachment of green alder on landforms with high geomorphic activity is marginal compared to the increase on landforms that are less disturbed by geomorphic processes as talus sheets (26 ha) and moraine deposits (19 ha). The low proportional cover and the high absolute increase on moraine deposits indicate a high potential for future increase of green alder within the moraine deposits.

The results showed that green alder encroachment is neither related to pixel based relief parameters nor landforms associated to the ecologic requirements of green alder as described in literature. Thus, the green alder cover is not restricted to a narrow ecological

niche. The differences in proportional cover between the orographic left and right side, the increase of green alder on slope angle classes of 34-60%, and also the recent increase of green alder cover on the orographic right side of the valley, that has a good accessibility but cannot be grazed by unherded large herds, leads to the assumption that the presence and absence of green alder is mostly controlled by land use.

6.5.2 Assessment of green alder encroachment in the near future

Even though green alder encroachment did not show to be related to specific ecologic requirements, using the gathered data on relief parameters and landforms that experienced an encroachment by green alder during the last 48 years can help to identify the areas that show a high affinity for encroachment and presumably encroach by shrubs in the near future. This helps to concentrate prevention efforts and shrub management on these areas. Analyzing the zonal statistics of the relief parameters for each landform and intersecting it with the area that remained grass in 2007, the area on which shrub encroachment appears most presumably was detected. Related to the landforms, results indicate a further increase of absolute green alder cover on the moraine deposits and bedrocks as well as on orographic right allocated talus sheets (Figure 6.5).

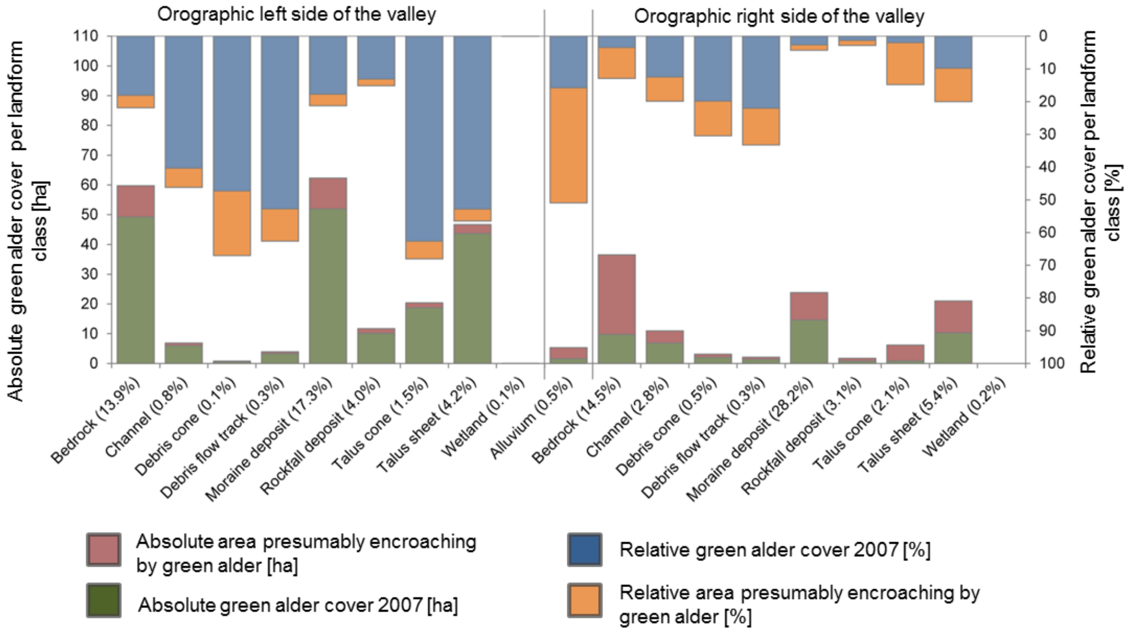


Figure 6.5: Green alder cover in 2007 and the most presumable green alder increase per landform class. Results are shown as absolute area (green) and relative to the total vegetated area per defined relief class (blue), calculated for the surface area. The number in brackets indicates the portion of each class to the whole vegetated area in the study area below 2400 m a.s.l.

The area situated on the the better accessible orographic right side of the valley shows higher absolute values for modelled green alder encroachment (Figure 6.5 and 6.6). This result indicates that the spreading of green alder on these areas was decelerated by the

continuance of land use management in the past, but that green alder potentially encroach, if land use experiences further extensification and abandonment. This result underlines the importance of land use management on the increase of green alder.

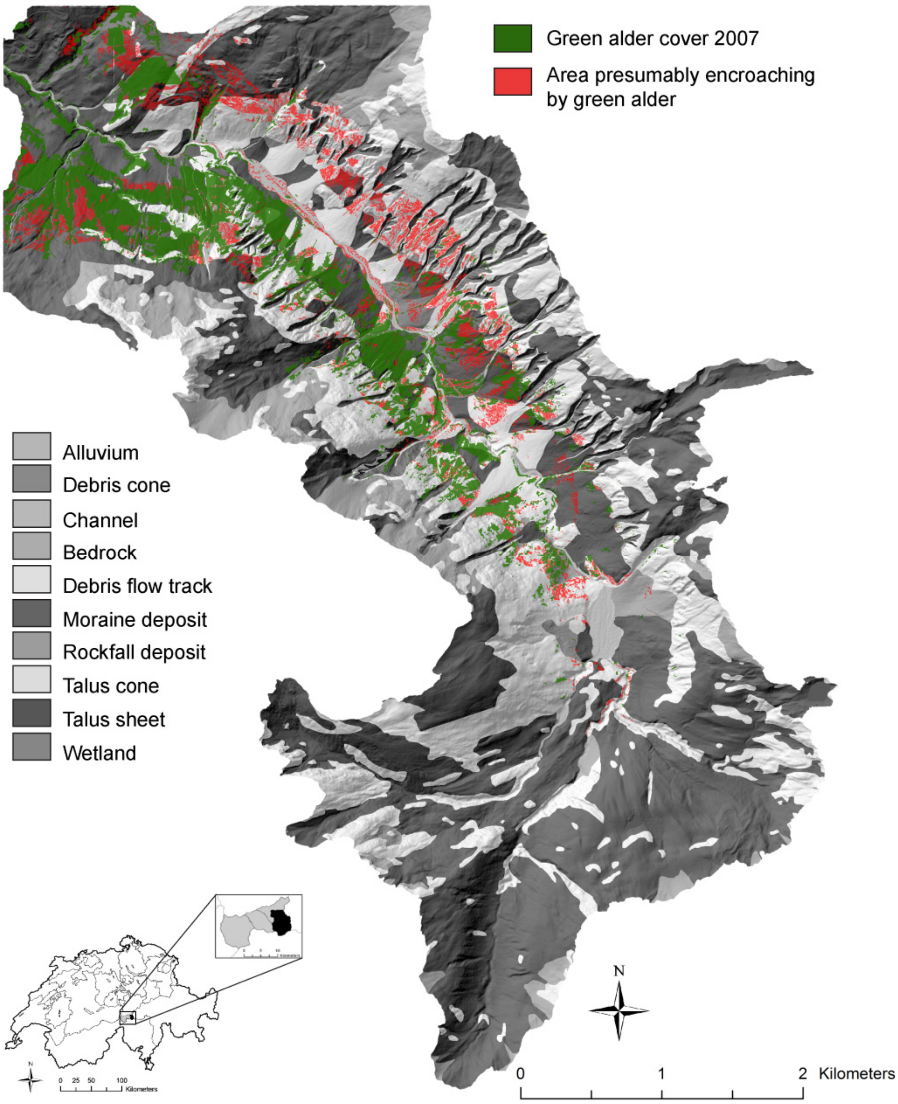


Figure 6.6: Spatial pattern of green alder cover in 2007 and the most presumable increase of green alder cover in the study area below 2400 m a.s.l.

6.6 Conclusion

Several authors described the ecological requirements of green alder as naturally restricted to steep, north-facing, moist slopes and depression zones with an affinity to high soil moisture and to high geomorphologic activity (Schröter, 1908; Richard, 1968; Hörsch, 2003).

The results of this study give evidence that, in the past, the occurrence or concentration of green alder on steep, north-facing, moist slopes coincides with areas that were not suitable for the long lasting traditional land use in the Alpine region and that only mowing and

pasturing kept the green alder on these unsuitable areas. The analysis of the green alder encroachment related to relief parameters and landforms indicate that the green alder cover is not restricted to narrow ecological niches of high disturbance represented by specific relief parameters and landforms. The spreading of green alder on areas that do not represent the mentioned habitat conditions indicates that the cover of *alnus viridis* or its subspecies *alnus brembana* is mostly controlled by land use intensity and that the habitat spectrum of green alder shows to be much wider than assumed. This leads to the conclusion that the area potentially affected by shrub encroachment is not restricted to north-facing, steep and moist slopes, depression zones and areas of high geomorphic activity and future encroachment of green alder is inevitable when land use ceases. The data presented in this study can help to identify areas with a high affinity for shrub encroachment for directing measures on these areas and to preserve open pasture landscapes.

Acknowledgements

The authors gratefully acknowledge the supply of data by Swisstopo. The support of the Korporation Ursern is also gratefully acknowledged.

6.7 References

Ambühl E, Huber HM, Niggli E, Huber W, Niggli M, Flück W. 2008. Geologische Karte Oberalppass 1:25000 (LK 1232). Swisstopo. Wabern.

Anthelme F, Michalet R, Barbaro L, Brun J-J. 2003. Environmental and Spatial Influences of Shrub Cover (Alnus viridis DC.) on Vegetation Diversity at the Upper Treeline in the Inner Western Alps. Arctic, Antarctic, and Alpine Research **35**, 48–55. DOI: 10.1657/1523-0430(2003)035[0048:EASIOS]2.0.CO;2.

Anthelme F, Villaret J-C, Brun J-J. 2007. Shrub encroachment in the Alps gives rise to the convergence of sub-alpine communities on a regional scale. Journal of Vegetation Science **18**, 355–362. DOI: 10.1111/j.1654-1103.2007.tb02547.x.

Barrio G, Alvera B, Puigdefabregas J, Diez C. 1997. Response of high mountain landscape to topographic variables: Central pyrenees. Landscape Ecology **12**, 95–115. DOI: 10.1007/BF02698210.

Bätzing W. 2005. Die Alpen Geschichte und Zukunft einer europäischen Kulturlandschaft . 3. Aufl. Beck. München. 1-431.

Bebi P, Baur P. 2002. Forest Expansion in the Swiss Alps: A Quantitative Analysis of Bio-physical and Socio-economic Causes Waldausdehnung in den Schweizer Alpen: Eine quantitative Analyse von bio-physikalischen und sozio-ökonomischen Ursachen. Centralblatt für das gesamte Forstwesen **3/4**, 2177–230.

Boscutti F, Poldini L, Buccheri M. 2013. Green alder communities in the Alps: Phytosociological variability and ecological features. Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology **148**, 917-934. DOI: 10.1080/11263504.2013.809813.

Brändli UB. 2010. Schweizerisches Landesforstinventar: Ergebnisse der dritten Erhebung 2004-2006 . Eidgenössische Forschungsanstalt für Wald Schnee und Landschaft (WSL) Birmensdorf, Bundesamt für Umwelt (BAFU). Bern. 1-312.

Braun-Blanquet J. 1964. Pflanzensoziologie; Grundzüge der Vegetationskunde. Springer-Verlag. Wien.1-865.

Bühlmann T, Hiltbrunner E, Körner C. 2014. Alnus viridis expansion contributes to excess reactive nitrogen release, reduces biodiversity and constrains forest succession in the Alps. Alpine Botany **124**, 187–191. DOI: 10.1007/s00035-014-0134-y.

Camacho O, Dobremez L, Capillon A. 2008. Des broussailles dans les prairies alpines. Organisation spatiale de l'activité et pratiques des éleveurs en vallée d'Abondance (Haute-Savoie, France). Revue de géographie alpine. Journal of Alpine Research **96**, 77–88.

Caviezel C, Hunziker M, Schaffner M, Kuhn NJ. 2014. Soil–vegetation interaction on slopes with bush encroachment in the central Alps – adapting slope stability measurements to shifting process domains. Earth Surface Processes and Landforms **39**, 509–521. DOI: 10.1002/esp.3513.

Caviezel C, Kuhn NJ, Meusburger K. 2010. Applicability of Alp Inspection Reports for the Reconstruction of Land-Use and Mass Wasting History in the Ursern Valley, Switzerland. Die Erde **141**, 301–319.

Coaz JF. 1881. Die Lauinen der Schweizeralpen .J. Dalp'sche Buch- und Kunsthandlung. Bern. 1-147.

Dikau R. 1988. Entwurf einer geomorphographisch - analytischen Systematik von Reliefeinheiten. Heidelberger Geographische Bausteine **5**, 1–45.

Farmer RE, Maley ML, Stoehr MU, Schnekenburger F. 1985. Reproductive characteristics of green alder in northwestern Ontario. Canadian Journal of Botany **63**, 2243–2247. DOI: 10.1139/b85-318.

Flury C, Huber R, Tasser E. 2013. Future of Mountain Agriculture in the Alps. In: The Future of Mountain Agriculture, Mann S (ed). Springer Berlin Heidelberg. 105–126.

Franklin J. 1998. Predicting the distribution of shrub species in southern California from climate and terrain-derived variables. Journal of Vegetation Science **9**, 733–748. DOI: 10.2307/3237291.

Gehrig-Fasel J, Guisan A, Zimmermann NE. 2007. Tree line shifts in the Swiss Alps: Climate change or land abandonment? Journal of Vegetation Science **18**, 571–582. DOI: 10.1111/j.1654-1103.2007.tb02571.x.

Gellrich M, Baur P, Koch B, Zimmermann NE. 2007. Agricultural land abandonment and natural forest re-growth in the Swiss mountains: A spatially explicit economic analysis. Agriculture, Ecosystems & Environment **118**, 93–108. DOI: 10.1016/j.agee.2006.05.001.

Gellrich M, Zimmermann NE. 2007. Investigating the regional-scale pattern of agricultural land abandonment in the Swiss mountains: a spatial statistical modelling approach. Landscape and Urban Planning **79**, 65–76.

Guisan A, Theurillat J-P, Kienast F. 1998. Predicting the potential distribution of plant species in an alpine environment. Journal of Vegetation Science **9**, 65–74. DOI: 10.2307/3237224.

IUSS Working Group WRB. 2006. World reference base for soil resources, 2006 : a framework for international classification, correlation and communication. Food and Agriculture Organization of the United Nations: Rome: 1-145.

Hörsch B. 2003. Modelling the spatial distribution of montane and subalpine forests in the central Alps using digital elevation models. Ecological Modelling **168**, 267–282. DOI: 10.1016/S0304-3800(03)00141-8.

Hörsch B, Braun G, Schmidt U. 2002. Relation between landform and vegetation in alpine regions of Wallis, Switzerland. A multiscale remote sensing and GIS approach. Computers, Environment and Urban Systems **26**, 113–139. DOI: 10.1016/S0198-9715(01)00039-4.

Huber B, Frehner M. 2012. Forschungsprojekt Grünerle. Bericht erstellt im Auftrag des Bundesamtes für Umwelt (BAFU). Chur.1-198.

Huber B, Frehner M. 2013. Die Verbreitung und Entwicklung der Grünerlenbestände in der Ostschweiz. Schweizerische Zeitschrift fur Forstwesen **164**, 87–94. DOI: 10.3188/szf.2013.0087.

Jenness JS. 2004. Calculating landscape surface area from digital elevation models. Wildlife Society Bulletin **32**, 829–839. DOI: 10.2193/0091-7648(2004)032[0829:CLSAFD]2.0.CO;2.

Kägi HU. 1973. Die traditionelle Kulturlandschaft im Urserental Beitrag zur alpinen Kulturgeographie . s.n.: Zürich. 1-212.

Landolt E. 2010. Flora indicativa: ökologische Zeigerwerte und biologische Kennzeichen zur Flora der Schweiz und der Alpen. Haupt. Bern.1-378.

MacDonald D, Crabtree J., Wiesinger G, Dax T, Stamou N, Fleury P, Gutierrez Lazpita J, Gibon A. 2000. Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response. Journal of Environmental Management **59**, 47–69. DOI: 10.1006/jema.1999.0335.

Maurer K, Weyand A, Fischer M, Stöcklin J. 2006. Old cultural traditions, in addition to land use and topography, are shaping plant diversity of grasslands in the Alps. Biological Conservation **130**, 438–446. DOI: 10.1016/j.biocon.2006.01.005.

Messenzehl K, Hoffmann T, Dikau R. 2014. Sediment connectivity in the high-alpine valley of Val Müschauns, Swiss National Park — linking geomorphic field mapping with geomorphometric modelling. Geomorphology **221**, 215–229. DOI: 10.1016/j.geomorph.2014.05.033.

Niedrist G, Tasser E, Lüth C, Dalla Via J, Tappeiner U. 2008. Plant diversity declines with recent land use changes in European Alps. Plant Ecology **202**, 195–210. DOI: 10.1007/s11258-008-9487-x.

Pauli H, Gottfried M, Grabherr G. 1996. Effects of Climate Change on Mountain Ecosystems. Upward Shifting of Alpine Plants. World Resource Review **8**, 382-390.

Paulsen J, Körner C. 2001. GIS-analysis of tree-line elevation in the Swiss Alps suggests no exposure effect. Journal of Vegetation Science **12**, 817–824. DOI: 10.2307/3236869.

Pellissier L, Anzini M, Maiorano L, Dubuis A, Pottier J, Vittoz P, Guisan A. 2013. Spatial predictions of land-use transitions and associated threats to biodiversity: the case of forest regrowth in mountain grasslands. Applied Vegetation Science **16**, 227–236. DOI: 10.1111/j.1654-109X.2012.01215.x.

Pfeffer K, Pebesma EJ, Burrough PA. 2003. Mapping alpine vegetation using vegetation observations and topographic attributes. Landscape Ecology **18**, 759–776. DOI: 10.1023/B:LAND.0000014471.78787.d0.

Pinder JE, Kroh GC, White JD, May AMB. 1997. The relationships between vegetation type and topography in Lassen Volcanic National Park. Plant Ecology **131**, 17–29. DOI: 10.1023/A:1009792123571.

Renschler CS, Doyle MW, Thoms M. 2007. Geomorphology and ecosystems: Challenges and keys for success in bridging disciplines. Geomorphology **89**, 1–8. DOI: 10.1016/j.geomorph.2006.07.011.

Richard L. 1968. Écologie de l 'Aune vert (Alnus viridis); facteurs climatiques et édaphiques. Documents pour la Cartographie de la Végétation des Alpes **6**, 107–158.

Richard L. 1990. Ecologie des mégaphorbiaies subalpines à aune vert de la Vanoise et des régions environnantes. I, Compréhension de la répartition actuelle des aunaies. Travaux scientifiques du Parc national de la Vanoise **17**,127–158.

Schröter C. 1908. Das Pflanzenleben der Alpen eine Schilderung der Hochgebirgsflora . Raustein. Zürich. 1-806.

Schubarth C, Weibel F. 2013. Die Bodennutzung in der Schweiz: Resultate der Arealstatistik. Bundesamt für Statistik (Schweiz), Sektion Geoinformation. Neuchâtel. 1-23. [Online] Available from: http://www.bfs.admin.ch/bfs/portal/de/index/news/publikationen.html?publicationID=5397. (Last access: 20.12.2014).

Senn-Irlet B, Mürner R, Martini E, Küffer N, de Marchi R, Bieri G. 2012. Saprobic fungi on wood and litter of Alnus alnobetula in the Swiss Alps. Mycotaxon [published online 2012] 1-34. [Online] Available from: http://mycotaxon.com/resources/checklists/SennIrlet-v120-checklist.pdf. (Last access: 20.12.2014).

Sponagel H. 2005. Bodenkundliche Kartieranleitung: mit 41 Abbildungen, .103 Tabellen und 31 Listen . Bundesanstalt für Geow. und Rohstoffe. Stuttgart : 1-438.

Summerfield MA. 2002. Global geomorphology: an introduction to the study of landforms. Prentice Hall. Harlow. Munich [u.a.].1-537.

Surber E. 1973. Das Brachlandproblem in der Schweiz. Eidgenössische. Anstalt für das forstliche Versuchswesen. Birmensdorf. 1-138.

Sutter R. 2009. Bodenerosion im Sömmerungsgebiet Erkennen – vermeiden – beheben. Agridea. Effretikon. 1-6. [Online] Available from: http://www.boden-uri.ch/userfiles/File/Informationen/RL_Bodenerosion_im_Soemmerungsgebiet_AGRIDEA_2009.pdf. (Last access: 20.12.2014).

Swanson FJ, Kratz TK, Caine N, Woodmansee RG. 1988. Landform Effects on Ecosystem Patterns and Processes. BioScience **38**, 92–98. DOI: 10.2307/1310614.

Swiss Federal Council. 1991. Bundesgesetz über den Wald vom 4. Oktober 1991 (Stand am 1.Juli 2013). 921.0 Bern 1-18. [Online] Available from: http://www.admin.ch/opc/de/classified-compilation/19910255/index.html#. (Last access: 20.12.2014).

Swiss Federal Council. 2010. Verordnung über Pflanzenschutz (Pflanzenschutzverordnung, PSV). (Stand am 1. Januar 2013). 916.20. Bern. 1-120. [Online] Available from:

http://www.admin.ch/opc/de/classified-compilation/20101847/index.html. (Last access: 20.12.2014).

Swisstopo. n.d. Air Photographs. Bildnummer: 19591640013791, Ort: GN 1959; Kontaktkopie 1:1, s/w, Bildnummer: 19791630018508, Ort: GN 1979; Kontaktkopie 1:1, s/w, Bildnummer: 19791600028554, Ort: GN 1979; Kontaktkopie 1:1, s/w, Bildnummer: 19791660018417, Ort: GN 1979; Kopie 1:1 (Digitalprint), Farbe, Bildnummer: 20077010491641, Ort: GN 2007; Kopie 1:1 (Digitalprint), Farbe, Bildnummer: 20077010511722, Ort: GN 2007.

Swisstopo. n.d. Camera calibration protocolls. [Online data download] Available from: http://www.swisstopo.admin.ch/internet/swisstopo/en/home/products/images/aerial/orientation/calibration.html. (Last access: 20.12.2014).

Swisstopo. n.d. swissALTI3D, Perimeter: Gemeinden (Andermatt, Hospental, Realp), Fläche: 175.0 km^2, Auflösung: 2 m, Dateiformat: TIFF, Koordinatensystem: CH1903 LV03 / LN02.

Tasser E, Leitinger G, Pecher C, Tappeiner U. 2011. Agricultural changes in the European Alpine Bow and their impact on other policies. Grassland Science in Europe, **16**, 27–38.

Tasser E, Tappeiner U. 2002. Impact of land use changes on mountain vegetation. Applied Vegetation Science **5**, 173–184. DOI: 10.1111/j.1654-109X.2002.tb00547.x.

Wettstein S. 2001. Der Einfluss abiotischer Faktoren auf die Morphologie der Grünerle. Botanica Helvetica **111**, 31–44.

Wiedmer E, Senn-Irlet B. 2006. Biomass and primary productivity of an Alnus viridis stand – a case study from the Schächental valley, Switzerland. Botanica Helvetica **116**, 55–64. DOI: 10.1007/s00035-006-0758-7.

WSL. 2012a. Veränderung der Gebüschwaldfläche: Hoch-/Tieflagen Produktionsregion. #24185/13599. LFI3–LFI4a [Online data download] Available from: https://www.lfi.ch/resultate/anleitung.php. (Downloaded: 28.11. 2013).

WSL. 2012b. Veränderung der Gesamtwaldfläche: Hoch-/Tieflagen Biogeografische Region. #24454/13997.LFI1–LFI3 [Online data download] Available from: https://www.lfi.ch/resultate/anleitung.php. (Downloaded: 28.11. 2013).

WSL. 2012c. Veränderung der Gesamtwaldfläche: Hoch-/Tieflagen Produktionsregion. #24184/13598. LFI3–LFI4a [Online data download] Available from: https://www.lfi.ch/resultate/anleitung.php. (Downloaded: 28.11. 2013).

WSL. 2012d. Veränderung der Normalwaldfläche: Hoch-/Tieflagen, Biogeografische Region. #24432/13963.LFI1–LFI3. [Online data download] Available from: https://www.lfi.ch/resultate/anleitung.php. (Downloaded: 28.11. 2013).

Wunderli R. 2011. “Sie hat sich halt unglaublich stark entwickelt” landwirtschaftlicher Strukturwandel in den Erzählungen von Bauern und Bäuerinnen aus Ursern. In: Der Geschichtsfreund **164**, 131–156.

Zhiming Z, Van Coillie F, De Wulf R, De Clercq EM, Xiaokun O. 2012. Comparison of Surface and Planimetric Landscape Metrics for Mountainous Land Cover Pattern Quantification in Lancang Watershed, China. Mountain Research and Development **32**, 213–225. DOI: 10.1659/MRD-JOURNAL-D-10-00119.1.

Chapter 7

7 Land abandonment and its effect on the previously managed eco-geomorphic balance

Chronosequence measurements of soil stability indices show the effects of vegetation succession on abandoned pastures on soil properties and hillslope stabilization. The study was published as:

Caviezel, C., Hunziker, M., Schaffner, M., and Kuhn, N.J. (2014): Soil-vegetation interaction on slopes with bush encroachment in the central Alps – adapting slope stability measurements to shifting process domains. Earth Surface Processes and Landforms, DOI: 10.1002/esp.351.

The contribution was selected for the ESPL Special Issue to celebrate the World Soil Day (2014), edited by M.J. Kirkby, as one of the most significant contributions that have appeared in ESPL since 2010 showing the increasing importance of interdisciplinary work.
Online ISSN: 1096-9837

EARTH SURFACE PROCESSES AND LANDFORMS
Earth Surf. Process. Landforms **39**, 509–521 (2014)
Copyright © 2014 John Wiley & Sons, Ltd.
Published online 9 January 2014 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/esp.3513

Soil–vegetation interaction on slopes with bush encroachment in the central Alps – adapting slope stability measurements to shifting process domains

C. Caviezel,[1]* M. Hunziker,[1] M. Schaffner[2] and N. J. Kuhn[1]
[1] Physical Geography and Environmental Change, Environmental Department, University of Basel, Switzerland
[2] Department of History, University of Basel, Switzerland

Received 15 January 2013; Revised 29 October 2013; Accepted 19 November 2013

*Correspondence to: C. Caviezel, Department of Environmental Sciences, University of Basel, Physical Geography and Environmental Change, Switzerland.
E-mail: c.caviezel@unibas.ch

ESPL
Earth Surface Processes and Landforms

ABSTRACT: In the European Alps many high mountain grasslands which were traditionally used for summer pasturing and haying have been abandoned during recent decades. Abandonment of mown or grazed grasslands causes a shift in vegetation composition and thus a change in landscape ecology and geomorphology. Alpine areas are very fragile ecosystems and are highly sensitive to changing environmental conditions, which can affect the geomorphic regime of these high energy environments. The effect of land use intensification on erosion rates is well documented, whereas the effect of land abandonment on erosion rates is still discussed controversially, particularly in relation to its short-term and long-term consequences. Generally, an established perennial vegetation cover improves the mechanical anchoring of the soil and the regulation of the soil water budget, including run-off generation and erosion. However, changing vegetation composition affects many other above- and below-ground properties like root density, diversity and geometry, soil structure, pore volume and acidity. Each combination of these properties can lead to a distinct scenario of dominating surface processes. The study of soil properties along a chronosequence of green alder (*alnus viridis*) encroachment on the Unteralptal in central Switzerland revealed that shrub encroachment changes soil and vegetation properties towards an increase of resistance to run-off related erosion processes, but a decrease of slope stability against shallow landslides. Copyright © 2014 John Wiley & Sons, Ltd.

KEYWORDS: land abandonment; green alder encroachment; chronosequence; internal soil friction; slope stability

Introduction

The ecology of mountain regions is characterized by a particularly sensitive human–environment relationship due to the long-term use and management of the land as pasture. The changing economic conditions for mountain farmers are causing a trend towards intensification of centrally located areas where farm machines can be used, whereas remote areas unsuitable for mechanization of farming experience a marginalization (Bätzing, 2003). The alpine terrain with its rugged topography and extreme climatic conditions is naturally disposed to soil erosion, leading to soil loss by shallow mass movements in steep grasslands in the Alps (Schauer, 1975; Dommermuth, 1995; Wiegand and Geitner, 2010). Land use intensification often increases landscape susceptibility to erosion as shown in the greater frequency of shallow landslides under intensive pasture use in the main Urserntal valley in central Switzerland (Caviezel *et al.*, 2010), and several other studies (Schauer, 1975; Dommermuth, 1995; Tasser *et al.*, 2003; Meusburger and Alewell, 2008). Studies on the effect of the currently spreading land abandonment are still rare.

Land abandonment and erosion risk

Land abandonment causes a shift in vegetation and is often followed by shrub encroachment (Anthelme *et al.*, 2002; Tasser *et al.*, 2005). This leads to a change in the appearance of the landscape, but also affects the local and regional geoecological balance based on complex interaction between natural factors and long-term land use and management aimed at reducing soil loss (Hunziker, 1995; Cernusca *et al.*, 1999; MacDonald *et al.*, 2000). As vegetation tends to revert to the former climax vegetation prevailing prior to land use activities (Tappeiner and Cernusca, 1993), it is expected that forests will develop beneath the timberline after running through different successional stages of typical plant societies of dwarf shrubs and trees (Tappeiner and Cernusca, 1993). Established forests (Rickli and Graf, 2009) and shrub areas (Graf *et al.*, 2003) are generally known to improve slope stability, anchoring the topsoil to the underlying bedrock (Morgan and Rickson, 2011). However, the changes in vegetation during the course of succession have a continuous effect on the entire ecosystem (Tappeiner and Cernusca, 1993). The vegetation compositions evolving during the course of succession may also persist for a long time (Tasser and Tappeiner,

2002) and hamper the rapid formation of the former climax vegetation and its perceived stabilizing effect on hillslope processes.

Land abandonment affects soil properties at different scales and through various processes. The changing vegetation composition affects the reinforcing effect of roots. In addition, vegetation change induces changes in soil texture and soil porosity, affecting internal particle friction and water budget (Wischmeier and Mannering, 1969; Cernusca *et al.*, 1999; Morgan and Rickson, 2011). Changing vegetation may also modify the soil water budget through transpiration and interception, and therefore changes the frequency at which soil becomes saturated and run-off or soil creeping occur (Morgan and Rickson, 2011). Considering the various effects of the vegetation, we postulate that measuring shear and penetration resistance in the topsoil between the anchoring roots should not be neglected when assessing slope stability.

Furthermore, land abandonment also changes soil properties by reducing the effects of pasturing, such as biomass removal, the addition of manure, as well as soil compaction by trampling or use of machinery. Above ground, land abandonment influences snow gliding processes; vegetation types, for example low dwarf shrubs, enhance snow gliding distances (Newesely *et al.*, 2000).

Land abandonment and shrub encroachment in the Swiss Alps

In the central Alps of Switzerland, green alder, an early successional species is a major component of the increasing subalpine shrub woodland. In the period between 1983/5 and 1993/5, the Swiss national forest inventory noted an increase of shrub woodland in the Swiss Alps of 17.9%; 56.9% of the shrubs were represented by green alder (*Alnus viridis*) (Brassel and Brändli, 1999). Due to their strong colonization ability and high seed production (Farmer *et al.*, 1985) green alder, naturally restricted to steep, north facing subalpine well drained slopes, take advantage of current land disuse and spread on abandoned subalpine pastures (Wiedmer and Senn-Irlet, 2006) and on more gentle slopes (Didier and Brun, 1997).

Green alder and slope stability

Recent research shows an indistinct effect of green alder on slope stability. On the one hand, green alder is used in bioengineering to mechanically stabilize slopes with its roots (Graf *et al.*, 2003). Tappeiner and Cernusca (1993) show an effect of green alder stands on soil water budget by diminishing run-off. However, Anthelme *et al.* (2001) consider green alder a 'keystone species' affecting 'many other ecosystem functions' (p. 58). Tasser *et al.* (2003) observed that 'areas abandoned long ago and densely covered with shrubs or *Alnus viridis* bushes' to be 'more prone to suffer from landslides' (p. 277), i.e. sliding clods in topsoils. A geomorphological explanation for this observation is not attempted in his study. Meusburger and Alewell (2008) investigated shallow landslide density in the Urserntal based on air photographs and concluded that shallow landslide density for the community of green alder shrubs older than 50 years is 33.2% compared with only 2.0% for areas invaded by shrubs between 1959 and 2008. Figure 1 summarizes hypothetical changes of parameters, induced by land abandonment, affecting ecosystem functions, which potentially could affect internal soil friction. The aim of the study is to quantify the change of soil parameters and to measure the internal soil friction.

Measuring slope stability

The slope stability is characterized as mechanical resistance to various stresses, such as those caused by gravity, moving water and mechanical loads (Morgan and Rickson, 2011). Exceeding the mechanical resistance results in erosion processes like soil creeping due to liquefaction, shallow landslides induced by excess load and positive water pore pressure and soil erosion due to surface run-off. The resistance to moving water and mechanical loads is a complex 'property', depending on: (i) the capacity of individual soil particles to resist detachment and transport, known as internal friction (Morgan, 2005); and (ii) the capacity of roots to anchor the entire soil layer to the underlying rock (Wischmeier and Mannering, 1969).

Internal mechanical soil resistance is usually determined by measuring the response of soil to a range of applied forces, such as torsional and penetration strengths. Zimbone *et al.* (1996) mention the mechanical resistance of soil, usually expressed as shear strength, as a widely proposed index of susceptibility to erosion. Zhang *et al.* (2001) consider the resistance to applied torsional and penetration strengths, e.g. the capacity to keep the particle at rest, as an index for soil stability. Therefore, shear strength of surface soil can serve as a measure of soil resistance to soil erosion by run-off and soil creeping due to liquefaction. The cohesiveness of soil particles and its resistance to shear forces varies with bulk density, soil texture, root

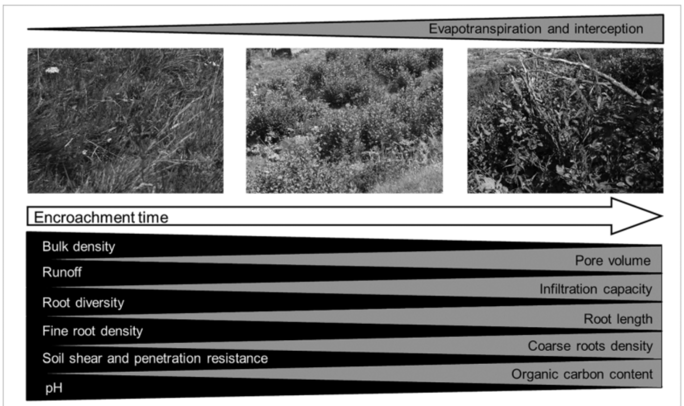


Figure 1. Hypothetical change of parameters affecting ecosystem functions (Tasser *et al.*, 2001, 2003; Anthelme *et al.*, 2003; Graf *et al.*, 2003).

density and root geometry, organic content and chemical properties (Wischmeier and Mannering, 1969; Tisdall and Oades, 1982; Angers and Caron, 1998; Mafian *et al.*, 2009). Besides the effect fine roots have on soil stability by binding soil particles, large roots act as stabilizing piles and restrain soil packages moving downwards improving slope stability (Morgan and Rickson, 2011).

The aim of this study is to analyze the manifold effects of green alder shrubs on soil properties affecting slope stability with special emphasis on internal soil friction rather than root anchoring of regolith to bedrock in the Unteralptal in central Switzerland. In this area, green alder cover has increased by about 50% since 1979 as a consequence of decreasing grazing pressure. The main objectives are to (i) determine trends in the soil parameters affecting soil stability (e.g. rooting, internal friction, bulk density organic content, pH) along a chronosequence of green alder encroachment and to characterize their contribution towards slope stability over the chronosequence; (ii) explain the changes of the soil parameters and interacting processes over time; and (iii) evaluate the changes in soil stability and their effect on slope stability.

Study site

The Unteralptal, a side valley of the main Urserntal in central Switzerland (46.37°N, 8.38°E), is ideally suited for the proposed study (Figure 2). The Unteralptal comprises an area of 35 km^2 stretching from the highest point at 2900 m asl. to the mouth of the main Urserntal near the town of Andermatt at 1442 m asl. (Ambühl *et al.*, 2008). The main vegetation types are alpine grasslands, dwarf-shrubs and shrubs. An overview of the current land cover is given in Table I. Settlements are limited to single summer farming huts. In the Unteralptal, traditional summer pasturing reaches back to at least the fourteenth century (Rebsamen, 1919). The current vegetation shows strong anthropogenic influences, due to grassland farming for centuries.

Geologically, the Unteralptal is part of the Gotthardmassiv and consists of paragneiss, migmatit and orthogneiss (Ambühl *et al.*, 2008). The glaciated U-shaped valley is about 10 km long and characterized by a rugged terrain. The climate is alpine with a mean air temperature of 3.4°C and a mean annual rainfall (1961–1990) of 1422 mm per year at the nearby MeteoSwiss climate station in Andermatt (1442 m asl.). Based on the FAO World Reference Base for soil resources (Food and Agriculture Organization of the United States, 2006) the dominant soil types in the catchment are Leptosols on steep valley slopes and Podzdocambisols and Cambisols on lower slopes. At the valley bottom Fluvisols and Gleysols developed. The predominant soil texture is silty sand and sandy silt.

Land use patterns in the Urserntal and its side valley the Unteralptal changed significantly over the last decades (Caviezel *et al.*, 2010). The observed changes include:

(i) remote pastures on the slope terraces like the formerly cattle grazing areas have temporarily been underused or even disused; partially, they were stocked by unherded sheep afterwards;
(ii) goat pastures disappeared as goats lost their importance and their number decreased dramatically. Goats are known to prevent shrub encroachment (Maag *et al.*, 2001);
(iii) steep areas that are difficult to access and have formerly been mown by hand were converted either to pastures and therefore are endangered through trampling and overgrazing or were abandoned and therefore encroached by shrubs;
(iv) finally, the population was formerly dependent on the collection of fire wood, mainly consisting of shrubs for heating. By the introduction of oil heating, firewood collection ceased, in doing so shrub encroachment was not hampered anymore.

In addition to the changes in land use, the number of farms declined from 114 farms in 1955 to 31 farms in 2007 (BfS, 2007). Stock numbers did not decline because animals from the low lands outside the main Urserntal were brought into the mountains for summer grazing. Overall, the number of sheep in the Unteralptal shows an increase from 321 to 1500 sheep between 1960 and 2000, while the number of cattle did not increase over the same time period (Archive of the Korporation Ursern, n.d.)

Methods

Landcover change

Landcover change was assessed using two air photographs of 1979 and 2007 and a topographical map 1:50 000 of 1926

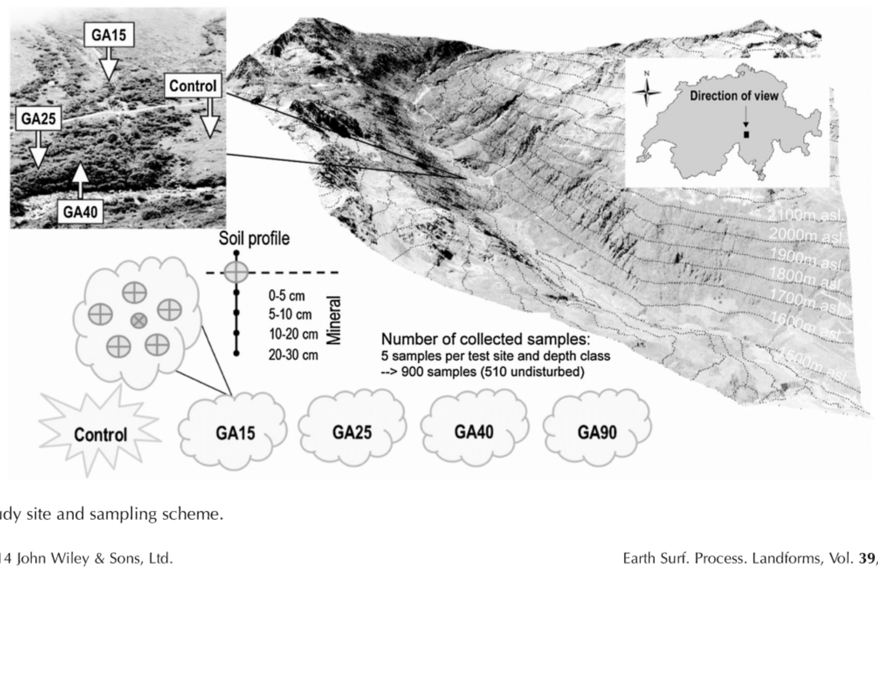


Figure 2. Study site and sampling scheme.

Copyright © 2014 John Wiley & Sons, Ltd.

Table I. Land cover based on the air photograph 2007

			Area [ha]	Proportion of total area [%]	Proportion of vegetated area [%]
Vegetated area	Dwarf shrubs and shrubs	*Calluna vulgaris, Rhododendron ferrugineum, Vaccinium myrtillus, Juniperus sibirica, alnus viridis*	248.6	7.0	11.0
	Grass	Pastures and alpine grassland	2010.4	56.9	89.0
Total vegetated area			**2259.1**	**63.9**	**100.0**
Unvegetated area	Lake		7.3	0.2	
	Riverbed		17.1	0.5	
	Rocks		381.5	10.8	
	Debris		801.0	22.7	
	Glacier		52.5	1.5	
	Road		3.2	0.1	
	Shadow	Not classified	10.7	0.3	
Total unvegetated area			**1262.6**	**35.7**	
Total area			**3532.3**	**100.0**	

(Eidgenössische Landestopographie, 1926) (Figure 3). In order to allow quantification of the different land cover types between different years, the photographs were georeferenced and orthorectified using the ENVI software package (Version 4.0) with the help of ground control points, the DEM with a resolution of 2 m (supplied by the LisAG, Kanton Uri) and the camera calibration protocol supplied by Swisstopo (Swisstopo, 2010). Shrubs and dwarf shrubs area were digitized manually by visual differences on the air photographs. Groundtruthing of shrub cover and mapping of vegetation species composition was done in August 2011. Even though the mapping of shrub cover on the topographic map took place at a different scale, the 1926 shrub cover is likely an overestimation as shrub and dwarf shrub area de facto show to be highly restricted. Rebsamen (1919) refers to the rusty-leaved alpenrose (*Rhododendron ferrugineum*) to be 'really seldom due to the high firewood utilization' (p. 57).

Sampling site selection

Using georeferenced and orthorectified aerial photographs taken in 1979, 1993 and 2007 and a topographic map released in 1926, areas of different aged green alder stands were identified by comparing the images. To avoid possible inconsistencies in the results caused by differences in topography three different terrain classes were assigned to the identified areas that experienced a land cover change. Terrain classes were generated performing an unsupervised classification in ArcGIS based on the parameters slope, curvature, elevation and exposition using a DEM with a resolution of 2 m. Three replicate chronosequences were taken for each terrain class to ensure sufficient comparable data. An overview of the sampling site characteristics is given in Table II. Soil samples were taken at four different stages of shrub encroachment identified on the areal images and the topographic map (stands on the map of 1926 having a minimum age of 85 years, new stands on the image of 1979 having a minimum age of 32 years and a maximum age of 84 years, new stands on 1993 having a minimum age of 18 years and a maximum age of 31 years and new stands on 2007 having a minimum age of 4 years and a maximum age of 17 years). To ensure accurate dating, a stem disk of the thickest stem at each site was also analyzed using dendrochronology. Age classes were then labeled by the mean age of all analyzed stands of an age class, i.e. 15, 25, 40 and 90 years old stands of green alder (in the following labeled as GA15; GA25; GA40 and GA90). In addition, soil was also sampled on permanent pastures, representing the status before encroachment (Control). Management of the actually grazed areas has not changed significantly, therefore this space for time analogy is acceptable (Caviezel and Kuhn, 2012).

All samples except those of GA90 were taken in July and August 2011, GA90 samples were taken in October 2011. Additional samples to improve the sparse data of GA90 were taken in August 2013. At the green alder stands, soil samples were taken within one half of the crown diameter of the dominant green alder. At each green alder stand and on the control plots five soil pits were sampled randomly by a metal cylinder core of 100 cm^3 volume at depths 0–5 cm; 5–10 cm; 10–20 cm and 20–30 cm (Figure 2). Due to the sometimes rocky soils only

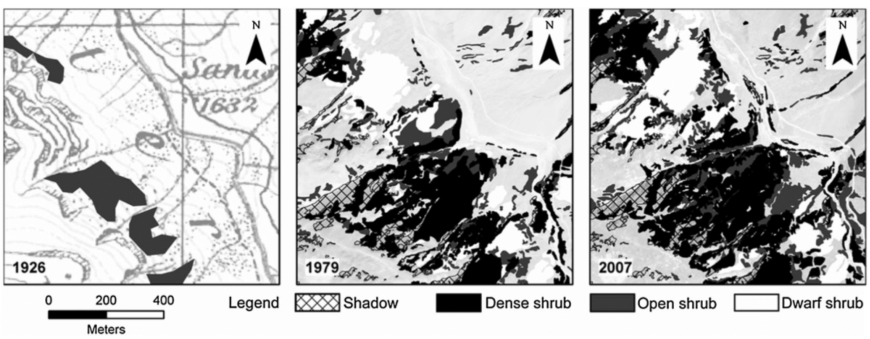


Figure 3. Example of shrub and dwarf shrub mapping for three different age classes.

Copyright © 2014 John Wiley & Sons, Ltd.

Table II. Characteristics of sampling sites

Control n = 9	Lithology	Mica schist
	Mean elevation asl.	1661 ± 51 Stdv.
	Mean slope [°]	18.42 ± 6.86 Stdv.
	Geomorphological formation	Moraine: 3, Talus fan: 6
	Aspect	N:2, Ne:4,Se:0, S:0, Sw:1, W:1, NW:1
	Soil texture	Silty sand, sandy silt
GA15 n = 9	Lithology	Mica schist
	Mean elevation asl.	1665 ± 48 Stdv.
	Mean slope [°]	25.03 ± 4.49 Stdv.
	Geomorphological formation	Moraine: 3, Talus fan: 6
	Aspect	N:3, Ne:3,Se:0, S:0, Sw:0, W:2, NW:1
	Stem age	15 ± 5 Stdv.
	Soil texture	Silty sand, sandy silt
GA25 n = 9	Lithology	Mica schist
	Mean elevation asl.	1670 ± 33 Stdv.
	Mean slope [°]	25.68 ± 6.72 Stdv.
	Geomorphological formation	Moraine: 3, Talus fan: 5, Alluvial: 1
	Aspect	N:3, Ne:3,Se:0, S:0, Sw:1, W:1, NW:1
	Stem age	25 ± 3 Stdv.
	Soil texture	Silty sand, sandy silt
GA40 n = 9	Lithology	Mica schist
	Mean elevation asl.	1689 ± 37 Stdv.
	Mean slope [°]	28.44 ± 6.91 Stdv.
	Geomorphological formation	Moraine: 3, Talus fan: 6
	Aspect	N:2, Ne:4,Se:0, S:0, Sw:1, W:0, NW:2
	Stem age	40 ± 5 Stdv.
	Soil texture	Silty sand, sandy silt
GA90 n = 9	Lithology	Mica schist
	Mean elevation asl.	1786 ± 75 Stdv.
	Mean slope [°]	41 ± 6.8 Stdv.
	Geomorphological formation	No Data:2, Talus fan:7
	Aspect	N: 3,Ne:6, Se:0, S:0, Sw:0, W:0, NW:0
	Stem age	Aged using topogarphical map of 1926
	Soil texture	Sandy silt

510 of 900 could be taken as undisturbed samples. The results shown in this study refer to the 510 undisturbed samples showing an equal distribution over all sampling sites.

Soil measurements

Torsional shear strength of the soil, as an index for the mechanical resistance toward tension stresses and internal soil friction, was measured by a hand vane tester (Pilcon hand vane tester). Due to the large coarse fraction in the soil, the smaller, 19 mm wide and 28 mm long vane was used at all depths. The resistance of soil to penetration, as an indication for soil consolidation, root penetrability and infiltration capacity as well as particle detachability, was determined by a cone penetrometer (Eijkelkamp hand penetrometer). Measurements of shear and penetration resistance were made at each of the five randomly distributed pits within one half of the crown diameter of the dominant green alder for each depth class before taking the soil sample. The shear vane tester and the penetrometer were placed at a representative of the site next to the place where the soil sample has been taken with the corer.

Root density was estimated in the field using the categories 'no rooting', 'very low rooting', 'low rooting', 'medium rooting', 'high rooting', 'very high rooting' and 'root felt' after (Sponagel, 2005), both for coarse (>2 mm) and fine root (<2 mm) (Sponagel, 2005) proportion. Rooting affects internal soil friction due to the binding of soil particles to each other and anchoring to solid bedrock (Morgan, 2005). Bulk density was measured by sampling the soil with a 100 cm^3 corer of 5 cm length. Bulk density and pore volume controlling infiltration capacity were calculated based on the weight of the dry soil collected with the corer. Actual soil moisture at the time of sampling was determined subtracting the weight of the oven-dried corer samples from the weight of the fresh samples. Infiltration capacity was calculated subtracting the median soil moisture of 36% at the time of sampling from the calculated pore volume. Carbon content, used as an index for aggregate stability (Kuhn *et al.*, 2012) was determined by LECO analyzer (RC-612). Soil pH, controlling vegetation composition and litter decomposition rates as well as nutrient supply, was analyzed in soil suspension (0.01 M $CaCl_2$) in the laboratory after sampling. To detect changes in soil properties along the chronosequence, significance statistics of the non-parametric data were performed using Mann–Whitney rank sum test. Interactions between soil parameters were analyzed by Spearman correlation for ordinal parameters and by Pearson correlation for metric parameters. All statistical analyses were performed using SPSS 20.0 statistical package.

Results

Shrub cover

Green alder, naturally restricted to steep, north facing and well drained slopes or avalanche corridors (Anthelme *et al.*, 2003), can be found across the study area, including on atypical places such as pastures with southern exposure.

Between 1979 and 2007, dense shrub cover in the Unteralptal increased by 18.7%, open shrub cover by 32.6% (Table III).

Copyright © 2014 John Wiley & Sons, Ltd.

Table III. Vegetation change in the Unteralptal 1926, 1979, 2007 (excluding shadow areas)

	Land cover change between 1926 and 1979 [ha]	Land cover change between 1926 and 1979 [%]	Land cover change between 1979 and 2007 [ha]	Land cover change between 1979 and 2007 [%]
Dense shrub	47.8	*[a]	24.6	18.7
Open shrub	−11.9	−24.9	11.7	32.6
Dwarf shrub	*[b]	*[b]	−3.6	−15.5
Shrub and dwarf shrub	**142.5**	**297.9**	**32.8**	**17.2**

[a]*Increase from 0 ha to 47.84 ha.
[b]*Not classified on the topographic map of 1926.

Chronosequences of bulk density, porosity, shear strength, organic carbon, root density and pH

The soil parameters analyzed do not show significant deviations for the three different terrain classes, therefore, the following results are summarized for all terrain classes. For all age classes, the upper five centimeters had a low bulk density (Figure 4(a)). Bulk density for all depth classes does not show a trend along the chronosequence, except for the significant decrease from age class GA40 to GA90 and the median deviation of GA15 to the control site at 5–10 cm depth (Figure 4(b)).

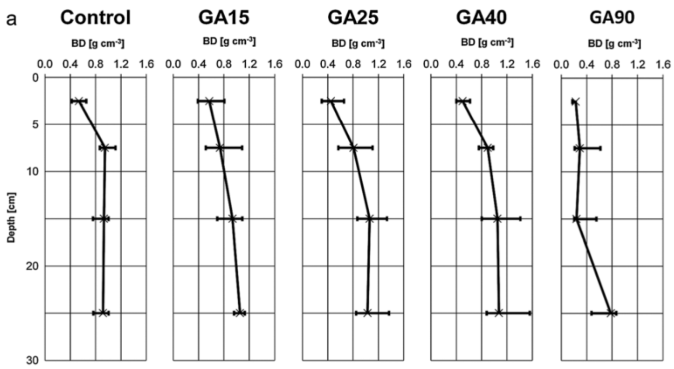
The pore volume of the different age classes (Figure 5(a)) allows quantifying potential maximum water infiltration capacity of the soil (Rowell *et al.*, 1997). The pattern of significant median deviation of pore volume (Figure 5(b)) corresponds to the pattern of bulk density median deviations (Figure 4(b)). Consequently, a significantly greater infiltration capacity (0–30 cm) corresponding to 123 mm m^{-2} rainfall can be assumed for the age class of GA90 compared with the other age classes (Control: 96 mm m^{-2}, GA15: 102 mm m^{-2}, GA25: 114 mm m^{-2}, GA40: 96 mm m^{-2}).

Soil moisture varied between 32 and 34 vol% for the samples taken in July and August (Control, GA15, GA25, GA40). This difference is relatively small and is therefore not considered to have a significant effect on the observed shear resistance and penetration value. Soil moisture at GA90 reached 53 vol%, hence an effect of soil moisture on penetration and shear resistance is possible, as moisture content and penetration resistance showed a negative correlation (−0.200, $P = 0.018$).

Significance values of median deviation of soil shear resistance for all age class combinations are shown in Figure 6(b). The shear resistances for the upper 20 cm show significantly greater values on the pasture area (control) than on the shrub areas, except for GA15 site at 10–20 cm. At 20–30 cm depth only GA90 differs significantly from the control site. The chronosequence from the control site to the age class GA25 shows a significant decrease of the medians for the upper 5 cm, for 5–30 cm depth the continuous decrease in median deviation along the chronosequence (Figure 6(a)) is not significant (Figure 6(b))

Soil penetration resistance shows significantly lower values for the differently aged green alder stands compared with the control plots for the top 20 cm, except for GA25 and GA40 at 10–20 cm. The continuous decrease of median penetration resistance in the top 5 cm is not significant (Figure 7(a),(b)). No continuous decrease of penetration resistance along the chronosequence could be detected for the soil depth of 5–30 cm, except the significant decrease between the age class GA40 and GA90 (Figure 7(b)).

The chronosequence for median carbon content in the upper top 5 cm shows first a significant decrease from the



b

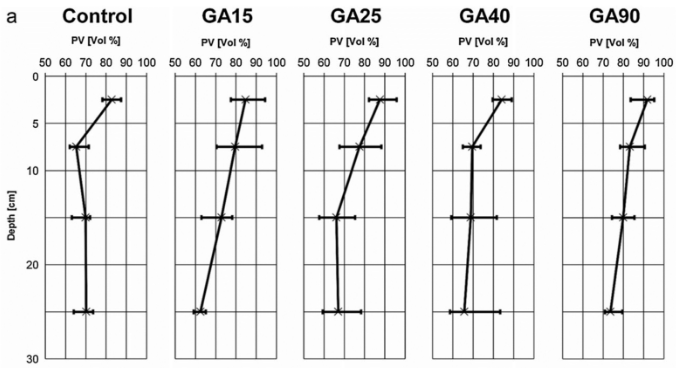
	Control	GA15	GA25	GA40	GA90
Control		0.570	0.160	0.472	**0.000**
GA15	**0.032**		0.100	0.356	**0.000**
GA25	0.102	0.674		0.274	**0.000**
GA40	0.072	0.284	0.598		**0.000**
GA90	**0.000**	**0.016**	**0.008**	**0.000**	

	Control	GA15	GA25	GA40	GA90
Control		0.896	0.200	0.138	**0.000**
GA15	0.052		0.226	0.100	**0.000**
GA25	0.148	1.042		0.970	**0.000**
GA40	0.130	0.604	0.898		**0.000**
GA90	**0.039**	**0.000**	**0.018**	**0.000**	

two tailed exact significance; legend: 0-5 cm, 5-10 cm (left table); 10-20 cm, 20-30 cm (right table)

Figure 4. (a) Median bulk density (BD) for the different age and depth classes. Error bars show 25% and 75% quartiles. (b) Significance values for median deviation of bulk density for all age class combinations and the four depth classes. Significant median deviation is shown in bold digits (two tailed exact significance after Mann–Whitney rank sum test).

Copyright © 2014 John Wiley & Sons, Ltd.



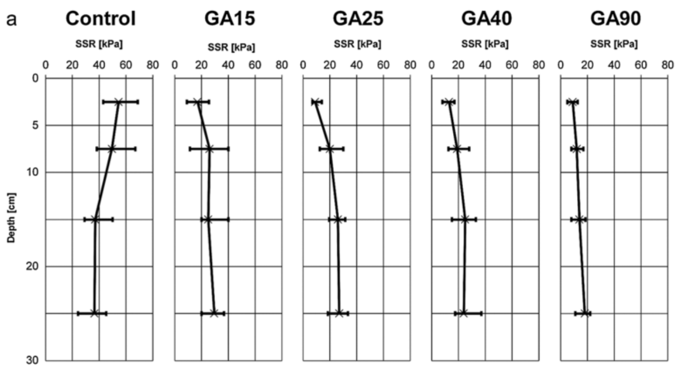
b

	Control	GA15	GA25	GA40	GA90
Control		0.752	0.154	0.456	**0.000**
GA15	**0.026**		0.134	0.452	**0.000**
GA25	0.062	0.712		0.292	**0.001**
GA40	0.050	0.276	0.542		**0.000**
GA90	**0.000**	**0.021**	**0.011**	**0.000**	

	Control	GA15	GA25	GA40	GA90
Control		1.000	0.236	0.156	**0.000**
GA15	0.076		0.190	0.106	**0.000**
GA25	0.148	0.874		1.000	**0.000**
GA40	0.116	0.692	0.966		**0.000**
GA90	**0.049**	**0.001**	**0.021**	**0.001**	

two tailed exact significance — 0-5 cm / 5-10 cm; 10-20 cm / 20-30 cm

Figure 5. (a) Median pore volume (PV) for the different age and depth classes. Error bars show 25% and 75% quartiles. (b) Significance values for median deviation of pore volume for all age class combinations and the four depth classes. Significant median deviation is shown in bold digits (two-tailed exact significance after Mann–Whitney rank sum test for non-parametric data).



b

	Control	GA15	GA25	GA40	GA90
Control		**0.000**	**0.000**	**0.000**	**0.000**
GA15	**0.000**		**0.004**	**0.036**	**0.000**
GA25	**0.000**	0.350		0.090	0.483
GA40	**0.000**	0.264	0.970		**0.010**
GA90	**0.000**	**0.000**	**0.001**	**0.000**	

	Control	GA15	GA25	GA40	GA90
Control		0.134	**0.004**	**0.002**	**0.000**
GA15	0.224		0.248	0.192	**0.000**
GA25	0.078	0.542		0.784	**0.000**
GA40	0.104	0.750	0.748		**0.000**
GA90	**0.000**	**0.004**	**0.041**	**0.020**	

two tailed exact significance — 0-5 cm / 5-10 cm; 10-20 cm / 20-30 cm

Figure 6. (a) Median soil shear resistance (SSR) for the different age and depth classes. Error bars show 25% and 75% quartiles. (b) Significance values for median deviation of soil shear resistance for all age class combinations and the four depth classes. Significant median deviation is shown in bold digits (two-tailed exact significance after Mann–Whitney rank sum test for non-parametric data).

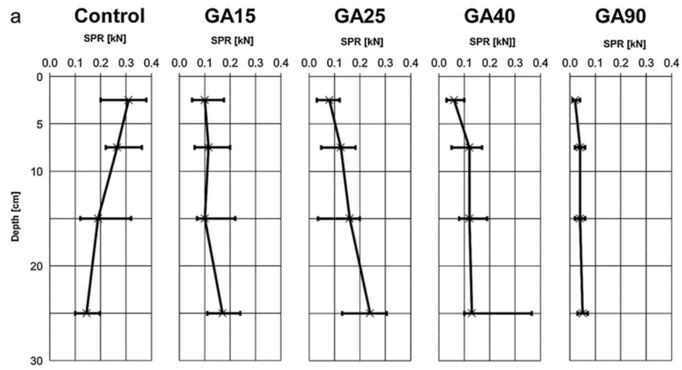
control site to GA15 and following a significant increase from GA15 to GA25 as well as for GA40 to GA90. For the depth 5–30 cm, the median of carbon content shows no significant changes along the chronosequence except the increase over all depth classes from GA40 to GA90. Values at GA90 tend to be highly variable for the upper 5 cm (Figure 8(a),(b)).

Soil acidity increases significantly for the upper 10 cm, except for the control site to GA15 at 0–5 cm and 5–10 cm depth (Figure 9(a),(b)). For 10–20 cm depth, a significant decrease in pH is observed for GA25 to GA40 and GA40 to GA90, at 20–30 cm depth only for GA40 to GA90.

Fine root density decreases with soil depth. While the ‘no rooting’ category at GA15 does not appear until 20–30 cm depth, ‘no rooting’ at the older green alder stands (GA25; GA40; GA90) appears at a soil depth of 10–20 cm (Figure 10, left). Rooting of coarse roots show greater values on green alder stands within all age and depth classes compared with the control site. GA90 shows the highest proportion of ‘high rooting’ for coarse roots (Figure 10, right).

Copyright © 2014 John Wiley & Sons, Ltd.

a



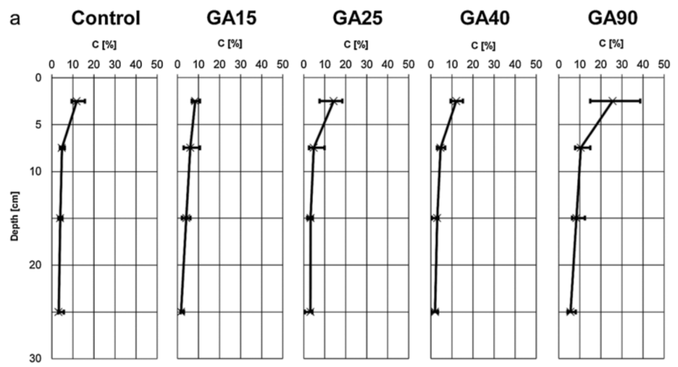
b

	Control	GA15	GA25	GA40	GA90		Control	GA15	GA25	GA40	GA90
Control		**0.000**	**0.000**	**0.000**	**0.000**	Control		**0.026**	0.082	0.072	**0.000**
GA15	**0.000**		0.150	**0.018**	**0.000**	GA15	0.446		0.764	0.836	**0.000**
GA25	**0.000**	0.632		0.334	**0.000**	GA25	0.180	0.352		0.886	**0.000**
GA40	**0.000**	0.434	0.648		**0.000**	GA40	0.794	0.794	0.466		**0.000**
GA90	**0.000**	**0.000**	**0.000**	**0.000**		GA90	**0.000**	**0.000**	**0.001**	**0.000**	

two tailed exact significance; 0-5 cm; 5-10 cm; 10-20 cm; 20-30 cm

Figure 7. (a) Median soil penetration resistance (SPR) for the different age and depth classes. Error bars show 25% and 75% quartiles. (b) Significance values for median deviation of penetration resistance for all age class combinations and the four depth classes. Significant median deviation is shown in bold digits (two-tailed exact significance after Mann–Whitney rank sum test for non-parametric data).

a



b

	Control	GA15	GA25	GA40	GA90		Control	GA15	GA25	GA40	GA90
Control		**0.001**	0.496	0.813	**0.000**	Control		0.723	0.156	**0.011**	**0.000**
GA15	0.210		**0.014**	**0.005**	**0.000**	GA15	0.052		0.397	0.124	**0.000**
GA25	0.870	0.337		0.300	**0.000**	GA25	0.492	0.713		0.448	**0.000**
GA40	0.868	0.345	0.757		**0.000**	GA40	**0.049**	0.927	0.368		**0.000**
GA90	**0.000**	**0.001**	**0.000**	**0.000**		GA90	**0.019**	**0.000**	**0.003**	**0.000**	

two tailed exact significance; 0-5 cm; 5-10 cm; 10-20 cm; 20-30 cm

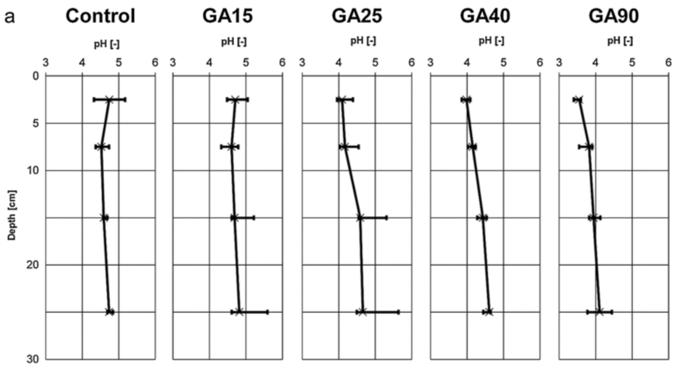
Figure 8. (a) Median carbon content (C) for the different age and depth classes. Error bars show 25 and 75% quartiles. (b) Significance values for median deviation of carbon content for all age class combinations and the four depth classes. Significant median deviation is shown in bold digits (two-tailed exact significance after Mann–Whitney rank sum test for non-parametric data).

Discussion

Soil parameter change over time and their contribution toward slope stability

Most noticeable changes of soil properties along the chronosequence of green alder stands in the Unteralptal are the decrease of shear and penetration resistance between the control sites and GA15 stands as well as the decrease in bulk density, and pH and the increase in carbon content between GA40 and GA90 stands (Table IV). While shear strength and penetration resistance show a change after 15 years of abandonment, bulk density, and carbon content do not change significantly during the first 40 years of green alder encroachment. This contrast of sensitivity to vegetation cover change indicates that green alder encroachment does not lead to a linear relationship of erosion risk with shrub cover or age. Overall, soil properties which are relevant for slope stability show two signals of change toward a greater erosion risk: the decreasing shear strength and penetration resistance between the control site and GA15, and the increasing porosity between GA40 and GA90. The associated increase in infiltration capacity between GA40 and GA90 is indicative of a reduced risk of soil erosion by run-off. However, the simultaneously augmented interflow could decrease the stability of the less compacted soil leading to soil creeping processes. Between GA15 to GA40, the

Copyright © 2014 John Wiley & Sons, Ltd.



b

	Control	GA15	GA25	GA40	GA90		Control	GA15	GA25	GA40	GA90
Control		0.824	**0.000**	**0.000**	**0.000**	Control		0.194	1.000	**0.002**	**0.000**
GA15	0.808		**0.000**	**0.000**	**0.000**	GA15	0.594		0.430	**0.000**	**0.000**
GA25	**0.022**	**0.038**		**0.036**	**0.000**	GA25	1.000	0.620		**0.006**	**0.000**
GA40	**0.000**	**0.000**	0.344		**0.000**	GA40	**0.008**	0.088	0.394		**0.000**
GA90	**0.000**	**0.000**	**0.000**	**0.000**		GA90	**0.000**	**0.001**	**0.070**	**0.002**	

two tailed exact significance — 0-5 cm; 5-10 cm; 10-20 cm; 20-30 cm

Figure 9. (a) Median pH for the different age and depth classes. Error bars show 25 and 75% quartiles. (b) Significance values for median deviation of pH for all age class combinations and the four depth classes. Significant median deviation is shown in bold digits (two-tailed exact significance after Mann–Whitney rank sum test for non-parametric data).

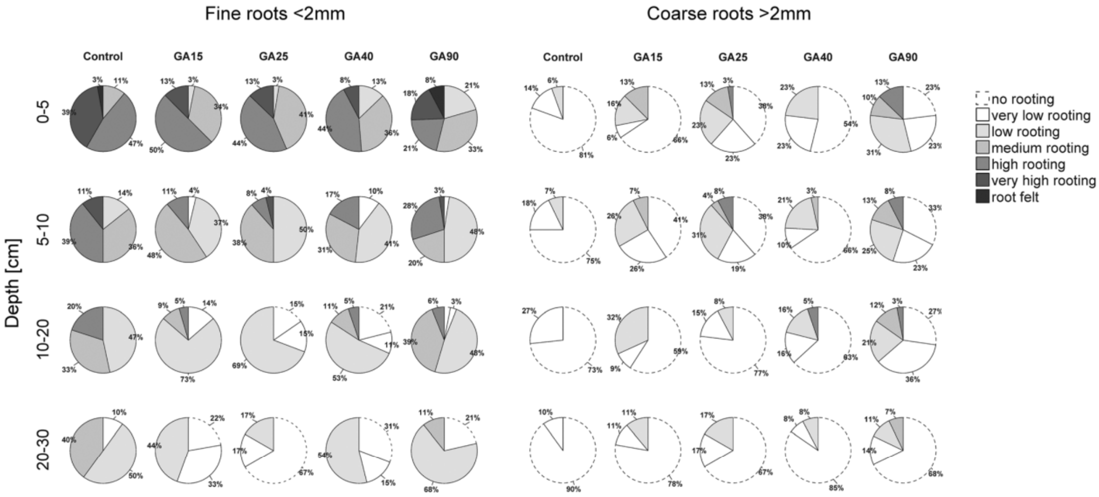


Figure 10. Rooting categories for fine roots (left) and coarse roots (right) for all age and depth classes.

soil properties do not change significantly, except the decreasing pH, affecting species- and root diversity (Tasser *et al.*, 2003).

As root systems lead to an increasing shear strength due to the binding of soil particles (Morgan, 2005), soil stability is expected to correlate with rooting categories. Surprisingly, only the control site shows positive but low correlation between the soil stability index shear strength and fine root (<2 mm) categories ($R^2 = 0.218$, $P = 0.04$). Green alder stands show a significant negative correlation between fine roots and shear resistance (GA90: $R^2 = {}^{-}0.388$, $P = 0.00$; GA40: $R^2 = -0.499$, $P = 0.00$; GA25: $R^2 = -0.419$ $P = 0.00$), except GA15 ($R^2 = -0.125$, $P = 0.240$). Analyzing the correlation over all age classes, no significant correlation was found for the Unteralptal ($R^2 = -0.078$, $P = 0.080$, Spearman correlation). Between shear resistance and coarse root categories (>2 mm) a low negative correlation was found ($R^2 = -0.331$, $P = 0.00$, Spearman correlation). Tasser *et al.* (2003) found that root density decreases with time of abandonment and argued that soil acidification is responsible for this decrease. In his study, green alder stands show a very low mean rooting density of 17 km m^{-2}, compared with extensive managed grasslands with a root density of 70–92 km m^{-2} (Tasser *et al.*, 2001). In our study, a clear decrease in root density could not be shown among the rooting categories in the Unteralptal (Figure 10). However, the decreasing trend of pH along the chronosequence (Figure 9(a),(b)) could be interpreted as a trigger leading toward a decreasing root density over time.

Comparing the different age classes and the control site, much higher shear and penetration resistance values were measured for the control plots even at the same root density (Figure 11). Anthelme *et al.* (2003) showed that species richness decreases due to the decreasing light availability for understory vegetation once green alder cover reaches 25–30%. Possibly, the lower resistance values observed in this study are therefore

Copyright © 2014 John Wiley & Sons, Ltd.

Table IV. Summary of soil parameters along the chronosequence and its significant (bold) deviation to the following chronosequence (GA90 refers to Control sites)

	Control	GA15	GA25	GA40	GA90
Median shear resistance [kPa]					
0-5 cm	**54.5**	**17.0**	9.0	**13.0**	**9.0**
5-10 cm	**49.5**	26.0	20.0	**19.0**	**12.0**
10-20 cm	37.0	**25.0**	26.0	**25.0**	**14.0**
20-30 cm	36.5	29.5	27.0	**24.0**	**18.0**
Median bulk density [g cm^3]					
0-5 cm	0.54	0.57	0.45	**0.50**	**0.28**
5-10 cm	**0.95**	0.74	0.81	**0.90**	**0.60**
10-20 cm	0.93	0.94	1.06	**1.05**	**0.64**
20-30 cm	0.92	1.05	1.03	**1.07**	**0.81**
Median carbon content [%]					
0-5 cm	**11.83**	**8.44**	14.23	**12.06**	**25.58**
5-10 cm	4.82	6.12	4.77	**4.62**	**10.49**
10-20 cm	4.01	4.24	3.24	**3.00**	**8.39**
20-30 cm	3.27	1.75	3.17	**2.00**	**5.61**

	Control	GA15	GA25	GA40	GA90
Median penetration resistance [kN]					
0-5 cm	**0.31**	0.10	0.08	**0.06**	**0.02**
5-10 cm	**0.27**	0.12	0.13	**0.12**	**0.04**
10-20 cm	**0.19**	0.10	0.16	**0.12**	**0.04**
20-30 cm	0.15	0.17	0.24	**0.13**	**0.05**
Median pore volume [%]					
0-5 cm	78.22	77.51	82.23	**79.64**	**88.48**
5-10 cm	**62.04**	70.44	67.61	**64.90**	**75.83**
10-20 cm	63.10	62.99	57.67	**59.24**	**74.35**
20-30 cm	64.08	59.10	59.33	**58.59**	**67.75**
Median pH [−]					
0-5 cm	4.24	**4.21**	**3.59**	**3.49**	**3.05**
5-10 cm	4.03	**4.11**	3.67	**3.66**	**3.32**
10-20 cm	4.09	4.19	**4.09**	**3.94**	**3.44**
20-30 cm	4.24	4.32	4.16	**4.11**	**3.61**

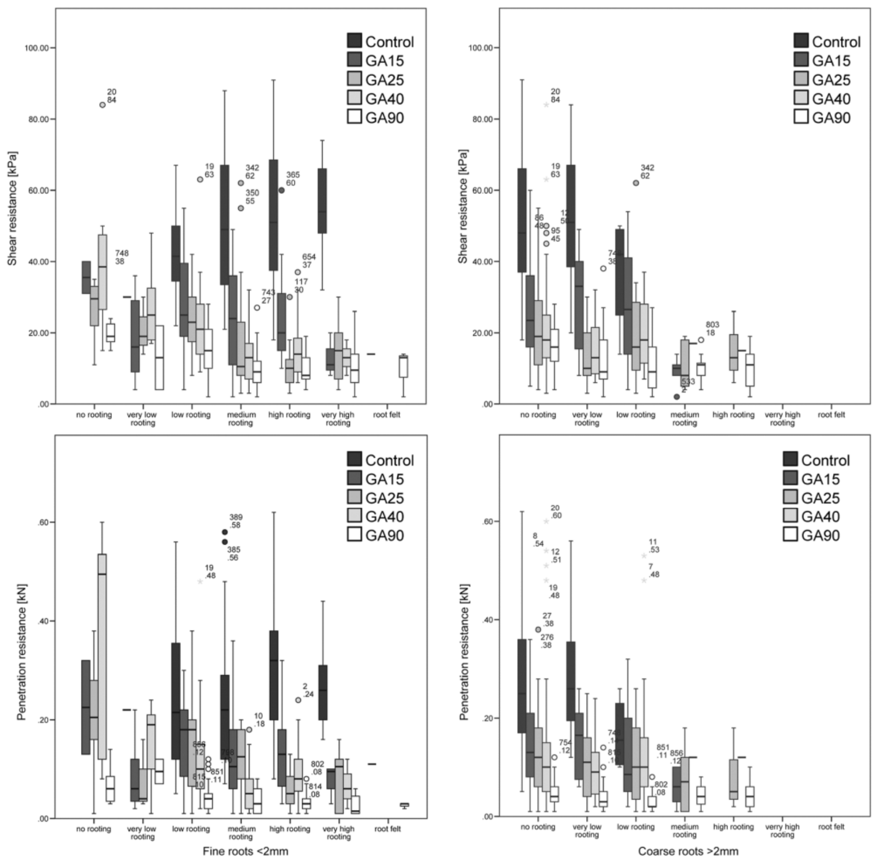


Figure 11. Shear and penetration resistance per rooting categories class for fine (left) and coarse roots (right).

caused by the decrease of species and root diversity, whereas root density plays a minor role for shear resistance, once green alder dominates the vegetation cover.

Generally, greater carbon contents are associated with a higher aggregate stability due to enhancement of internal friction by gluing soil particles (Tisdall and Oades, 1982). Our data

Copyright © 2014 John Wiley & Sons, Ltd.

show a negative correlation between carbon content and penetration resistance ($R^2 = -0.500$, $P = 0.000$) and carbon content and shear resistance ($R^2 = -0.414$, $P = 0.000$). In addition, there is a strong negative correlation between carbon content and bulk density ($R^2 = -0.927$, $P = 0.000$). Therefore, the extreme low bulk density in GA90 from 0 to 20 cm (Figure 8(a)) could be explained by the higher litter, e.g. the high content of organic carbon. In addition, the sharp dip in PV from the upper 5 to the following 10 cm (Figure 5(a)) can be explained by the high amount of decaying litter and roots indicated by the higher amount of organic carbon in the depth class 0–5 cm (Figure 8(a)).

The decrease in internal friction between particles correlates with the decrease of bulk density ($R^2 = 0.474$, $P = 0.000$ for shear resistance, $R^2 = 0.553$, $P = 0.000$ for penetration resistance). The data indicate that while carbon content may lead to more stable soil aggregates, the overall structure of the topsoil horizon becomes more porous and thus loses mechanical resistance to gravity induced forces.

Summarizing the changes of soil parameters along the chronosequence and their contribution toward slope stability, the following trends can be observed: (i) internal soil friction decreases, increasing the risk of creeping; (ii) indices of soil resistance to soil erosion by run-off increases due to the higher infiltration capacity; (iii) root density plays a minor role, but species diversity and therefore root diversity appears to be of importance for soil and slope stability; and (iv) the change of the soil parameters is neither linear nor co-evolving.

Surface water budget and soil erosion

Surface processes depend not only on soil and vegetation properties, but also on the driving forces triggering the erosion processes. In the Unteralptal, the driving factor for soil erosion by run-off, soil creeping due to liquefaction and landslides due to overload is rainfall and the soil moisture associated with high magnitude rainfall events (Caviezel and Kuhn, 2012). Vegetation change affects the probability of soil water saturation through the change of evapotranspiration and soil porosity. To assess the risk of run-off development or mass wasting as a consequence of soil water saturation, porosity and rainfall amount of known erosive rainfall events were compared. Evapotranspiration differences between shrub and grass cover can be ignored as published information on evapotranspiration during a vegetation period reveals that evapotranspiration on a 17-year-old green alder stand accounts for nearly the same amount (41.1%) as pasture (42.6%) of annual rainfall, equaling 2.3 mm d^{-1} (Körner *et al.*, 1978).

Former studies in the Urserntal revealed that mass movements generally happen during or after high magnitude rainfall events lasting 2–3 days (Meusburger and Alewell, 2008; Caviezel *et al.*, 2010). During these events the effect of the evapotranspiration on water budget is limited, due to the reduction of evapotranspiration on rainy days (Körner *et al.*, 1978). Soil water storage capacity calculated based on our data accounts to 96 mm m^{-2} at the control site, 102 mm m^{-2} at GA15, 114 mm m^{-2} at GA25, 96 mm m^{-2} at GA40 and 123 mm m^{-2} at GA90. Three-day rainfall events reaching more than 100 mm m^{-2} occur on average twice annually while events reaching more than 123 mm m^{-2} occur once annually. Comparing the rainfall magnitude with the soil water storage capacity indicates that water saturation and therefore liquefaction, creep and shallow landslides induced by positive pore pressure (Carson and Kirkby, 2009) probably increase, while run-off related erosion processes experience a reduction. This increase, however, might be moderated because the amount of percolation water is also expected to increase with time of abandonment due to the greater porosity (Cammeraat *et al.*, 2007; Tasser *et al.*, 2005). The increasing frequency of intensive rainfall events above the observed water storage capacity in the Ursern region (Caviezel and Kuhn, 2012), infers that soil porosity is a crucial parameter controlling type and frequency of soil erosion processes including creeping due to liquefaction as well as soil erosion by run-off.

Shrub encroachment and erosion processes

Recent research shows that the greater number of coarse roots (Figure 10) have a higher ability to penetrate rock fragments (Morgan and Rickson, 2011), to anchor the soil regolith layer to the slope and to improve topsoil stability by preventing clods from sliding (Figure 12) (Wiegand and Geitner, 2010). On the other hand, due to the decreasing internal soil friction that enables soil particles to move between the coarse roots (Figure 12), erosion processes like soil creeping due to liquefaction will increase. The measurements of this study show that the change of vegetation cover leads to a change of the process domains concerning slope stability.

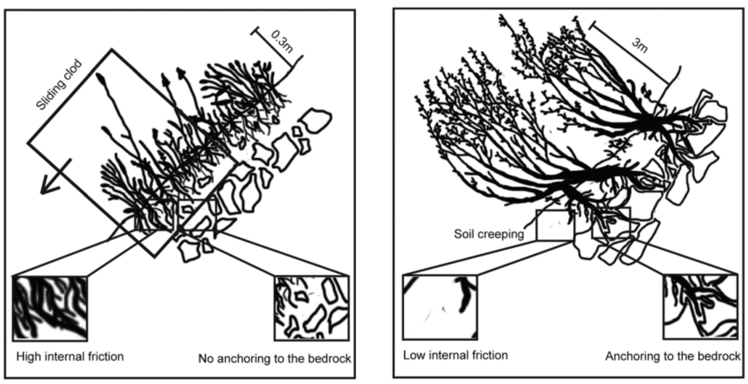


Figure 12. Conceptual illustration of potential erosion processes on grassland and on a green alder stand. Coarse roots show very low values at grasslands, while root diversity is scarce at the green alder stand. The intermediate state would show a reduction in shear and penetration resistance but no reduction in bulk density and pore volume.

Copyright © 2014 John Wiley & Sons, Ltd.

Conclusion

The study along the chronosequence in the Unteralptal revealed that vegetation succession does not necessarily generate a clear signal of increasing slope stability of the relevant soil properties as a change from grazing to forest would suggest. The changes of soil parameters, induced by the encroachment of green alder, show the following trends: (i) internal soil friction tends to decrease at the beginning of land abandonment; such a decline of internal friction is known to reduce the capacity of soil particles to resist detachment; and (ii) bulk density decreases and consequently pore volume increases, but the change is delayed. Even though pore volume does not change significantly for the first 40 years of encroachment, soil stability decreases due to the reduction of internal friction. Water storage capacity tends to increase after 40 years of shrub encroachment. This increase could have a major impact on the soil water budget and thus regulate run-off or mass wasting related erosion processes. While erosion by run-off can be expected to decrease, soil movement through positive pore pressure is expected to increase. No clear signal of soil pH and carbon content with regards to the improvement of internal friction and slope stability could be detected. The effect of the decreasing pH on root diversity and its effect on internal friction and slope stability could only be deduced to be negative. Root density, diversity and size indicate a change from stabilizing the topsoil to anchoring topsoil to bedrock. The effect, however, is limited by the decline in root diversity.

Overall, the results of this study show that shrub encroachment can lead to a complex transition of soil properties and hillslope processes. An association of the increasing alpine shrub woodland cover with an increasing slope stability appears not warranted. Moreover, green alder is thought to be temporally resistant and to inhibit the development of arboreal coniferous species (Anthelme *et al.*, 2002), upholding the negative effect on internal soil friction. Considering that, according to the Swiss federal forest law (Schweizerische Eidgenossenschaft, 2013), closed shrub areas are classified as forest, it is necessary to question the increased slope stability on forested areas. The potentially complex interactions between changing soil and vegetation caused by encroaching green alder in the Unteralptal reveals that neither a general association of land cover with surface processes nor a single soil parameter are sufficient to assess the impact of land use change on slope stability.

Acknowledgements—The authors gratefully acknowledge the supply of data by MeteoSwiss, the LisAG and Swisstopo. The support of the Korporation Ursern, in particular of Columban Russi and Alexander Renner, is also gratefully acknowledged.

References

Ambühl E, Huber HM, Niggli E, Huber W, Niggli M, Flück W. 2008. Oberalppass (LK 1232) Topographic map. Wabern b. Bern.

Angers DA, Caron J. 1998. Plant-induced changes in soil structure: processes and feedbacks. *Biogeochemistry* **42**: 55–72. DOI: 10.2307/1469338

Anthelme F, Cornillon L, Brun J-J. 2002. Secondary succession of Alnus viridis (Chaix) DC. in Vanoise National Park, France: coexistence of sexual and vegetative strategies. *Annals of Forest Science* **59**: 419–428. DOI: 10.1051/forest:2002016

Anthelme F, Grossi JL, Brun JJ, Didier L. 2001. Consequences of green alder expansion on vegetation changes and arthropod communities removal in the northern French Alps. *Forest Ecology and Management* **145**: 57–65.

Anthelme F, Michalet R, Barbaro L, Brun J-J. 2003. Environmental and spatial influences of shrub cover (Alnus viridis DC.) on vegetation diversity at the upper treeline in the inner western Alps. *Arctic, Antarctic, and Alpine Research* **35**: 48–55. DOI: 10.1657/1523-0430(2003)035[0048:EASIOS]2.0.CO;2

Archive of the Korporation Ursern. n.d. Alp inspection reports and meeting protocols from 1934–2000.

Bätzing W. 2003. Die Alpen: Geschichte und Zukunft einer europäischen Kulturlandschaft. Beck, München.

BfS. 2007. Anzahl Landwirtschaftsbetriebe im Urserntal 1939–2007, unterteilt nach Gemeinden; Betriebszählungen, Anbauerhebungen.

Brassel P, Brändli UB. 1999. Schweizerisches Landesforstinventar: Ergebnisse der Zweitaufnahme 1993–1995. P. Haupt, Birmensdorf.

Cammeraat E, Beek R, Kooijman A. 2007. Vegetation succession and its consequences for slope stability in SE Spain. Vegetation succession and its consequences for slope stability in SE Spain. In *Developments in Plant and Soil Sciences*, Stokes A, Spanos I, Norris JE, Cammeraat E (eds). Eco-and Ground Bio-Engineering: The Use of Vegetation to Improve Slope Stability. Springer: Netherlands; **103**: 273–285.

Carson A, Kirkby J. 2009. *Hillslope Form and Process*. Cambridge University Press: London.

Caviezel C, Kuhn NJ. 2012. Causes of temporal variations in mass wasting occurrence in the Ursern valley, Switzerland. *GEOÖKO* **33**: 89–109.

Caviezel C, Kuhn NJ, Meusburger K. 2010. Applicability of Alp inspection reports for the reconstruction of land-use and mass wasting history in the Ursern valley, Switzerland. *Die Erde* **141**: 301–319.

Cernusca A, Tappeiner U, Bayfield N. 1999. Land use changes in European mountain ecosystems: Ecomont. Concepts and results. Accademia Europea di Bolzano, Berlin.

Didier L, Brun J. 1997. Reboisements de protection et sous-utilisation des alpages□: impacts écologiques et paysagers. Exemple de la série R.T.M. de la Grollaz, moyenne Maurienne, Alpes françaises du Nord (1997). Ecologia mediterranea

Dommermuth C. 1995. Beschleunigte Bodenabtragungsvorgänge in der Kulturlandschaft des Nationalparks Berchtesgaden. *Forstwissenschaftliches Centralblatt vereinigt mit Tharandter forstliches Jahrbuch* **114**: 285–292. DOI: 10.1007/BF02742232

Eidgenössische Landestopographie. 1926. Topographischer Atlas der Schweiz, Sustenpass.

Farmer RE, Maley ML, Stoehr MU, Schnekenburger F. 1985. Reproductive characteristics of green alder in northwestern Ontario. *Canadian Journal of Botany* **63**: 2243–2247. DOI: 10.1139/b85-318

Food and Agriculture Organization of the United Nations. 2006. World reference base for soil resources, 2006: a framework for international classification, correlation and communication. Food and Agriculture Organization of the United Nations: Rome.

Graf C, Böll A, Graf F. 2003. Pflanzen im Einsatz gegen Erosion und oberflächennahe Rutschungen. Eid. Forschungsanstalt für Wald, Schnee und Landschaft [online] Available from: http://test.slf.ch/wsl/dienstleistungen/publikationen/pdf/5628.pdf (Accessed 11 September 2012).

Hunziker M. 1995. The spontaneous reafforestation in abandoned agricultural lands: perception and aesthetic assessment by locals and tourists. *Landscape and Urban Planning* **31**: 399–410. DOI: 10.1016/0169-2046(95)93251-J

Körner C, Hoflacher H, Wieser G. 1978. Untersuchungen zum Wasserhaushalt von Almflächen im Gasteiner Tal. *In Oekologische Analysen von Almflächen im Gasteinertal; Innsbruck*. Oesterr MaB-Hochgebirgsprogramm: Hohe Innsbruck Tauern; 67–79.

Kuhn NJ, Armstrong EK, Ling AC, Connolly KL, Heckrath G. 2012. Interrill erosion of carbon and phosphorus from conventionally and organically farmed Devon silt soils. *CATENA* **91**: 94–103. DOI: 10.1016/j.catena.2010.10.002

Maag S, Nösberger J, Lüscher A. 2001. Mögliche Folgen von Bewirtschaftungsaufgabe von Wiedsen und Weiden im Berggebiet - Ergebnisse des Komponentenprojektes D, Polyprojekt PRIMALP [online] Available from: http://e-collection.library.ethz.ch/eserv/eth:25334/eth-25334-01.pdf (Accessed 23 November 2012)

MacDonald D, Crabtree J, Wiesinger G, Dax T, Stamou N, Fleury P, Gutierrez Lazpita J, Gibon A. 2000. Agricultural abandonment in mountain areas of Europe: environmental consequences and policy response. *Journal of Environmental Management* **59**: 47–69. DOI: 10.1006/jema.1999.0335

Mafian S, Huat BBK, Ghiasi V. 2009. Evaluation on root theories and root strength properties in slope stability. *Euopean Journal of Scientific Research* **30**: 594–607.

Copyright © 2014 John Wiley & Sons, Ltd.

Meusburger K, Alewell C. 2008. Impacts of anthropogenic and environmental factors on the occurrence of shallow landslides in an alpine catchment (Urseren Valley, Switzerland).

Morgan RPC. 2005. *Soil Erosion and Conservation*. John Wiley & Sons: Malden, Mass.

Morgan RP, Rickson RJ. 2011. *Slope Stabilization and Erosion Control: A Bioengineering Approach*. Taylor & Francis Group: London.

Newesely C, Tasser E, Spadinger P, Cernusca A. 2000. Effects of land-use changes on snow gliding processes in alpine ecosystems. *Basic and Applied Ecology* **1**: 61–67. DOI: 10.1078/1439-1791-00009

Rebsamen. 1919. Zur Anthropogeographie der Urner-Alpen. Wetzikon

Rickli C, Graf F. 2009. Effects of forests on shallow landslides – case studies in Switzerland. *Forest Snow Landscape Research* **82**: 33–44.

Rowell DL, Rsch-Supan MB, Munch JC. 1997. *Bodenkunde: Untersuchungsmethoden Und Ihre Anwendungen*. Springer-Verlag GmbH: Berlin.

Schauer T. 1975. Die Blaikenbildung in den Alpen. Bayer. Landesamt f. Wasserwirtschaft

Schweizerische Eidgenossenschaft. 2013. Bundesgesetz über den Wald vom 4. Oktober 1991 (Stand am 1.Juli 2013). Available on: http://www.admin.ch/opc/de/classified-compilation/19910255/201307010000/921.0.pdf [access 10/2013]

Sponagel H. 2005. *Bodenkundliche Kartieranleitung: mit 41 Abbildungen, 103 Tabellen und 31 Listen*. Bundesanstalt für Geow. und Rohstoffe: Hannover.

Swisstopo. 2010. Camera calibration protocolls. Available on http://www.swisstopo.admin.ch/internet/swisstopo/de/home/products/images/aerial/orientation/calibration.html [access 06/2010]

Tappeiner U, Cernusca A. 1993. Alpine meadows and pastures after abandonment. *Results of the Austrian MaB-programme and the EC-STEP project INTEGRALP. Pirineos* **141**: 97–118.

Tasser E, Tappeiner U. 2002. Impact of land use changes on mountain vegetation. *Applied Vegetation Science* **5**: 173–184. DOI: 10.1111/j.1654-109X.2002.tb00547.x

Tasser E, Mader M, Tappeiner U. 2003. Effects of land use in alpine grasslands on the probability of landslides. *Basic and Applied Ecology* **4**: 271–280.

Tasser E, Tappeiner U, Cernusca A. 2001. *Südtirols Almen im Wandel: ökologische Folgen von Landnutzungsänderungen*. Europäische Akademie Bozen.

Tasser E, Tappeiner U, Cernusca A. 2005. Ecological effects of land-use changes in the European Alps. In *Global Change and Mountain Regions: An Overview of Current Knowledge*. Springer; 409–420.

Tisdall JM, Oades JM. 1982. Organic matter and water-stable aggregates in soils. *Journal of Soil Science* **33**: 141–163. DOI: 10.1111/j.1365-2389.1982.tb01755.x

Wiedmer E, Senn-Irlet B. 2006. Biomass and primary productivity of an Alnus viridis stand – a case study from the Schächental valley, Switzerland. *Botanica Helvetica* **116**: 55–64. DOI: 10.1007/s00035-006-0758-7

Wiegand C, Geitner C. 2010. Shallow erosion in grassland areas in the Alps. What we know and what we need to investigate further. In *Challenges for Mountain Regions – Tackling Complexity*, Borsdorf A, Grabherr G, Heinrich K, Scott B, Stötter J (eds). Vienna: Innsbruck, Wien; 76–83.

Wischmeier WH, Mannering JV. 1969. Relation of soil properties to its erodibility. *Soil Science Society of America Journal* **33**: 131–137.

Zhang B, Zhao Q, Horn R, Baumgartl T. 2001. Shear strength of surface soil as affected by soil bulk density and soil water content. *Soil and Tillage Research* **59**: 97–106. DOI: 10.1016/S0167-1987(01)00163-5

Zimbone SM, Vickers A, Morgan RPC, Vella P. 1996. Field investigations of different techniques for measuring surface soil shear strength. *Soil Technology* **9**: 101–111. DOI: 10.1016/0933-3630(96)00002-5

Copyright © 2014 John Wiley & Sons, Ltd.

Chapter 8

8 Synthesis

8.1 Change in land use and climate and its effect on the managed eco-geomorphic balance of the Urserntal

In the European Alps, the traditional agricultural use was of low intensity and adapted to natural site factors (Bätzing, 2005; Strijker, 2005; Soliva et al., 2008). In addition, the work intensive maintenance practices and grazing regulations (MacDonald et al., 2000) guaranteed the sustainable productivity in the Alpine regions for several centuries. This long lasting traditional land use created a man-made cultural landscape of high diversity. The mutually dependent ecosystem- and geomorphic processes (Renschler et al., 2007) were kept in an artificial balance by the low intensive use and management. The observed increase of soil degradation processes in the Alpine region during the last decades, reported in several studies (Tappeiner and Cernusca, 1993; Dommermuth, 1995; Newesely et al., 2000; Tasser et al., 2003; Meusburger and Alewell, 2008), serves as evidence for a change in the managed eco-geomorphic balance.

Land use in the Urserntal is well documented and shows the typical pattern for mountain agriculture in the Alps. Further on, an increase of soil degradation processes was observed in the valley (Meusburger and Alewell, 2008). Abandonment of work intensive maintenance measures and low intensive land use alters land cover, ecosystem- and geomorphic- processes (Renschler et al., 2007). The literature review presented at the beginning of the thesis, identified several processes, induced by a change in land use, land management and climate change that affect the artificial developed ecosystem and therefore the managed eco-geomorphic balance. Generally, missing spatial and temporal information on degradation processes as well as deficient information on processes on marginal areas, limit the ability to identify location specific soil degradation processes to define their magnitude and frequency and to relate them to triggering factors. This PhD

thesis intended to determine the effects of land use and climate change on the managed eco-geomorphic balance in Alpine regions using historical data. Specifically, the following research questions were studied:

1. Is it possible to link the spatial and temporal appearance of mass wasting events in the Urserntal to changes in land use practices or climate change, or both?
2. Is shrub encroachment a suitable proxy for land abandonment?
3. How does land abandonment affect the previously managed eco-geomorphic balance?

The following subsections 8.1.1-8.1.3 briefly summarize the results of the presented papers and the manuscript presented in the chapters 4-7. The summary attempts to answer the major research questions that were raised in the introduction and to finally evaluate the impact of land use and climate change on the managed eco-geomorphic balance in Alpine regions.

8.1.1 The spatial and temporal pattern of mass wasting events in the Urserntal in relation to changes in land use practices or climate change

By analyzing the spatial and temporal pattern of mass wasting events in the Urserntal we the reported increase of mass wasting frequency in the Urserntal could be related to the abandonment of use restrictions on the geological sensitive areas of the Mesozoic layer in the early 1970s. Traditionally, the land use on these areas was highly regulated by the corporation and the violation of the use restrictions was penalized. This indicates the awareness of the corporation that managed land use is needed to keep the eco-geomorphic balance and to ensure productivity on these sensitive areas. Additionally, the severe use restrictions and punishments indicate that the area was traditionally of high economic value. In the late 1960s, the structural changes in agriculture led to the demand of a less labor intensive use of these near and easy accessible areas. In the following years, the use restrictions were abolished and mass wasting frequency increased. This development emphasizes the need of the farmers for easy access to the pastures. The reports of the farmers that were commissioned to oversee the pasture area also point out that the neglect of drainage measures on the mentioned sensitive areas led to several landslides (Caviezel et al., 2010). This development also indicates how the dependence on the resource soil in mountain agricultural has changed and land degradation is tolerated when agricultural production depends less on land. The presented results illustrate how the simple abolishment of management changes the previously managed

eco-geomorphic balance that was kept in what was perceived as a balance by traditional use restrictions. The question remains whether a change in climate characteristics coincides with the abolishment of use restrictions and represents the trigger for the increase of mass wasting frequency. Farmers and reports pointed out that landslides and debris/mud flows generally happen during or after high magnitude rainfall events lasting 2-3 days (Caviezel et al., 2010). The analysis of rainfall data allowed distinguishing between rainfall events with a magnitude of 60 mm d^{-1} or 125 mm $3d^{-1}$ as triggering events. Even though high magnitude rainfall events appear to trigger mass wasting events, the risks of land degradation cannot be associated with climate change alone. The frequency analysis of triggering events revealed that the period of highest mass wasting frequency does not correlate with the period of highest magnitude rainfall events. While highest frequency of mass wasting events was found shortly after the abandonment of use restrictions, highest frequency of triggering rainfall events was found thereafter. Thus, the abolishment in use restrictions on the geologic sensitive areas of the Mesozoic layer is of high importance for the increase of mass wasting processes. However, this result does not mean that climate change would not affect the managed eco-geomorphic balance. Future scenarios foresee that mean and extreme precipitation values may undergo a seasonal shift, with more spring and autumn heavy precipitation events than at present, and fewer in summer (Beniston, 2006; Stoffel et al., 2014). As landslides and debris flows were also detected to happen in late autumn and early spring and not only after devastating thunderstorms, the predicted change in the seasonal pattern of increased precipitation in spring and autumn that will less often fall as snow in lower altitudes, are expected to result in an increase of landslide risk. In consideration of future climate change, the results of the presented study emphasizes the significant potential of conscious land use management, where especially grazing regulations and maintenance measures contribute to the climate change impact adaption and mitigation.

8.1.2 Shrub encroachment as proxy for land abandonment

As the spatial cover of data on land degradation and maintenance measures in the inspection reports is limited to areas of economic interest, the identification of areas that experienced land use abandonment as well as the impact of abandonment on the previously managed eco-geomorphic balance are difficult to determine. Therefore, proxies, as for example the chronologic encroachment by shrubs, are needed to reconstruct land abandonment. The analysis of vegetation change in the Unteralptal showed a considerable increase of green alder cover by 63%. The small scaled analysis of green alder encroachment illustrated that a climatic induced expansion near the tree

line is not of significant importance for the increase of shrub cover in the Unteralptal. Further analysis of topographic and geomorphic parameters indicates that the habitat spectrum of green alder is much wider than assumed and that the presence and absence of green alder is mostly controlled by land use and management. Thus, the increase of shrub cover is related to land use change. The past concentration of green alder on moist, north-facing, steep slopes and areas of high geomorphic activity can therefore be considered an artifact of land use as the mentioned areas coincide with areas that were not suitable for the long lasting traditional land use. The increase of shrub on former pasture areas therefore represents the abandonment of land use and land management. The declining extent of the total grazing area illustrate the loss of importance of the soil resource in mountain agricultural and point towards a new risk for the managed eco-geomorphic balance in Alpine regions.

8.1.3 Land abandonment and its effect the previously managed eco-geomorphic balance

Considering that land use has been abandoned on an average of 20%, and in some areas on 70% of the agricultural land of the Alps between 1980 and 2000 (MacDonald et al., 2000; Tappeiner, 2003), understanding the consequences of land abandonment seems to be essential for alpine ecology. Land use abandonment alters various ecosystem properties that have developed by long lasting traditional land use and management. The brief literature review indicates that the interaction between the factors affecting the previously managed eco-geomorphic balance between vegetation and slope processes in Alpine regions are complex and can vary depending on former land use intensity, species composition on the abandoned areas, the rate of encroachment and the time after abandonment. After the abandonment, vegetation changes in the course of succession have continuous effects on the entire ecosystem (Tappeiner and Cernusca, 1993). Shortly after the stopping of mowing or grazing, for example, long grass forms downward directed mats, which offer ideal gliding conditions for the snow. By entrainment of frozen stones and vegetation and by tearing or even uprooting stronger plants like dwarf shrubs and herbs by the gliding snow, the process leads to soil injuries acting as starting point for erosion processes (Newesely et al., 2000). However, Newesely (2000) also showed that snow gliding processes first increase with the reduction of agricultural use and decrease when big dwarf shrub communities have established in the course of succession. For the Urserntal, the existing studies do not provide definite results on the erosivity of snow movement (Meusburger and Alewell, 2008; Meusburger et al., 2013). According to Meusburger et al. (2013), the correlation between winter erosion and snow glide rates for

sites of different vegetation compositions are weak. However, excluding green alder areas from the data analysis, the relationship is improved and explains 73% of the variability of soil erosion rate by the measured snow glide distance ($p < 0.005$). The results underline the complexity of the interaction between vegetation composition and soil processes. Succession towards established shrub areas and forests is generally known to improve slope stability (Graf et al., 2003; Rickli and Graf, 2009) by anchoring the topsoil to the underlying bedrock (Morgan and Rickson, 2011). The study presented in chapter 7 takes a closer look on the areas that changed towards established green alder woodlands in the Unteralptal during the last 90 years. The study revealed that soil properties that are relevant for soil erosion by water and mass movement show two signals of change towards a change of erosion processes: First, the shear and penetration resistance decreased after 15 years of encroachment and second, porosity, associated with an increase in infiltration capacity, increased between 40 and 90 years of encroachment. The increased porosity could decrease the stability of the less compacted soil leading to soil creep processes, while the increased infiltration capacity reduces soil erosion by running water. The measurements of this study show that the change of vegetation cover leads to a change of the process domains concerning slope stability. The abandonment of land use and management on the former pasture area in the Unteralptal is therefore considered to affect the eco-geomorphic balance, which was previously managed by controlled pasturing.

In the European Alps, green alder is a major component on the increasing subalpine woodland. Several studies report that green alder is spreading on abandoned subalpine pastures in the Alpine region (Anthelme et al., 2003; Camacho et al., 2008; Wiedmer and Senn-Irlet, 2006). Moreover, green alder showed to inhibit the development of arboreal coniferous species (Anthelme et al., 2002). Thus, green alder build established woodlands. In the Swiss Alps, the area encroached by green alder accounts to 121.8 ha calculated by the conventional planimetric approach (WSL, 2012a, 2012b, 2012c, 2012d). Considering the presented differences in green alder cover in the Unteralptal for calculations performed by the planimetric approach (104.2 ha) compared to the generation of surface values (136.6 ha), the green alder cover in alpine areas is supposed to be underestimated by about 30%. The wide extent of green alder encroachment in Swiss Alpine regions and the importance of green alder as major component on subalpine shrub woodland on former pastures in the whole Alpine arc underline the importance of these findings. Further on, the Swiss Federal Council defines newly colonized areas as forest when the stands reach an age 10-20 years, (Swiss Federal Council, 1992, WaV Art 1c) and includes also woodlands in the forest definition (Swiss Federal Council,

1991,WaG Art.2, 2010, PSV Anhang 11 Art. 2). The study in the Unteralptal revealed that it is necessary to question the increased slope stability on forested areas as an association of increasing shrub woodland cover with an increasing slope stability is not warranted.

8.2 Conclusion

With the revision of agricultural policy since the beginning of the 1990s the support for agriculture has been continuously separated from production. However, during the last century, agricultural policy, structural changes in agriculture and the global market had major effects on land use history. Summer grazing areas decreased by about 900 km^2 between 1891/1911 and 2004/2009 (Baur et al., 2007; Schubarth and Weibel, 2013). According to Mather and Fairbairn (2000), the forested area in Switzerland approximately doubled during the last 150 years. One could argue that this process is part of renaturalization. Nevertheless, it has to be kept in mind that the eco-geomorphic balance in the Alps depends on a diverse managed landscape (Spiegelberger et al., 2006). Further on, land abandonment often coincides with the intensification of land use on better accessible areas.

Beside the change in land use and land cover, the change in climate characteristics poses a further risk to the managed eco-geomorphic balance of mountain regions. The results presented in this PhD thesis indicate that the risk of mass wasting may increase as a consequence of climate change if more precipitation events above the critical threshold for triggering a mass wasting fall as rainfall. Nevertheless, the results also show the significant potential of land management, especially grazing regulations and maintenance, to mitigate the negative effects of climate change on land degradation. Concerning the type of land use change, the presented studies illustrate that both intensification as well as land abandonment have an effect on the managed eco-geomorphic balance. The type, magnitude and frequency of degradation events thereby changes depending on whether land use is intensified or abandoned. The effect of land use intensification on the managed eco-geomorphic balance is visible, manifesting itself in reported landslides of a regular frequency. Land abandonment, in contrast, does not visibly affect the previously managed eco-geomorphic balance as the soil creeping processes on abandoned areas are slow and not noticed by the farmers. Since abandoned areas are not of economic interest, the perception of the change in the previously managed eco-geomorphic balance and soil degradation processes is reduced. Further on, land abandonment infers that there is no economic need to protect eco-geomorphic balance by conscious management on these areas. The argument that forest re-growth is part of renaturalization and that

forested areas could be reverted into pastures if soil and food resources are needed, should be considered with caution as forest and shrub encroachment can totally modify soil properties. For green alder for example, the erosion risk on areas reverted to pastures after years of shrub encroachment is estimated to accelerate due to the low inner friction of the soil and the missing roots after clearing. Further on, the possibility to revert green alder woodlands in pastures again must be questioned. According to Bühlmann et al. (2014), the experiences of local farmers in the Urserntal show that clear cutting does neither help turning a shrub area into a forest nor does it contribute to the reversion of the shrub area into pasture again. Therefore, the extensive use of summer grazing pastures and meadows, essential for preserving open land resources, should be safeguarded for future generations. According to Hoffmann et al. (2010), mountain farming and agricultural policies will play an increasingly important role in the conservation of natural resources and cultural landscapes in the future. However, not even the last government interventions, the agriculture policy for 2014/17 that shifts the subsidies from livestock centered payments encouraging intensive farming, to subsidies dependent on acreage of land use, will be able to preserve traditional low intensive farming on marginal areas and avoid the further polarization of land use all over the Swiss Alpine region, as the number of cattle on summer grazing areas is expected to decrease (Flury et al., 2012).

Literature review as well as the research in the Urserntal illustrate that both land use intensification as well as of land use abandonment lead to complex interaction between the factors controlling the managed eco-geomorphic balance. Process frequency and intensity of soil degradation processes depend on natural site factors, former use intensity and management, the type of intensification or the vegetation associations that follow the abandonment and the time after abandonment. The multiple variables controlling slope and soil stability and their complex interaction underline the importance of interdisciplinary research on the linkage between soil, ecology and human impact. In addition, the complex interaction between the factors controlling the managed eco-geomorphic balance emphasizes the need for a regional assessment on the effect of changes in land use and climate on this balance. Thereby, the analysis of historic data provides regional knowledge on the interaction between the factors controlling eco-geomorphic managed balance and on land use history. This knowledge can help to concentrate subsidies and management efforts on endangered areas. The study in the Urserntal for example revealed that land use intensification affects the eco-geomorphic managed balance predominantly on geologic sensitive areas of the Mesozoic layer. As shown in chapter 4, maintenance measures and grazing regulations are able to mitigate the negative effects of land use on slope and soil stability. Likewise, the knowledge about which areas are potentially susceptible to be encroached by shrubs in the near future would help to

concentrate prevention efforts and agricultural subsidies on these areas. However, agricultural policy would need to develop concepts and instruments on a regional level that facilitate directed measurements on areas where the eco-geomorphic managed balance shows to be highly affected by land use change. Since Swiss agricultural policy is regulated mostly at a national level, regional concepts are difficult to introduce. In the Urserntal for example, the introduction of grazing concepts following the traditional land use regulations could be supported. Additionally, agricultural efforts and payments could concentrate on enhancing hay making on the areas that showed to be prone for shrub encroachment. A further example for a regional concept could involve the supporting of the shepherding of a herd of goats or traditional sheep breed of the Engadin sheep, which are known to keep landscapes open by browsing on woody plants (Bühlmann et al., 2014), and to concentrate grazing on areas that showed to be prone for shrub encroachment.

The regional understanding of the factors controlling the eco-geomorphic managed balance allows to identify processes affecting this balance and to concentrate prevention efforts on the most vulnerable areas. This would improve the efficiency of agricultural subsidies and efforts, improve the sustainable land use in Alpine regions and help to preserve alpine soils.

Bibliography

9 Bibliography

This bibliography does not contain references that are limited to chapter 4 5 6 and 7. For references on the chapters 4, 5, 6, and 7 see pages: 44-45; 65-67; 91-95 and 109-110.

Alewell C, Bebi P. 2011. Forest development in the European Alps and potential consequences on hydrological regime. M. Bredemeier et al. (eds.). Forest Management and the Water Cycle: An Ecosystem-Based Approach, Ecological Studies **212**, 111–126. DOI10.1007/978-90-481-9834-4_6.

Anthelme F, Cornillon L, Brun J-J. 2002. Secondary succession of Alnus viridis (Chaix) DC. in Vanoise National Park, France: coexistence of sexual and vegetative strategies. Annals of Forest Science **59**, 419–428. DOI: 10.1051/forest:2002016

Anthelme F, Grossi JL, Brun JJ, Didier L. 2001. Consequences of green alder expansion on vegetation changes and arthropod communities removal in the northern French Alps. Forest Ecology and Management **145**, 57–65.

Anthelme F, Michalet R, Barbaro L, Brun J-J. 2003. Environmental and Spatial Influences of Shrub Cover (Alnus viridis DC.) on Vegetation Diversity at the Upper Treeline in the Inner Western Alps. Arctic, Antarctic, and Alpine Research **35**, 48–55. DOI: 10.1657/1523-0430(2003)035[0048:EASIOS]2.0.CO;2.

Anthelme F, Villaret J-C, Brun J-J. 2007. Shrub encroachment in the Alps gives rise to the convergence of sub-alpine communities on a regional scale. Journal of Vegetation Science **18**, 355–362. DOI: 10.1111/j.1654-1103.2007.tb02547.x.

Archive of the Korporation Ursern. n.d. Alp inspection reports and meeting protocols from 1934-2000. Korporationsarchiv Andermatt.

Baldock D. 1996. Farming at the margins: abandonment or redeployment of agricultural land in Europe . Institute for European Environmental Policy and Landbouw-Economisch Instituut (Netherlands) (eds). IEEP and LEI-DLO. London. 1-202.

Bätzing W. 2005. Die Alpen Geschichte und Zukunft einer europäischen Kulturlandschaft . 3. Aufl. Beck. München. 1-431.

Baumann W, Moser P. 2012. Agrarpolitik – In: Historisches Lexikon der Schweiz (HLS). Bern 1-3. [Online] Available from: http://www.hls-dhs-dss.ch/textes/d/D13789.php. (Last access: 20.12.2014)

Baur P. 2006. Notwendigkeit, Möglichkeit und Grenzen marktwirtschaftlicher Anreize zur Förderung der Artenvielfalt in der Agrarlandschaft. Bundesamt für Naturschutz, Bonn. BfN; Skripten **179**, 49–64.

Baur P, Müller P, Herzog F. 2007. Alpweiden im Wandel. Forschungsanstalt Agroscope Reckenholz-Tänikon ART. Zürich. Agrarforschung **14**, 254–259.

Bebi P, Baur P. 2002. Forest Expansion in the Swiss Alps: A Quantitative Analysis of Bio-physical and Socio-economic Causes Waldausdehnung in den Schweizer Alpen: Eine quantitative Analyse von bio-physikalischen und sozio-ökonomischen Ursachen. Centralblatt für das gesamte Forstwesen **3/4**, 2177–230.

Beniston M. 2003. Climatic Change in Mountain Regions: A Review of Possible Impacts. Climatic Change **59**, 5–31. DOI: 10.1023/A:1024458411589.

Beniston M. 2006. August 2005 intense rainfall event in Switzerland: Not necessarily an analog for strong convective events in a greenhouse climate. Geophysical Research Letters **33,** 1-5. DOI: 10.1029/2005GL025573.

Beniston M, Keller F, Goyette S. 2003. Snow pack in the Swiss Alps under changing climatic conditions: an empirical approach for climate impacts studies. Theoretical and Applied Climatology **74**, 19–31. DOI: 10.1007/s00704-002-0709-1.

Beniston M, Stoffel M, Hill M. 2011. Impacts of climatic change on water and natural hazards in the Alps: Can current water governance cope with future challenges? Examples from the European “ACQWA” project. Environmental Science & Policy **14**, 734–743. DOI: 10.1016/j.envsci.2010.12.009.

BfS. 2007. Anzahl Landwirtschaftsbetriebe im Urserntal 1939-2007, unterteilt nach Gemeinden; Betriebszählungen, Anbauerhebungen. Betriebszählungen, Anbaustatistiken, Auszug aus der elektronischen Datenbank des Bundesamts für Statistik (BfS). Neuchâtel.

BfS. 2011. Landwirtschaftliche Betriebe, Landwirtschaftliche Nutzfläche (LN) und Nutztiere auf Klassifizierungsebene 2 bei Kanton, Zone, Betriebsform, Jahr und Variable. Online Datenbank STAT-TAB [Online data download] Available from: http://www.pxweb.bfs.admin.ch/dialog/statfile.asp?lang=1. (Downloaded: 12.02. 2014)

BfS. 2013a. Arealstatistik: Standardnomeklatur (NOAS04) nach Bezirk und Gemeinde, in Hektaren. Online Datenbank STAT-TAB [Online data download] Available from: http://www.pxweb.bfs.admin.ch/dialog/statfile.asp?lang=1. (Downloaded: 11.03. 2014)

BfS. 2013b. Landwirtschaftliche Betriebe, Landwirtschaftliche Nutzfläche (LN) und Nutztiere auf Klassifizierungsebene 1 bei Jahr, Kanton (-) / Bezirk (>>) / Gemeinde (......) und Variable. Online Datenbank STAT-TAB [Online data download] Available from: http://www.pxweb.bfs.admin.ch/dialog/statfile.asp?lang=1. (Downloaded: 17.09. 2014)

Bolliger J, Hagedorn F, Leifeld J, Böhl J, Zimmermann S, Soliva R, Kienast F. 2008. Effects of Land-Use Change on Carbon Stocks in Switzerland. Ecosystems **11**, 895–907. DOI: 10.1007/s10021-008-9168-6.

Bosshard A, Schläpfer F, Jenny M. 2010. Weissbuch Landwirtschaft Schweiz: Analysen und Vorschläge zur Reform der Agrarpolitik. Haupt Verlag AG. Bern. 1-272

Brändli UB. 2010. Schweizerisches Landesforstinventar: Ergebnisse der dritten Erhebung 2004-2006. Eidgenössische Forschungsanstalt für Wald Schnee und Landschaft (WSL) Birmensdorf, Bundesamt für Umwelt (BAFU). Bern. 1-312.

Brugger EA, Furrer GJ, Messerli B, Messerli P. 1984. Entwicklung des schweizerischen Berggebietes zwischen Eigenständigkeit und Abhängigkeit aus ökonomischer und ökologischer Sicht. Hauptverlag. Bern. 1-1097.

Bühlmann T, Hiltbrunner E, Körner C. 2014. Alnus viridis expansion contributes to excess reactive nitrogen release, reduces biodiversity and constrains forest succession in the Alps. Alpine Botany **124**, 187–191. DOI: 10.1007/s00035-014-0134-y.

Camacho O, Dobremez L, Capillon A. 2008. Des broussailles dans les prairies alpines. Organisation spatiale de l'activité et pratiques des éleveurs en vallée d'Abondance (Haute-Savoie, France). Revue de géographie alpine. Journal of Alpine Research **96 (3)**, 77–88.

Caviezel C, Hunziker M, Kuhn NJ. 2015. Green alder (*Alnus viridis*) encroachment in the Unteralptal, central Switzerland: A temporal and spatial analysis. *in prep*.

Caviezel C, Hunziker M, Schaffner M, Kuhn NJ. 2014. Soil–vegetation interaction on slopes with bush encroachment in the central Alps – adapting slope stability measurements to shifting process domains. Earth Surface Processes and Landforms **39**, 509–521. DOI: 10.1002/esp.3513.

Caviezel C, Kuhn NJ. 2012. Causes of temporal variations in mass wasting occurrence in the Ursern valley, Switzerland. GEOÖKO **33**, 89–109.

Caviezel C, Kuhn NJ, Meusburger K. 2010. Applicability of Alp Inspection Reports for the Reconstruction of Land-Use and Mass Wasting History in the Ursern Valley, Switzerland. Die Erde **141**, 301–319.

Cocca G, Sturaro E, Gallo L, Ramanzin M. 2012. Is the abandonment of traditional livestock farming systems the main driver of mountain landscape change in Alpine areas? Land Use Policy. Land Use Policy **29**, 878–886. doi:10.1016/j.landusepol.2012.01.005.

Didier L, Brun J. 1997. Reboisements de protection et sous-utilisation des alpages : impacts écologiques et paysagers. Exemple de la série R.T.M. de la Grollaz, moyenne Maurienne, Alpes françaises du Nord (1997). Ecologia mediterranea **23**, 107–119.

Dirnböck T, Dullinger S, Grabherr G. 2003. A regional impact assessment of climate and land-use change on alpine vegetation. Journal of Biogeography **30**, 401–417. DOI: 10.1046/j.1365-2699.2003.00839.x.

Dommermuth C. 1995. Beschleunigte Bodenabtragungsvorgänge in der Kulturlandschaft des Nationalparks Berchtesgaden. Forstwissenschaftliches Centralblatt vereinigt mit Tharandter forstliches Jahrbuch **114**, 285–292. DOI: 10.1007/BF02742232.

Dudda E. 2012. Ungewisse Zukunft der Alpwirtschaft. Landwirtschaftlicher Informationsdienst LID 27th July. Bern. [Online] Available from:http://www.lid.ch/index.php?id=9320&tx_infoservices_pi1[showUid]=23958&cHash=ab0bef18b1. (Last access: 20.12.2014).

Flury C, Huber R, Tasser E. 2013. Future of Mountain Agriculture in the Alps. In: The Future of Mountain Agriculture, Mann S (ed). Springer. Berlin. Heidelberg. 105–126.

Flury C, Zimmermann A, Mack G, Möhring A. 2012. Auswirkungen der Agrarpolitik 2014−2017 auf die Berglandwirtschaft. Bericht Forschungsprogramm AgriMontana. Tänikon. [Online] Available from: http://www.agroscope.admin.ch/agrimontana. (Last access: 20.12.2014).

Frei C, Schär C. 2001. Detection probability of trends in rare events: Theory and application to heavy precipitation in the Alpine region. Journal of Climate **14,** 1568-1584.

Fuhrer J, Beniston M, Fischlin A, Frei C, Goyette S, Jasper K, Pfister C. 2006. Climate risks and their impact on agriculture and forests in Switzerland. In Climate Variability, Predictability and Climate Risks, Wanner H, Grosjean M, Röthlisberger R, and Xoplaki E (eds). Springer Netherlands **79**, 79–102. DOI 10.1007/s10584-006-9106-6.

Gall H. 1985. Bodenerosion und Bodenerhaltung im Gebirgsland am besonderen Beispiel Nordtirols. Kufstein. 1-124.

Gamper SM, Tasser E, Tappeiner U. 2007. Short-time effects of land-use changes on O-horizon in subalpine grasslands. Plant and Soil **299**, 101–115. DOI: 10.1007/s11104-007-9366-6.

Gehrig-Fasel J, Guisan A, Zimmermann NE. 2007. Tree line shifts in the Swiss Alps: Climate change or land abandonment? Journal of Vegetation Science **18**, 571–582. DOI: 10.1111/j.1654-1103.2007.tb02571.x.

Gellrich M, Baur P, Koch B, Zimmermann NE. 2007a. Agricultural land abandonment and natural forest re-growth in the Swiss mountains: A spatially explicit economic analysis. Agriculture, Ecosystems & Environment **118**, 93–108. DOI: 10.1016/j.agee.2006.05.001.

Gellrich M, Baur P, Zimmermann NE. 2007b. Natural forest regrowth as a proxy variable for agricultural land abandonment in the Swiss mountains: a spatial statistical model based on geophysical and socio-economic variables. Environmental Modeling & Assessment **12**, 269–278. DOI: 10.1007/s10666-006-9062-6.

Gellrich M, Zimmermann NE. 2007. Investigating the regional-scale pattern of agricultural land abandonment in the Swiss mountains: a spatial statistical modelling approach. Landscape and Urban Planning **79**, 65–76.

Gottfried M, Pauli H, Grabherr G. 1998. Prediction of Vegetation Patterns at the Limits of Plant Life: A New View of the Alpine-Nival Ecotone. Arctic and Alpine Research **30**, 207–221. DOI: 10.2307/1551968

Graf C, Böll A, Graf F. 2003. Pflanzen im Einsatz gegen Erosion und oberflächennahe Rutschungen. Merkblatt für die Praxis **37**, 1-8. Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft. Birmensdorf. [Online] Available from: http://www.wsl.ch/dienstleistungen/publikationen/pdf/5628.pdf. (Last access: 20.12.2014).

Hoffmann C, Stiefenhofer A, Streifeneder T. 2010. The agro-structural change in the Alps and its outlook until 2020. A model based on key determinants. 118th seminar of the EAAE (European Association of Agricultural Economists) "Rural development: governance, policy design and delivery" August, 25-27 2010. Ljubljana. 699-712. [Online] Available from: http://ageconsearch.umn.edu/bitstream/95316/2/Hoffmann-The_agro-_structural_change_in_the_Alps_and_its_outlook_until_2020_A_model_based_on_key_determinants-197.pdf. (Last access: 20.12.2014).

Huber B, Frehner M. 2013. Die Verbreitung und Entwicklung der Grünerlenbestände in der Ostschweiz. Schweizerische Zeitschrift für Forstwesen **164**, 87–94. DOI: 10.3188/szf.2013.0087.

Huber R, Iten A, Briner S. 2012. Weiterentwicklung des Direktzahlungssystems: Auswirkungen auf die Landnutzung im Berggebiet. Agrarforschung Schweiz **3 (7-8)**, 354–359.

Hürlimann M, Buser B, Zgraggen K, Rieder P. 2004. Regionalwirtschaftliche Studie zur Schaffung von Entscheidungsgrundlagen - Studie des Instituts für Agrarwirtschat (IAW) im Rahmen von “Ursern Network.” ETH. Zürich. 1-50.

Keiler M, Knight J, Harrison S. 2010. Climate change and geomorphological hazards in the eastern European Alps. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences **368**, 2461–2479. DOI: 10.1098/rsta.2010.0047.

Kirtman B, Power SB, Adedoyin JA, Boer GJ, Bojariu R, Camilloni I, Doblas-Reyes FJ, Fiore AM, Kimoto M, Meehl GA, Prather M, Sarr A, Schär C, Sutton R, van Oldenborgh GJ, Vecchi G, Wan HJ. 2013. Near-term Climate Change: Projections and Predictability. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds.)].Cambridge University Press. Cambridge. New York. [Online] Available from: http://www.climatechange2013.org/images/report/WG1AR5_Chapter11_FINAL.pdf. (Last access: 20.12.2014).

Körner C, Hoflacher H, Wieser G. 1978. Untersuchungen zum Wasserhaushalt von Almflächen im Gasteiner Tal. In: Oekologische Analysen von Almflächen im Gasteinertal. Oesterr MaB-Hochgebirgsprogramm. Hohe Tauern. 67–79.

Lanz S. 2012. Article on economics: Main aspects of the Agricultural Policy for 2014-2017. Federal Office for Agriculture FOAG. Bern. 1-7. [Online] Available from: http://www.blw.admin.ch/index.html?lang=en&download=NHzLpZeg7t,lnp6I0NTU042l2Z6ln1ad1IZn4Z2qZpnO2Yuq2Z6gpJCEd4R,gWym162epYbg2c_JjKbNoKSn6A--.(Last access: 20.12.2014).

MacDonald D, Crabtree J., Wiesinger G, Dax T, Stamou N, Fleury P, Gutierrez Lazpita J, Gibon A. 2000. Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response. Journal of Environmental Management **59**, 47–69. DOI: 10.1006/jema.1999.0335.

Mather AS, Fairbairn J. 2000. From floods to reforestation: the forest transition in Switzerland. Environment and History **6**, 399–421. DOI: 10.3197/096734000129342352.

Maurer K, Weyand A, Fischer M, Stöcklin J. 2006. Old cultural traditions, in addition to land use and topography, are shaping plant diversity of grasslands in the Alps. Biological Conservation **130**, 438–446. DOI: 10.1016/j.biocon.2006.01.005.

Meusburger K. 2010. Soil erosion in the Alps: causes and risk assessment. Dissertation an der Universität Basel. 1-117. [Online] Available from: http://edoc.unibas.ch/1219/1/Diss_Meusburger_digital.pdf. (Last access: 20.12.2014).

Meusburger K, Alewell C. 2008. Impacts of anthropogenic and environmental factors on the occurrence of shallow landslides in an alpine catchment (Urseren Valley, Switzerland). Natural Hazards and Earth System Sciences, **8**, 509-520.

Meusburger K, Alewell C. 2014. Soil Erosion in the Alps - Federal Office for the Environment, FOEN. Bern. 1-116. [Online] Available from: http://www.bafu.admin.ch/publikationen/publikation/01761/index.html?lang=en. (Last access: 20.12.2014).

Meusburger K, Leitinger G, Mabit L, Mueller MH, Alewell C. 2013. Impact of snow gliding on soil redistribution for a sub-alpine area in Switzerland. Hydrol. Earth Syst. Sci. Discuss. **10**, 9505–9531. DOI: 10.5194/hessd-10-9505-2013.

Newesely C, Tasser E, Spadinger P, Cernusca A. 2000. Effects of land-use changes on snow gliding processes in alpine ecosystems. Basic and Applied Ecology **1**, 61–67. DOI: 10.1078/1439-1791-00009.

Niedrist G, Tasser E, Lüth C, Dalla Via J, Tappeiner U. 2008. Plant diversity declines with recent land use changes in European Alps. Plant Ecology **202**, 195–210. DOI: 10.1007/s11258-008-9487-x.

Pauli H, Gottfried M, Grabherr G. 1996. Effects of Climate Change on Mountain Ecosystems. Upward Shifting of Alpine Plants. World Resource Review **8**, 382-390.

Pellissier L, Anzini M, Maiorano L, Dubuis A, Pottier J, Vittoz P, Guisan A. 2013. Spatial predictions of land-use transitions and associated threats to biodiversity: the case of forest regrowth in mountain grasslands. Applied Vegetation Science **16**, 227–236. DOI: 10.1111/j.1654-109X.2012.01215.x.

Rebetez M, Lugon R, Baeriswyl PA. 1997. Climatic change and debris flows in high mountain regions: The case study of the Ritigraben Torrent (Swiss Alps). Climatic Change **36**, 371–389. DOI: 10.1023/A:1005356130392.

Renschler CS, Doyle MW, Thoms M. 2007. Geomorphology and ecosystems: Challenges and keys for success in bridging disciplines. Geomorphology **89**, 1–8. DOI: 10.1016/j.geomorph.2006.07.011.

Rickli C, Bucher H. 2003. Oberflächennahe Rutschungen, ausgelöst durch die Unwetter vom 15.-16.7.2002 im Napfgebiet und vom 31.8.-1.9.2002 im Gebiet Appenzell. Projektbericht zuhanden des Bundesamtes für Wasser und Geologie BWG. Eidgenössische Forschungsanstalt für Wald Schnee und Landschaft WSL. Birmensdorf. 1-98. [Online] Available from: http://www.wsl.ch/fe/gebirgshydrologie/wildbaeche/projekte/Hanmurendatenbank/Napf_Appenzell. (Last access: 20.12.2014).

Rickli C, Graf F. 2009. Effects of forests on shallow landslides–case studies in Switzerland. Eidgenössische Forschungsanstalt für Wald Schnee und Landschaft WSL. Birmensdorf. For. Snow Landsc. Res **82**, 33–44. [Online] Available from: http://wslf.ch/dienstleistungen/publikationen/pdf/9696.pdf. (Last access: 20.12.2014).

Rickli C, Kamm S, Bucher H. 2008. Ereignisanalyse Hochwasser 2005 Teilprojekt Flachgründige Rutschungen Projektbericht. Forschungsprojekt: "Flachgründige Rutschungen", Teilprojekt der Ereignisanalyse Unwetter 2005, WSL/BAFU. Birmesdorf. 1-114. [Online] Available from: http://www.wsl.ch/fe/gebirgshydrologie/wildbaeche/projekte/Hanmurendatenbank/Rutschungen. (Last access: 20.12.2014).

Rieder P, Phan-huy SA. 1994. Grundlagen der Agrarmarktpolitik. vdf Hochschulverlag. ETH. Zürich. 1-408.

Ruef A, Stettler M. 2004. Welche Zukunft für den Bergwald und die Berglandwirtschaft in der Schweiz? Fallstudien Gündlischwand und Grindelwald im Berner Oberland. Schweizerische Zeitschrift für Forstwesen **155**, 492–500.

Schauer T. 1975. Die Blaikenbildung in den Alpen . Bayerisches. Landesamt für Wasserwirtschaft. München. 1-29.

Schmidlin J. 2008. Direktzahlungen für die Schweizer Landwirtschaft; Ungelöste Probleme in den Bereichen Umwelt, Natur und Landschaft. Agrofutura. Frick. 1-37. [Online] Available from: http://www.pronatura.ch/systeme-de-paiements-

directs?file=tl_files/dokumente_fr/2_nos_themes/agriculture/Direktzahlungen_fur_die_Schweizer_Landwirtschaft.pdf. (Last access: 20.12.2014).

Schubarth C, Weibel F. 2013. Die Bodennutzung in der Schweiz: Resultate der Arealstatistik. Bundesamt für Statistik (Schweiz), Sektion Geoinformation. Neuchâtel. 1-23. [Online] Available from: http://www.bfs.admin.ch/bfs/portal/de/index/news/publikationen.html?publicationID=5397. (Last access: 20.12.2014).

Soliva R, Rønningen K, Bella I, Bezak P, Cooper T, Flø BE, Marty P, Potter C. 2008. Envisioning upland futures: Stakeholder responses to scenarios for Europe's mountain landscapes. Journal of Rural Studies **24**, 56–71. DOI: 10.1016/j.jrurstud.2007.04.001.

Spiegelberger T, Matthies D, Müller-Schärer H, Schaffner U. 2006. Scale-dependent effects of land use on plant species richness of mountain grassland in the European Alps. Ecography **29**, 541–548.

Steinwidder A, Schneider M, Wachendorf M, Starz W, Pötsch EM. 2011. The future of organic grassland farming in mountainous regions of Central Europe. Grassland Science in Europe, **16**, 286–296. [Online] Available from: http://orgprints.org/19338/1/The_future_of_organic_grassland_farming_in_mountainous_regions_of_Central_Europe.pdf.(Last access: 20.12.2014).

Stöcklin J, Bosshard A, Klaus G, Rudmann-Maurer K, Fischer M. 2007. Landnutzung und biologische Vielfalt in den Alpen. Nationales Forschungsprogramm 48 "Landschaften und Lebensräume der Alpen" des Schweizerischen Nationalfonds. vdf Hochschulverlag AG. Zürich. 1-191

Stoffel M, Mendlik T, Schneuwly-Bollschweiler M, Gobiet A. 2014. Possible impacts of climate change on debris-flow activity in the Swiss Alps. Climatic Change **122**, 141–155. DOI: 10.1007/s10584-013-0993-z.

Streifeneder T. 2010. Die Agrarstrukturen in den Alpen und ihre Entwicklung unter Berücksichtigung ihrer Bestimmungsgründe: eine alpenweite Untersuchung anhand von Gemeindedaten . Herbert Utz Verlag GmbH. München. 1-286.

Streifeneder T, Hoffmann C, Ruffini FV. 2007a. Der Agrarstrukturwandel in den Alpen 1980-2000: Ein Vergleich harmonisierter Agrarstrukturindikatoren auf Gemeindeebene im Alpenkonventionsgebiet. Conference Paper, 47th Annual Conference, German Association of Agricultural Economists (GEWISOLA), September 26-28, 2007. Freising/Weihenstephan [Online] Available from: http://oega.boku.ac.at/fileadmin/user_upload/Tagung/2007/07_streifeneder_hoffmann.pdf. (Last access: 20.12.2014).

Streifeneder T. 2009. Die Agrarstrukturen in den Alpen und ihre Entwicklung unter Berücksichtigung ihrer Bestimmungsgründe. Dissertation an der Ludwig-Maximilians-Universität München. München. 1-246. [Online] Available from: http://edoc.ub.uni-muenchen.de/11975/1/Streifeneder_Thomas_Ph.pdf. (Last access: 20.12.2014).

Streifeneder T, Tappeiner U, Ruffini FV, Tappeiner G, Hoffmann C. 2007b. Selected Aspects of Agro-structural Change within the Alps. Revue de géographie alpine/Journal of Alpine Research **3**, 41–52. DOI: 10.4000/rga.295.

Strijker D. 2005. Marginal lands in Europe—causes of decline. Basic and Applied Ecology **6**, 99–106. DOI: 10.1016/j.baae.2005.01.001.

Surber E. 1973. Das Brachlandproblem in der Schweiz. Eidgenössische Anstalt für das forstliche Versuchswesen. Birmensdorf. 1-138.

Sutter R. 2009. Bodenerosion im Sömmerungsgebiet Erkennen – vermeiden – beheben. Agridea. Effretikon. 1-6. [Online] Available from: http://www.boden-uri.ch/userfiles/File/Informationen/RL_Bodenerosion_im_Soemmerungsgebiet_AGRIDEA_2009.pdf. (Last access: 20.12.2014).

Swiss Confederation. 1999. Federal Constitution of the Swiss Confederation. 101. (Status as of 18 May 2014) Bern. 1-78. [Online]. Available from: http://www.admin.ch/ch/e/rs/1/101.en.pdf. (Last access: 20.12.2014).

Swiss Federal Council. 1991. Bundesgesetz über den Wald vom 4. Oktober 1991 (Stand am 1.Juli 2013). 921.0 Bern 1-18. [Online] Available from: http://www.admin.ch/opc/de/classified-compilation/19910255/index.html#. (Last access: 20.12.2014).

Swiss Federal Council. 1992. Verordnung über den Wald, (Waldverordnung). 921.01. Bern. 1-26. [Online] Available from: http://www.admin.ch/opc/de/classified-compilation/19920310/index.html. (Last access: 20.12.2014).

Swiss Federal Council. 1998. Verordnung über den landwirtschaftlichen Produktionskataster und die Ausscheidung von Zonen (Landwirtschaftliche Zonen-Verordnung). 921.1 Bern. 1-4. [Online] Available from: http://www.admin.ch/opc/de/classified-compilation/19983417/index.html. (Last access: 20.12.2014).

Swiss Federal Council. 2010. Verordnung über Pflanzenschutz (Pflanzenschutzverordnung, PSV). (Stand am 1. Januar 2013). 916.20. Bern. 1-120. [Online] Available from: http://www.admin.ch/opc/de/classified-compilation/20101847/index.html. (Last access: 20.12.2014).

Swiss Federal Council. 2013. Verordnung über die Direktzahlungen an die Landwirtschaft (Direktzahlungsverordnung, DZV). (Stand am 1. Januar 2014). 910.13. Bern. 1-108. [Online] Available from: http://www.admin.ch/opc/de/classified-compilation/20130216/index.html. (Last access: 20.12.2014).

Swiss Federal Office for Agriculture. 2009. Swiss agriculture on the move. The New Agriculture Act Ten years on [Online] Available from: http://www.blw.admin.ch/aktuell/index.html?download=NHzLpZeg7t,lnp6I0NTU042l2Z6ln1ad1IZn4Z2qZpnO2Yuq2Z6gpJCEdIJ9gGym162epYbg2c_JjKbNoKSn6A--&lang=en. (Last access: 20.12.2014).

Tappeiner U. 2003. The EU agricultural policy and the environment: Evaluation of the Alpine region. Accademia Europea di Bolzano.1-275.

Tappeiner U, Cernusca A. 1993. Alpine meadows and pastures after abandonment. Results of the Austrian MaB-programme and the EC-STEP project INTEGRALP. Pirineos **141**, 97–118.

Tasser E, Tappeiner U, Cernusca A. 2001. Südtirols Almen im Wandel: ökologische Folgen von Landnutzungsänderungen. Europäische Akademie Bozen. 1-260.

Tappeiner U, Tasser E, Leitinger G, Cernusca A, Tappeiner G. 2008. Effects of Historical and Likely Future Scenarios of Land Use on Above- and Belowground Vegetation Carbon Stocks of an Alpine Valley. Ecosystems **11**, 1383–1400. DOI: 10.1007/s10021-008-9195-3.

Tappeiner U, Tasser E, Tappeiner G. 1998. Modelling vegetation patterns using natural and anthropogenic influence factors: preliminary experience with a GIS based model applied to an Alpine area. Ecological Modelling **113**, 225–237.

Tasser E, Leitinger G, Pecher C, Tappeiner U. 2011. Agricultural changes in the European Alpine Bow and their impact on other policies. Grassland Science in Europe **16**, 27–38.

Tasser E, Mader M, Tappeiner U. 2003. Effects of land use in alpine grasslands on the probability of landslides. Basic and Applied Ecology **4**, 271–280.

Tasser E, Tappeiner U. 2002. Impact of land use changes on mountain vegetation. Applied Vegetation Science **5**, 173–184. DOI: 10.1111/j.1654-109X.2002.tb00547.x.

Theurillat JP, Guisan A. 2001. Potential impact of climate change on vegetation in the European Alps: a review. Climatic change **50**, 77–109.

Walther GR, Beissner S, Burga CA. 2005. Trends in the upward shift of alpine plants. Journal of Vegetation Science **16**, 541–548. DOI: 10.1111/j.1654-1103.2005.tb02394.x.

Walther P. 1986. Land Abandonment in the Swiss Alps: A New Understanding of a Land-Use Problem. Mountain Research and Development **6**, 305–314.

Wiedmer E, Senn-Irlet B. 2006. Biomass and primary productivity of an Alnus viridis stand – a case study from the Schächental valley, Switzerland. Botanica Helvetica **116**, 55–64. DOI: 10.1007/s00035-006-0758-7.

WSL. 2012a. Veränderung der Gebüschwaldfläche: Hoch-/Tieflagen Produktionsregion. #24185/13599. LFI3–LFI4a [Online data download] Available from: https://www.lfi.ch/resultate/anleitung.php. (Downloaded: 28.11. 2013).

WSL. 2012b. Veränderung der Gesamtwaldfläche: Hoch-/Tieflagen Biogeografische Region. #24454/13997.LFI1–LFI3 [Online data download] Available from: https://www.lfi.ch/resultate/anleitung.php. (Downloaded: 28.11. 2013).

WSL. 2012c. Veränderung der Gesamtwaldfläche: Hoch-/Tieflagen Produktionsregion. #24184/13598. LFI3–LFI4a [Online data download] Available from: https://www.lfi.ch/resultate/anleitung.php. (Downloaded: 28.11. 2013).

WSL. 2012d. Veränderung der Normalwaldfläche: Hoch-/Tieflagen, Biogeografische Region. #24432/13963.LFI1–LFI3. [Online data download] Available from: https://www.lfi.ch/resultate/anleitung.php. (Downloaded: 28.11. 2013).

Wunderli R. 2011. “Sie hat sich halt unglaublich stark entwickelt” landwirtschaftlicher Strukturwandel in den Erzählungen von Bauern und Bäuerinnen aus Ursern. Der Geschichtsfreund **164**, 131–156.

Von Wyl B. 1987. Beitrag naturnaher Nutzungsformen zur Stabilisierung von Ökosystemen im Berggebiet, insbesondere zur Verhinderung von Bodenerosion. Schweizerische landwirtschaftliche Forschung **4**, 405–464.

Zischg A, Flury C, Costa R, Huber B, Berger S. 2011. PLANAT Aktionsplan 2009-2011; Einzelprojekt B 11: Auswirkungen der landwirtschaftlichen Bewirtschaftung auf die Naturgefahren. Nationale Plattform für Naturgefahren PLANAT. BAFU. Bern. 1-154. [Online] Available from: http://www.planat.ch/fileadmin/PLANAT/planat_pdf/alle_2012/2011-2015/PLANAT_2011_-_Auswirkungen_der_landwirtschaftlichen_Bewirtschaftung.pdf. (Last access: 20.12.2014).

Acknowledgments

First of all I want to thank my supervisor Professor Dr. Nikolaus Kuhn for taking me on as his student and for the chance to go further in research. His continuous encouragement and confidence gave me the opportunity to gather research experiences even beyond my study site. Further on, I thank PD Dr. Margreth Keiler for her willingness to supervise my work. I also like to thank Prof. em. Dr. Martin Schaffner for his guidance and support. Further thanks go to the Korporation Ursern, without their collaboration, this work would not have been completed. Driving licenses and accommodation reduced walking distances significantly. Special thanks go to Alexander Renner for leaving me his hunting hut and Columban Russi for all the insights in the everyday life of the Urserntal.

I am also very grateful to my colleagues and friends on the 3rd floor for their support and friendship. In particular, thanks are given to Ruth Strunk and Marianne Caroni for teaching me the basics needed to work in a soil laboratory, Rosmarie Gisin for all her background work keeping the things running, Wolfgang Fister for the far-reaching conversations in his office, and Matthias Hunziker for his mostly imperturbable guidance through shrub and data forests that kept me continuing, we had a great time.

I also like to thank the Nikolaus und Bertha Burckhardt-Bürgin-Stiftung for providing me financial support.

On a personal level I like to thank my parents, they gave me the chance to experience and live mountain farming, simultaneously they encouraged me for whatever kept my interest. Thanks for your open mind and your open house. I am also very thankful to Fabian Itel for his patience and readiness whenever I had a “very urgent question” or a “really unsolvable problem”.

Thanks to all of you.