Publizierbarer Endbericht

gilt für Studien aus der Programmlinie Forschung

A) Projektdaten

Allgemeines zum Projekt	
Kurztitel:	CentForCSink
Langtitel:	The effects of 20th century legacies and climate change on the 21st century carbon sink of a temperate forest landscape
Zitiervorschlag:	
Programm inkl. Jahr:	7th Call Austrian Climate Research Programme – ACRP (2014)
Dauer:	01. April 2015 bis 31. Jänner 2018
KoordinatorIn/ ProjekteinreicherIn:	Mag. Kobler Johannes/Dr. Thomas Dirnböck, Umweltbundesamt GmbH
Kontaktperson Name:	Mag. Kobler Johannes
Kontaktperson Adresse:	Umweltbundesamt, Spittelauer Lände 5, 1090 Wien
Kontaktperson Telefon:	+43-(0)1-313 04/3445
Kontaktperson E-Mail:	johannes.kobler@umweltbundesamt.at
Projekt- und KooperationspartnerIn (inkl. Bundesland):	P1 Universität für Bodenkultur Wien (University of Natural Resources and Life Sciences), Wien P2 Bundesforschungs-und Ausbildungszentrum für Wald, Naturgefahren und Landschaft (Federal Research and Training Centre for Forests, Natural Hazards and Landscape), Wien P3 Alpen-Adria-Universität Klagenfurt (Institute of Social Ecology Vienna), Wien Werkvertragsnehmer: Karlsruhe Institute of Technology, Institute of Meteorology and Climate Research, Atmospheric Environmental Research (IMK-IFU), Bayern (Deutschland)
Schlagwörter:	
Projektgesamtkosten:	282.303,00 €
Fördersumme:	282.303,00 €

Allgemeines zum Projekt	
Klimafonds-Nr:	KR14AC7K11960
Erstellt am:	26.04.2018

B) Projektübersicht

1 Kurzfassung

Die Wälder der gemäßigten Breiten gelten als bedeutende Kohlenstoffsenke (d.h. positive Netto-CO_2-Aufnahme). Als solche, haben sie das Potential die heutzutage erhöhten atmosphärischen CO_2 Konzentrationen zu verringern und somit die negativen Folgen des Klimawandels (Erderwärmung) zu dämpfen. Aus diesem Grund definierten internationale Gremien, die darauf abzielen, die schädlichen Auswirkungen des Klimawandels auf die menschliche Gesellschaft abzumildern, Wälder als Kohlenstoffsenke, die in der nationalen Kohlenstoffbilanzierung berücksichtigt werden können. Die räumlichen Muster der Senkenfunktion und ihre zeitliche Dynamik werden von einer Reihe von Faktoren beeinflusst (z.B. atmosphärischen CO_2-Konzentration, N-Eintrag, klimatische und biologische Waldstörungen, menschliche Waldnutzung). Klimatische und biologische Waldstörungen gehören seit jeher zu wichtigen Treibern des Kohlenstoffkreislaufes von Wäldern. Ihr Einfluss verstärkte sich jedoch durch die menschliche Waldbewirtschaftung und seit Mitte des 20. Jahrhunderts durch den Klimawandel. Die menschliche Nachfrage nach der Ressource Holz prägte bis in die Mitte der 20. Jahrhunderts das Kohlenstoffspeicherungspotential der Wälder. Seither steigt der Einfluss des Klimawandels auf den Kohlenstoffkreislauf der Wälder.

CentForCSink untersuchte den Einfluss von historischer Waldnutzung, (vergangener und zukünftiger) natürlicher Störungsereignisse (Wind und Borkenkäfer) und des Klimawandels auf die Kohlenstoffsenke der Wälder des Nationalpark (NP) Kalkalpen OÖ im 20. und 21. Jahrhundert.

Die Hauptziele des Projekts waren 1.) die Quantifizierung der Auswirkung historischer Waldnutzung/-bewirtschaftung und natürlicher Störungsereignisse auf die heutigen und zukünftigen Kohlenstoffdynamiken der Wälder des NPs, 2.) die Quantifizierung der Auswirkungen von Klimawandel und Waldstörungen auf die klimaregulierende Funktion des Waldes im 21. Jahrhundert (auf Landschaftsniveau) und 3.) die Quantifizierung der Auswirkungen der Sukzession nach (Wald-)Störung – unter Berücksichtigung der Krautschicht und der Waldverjüngung – auf die Kohlenstoffsenke der Wälder NPs in der Periode 2000 bis 2014, die durch die Stürme (Kyrill (2007), Paula (2008) und Emma (2008)) geprägt war. CentForCSink leistet damit einen Beitrag, die Unsicherheiten der Kohlenstoffbilanzierung bewaldeter Landschaften im Allgemeinen und speziell mit dem österreichischen Kohlenstoffbudget zu verringern.

Methodisch basierte CentForCSink auf Waldökosystemmodellierung mit zwei etablierten prozessbasierten Modellen – iLand und LandscapeDNDC. Feldmessungen und die Verwendung von langzeitlichen Monitoringzeitreihen ermöglichten eine gut abgesicherte Simulation vergangener und zukünftiger Entwicklungen. Die Erhebung historischer Forstdaten ermöglichte eine detaillierte Rekonstruktion des Waldbildes zu Beginn des 20. Jahrhunderts, beziehungsweise der damaligen Waldbewirtschaftung und Störungen. Die Initialisierung der Waldvegetation zu Beginn des 20. Jahrhunderts auf Basis dieser historischen Archivdaten erfolgte mit einer neu entwickelten Spin-Up Methode. Die Modellierungen in iLand und LandscapeDNDC wurden zur besseren Vergleichbarkeit der Resultate mit denselben Eingangsdaten durchgeführt.

Die Hauptaktivitäten zur Erreichung der Projektziele waren die Simulation des Kohlenstoffkreislaufes der Wälder des NP ab 1905 auf Basis der rekonstruierten historischen Waldlandschaft bis heute und darüber hinaus bis 2099 (Ziel 1), sowie die Simulation der zukünftigen zeitlichen Verläufe der klimaregulierenden Parameter CO_2, Albedo und latenter Wärmefluss (Ziel 2). Zur besseren Quantifizierung ihres relativen Beitrags wurde dabei der Strahlungsantrieb als Zielgröße verwendet. Die Modelläufe erfolgten auf Basis von unterschiedlichen Klima(änderungs-)szenarien. Die Störungen wurden dynamisch in iLand modelliert bzw. gemäß der historischen Beobachtungen implementiert. Die Modellierung des Kohlenstoffkreislaufes im NP Kalkalpen mit LandscapeDNDC (Ziel 3) konzentrierte sich auf die Periode zwischen 2000 und 2014, die durch die Stürme Kyrill, Paula und Emma geprägt war. In Ergänzung zu den Modellierungen mit iLand wurde hier die Baumverjüngung und die Krautschicht räumlich explizit in der Modellierung berücksichtigt.

Die gesamte Kohlenstoffsenke im Wald bis 2099 wurde durch Holzentnahme und natürliche Störungen im vergangenen Jhd. positiv beeinflusst (kumulativ 43,8 tC ha^{-1}), während der Klimawandel die Kohlenstoffaufnahme reduzierte (kumulativ 24,0 tC ha^{-1}). Historisches Waldmanagement (und seine Einstellung im Zuge der Einrichtung des NPs) hatten einen wesentlich stärkeren positiven Einfluss auf die zukünftige Kohlenstoffsenke (kumulativ 40,6 tC ha^{-1}) als die natürlichen Störungsereignisse der Vergangenheit (kumulativ 3,5 tC ha^{-1}). Der Klimawandel erhöht die Störungsereignisse (vor allem Borkenkäferbefall) um +27,7% (+1.716,9 ha) in den nächsten 200 Jahren. Negative Rückkopplungen aufgrund der gleichzeitig ablaufenden Veränderung der Baumartenzusammensetzung zugunsten von Laubbaumarten (+28,0%) verringern die Störaktivität auf lange Sicht um -10,1% (-626,0 ha) vor allem aufgrund der Reduktion der für Borkenkäfer zur Verfügung stehenden Wirtsbäume. Der Klimawandel und die daraus resultierende zukünftige Walddynamik reduziert die klimaregulierende Funktion der Landschaft erheblich und erhöhen den Strahlungsantrieb der nächsten 200 Jahre um bis zu +10,2% (+1.765,2 GJ ha^{-1} a^{-1}). Insgesamt wird der Strahlungsantrieb am stärksten durch den Kohlenstoffverlust angetrieben.

Feldmessungen zeigten, dass die räumliche Variabilität der Kohlenstoffdynamik in (gestörten) Wäldern unter anderem durch die Kohlenstoffkreisläufe der Krautschicht bestimmt wird. Die Implementierung der Waldverjüngung und der Krautschicht in der LandscapeDNDC-Modellierung zeigte, dass diese beiden Kompartimente die kumulative Kohlenstoffsenke zwischen 2000 und 2014 im gesamten Gebiet (Höhenlagen >1200 m Seehöhe wurden nicht berücksichtigt) um 33% (537 ktC) erhöhten. In diesem Zeitraum verringerten Waldstörungen die Kohlenstoffsenke von ungestörten Wäldern substantiell von 1,9-3,3 tC ha^{-1} a^{-1} auf 0,8-2,8 tC ha^{-1} a^{-1}. Die positive Wirkung von Waldverjüngung und Krautschicht auf die Kohlenstoffsenke nach der Störung stieg mit dem Grad der Störung. In den erheblich gestörten Flächen betrug die Kohlenstoffsenke des Unterwuchses (Baumverjüngung und Krautschicht) 2,7 tC ha^{-1} a^{-1}, in den ungestörten Standorten nur 0,7 tC ha^{-1} a^{-1}.

2 Executive Summary

The increase of atmospheric CO_2 levels and its effect on global climate poses a huge challenge to society. As the globally wide-spread forest ecosystems act as sustained C sinks (i.e. positive net CO_2 uptake) during large parts of their life cycle, allocating most of the absorbed atmospheric CO_2 to stable (sustained) carbon (C) pools, CO_2 exchange of these ecosystems affect both the temporal trajectories of global atmospheric CO_2 levels and the global climate system. Therefore, international panels aiming to mitigate the detrimental effects of climate change to human society have identified forests as potential C sink which can be included in national carbon balance reporting. However, the C sequestration rate of forest ecosystems and thus its temporal trajectories are, have been and will be affected by numerous temporally fluctuating drivers such as atmospheric CO_2 level, N deposition, climatic and biotic disturbance agents and human forest use. Therefore, the "true" potentials of the C sink of today's forests and future trajectories of temperate forest C sink have substantial uncertainties.

CentForCSink aimed to study the effects of 20th century legacies (i.e. land use, climate and disturbances) on the current C sink of a temperate forest landscape (National Park Kalkalpen) and its future trajectories in the 21st century under a broad range of potential climate change and disturbance scenarios.

CentForCSink thus contributed to lowering the uncertainties associated with forest C budgets at the landscape scale in general, and specifically within the context of the Austrian C budget.

The main objectives of the project were 1.) to assess the contribution of past legacies (i.e. forest management, large disturbance events) on recent and future C dynamics, 2.) to investigate the climate change impacts on the future climate regulation function at the landscape/catchment scale and 3.) to quantify the effects of post-disturbance succession, considering the forest herb layer and tree regeneration, on the C sink (i.e. net ecosystem production, NEP) between 2000 and 2014 when the storms Kyrill (2007), Paula (2008) and Emma (2008) hit the area causing wind throw and subsequent bark beetle outbreaks.

Methodologically, CentForCSink relied on in-depth forest ecosystem modelling with two well established process-based models – iLand and LandscapeDNDC. Simulations were combined with spatial explicit forest C cycle-related field measurements and analysis of existing (long-term) data from LTER Zöbelboden. We acquired a detailed description of the historic state of forest vegetation, forest management and natural disturbances from forest archives of local and national forest agencies. LandscapeDNDC was used with the same model initialization, vegetation characteristics and disturbance events as in iLand to increase comparability of the results. LandscapeDNDC focused particularly on the implementation of tree regeneration and forest understory.

The future forest C sink until 2099 was driven by past disturbances (cumulative NEE of on average -43.8 tC ha^{-1}), while climate change reduced forest C uptake (cum. NEE +24.0 tC ha^{-1}). Historic management (and its cessation) (cum. decrease in NEE until 2099 of -40.6 tC ha^{-1}) had a considerably stronger positive influence on the future C balance than the natural disturbance episodes of the past (-3.5 tC ha^{-1}). Simulations without past disturbances resulted in an increase in carbon storage of 43.9 tC ha^{-1} (+11.0%) in 2013 compared to the baseline scenario (i.e., including natural and human disturbance). The effect of disturbances was strongly dominated by forest management (97.7%), with only a small influence of the two episodes of natural disturbance. Moreover, climate change increased disturbances by +27.7% (+1,716.9 ha) over the next 200 years and specifically bark beetle activity during the 21st century. However, negative feedbacks from a simultaneously changing tree species composition (+28.0% broadleaved species) decreased disturbance activity in the long run by -10.1% (-626.0 ha), mainly by reducing the host trees available for bark beetles. Climate change and the resulting future forest dynamics significantly reduced the climate regulation function of the landscape, increasing radiative forcing by up to +10.2% (+1,765.2 GJ ha^{-1} yr^{-1}) on average over the next 200 years. Overall, radiative forcing was most strongly driven by C exchange.

Field measurements showed that spatial variability in C dynamics in (disturbed) forests is inter alia driven by understory biomass and dynamics. By considering tree regeneration and understory biomass in LandscapeDNDC modelling exercises, we could show that the understory added 33% to the cumulative NEP (i.e. C sink) of 537 ktC between 2000 and 2014 in the area below 1200 m a.s.l.. The C sink was higher in undisturbed forest (1.9-3.3 tC ha^{-1} y^{-1}) than in wind and bark beetle disturbed (0.8-2.8 tC ha^{-1} y^{-1}) areas. Both, effects of tree regeneration and of the herb/grass layer on the C sink increased with disturbance severity. Tree regeneration alone had four times a C sink effect in the highly disturbed sites in the year after peak disturbance as compared to undisturbed sites. In this year, the total understory effect on the C sink was 2.7 tC ha^{-1} y^{-1} in sites with high disturbance severity while only 0.7 tC ha^{-1} y^{-1} in undisturbed sites.

We conclude that neglecting disturbance legacies can substantially bias assessments of future forest dynamics, and that future changes in forest dynamics can cause amplifying climate feedbacks from temperate forest ecosystems. Furthermore, we showed that C sink strength can only be assessed by taking the understory into account, and we found that failed tree regeneration, which is a serious issue in mountain forests of the European Alps can substantially weaken forest C sink strength, particularly after stand replacing disturbances.

3 Hintergrund und Zielsetzung

The increase of atmospheric CO_2 levels and its effect on global climate poses a huge challenge to society. As the globally wide-spread forest ecosystems act as sustained C sinks (i.e. positive net CO_2 uptake) during most time of their life cycle, allocating most of the absorbed atmospheric CO_2 to stable (sustained) C pools, CO_2 exchange of these ecosystems affect both – the temporal trajectories of global atmospheric CO_2 levels and the global climate system. Therefore, international panels aiming to mitigate the detrimental effects of climate change to human society have defined forests as C sink which can be included in national carbon balance reporting. However, the C sequestration rate of forest ecosystems and thus its temporal trajectories are, have been and will be affected by numerous temporally fluctuating drivers such as atmospheric CO_2 level, N deposition, climatic and biotic disturbance agents and human forest use. Therefore, the "true" potentials of the C sink of today's forests and future trajectories of temperate forest C sink have substantial uncertainties.

CentForCSink aimed to study the effects of 20th century legacies (i.e. land use, climate and disturbances) on the current C sink of a temperate forest landscape (National Park Kalkalpen) and its future trajectories in the 21st century under a broad range of potential climate change and disturbance scenarios.

As such, CentForCSink will contribute to the lowering of the uncertainties associated with forest C sink budgets at the landscape scale in general and specifically with the Austrian C budget.

The main objectives of the project were 1.) to assess the contribution of past legacies (i.e. forest management, large disturbance events) on recent and future C dynamics, 2.) to investigate the climate change impacts on the future climate regulation function at the landscape/catchment scale and 3.) to quantify the effects of post-disturbance succession, considering the forest herb layer and tree regeneration, on the C sink (i.e. net ecosystem production, NEP) between 2000 and 2014 when the storms Kyrill (2007), Paula (2008) and Emma (2008) hit the area causing wind throw and subsequent bark beetle outbreaks.

4 Projektinhalt und Ergebnis(se)

Aim:

CentForCSink aimed to study the effects of 20th century legacies (i.e. land use, climate and disturbances) on the current C sink of a temperate forest landscape (National Park Kalkalpen) and its future trajectories in the 21st century under a broad range of potential climate change and disturbance scenarios.

Main objectives:

The overarching objectives of the project were 1.) to assess the contribution of past legacies (i.e. forest management, large disturbance events) on recent and future C dynamics, 2.) to investigate the climate change impacts on the future climate regulation function at the landscape/catchment scale and 3.) to quantify the effects of post-disturbance succession, considering the forest herb layer and tree regeneration, on the C sink (i.e. net ecosystem production, NEP) between 2000 and 2014 when the storms Kyrill (2007), Paula (2008) and Emma (2008) hit the area causing wind throw and subsequent bark beetle outbreaks.

Main activities:

The main activities to reach the defined objectives were to use iLand to simulate the forest vegetation and associated C cycles starting from the year 1905 to its current state and beyond into the future, incorporating a number of climate (change) and disturbance scenarios. In particular, we experimentally permutated disturbances between 1905 and 2013, and analyzed the effect of these permutations on the future carbon cycle. In addition to the C exchange, we investigated the effects of climate change and disturbances on albedo and latent heat flux. To quantify the individual contribution of each service to the climate regulating function of forests, we converted them into their radiative forcing.

LandscapeDNDC simulated the forest C cycles during the mentioned high disturbance period (2000 – 2014). LandscapeDNDC focused particularly on the implementation of tree regeneration and forest understory. Model parameterization and validation was based on empirical data from LTER Zöbelboden.

To successfully and efficiently reach the defined objectives, we defined 4 tasks.

Field measurements aimed to study the C dynamics of the dominant forest ecosystems (and its disturbance-induced early succession stages) within the IM LTER site Zöbelboden. Main objective is the quantification of the dominant C pools and fluxes and its intra-annual dynamics of the ecosystems mentioned above. The main activities focused on the measurement of the temporal dynamics of major forest C pools and fluxes at selected plots within the study area. Thereupon, the field data and already existing long-term monitoring data were processed to calculate detailed forest C budgets (e.g. soil and plant C pools, net primary production (NPP), soil C efflux (SR), net ecosystem production (NEP)) of these plots.

The recent and future forest C sink at the catchment scale aimed to study the effects of a.) recent (wind- and bark beetle-) disturbance events and b.) forthcoming climate change and disturbance scenarios on the temporal trajectories of the carbon sink of the forests of the IM LTER site Zöbelboden. Main objectives and activities are described in chapters Main objectives (Objective 3) and Main activities.

Historical land use and disturbance regimes at the landscape scale aimed to study the effects of forest management and disturbance events on the forests of the National Park during the 20th century. Main objective was the quantitative characterisation of the National Park forests at stand level at 3-4 time slices (1900, 1930, 1960) and continuous empirical data of forest management within these time slices. Main activities were the provision of historical forest data from national and local forest archives for temporal upscaling during iLand modelling and the determination of spatio-temporal patterns of land use and disturbances at the landscape level.

The past and future forest C sink at the landscape scale aimed to study the effects of historic (i.e. 20th century) disturbance events and (disturbance–induced and planned) forest management and forthcoming climate change and disturbance scenarios on the trajectories at the IM LTER site Zöbelboden. Main objectives and activities are described in chapters Main objectives (Objective 1 and 2) and Main activities.

Results:

Objective 1: Assess the contribution of past legacies (i.e. forest management, large disturbance events) on recent and future C dynamics

The effect of past disturbance and future climate on 21st century carbon sequestration

Our simulations reveal a strong impact of past disturbances on the current state of total ecosystem carbon (Fig. 1). Simulations without disturbances resulted in an increase in carbon storage of 43.9 tC ha^{-1} (+11.0%) in 2013 compared to the baseline scenario (i.e., including natural and human disturbance). The effect of disturbances was strongly dominated by forest management (97.7%), with only a small influence of the two episodes of natural disturbance. Past disturbances also resulted in a considerable carbon uptake beyond 2013 (Fig. 1), inter alia, as a result of a persistent recovery of growing stock. Past forest management had a strong and continuous positive legacy effect on the future cumulative carbon uptake of the landscape (cumulative decrease in NEE until 2099 of -40.6 tC ha^{-1}, $p<0.001$). The second disturbance episode caused a release of carbon (positive NEE) over the first years of future simulations, followed by a reversal of the trend towards a negative NEE effect. Its overall impact on cumulative NEE at the end of the simulation period was -3.5 tC ha^{-1} ($p=0.191$), i.e. over the 21st century the recent disturbance period had an overall positive effect on forest C sequestration. The first disturbance episode had almost no effect on the future carbon dynamics (NEE effect of -0.2 tC ha^{-1}, $p=0.792$). Simulations of the total legacy effect of past disturbances (both natural and human) resulted in a cumulative NEE of on average -43.8 tC ha^{-1} ($p<0.001$) until 2099, indicating the recovery of forest ecosystems from past disturbance. Climate change weakened the carbon sink strength on the landscape, mainly as a result of climate-mediated differences in successional trajectories of forest ecosystems. On average, climate change increased the cumulative NEE until 2099 by +24.0 tC ha^{-1} ($p<0.001$), and thus reduced the carbon uptake of the landscape relative to a continuation of historic climate (Fig. 1).

Objective 2: Investigate the climate change impacts on the future climate regulation function at the landscape/catchment scale

Changing provisioning of climate regulation services

Climate change impacts on forest dynamics have an amplifying effect on climate change, as indicated by an increase in radiative forcing by between +1,564.4 GJ ha^{-1} yr^{-1} (disturbed+) and +1,765.2 GJ ha^{-1} yr^{-1} (undisturbed) on average over the simulation period compared to baseline climate (Fig. 2). The relative increase in radiative forcing as a result of climate change varied between +9.4% (disturbed+) and +10.2% (disturbed). Similarly, disturbances reduced the cooling effect of forests and increased radiative forcing by + 847.3 GJ ha^{-1} yr^{-1} (disturbed) and +1,446.2 GJ ha^{-1} yr^{-1} (disturbed+) under baseline climate (+4.9% and +8.7%, respectively), as well as by +842.9 GJ ha^{-1} yr^{-1} (disturbed) and +1,245.4 GJ ha^{-1} yr^{-1} (disturbed+) under climate change (+5.4% and +8.2%, respectively).

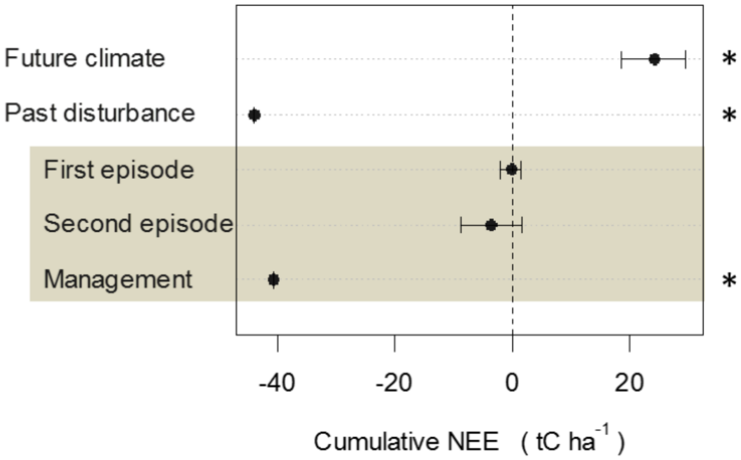

Figure 1: Effects of future climate and past disturbance on the cumulative NEE of the period 2014 – 2099. Effect sizes are calculated from a comparison between climate change and historic climate (both without disturbance) as well as disturbed and undisturbed scenarios (both under historic climate conditions), respectively. Whiskers give the 95% confidence interval around the effect size, and asterisks indicate significant indicators (α=0.05). In addition to the overall effect of past disturbance, they were subdivided into the effect of the first and second episodes of natural disturbance as well as human-induced disturbance via management (shaded box).

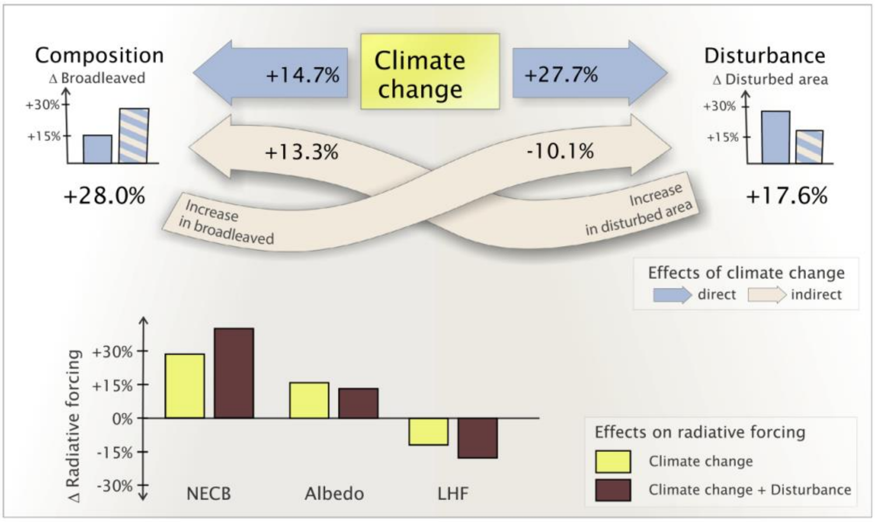

Figure 2: Climate change impacts on forest dynamics and climate regulating functions at KANP. Presented are direct impacts of climate change (blue arrows and bars), and indirect effects of climate change (grey arrows) via feedbacks between tree species composition and disturbances (upper panel). Banded blue and grey bars give the net total effect of direct and indirect climate change effects. Note that changes in tree species composition refer to percentage points while changes in disturbances indicate relative differences. Climate change (yellow) and climate change + disturbance (brown) induced impacts on radiative forcing from changing NECB, albedo, and latent heat flux (LHF) are presented in the lower panel of the figure. All values are averages over all climate change scenarios studied, reported relative to baseline climate. Values from changes in composition, disturbances and NECB pertain to the cumulative effect after 200 years of simulation, while changes in the radiative forcing from albedo and latent heat flux refer to the average over the last 20 years of the simulation in order to account for yearly variation.

While changes in carbon stocks and albedo increased mean radiative forcing as a result of climate change (+1,441.1 GJ ha^{-1} yr^{-1} and +725.1 GJ ha^{-1} yr^{-1}, respectively), latent heat flux reduced radiative forcing under climate change (–469.5 GJ ha^{-1} yr^{-1}), and thus compensated 21.7% of the changes in carbon and albedo (Fig. 2). Disturbances decreased the radiative forcing from both albedo and latent heat flux (–138.1 GJ ha^{-1} yr^{-1} and –189.9 GJ ha^{-1} yr^{-1}), but increased radiative forcing from NECB (+1,397.9 GJ ha^{-1} yr^{-1}). Consequently, disturbance-induced changes in albedo and latent heat flux compensated 23.5% of the radiative forcing effects of NECB losses.

Objective 3: Quantifying the effects of post-disturbance succession, considering the forest herb layer and tree regeneration, on the C sink (i.e. net ecosystem production, NEP) between 2000 and 2014 when the storms Kyrill (2007) and Paula (2008) hit the area causing wind throw and subsequent bark beetle outbreaks.

Total NEP in the study area between 2000 and 2014 was positive summing up to 537 – 716 kt C in the different scenarios, i.e. the annual C sink was 36 – 48 kt C. Calculated at a per hectare rate, this was on average between 36.5±25.1 to 48.7±20.7 t C ha^{-1}, maximal NEP reached between 109.4 to 116.9 t C ha^{-1} (Fig. 3a and b). In the NN and R scenario cumulative NEP was negative in a small part of the area (Fig. 3a), with minimal values of -6.9 and -3.5 t C ha^{-1} respectively. Total cumulative NEP from 2000 to 2014 was highest in the HR scenario and lowest in the NN scenario. The difference was 179 kt C, hence we estimated 33% higher NEP by taking tree regeneration and the herb layer into account. This total understory effect on NEP was 12.2±12.8 t C ha^{-1} on average and was negative in 19% of the study area (Fig. 3c). Second highest NEP was found with the R scenario, here the difference in NEP to the NN scenario was 122 kt C (23% higher NEP) followed by the H scenario with a NEP difference of 51 kt C (10% higher NEP).
Mean annual GPP, NPP, TER, heterotrophic C respiration, and increments in SOC per modelled grid cell (1 ha) increased in the following order: NN<R<H<HR scenario except for mean annual NEP, where the H scenario was smaller than the R scenario (Fig. 4).

Disturbed versus undisturbed areas

We differentiated undisturbed, low, medium, and highly disturbed areas by wind, snow, and bark beetle by setting thresholds to between the highest 5% and 1% (=low, 4.2% of the study area), 1% and 0.1% (medium, 0.9% of the study area) and the highest 0.1% (high, 0.1% of the study area) stem wood damages respectively between 2005 and 2015. These disturbance thresholds of stem wood damages were > 47.3 m³ ha-1, > 210.8, and > 392.7 m³ ha^{-1}, respectively. Stem wood disturbance was zero in undisturbed areas. Disturbances started in the year 2005, increased till 2010, and decreased towards zero in the following years. NEP diverged between undisturbed and disturbed sites with higher NEP in undisturbed sites (1.86-3.28 tC $ha^{-1}y^{-1}$) than in disturbed (0.82-2.78 tC $ha^{-1}y^{-1}$) areas. These differences were highest in the year 2011 with three times the NEP in the sites with high disturbance severity compared to undisturbed sites. Beginning with the year 2008, disturbance severity clearly lowered NEP among disturbed sites (Fig. 5a).

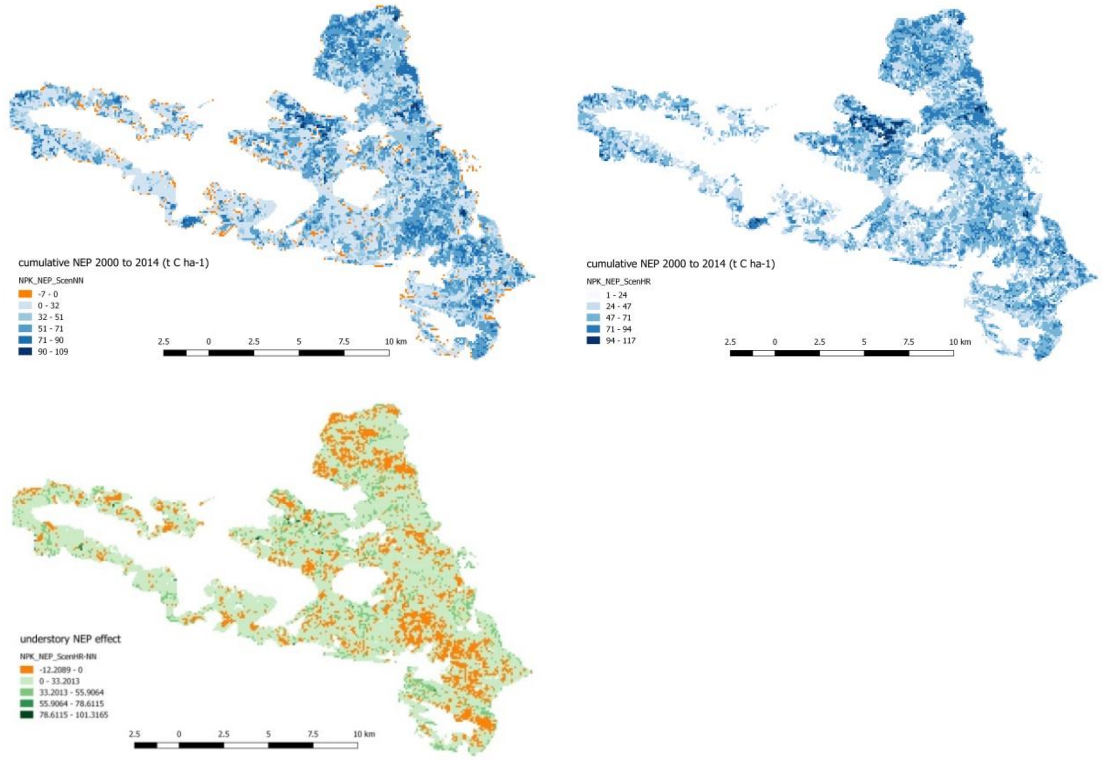

Figure 3. Cumulative net ecosystem production (NEP) from 2000 to 2014 in the NN scenario (a: upper left, no herb, no regeneration), the HR scenario (b: upper right, herb+regeneration) and effect of understory on NEP (c) as the difference between the HR (herb + regeneration) and the NN scenario (no herb, no regeneration). Negative values indicate net C sources and negative effects of HR on NEP respectively.

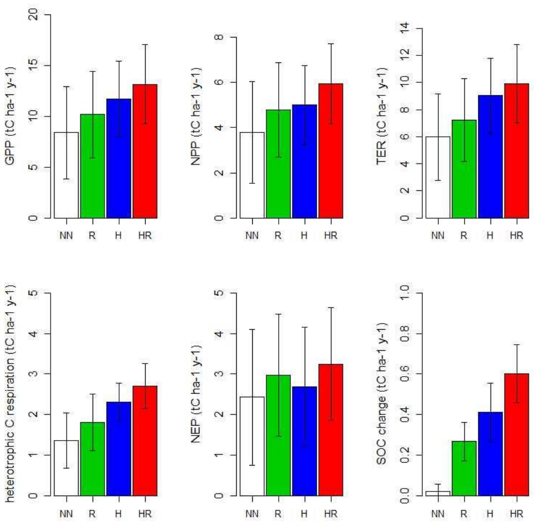

Figure 4. Mean and standard deviation of annual GPP, NPP, TER, heterotrophic soil C respiration, NEP, and changes in SOC in the four scenarios. NN – No herb layer or tree regeneration, R - No herb layer but tree regeneration, H - Herb layer but no tree regeneration, HR- Herb layer and tree regeneration.

Tree regeneration caused a 0.16-1.90 tC $ha^{-1}y^{-1}$ higher NEP in all model scenarios in all years but in the year 2009 (sites with high disturbance severity) and 2012 (undisturbed sites) (Fig. 5b). From 2010 onwards, the effect of tree regeneration on NEP was higher in disturbed sites than in undisturbed and higher with increasing disturbance severity. The maximal effect of tree regeneration occurred in the year 2011 with four times a NEP effect in the highly disturbed sites as compared to undisturbed sites (Fig. 5b).

The herb/grass layer affected higher NEP in all but four years between 2005 and 2014 and was smaller than the effect of tree regeneration (Fig. 5c). Similarly with tree regeneration, the effect of the herb/grass layer was higher in disturbed sites than in undisturbed, higher with increasing disturbance severity and maximal effects in the year 2011. In this year, the effect on NEP was 1.57 tC $ha^{-1}y^{-1}$ in sites with high disturbance severity while zero in undisturbed sites (Fig. 5c).Taking effects of tree regeneration and herb/grass development together (difference between the HR and the NN scenario) NEP is positively affected in all years, particularly in disturbed sites (Fig. 5d). There, disturbance severity clearly increased the effect of the understory on NEP from the year 2008 onwards. In the year 2011, the effect on NEP was 2.66 tC $ha^{-1}y^{-1}$ in sites with high disturbance severity while only 0.66 tC $ha^{-1}y^{-1}$ in undisturbed sites.

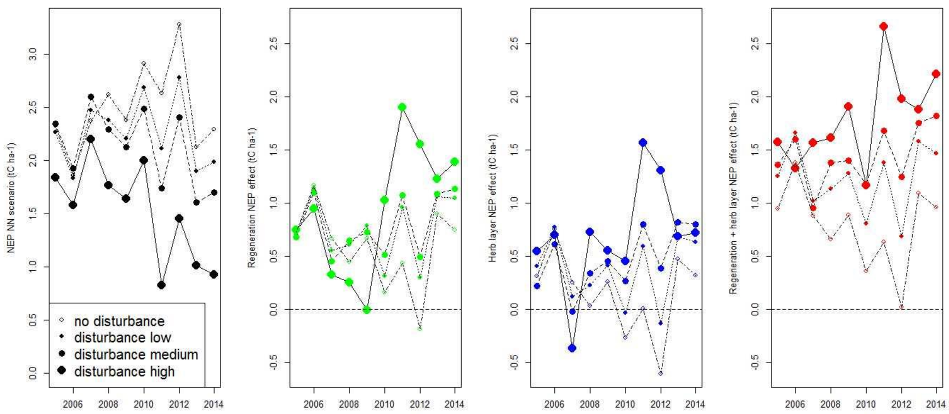

Figure 5. Annual mean NEP in the NN scenario and annual mean effects on NEP of the tree regeneration (b, scenario R – scenario NN), the forest herb layer (c, scenario H – scenario NN) and both (d, scenario HR – scenario NN) differentiated in undisturbed sites and three disturbance severity classes: low (from the highest 5% to the highest 1% stem wood damages), medium(from the highest 1% to the highest 0.1% stem wood damages), and high (0.1% highest stem wood damages) between 2005 and 2015.

Future projections

Climate scenario development and impact assessment has been carried out using iLand. Since LandscapeDNDC was also set up for the entire National Park area, a joint analysis using both models with a broader scope on ecosystem services (radiative forcing including N_2O, CH_4, Nitrate leaching, etc.) is in preparation. Currently regional simulations until 2100 are processed with LandscapeDNDC.

5 Schlussfolgerungen und Empfehlungen

The future forest C sink until 2099 was driven by past disturbances (cumulative NEE of on average -43.8 tC ha^{-1}), while climate change reduced forest C uptake (cum. NEE +24.0 tC ha^{-1}). Historic management (and its cessation) (cum. decrease in NEE until 2099 of -40.6 tC ha^{-1}) had a considerably stronger positive influence on the future C balance than the natural disturbance episodes of the past (-3.5 tC ha^{-1}). Simulations without past disturbances resulted in an increase in carbon storage of 43.9 tC ha^{-1} (+11.0%) in 2013 compared to the baseline scenario (i.e., including natural and human disturbance). The effect of disturbances was strongly dominated by forest management (97.7%), with only a small influence of the two episodes of natural disturbance. Moreover, climate change increased disturbances by +27.7% (+1,716.9 ha) over the next 200 years and specifically bark beetle activity during the 21st century. However, negative feedbacks from a simultaneously changing tree species composition (+28.0% broadleaved species) decreased disturbance activity in the long run by -10.1% (-626.0 ha), mainly by reducing the host trees available for bark beetles. Climate change and the resulting future forest dynamics significantly reduced the climate regulation function of the landscape, increasing radiative forcing by up to +10.2% (+1,765.2 GJ ha^{-1} yr^{-1}) on average over the next 200 years. Overall, radiative forcing was most strongly driven by C exchange.

Field measurements showed that spatial variability in C dynamics in (disturbed) forests is inter alia driven by understory biomass and dynamics. By considering tree regeneration and understory biomass in LandscapeDNDC modelling exercises, we could show that the understory added 33% to the cumulative NEP (i.e. C sink) of 537 ktC between 2000 and 2014 in the area below 1200 m a.s.l.. The C sink was higher in undisturbed forest (1.9-3.3 tC ha^{-1} y^{-1}) than in wind and bark beetle disturbed (0.8-2.8 tC ha^{-1} y^{-1}) areas. Both, effects of tree regeneration and of the herb/grass layer on the C sink increased with disturbance severity. Tree regeneration alone had four times a C sink effect in the highly disturbed sites in the year after peak disturbance as compared to undisturbed sites. In this year, the total understory effect on the C sink was 2.7 tC ha^{-1} y^{-1} in sites with high disturbance severity while only 0.7 tC ha^{-1} y^{-1} in undisturbed sites.

We conclude that neglecting disturbance legacies can substantially bias assessments of future forest dynamics, and that future changes in forest dynamics can cause amplifying climate feedbacks from temperate forest ecosystems. Furthermore, we showed that C sink strength can only be assessed by taking the understory into account, and we found that failed tree regeneration, which is a serious issue in mountain forests of the European Alps, can substantially weaken forest C sink strength, particularly after stand replacing disturbances.

CentForCSink substantially contributed to lowering the uncertainties associated with recent forest C budgets at the landscape scale and their future temporal dynamics during the 21st century. Moreover, the results presented here have important implications for improving the Austrian C budget. Particular highlights of the project are the (spatial explicit) consideration of forest disturbance, tree regeneration and understory biomass and its effects on the forest C sink. Moreover, we studied the climate regulation function of forests more comprehensively than previous analyses, by jointly considering the effects of C exchange, albedo and latent heat flux on the radiative forcing exerted from the forest landscape under study.

C) Projektdetails

6 Methodik

The past and future forest C sink at the landscape scale (iLand)

We simulated the contribution of past forest disturbances (natural and anthropogenic) and climate change on the recent and future forest carbon dynamics of the landscape. In addition, we set up a simulation experiment to disentangle the future climate change and disturbance effects on the total climate regulating function (including carbon storage, albedo and latent heat flux) of forests.

Study area

To assess the contribution and effect of past forest disturbances on recent and future C dynamics (objective 1), we selected the part of Kalkalpen National Park (KANP) with the highest data availability, resulting in an area of 7,609 ha. To investigate the climate change impacts on the future climate regulation function (objective 2), we started simulations from the net forest area of KANP (13,865 ha) at its current state (year 2013).

Simulation model

iLand is a high-resolution process-based forest model, designed to simulate the dynamic feedbacks between vegetation, climate and disturbance regimes (Seidl et al., 2012a, 2012b). It simulates processes in a hierarchical multi-scale framework, i.e., considering processes at the individual tree (e.g., growth, mortality as well as competition for light, water, and nutrients), stand (e.g., water and nutrient availability), and landscape (e.g., seed dispersal, disturbances) scale as well as their cross-scale interactions.

Reconstructing forest vegetation, management and disturbance history

We reconstructed the state of forest vegetation at the beginning of the 20th century as well as the forest management activities and disturbance history based on historical data from archives. The study area has a long history of intensive timber harvesting for charcoal production. The oldest historic vegetation data available for the landscape were from an inventory conducted between the years 1898 and 1911; we subsequently used the year 1905 (representing the area-weighted mean year of inventory) as the starting point for our analyses. The historic vegetation data available from archival sources included information on growing stock and age classes for 11 tree species for the entire landscape, recorded at the level of 2,079 stand polygons.

In addition to deriving the state of the forest in 1905, we reconstructed management activities (thinnings, final harvests, artificial regeneration) and natural disturbances (wind and bark beetles) until 2013 (Fig. 6).

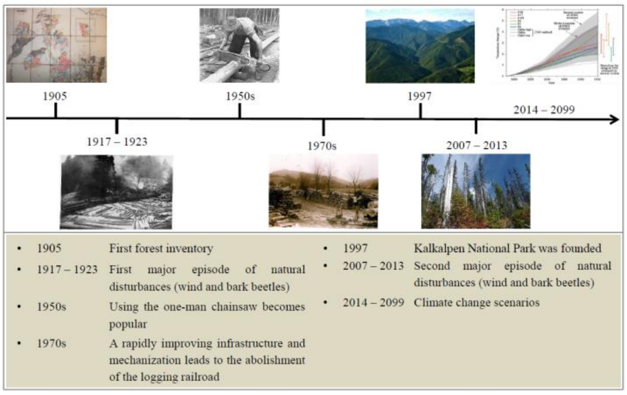

Figure 6: Timeline of important historic events of relevance for the simulation of the study landscape.

From 1905 to 1917 timber extraction was fairly low. Between 1917 and 1923, however, a major disturbance episode by wind and bark beetles hit the region. Due to a lack of laborers in the last year of World War I a major windthrow in 1917 could not be cleared, and the resulting bark beetle outbreak affected large parts of the landscape. Overall, wind and bark beetles disturbed approximately one million cubic meters of timber in the region of our study area between 1917 and 1923 (Soyka, 1936; Weichenberger, 1994). After 1923, forest management resumed at low intensity and no major disturbances were recorded. Following World War II, a network of forest roads was built in order to gradually replace transportation by railroads. The introduction of motorized chain saws further contributed to an intensification of harvests. By 1971, forest railroads were completely replaced by motorized transportation on forest roads, resulting in a further increase in the timber extracted from the landscape. With the landscape becoming part of KANP forest management ceased in 1997. A second major episode of natural disturbances affected the landscape from 2007-2013, when a large bark beetle outbreak followed three storm events in 2007 and 2008. This second disturbance episode was reconstructed from disturbance records of KANP in combination with remote sensing data (Seidl and Rammer, 2016; Thom et al., 2017).

Landscape initialization and drivers

On average over the landscape, the growing stock was 212.3 $m^3\ ha^{-1}$ in 1905. The most common species were Norway spruce (with a growing stock of on average 116.3 $m^3\ ha^{-1}$), European beech (68.0 $m^3\ ha^{-1}$), and European larch (Larix decidua [Mill.], 21.5 $m^3\ ha^{-1}$). With an average growing stock of 4.2 $m^3\ ha^{-1}$ silver fir was considerably underrepresented on the landscape relative to the potential natural vegetation composition. Despite these detailed data on past vegetation not all information for initializing iLand were available from archival sources, e.g., diameters at breast height (dbh) and height of individual trees, as well as tree positions, regeneration and belowground carbon-pools had to be reconstructed by other means. To that end we developed a new method for initializing vegetation in iLand, combining spin-up simulations with empirical reference data on vegetation state, henceforth referred to as legacy spin-up. Simulations were run from 1905 until 2099, considering four different climate scenarios for the period 2013 – 2099. Climate change was represented by three combinations of global circulation models (GCM) and regional climate models (RCM) under A1B forcing, including CNRM-RM4.5 driven by the GCM ARPEGE, and MPI-REMO, as well as ICTP-RegCM3, both driven by the GCM ECHAM5.To evaluate the impact of past disturbances and future climate on the 21st century carbon sink strength, we ran simulations under a combination of different disturbance histories and climate futures. Specifically, we experimentally permutated disturbances between 1905 and 2013, and analyzed the effect of these permutations by continuing the simulations until the end of the 21st century. After 2013 four different climate scenarios were simulated for all alternative disturbance histories.

To assess the climate change impacts on the future climate regulation function we performed another simulation series, all starting from the year 2013 and simulating 200 years. We simulated three different disturbance scenarios under each climate scenario, i.e., a control scenario without disturbances (undisturbed), a scenario simulating wind and bark beetle disturbances dynamically under historic wind conditions as described above (disturbed), and an alternative disturbance scenario simulating wind and beetle dynamics assuming an increase in wind speeds by 10% in the future (disturbed+).

Radiative forcing

Forests play an important role in the regulation of the world's climate not only by storing and releasing large amounts of carbon, but also via biophysical processes that alter the energy balance of the earths' surface. Despite their very different physical foundations, the three climate regulating functions considered here can be converted to a common currency, referred to as radiative forcing (RF). RF describes a change in the planetary energy budget, i.e., the difference between the incoming insolation absorbed by the earth's surface and the outgoing energy reflected back to space (Hansen et al., 1997). The convention used here is that positive values of RF describe a net positive energy balance at the surface of the earth resulting in a warming effect, while negative values refer to a cooling effect. We analyzed the climate regulating function of the forests at KANP by quantifying the effect of changes in carbon stocks, surface albedo, and latent heat flux on radiative forcing.

The recent and future forest C sink at the catchment scale (Landscape DNDC)

The study area was the entire forested National Park area below 1200 m a.s.l. (160 km²), i.e. we restricted our analysis to montane mixed conifer-deciduous forests which are comparable to those observed and studied in LTER Zöbelboden.

Simulation design and model setup

The investigated time period spans 15 years from 2000 to 2014 including disturbance events due to the storms Kyrill, Paula and Emma, which hit Europe in the years 2007 and 2008. In order to explore the effect of ground vegetation and tree regeneration on ecosystem carbon fluxes, a total of four scenarios have been simulated distinguishing different assumptions regarding understory constitution (see Tab. 1).

Table 1. Four model scenarios including or excluding herb layer and tree regeneration

	herb layer	**tree regeneration**
HR	yes	yes
H	yes	-
R	-	yes
NN	-	-

All simulations have been carried out using the LandscapeDNDC simulation framework for terrestrial ecosystem models. LandscapeDNDC represents the vertical structure of lateral homogenous ecosystem including the soil and canopy domain. Areal representation of heterogeneous landscapes is accomplished by addition of individual grid cells. For this study, the horizontal spatial heterogeneity was described by a sparse 100x100m raster for the complete 160 km² study region. The vertical discretization of the canopy was described dynamically depending on vegetation height at a given point of time. The number of canopy layers was bound between 2 and 40. For a vegetation height h <= 20m, the vertical resolution was set invariant to 0.5m. For h > 20m, canopy layers were equally enhanced in order to satisfy total vegetation height. The vertical soil resolution varied between 2 cm (top soil layers) and 5 cm (lower soil layers). The temporal resolution of the simulation was set to one hour.

Vegetation: PSIM, the growth module, represents the vegetation in form of a single or limited number of individual homogenous cohorts, in the following named vegetation units. Depending on the specific grid cell and simulation scenario the maximum number of vegetation units in this study is bound by six.

Understory: While number of individuals, which is given as model input, and dynamically calculated crown dimension determine the area coverage of trees, there is no process-based calculation of herb layer coverage. For this study, we included an empirical function that determines area coverage of herbs depending on the overstory tree coverage. Apart from the area of herb coverage, initial biomass and vegetation height was taken from empirical data.

Disturbance: Since LandscapeDNDC does not include dynamic calculation of forest disturbances, all disturbances have been derived with iLand prior to the simulation and incorporated in form of time-specific disturbance events. Three different disturbance types are distinguished, i.e., wind throw, bark beetle and snow break. For wind throw events, vegetation units are affected descending with tree height. Bark beetle attacks as well as snow break preferably affects coniferous vegetation units. For snow break, vegetation units are also affected descending with tree height. Additional model drivers for the chosen setup include daily information of weather, nitrogen composition and one-time initial information of the soil and vegetation domain.

Climate: We used simulated climate data from the GCM/RCM combination ECHAM5 and REMO in the analysis. Climate was bias-corrected against observational data from the Austrian Central Meteorological Service ZAMG using quantile mapping. The bias-corrected RCM output (available at 1km horizontal resolution) was further downscaled statistically to 100m grid cells using daily lapse rates. This approach accounts for varying lapse rates depending on the condition of the atmosphere, and is thus able to capture e.g., temperature inversion due to cold air pooling. Note that this climate data represents the typical weather variation in the study area but does not reflect the actual weather from 2000 to 2014.

Soil initialization: LandscapeDNDC requires depth-specific initial information of major soil properties, i.e., organic carbon and nitrogen content, bulk density, pH-value, texture and soil hydrologic parameters. Since respective information is not available for the complete study region, soil identifications that have been conducted in former studies are spatially assigned depending on area-wide (spatially explicit) information of elevation, soil type, soil depth, slope and aspect, which have been available from other studies.

Vegetation initialization: The initialization of the vegetation was based on (Thom et al. 2017) who compiled an area-wide inventory of vegetation structure from forest planning data, aerial photo analysis and LiDAR with a spatial resolution of 10x10m valid for the year 1999. The inventory contains tree type- and age class-specific stand information, i.e., number of trees, diameter at breast height and height-diameter ratio. Respective information has been aggregated to the 100x100m simulation resolution and simplified regarding stand heterogeneity. Excluding understory, the number different tree species as well as the number of age classes for one tree species have been both limited by two resulting in a maximum of four simulated vegetation units. Depending on the scenario, two extra vegetation units, i.e., herbs and tree regeneration have been included.

Tree disturbances: The data product used in iLand modelling is given in form of a 10x10m raster, which contains a yearly and spatially explicit specification of disturbed tree volume [m^3] and disturbance types, i.e., windfall, bark beetle attack and snow disturbance. The 10x10m raster has been additively aggregated to the simulation resolution of 100x100m. For simplification, yearly disturbance events have been assigned to single fixed days of year, i.e., 15th January for snow disturbance, 1th September for windfall and 15th September for bark beetle attack.

Hansen, J., Sato, M., Ruedy, R., 1997. Radiative forcing and climate response. J. Geophys. Res. 102, 6831–6864.

Seidl, R., Rammer, W., 2016. Climate change amplifies the interactions between wind and bark beetle disturbances in forest landscapes. Landsc. Ecol. in press, doi:10.1007/s10980-016-0396-4. https://doi.org/10.1007/s10980-016-0396-4

Seidl, R., Rammer, W., Scheller, R.M., Spies, T.A., 2012a. An individual-based process model to simulate landscape-scale forest ecosystem dynamics. Ecol. Modell. 231, 87–100. https://doi.org/10.1016/j.ecolmodel.2012.02.015

Seidl, R., Spies, T.A., Rammer, W., Steel, E.A., Pabst, R.J., Olsen, K., 2012b. Multi-scale drivers of spatial variation in old-growth forest carbon density disentangled with Lidar and an individual-based landscape model. Ecosystems 15, 1321–1335. https://doi.org/10.1007/s10021-012-9587-2

Soyka, W., 1936. Die Borkenkäferverheerungen in Reichraming und ihre Bekämpfung. Allg. Forst- und Jagdzeitung 54, 155–156.

Thom, D., Rammer, W., Dirnböck, T., Müller, J., Kobler, J., Katzensteiner, K., Helm, N., Seidl, R., 2017. The impacts of climate change and disturbance on spatio-temporal trajectories of biodiversity in a temperate forest landscape. J. Appl. Ecol. 54, 28–38. https://doi.org/10.1111/1365-2664.12644

Weichenberger, J., 1994. Die Holztrift im Nationalpark Kalkalpen Teil 1: Bestandsaufnahme, Jahresberichte. Leonstein.

7 Arbeits- und Zeitplan

WP / Months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
1. Field measurements																																		
1.1. Definition of field design																																		
1.2. Installation of infrastructur within the defined strata																																		
1.3. Field measurements																																		
2. The recent and future forest C sink at the catchment scale																																		
2.1. Calculation of the C sink of the defined strata																																		
2.2. Analysis of long-term tree increment data																																		
2.3. Preparation of driver data and model initialization																																		
2.4. Evaluation of the L-DNDC models																																		
2.5. Simulation of the effects of recent wind disturbances on the C sink of the catchment																																		
2.6. Simulation of future C trajectories under scenarios of climate change																																		
2.7. Simulation of future C trajectories under climate change, disturbance and iLand outputs																																		
2.8. Analysis of iLand and L-DNDC outputs																																		
3. Historical land use and disturbance regimes at the landscape scale																																		
3.1. Interview Transcription																																		
3.2. Archive research																																		
3.3. Database design and generation																																		
3.4. Statistically based analysis of historical land use and disturbance																																		
4. The past and future forest C sink at the landscape scale																																		
4.1. Preparation of driver data and model initialization																																		
4.2. Evaluation of the iLand model at different scales																																		
4.3 Simulation of the C trajectory for the past century																																		
4.4 Simulation of future C trajectories under scenarios of climate change																																		
4.5 Attributing future C changes to past management and future climate																																		
4.6. Analysis of iLand and L-DNDC outputs																																		
5. Synthesis, publication, dissemination																																		
4.1. preparation and submission of papers																																		
4.2. presentations at conferences and workshops																																		
6. Project management																																		
5.1. Project meetings, reports																																		
	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1

8 Publikationen und Disseminierungsaktivitäten

Title	Authors	Journal	Journal Impact Factor	Status
The impact of future forest dynamics on climate: Interactive effects of changing vegetation and disturbance regimes	Thom, Dominik, Rammer, Werner, Seidl, Rupert	Ecological Monographs	8.759	https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1002/ecm.1272
Disturbance legacies have a stronger effect on future carbon exchange than climate in a temperate forest landscape	Thom, Dominik, Rammer, Werner, Garstenauer, Rita, Seidl, Rupert	Biogeosciences (in review)	3.851	https://www.biogeosciences-discuss.net/bg-2018-145/
Long-Term Socio-Ecological Research in Practice: Lessons from Inter- and Transdisciplinary Research in the Austrian Eisenwurzen	Garstenauer, Rita, Gaube, Veronika Haberl, Helmut Kainz, Martin, Kreiner, Daniel, Mayer, Renate, Mirtl, Michael, Sass, Oliver, Schauppenlehner, Thomas, Stocker-Kiss, Andrea, Wildenberg, Martin	Sustainability	1.789	http://www.mdpi.com/2071-1050/8/8/743
Effects of slope aspect and altitude on carbon cycling processes in a temperate mountain forest catchment	Kobler, Johannes, Zehetgruber, Bernhard, Dirnböck, Thomas, Jandl, Robert, Mirtl, Michael, Schindlbacher, Andreas	-	-	In preparation (to be submitted until June 2018)
Significant understory effects on carbon sequestration in European mountain forests	Dirnböck, Thomas, Kraus, David, Grote, Rüdiger, Kiese, Ralf, Klatt, Steffen, Kobler, Johannes, Schindlbacher, Andreas, Seidl, Rupert, Thom, Dominik,	-	-	In preparation (to be submitted until July 2018)

Other publications				
Title	**Authors**	**Journal**	**Journal Impact Factor**	**Status**
CentForCSink - Die Entwicklung der Kohlenstoffsenke im Nationalpark Kalkalpen	Dirnböck, Thomas	BOKU – Das Magazin der Universität Wien (Magazin 4, 2015)		https://www.boku.ac.at/fileadmin/data/H01000/H10090/H10400/H10420/BOKU_Magazin/2015/BOKU_Magazin_4_15_web.pdf
Der Einfluss von Sturm- und Borkenkäferschäden auf die Kohlenstoffbilanz von Wäldern der Nördlichen Kalkalpen	Dirnböck, Thomas	Im Gseis, Das Nationalpark Gesäuse Magazin		https://www.nationalpark.co.at/phocadownload/magazin/Im_Gseis_28.pdf

Conferences and Workshops where CentForCSink has been presented		
When	**Where**	**What**
6.4.-8.4.2015	Task Force Meeting of the International Cooperation Program Integrated Monitoring - Minsk	Disturbance effects on forest carbon cycle
15.06.2015	69. Minisymposium - ZUG — Centre for Environmental History — IFF, Schottenfeldgasse 29/6, 1070 Vienna, Austria	Historische Nutzungs- und Störungsregime im Reichraminger Hintergebirge, ca. 1880 – 2015
02.12.2015	Seminar series at Cary Institute, Millbrook, NYS, US	Long-term climate and nitrogen effects in Austrian and European forest ecosystems
28.03.2016	Biogeoscience Seminar, Boston University, MA, US	Disturbance impacts on European temperate forest ecosystems
06.10.2016	Science VHS Wien	Österreichs Wald im Klimawandel: Klimaopfer oder Klimaretter?
24.4.-28.4.2017	EGU Vienna (BG2.16/CL5.24/SSS9.40 - Response of terrestrial ecosystems to climate change: Learning from experimental manipulations and natural gradients) - Vienna	Effects of slope aspect and site elevation on seasonal soil carbon dynamics in a forest catchment in the Austrian Limestone Alps
26.4.-29.4.2017	2nd International Conference on Forests, Neuschönau, Germany	Disturbances mitigate climate change effects on biodiversity
2.5.-3.5.2017	LTER-Austria Jahreskonferenz 2017 in der Biologischen Station Neusiedler See - Neusiedl	Effects of slope aspect and site elevation on seasonal soil carbon dynamics in a forest catchment in

		the Austrian Limestone Alps
23.-24.5.2017	Klimatag Session C2 Boden - Vienna	CentForCSink - Effekte von Waldnutzung, Waldstörung und Klimawandel auf die Kohlenstoffsenke einer Waldlandschaft der Nördlichen Kalkalpen
23.-24.5.2017	Klimatag Session A2 Wald - Vienna	Dynamische Änderungen der klimaregulierenden Funktion der Wälder des Nationalparks Kalkalpen im Klimawandel
1.6.-2.6.2017	Österreichische Forsttagung 2017 - Wien	Diversität und Resilienz im Waldmanagement
20.8.-24.8.2017	BIOGEOMON (9th International Symposium on Ecosystem Behavior) Session 3: Biosphere-atmosphere interactions in an era of global change - Litomyšl Chateau, Czech Republic	Effects of slope orientation and site elevation on seasonal soil carbon dynamics in forested montainous areas
2.9.-3.9.2017	6th International Symposium for Research in Protected Areas 2017	From long-term ecosystem monitoring to regional modelling of ecosystem function in the National Park Kalkalpen, Austria
18.9. - 22.9.2017	IUFRO 125th Anniversary Congress, All Division 7 (Forest Health) Meeting Freiburg, Germany.	Changing disturbance regimes and their impact on the climate regulating function of forests.
18.9. - 22.9.2017	IUFRO 125th Anniversary Congress Freiburg, Germany.	Intensive ground vegetation growth mitigates the carbon loss from forest clearings
2.11. - 5.11.2017	Annual Meeting of the Social Sciences History Association (Exogenous and endogenous shocks on land use and its outcome on people and places) - Montreal	Seizing the Moment for Long-Term Effect: The socio-ecological legacy of a Bark-Beetle Control Campaign in the 1919 during the 20th Century in Rural Austria
06.11.2017	Luft, Wald, Boden, Wasser: 25 Jahre Umweltbeobachtung am Zöbelboden - Reichraming	Zurück in die Zukunft des Waldes der Kalkalpen
27.11.2017	Adventtagung der Land & Forstbetriebe Steiermark - Graz	Strategien für eine Welt im Wandel: Diversität und Resilienz im Waldmanagement
28.11.-1.12.2017	eLTER conference, Malaga	Effects of slope aspect and site elevation on seasonal soil carbon dynamics in a forest catchment in the Austrian Limestone Alps

09.02.2018	Gund Tea Series - Gund Institute for Environment, Burlington, USA	Biodiversity and ecosystem services under threat: The impacts of climate change and disturbances on forest ecosystems.
8.4.-13.4.2018	EGU Vienna (SSS6.6 - Forest disturbances and soil organic matter: response and recovery) - Vienna	Post-disturbance ground vegetation effects on carbon sequestration in a temperate forest landscape