Rapport final

Intitulé du projet :

Ecosystem service proVIsion from coupled planT and microbial functionAL diversity in managed grasslands

Acronyme : VITAL

Projet financé par :

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- *le Ministère de l'Ecologie, du Développement durable et de l'Energie (MEDDE)*
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Ecosystem service proVIsion from coupled planT and microbial functionAL diversity in managed grasslands

Le projet VITAL, financé par l'Era-Net BiodivERsA, vise à tester l'hypothèse générale que la fourniture de plusieurs services écosystémiques dans les prairies semi-naturelles, et sa vulnérabilité aux changements de gestion, peut être expliquée par le couplage de la diversité fonctionnelle microbienne du sol et des plantes, et de ses impacts sur les cycles du carbone et de l'azote. Des expérimentations, allant de la plante isolée à l'échelle de la prairie, ont été conduites sur trois sites de montagne (Alpes françaises, Tyrol autrichien et nord de l'Angleterre). Elles ont permis de valider notre hypothèse initiale selon laquelle une combinaison de la diversité fonctionnelle des plantes et des paramètres fonctionnels microbiens constitue le déterminant des services écosystémiques « clé » des prairies de montagne. Plus précisément, nous avons démontré que les paramètres fonctionnels des plantes et des microorganismes du sol sont liés, et qu'ils sont associés aux processus « clés » des cycles du carbone et de l'azote déterminants pour les services écosystémiques pertinents pour les agriculteurs et les acteurs régionaux des prairies de montagne, tels que la production des prairies pour l'élevage, la régulation de la fertilité des sols et la qualité de l'eau, la séquestration du carbone ainsi que les valeurs esthétiques et culturelles. Nous avons ensuite utilisé ces résultats pour modéliser les services écosystémiques à l'échelle du paysage. Nous avons ainsi constaté que l'extensification de la gestion favorise les communautés végétales et les communautés microbiennes associées du sol liées à des processus plus lents de recyclage de l'azote et plus conservateurs du carbone, conduisant à la rétention de l'azote et la séquestration du carbone dans le sol. Les scénarios menant à une utilisation moins intensive des terres, comme une sécheresse extrême, favorisent la séquestration du carbone et la rétention de l'azote au détriment de la production de fourrage et de la valeur culturelle, servant ainsi les intérêts régionaux aux dépens d'intérêts locaux. La mise en œuvre de mesures politiques devrait tenir compte de ces compromis, ainsi que des coûts additionnels et de la flexibilité nécessaires pour maintenir une gestion traditionnelle extensive et sa plurifonctionnalité, en termes de fourniture de services écosystèmiques.

Résumé :

Le projet VITAL, financé par l'Era-Net BiodivERsA, vise à étudier comment le couplage entre la biodiversité végétale et la biodiversité microbienne du sol détermine la fourniture de services écosystémiques multiples par les prairies semi-naturelles.

Nous avons tout d'abord effectué un ensemble d'expérimentations, allant de la plante isolée à l'échelle de la prairie, sur trois sites de montagne localisés dans les Alpes Françaises (Lautaret), le Tyrol autrichien (vallée de Stubai) et le nord de l'Angleterre (Yorkshire Dales) pour étudier les liens existant entre les caractéristiques des plantes (appelées « traits fonctionnels ») et leurs valeurs à l'échelle des communautés végétales (dénommées « paramètres de la diversité fonctionnelle »), les caractéristiques des communautés microbiennes du sol et des processus associés aux cycles du carbone et plus particulièrement de l'azote dans le sol. La fourniture de services écosystémiques multiples est une des caractéristiques fondamentales des systèmes herbagers, comme le révèle la science participative avec les acteurs locaux et régionaux.

Une première série d'expériences effectuées à l'échelle de la plante isolée ont eu pour but de déterminer si certains traits bien connus et facilement mesurables, liés à la vitesse de croissance des plantes et aux recyclages des nutriments, comme le syndrome foliaire d'acquisition (« Leaf Economic Spectrum »), constituent de bons indicateurs (1) des processus de l'absorption racinaire de l'azote et de la libération (rhizodéposition) de composés carbonés par les racines, et (2) des effets des plantes sur les communautés microbiennes du sol associées à deux processus « clés » de transformation de l'azote que constituent la nitrification et la dénitrification.

Les résultats obtenus montrent que:

(1) Le syndrome foliaire d'acquisition est en effet un bon indicateur des capacités d'absorption de l'azote des plantes. Les plantes « exploitatives » qui présentent une croissance et un recyclage des nutriments rapides peuvent prélever rapidement l'azote ammoniacal et nitrique du sol. Les plantes « conservatives » qui, à l'inverse, présentent une croissance et un recyclage des nutriments plus lents ont des capacités d'absorption plus faibles, mais sont relativement mieux adaptées au prélèvement de l'ammonium qui tend à être plus abondant dans les sols moins fertiles. Par ailleurs, nos résultats montrent que la rhizodéposition n'est pas liée au syndrome foliaire d'acquisition mais à la densité racinaire des plantes.

(2) L'effet espèce ainsi que le syndrome foliaire d'acquisition constituent aussi des indicateurs pertinents pour la composition des communautés fongiques et le développement des mycorhizes dans les sols non fertilisés. L'effet espèce affecte également les activités des communautés microbiennes nitrifiantes, ces effets étant plutôt liés à des traits racinaires, en particulier la capacité d'absorption, qui conduisent à une compétition pour le prélèvement de l'ammonium entre les plantes et les communautés microbiennes nitrifiantes. Les communautés dénitrifiantes et leurs activités sont quant à elles fortement affectées par les conditions environnementales, et peuvent parfois dépendre d'un effet espèce et en particulier, de la vitesse potentielle de croissance des plantes.

Les expériences effectuées à l'échelle des communautés ont confirmé, pour les communautés artificielles avec une diversité fonctionnelle manipulée et pour les prairies soumises à différentes intensités de gestion, la pertinence des traits des plantes (en particulier les traits racinaires) et de la composition des communautés microbiennes du sol. Nous avons constaté que la combinaison de la diversité fonctionnelle des végétaux et des paramètres fonctionnels microbiens détermine les processus « clés » des cycles du carbone et de l'azote à l'origine des services écosystémiques des prairies de montagne. Plus précisément, nous avons démontré que les paramètres fonctionnels des plantes et des microorganismes sont associés aux

processus « clés » des cycles du carbone et de l'azote, avec des traits de plantes principalement liés à des processus situés au dessus du sol tels que la production de biomasse et des paramètres microbiens principalement liés à des processus pédosphériques tels que la rétention du nitrate, le cas de la séquestration de carbone étant intermédiaire. Nous avons globalement observé que l'extensification de la gestion favorise les communautés végétales et microbiennes du sol liées à des processus des cycles du carbone et de l'azote plus lents et plus « conservatifs », et donc la séquestration du carbone et la rétention de l'azote.
Nous avons ensuite utilisé ces résultats pour modéliser les services écosystémiques à l'échelle du paysage et étudier leurs réponses à des scénarios de changements climatiques et sociétaux élaborés en co-construction avec les agriculteurs et les experts régionaux. Les scénarios menant à une utilisation moins intensive des terres, comme une sécheresse extrême, favorisent la séquestration du carbone et la rétention de l'azote au détriment de la production de fourrage et de la valeur culturelle, servant ainsi les intérêts régionaux aux dépens des intérêts locaux. De tels compromis reposent sur des compromis fonctionnels écologiques liés au fonctionnement à l'échelle de la plante et des impacts des plantes sur les communautés microbiennes du sol.
Ainsi, le projet VITAL a mis en évidence les rôles « clés » de la diversité fonctionnelle des plantes et de la diversité microbienne du sol pour la fourniture de services écosystémiques essentiels d'intérêt local et régional. Il contribue ainsi aux initiatives actuelles qui visent à attirer l'attention sur l'importance du rôle « invisible » de la biodiversité dans le maintien des services que rendent les écosystèmes à la société. Compte tenu de l'importance croissante de la notion de services écosystémiques dans plusieurs mesures politiques au cours de la dernière décennie, les résultats de VITAL ont été pris en considération par les gestionnaires dans la mise en œuvre de mesures agro-environnementales, en particulier pour soutenir la fauche des prairies alpines, ou la restauration des prairies peu fertiles dans le Nord de l'Angleterre. Les connaissances sur les compromis écologiques fondamentaux parmi les services écosystèmiques est essentiel pour orienter l'élaboration de politiques multisectorielles ainsi que les plans de gestion, tout en tenant compte du contexte socio-économique contraignant de l'élevage de montagne et les besoins de soutien à l'apprentissage technique et actif des communautés agricoles.

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Final project report

Project acronym: VITAL

Project number:

Ecosystem service proVIsion from coupled planT and microbial functionAL diversity in managed grasslands

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1. Short description for publicity

VITAL aimed to address the general hypothesis that the delivery of multiple ecosystem services in semi-natural grasslands, and its vulnerability to changing management, can be explained by the coupling among plant and soil microbial functional diversity, and its impacts on carbon and nitrogen turnover. Overall, using experiments from the individual plant to the field scale at three mountain sites (in the French Alps, Austrian Tyrol and Northern England), we have validated our initial hypothesis that a combination of plant functional diversity and microbial functional parameters determine key mountain grassland ecosystem services. Specifically, we demonstrated that plant and microbial functional parameters are linked, and that they are together associated with key carbon and nitrogen turnover processes underpinning ecosystem services relevant to farmers and regional stakeholders of mountain grasslands, such as grassland production for livestock rearing, regulation of soil fertility and water quality, carbon sequestration and aesthetic and cultural values. We then applied these findings to model ecosystem services at landscape scale. We found that overall, extensification of management promotes plant and associated soil microbial communities linked to slower and more conservative C and N cycling processes, and thus C sequestration and N retention. Scenarios leading to less intensive land use, such as extreme drought, promote C sequestration and N retention at the expense of fodder production and cultural value, thus favouring regional as opposed to local interests. Implementation of political instruments should take into account such trade-offs, along with additional costs and flexibility required to maintain traditional extensive management and its mutifunctionality, in terms of ecosystem service delivery.

2. Summary

VITAL aimed to investigate how the coupling among plant and soil microbial biodiversity underpins the delivery of multiple ecosystem services by semi-natural grasslands.

First we used a series of experiments from the individual plant to the field scale at three mountain sites in the French Alps (Lautaret), Austrian Tyrol (Stubai Valley) and Northern England (Yorkshire Dales) to investigate the linkages between plant characteristics (know as 'plant traits') and their collective values at the field scale (referred to as 'functional diversity parameters'), characteristics of soil microbial communities and processes associated with carbon and especially nitrogen turnover in soils. Provision of multiple ecosystem services, or 'multifunctionality' is a core characteristics of these grassland systems, as revealed by participatory work with local and regional stakeholders.

A first set of experiments focused on the individual plant scale to ask whether some well known and easily measurable plant traits, associated to the speed at which they grow and turn over nutrients, known as the 'leaf economics spectrum', were valid indicators of: (1) detailed processes of plant nitrogen uptake and release (rhizodeposition) of carbon-based compounds through their roots, and (2) plant effects on soil microbial communities associated with two key nitrogen transformation processes, nitrification and denitrification. We found that:

(1) The 'leaf economics spectrum' was indeed a good indicator of plant nitrogen uptake abilities, with 'exploitative' plants with faster growth and nutrient turnover being able to uptake both ammonium and nitrate faster; 'conservative' plants with slower growth and nutrient turnover were slower at ammonium and nitrate uptake, but relatively better at accessing ammonium which tends to prevail in less fertile soils. On the other hand, rhizodeposition was not related to the 'leaf economics spectrum', but simply to the density of plant roots.

(2) Plant species identity, and the 'leaf economics spectrum' were also relevant to the composition of fungal communities and to the development of mycorrhizae in unfertilized soil. However, while plant identity also affected the activities of nitrifying microbial communities, these effects were rather linked to root traits, especially the ability to uptake and thus compete for ammonium. Denitrifying communities and their activities were strongly affected by soil environmental conditions, and also, though not always, depended on plant identity and especially potential growth rate.

Experiments at community level, for artificial communities with manipulated functional diversity and for grasslands under differing management intensities, confirmed the relevance of plant traits, and especially root traits, to the composition of soil microbial communities. We found that a combination of plant functional diversity and microbial functional parameters determine key carbon and nitrogen turnover processes underpinning mountain grassland ecosystem services. Specifically, we demonstrated that plant and microbial functional parameters are together associated with key carbon and nitrogen turnover processes, with plant traits predominantly linked with above-ground processes such as biomass production and microbial parameters predominantly linked with below-ground processes such as nitrate retention, the case of soil carbon sequestration being intermediate. We observed that overall, extensification of management promotes plant and associated soil microbial communities linked to slower and more conservative carbon and nitrogen cycling processes, and thus carbon sequestration and nitrogen retention.

We then applied these findings to model ecosystem services at landscape scale and their responses to scenarios of climate and societal change built in collaboration with farmers and regional experts. Scenarios leading to less intensive land use, such as extreme drought, promoted carbon sequestration and nitrogen retention at the expense of fodder production and cultural value, thus favouring regional as opposed to local interests. Such trade-offs were underpinned by ecological functional trade-offs, originating from plant level functioning and plant impacts on soil microbial communities.

Thus, VITAL has highlighted the key roles of plant functional diversity and soil microbial diversity for the provision of essential ecosystem services of local and regional interest. In doing so, it adds to ongoing initiatives drawing attention to the importance of considering the 'invisible' side of biodiversity for sustaining benefits of ecosystems to society. Given the increasing significance of the ecosystem service concept in several political instruments during the last decade, VITAL results have been considered by managers with respect to the implementation of agri-environmental measures, in particular to support the continued mowing of alpine grasslands, or the restoration of low fertility grasslands in Northern England. Knowledge on fundamental ecological trade-offs among ecosystem services is essential to guide the development of feasible, multi-sectoral policies and management plans, while considering the constraining socio-economic context of mountain livestock farming and needs for technical and active learning support for farming communities.

3. Objectives of the research

VITAL aimed to address the general hypothesis that the delivery of multiple ecosystem services in semi-natural grasslands, and its vulnerability to changing management can be explained by the coupling among plant and soil microbial functional diversity, and its impacts on carbon and nitrogen turnover. We aimed to produce a conceptual model of relationships among plant and microbial functional diversity, and multiple ecosystem service delivery, that would also be relevant to local and regional development.

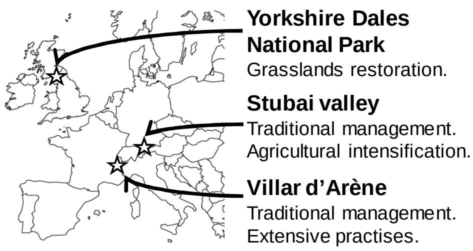
We addressed six specific objectives:

1. To identify key ecosystem services associated with the maintenance of fertility in mountain grasslands, how these are perceived to be affected by management, and linkages among different services.
2. To identify indicators for the mechanisms underlying the coupled responses of plant and microbial functional diversity to management.
3. To develop a conceptual model linking plant functional responses to management, their effects on microbial functional diversity, and their coupled effects on ecosystem services.
4. To validate the conceptual model along gradients of management intensity in the field.
5. To project future ecosystem service delivery according to alternative scenarios.
6. To identify and meet the needs of local stakeholders, land managers and policy makers

4. Project activities and achievements

General description of activities over the duration of the project

VITAL research was implemented at three mountain grassland sites with contrasting climate, management and soils: the French Alps (Lautaret / Villar d'Arêne); the Austrian Alps (Stubai Valley); and the English uplands (Yorkshire Dales). These regions are all used primarily for livestock rearing with heterogeneous management intensity and therefore soil fertility within each site, and represent a diversity of agricultural dynamics across European mountain grasslands over the last 50 years. In addition to agriculture, tourism is a dominant economic activity in all three regions, which are recognized for their aesthetic, cultural and conservation value and offer many opportunities for recreation. In Austria agro-tourism is well developed, and Lautaret and the Yorkshire Dales are designated National Parks.



WP1 was coordinated by UIBK and involved in 2009 the design of an interview guide and guidelines for focus groups (UIBK), carrying out the interviews and focus group meetings (UIBK, LECA, ULAN) (see Table 1 in Lamarque et al. Regional Environmental Change 2011 for the quantitative details on stakeholders sampled), data analysis (LECA), and the writing of a common paper in 2010 (led by LECA with UIBK and ULAN).

WP2 involved a complex series of complimentary experiments, done under controlled conditions, aiming to assess the detailed mechanisms driving functional interactions among plants depending on their traits, and microbial communities associated with nitrogen turnover in soils, and especially nitrification and denitrification.

WP2a assessed some poorly known plant ecophysiological traits, N uptake and C rhizodeposition, using advanced isotope labelling techniques at EVA and UB respectively in 2010-2011. LECA, UIBK and ULAN provided plant material for grassland species selected collectively to represent *a priori* a wide spectrum from very conservative to more exploitative species at each site, as well as across sites. Plant culture (1152 plants from 14 populations from 10 species for N uptake; 4 species for rhizodeposition), laboratory measurements and data analyses were carried out by EVA and UB respectively. LECA, ULAN and UIBK had input into paper writing.

WP2b addressed interactions among plant species identity, traits at individual level and the composition and potential activities of nitrifying and denitrifying soil microbial communities in soils on which the same plant species were grown individually. First, a rhizotron experiment was established for the same species as in WP2a, using EVA plant culture facilities and staff, and soil collected by HELM at the Scheyern field station in May 2009 with the help of the UB postdoc, fertilised or not (total 320 plants). EVA measured a large panel of leaf (Specific Leaf Area -SLA; Leaf Dry Matter Content -LDMC, Leaf Mass Ratio-LMR and Leaf Area Ratio –LAR) and root traits (root dry matter concentration -RDMC; Shoot/Root Ratio- SRR; specific root length-SRL; average root diameter; Root N Content- RNC; Relative growth rate- RGR) related to C and N status. During autumn 2009 and 2010, LEM and HELM sampled soils after one month for quantification of microbial properties including nitrification and denitrification potential activities under standardised conditions (LEM; 160 plants). DNA extracted from different soil samples (HELM) was analysed during 2011 to quantify microbial gene abundance of nitrification and denitrification by qPCR (HELM and LEM). HELM quantified soil NH_4^+ and NO_3^- concentrations from soil extractions performed by LEM. Data analyses were carried out by LEM with initial technical support by LECA, and a manuscript written by LEM, EVA, HELM and LECA. Given the absence of mycorrhizal development over the short culture period, LECA also analysed, using 454 pyrosequencing, soil fungal communities of two of the grass species. These data were analysed and a paper was written by LECA in collaboration with EVA and HELM.

A second experiment in addition to the original work plan was performed by HELM in order to investigate denitrification activities, which may have been limited under the conditions of the rhizotron experiment. This study aimed to investigate microbial communites in the rhizosphere of 3 subalpine species with different N uptake strategies grown each for 28 days in a greenhouse (between July and November 2011). The influence of anoxic conditions, known to favour denitrification processes, and which might thus facilitate microbes during the competition for nitrate, was examined. The rhizosphere microbial community was investigated by quantification of functional genes involved in nitrification (bacterial and archaeal *amoA*) and denitrification (*nirK*, *nirS*, *nosZ*) by real-time PCR. Soil ammonium and nitrate concentrations were determined. Potential enzyme activities of nitrification and denitrification were analysed. HELM was responsible for data analyses and paper writing.

A final and third pot experiment was designed in 2011 to specifically address fungal and especially mycorrhizal communities, which take longer to develop, here 3 months, for 3 grass species under 2 levels of N fertilisation and sterilized / non-sterilized soils. These were quantified using mycorrhizal counts and 454 pyrosequencing of the ITS region (LECA), along with soil and plant traits (EVA and LECA), and bacterial potential nitrifying and denitrifying (LEM). Data analysis and paper writing by LECA with LEM and EVA are in progress.

WP3 involved a large mesocosm experiment established at each of the 3 sites during summer 2010 following a protocol designed by ULAN and LECA. At each site (ULAN, LECA, UIBK), we manipulated the relative abundances of 4 plant species, varying in their plant functional traits as measured in WP2, planted in mesocosms with uniform soil during summer 2009. With the addition of a fertilisation treatment this design, with 4 replicates of each treatment, produced a total of 64 mesocosms in France and the United Kingdom, whereas in Austria a smaller number of mesocosms (40) was used due to problems with establishment of some plant species. Each site was then responsible for the maintenance and measurements on their own mesocosms, up until harvest in summer 2011. Measurement protocols were identical in WP3 and WP4, to ensure comparability. The collective data set was managed by ULAN. Data analyses in progress are led by ULAN and LECA, in collaboration with LEM, HELM and UIBK, as will be the writing of papers. A microcosm experiment, which was in addition to the stated aims of WP3, was also set up at ULAN to test how plant traits impact on plant competitive interactions via modification of soil conditions (plant-soil feedback) and plant-plant interactions. This experiment was set up with input from LECA, and data analysis and the writing is being performed by ULAN.

WP4 carried out simultaneous measurements of soil parameters, plant traits, microbial diversity and functional properties and ecosystem functioning parameters in actual field situations at the three sites, across contrasting different land use intensities within each site, 2 at Stubai, 3 in the Yorkshire Dales and 3 at Lautaret. Measurement protocols were coordinated by LECA and UIBK, discussed at project meetings and on line with partners and made available on the project's intranet (2009-10). They are presented in Grigulis et al. (2013). A common training for field methods and trait measurements was led by LECA in June 2009 at the English site, and real time online support was provided to ULAN and UIBK throughout their field campaigns and lab analyses. Analyses of plant and soil samples for WP3 and WP4 were organised across the partners as follows. Each site (ULAN, LECA, UIBK) was responsible for composition, biomass and plant above- and below-ground trait measurements, as well as for analyses of eight soil fertility parameters and for quantification of ecosystem properties: biomass production, potential N mineralization, NO_3- and NH_4+ potential leaching, microbial biomass N and soil organic matter content. Soil samples were sent to responsible partners for measurements of microbial functional group composition (PLFA at ULAN), potential bacterial enzymatic activities (DEA, MNA at LEM), microbial gene abundances (nirS, nirK, nosZ, AOA, AOB at HELM; *Nitrospira* et *Nitrobacter* at LEM), and fungal diversity (LECA). Near Infra-red Spectrometry analysis of vegetation samples for quantification of digestibility and forage N was under the responsibility of LECA. Following common decisions at the annual project meeting in May 2011, LECA and UIBK have led data analyses and the writing of four papers, in collaboration with ULAN and HELM. An additional root decomposition experiment was made at the Stubai site, with field measurements and soil analyses by UIBK and analyses of microbial activities and microbial community composition by HELM.

WP5 was conducted in close collaboration between LECA and UIBK for the common design of a participative scenario building strategy, and the selection of the list of ecosystem services and models for each site. The plan was then implemented by each of the teams at the Lautaret and Stubai sites respectively, using specific approaches tailored to site specificities, e.g. in terms of stakeholder groups and interests, and in terms of modelling strategies. LECA was able to apply trait-based models directly derived from WP4 and parameter values from previous studies at the Lautaret site, whereas given that WP4 covered only a subset of relevant land uses at the Stubai sites statistical data from previous projects were applied per land use type. Modelling, data analyses and paper writing were completed by each team. A further common modelling exercise was led by UIBK for soil water retention, with support from LECA for parameterization and implementation at Lautaret.

WP6 was led by UIBK, with collaboration by LECA on products for stakeholders and the writing of the policy report. UIBK, LECA and ULAN organized field demonstrations and regular dialogue with stakeholders at their sites. LECA was responsible for the design and maintenance of the project web site, and as the coordinator led the publication of two articles in international magazines for policy makers. UIBK designed and supervised the development of an education product for the training of high school students on grassland ecosystem services and their links to management, plant traits and microbial diversity.

Scientific outcomes

WP1: Fertility and multifunctionality of mountain grasslands

Objective: To identify with stakeholders key ecosystem services associated with the maintenance of fertility in mountain grasslands, how these are perceived to be affected by management, and linkages among different services.

The concept of ecosystem services is increasingly being used by scientists and policy makers. However, most studies have focused on factors that regulate ecosystem functions (i.e. the potential to deliver ecosystem services) or the supply of ecosystem services. In contrast, demand for ecosystem services (i.e. the needs of beneficiaries) or understanding of the concept, and the relative ranking of different ecosystem services by beneficiaries has received limited attention. We identified at each of the three VITAL sites the ecosystem services of grasslands that different stakeholders identify (which ecosystem services for whom), the relative rankings of these ecosystem services, and how stakeholders perceive the provision of these ecosystem services to be related to agricultural activities. We found differences: (1) between farmers' perceptions of ecosystem services across regions; and (2) within regions, between knowledge of ecosystem services gained by regional experts through education and farmers' local field-based knowledge. Nevertheless, we identified a common set of ecosystem services that were considered important by stakeholders across the three regions, including soil stability, water quantity and quality, forage quality, conservation of botanical diversity, aesthetics and recreation (for regional experts), and forage quantity and aesthetic (for local farmers) (Table 1). Stakeholders held contrasting representations of the effects of agricultural management on ecosystem services delivery, depending on their perceptions of the relationships between soil fertility and biodiversity: when driven by fertilisation, soil fertility was perceived as being incompatible with biodiversity and with several ecosystem input and non-market services; whereas soil fertility managed through low to medium intensity practices was seen as promoting biodiversity and thereby on multiple ecosystem services. Overall, differences in perceptions highlighted in this study show that practitioners, policy makers and researchers should be more explicit in their uses of the ecosystem services concept to be correctly understood, and to improve communication among stakeholders.

Classification	Ecosystem services	Most important ES to experts	Most important ES to farmers
Input	Pollination	X	
	Soil fertility	X	X
	Soil stability	X	
	Soil moisture		X
	Water quantity	X	
Marketed	Forage quality	X	X
	Forage quantity	X	X
Non-marketed	Conservation of botanical diversity	X	X
	Habitat for fauna	X	
	Aesthetic	X	X
	Cultural value		
	Natural hazards regulation	X	
	Recreation	X	
	Water quality	X	
	Climate regulation/ C sequestration	X	

Table 1: Similarities and differences in ecosystem services considered to be the five more important by regional experts and farmers of each region. (from Lamarque et al. 2011b)

WP2. Functional indicators for plant and soil microbial diversity responses to management

Objective: To identify indicators of plant and microbial functional diversity responses to management.

a. Plant functional traits related to carbon and nitrogen turnover in soils

Specific objective: To assess whether plant functional responses to management intensity are linked to (eco)physiological traits involved in below-ground C and N turnover.

(i) Assimilation of various N forms: Leaf functional traits have been identified as indicators for an axis of plant specialisation from conservation to exploitation of mineral resources. However, the extent that functional traits and resource use strategies reflect the ability of plant species to take up N at the root level is poorly understood. We estimated root uptake of NH_4^+ and NO_3^- and functional traits for 8 grass species sampled across the three VITAL sites, with *Dactylis glomerata* being a common species across all sites. Plants were grown in hydroponic conditions to estimate functional traits and uptake parameters under standardised conditions, and ^{15}N labelling was used to determine species uptake of N inorganic forms. Species with high Specific Leaf Area (SLA) and low Leaf Dry Matter Concentration (LDMC) (exploitative syndrome), had higher uptake capacities and affinity for both N forms (Figure 1). We did not observe a trade-off between the uptakes for the two N forms, but species differed in their preferences for NH_4^+ and NO_3^- (NH_4^+/NO_3^- Imax ratio), even though they all had greater preference for NH_4^+ (Grassein et al. in review). We conclude leaf traits widely used to describe resource use strategies under the "leaf economics spectrum" can also be proxies to estimate species N uptake ability. This relationship between the leaf economics spectrum and N uptake strategies was confirmed using a wider set of functional traits measured at the root and leaf level, which were linked with to potential N uptake of 3 grass species at the Lautaret site: *Bromus erectus*, *Dactylis glomerata* and *Festuca paniculata* (Grassein et al. in prep.).

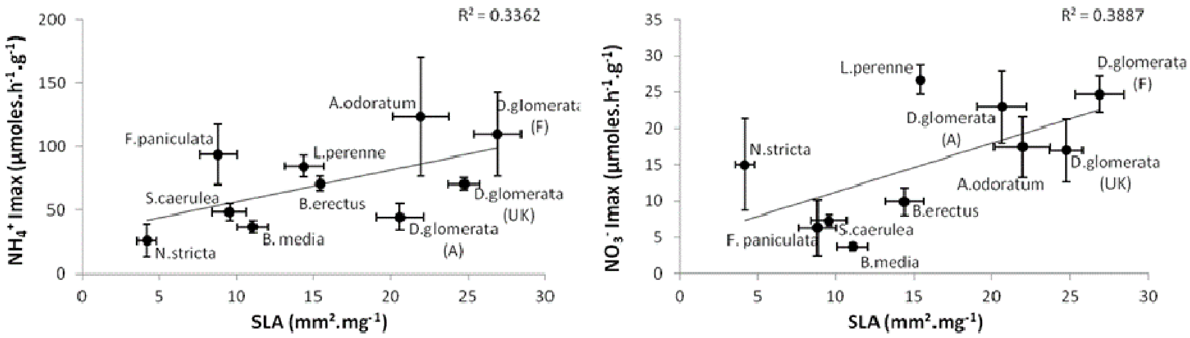


Figure 1: Relationship between SLA and NH_4^+ (A) and NO_3^- (B) maximum influx (Imax) of eight grassland species collected in one or three sites (A: Austria; F: France; UK: United Kingdom). (Grassein et al. in review)

(ii) C-N metabolisms interactions in response to N fertility gradients: Rhizodeposition is believed to play an important role in mediating nutrient availability to plants. However, owing to methodological difficulties (i.e. narrow zone of soil around roots and rapid assimilation by soil microbes), our understanding of how rhizodeposition varies between plant species, or in response to environmental variables such as soil fertility, remains limited. Here, we quantified rhizodeposition among four grass species from the Lautaret and Yorkshire Dales sites, characterized by contrasted nutrient acquisition strategies, and how this varied with nitrogen fertilisation. To do this, we developed a continuous ^{13}C labelling method that allowed: (1) homogenous labeling of the plant species under controlled growth conditions; and (2) the separation of plant-derived CO_2–C from microbial-derived CO_2–C.in the rhizosphere. We found that total and specific rhizodeposition of C was largely related to total root biomass rather than to functional traits associated with plant nutrient economy. Also, N fertilisation tended to increase rhizodeposited C, possibly due to increased assimilation rates and increased sink strength for plants.

b. Functional markers of plant trait effects on microbial activities and biodiversity

Specific objective: To explore how plants, in terms of identity, traits and strategy for N-resources acquisition, can influence activities of soil microorganisms (nitrifiers and denitrifiers) involved in N turnover and fungi.

(i) *Short term effects of plant identity and traits on soil microbial communities associated with N cycling*

Ten grassland plants (*Dactylis glomerata* from the 3 sites*, Anthoxanthum odoratum, Bromus erectus, Briza media, Festuca paniculata, Sesleria caerulea, Nardus stricta and Achillea millefolium)*, collected from the three sites, and chosen for their contrasted plant traits values and nutrient acquisition strategies, were grown in rhizotrons for one month under two fertilisation levels. A large panel of leaf and root traits related to C and N status were measured. The associated potential microbial activities on adherent and non-adherent soil to roots (i.e. denitrification rate (DEA), maximal nitrification rate (MNA) and NH_4^+ affinity of the microbial community (NHScom)) were determined. Plant identity appeared as a key parameter of biotic interactions between microbial denitrifying and nitrifying activities and plants. As expected, these biotic interactions were more intense closer to the root systems (*i.e.* adherent soil). Some plant traits were found to be good predictors of microbial activities. However, these traits differed across microbial activities. MNA could be partly predicted by root traits (i.e. SRL, RNC and $K_mNH_4^+$ measured in hydropony – see a.(i)) and DEA by RGR (Figure 2). Fertilisation modified these relationships, strongly for MNA (only SRL remained significant) and weakly for DEA (lower explanatory power). However no relationship between the "leaf economics spectrum" and microbial activities was found for DEA or MNA. Our results indicated that in less fertile soil, nitrification parameters were strongly related to root or N-uptake traits, whereas denitrification was linked to whole plant traits. We conclude, therefore, that plant traits are powerful tools for better understanding of plant-microorganism relationships, but different traits need to be considered for different microbial activities (Cantarel et al. in prep.).

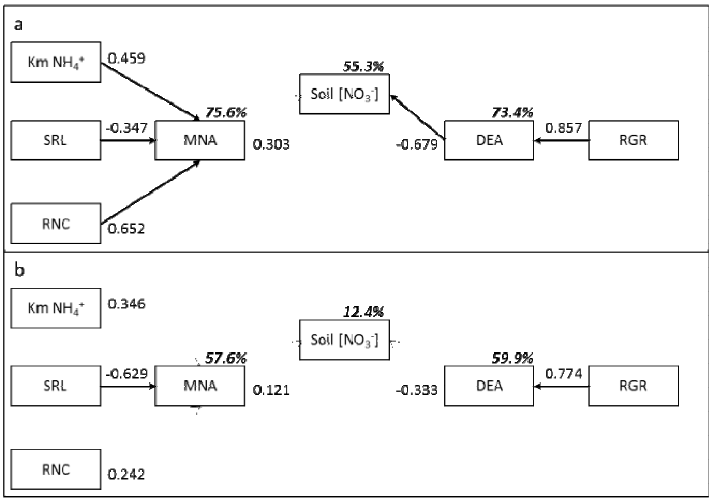


Figure 2: Structural equation models for effects of plant traits on key microbial parameters (DEA and MNA) for adherent soil samples in (a) unfertilized and (b) fertilized soil samples (n=10). Path coefficients (values indicated next to the *arrows*) correspond to the standardized coefficients calculated based on the analysis of correlation matrices. Percentage of explained variance is shown in italic and bold. Black arrows show significant relationships ($p<0.05$) and dotted arrows non significant relationships ($p>0.05$).

The fungal communities associated with *F. paniculata* and *D. glomerata* were determined by 454 pyrosequencing of the ITS1 region. Distinct fungal communities were associated with each plant species, and communities also diverged between rhizosphere and bulk soils for each species, though no significant fertilisation effects were detected.. Both plant species and location effects were reflected in the global composition of the fungal communities, and in the abundance rather than in the composition of abundant molecular operational taxonomic units (MOTUs). The observed differences in fungal communities coincide with differing patterns of plant root growth, with *D. glomerata* having greater root mass, length and area than *F. paniculata*, and may be linked to root trait effects on nitrogen uptake (Mouhamadou et al. in revision).

(ii) Competition of subalpine grassland plant species and microbes for nitrogen in the rhizosphere under different redox conditions in soil[1]: The aim of this study was to determine how soil redox conditions influence the N uptake rates of microbes and plants. This was done in a greenhouse experiment using plants with different exploitation strategies and distinct preferences for NH_4^+ vs. NO_3^-. Plants were grown in a nutrient poor, sandy soil, which was fertilized with an N amount equal to 100 kg NH_4NO_3 ha^{-1}, and planted with *A. millefolium*, *B. media* and *B. erectus*. To measure N uptake rates of NH_4^+or $NO_3$by microbes and plants, soils were supplied with either $^{15}NH_4NO_3$ or $NH_4{}^{15}NO_3$. Redox potential was adjusted using different water regimes reflecting 50% respectively 80% of the maximum water holding capacity (mWHC). Plants were grown in an atmosphere using $^{13}CO_2$ (99 %) to study C-fluxes from the plant into the soil. Under 50 % of the maximum water capacity, nitrification was the dominating microbial process, and denitrification was observed to a very low degree. Therefore, at low water content, soils were characterized by increased NO_3^- concentrations. Plants, independent from their ecophysiology, were not able to benefit from these increase NO_3^- levels in soil, most likely because they suffered under the low soil water content. Under increased water levels in soil, denitrification was the dominant process

1

This experiment was performed in addition to the experiments planned in the proposal, as the experiments performed in the rhizotrons did not allow to draw any conclusions on the influence of denitrifiers on competition for nitrogen with plants due to the low water content used. The described experiments were performed without funds from VITAL.

resulting in a fast depletion of NO_3^- in soil. However, due a reduced activity of nitrifiers, NH_4^+ was not transformed by microbes and was mainly used by plants. This resulted in increased N levels in the plants. In turn, these improved plant performance and assimilation; as a result, higher exudation rates were also observed, which additionally reduced the soil redox potential due to an increased activity of heterotrophic microbes and subsequently denitrification rates. This additionally reduced abundance and activity of nitrifiers over time. An influence of the different plants and their functional traits was not visible. Overall, these results indicate that the microflora associated to the rhizosphere is not only influenced by plant functional traits but to a large degree also by abiotic soil parameters like water availaibility or redox conditions, which need to be taken into accout if functional properties of the plant micobiome should be understood (Figure 3; Kastl et al. in prep.).

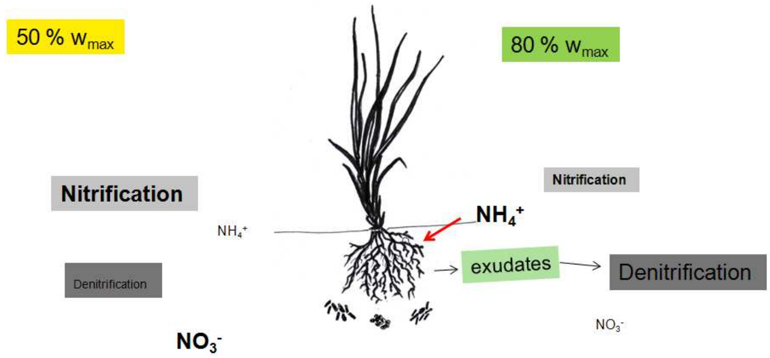


Figure 3: Nitrogen dynamics in soils with different redox potentials

(iii) *Effects of plant identity and traits on bacterial and fungal communities associated with N cycling:* The short term rhizotron approach, used in experiment *(i)*, did not allow sufficient mycorrhizal development. We tested the effects of 3 grass species with contrasting nutrient economies (*F. paniculata, D. glomerata* and *B. erectus* from the Lautaret site) on soil bacterial activities and fungal communities. Plants were grown for 3 months in pots at two levels of fertilisation, on soil that was sterilized or not. Root and soil fungal communities were determined by microscopic and molecular analyses, while other parameters were measured as in *(i).* Plant biomass and N uptake were significantly greater in exploitative than in conservative species. Similarly, denitrification activities were significantly greater in soil under the more exploitative species. N fertilisation did not impact these activities. Mycorrhizal intensity was greater in the roots of the conservative species in un-fertilized soil only. In addition, the absence of fungal structures in the sterilized soils suggests that each plant recruited fungal communities only from the soil. These results confirm that plants exert a key control on microbial resources, which is driven by their functional traits. Moreover, effects of plant traits on bacterial activities appear to be independent from N fertilisation, whereas for root fungal communities, their influence differs depending on fertility. The molecular characterization of the soil fungal communities is in progress.

c. Synthesis

Table 2: Variations in measured plant functional parameters from conservative to exploitative plants across experiments.

	Hydrop. Cond.	Exsud. Barcelona	Rhizotron	Megatron
SLA	↗		↗	↗
LDMC	↘	↘	↘	↘
LNC		↘		↘
RNC	↗	↗	↗	↗
RootBiomass		↗	↗	↗
NO_3^- Imax	↗			
NH_4^+ Imax	↗			
NH_4^+:NO_3^- Imax	↘			
Exsudation		↗		

Across experiments, plant traits co-varied in a consistent way from conservative to exploitative plants, with leaf traits following expected trends and root traits (RNC & Root Biomass) decreasing. Mycorrhizal abundances in experiment (iii) decreased from conservative to exploitative plants in the unfertilized treatment only. In both rhizotrons (i) and pots (iii), nitrification and denitrification activities did not strictly match expectations based on above-ground traits. We conclude that plant traits should be considered individually, and that a specific focus on root traits is required to understand plant-microbes interactions.

WP3: Linking plant functional responses to management, their impacts on microbial functional diversity, and their coupled effects on ecosystem services related to C and N cycling.

Objective: To develop a conceptual model linking plant functional responses to management, their impacts on microbial functional diversity, and their coupled effects on ecosystem services related to C and N cycling.

Here, we tested, in model grassland mesocosms, how changes in the dominance distribution of plant traits act as an important determinants of plant productivity, soil microbial community composition, and process rates of C and N cycling. Specific hypotheses tested were that: (i) that increased dominance of plant traits linked to exploitative strategies will promote bacteria relative to fungi, and the activity of microbes involved in the mineralisation of N and C; and (ii) increased dominance of plant traits linked to conservative strategies will promote fungi relative to bacteria, and microbial species associated with more conservative nutrient cycles and nutrient retention. The research in WP3 complimented the field-based studies of WP4, in that they provide a controlled experimental test of relationships between plant functional traits, soil microbial communities, and the processes that underpin multiple ecosystem (ES) service delivery in grassland.

To test the above, we designed a large mesocosm experiment that was established at each of the 3 sites. At each site, mixtures of 4 plant species, varying in their plant functional traits along the conservative-exploitative spectrum, were established in mesocosms with uniform soil during summer 2009. In these plant mixtures, the relative dominance for a fixed richness of 4 plant species, and the identify of the dominant species, was manipulated, by planting different mixtures within a set grid, to produce a range of community weighted mean (CWM) values for selected traits. At the start of the growing season, in spring 2010 and 2011, we added slow release N fertiliser (equivalent to 100 kg N ha^{-1} an^{-1}) to half of the mesocosms, to test for the impact of N addition on microbial and biogeochemical soil properties across the plant treatments.

Across all sites, soil and vegetation were sampled using a common set of agreed methods and sampling protocols, identical to those used in WP4 (see below), to ensure comparability. Briefly, at harvest (summer 2011), the biomass of individual plant species and above-ground plant traits were measured. From these data, we calculated a community-weighted mean (CWM) for each experimental unit. Roots were sampled from a dedicated soil core in each mesocosm, to determine community-level root traits. For soils, we measured i*n situ* available soil inorganic N using ion exchange resin bags inserted into the soil surface over the growing season, and soil samples were taken for assessment of total N, total C, microbial N biomass, microbial community composition, using phospholipid fatty acids (PLFA), potential enzymatic activities (DEA, MNA, Potential Nitrogen Mineralisation), and qPCR analysis of microbial communities abundances (ammonia oxidizers, nitrite reducers, nitrite oxiders).

Data analysis is currently underway, as lab analyses were only completed late 2012, and includes correlative modelling to quantify relationships between selected plant traits, both above-ground and below-ground, microbial communities, and soil processes. Data are being analyzed using a hypothesis driven process, using initial multivariate and univariate data exploration, which will support structural equation modelling to explore mechanistically based *a priori* hypothetical models of causal effects between plant traits, microbial parameters and several key ecosystem services.

An additional, complimentary glasshouse experiment was set up in 2011 at Lancaster University, in order to investigate the response of plant traits to inter-specific competition, and the consequences for soil properties. This study involved growing 16 plant species, ranging from fast growing exploitative to slow growing conservative species, in soils conditioned with two contrasting plant communities, with two, four and six species combinations of these species. The experiment was harvested in spring 2012 and analysis of above-ground and below-ground biomass and plant traits was carried out during summer 2012. Results are currently under analysis.

Main Results: A large number of relationships between plant traits, microbial properties, and soil processes related to C and N cycling have been identified across all three sites, although the nature and significance of these relationships varied much across sites (Baxendale et al. in prep). Despite this, we highlight here some key relationships that support our overarching hypotheses, as stated above. First, we found that, across all 3 sites, the fungal-to-bacterial PLFA ratio, which is a measure of the relative abundance of fungi and bacteria in the microbial community, was positively related to root density (Figure 4). In other words, fungi became increasingly abundant, relative to bacteria, with increasing root density across all sites, confirming that this below-ground plant trait is a key driver of microbial community composition in grassland soils. The fungal-to-bacterial PLFA ratio was also related to certain above-ground plant traits, but relationships varied across sites and were less strong. For example, the fungal-to-bacterial PLFA ratio was related to CWN leaf N content across all sites, and to CWM plant height in the UK and Austria, but not France (Figure 4). Together, these findings suggest that below-ground plant traits, as opposed to above-ground traits, are better predictors of soil microbial community properties in grassland, which supports what was also found in WP4. The fungal-to-bacterial PLFA ratio was also significantly related to soil C content, although the direction of this relationship varied across sites (Figure 4). Soil C content, a measure of the ecosystem service of soil C storage, was greater in soils dominated by fungi relative to bacteria in Austria, whereas the opposite occurred in France and the UK. This is contrary to what was expected, given our hypothesis that high fungal abundance, which is associated with conservative plant traits, is also associated with greater soil C storage. However, we highlight that it caution is needing when drawing conclusions on soil C storage in such short-term studies. We also explored relationships between plants traits and the abundance of N converting microbes across all three sites. Although not necessarily a direct functional link, the abundances of *nirS* and *nirK* genes were positively correlated to leaf N concentration across all sites, although the strength of these relations varied across sites, and ammonia oxidizing archaea, but not bacteria were correlated to leaf N to varying degrees. These results are currently being used to refine the hypothetical models, which will then be used to test structural equation models cascading from plant traits, to microbial parameters and to N cycling processes (Baxendale et al. in prep).

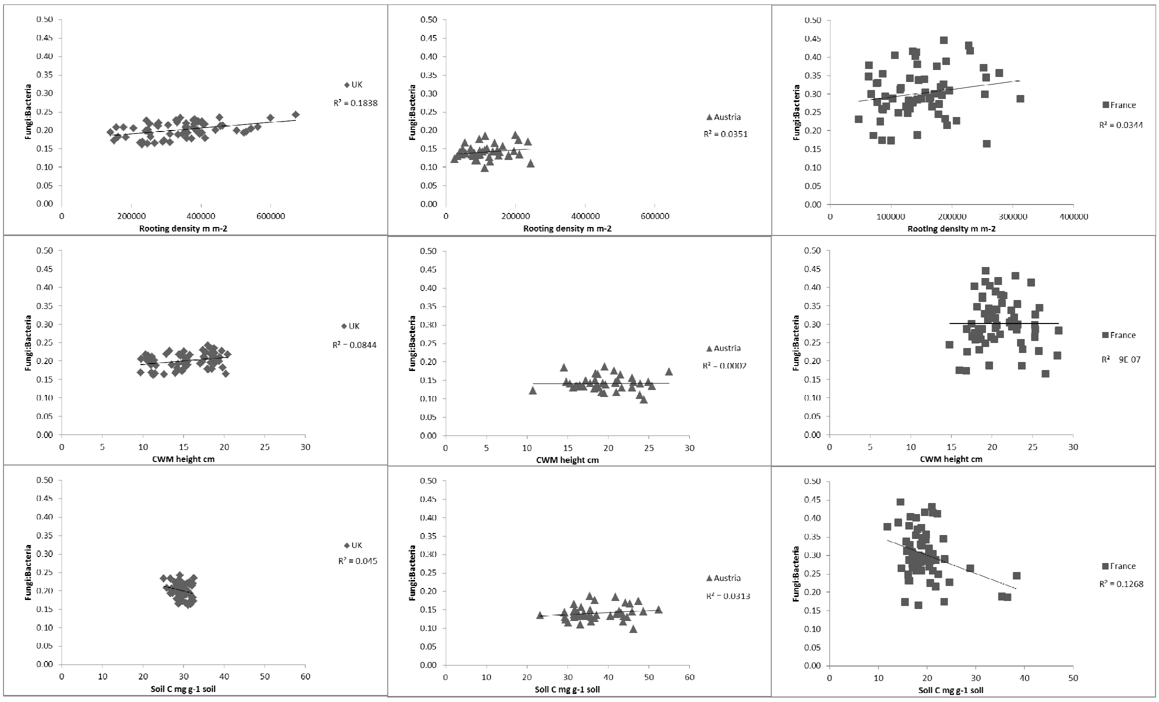


Figure 4. Relationships between root density (top row), CWM plant height (middle row), and soil carbon content bottom row), and the relative abundance of bacteria and fungi (measured by PLFA), across the three experimental sites (columns).

WP4: Linking plant and microbial functional diversity, and ecosystem service (ES) delivery under field conditions along management gradients

Objective: To test the robustness of the conceptual model of plant trait-microbial trait-ES relationships established by WP3 along actual fertility/management intensity gradients at the three field sites.

In WP4, we studied the strength of the above mentioned relationships in grasslands along actual fertility/management intensity gradients at the three contrasting long-term research sites in the Austrian Tyrol ('Stubai' henceforth; 2 intensities), northern England ('Yorkshire Dales' henceforth; 3 intensities) and the French Alps ('Lautaret' henceforth; 3 intensities).

We measured above- and below-ground plant traits, microbial parameters related to N-cycling (potential enzyme activities, composition, gene abundances, biomass) and major ecosystems functions (forage production, litter mass, soil organic matter content, potentially nitrogen leaching …). The responses of microbial activities and abundances of key microbial groups in the N-cycle to land use and to plant functional diversity were evaluated at peak biomass. This approach allowed us to quantify the relationships between plant diversity and microbial community and the delivery of multiple ecosystem services along management intensity gradients. The research teams developed common sampling strategies and protocols, available through the VITAL project intranet, and

further used by WP3. Within each site, individual grasslands (ca 1 ha each) were representative of current management trends, including abandonment, grazing and/or mowing, with varying fertilisation regimes.
All plant (below and above-ground parts) and soil sampling were carried out in 4 quadrats within each grassland between July and August 2010. Total above-ground biomass, standing litter and vegetation composition were estimated using the BOTANAL method. Above-ground plant traits (vegetative height – VH; specific leaf area – SLA; leaf dry matter content – LDMC; leaf C and N concentrations – LCC and LNC) were measured following standard protocols for each of the species that collectively made up 80% of the cumulated biomass. For each trait, community-weighted mean (CWM) and functional divergence (FD) were calculated using the F-Diversity package. Roots were sampled from a dedicated soil core in each quadrat. Root morphology measurements were done to determine total root length and average root diameter. Subsequently, community weighted means root dry matter content (RDMC), C and N concentrations (RNC, RCC) and specific root length (SRL) were measured.
In situ available soil inorganic N was measured using ion exchange resin bags inserted 5-15 cm deep over the growing season at 6 weeks intervals from May until October), once over the winter period (November to April), and at 6 weeks intervals during the following growing season from May to October 2011. Five upper soil cores (5-10 cm) per quadrat were sampled in July-August 2010. Subsamples were processed for soil analyses (total N, total C, microbial N biomass, potential leaching of soil nitrate and ammonium, bulk density, PLFA, SOM, pH…), potential enzymatic activities (DEA, MNA, PNM), and qPCR analysis of microbial communities abundances (Ammonia oxidizers, Nitrite reducers, Nitrite oxiders).
Data analysis included correlative modelling to quantify the respective contributions of soil properties and plant traits to variations in microbial functional parameters and in ecosystem properties associated to ecosystem services of interest (WP1). Data were analyzed using a hypothesis driven process, based on linear mixed models with restricted maximum likelihood (REML) estimates (Grigulis et al. 2013; Legay et al. in prep). Structural equation modelling was also used to explore mechanistically based *a priori* hypothetical models of causal effects between microbial parameters and several key ecosystem services (Pommier et al. in prep.).

Main Results: This first trait-based study providing a direct quantification in the field allowed the relative roles of plant and microbial functional traits on key ecosystem functions to be determined by following a sequential approach in which plant traits were fitted first, followed by the additional effects of soil micro-organisms (Grigulis et al. 2013). The analysis showed that there was a continuum from standing green biomass and standing litter, linked mostly with plant traits, to potential N mineralization and potential leaching of soil inorganic N, linked mostly with microbial properties. Plant and microbial functional parameters were equally important in explaining % organic matter content in soil. A parallel continuum ran from plant height, linked with above-ground biomass, to plant quality effects captured by the leaf economics spectrum, which were linked with the recycling of carbon (C) and N. More exploitative species (higher specific leaf area, leaf N concentrations and lower leaf dry matter content) and taller swards, along with soil microbial communities dominated by bacteria, with dominated by bacteria, with rapid microbial activities, were linked with greater fodder production, but poor C and N retention (Figure 5). Conversely, dominance by conservative species (with opposite traits) and soil microbial communities dominated by fungi, and bacteria with slow activities, were usually linked with low production, but greater soil C storage and N retention. We conclude that grassland production, C sequestration and soil N retention are jointly related to plant and microbial functional traits. Managing grasslands for selected, or multiple, ecosystem services will thus require a consideration of the joint effects of plant and soil communities.

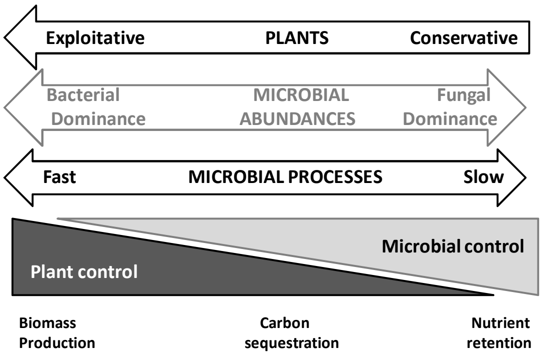


Figure 5 : Schematic overview of simultaneous variations in plant functional strategies, microbial functional composition and activities, and ecosystem processes and services (from Grigulis et al. 2013).

When incorporating soil abiotic properties that reflect historical and present management in upland grasslands into the models, they were as expected the primary drivers of soil microbial functional parameters (Legay et

al. in prep). Nevertheless, indirect pathways via above- and below-ground plant functional traits were also retained, and increased models fit to predict microbial community structure (microbial gene abundances of N-related processes and F/B ratio), though this was not true for potential microbial activities. The strongest predictive power originated from below-ground traits, suggesting that they are the most closely linked to microbial community structure. We explained these findings by coordinated responses of plant traits and microbial communities to soil abiotic conditions as a result of mechanisms allowing an increase of labile C supply from plants to soil microbial communities (Legay et al. in prep.). These responses could be driven either by plant communities increasing soil nutrient availability, or by microbial communities increasing their capacity to uptake C. Further, more mechanistic investigations are required to better understand the mechanisms by which soil abiotic properties indirectly impact on microbial functional parameters via plant functional traits.
To refine our analysis of the relative contribution of N-cycling bacteria and archea to grassland ecosystem services, we focused on two services strongly associated with microbial properties (Grigulis et al. 2013), nitrate leaching and soil organic matter content. Site specificity, soil properties and plant traits that could directly and indirectly impact these putative links were assessed using a structural equation model framework, based on known ecophysiological properties of these microbial groups. Our models suggest that microbial traits drive several ecosystems processes directly (e.g. nitrification on NO_3 leaching) or indirectly. Both below- and above-ground plant traits modulated microbial functioning, and thereby ecosystem services. Site-level environmental factors, such as soil texture and climate, also strongly modified these relationships (Pommier et al. in prep.).
A further analysis tested to what degree the abundance of N converting microbes is shaped by land management across the 8 grasslands. While we found no consistent effect of land use on denitrifiers, ammonia oxidizing bacteria and archaea overall increased with increasing management intensity (Krainer et al. in prep.). Overall, the composition of fungal communities identified by sequencing of the ITS1 region also differed across management types for the Lautaret and Stubai sites, while there was no management effect in the Yorkshire Dales. These patterns were linked to environmental and plant trait parameters, with pH and below-ground biomass, and to a lesser extent the Fungal-to-Bacteria ratio and soil organic matter content, being significantly linked with fungal community composition (Geremia et al. in prep.).
Finally, a root decomposition experiment was conducted at the Stubai site, with the aim of testing how grassland management impacts on root decomposition and identifying underlying microbial mechanisms. It demonstrated a reduction of decomposition rates on an abandoned site, related to high lignin concentrations, whilst potential cellulase activity was increased. Further analyses of microbial activities and microbial community composition are underway (Krainer et al., in prep. b).

WP5. Projecting future delivery of ecosystem services by mountain grasslands

Objective: To project future ecosystem service delivery according to alternative scenarios.

Land-use and climate change are primary causes of changes in the supply of ecosystem services. While the consequences of climate change on ecosystem properties and associated services are well documented, the cascading impacts of climate change on ecosystem services through changes in land use are largely overlooked. We used common broad storylines combining climate change relevant to each site and societal changes, especially regarding markets and agricultural and environmental policies, in order to project land use maps for each scenario at the Lautaret and Stubai sites. Changes in ecosystem service provision were quantified using statistical models for the range of ecosystem services identified in WP1 at each site.

Lautaret: We modeled expected spatio-temporal trajectories of land management under four climate and socio-economic scenarios for 2030, which were constructed using an advanced participatory approach. First, regional experts from nature conservation and agricultural extension were involved in the co-development of detailed qualitative climate and socio-economic scenarios, expressed as coherent storylines. Second, to translate these storylines into quantitative land management scenarios, we used a role playing game whereby local stakeholders were put in an imaginary future situation and asked to make decisions under scenario constraints. For each scenario, game outcomes were used to map future land management at parcels to landscape scales. Main adaptations were conversion from mowing to grazing and increasing manured area, with varying proportions and locations for these two types of changes differing across scenarios (Lamarque et al. in revision a).
We then used a trait-based framework based on results from WP4 to understand changes in trade-offs among ecosystem services in response to the 4 scenarios (Lamarque et al. in revision b). Statistical models of ecosystem service from WP4 'were parameterised using results and knowledge from ancillary experiments at the

site. Using a simulation experiment, we discriminated direct effects of climate change on ecosystem functioning related to plant functional properties, from indirect effects through farmers' adaptations. Ecosystem service supply was, overall, more sensitive to climate than to induced management change: there was a significant reduction in services associated with agronomic and cultural values that are of interest to farmers and locals under more drastic drought, while regulation services, including soil C sequestration and N retention, which are of greater interest to regional stakeholders, increased (Figure 6). These responses largely reflected the restricted extent of management change in this constrained system, which was incorporated when scaling up plot level climate and management effects on ecosystem properties to the entire landscape. The trait-based approach revealed how the combination of common driving traits and common responses to changed fertility determined interactions and trade-offs among ecosystem services that were stable across scenarios. Specifically, as expected from theory (Lavorel & Grigulis 2012), the implication of 'Leaf Economics Spectrum' traits in several models of ecosystem properties (WP4) resulted in strong trade-offs, e.g. among production associated with more exploitative traits, and soil carbon or nutrient retention associated with conservative traits.

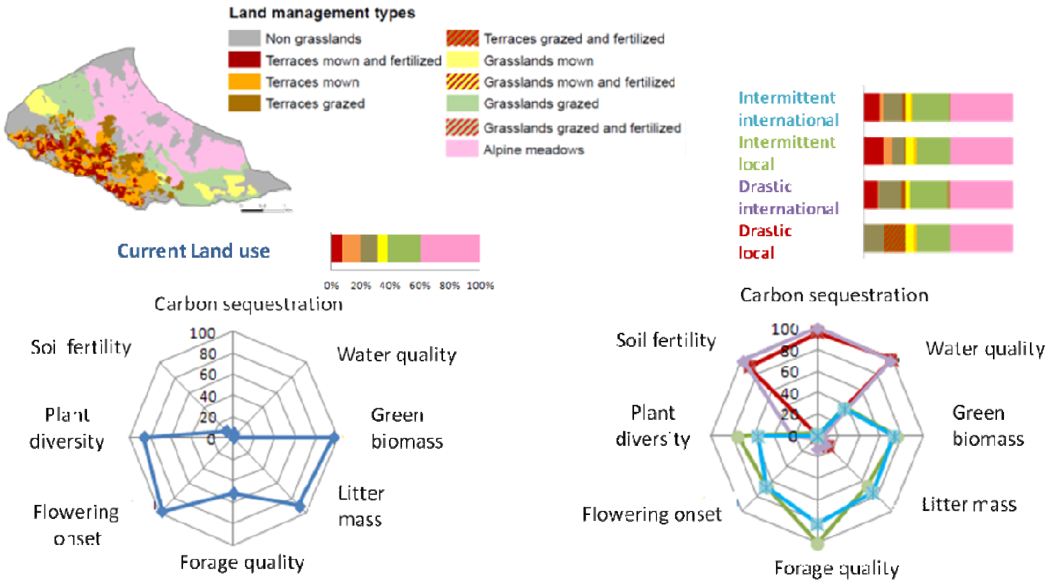


Figure 6: Projections of ecosystem properties underpinning ecosystem services at the Lautaret site using 4 alternative climate and socio-economic scenarios downscaled to landscape management maps (from Lamarque et al. in revision b)

Stubai Valley: In the participative approach to develop future scenarios of grassland management, two socio economic scenarios were used: *(1) localized scenario* and *(2) globalized scenario*. The terms 'localized' and 'globalized' refer to the direction of socio-economic development. Starting from the status quo, we defined three different underlying climate scenarios: *(a) 5-year scenario*, *(b) 20-year scenario*, and *(c) worst-case scenario*. Current and future delivery of numerous ecosystem services for our study site was modeled for the status quo and future landscape patterns (Figure 7). Considering the *status quo* (year 2011), delivery of ecosystem services is the following. The aesthetic value is highest for meadows of low land-use intensity, followed by larch meadows. Moreover, alpine pastures and meadows are preferred to abandoned grassland, whereas meadows of high land-use intensity are least attractive. Concerning carbon sequestration, meadows of very low land-use store more carbon than alpine pastures, whereas meadows of high land-use intensity and arable land store the least carbon. Highest forage quantities and best forage quality are produced by meadows of high land-use intensity on the valley floor. Natural hazard regulation is lower for alpine pastures than for meadows of low land-use intensity due to higher soil compaction and higher surface runoff. The ecosystem service soil stability strongly depends on the slope gradient and the vegetation cover. Regarding the future scenarios of grassland management, the total ecosystem service value for all scenarios is lower than the status quo. However, details for the investigated specific ecosystem services reveal an ambivalent behavior. In other words, less precipitation and higher temperatures generally lower the risk of natural hazards because of less snow cover and reduced surface runoff. However, although areas for forage production are extended, the mean forage quality and quantity decrease because pastures are lower in forage quality and quantity than meadows. To conclude, C sequestration, natural hazard regulation and soil stability increase, while mean forage quality and quantity will decrease.

Figure 7: Future trends in normalized ecosystem services. All scores are normalized by their status quo levels (from Schirpke et al. 2012).

WP6: Dialogue with local stakeholders, land managers and policy makers

Objective: To identify and meet the needs of local stakeholders, land managers and policy makers: (i) to link research and local acceptance; (ii) to raise awareness of biodiversity and ecological processes underlying ES delivery, and of impacts of management change; and (iii) to enhance mutual learning between scientists and stakeholders.

To ensure an efficient involvement of experts and stakeholders we used several methods along a common protocol between the research sites. First, we identified important stakeholders: (1) regional experts working for governmental institutions, regional institutions or NGOs who represent the most important sectors of activity (agriculture, nature conservation, tourism or rural development) and act as decision makers; and (2) local beneficiaries who are consumers (farmers and inhabitants) and/or producers (farmers). Second, expert consultation resulted in knowledge on the perception of ecosystem services, whereas focus group discussions revealed insights into the regional specific challenges and thus those ES perceived locally as most important (WP1). Dedicated workshops focused on the development and downscaling of regionally relevant scenarios into storylines and likely future management changes (WP5). Furthermore, continuous stakeholder engagement was ensured through information leaflets, field demonstrations of used experimental and monitoring methods, as well as presentations and discussion of most important results. In total 45 regional experts were involved in VITAL's research: 22 from the agricultural sector and 23 from non-agricultural sectors. An internal review proved the coherence between the identified goals through stakeholder dialogue and the work carried out.

A stakeholder-based report for policy makers taking into account national and EU level was produced to raise awareness of the importance of biodiversity and ES and to translate the most important results of VITAL in environmental practice and education. We highlighted that: (i) an increasing significance of the ES concept in several political instruments during the last decade; (ii) implementation of political instruments should take into account trade-offs between ES, additional costs and flexibility required by extensive mountain agricultural systems to manage ecosystem services sustainably and the need to inform farmers about ecosystem services by an active learning approach; and (iii) implementation of political instruments should be based on relevant indicators to measure ecosystem services supply.

Furthermore professional inputs were also disseminated into education. For this the online tool kit 'Meadows Matter' was developed and is now being tested in a secondary school. This tool kit was designed to help students and managers to create a conceptual understanding of ecosystem services. It consists of five different modules, each comprising various learning activities, which allow the users to directly 'experience' the concept of ecosystem services through a multi-methodological approach. The learning activities address all senses and build upon students' existing knowledge. The tool kit is conceived for high school students, but all activities can be adapted for adult learners needs.

Synthesis

Overall, we have validated our initial hypothesis that a combination of plant functional diversity and microbial functional parameters determine key mountain grassland ecosystem services from the individual plant to the field scale. Moreover, we have applied these findings, at the individual and field-scale, to model landscape scale ecosystem services. Specifically, we demonstrated that.

(1) The Leaf Economics Spectrum, along with plant size, is highly relevant for plant mineral N uptake and for understanding how plants affect soil microbial communities associated with N cycling, from the individual plant to the community level scale.

(2) Nevertheless, the incorporation of root traits into analyses brings additional, and some times more relevant, understanding of plant effects on soil microbial communities, which supports the need to extend the Plant Economics Spectrum to integrate above-ground and below-ground traits.

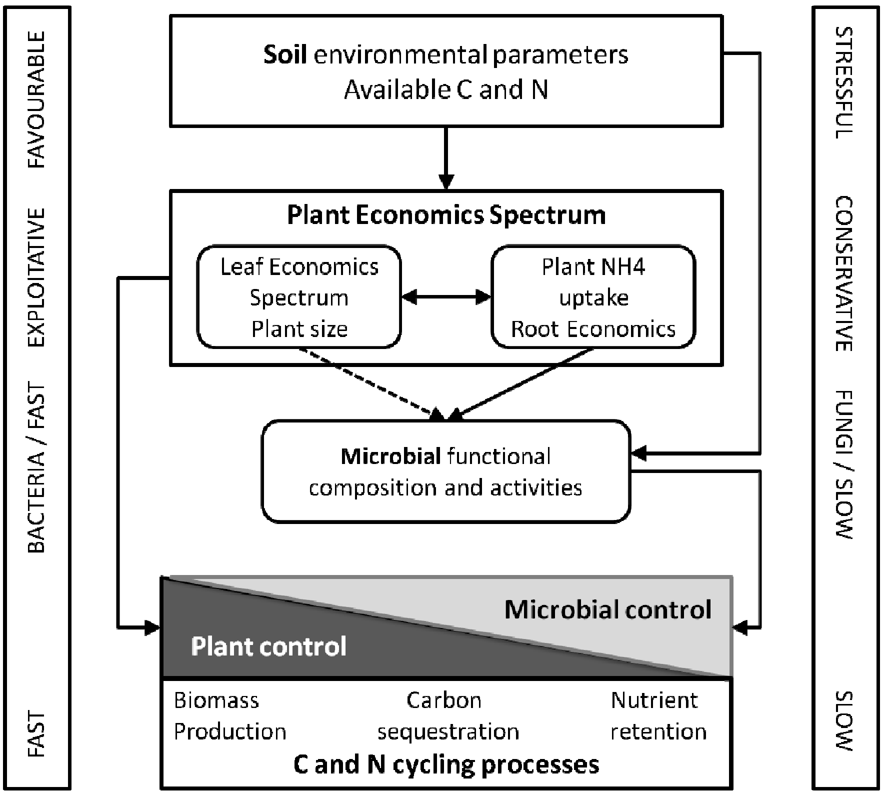
(3) Plant and microbial functional parameters are together associated with key C and N cycling processes underpinning ecosystem services relevant to farmers and regional stakeholders of mountain grasslands.

(4) Overall, extensification of management promotes plant and associated soil microbial communities linked to slower and more conservative C and N cycling processes, and thus to C sequestration and N retention.

(5) Scenarios leading to less intensive land use, e.g. extreme drought, promote C sequestration and N retention at the expense of fodder production and cultural value, thus favouring regional as opposed to local interests.

(6) Implementation of political instruments should take into account such trade-offs, along with additional costs and flexibility required to maintain traditional extensive management and its mutifunctionality, in terms of ecosystem service delivery.

Figure 8 summarises these findings .



List of scientific publications (publications and manuscript with a * are provided as Appendix)

Publications in international journals

Lamarque, P., Quétier, F. & Lavorel, S. (2011) The diversity of the ecosystem services concept: implications for quantifying the value of biodiversity to society. *Compte-Rendus de l'Académie des Sciences, Biologie,* 334, 441-449. (WP1) *

Lamarque, P., Tappeiner, U., Turner, C., Bardgett, R.D., Szukics, U., Schermer, M. & Lavorel, S. (2011) Stakeholders understanding of soil fertility and biodiversity and representations of grassland ecosystem services. *Regional Environmental Change,* 11, 794-804. (WP1) *

Baptist, F., Aranjuelo, I., Lopez Sangil, L., Molero, G., Ba Forne, S., Rovira, P., Legay, N. & Nogués, S. (in prep.) Rhizodeposition of organic carbon by plants of contrasting strategies for resource acquisition: responses to different fertilisation regimes. (WP2)

Baptist, F., Tcherkez, G., Aubert, S., Pontailler, J.-Y., Choler, Ph., Nogués, S. (2009) 13N and 15N allocations of two alpine species from early and late snowmelt locations reflect their different growth strategies. Journal of Experimental Botany 60: 2725-2725 (WP2) *

Cantarel, A.A.M., Pommier, T., Desclos-Theveniau, M., Diquelou, S., Dumont, M., Grassein, F., Kastl, E.-M., Lainé, P., Lavorel, S., Lemauviel-Lavenant, S., Personeni, E., Schloter, M. & Poly, F. (in prep.) Using plant traits to explain plant-microorganisms relationships for N-resources acquisition. (WP2)

Grassein, F., Desclos-Theveniau, M., Lemauviel-Lavenant, S., Bardgett, R., Bahn, M., Lavorel, S. & Laîné, P. (submitted) Relationship between functional traits and inorganic nitrogen acquisition for different species of three European grasslands *New Phytologist*. (WP2) *

Grassein, F., Legay, N., Arnoldi, C., Segura, R., Laîné, P., Lavorel, S. & Clément, J.C. (in prep.) Different plants strategies in N uptake translate into leaf and root functional traits syndromes. (WP2)

Kastl, E., Hufnagel, G., Gschwendtner, S., Engel, M., Buegger, F., Schloter, M. (in prep.) Influence of different redox conditions on the abudance and activity of nitrite reducers and ammonium oxidizers in the rhizosphere of different grasses (WP2)

Mouhamadou, B., Puissant, J., Personeni, E., Desclos, M., Kastl, E.M., Schloter, M., Roy, J., Geremia, R.A. & Lavorel, S. (in revision) Effects of two grass species with contrasting nutrient economies traits on soil fungal communities. *Biology and Fertility of Soils*. (WP2) *

Bardgett, R.D. (2011) Plant–soil interactions in a changing world. *Faculty1000 Reports - Biology,* August 2011, 3, 16 - http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3155187/ . (WP3)

Baxendale, C. et al.(in prep.) Cascading influences of plant community on soil microbial community and N cycling in a modelled system. (WP3)

Baxendale, C. et al. (in prep.) Plant-soil feedbacks and interspecific competition from a plant trait perspective (WP3)

Geremia, R., Bonneville, J.M. et al. (in prep.). Turnover in soil fungal diversity in response to grassland management as related to plant functional traits and soils. (WP4)

Grigulis, K., Lavorel, S., Krainer, U., Legay, N., Baxendale, C., Dumont, M., Kastl, E., Arnoldi, C., Bardgett, R., Poly, F., Pommier, T., Schloter, M., Tappeiner, U., Bahn, M. & Clément, J.-C. (2013) Combined influence of plant and microbial functional traits on ecosystem processes in mountain grasslands *Journal of Ecology,* 101, 47-57. (WP4)*

Krainer U., Kastl E.M., Baxendale C., Legay N., Tappeiner U., Poly F., Pommier T., Bardgett R., Grigulis K., Lavorel S., Clement J. C., Schloter M. & Bahn M. (in prep.) Abundance of nitrogen converting microbes shaped by environmental properties across grassland management gradients. In prep. (WP4)

Krainer, U. et al. (in prep.*)* Microbial root decomposition in a managed and abandoned mountain grassland in the Stubai Valley. In prep. (WP4)

Lavorel, S. (2013) Plant functional effects on ecosystem services. *Journal of Ecology,* 101, 4-8. (WP4) *

Lavorel, S. & Grigulis, K. (2012) How fundamental plant functional trait relationships scale-up to trade-offs and synergies in ecosystem services. *Journal of Ecology,* 100, 128-140. (WP4) *

Lavorel, S., Grigulis, K., Lamarque, P., Colace, M.-P., Garden, D., Girel, J., Douzet, R. & Pellet, G. (2011) Using plant functional traits to understand the landscape-scale distribution of multiple ecosystem services. *Journal of Ecology,* 99, 135-147. (WP4) *

Legay, N., Baxendale, C., Krainer, U., Lavorel, S., Grigulis, K., Dumont, M., Kastl, E., Arnoldi, C., Bardgett, R., Poly, F., Pommier, T., Schloter, M., Tappeiner, U., Bahn, M. & Clément, J.-C. (in prep.) The relative importance of above-ground and below-ground plant traits as drivers of microbial properties in grasslands. *Ecology*. (WP4)

Legay, N., Grassein, F., Robson, T.M., Personeni, E., Bataillé, M.P., Lavorel, S. & Clément, J.C. (submitted) Nitrogen uptake dynamics after snowmelt and peak biomass between plant and soil communities in subalpine grasslands. *Global Change Biology*. (WP4) *

Pommier, T., et al. Microbial key activities sustain important grassland ecosystem services. In prep. (WP4)

Gos, P. & Lavorel, S. (2012) Stakeholders' expectations on ecosystem services affect the assessment of ecosystem services hotspots and their congruence with biodiversity. *International Journal of Biodiversity Science, Ecosystem Services & Management,* 8, 93-106. (WP5) *

Lamarque, P., Artaux, A., Nettier, B., Dobremez, L., Barnaud, C. & Lavorel, S. (in revision) A participatory approach to generate fine-scale projections of land management in constrained livestock systems. *Landscape and Urban Planning* (WP5) *

Lamarque, P.[1], Lavorel, S.[1], Mouchet, M. & Quétier, F. (in revision) Plant trait-based models identify direct and indirect effects of climate change on bundles of grassland ecosystem services. *Proceedings of the National Academy of Sciences* ([1] joint first authors). (WP5) *

Leitinger G, Ruggenthaler R, Lamarque P, Hammerle A, Schirpke U, Lavorel S, Tappeiner U (in prep.). Impact of land use- and climate change on plant available water in climatically different regions in the Alps. *Ecohydrology.* (WP5)

Schirpke U.[1], Leitinger G.[1], Tasser E., Schermer M., Steinbacher M., Tappeiner U. (2012). Multiple ecosystem services on landscape level of an Alpine region: past, present, and future. *International Journal of Biodiversity Science, Ecosystem Services & Management*. ([1] joint first authors). DOI: 10.1080/21513732.2012.751936. (WP5) *

Schirpke U., Tasser E., Tappeiner U. (2013). Predicting scenic beauty of mountain regions. *Landscape and Urban Planning,* 111: 1-12. (WP5) *

Kerle S, Kapelari S, Tappeiner U, (in prep.) Meadows matter - a concept map based tool kit to teach grassland ecosystem services, for *Journal of Environmental Education* (WP6)

WP6 publications in other media

Lamarque, P. & Lavorel, S. (2010) La Feuille du Lautaret n°1: Les services écosystémiques. Laboratoire d'Ecologie Alpine, Grenoble. *

Lamarque, P. & Lavorel, S. (2011) La Feuille du Lautaret n°2: Sécheresses en 2003, 2009, … et après ? Préparons nous à l'avenir ! . Laboratoire d'Ecologie Alpine, Grenoble. *

Lavorel, S. (2012) Plant and microbial diversity sustain ecosystem services. *PanEuropean Networks,* May 2012. *

Lavorel, S., Tappeiner, U. & Bardgett, R.D. (2011) Vital Statistics. *International Innovation,* May 2011, 87-89. *

Table of deliverables

All deliverables have been completed, or are near completion, as evidenced by the list of publications.

There was an overall delay in all deliverables of WP2 due to initial difficulties in soil selection and plant growth leading to: 1) the availability of the last plant samples only in Oct. 2010 and 2) competition between analysis of WP2 data and urgent sample analyses for the WP4 and WP3 experiments, as well as additional measurements in the new WP2 pot experiment (iii). Lastly the change of Postdoctoral fellow at LEM in 2011 delayed the final analysis and writing of results (now near submission – Cantarel et al.).

We decided at the start of the project to change the time lines for WP4 (implemented as soon as 2009 rather than in 2010) and WP3 (delayed by one year in order to guarantee plant establishment). As a result the first outputs of WP4 were early, and overall completed analyses and publications are plentiful. Conversely, the outputs of WP3 have then been delayed, largely because the experiment and extensive analysis of plant and soil properties across the three sites took longer than expected. The experiment involved substantial sampling and analysis of soil and plant material, and, as a result of this, and pressures to complete other WP's,e especially WP4, the complete dataset wasn't available until Autumn 2012. We had a workshop to discuss data analysis in October 2012, and, as a result, data analysis is now well advanced, key findings have been identified, and we are now in a position to prepare papers for submission to international journals.

No.	Title	Lead partner	Date delivered and comments
D0.1	Consortium agreement	LECA	June 2010
D1.1	List for each site of services that stakeholders associate with fertility, perceived relationships between services, and associated indicators. To be published as a single paper across the three sites.	UIBK, LECA	Paper accepted Jan. 2011, published Dec. 2011
D6.1	Stakeholders input for selected ES and biodiversity dynamics, stakeholders information demand	UIBK	Dec. 2009
D2.3	Data set about microbial community structure and activities under different N fertiliser regimes and under different plant species	HELM	April 2011, with changes in technique to qPCR and additional analyses on nitrite reducting genes by LEM
D0.2	First annual scientific and financial report	LECA	Jan. 2010
D2.4	Plant and associated microbial traits for species to be used in the mesocosm experiment by WP2	LECA	Apr. 2009
D2.5	Indicators for microbial response (to be used in WP3 and WP4)	LEM	Feb. 2010
D2.1	Journal paper submission: plant N-form uptake strategies along management / N fertility gradient and relationship to soft leaf and root traits	EVA	Paper re-submitted Jan. 2013
D2.6	Journal paper submission: direct and indirect effects of fertility on microbial community structure and N-related activities – linkages with plant functional traits	HELM	submission of paper now led by LEM - March 2013; a paper on the additional experiment at HELM will be submitted in April 2013
D2.7	Inventory of mycorhyzal species interacting with each of the 18 plant species	LECA	one paper submitted Jan. 2012 - additional mega-rhizotron experiment completed, paper to be submitted Apr. 2013
D0.3	Second annual scientific and financial report	LECA	Jan. 2011
D2.2	Journal paper submission: metabolic linkages between the C and N cycles for 18 species associated with different N fertility levels – a metabolomic and fluxonomic approach	UB	Only 4 species were possible. Paper to be submitted Apr. 2013 with help from LECA PhD student
D3.1	Literature review on coupling of plant and microbial functional diversity in grasslands	ULAN	Done
D5.1	Downscaled management scenarios for the Lautaret and Stubai sites complete	LECA	Sept. 2011. One paper in revision (LECA)
D6.2	Internal review of coherence between the work carried out and the identified goals through stakeholder dialogue	UIBK	Oct. 2011
D0.4	Third annual scientific and financial report	LECA	Jan. 2012
D3.2	Report on the influence of plant trait dominance on microbial functional diversity and nutrient cycling at site level	ULAN	Delayed due to inversion of planning for WP3 and WP4. Data analysis currently in progress and a paper, led by ULAN, to be submitted by August 2013
D5.2	Model chain for the projection of multiple ES under future management scenarios	LECA, UIBK	Dec. 2011

D4.1	Cross-site database including information along management gradients in grasslands at each site on: 1) Variation in community weighted values and functional evenness and divergence indices for soft and hard plant functional traits; 2) Microbial functional diversity and activities; 3) Spatial distribution of mycelia from key mycorrhizal fungi; 4) C and N cycling pools and fluxes	UIBK, LECA	1, 2, 4: June 2011. 3: in progress
D3.3	Cross-site publication submitted on the use of plant trait dominance as a predictor multiple ecosystem service delivery in mixed grassland communities	ULAN	Delayed due to inversion of planning for WP3 and WP4. Analyses by LECA in progress, paper submission August 2013
D3.4	Cross-site publication submitted on the effects of plant functional diversity on mycorrhizal networks	ULAN	Delayed due to inversion of planning for WP3 and WP4
D4.2	Tested and validated model linking plant and microbial functional diversity in grasslands, paper submitted to a leading international ecology journal	ULAN	Paper now led by LECA to be submitted Feb. 2013
D5.3	Scenario projections for the Lautaret and Stubai sites under downscaled scenarios using statistical and dynamic modelling and evaluation of uncertainties. (paper submission at month 48)	LECA, UIBK	Sept. 2012. One paper published (UIBK), one paper in revision (LECA)
D5.4	Scenario projections for the three sites under simplified management scenarios using statistical modelling	LECA	Sept. 12 for Lautaret and Stubai. A qualitative approach for ULAN will be considered in summer 2013
D4.3	Tested and validated model linking plant and microbial functional diversity and activity with ecosystem C and N cycling in grasslands, paper submitted to a leading international ecology journal	LECA	Paper accepted Sept. 2012, published Jan. 2013
D5.5.	Patterns of multifunctionality in scenarios, and relationships to plant and microbial functional diversity (paper submission at month 48)		One paper published (UIBK), one paper in revision (LECA) (as D5.3)
D6.3	Stakeholder-based report for policy makers of options for policy measures to be taken on national and/or EU level		Jan. 2013
D0.5	Final scientific and financial report		Feb. 2013
D4.4	Field assessment of mechanisms providing ecological constraints and opportunities to multifunctionality, paper submitted to a leading multidisciplinary journal		Paper accepted Oct. 2011, published Jan. 2012. A further WP2-3-4 synthesis paper will be prepared when all individual papers are accepted.
D6.4	Toolkit for managers of mountain grasslands and students		Jan. 2013

List all staff and students supported by or affiliated with this project

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UIBK	Univ.-Prof. Dr. Ulrike TAPPEINER, Assoz.-Prof. Mag. Dr. Michael BAHN, Ass. Prof. Dr. Georg LEITINGER, Mario DEUTSCHMANN (Technician)	Dr. Ute SZUKICS (PostDoc), Mag. Romed RUGGENTHALER, Mag. Johannes RÜDISSER, Mag. Melanie STEINBACH, Roland HASIBEDER MSc *Field assistants:* Raphael Hundegger, Raffael Kapelari, Nicolas Lutz, Matthias Zangerle, Mag. Valerie Klein, Mag. Christian Anich, Sarah Kerle, Heidrun Leonhardt, Richard Hastik, Christine Entleitner, Sabine Seel, Marina Köchle	
LEM	Dr Franck POLY (CR), Dr Thomas POMMIER (CR), Nadine GUILLAUMAUD (T), Catherine LERONDELLE (IE)	Dr Maxime DUMONT (post doc), Dr Amélie CANTAREL (post doc), Caroline MOIROT (Technician)	
HELM	Prof. Dr. Michael SCHLOTER, Kornelia GALONSKA (technician), Susanne KUBLIK (engineer)	Eva-Maria KASTL (PhD)	Dr Marion ENGEL (HELM postdoc)
ULAN	Prof. Richard BARDGETT, Helen QUIRK (lab manager)	Catherine TURNER (PhD) Field assistants: Louise WALKER, Jake BISHOP	
EVA	Philippe LAINE (MCF UCBN), Emmanuelle PERSONENI (MCF UCBN), Servane LEMAUVIEL-LAVENANT (MCF UCBN), Sylvain DIQUELOU (MCF UCBN) Raphael SEGURA (Technician INRA), Anne Francoise AMELINE (Technical assistant INRA), Marie Paule BATAILLE (Technician UCBN), Josette BONNEFOY (Technician INRA)	Dr Marie DESCLOS (PostDoc), Anne-Sophie DESFEUX (Technician)	Dr Fabrice GRASSEIN (Post Doc – Région Basse-Normandie)
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Students

Partner	Student	Field	Major Professor	Degree	Dissertation / thesis title
LECA	Nicolas LEGAY	Ecology	Sandra Lavorel / Jean-Christophe Clément	PhD	Relationship between plant functional diversity, soil microbial community diversity, and nitrogen cycling in subalpine grasslands
LECA	Pénélope LAMARQUE	Ecology	Sandra Lavorel	PhD	Ecosystem services in a mountain grassland socio-ecological system
LECA	Iris BUMB	Ecology	Sandra Lavorel	Master's	Effets de la composition fonctionnelle sur la productivité et la qualité des fourrages
LECA	Natacha CLAIRET	Ecology	Jean-Christophe Clément	BSc	No dissertation
LECA	Rémy COURSET	Ecology	Jean-Christophe Clément	BSc	No dissertation
LECA	Edith PRIMAT	Ecology	Jean-Christophe Clément	BSc	Impact de l'abandon des pratiques agricoles traditionnelles sur la diversités des plantes, et sur le cycle de l'N dans les prairies subalpines
LECA	Maud GRARD	Political Science and Environment	Sandra Lavorel	MSc	Rôle des politiques publiques dans la dynamique des services écologiques des prairies de montagne
LECA	Aloïs ARTAUX	Ecology / Agronomy	Sandra Lavorel	MSc	Adaptation des systèmes herbacés subalpins à la recrudescence des sécheresses dans le cadre du changement global
UIBK	Sarah KERLE	Ecology and Biodiversity	Ulrike Tappeiner	MSc	Communicating the Concept of Ecosystem Services. An online tool-kit for high school students to develop a coherent knowledge base on the theme
UIBK	Caroline PERLE	Secondary school teacher accreditation	Ulrike Tappeiner	Mag.	Not yet completed
UIBK	Katharina NIEDERBACHER	Secondary school teacher accreditation	Ulrike Tappeiner	Mag.	Auswirkungen von Klimaveränderungen auf die Primärproduktion von Mähwiesen
UIBK	Uta SCHIRPKE	Biology/Ecology	Ulrike Tappeiner	PhD	GIS-basierte Modellierung von Landnutzungsszenarien und Ökosystemdienstleistungen in Berggebieten
ULAN	Catherine BAXENDALE	Ecology	Richard Bardgett	PhD	Linking plant traits to microbial community and soil properties
HELM	Eva-Maria KASTL	Microbiology	Michael Schloter	PhD	Impact of soil microorganisms on the stability of alpine grassland ecosystems
HELM	Franziska BAUER	Microbiology	Michael Schloter	MSc	Competition of subalpine grassland plant species and microbes for nitrogen in the rhizosphere under different redox conditions in soil
EVA	Agnès MONNIER	Science et technologie – Biologie des populations et des Ecosystèmes	Philippe Laîné	MSc	Caractérisation de l'absorption de l'ammonium chez trois espèces subalpines : effet d'une coupe
EVA	Alexandre COLLIN	Science et technologie – Biologie des populations et des Ecosystèmes	Philippe Laîné	MSc	Etude des capacités d'absorption du nitrate et de l'ammonium chez trois plantes subalpines (*Dactylis glomerata* L., *Achillea millefolium* L., *Sesleria caerulea* L.) du Col du Lautaret
EVA	Anne BISSON	Biology and Ecology	Emmanuelle Personeni	BSc	No dissertation

EVA	Caroline LEFLAMANC	Biology and Ecology	Emmanuelle Personeni	BSc	No dissertation
EVA	Grégory BRUNEAU	Biology and Ecology	Emmanuelle Personeni	BSc	No dissertation
EVA	Thaïs GENARD	Biology and Ecology	Philippe Laîné	BSc	No dissertation
UB	Alexandra CREME	Ecophysiology	Salvador Nogués	MSc	Carbohydrate and nitrogen stores in *Festuca paniculata* under mowing explain dominance in subalpine grasslands

5. Dissemination of results and knowledge transfer

Participation in scientific events; posters and presentations

Conference presentations

Oral presentations:

Bardgett, R.D.B. (2011) Harnessing plant-soil interactions for the enhancement of carbon sequestration in soil. *Plenary Lecture, Soil Science in a Changing World*. Wageningen, The Netherlands.

Bardgett, R.D.B. (2012) Above-ground-below-ground interactions: past, present and future. *Keynote Address, Above-ground-below-ground interactions: technologies and new approaches*. Charles Dawin House, London, UK.

Bardgett, R.D.B. (2012) Plant-soil interactions in a changing world. *Gatsby Lecture*. York.

Bardgett, R.D.B. (2012) The root of the problem: plant-soil interactions in a changing world. *Plenary Lecture, Current Themes in Ecology: Soil, Biodiversity and Life*. Wageningen, The Netherlands.

Baxendale, C. (2012) The role of above-ground and below-ground plant traits in driving microbial abundance and activity. *Above-ground-below-ground Interactions: technologies & new approaches*. Charles Darwin House, London, UK.

Baxendale, C. (2012) The role of above-ground and below-ground plant traits in driving microbial abundance and activity. *British Ecological Society*. Birmingham University, Birmingham, UK.

Cantarel, A., Pommier, Th., Dumont, M., Personeni, E., Lemauviel-Lavenant, S., Lainé P., & Poly, F. Relations entre traits fonctionnels végétaux et traits fonctionnels microbiens d'un sol prairial et impact d'une fertilisation azotée. 10ième Rencontres plantes/bactéries d'Aussois- 2012- 30 janvier - 3 février 2012 Aussois- France

Dumont, M., Pommier, Th., Personeni, E., Desclos, M., Laîné, P., Poly, F. (2010) Relation entre traits fonctionnels végétaux et traits fonctionnels microbiens dans l'utilisation des formes azotées minérales. *Ecologie 2010*. 2-5 Sept. Montpellier, France.

Lamarque, P., Lavorel, S., Quétier, F. & Mouchet, M. (2012) Direct and indirect effects of climate change on bundles of grasslands ecosystem services. *MtnClim 2012, Annual meeting of Consortium for Integrated Climate Research in Western Mountains*. Estes Park, Colorado.

Lavorel, S. (2011) How biodiversity underlies ecosystem services in terrestrial systems. *Research priorities to sustain Ecosystem Services. Conference of the European Platform for Biodiversity Research Strategy*. Budapest, Hungary. (invited presentation)

Lavorel, S. (2011) How fundamental plant functional trait relationships scale up to trade-offs and synergies in ecosystem services - Journal of Ecology Centennial Symposium. *98th Annual Meeting of the British Ecological Society - Journal of Ecology Centennial Symposium*. Sheffield, UK. (invited presentation)

Lavorel, S. (2011) Plant functional effects on ecosystems. *41st Annual Meeting of the Ecological Society of Germany, Austria and Switzerland*. Oldenburg, Germany. (invited plenary presentation)

Lavorel, S. (2012) Plant functional effects on ecosystem services. *Annual meeting of the Royal Society of Statistics, Environment section*. London, U.K. (invited presentation)

Lavorel, S., Courbaud, B., Dobremez, L., Nettier, B., Lamarque, P., Véron, F. & Bonet, R. (2012) Adaptation of mountain regions to drought recurrence in a context of global change. *MtnClim 2012, Annual meeting of Consortium for Integrated Climate Research in Western Mountains - Machida Session*. Estes Park, Colorado. (invited presentation)

Lavorel, S., Grigulis, K., Krainer, U., Legay, N., Baxendale, C., Dumont, M., Kastl, E., Arnoldi, C., Bardgett, R., Poly, F., Pommier, T., Schloter, M., Tappeiner, U., Bahn, M. & Clément, J.-C. (2012) How plant functional traits cascade to microbial function and ecosystem services in mountain grasslands. *European Geosciences Union - General Assembly 2012*. Vienna, Austria.

Lavorel, S., Grigulis, K. & Lamarque, P. (2010) Using plant functional traits to understand the landscape distribution of multiple ecosystem services. *Global Land Project Open Science Meeting*. Phoenix, AZ.

Lavorel, S., Grigulis, K., Lamarque, P., Colace, M.-P., Garden, D. & Girel, J. (2010) Using plant functional traits to understand the landscape distribution of ecosystem services. *Solutions for Sustaining Natural Capital and Ecosystem Services*. Salzau, Germany.

Lavorel, S., Grigulis, K., Lamarque, P., Colace, M.-P., Garden, D. & Girel, J. (2010) Using plant functional traits to understand the landscape distribution of multiple ecosystem services. Alter-Net workshop: *Ecosystem services and Biodiversity: what is the link between the two?* , Vienna, Austria.

Lavorel, S., Grigulis, K., Lamarque, P., Colace, M.-P., Garden, D. & Girel, J. (2010) Using plant functional traits to understand the landscape distribution of multiple ecosystem services from subalpine grasslands. *International*

GMBA-DIVERSITAS conference "Functional significance of mountain biodiversity" Chandolin, CH. (invited presentation)

Lavorel, S., Grigulis, K., Krainer, U., Legay, N., Baxendale, C., Dumont, M., Kastl, E., Arnoldi, C., Bardgett, R., Poly, F., Pommier, T., Schloter, M., Tappeiner, U., Bahn, M. & Clément, J.-C. (2012) How plant functional traits cascade to microbial function and ecosystem services in mountain grasslands. *3rd European Congress of Conservation Biology*. Glasgow, U.K. (invited presentation)

Lavorel, S., Lamarque, P., Courbaud, B., Dobremez, L., Nettier, B. & Véron, F. (2012) Adaptation des territoires marginaux aux changements globaux - Le cas des territoires de montagne. *Les Changements globaux : enjeux et défis.* Comité National Français pour les Changements Globaux (CNCFG), Toulouse, France. (invited presentation)

Lavorel, S., Lamarque, P. & Gos, P. (2011) Evaluer les services écosystémiques : Concepts et méthodes en écologie. *Séminaire Elevage et environnement en régions chaudes*. Montpellier. (invited presentation)

Legay, N., Grassein, F., Lavorel, S., Personeni, E., Bataillé, M.-P., Robson, M. & Clément, J.-C. (2012) Seasonal variation and land-use effects on competition for nitrogen uptake between plant and soil microbial communities in subalpine grasslands. *British Ecological Society*. Birmingham, U.K.

Schirpke, U., Leitinger, G., Tasser, E. Tappeiner, U. (2012) Impatti futuri sui servizi ecosistemici nelle Alpi: il caso della valle dello Stubai (Austria). XXII Congresso S.It.E., 10.-14.09.2012, Alessandria (I) Schirpke, U., Leitinger, G., Schermer, M., Tappeiner, U. (2012) Wie reagieren Landwirte im Stubaital (A) auf den globalen Wandel? IALE-D Jahrestagung 2012, 24.-26.10.2012, Eberswalde, Germany

Tappeiner, U. et al. (2013) Mountains under watch: Many eyes see more!. International Conference "Mountains under watch 2013: Observing climate change effects in the Alps", Forte di Bard, Aosta, Italy.

Posters:

Lamarque, P., Lavorel, S., Grigulis, K., Colace, M.-P. & Lembke, M. (2009) Determinants of spatial distribution of ecosystem services hotspots provided by mountain grasslands. *Diversitas Second Open Science Conference*. Cape Town.

Lamarque, P., Quétier, F., Artaux, A., Nettier, B., Dobremez, L. & Lavorel, S. (2012) A Participatory Approach to Model Ecosystem Services in the Future. *Planet under Pressure*. London.

Lamarque, P., Tappeiner, U., Turner, C., Bardgett, R., Szukics, U., Schermer, M. & Lavorel, S. (2010) From a diversity of stakeholders' representations to a complex model of ecosystem services. *Solutions for Sustaining Natural Capital and Ecosystem Services*. Salzau, Germany.

Lavorel, S., Grigulis, K., Gos, P. & Lamarque, P. (2012) Understanding ecosystem services trade-offs in agroecosystems. *Planet under Pressure*. London.

Legay, N., Grassein, F., Lavorel, S., Personeni, E., Bataillé, M.-P., Robson, M. & Clément, J.-C. (2012) Seasonal variation and land-use effects on competition for nitrogen uptake between plant and soil microbial communities in subalpine grasslands. *British Ecological Society*. Birmingham, U.K.

Schirpke, U., Leitinger, G., Tasser, E., Bahn, M., Tappeiner, U. (2012) Modellierung von Ökosystemdienstleistungen in Berggebieten: Beispiel Stubaital (Österreich). IALE-D Jahrestagung 2012, 24.-26.10.2012, Eberswalde (D)

Seminars and workshop presentations

Grassein F., Legay N. and Lainé. P. 2011, Régime azoté de trois espèces des praires subalpines. Réunion annuelle des doctorants du LECA, 25 March 2011, Grenoble.

Grassein F., Legay N. and Lainé. P. 2011, Régime azoté de trois espèces des praires subalpines. GDR Traits, 12 April 2011, Montpellier.

Lamarque, P. & Lavorel, S. (2010) From a diversity of stakeholders' representations to a complex model of ecosystem services. *Global Land Project workshop: Representation of ecosystem services in the modelling of land systems*. Aberdeen, Scotland.

Lamarque, P., Tappeiner, U., Turner, C., Bardgett, R., Szukics, U., Schermer, M. & Lavorel, S. (2010) From a diversity of stakeholders' representations to a complex model of ecosystem services. *Decision making, land use, water use and ecosystem services - PhD workshop*. Bayreuth, Germany.

Lamarque, P., Quétier, F., Artaux, A., Nettier, B., Dobremez, L. & Lavorel, S. (2011) Une approche participative pour modéliser les effets de scénarios climatiques sur les services des ecosystèmes. *Colloque des Zones Ateliers*. Rennes, France.

Lavorel, S. (2010) Biodiversidade e serviços ambientais. *Fronteiras da Biodiversidade 2010: Fauna, Flora e Políticas para a Conservação da Biodiversidade no RS*. Porto Alegre, Brazil.

Lavorel, S. (2010) Plant functional effects on ecosystems. Max Planck Institute for Biogeochemistry, Jena, Germany.

Lavorel, S. (2011) Plant functional effects on ecosystems - A synthesis and application to mountain grasslands. *University of Innsbruck, Institute of Ecology*. Innsbruck, Austria.

Lavorel, S. (2012) Los servicios ecosistémicos: un concepto y una herramienta para la gestión de la naturaliza y la conservación de la biodiversidad. *Club Académico, Dia Ciencia.* Universidad del Rosario, Bogota, Colombia.

Lavorel, S. (2012) Using plant functional traits to understand ecosystem services dynamics in a global change context - a transdisciplinary study in mountain grasslands. *CSIRO Seminar*. Canberra, Australia.

Lavorel, S., Grigulis, K. & Lamarque, P. (2010) Using plant functional traits to understand the landscape distribution of ecosystem services from subalpine grasslands. *Centre for Population Biology seminar series*. Silwood Park, U.K.

Lavorel, S., Grigulis, K. & Lamarque, P. (2012) How plant functional traits cascade to microbial functions and ecosystem services in mountain grasslands. *INSTAAR,* Boulder, Colorado, U.S.A..

Lavorel, S., Grigulis, K., Lamarque, P., Colace, M.-P., Garden, D. & Girel, J. (2010) Using plant functional traits to understand the landscape distribution of ecosystem services. *CSIRO Sustainable Ecosystems seminar series*. Canberra, Australia.

Legay, N., Clément, J.C., Poly, F., Pommier, T., Kastl, E. & Lavorel, S. (2011) Chemical vs. structural root traits as drivers of the microbial traits in grasslands. *Colloque des Zones Ateliers*. Rennes, France.

Interactions and joint activities

WP1, 5 and 6 involved participatory research regional experts working for governmental institutions, regional institutions or NGOs in the sectors of agriculture, nature conservation, tourism or rural development. Table 3 summarises these interactions:

		Lautaret	Stubai	Yorkshire Dales
Regional experts	Agricultural sector	6	6	3
	Non agricultural sector (Nature conservation, tourism,…)	7 (1 tourism, 6 Nature Conservation)	3 (2 tourism and 1 Nature Conservation)	4 (Nature Conservation)
Farmers and other local beneficiaries	Farmers	8	18	4

Table 3: Summary of stakeholders involved in VITAL's activities

At the Lautaret site, close collaboration was established with Cemagref / Irstea for the study of farming systems and farmers' adaptation responses to drought as part of the MEEDDM / MEDDTL GICC project SECALP[2], which fed scenario development for WP5. The role playing game was developed in collaboration with INRA experts, including Dr Cécile Barnaud (Toulouse). The Ecrins National Park, CERPAM (Centre d'Etudes et de Réalisations Pastorales Alpes Méditerranée) and the Hautes-Alpes Agricultural Office (Chambre d'Agriculture des Hautes-Alpes) have also been a key partners in the development and implementation of VITAL and SECALP.

At Stubai close collaboration was established with the research centre Mountain Agriculture for the development of land-use and climate change scenarios and farmers adaptation strategies (WP5). Moreover experts of EURAC.research (Italy), mainly Dr. Erich Tasser have been key partners in modeling ES for Stubai.

ULAN developed close links with Natural England, who owns the Colt Park site, and with the local farmer community. This has facilitated the setting up of a new field experiment, funded by BBSRC, to explore how restoration management impacts on ES via plant traits.

2 Lavorel, S., Courbaud, B., Dobremez, L., Nettier, B., Lamarque, P., Véron, F. & Bonet, R. (2011) Adaptation des territoires alpins à la recrudescence des sécheresses dans un contexte de changement global (rapport final). *Programme GICC2*. Ministère de l'Ecologie, du Développement Durable, des Transports et du Logement.

BiodivERsA network

VITAL was presented at the BiodivERsA 2008 project launching meeting, in Lisbon (Sept. 2009).

We participated in the BiodivERsA questionnaire survey on stakeholder engagement and input for guidelines for best practice of stakeholder engagement for BiodivERsA projects (prepared by E. Moore, Joint Nature Conservation Committee, UK). We will participate in the follow up workshop in April 2013.

VITAL results were presented at the BiodivERsA special symposium at the European Congress of Conservation Biology in Glasgow, 1 Sept. 2012:

Lavorel, S., Grigulis, K., Krainer, U., Legay, N., Baxendale, C., Dumont, M., Kastl, E., Arnoldi, C., Bardgett, R., Poly, F., Pommier, T., Schloter, M., Tappeiner, U., Bahn, M. & Clément, J.-C. (2012) How plant functional traits cascade to microbial function and ecosystem services in mountain grasslands. *3rd European Congress of Conservation Biology*. Glasgow, U.K. (invited presentation)

Information / technology transfer

Monitoring methods and research results were communicated on a regular basis to stakeholders, farmers and interested locals in workshops at Lautaret; Stubai Valley and Yorkshire Dales. A field demonstration event and presentations were organized for each site in 2011-12.

LECA has been involved in the Alpages Sentinelles network[3], which develops a participative and transdisciplinary climate change observation system for French alpine grasslands. Expertise from VITAL has been a strong point for the design and implementation of observation methods.

Outreach to the general public

VITAL established an active web site for communication to professionals and the public (*http://sajf.ujf-grenoble.fr/spip.php?rubrique260*)

Table 4 summarises participative and transfer activites undertaken by LECA, UIBK and ULAN at their respective sites.

An information leaflet was produced at each site at the onset of the project in 2009, and sent to all stakeholders and farmers involved in the Workshop series. In addition, informal interactions at research sites allowed real time transfer and information exchange.

VITAL results were presented in two publications for policy makers and decision making audiences:

Lavorel, S. (2012) Plant and microbial diversity sustain ecosystem services. *PanEuropean Networks,* May 2012.

Lavorel, S., Tappeiner, U. & Bardgett, R.D. (2011) Vital Statistics. *International Innovation,* May 2011, 87-89.

Public presentations:

Bardgett, R. (2013) Soils and meadow restoration. *Arnside Natural History Society*.

Lavorel, S. (2011) La biodiversité des alpages. Université Populaire de Cluses (Haute-Savoie), France.

Lavorel, S. (2010) Biodiversidade e serviços ambientais. *Fronteiras da Biodiversidade 2010: Fauna, Flora e Políticas para a Conservação da Biodiversidade no RS*. Porto Alegre, Brazil.

Lavorel, S. (2012) Enjeux, apports et défis de l'approche du développement durable au travers des services écosystémiques. *Science et Développement durable: 20 après Rio, quelles perspectives?* CNRS, INEE, Paris, France.

Lavorel, S. (2012) Los servicios ecosistémicos: un concepto y una herramienta para la gestión de la naturaliza y la conservación de la biodiversidad. *Club Académico, Dia Ciencia.* Universidad del Rosario, Bogota, Colombia.

3 http://www.ecrins-parcnational.fr/actus/51/407-alpages-sentinelles-du-changement-climatique.html

Site	Date	Content	Stakeholders
Lautaret	21 Apr. 2009	Public presentation of the VITAL project	Villar d'Arène farmers
Stubai	7 Aug. 2009	Public presentation of the VITAL project	Farmers in Mieders, Stubaital
Yorkshire Dales	October 2009	Public presentation of the VITAL project	Farmers, Natural England
Lautaret	Dec. 2009	Individual interviews on the perception ofbiodiversity, soil fertility and ES	Regional experts
Lautaret	8 Jan. 2010	Public presentation on farming systems and adaptation responses to drought	Villar d'Arène farmers
Lautaret	27 Jan. 2010	Group interview on perception about biodiversity, soil fertility and ecosystem services	Villar d'Arène farmers and local stakeholders
Yorshire Dales	18 Feb. 2010	Individual interviews on the perception ofbiodiversity, soil fertility and ES	Regional experts
Yorshire Dales	26 Apr. 2010	Group interview on perception about biodiversity, soil fertility and ecosystem services	Local Yorkshire Dales farmers
Lautaret	17 Feb. 2011	Scenario building workshop	Regional experts
Lautaret	8 Apr. 2011	Role playing game on management scenarios under drought	Villar d'Arène farmers
Yorkshire Dales	6 Oct. 2011	presentation of VITAL project and results	Local farmers and local and regional stakeholders
Stubai	24 Nov. 2011	presentation of VITAL project and results	Farmers association (Gebietsbauernrat), Fulpmes, Stubaital
Lautaret	12 Jan. 2012	Role playing game on feedbacks from ES change to management decisions	Villar d'Arène farmers
Lautaret	12 juin 2012	Field day focusing on plant-soil interactions and their consequences for ES	Villar d'Arène farmers, Ecrins National Park and Agricultural extension officers
Lautaret	21 mars 2013	Final public presentation of VITAL outcomes	Villar d'Arène farmers, local stakeholders and regional experts.

Table 4: Summary of participatory and outreach activities at the three sites.

Education projects

As a science communication activity, we developed an education tool kit ('Meadows Matter') for students to acquire necessary knowledge around meadow ecosystem services. Module 1 deals with differences in grassland types and plant diversity, Module 2 demonstrates how organisms, above- and below-ground, are linked through food chains, Module 3 focuses on soil ecology, including soil formation, soil types, diversity, ecology and ecological functions of soil organisms as well as about agricultural influences on soil properties, Module 4 is dedicated on thenitrogen, the carbon and the water cycle and Module 5 synthesizes gained knowledge of previous modules to the concept of ecosystem services. The toolkit is based on several learning activities, card games and one outdoor (optional indoor) activities. 'Maedows matters' is currently being tested in a secondary school. Results of this implementation will be described in two Master thesis conducted at the Univ. of Innsbruck (C. Perle, in prep.; K. Niederbacher in prep.). After the final test and publication the toolkit will be freely available at our web site.

6. Uses and impacts

List of products intended for policy makers or other policy and management stakeholders derived from this project

In addition to the two short publications, WP6 produced a stakeholder-based report for policy makers of options for policy measures to be taken on national and/or EU level. This will be made available via the VITAL web site, and a scientific publication is considered. Besides, we will look for options for publication in a magazine with broad dissemination to European and national policy makers, but budget is no longer available to consider one of the previously used media (PanEuropean Networks, International Innovation), which are expensive.

We will consider any options for further dissemination of VITAL results and conclusions on ecosystem services provided by mountain grasslands in relation to their management and biodiversity. Both LECA and UIBK are closely involved with managers and regional policy makers through their various projects, and will continue to communicate results in formal and informal venue.

Impact statement

VITAL has highlighted and communicated to scientific audiences, agricultural and nature conservation managers, and policy makers the key roles of plant functional diversity and soil microbial diversity for the provision of essential ecosystem services of local and regional interest, including grassland production for livestock rearing, regulation of soil fertility and water quality, carbon sequestration, aesthetic and cultural values. In doing so, it adds to ongoing initiatives in European countries drawing attention to the importance of considering the 'invisible' side of biodiversity for sustaining benefits to society. Incorporation of this knowledge into indicator and monitoring systems is only in its infancy. Given the increasing significance of the ES concept in several political instruments during the last decade, VITAL results have been considered for instance with respect to the implementation of agri-environmental measures, in particular to support the continued mowing of alpine grasslands (collaboration with the Ecrins National Park), or the restoration of low fertility grasslands in Northern England. Further, VITAL results have demonstrated the nature and causes of trade-offs among ecosystem services as a result of functional trade-offs in plants and in soil microbial communities. Such knowledge is essential to guide the development of feasible, multi-sectoral policies and management plans, while considering the constraining socio-economic context of mountain livestock farming. VITAL has also explicitly considered climate change issues through its scenarios, highlighting to managers and regional policy makers the importance of farmers' management responses and their consequences for biodiversity and ecosystem service provision. This has strong implications for agricultural, environmental and regional development policies, and for technical and active learning support for farming communities.

Follow up activities and plans for further exploitation of the results

As indicated in the list of publications, a number of publications additional to those committed as Deliverables in the VITAL work plan have already been produced, or are in prep.. Several experiments additional to the initial work plan were also undertaken in WP2 (experiments (ii) and (iii)) and in WP3

(2 microcosm experiments), in order to pursue complimentary hypotheses resulting from initial results and observations. Conference presentations by PIs in particular will continue to communicate VITAL results and implications.

VITAL results and insights were used to propose the new project REGARDS, funded as part of the BiodivERsA 2012 call. Under this new project LECA, LEM and UIBK, along with new partners, will build on this knowledge, data and models in order to explore the resilience of mountain grasslands to climate and societal change.

Field methods developed during VITAL and trait-based models of ecosystem services are now used by LECA and UIBK in follow up research projects on other research sites, including at the Central French Alps LTSER in the Vercors (ANR SYSTERRA project MOUVE), the Grenoble urban region (FRB Biodiversity Scenarios and Modelling project ESNET), and in the Italian emerging LTER-site Matscher Tal/val Mazia (EURAC project Climate Change). They will also be transferred to interested partners of the FP7 OPERAs project, including ETH Zürich who is implementing trait-based ecosystem service model in an agent-based platform and into landscape visualisation tools.

7. Data Management and timeline for open access

Three data bases, one for each of WP2, WP3 and WP4 were built to host the results on plant functional parameters, microbial parameters, soil parameters and ecosystem properties for various experiments (WP2) and for the three sites (WP3&4). These have been internally available.
Open access is not considered within the short term, until results are fully analysed and published. Based on experience from previous multi-partner and multi-site projects we envisage a 3-year delay until open access can be provided. Plant trait data will be transferred to the TRY data base *www.try-db.org*. The French botanical, soil and plant trait data have been transferred to the DIVGRASS data base (FRB, CESAB). Each of the Lautaret and Stubai sites maintain Geographic Information Systems of their sites, to which the new information layers on ecosystem services have been incorporated for further use by scientific projects and managers. For instance, LECA has already transferred data to the Ecrins National Park for work on agri-environment measures for the maintenance of mowing of alpine grasslands.