increase - An Integrated Network on Climate Research Activities on Shrubland Ecosystems

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INCREASE - FINAL REPORT

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1.1 Executive Summary

The challenge

The climate is changing and ecosystems will face changes in atmospheric CO2, temperature and precipitation. Climate change poses a serious challenge for the scientific community to develop new concepts for research and modelling to provide better and more realistic answers and predictions related to climate change impacts on ecosystems. INCREASE is an EU-funded network of seven large-scale climate change manipulation experiments initiated in 1998 to meet the challenges of climate change. The methodology to be used in INCREASE mimics this global increase in minimum temperature by covering the ecosystem at night by IR-reflective material – i.e. passive night time warming, Further, we apply extended summer drought. Both climatic manipulations create realistic changes in climatic conditions similar to the predictions of change in climate models e.g. increasing minimum temperature and extended summer drought. Further, the location of the infrastructures along natural gradients in temperature (north-south) and precipitation (east-west) in Europe, is an extra dimension of this network of infrastructures.

The objectives

In increase, 1) we evaluate, test and optimize technologies and methodologies for non-intrusive and realistic field manipulation of climate change in shrubland ecosystems. Similarly, 2) we test and disseminate non-destructive methodologies for studies of climate change effects on ecosystems to diminish artefacts and prolong the life time of the experiments. Two major objectives were to 3) gather and disseminate a comprehensive database on the impact of climate change on shrubland ecosystem through time and to 4) develop and test an ecosystem model for shrublands. The last objective was to provide access to large-scale field-based climate change experiments to the wider scientific community.

The methodology

The aims have been achieved by bringing together a multidisciplinary group of researchers and technicians and by collaboration with scientists and networks outside the project. Based on synthesis of current knowledge, identified gaps and further tests and improvement of methodologies, we have produced guidelines, best practice protocols and models beneficial for future research.

The achievements

The "non-intrusive technology" for realistic climate manipulations and non-destructive sampling methodologies have further been developed and the results communicated at conferences and workshops and published either as scientific papers or open access protocols available at our homepage. It includes an automatic system for measurements of both Net Ecosystem Exchange of CO_2 and dark respiration. INCREASE has offered unique facilities for European scientists to study longer term effects of climate change on shrubland ecosystems. In total, the eight installations have hosted 65 user projects with 111 scientists and provided 1921 user days. During the first 10 years in operation, extensive climate change research took place. We have gathered and synthesized background and foreground data resulting in >30 scientific publications and a comprehensive database. Major achievements have been development of the COUP model for shrubland ecosystems, water balance estimation tools and phenological models and developed an automated camera system for high temporal resolutions for monitoring vegetation dynamic and phenology.

1.2 Summary of Project Context and Objectives

1.2.1 State of the art and challenges

The climate is changing and ecosystems will face changes in atmospheric CO2, temperature and precipitation. All are key factors in the regulation of biological processes and will affect natural ecosystems. Climate change poses a serious challenge for the scientific community to develop new concepts for research and modelling to provide better and more realistic answers and predictions related to climate change impacts on ecosystems. Climate change research is further challenged due to the complexity of multiple climate change drivers as well as their combination.

Global warming is basically caused by a reduction in the loss of long wave IR-radiation from the earth back into the atmosphere. The temperature increase observed so far has mainly been due to increased minimum temperatures (night). INCREASE is an EU-funded network of seven large-scale climate change experiments, where the first were initiated in 1998 during two previously EU-funded projects: CLIMOOR (1998-2000) and VULCAN (2001-2004) to meet the challenges of climate. The methodology to be used in INCREASE mimics this global warming by covering the ecosystem at night by IR-reflective material – i.e. passive night time warming. The night time warming has an effect of warming on soil and plants by up to 2 ºC. In addition, automated transparent covers activated by rainfall sensors are used to impose a drought period during the summer. Both climatic manipulations create realistic changes in climatic conditions similar to the predictions of change in climate models e.g. increasing minimum temperature and extended summer drought.

The non-intrusive character of the experimental design and the extended use of non-destructive sampling methods within the infrastructures have prevented the ecosystem in the infrastructures from destruction. The long term stability and the realistic manipulations are unique for field experiment with climate manipulations. Further, the location of the infrastructures along natural gradients in temperature (north-south) and precipitation (east-west) in Europe, is an extra dimension of this network of infrastructures.

1.2.2 Objectives and project content

The main objectives of INCREASE are in brief:

- To evaluate, test and optimize technologies and methodologies for non-intrusive and realistic field manipulation of climate change in shrubland ecosystems
- To test and disseminate non-destructive methodologies for studies of climate change effects on ecosystems
- To provide access to large-scale field-based climate change experiments to the wider scientific community
- To gather and disseminate a comprehensive data base of experimental data.
- To develop and disseminate a dynamic ecosystem model for shrubland ecosystems

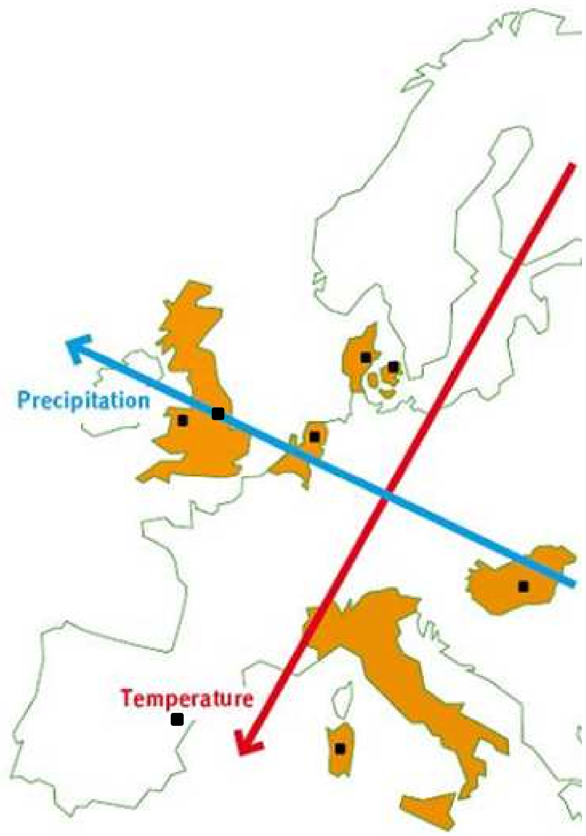
The aims have been achieved by bringing together a multidisciplinary group of researchers and technicians and by collaboration with scientists and networks outside the project. Based on synthesis of current knowledge, identified gaps and further tests and improvement of methodologies, we have produced guidelines and best practice protocols beneficial for future research.

Within INCREASE we have further developed the "non-intrusive technology" for realistic climate manipulations and non-destructive sampling methodologies. The participating infrastructures have offered unique facilities for European scientists to study longer term effects of climate change on shrubland ecosystems. **In** total, the eight installations have hosted 65 user projects with 111 scientists and provided 1921 user days. The INCREASE project is based on long term climate manipulation experiments. During the first 10 years in operation, extensive climate change research took place. We have gathered and synthesized background and foreground data resulting in >30 scientific publications and a comprehensive database based on the long data records from the infrastructures.

1.2.3 Approach and infrastructures

INCREASE is an integrated infrastructure initiative combining networking activities, trans-national access and joint research activities. The project has been organised as a network of seven research infrastructures consisting of large scale field experiments for studies of climate effects on shrubland ecosystems in Europe. Furthermore, the network also includes one phytotron.

The experimental set-up combines 2 different approaches to study climate effects on ecosystems, the "space for time" substitution by investigating ecosystems along the temperature and precipitation gradients in Europe and by ecosystem manipulations. In summary, we superimpose manipulations with water and temperature on existing gradients with respect to the same factors. The locations of the infrastructures along natural gradients in temperature and precipitation in Europe provide an extra dimension, from the cold heath vegetation in Denmark to the warmer garigue in Italy and from the dry land of Hungary to the wetlands of Wales.



Together with the long-term measurements it provides three levels of information:

- Between year data
- Treatment data from climate manipulations
- Across gradient data

1.2.4 Consortium

The INCREASE community has a multidisciplinary profile with expertise within organisms and community ecology, ecophysiology, microbiology, hydrology, biogeochemistry, bio-meteorology, physics, technical design, modeling and data management and we have therefore been able to develop both technologies for climate change experiments and methodologies for assessment of environmental impacts on ecosystem functioning with a minimum of artefact.

The project is coordinated by University of Copenhagen, Denmark with participation of partners throughout Europe; Italy, UK, Hungary, The Netherlands, Denmark and an associated partner in Spain.

1.2.5 Key results and their potential impact

One of the key objectives in INCREASE was to evaluate, test and improve **climate change manipulation technology**. Some of the key findings are published in a peer-reviewed paper (Bruhn et al. 2013). We documented the curtain warming technique and published recommendations of this technique. Further, we tested for artefacts as the technology has been criticized. We found that the Infrared-reflective curtains decreased the relative humidity (RH) measured during the night by 5% and increased the nighttime air temperature by 1.1 ◦C. However, dew point remained unaffected and there was no relation between nighttime RH or nighttime dew and incoming daytime radiation. The RH did not reach saturation during windy nights (about WS > 3 m s^{-1}) in either warming or control treatments. We concluded that although the employment of IR-reflective curtains at nighttime may alter the RH, it is a small change.

The INCREASE project has developed or implemented **non-destructive methods for assessment of climate change effects** on the functioning of shrubland ecosystems. These technologies are of valuable support for ecologists and environmental scientists, which often need to find a compromise between the costs of managing large experimental areas and the need to minimize the area affected by destructive sampling. The focus has been on methodologies for assessment of 1) above- and belowground vegetation responses 2) Net Ecosystem Exchange and 3) soil organic carbon dynamics.

Climate changing affects the main factors controlling **plant growth and timing of phenological events**. This will impact ecosystem structure and functioning. To address the issues of direct ground-based monitoring of plant growth and phenology, we have tested, calibrated and implemented a number of inexpensive methods including NDVI, LAI, aerial photos and visible spectrum digital cameras and compared the methods with the more time consuming ground-based measures using pin-point or plant biomass harvest. There is no clear recommendation as each method has some advances. However, we can recommend a combination of the non-destructive pin-point method giving a 3-D picture of the vegetation with high resolution of community composition and with a fast and more frequent analysis as NDVI for green biomass development and/or photocamera obtaining samples at very high temporal resolutions for monitoring vegetation dynamic and phenology. Within INCREASE, we developed a prototype of the Automated Phenological Observation System (APOS) using standard, commercially available camera, connected to an automated robotic system, which easily can be copied and used under other conditions.

An important ecosystems service of shrublands is carbon sequestration. We focussed on testing and implementing methods with a non- or low-destructive nature to study ecosystem carbon exchange and underlying processes. We have developed and tested a prototype chamber for Net Ecosystem Exchange of CO2 and an **automatic Net Ecosystem Exchange (NEE) chamber system** was developed. We aimed to develop a chamber that can measure not only NEE, but Ecosystem Respiration (ER) and Gross Ecosystem Photosynthesis (GEP) directly, because ER and GEP resembles the processes while NEE is simply the sum of two opposing processes and therefore difficult to model directly. In order to do this, measurements must be made automatically and both under light and darkened conditions, respectively. The developed chamber system (ECO2flux chamber) is a unique and novel approach for an automated ecosystem CO2 flux system. The main parts of the chamber are available as industrial materials normally used for ventilation and scaffold constructions etc. and thus easy to replicate.

Belowground studies of roots are much more complicated than aboveground plant studies, and root biomass, production and root turnover are often difficult to assess. One tool for studying roots belowground is **minirhizotrons**. They are transparent acrylic tubes installed in the soil, a non-destructive method where birth and death of individual fine roots can be followed through time with a camera or scanner. The scanned images give information about root diameter, length, branching, and root hairs on individual roots. Within INCREASE we optimized the methodology and produced thorough protocols based on free software. The protocol is available at the public INCREASE home page and forms the basis of a scientific method paper. Further, **13C isotopic labeling methodology** was developed, tested and published as a method to assess carbon allocation belowground and partitioning among roots, microorganisms and soil.

The infrastructures are based on a **common climate manipulation set-up** and **common protocols** (best practice) for measurements. Both have been tested and optimized during INCREASE and the results are public available for inspiration, structuring of research and avoidance of pitfalls. Data from background > 10 years of operation and foreground of the infrastructures have been gathered in a **comprehensive database**, which has supported the high number of internal and external users of the infrastructure and further will serve scientists globally in the future.

Modeling of processes to ecosystems have been a central part of INCREASE with the purposes of improving our understanding of the generality of processes that drive changes in shrubland ecosystems. We have developed an ecosystem model for schrublands based on the COUP model and it has been successfully applied across all INCREASE sites. We have provided a soil water balance model tool to assess the effectiveness of novel climate manipulation experimental systems. In addition, the simplified soil water balance model was also embedded in an Excel workbook that simulates the daily and seasonal water balance for shrubland ecosystems and the software released in a "beta" version.

The socio-economic relevance of the work can be divided into two categories i) the feedbacks to society of the climate change impact on shrublands (e.g. fire risk, water chemistry, biodiversity, carbon sequestration etc) and ii) the value of the knowledge for the scientific community due to scientifically innovative and improved manipulation technology, guidance for new experiments, protocols for non-intrusive methodologies, data sharing through the INCREASE database, upscaling of results for improved understanding. Further, INCREASE has provided 1921 user days to 111 scientists. Considering the nationality of the lead scientist, 15 EU countries were represented and 3 non-EU. Further, the network has educated 10 PhD's – the new generation of scientists with expertise in climate change issues and further provided the scientific community with > 30 peer review publications.

1.3 Main S&T Results/Foregrounds

1.3.1 Optimization of technologies and methodologies for non-intrusive field manipulation of climate change in shrubland ecosystems

Climate is changing leading to changes in main factors controlling plant growth. This will impact ecosystem structure and functioning and in turn, through feedback mechanisms, potentially accelerate the climatic changes. High priority should therefore be given to ecosystem experiments and long-term observations in order to improve our understanding of ecosystem processes and further develop ecosystem models (e.g. Beier et al., 2004). In order to obtain validation data for such models, it is essential to simulate climate changes at field scale with effective, reliable, and realistic techniques.

Global warming is basically caused by a reduction in the loss of long wave IR-radiation from the earth back into the atmosphere. The temperature increase observed so far has been due to increased minimum temperatures (night). INCREASE is an EU-funded network of seven large-scale climate change experiments. The methodology used in INCREASE mimics this global warming by covering the ecosystem at night by IR-reflective material – i.e. passive night time warming. The night time warming has an effect of warming on soil and plants by up to 2 ºC. In addition, automated transparent covers activated by rainfall sensors are used to extend drought period during the summer. Both climatic manipulations create realistic changes in climatic conditions similar to the predictions of change in climate models e.g. increasing minimum temperature and extended summer drought.

1.3.1.1 Warming technologies

Warming technologies were evaluated in terms of performance, economy and side effects in an Increase Workshop, Roskilde, Denmark, 7.-9. September 2009. The workshop recommendations for prioritized needs were: Get close to the scenarios, daytime warming important, improve winter heating, improve summer heating and increase precipitation. These recommendations was taken into account when designing the below test site.

In order to improve the passive nighttime warming system a test site was constructed at DTU for the purpose to experimentally evaluate potential improvements of the passive warming by IR-reflective curtains.

The experimental site at Risø-DTU (55◦41’19’’N, 12◦ 06’18’’E) which started in August 2010, included 9 rectangular plots (3.2 m × 3.4 m) surrounded by a steel frame. The plots were positioned in three rows and each row contained three plots with the longest sides of the plots pointing in East-West direction. Three different warming systems were applied in three replicates, one of each system in each row. The three systems were:

• an automatic curtain build of hollow double layer aluminium lamellas (Alu-lamellas) positioned horizontally c. 75 cm above the soil surface on the steel frame surrounding the plot

• a similar system but with polystyrene filled aluminum lamellas (AluIns-lamellas) positioned horizontally c. 75 cm above the soil surface on a steel frame

• a control plot without the curtain, but with the steel frame and an aluminum mock-up simulating the physical design of the enclosure for the motor and spring

The curtains were rolled out to cover the vegetation 30 min after sunset and retracted 30 min before sunrise except for the following events:

• Rain – curtains were retracted in case of rain during the Night (sensitivity <0.1 mm).

• Wind – the curtains were removed at high wind speeds (>10 m s−1).

• Dewfall – the curtains were removed in case of dewfall (max 30 min.).

The response time for the curtains, from full coverage of the plots to a complete withdrawal or vice versa was 16 s.

In addition to the basic automatic nighttime operation of the curtains a set of manual operations were tested in campaigns in order to identify possible improvements of nighttime warming and/or interactions among controlling factors. The following setups were conducted in different combinations:

(1) Additional insulation of the curtains: extruded polystyrene blocks (c. 10 cm×60 cm×80 cm, H×L×W) were placed on top of the polystyrene filled aluminum lamellas (AluIns-lamellas) after the curtains were pulled out at sunset and removed before withdrawal of the curtains at sunrise.

(2) Extension of the cover time of the curtains (pre-sunset): The curtains were operated to cover the plots earlier in order to cover the plots for a longer period.

(3) Reduced horizontal wind movement underneath the curtains: Vertical wind screens (0.9 m×4.0 m, H×L) made of a steel frame and plastic sheeting placed from edges of the plots on three sites (North, South and West)

(4) Additional heat storage: Water filled containers (5 l polyethylene HD, 72 per plot, c. 23 cm×18 cm×12 cm, H×L×W) were placed on three plot edges (North, South and West, 24 per edge) and kept in the same position during the campaign.

Here we highlight the major results from the test site. More details can be found in Bruhn et al. 2013.

Far-IR reflection by curtains. The far-IR (10–12 µm) reflection properties by small samples of different types of curtain materials were tested using a gold integrating sphere (Table to the right). Based on these measurements we decided to test the potential of the hard aluminum lamellas (Alu-lamellas) with a far-IR reflection of 95–96% at the DTU-field site. This material was chosen because of its robustness and high

Long-wave (10–12 µm) IR-reflective properties of different curtain materials.

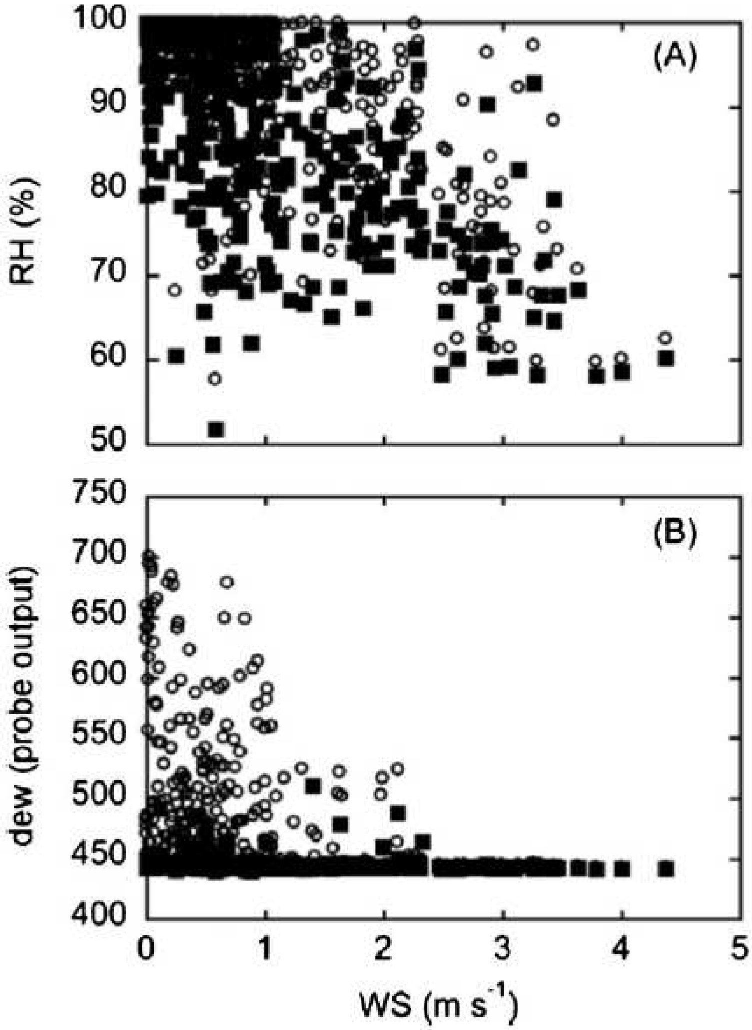
Material	Reflection (%)	Absorption (%)	Transmittance (%)
White fabric (CLIMAITE), old	10	90	0
Alu-mesh (Vulcan), old, shining site	50	40	10
Alu-mesh (Vulcan), old, dull site	10	80	10
Alu-mesh (Vulcan), new, shining site	70	28.5	1.5
Alu-mesh (Vulcan), new, dull site	15	83.5	1.5
Alu-lamella (DTU), new	96	4	0
Alu-lamella (DTU), old	95	5	0
Alu-lamella (chrome), new	91	9	0
Alu-lamella (anodized), new	3	97	0
Alu blanket, new	65	35	0
Gold blanket, new	70	30	0
Alu-flex (wall insulation), new	100	0	0
Alu-flex (wall insulation), new	96	4	0

0

far-IR reflection percentage. Other IR reflection/insulation materials, such as Air-flex and the commercially available rescue blanket, which would have high reflectivity, were believed be too fragile for long-term field testing.

As already proven by Mikkelsen et al. (2008) and Beier et al. (2004) “nighttime warming only” by the use of IR-reflective curtains does in fact not result in a nighttime warming only. Indeed, both air temperature and soil temperature of the experimental plots experienced what could be termed a carryover effect into daytime, soil temperature in particular. This was reconfirmed in this study at the field site.

Relative humidity and dew (point) under the curtains. In this study, we found at Porto Conte that the IR-reflective curtains decreased the RH measured during the night by 5% ($p < .0001$) and increased the nighttime air temperature by 1.1 ◦C ($p < 0.0001$). However, dew point remained unaffected ($p < 0.38$) and there was no relation between nighttime RH or nighttime dew and incoming daytime radiation. The RH did not reach saturation during windy nights (about WS > 3 m s−1) in either treatments (Top panel Fig. to the right). Similarly, at nighttime with high wind speed no dew was formed in both control and warming (Bottom panel Fig. 2 to the right).



Perspectives. Here we have demonstrated some feasible avenues for increasing the achieved ΔT when using IR-reflective curtains at field scale: (i) improving the long wave IR reflection of the curtains, (ii) reducing the lateral wind speed, and (iii) insulating the curtains. Because of the achieved ΔT by the use of IR-reflective curtains is so dependent on climate (incoming energy at daytime, cloud cover, and wind speed) it is obvious that the net warming effect of IR-reflective curtains will vary along geographical and thereby climatic gradients. Lastly, although it may seem counterintuitive, we speculate that in long-term field experiments, less use of the curtains under conditions with no effects or cooling effects may indeed result in an improved overall increase in temperature. The reasoning is that curtains may lose some of their effect by wear and tear due to wind damage of the fabric and/or the roller system. Thus, more ‘intelligent’ employment of curtains within certain boundaries of weather conditions may be a way forward.

1.3.2 Improvement and developing non-destructive techniques and methods for measurements of vegetation responses.

In most long-term field-scale manipulation experiment, like the INCREASE infrastructures, the area which is manipulated is often limited due to methodological constraints. Therefore, there is an urgent need for implementation of technologies and methods to enable non-destructive measurement of essential ecosystem characteristics. We have tested and further developed methodologies for measurements of vegetation indices as biomass, NEE, phenology and growth and belowground carbon dynamic with focus on root dynamic, soil carbon and respiration.

1.3.2.1 Direct measurements of Canopy

Changes in biomass allocation (leaf, stems, and roots), changes in the relative cover of species, and changes in standing biomass can be considered as the ultimate effects of climate on the plant community. As such, the assessment of these quantities is at the core of the experiment and is often the most important means of reference or validation for modelling purposes.

In order to follow the changes in biomass as caused by the climate treatments, the non-destructive pin-point method was implemented in the project in order to increase the information that could be retrieved from these measurements: Pin-point data from multiple permanent vegetation quadrats can be used in combination with structural equation modelling to investigate competitive interactions between plant species (Ransijn et al. submitted). This methodology can be used to predict plant community dynamics. Although the ground based pin-point method was found to be a valuable tool for assessment of plant biomass and plant communities by the detailed 3D picture it gives, it is a very time consuming method and only one or a few measurements are possible over a growing season. Another drawback is the relatively small sample areas, which makes the method less suitable for more heterogeneous ecosystems

1.3.2.2 Canopy reflectance

The Normalized Differential Vegetation Index (NDVI) is, perhaps, the most known and used reflectance index; based on the canopy reflectance of radiation in the near infrared (around 800 nm) and in the chlorophyll absorbance wavelength (typically 680 nm). But other wavelengths are also possible. It correlates to the amount of healthy green leafs and the Leaf Area Index of the vegetation. Calibration of NDVI with leaf area index and biomass can be done with destructive measurements outside the experimental plots. NDVI data can be used to follow temporal changes in LAI in the treatment plots. Such a methodology allowed to non-destructively monitor the effects of climate on LAI as an alternative or supplement to the pin-point method. The advantage is the time needed to perform the measurement (3 to 5 hours), which facilitates more frequent measurements to track seasonality. We tested the Spectrosense2 with 4 channel sensor (Channel 1 510, Channel 2 800 nm both NDVI with 5nm bandwidths, Channel 3 - 531, Channel 4 - 570 nm both PRI 5nm bandwidths) from Skye InstrumentsIt was easy, robust and takes incoming light into account and thus it is not depending on clear sky. The disadvantage is the amount of information on the structureand species composition of the canopy that is not comparable with that of the pin-point method and the possible saturation in dense canopies as Calluna heathlands.

Hyperspectral reflectance is the amount of radiation reflected by the canopy along the radiation spectrum with a high spectral resolution in the order of 3-10 nm. **Tools for the remote sensing of vegetation have**

developed considerably in the past decades, and Hyperspectral remote sensing, with sensors that typically have hundreds of narrow contiguous spectral bands between 400 nm and 2500 nm, has the potential to measure specific vegetation variables far beyond the simple measurements done by the 4-channel sensor. Species are characterized by their own spectrum which depends on the optical properties of leaves (leaf thickness, pigment concentration, water content among others) and the canopy structure (LAI, leaf angle distribution).

Studies have demonstrated that Hyperspectral reflectance can provide essential information on the biochemical characteristics of the vegetation and plant physiological performance (Mänd et al., 2010). Among these, the PRI and the FRI indexes were shown to be correlated with the Non-Photochemical Quenching and with the Photochemical activity of Photosystem II. Other indexes can be used to retrieve information on accessory pigments as Anthocyanins and Carotenoids

In terms of understanding the processes underlying changes in NEE and evapotranspiration, LAI remains by far the most important parameter as it reflects the transpirative surface of the canopy and its capacity to intercept light. The success of the NDVI index to retrieve stand Leaf Area Index (LAI) is expressed by its wide use in remote sensing, however the possibility to use the NDVI in mixed stands or heterogeneous canopies is increasing only lately. The relationship between NDVI and LAI is species-specific and it is thus necessary to retrieve species composition from remote sensing or with other direct approaches. Hyperspectral technology can be used to identify the species spectral signature and thus allows to develop models that automatically identify the species. Once the model is trained on the spectral library for the species identification , species specific calibrations between spectral indexes and structural and physiological traits can be applied and weighted on the stand's species composition.

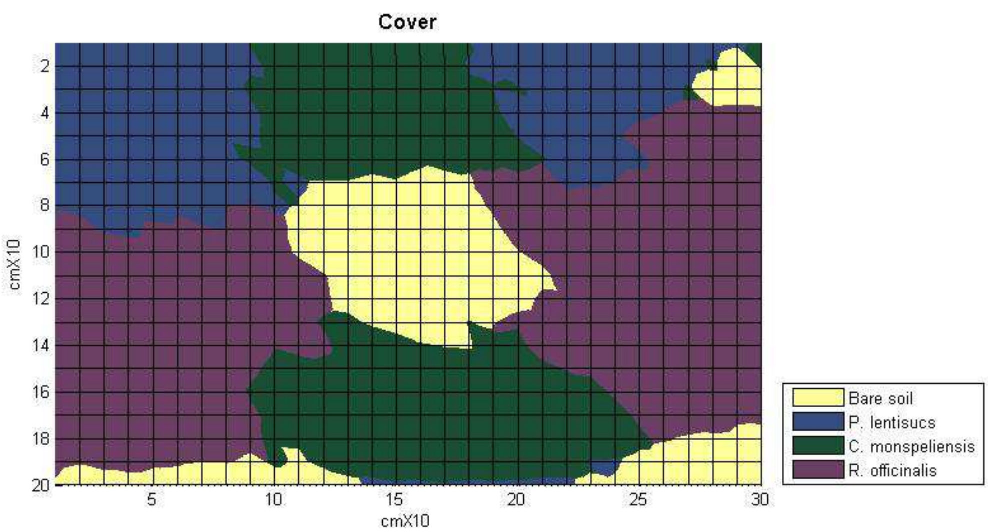


Figure 3. The spectral signature of different species

In the INCREASE project, the spectral signature of different species was acquired allowing to assess its relative cover inside the experimental plots (Fig. 3): by acquiring the hyperspectral reflectance along a regular grid, the method allows to determine the species present in that point. Besides NDVI, an enormous amount of reflectance indexes were developed correlating physical and biochemical properties of the canopy with its optical properties. After the species-specific calibration of these indexes with leaf pigments, water content, photosynthetic performance, the method allows to indirectly monitor changes of a multitude of ecophysiological properties non-destructively.

PRI is based on the reflectance measured at 570 nm and 531 nm and correlates with the turnover of the xanthophyll cycle which is used by plants to dissipate the excess radiation intercepted by the leaf. As such, PRI is proportional to the photosynthetical performance. PRI and fluorescence measurements were performed in parallel allowing to monitor the photosynthetical performance of the species and the way they were affected by the climate treatment. PRI measurements need to be done with a very narrow bandwidth. Comparison of reflectance measurements made with the SpectroSense instrument with reflectance measurements made with a more precise spectrometer shows that SpectroSense measurements (with a broader bandwidth) cannot be used for PRI calculations.

1.3.2.3 Fotocamera

Both pin point and reflectance measurements have a small footprint. That means that information is collected for only a small area. Data collection from larger footprints is desirable given the small scale heterogeneity present in most ecosystems. Ordinary RGB (red, green and blue) digital photography from ca 8 meters above the experimental plots was used to investigate the effect of climatic treatments on vegetation greenness. A greenness index can be calculated with the reflectance values of the red, green and blue channels. Alternatively one could use a camera sensitive in the near infrared domain to monitor NDVI. Aerial photography has the advantage that responses of different species can be separated (if one can discriminate between them) and that data is based on the complete experimental plots instead of a small part of them.

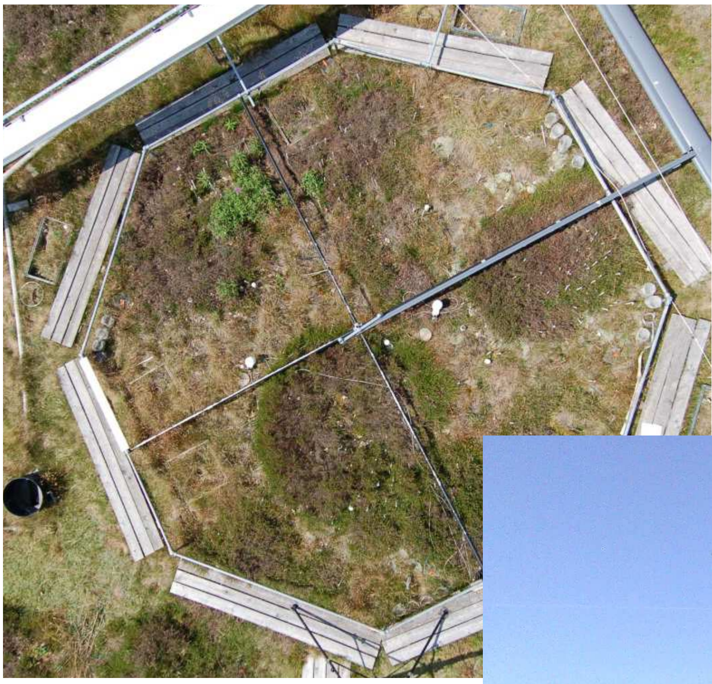


Figure 4: Aerial photograph of an experimental plot at the INCREASE/CLIMAITE site at Brandbjerg, Denmark.

Figure 5: Telescope pole set-up for aerial photography .

1.3.2.4 Semi-automatic phenological observation

Climate change is likely to induce phenological shifts in the vegetation thereby affecting ecosystem functions and interactions among species. Several phenological models are described in the literature, which are able to predict bud burst and leaf senescence based on the correlation between the day of the phenological event and the accumulation of heat. In the INCREASE project, we used The Modified Chill Days Model (C_D), . It is based on the Chill Days Model that was first developed by Cesaraccio et al. (2004) to predict the release of dormancy and, since, it has been widely used in the literature (Yuan et al. 2007; Ledbetter & Sisterson 2008; Chung et al. 2009; Farajzadeh et al. 2010; Rodríguez-Rajo et al. 2011; Chung et al. 2011). As described in Cesaraccio et al. 2004, the model is a sequential dormancy model with an abrupt change from chilling to temperature forcing and it is based on the idea that chill days (C_d) accumulate to break rest, while heating accumulates during anti-chill days (C_a) to overcome quiescence.

The model was successfully validated using thirty years of phenological meteorological data and phenological observations, downloaded from the Pan European Phenology Database. Three widespread European species (*Fagus sylvatica*, *Quercus robur* and *Betula pendula*) growing at different sites in different countries (Germany, Switzerland, Slovenia and Croatia) were used for the analysis.

1.3.2.4 APOS: An Automated Phenological Observation System

Although the importance of phenology for understanding the consequences of global environmental change on vegetation is evident in many recent researches, some concerns are related to traditional monitoring of phenology: data recording is labor intensive and costly; quality of data depends heavily upon the skills and effort of the observers; data can be affected to a certain degree of subjective inaccuracy; they are typically discontinuous and geographically limited. To address the issues of direct ground-based phenological monitoring, recently, the use of inexpensive visible spectrum digital cameras for proximal sensing of phenological events has become more common. One of the advantages of repeated photography is that it allows obtaining samples at very high temporal resolutions, often at daily or hourly intervals, for monitoring vegetation phenology. Moreover, mounting these systems on towers or other platforms provides data at an intermediate scale of observation, allowing a contrast between field-based observations and satellite-derived measures.

An experimental research was conducted with the purpose of designing and developing an automated system for monitoring phenological occurrences over the season. A prototype of the Automated Phenological Observation System (APOS) was developed using a standard, commercially available cameras, connected to an automated robotic system. APOS is designed to perform the following major functions: (1) image acquisition, to frame and pan an area in accordance with the visual coverage of the study site; (2) image transmission, via broadband access to the Internet; (3) image processing, i.e. image stitching and post-elaboration. Once that the camera is connected to the robotic mount, an integrated wizard guides through the key steps for setting up parameters by using an integrated display. To define the rectangular area of the panorama, the upper left photo and lower right photo has to be set. All APOS components work together to transfer the images acquired in the field to a remote server where further sharing and elaboration are made, in particular stitching using a specific software to obtain a high resolution panorama.

APOS has been permanently installed at the Mediterranean site in Italy since May 2012 and monitoring of shrublands phenological stages occurrences was conducted continuously since October 2012.

The desired panorama includes three experimental plots for climate manipulations: control (no manipulation), warming (overnight cover), and drought (interception of the periodic precipitation) treatments. The system was set to acquire one panorama per day at noon. To obtain one panorama, a total of 36 shots are taken (3 rows x 12 columns) with a degree of picture overlapping equal to 30%. On each panorama ROIs (Regions of Interest) focusing major species of the shrubland ecosystem were identified. Image data on shrubland species were systematically recorded and stored in a remote server. A post processing image analysis was performed to obtain information on vegetation status (i.e. colour signals and phenological behaviors).

The resulting data from digital image systems can be a valuable support tool for ecologists, environmental scientists, and land managers providing information useful to interpret phenological responses of plants to climate change, to validate satellite-based phenology data, and to provide input to adaption strategies plans to climate change.

Figure 6 – The Automated Phenological Observation System (APOS) installed at the Mediterranean site in Italy.

Concluding remarks

The INCREASE project has developed or implemented non-destructive techniques and methods to measure and analysis the effects of climate on the functioning of shrubland vegetation. These technologies are of valuable support for ecologists and environmental scientists who often need to find a compromise between the costs of managing large experimental areas and the need of a minimum area that can assure artefacts caused by destructive sampling. These technologies, which could be used in other experiments, and possibly at different scales with minor modifications, also allow to increase the frequency of observations and/or reduce the time needed for them.

An important aspect of these techniques is that they allow to acquire measurements directly at community level, which is the real focus of the experiments, whereas manual measurements only allow to work at individual level.

1.3.3. To test and apply non-destructive methods for ecosystem carbon assessment and important underlying processes of root dynamics and carbon transformations in the soil.

An important ecosystems service of shrublands is carbon sequestration. As a result, ecosystem carbon dynamics is such an essential characteristic. Therefore, we testing and implementing methods with a non- or low-destructive nature to study ecosystem carbon exchange and underlying processes. Figure 1 gives an overview of important ecosystem carbon pools and fluxes that were assessed at the INCREASE sites. In this final report of the INCREASE infrastructure project, we focus on low- or non-destructive methods like (1) gas flux chambers equipped with a gas analyser for analysing Net Ecosystem Carbon Exchange (NEE), (2) low-destructive trenching techniques for partitioning respiration, (3) mini-rhizotrons for root biomass and turnover studies and (4) studying soil carbon dynamics with biomarkers for microbial biomass and by using carbon isotopes (^{13}C and ^{14}C).

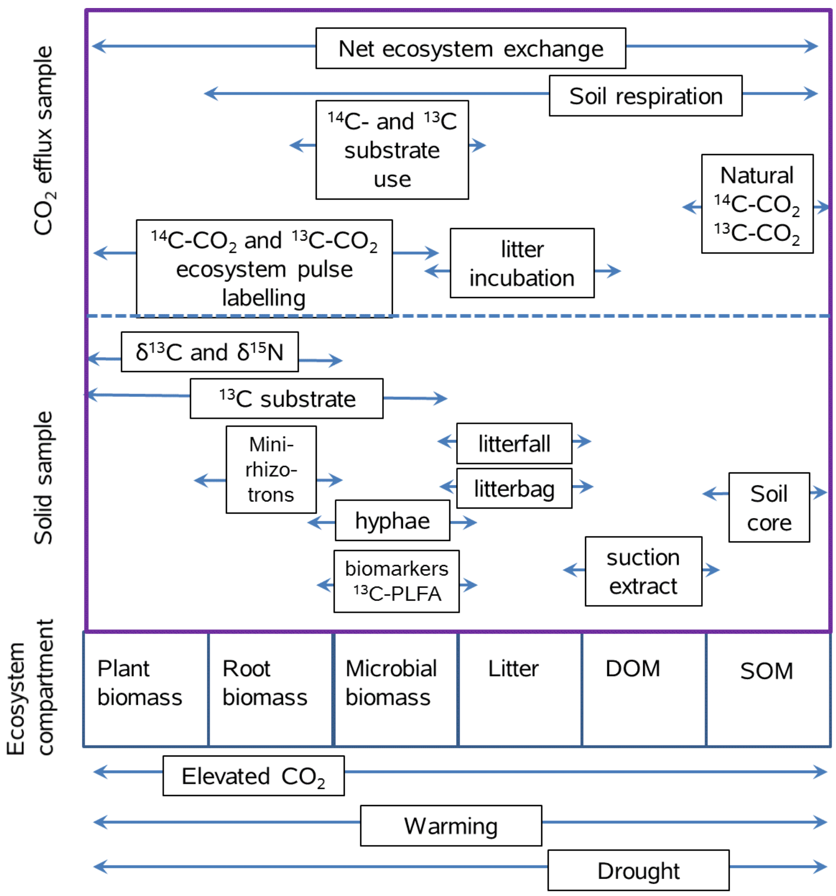


Figure 7: *Overview of the carbon pool and flux assessment techniques used at INCREASE sites. Long-term climate change experiments have often high running costs for maintenance and equipment. Therefore the manipulated areas are often small and low- or non-destructive methods are preferred. The objective of INCREASE was to further investigate the use of these low- or non-destructive techniques.*

1.3.3.1 Net Ecosystem carbon Exchange (NEE)

A new automatic Net Ecosystem Exchange (NEE) chamber system has been developed in the INCREASE project. When initiating this task, we aimed to develop a chamber that can measure not only NEE, but Ecosystem Respiration (ER) and Gross Ecosystem Photosynthesis (GEP) directly, because ER and GEP resembles *the processes* while NEE is simply the sum of two opposing processes and therefore difficult to model directly. In order to do this automatically and near-continuously, measurements must be made automatically and both under light and darkened conditions, respectively. During light conditions, NEE in an ecosystem with photosynthetically active plants will be the net flux of two opposing fluxes – ER (generating a CO_2 efflux from the system) and GEP (generating an uptake of CO_2 to the system), i.e. NEE = ER + GEP. When the chamber is darkened, photosynthesis seizes and NEE = ER. Assuming ER is unchanged GEP can then be estimated by difference between measurements under light and dark conditions, i.e. GEP = NEE – ER. A second aim of the new chamber was to develop a non-destructive base for the chamber in order to minimize the disturbance of chamber installation in the field. Traditionally, chamber bases for these kinds of measurements have been installed 2-30 cm into the soil to minimize lateral mass inside the soil during measurements. However, chamber base installation into the soil causes severe root cutting and isolation of mesocosm ecosystem within the base from the ecosystem outside. A third aim of the new chamber was to focus on the development of the chamber itself and base measurements and data storage on already existing and commercially available equipment. We decided to go with state-of-the-art equipment from LICOR. More specifically, we decided to make the chamber compatible with the LICOR8100/8150 multiplexer system. The advantage of this solution is the obvious flexibility of combining the new chamber with existing and also commercially available soil respiration chambers during field scale applications as well as the availability of hardware and software for data storage and handling.

The developed chamber system (ECO_2flux chamber) is a unique and novel approach for designing an automated ecosystem CO_2 flux system. The main difference from other types of CO_2 flux chambers is that the ECO_2flux chamber closes from the ground to the desired height where it then meets the lid. Movements of both chamber and lid are caused by movement over only one axis, i.e. the central shaft. Within the shaft lie two motors, which move the 'arms' of the lid and chamber tubes. When inactive, the chamber rests close to the ground (Figure 2). The main parts of the chamber are available as industrial materials normally used for ventilation and scaffold constructions etc. The chamber is very robust, easy to install and can be used during almost any weather conditions. Due to a novel chamber base, the disturbance of the vegetation and the soil in particular is minimized.

An example of a field trial with a chamber is shown in Fig. 3. The ecosystem being measured here is a grassland. In this setup, a high frequency of measurements was used (every 15 minutes). Such high frequency would normally not be recommended, as the total daytime when plants are deprived light (during darkened measurements) should be minimized to prevent possible biases in results. However, for testing chamber performance a high frequency is preferable. Note that GEP should be zero at nighttime (here from around 18:00) which it basically is here. The small deviations from zero indicate the level of uncertainty in the whole system. Notice how well GEP follows the measured PAR levels inside the chamber.

Figure 8. *Chamber test at field-site 'Brandbjerg'.*

To our knowledge, this chamber is the first in the world to be capable of being both transparent and darkened. The chamber may be used together with commercially available state-of-the-art equipment from LICOR, which may make the chamber interesting for many users of already existing multiplexted LICOR systems.

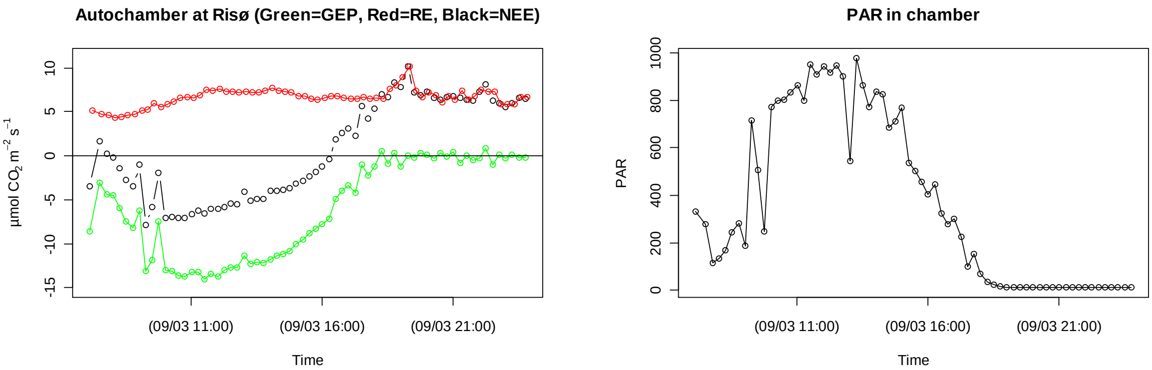


Figure 93. *An example of an high-frequency field trial over 16h with measurements every 15 min. In the left panel NEE (black), RE (red) and GEP (green) is indicated. PAR is indicated in the right panel for the same period.*

Numerous tests, of which only one example is shown here, have shown that measurements are highly reproducible over time. The developed chamber may greatly improve our ability to model ecosystem level fluxes of CO_2 (and potentially other gases) in short-statured ecosystems, i.e. not only shrublands as within the INCREASE community but potentially grasslands, croplands and tundra ecosystems, where this kind of temporal resolution data is still very sparse. There is therefore a significant potential for new advancements in our knowledge of carbon turnover in ecosystems by experimental application of this chamber. Accordingly, we have included the chamber in several grant proposals.

1.3.3.2. Partitioning of respiration

The production of CO_2 in soils is almost entirely from two sources: autotrophic respiration, which is associated with the activity of roots and rhizosphere organisms, and from heterotrophic respiration, associated both with the bacterial and fungal decomposition of organic matter and the soil faunal activity. Root exclusion by trenching is a well-accepted method to partition total soil respiration (R_S) into autotrophic

(R_A) and heterotrophic (R_H) respiration (Figure 4). Parallel measurements of total soil respiration in the intact soil and heterotrophic respiration in the trenched soil without roots is extrapolated by a statistic model to be able to calculate autotrophic respiration by difference. The size of the trenched plots is a function of the size of the plants and of the heterogeneity of the soil. In our heathland they were 60 by 60 cm (area 3600 cm^3). This method was used outside the manipulation plots in a chronosequence of Calluna vulgaris heathlands, with our vegetation as the oldest one. The method worked fine in those measurements. They showed that annual C loss by autotrophic respiration decreased with age, whereas heterotrophic was constant. The effect was that C loss by total respiration also decreased with age.

Figure 10. *Preparing (15 cm wide, 45 cm deep) trenched plots of 60 by 60 cm, at Oldebroek.*

Then, we tried to mimic the same method in our manipulation plots, but now with a low-destructive character. Instead of a trenched plot of 60 by 60 cm, we installed a 45 cm long PVC tube in the soil with a diameter of 10 cm (area 78.5 cm^3). The results showed that the heterogeneity of the soil prevented this relatively small area being used for this method. The conclusion was that for the area of the manipulation plot (20 m^2) and the long-term character of the measurements, this root exclusion method by trenching could not be carried out in a low-destructive manner.

1.3.3.3 Root biomass and turnover

Belowground studies of roots are much more complicated than studies of the aboveground plant, and root biomass, production and estimates of root turnover are often very difficult to assess. One tool for studying roots belowground is minirhizotrons. Minirhizotrons are transparent acrylic tubes installed in the soil, and are a non-destructive method where birth and death of individual fine roots can be followed through time with a camera or scanner. The most known root acquisition devices on the market are the root camera from Bartz Technology Corporation (USA) and the root scanner from CID Inc. (USA). The camera has en image area of 1.35 cm x 1.8 cm, while the root scanner image is 21.6 × 19.6 cm.The images from the scanner give information about root diameter, length, branching, orientation and root hairs on individual roots. By repeated scanning of roots it is possible to follow individual roots for several years and estimate longevity and turnover. However minirhizotrons do not measure the root biomass.

Figure 11. *Scanning roots within the minirhizotrons at Brandbjerg.*

Generally there is no easy way of converting root length observations from minirhizotrons to standing root biomass. To convert root length from images to standing biomass, a conversion factor must be developed, as well as some assumptions regarding depth of view (of the scanner). A depth of view of 2-3 mm has been used although this is an arbitrary number. Furthermore, to upscale root length to root biomass requires an estimate of the specific root length (SRL, m/g). This SRL should be obtained from a destructive root sampling from the site.

An estimate of root turnover was also expected to be available from the minirhizotron images. As birth and death of individual roots can be followed in the images, we expected to be able to calculate the root lifespan and hence the turnover. However after 1.5 years of image acquisition, , less than 19% of the roots had disappeared from the images. This number was too small to calculate a turnover estimate, and we can conclude, that a longer time period is needed when studying roots in heath lands. Furthermore a better image quality would strongly improve the determination between dead and live roots. The data is part of a paper soon to be submitted.

In the INCREASE project, we tested the larger scan image from CID, which is valuable in many ecosystems, but it might also lead to problems in soils with high root density prolonging root analysis indefinite. In that case, it will be necessary to take out sub-samples to get a possibility to track roots individually in a realistic time frame. A methodological paper will in near future be submitted. This paper describes the practical processes around establishing studies of root growth using minirhizotrons in soils with many fine roots, and the development of specialized software to deal with the image preparation. Recommendations, observations and best practices based on experience from the INCREASE project and the use of the Contract Image Sensor (CIS) typed root scanner with model number CI-600 from CID. Inc., are described and discussed.

1.3.3.4 Soil carbon dynamics

1.3.3.4.2 Substrate mineralization

Rhizodeposition is carbon input to soil organic matter through roots. Climate change drivers, drought, warming and especially elevated CO2 are understood to alter the quality and quantity of carbon inputs to soil through rhizodeposition. Rhizodeposition stimulates soil biological activity and influences the turnover of soil organic matter., The question is if an increased flux of carbon compounds to the soil may contribute to soil organic matter accumulation or increase, the rate of soil organic matter mineralisation through priming of old carbon.

We tested a low destructive ^{14}C labelled substrate induced respiration (SIR) method to determine if the kinetics of microbial CO_2 evolution was altered by climate change treatments, and to relate any changes to ecosystem function of the substrate. This type of profiling is commonly referred to as community level physiological profiling. Commercially available SIR methods such as Biolog or MicroResp™ only measure total catabolic respiration, however, our assay can determine the catabolic utilisation profile, C turnover, and C pool allocation of low-molecular-weight substrates on whole soil. This has the advantage of enabling the attribution of respired $^{14}CO_2$ to the metabolism of radiolabelled substrates, and enabling the study of microbial uptake kinetics and turnover using substrates varying in structural complexity and recalcitrance.

Four functional types of ^{14}C labelled substrates were used, namely (i) simple sugars (fructose, glucose, sucrose), (ii) an equimolar cocktail of 15 amino acids, (iii) organic acids (acetate, malate, oxalate, succinate, citrate), and (iv) the amine sugar N-acetyl-glucosamine a fungal breakdown product.

We found that a double term first order decay model best described our data (Equation 1). Using this model *f* describes the amount of ^{14}C-labelled substrate or metabolite remaining in the soil at time *t*, and the exponential coefficient k_1, describes the initial rapid uptake and respiration of ^{14}C labelled substrate by the microbial community following application. k_2 describes a slower secondary mineralisation phase which we ascribe to immobilisation in microbial biomass and transformation of organic metabolites (microbial turnover) in addition to material absorbed to unavailable soil complexes or metabolites. The terms a_1 and a_2 relate to the proportion of ^{14}C labelled substrate that is associated with each exponential coefficient at time (*t*). The mean residence time (MRT) or substrate half-life ($t_{1/2}$) can be calculated according to Equation 2. Turnover of each pool can then be calculated as the inverse of the mean residence time (1/MRT).

$$f = y_0 + a_1 e^{-k_1 t} + a_2 e^{-k_2 t}$$ Equation 1.

$$t_{1/2} = \frac{\ln(2)}{k_n}$$ Equation 2.

Our main findings showed that the overarching controls on the mineralisation of low-molecular-weight substrates were site pH, moisture, and organic matter content. We were unable to detect a trend in substrate quality mineralisation between treatments but found that below a mean annual temperature of 12 °C catabolic processes are increased by treatment, but carbon allocation remains unaltered. Drought tended to slow catabolic respiration linearly and microbial turnover exponentially reduced below a soil moisture content of 18%. Geographical variation, pH and moisture, had the largest influence on microbial processes, with the exception of a soil phosphate interaction at the Hungarian site.

1.3.3.4.4 ^{14}C Natural abundance (Bomb-C technique)

The Bomb-C technique works by comparing contrasted radiocarbon signatures of the recent and older C, as a result of the nuclear bomb tests in the atmosphere during the 1950s. The use of 'bomb-C' technique has a great advantage, which is the ability to determine the age of C stored in or lost from the soil, with a minimal disturbance of the soil-plant subsystem.

We tested this technique at the Peaknaze field site to assess age of carbon in the soil respiration. The technique worked very well, and we were able to demonstrate results revealing a high heterogeneity in the ^{14}C signature of the soil efflux (ranging from 105.49 to 110.13 % Modern). We found no significant effect of the warming treatment, however we did identify a trend towards the release of older carbon from the drought plots. On average, the carbon being released from the plots was fixed between six and eight years ago; this suggests that the autotrophic respiration may be the dominant source of CO_2 in the soil efflux at this site.

1.3.3.4.4 ^{13}C tracer experiment

A low-destructive method to follow and identify separable carbon flows through all ecosystem compartments is the technique of pulse labelling (Högberg et al. 2008). During pulse labelling, a concentrated input of ^{13}C-enriched substrate as CO_2 or a carbon containing substrate solution is amended to the undisturbed living ecosystem in a restricted period of time (Figure 6). Ecosystem carbon processes will assimilate and transfer the labelled carbon, which reflects the rate and the quantity of carbon transfer between pools. Also, the recent development of techniques for the ^{13}C analysis in specific compounds, constituted a remarkable advance in the study of microbial processes in the soil, such as utilization of rhizodeposits by soil microbes. An example is that the analysis of ^{13}C in specific compounds such as Phosphor Lipids Fatty Acids (PLFA), a biomarker for specific groups of microbes, allows determining which functional microbial groups actively assimilate ^{13}C-labelled added substrates (Reinsch et al. 2013). One pilot study and two large scale field ^{13}C labelling experiment were carried out at the Danish site Brandbjerg. The labeling was combined with a ^{15}N addition in the last study, which made it possible to include studies of the interaction with N. The combining the results from the campaign in 2011 and 2013 gives important knowledge on short term 1-8 days allocation of C to ecosystem C pools and fluxes. A method paper has been published based on the 2011 experiment (Reinsch and Ambus, 2013) and a number of more specific papers are in progress dealing with different soil pools and processes e.g. priming, role of soil fauna, root C and nutrient.

Figure 12. *Set-up of the ^{13}C pulse-labelling experiment at Brandbjerg, Denmark. Ballons contained 13C labelled air in ambient and elevated CO2 concentration (510 ppm).*

At one of the UK sites (Clocaenog) we aimed to study the patterns of rhizodeposition utilisation by microbes along a soil moisture gradient, by applying a ^{13}C pulse-labelling at the late growing-season. This work was part of a broader study, analysing the belowground C cycle in the organic soils at Clocaenog (Figure 7). Transparent domes of 50 cm of diameter and 1m of height enclosing *Calluna vulgaris* individuals were used to apply repeated pulses of $^{13}CO_2$ during 8 hours. The domes were sealed to a core, which was inserted into the ground at least ten days before the pulse, and had several sealed septa to collect gas samples at different times during the pulse period, in order to estimate the evolution of the $^{13}CO_2$ concentration (see figure below). Plants (leaves) and soils from the rooting zone of the labelled shoots were collected at different times since the labelling. Sampling frequency during the first hours after the pulse was higher than later during the experiment. Soils were freeze-dried, sieved to ≤ 50 mm and PLFA were extracted following a modified Bligh Dyer extraction procedure. Fatty acid methyl esters (FAMES) were analysed by capillary gas chromatography combustion-isotope ratio mass spectrometry (GC-C-IRMS). One of the most important problems was achieving a significant amount of ^{13}C signal belowground, in order to get a significant labelling of individual FAMES. Despite the applied ^{13}C dose was considerably high, and that the achieved leaf ^{13}C signature was as high as +185 ‰, the dilution of the tracer into the large pool of unlabelled root biomass of this clonal species was remarkable (average root ^{13}C signature in samples collected within the 48h after the pulse was -28.48‰). Consequently, the FAMEs showed a low level of ^{13}C enrichment. Natural ^{13}C signature of the 16 common FAMEs that could be identified in all the soil samples ranged from -31.6 to -21.8 ‰, and a significant enrichment was detected in only 5 of these 16 FAMEs, with a maximum enrichment of 3.5 ‰.

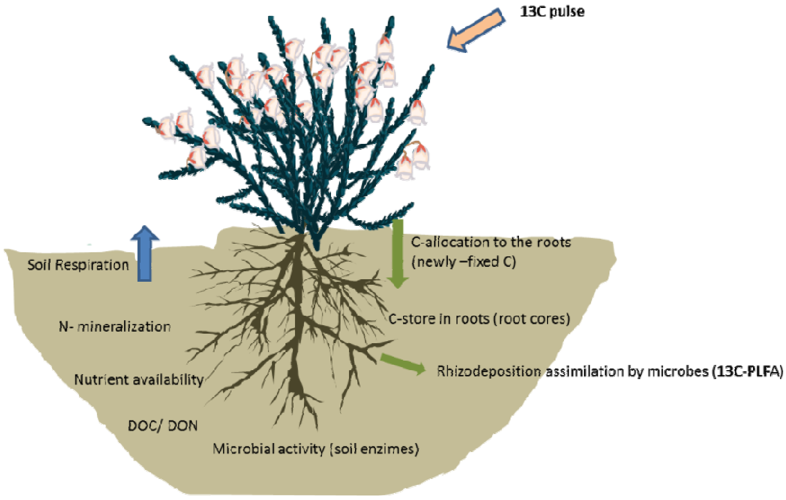


Figure 13. *Processes studied along a soil moisture gradient at the Clocaenog site.*

These studies illustrate the complexity of applying in-situ pulse-labelling experiments in ecosystems dominated by woody plants, which is even more challenging with $^{13}CO_2$ than with $^{14}CO_2$ because of their respective atmospheric backgrounds and detection limits. If specific compounds of the soil microbial biomass are of main interest, then strong doses should be applied. However, the $^{13}CO_2$ concentration inside the chamber should not be much higher than ambient values, because that would lead to unrealistic high CO_2 partial pressure just after the $^{13}CO_2$ application. The application of ^{13}C pulse-labelling experiments is not exempt from disadvantages due to the complexity of the experimental setup and the cost of the analytical measurements, particularly if specific- compounds analyses are conducted. A major constraint to the application of this labelling technique is the potential contamination of the ecosystem with the tracer, which could compromise the validity of current or future measurements of the isotope natural abundances.

1.3.4 The Soil Water Balance Model

Under the WP16, a simplified **soil water balance model** (SWBM) was validated and applied at all sites where the driving data came available. The main aims were (i) to provide a simplified tool for better understanding the seasonal fluctuations of the soil water balance of natural ecosystems, and (ii) to determine the effects of climate manipulation and potential climate change on actual evapotranspiration, soil water availability, hydric stress, etc., of shrubland ecosystems across a north-south gradient.

The SWBM operates with a daily iteration time step, and is driven by time series of corrected rainfall (*Rc*) and actual evapotranspiration (ET_a). Since observed daily rainfall amounts less than 20% of potential evapotranspiration (ET_o) are entirely evaporated and can usually be ignored in the water balance calculations, *Rc* is set equal to 0 when rainfall (*R*) is less than 0.2ET_o. Daily ET_a values are obtained from the calculation of ET_o in combination with empirically determined vegetation coefficients. These coefficients, when multiplied by potential evapotranspiration, are used to calculate vegetation evapotranspiration. Over the past 40years, relatively good techniques have been developed to predict vegetation coefficients that reflect changes in soil moisture stress and other conditions. Some of the techniques have been refined using weighing lysimeters; others have liberally used field observations of soil moisture content and changes. In this work, the method used for determining vegetation coefficients (*Kc*) consists in splitting the computation into 2 components (the so-called dual coefficient methodology). One represents the transpiration component; the second the evaporation. A third component, lack of soil moisture and its impact on transpiration reduction, is also included.

The SWBM provided estimates of soil-water storage, evapotranspiration and water surplus by site and treatment. Further, it provided estimates of the seasonal variation of soil water content as a function of site specific input and duration and intensity of climatic manipulations. Results derived from the SWBM are suitable for ecological and environmental applications investigating the spatial and temporal variability of soil water content. In addition, an MS-Excel application was written and circulated for providing a new tool for simulation and estimation of the water balance of shrubland ecosystems for the internal and external users of the research infrastructure network. In addition, the application of the SWBM throughout the sites and the seasons have shown the importance of having good soil and phenological information from the experimental sites.

The study of soil water regime of natural and semi-natural ecosystems has become more important in recent years because there is growing evidence of an increased annual variability of precipitation and a higher frequency of climatic extremes as a result of global climate change. Even in areas not affected by climatic extremes, the distribution of rainfall during a growing season changes from one year to another, affecting both growth and the ecological stability of natural ecosystems. Apart of the direct physical effect of increased temperature, climate warming interferes with ecosystems through changes of soil moisture regime. For these reasons, quantifying the effects of climate change on water budget may help to assess the potential associated response of ecosystems.

Studies of soil water in ecosystems are necessary to determine vulnerability and responses of vegetation to the expected climate changes. In particular, the soil water balance budget technique can provide useful information on actual evapotranspiration (ET_a), soil water availability or hydric stress.

1.3.5 Fire risk assessment

Wildland fires, considered as the most impacting disturbance process in natural ecosystems, plays a fundamental role in Mediterranean shrubland ecosystems. According to the successional strategies of the Mediterranean vegetation, large areas covered by Mediterranean maquis and shrublands in Europe are a direct consequence of human activities and fires. Besides, wildfires cause economic, ecologic and social losses, and fatalities are not unfrequent. Burnable vegetation (i.e. fuel) structure, in particular fuel load and density, determines the intensity of fire, while weather influences the fire propagation. The chance of a fire occurrence and spread, expressed as fire danger, is usually estimated integrating the factors influencing it (weather, alone or in conjunction with fuel and orography) in the so called fire danger models (or fire danger indexes). The fire danger assessment represents a key activity for land and ecosystems management, fire prevention, prevision, and active fire fighting. Several fire danger indexes have been developed, both for scientific and operational purposes, empirical or process-based, implemented in simple executable applications or more complex fire danger rating systems (e.g. the Canadian Forest Fire Danger Rating System).

Changes in climate are expected to have a significant impact on fire occurrence, and a general increase of fire danger is expected because of the strong influence of climate changes on vegetation, in particular fuel load and water status, factors affecting fire behavior. Also changes in climate extremes will likely have strong impacts on wildfire behaviour and, more in general, on fire regimes.

Most of the available literature on the assessment of fire danger changes under climate warming conditions is based on the application of fire danger models at regional/continental scale coupled with climatic scenarios/datasets. These analyses are often characterized by a low resolution, high degree of simplifications, and several assumptions. The INCREASE project provides an alternative approach for the evaluation of the impacts of climate change. The scale of observation at INCREASE experimental sites, having a common ecosystem but different climate treatments, provides an opportunity to improve evaluation models.

In the INCREASE experimental sites, subjected to increasing temperature and reduction of rainfall amount were artificially and independently, a fire danger model was applied in each treatment using several year of data, aiming to evaluate the impact of temperature warming and drought on fire danger and, more in general, on the European shrubland ecosystems. The applied fire danger index is called IFI – Integrated Fire Danger Index. It accounts for meteorological, ecophysiological, topological and vegetational characteristics of the Mediterranean ecosystems, and it is suitable for applications in areas where the water availability is a limiting factor. IFI is structured for applications near real time (using current weather data or short-term weather forecast) but could be used for fire danger predictions or projections using climate data from IPCC climate scenarios or seasonal climate forecast.

As example of the obtained results, the Table 1 reports the weather data measured in the Italian experimental site during the year 2010.

Table 2. Temperature and rainfall data measured in the Italian INCREASE site during the year 2010.

	Tavg (°C)	Tmax (°C)	Tmin (°C)	Rainfall (mm)
control	16.3	22.7	9.8	823.6
warming	16.9	23.0	10.9	823.6
drought	16.8	23.4	10.2	636.0

With respect to the treatments, an increase in temperatures was observed in warming and drought plots. The rainfall amount was lower (-22.8%) in the drought control. The impact of these climate variations on the potential fire danger was then assessed.

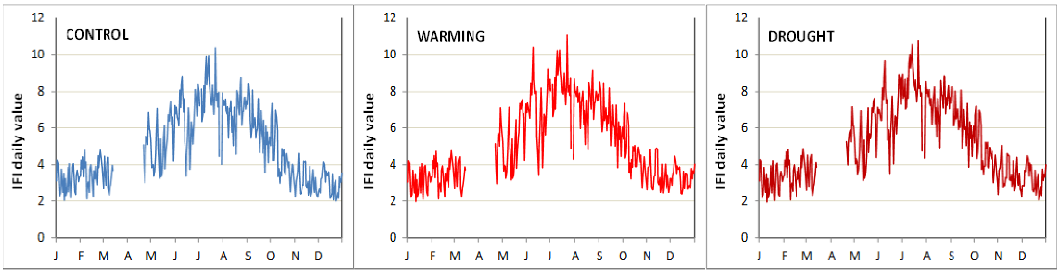


Figure 14. Daily values of IFI at treatment scale in the Italian INCREASE site during the 2010.

Table 3. Mean monthly values of IFI. Italy, 2010.

	C	W	D
J	3.1	3.1	3.1
F	3.6	3.6	3.6
M	3.4	3.4	3.5
A	5.1	5.2	5.5
M	5.1	5.2	5.3
J	6.5	7.0	6.9
J	7.7	8.2	8.3
A	6.9	7.4	7.4
S	6.0	6.4	6.4
O	4.3	4.6	4.7
N	3.0	3.3	3.4
D	3.0	3.4	3.3
	4.82	**5.06**	**5.11**

As expected, an increase in the potential fire danger value was observed both in the warming (+5.07%) and drough (+6.03%) treatments with respect to the control.

The analysis carried out under the activities of the INCREASE project allowed to characterise the fire danger and which of the shrubland ecosystems of Europe are exposed. Data also showed that these ecosystems are particularly vulnerable to changes in temperature and precipitation regimes, showing that, in general, an increase in the fire danger is expected under climate change conditions. Mitigation strategies, in particular fuel management (e.g. reduction of fuel load) could help to reduce the wildfire intensity rates in these ecosystems and, more in general, to reduce the impacts of the increasing of the fire danger levels.

1.3.6 INCREASE comprehensive data base of experimental data.

The INCREASE database (DB) project was developed with the aim to provide a comprehensive integrated database containing information and data from experiments on the potential effects of climate change on shrubland ecosystems in Europe. Specific objectives consisted in improving capacities in the protection, management and storage of data and results from the research infrastructure network, and in providing a web-based access to data and results for a larger research community at European and global level.

Data have been collected at six research infrastructures where large scale field experiments were conducted for a period of time ranging from 4 to 12 years. Data include experimental observations and scientific results on the effects of climatic treatments on vegetation and soil. These data represent a relevant source of knowledge for research studies on ecology, ecophysiology, and climate change impact studies. The activities of the Work Package 5 took advantage of being coordinated with similar initiatives such as the ESF project CLIMMANI (Climate Change – Manipulation Experiments in Terrestrial Ecosystems), whose general purpose is to facilitate networking between past and current terrestrial ecosystem research.
In addition, the INCREASE DB was designed with the purpose of obtaining the following general features: (1) flexibility: i.e. sites, set of measurands, measurands, users, roles, properties, etc., can be added at any time; (2) robustness: i.e. the ability to cope with errors during execution and to continue to operate regardless abnormalities in input, calculations, etc. (invalid or unexpected inputs, system failures, etc.); (3) performance optimization: i.e. the optimizations of the resources used to create an efficient query environment, to

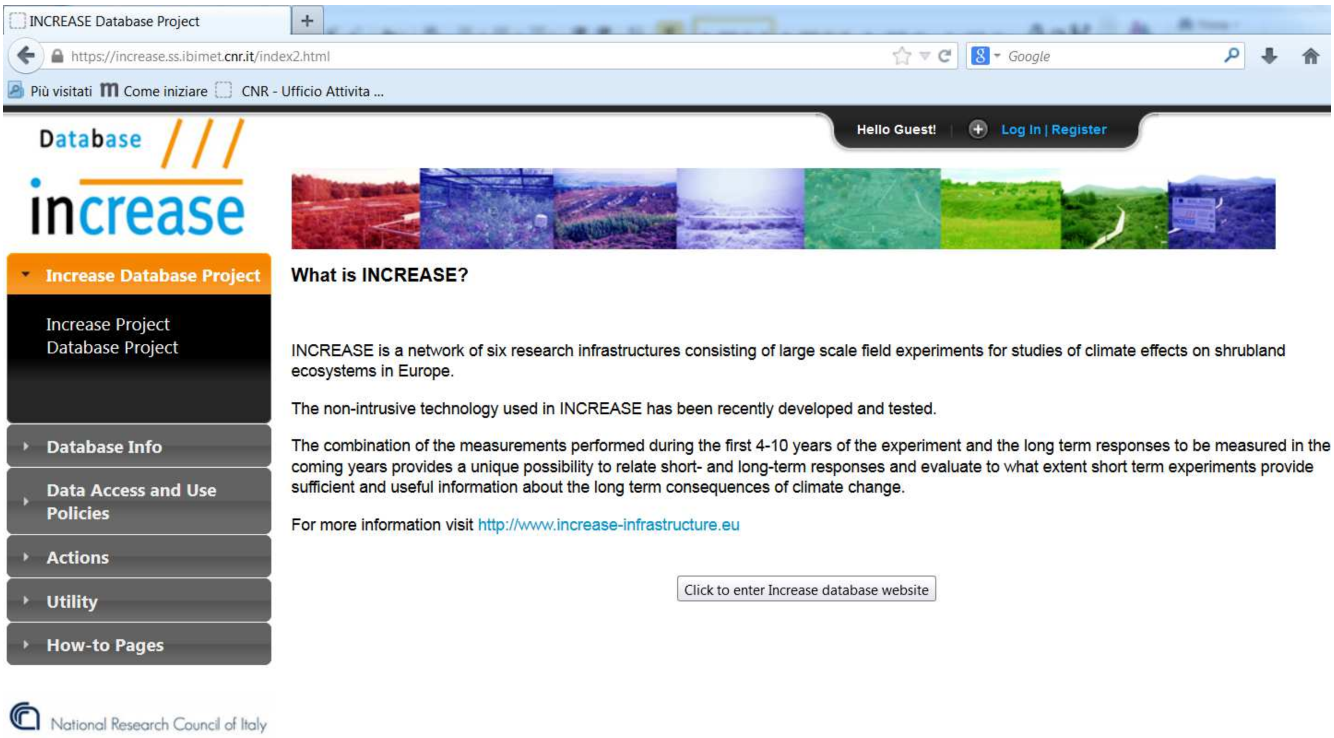
reduce the cost of each operation, and to devise the best strategies to access data; (4) minimizing environmental impact: i.e. the adoption of strategies for saving power required to maintain and manage all the equipment; (5) modularity, standards compliance and security were also took into consideration during database design and implementation stages.

Prior to the implementation of the INCREASE DB working version, a set of different tests were done for validating and for verifying the DB performances. To this aim, a database test environment was implemented and different configurations to be set later into the first working version of the INCREASE DB were checked. All categories of metadata and data, which were previously identified on the base of information provided by the partners, were uploaded into the database test environment. The test DB was also populated with about 90,000 data records of the Porto Conte site (IT).

Tests were performed on two different levels: (1) targets (Units, Integration, System) and (2) objectives (alpha and beta tests, performance/stress test, security). The access to the INCREASE database is provided by a website specifically designed, available at the following link: https://increase.ss.ibimet.cnr.it. The website allows users to interact with

the INCREASE DB by specific roles and permissions (System administrator, Uploaders – site coordinators and contributors, Downloaders – INCREASE community and authorized external users, Report viewer – external users, Users associated with specific sites).

Figure 15– Home page of the INCREASE DB website.



The website informative and functional pages include:

Increase Database Project: where general information on the INCREASE Project and details about the INCREASE database purposes are reported.

Database Info: which describes Experimental Sites, Collected Variables, Data Availability (i.e. information about data collected for each site and periods), Metadata Report (report on metadata for each site, domain and variable requested by the user), Data Access and Use Policies, and Application Form page containing the application form for data access from external users.

Actions: including Upload Data Files, Check Upload, Download Data.

Utility: Change Password and Download Templates.

How-to Pages: where instructions on how to fill out templates are available.

Maintenance of the INCREASE database was conducted to monitor the operation and functioning of the system, and, when necessary, to repair and enhance the system. Ordinary maintenance included user list updating, user support, maintenance systems engineering (e.g. analysis of log and checking of server performance).

In addition, an extensive set of procedures was implemented in order to better check provision of data and enhance database performances. Furthermore, feedbacks from users were also taken into consideration.

Usage statistics of the working version of the INCREASE DB were calculated since its online activation, such as the number of uploaded records per site and domain, the number of unique visitors of the website per month, the number queries by internal users in relation to data download operations.

In conclusion, the INCREASE DB project ended with successful results. There are no predictable major problems that will prevent future improvements of this project, taking also into account the opportunities of cooperating with other similar projects.

1.3.7 Large Scale Experimentation & Standardisation a prerequisite for models and upscaling

1.3.7.1 Common climate change experiments along gradient

There is general consensus that a combination of ecosystem-scale experiments and modelling is needed in order to understand and predict the future impact of climate change on ecosystems (Beier, 2004). Dynamic ecosystem models are useful for integrating our understanding from the individual process studies and thereby provide common tools for forecasting future short and long-term changes in ecosystem functioning (Norby and Luo, 2004). This is, however, a major challenge and will only be useful if the general understanding of how the individual factors interact is good enough. For this, multifactor experiments at the ecosystem scale are crucial both to generate the knowledge needed to build the models and to test and validate the results. INCREASE has taken this further by conducting the same type of experiment across a spatial and climatic gradient. The results therefore combine the short-term effects obtained through experiments at the individual sites with knowledge of long-term differences and stability of the ecosystem processes along the gradient. This further provides insight into the ecosystem processes and direction of change from the present to the future state.

1.3.7.2 Common protocols

The use of common protocols is very important for the development of comparable data sets and strength of the data as a tool for ecosystem modelling. Since the four first infrastructures were established as part of the EU-project Climoor in 1998, followed by another 2 similar set-ups during the EU-funded project VULCAN 2000-2004, we have had common protocols. However, in periods 2004-2009 the infrastructures had no common funding and it was difficult to secure common datasets as work was related to national projects with changing focus. During the INCREASE project, we have worked intensely to homogenize sampling and data handling. This has been a major achievement for the calibration and validation of models, for the cross site synthesis and for the future use of background and foreground from INCREASE.

1.3.8. Ecosystem model for shrubland ecosystems

Previous studies have demonstrated strong potentials for using models to predict climate change impacts on ecosystems (Luo *et al.* 2008; Gerten *et al.* 2008; Vicca *et al.* 2014). Because the biosphere and the atmosphere are very tightly coupled via positive and negative feedback loops (Arneth et al. 2010, Heimann and Reichstein, 2008) climate change projections depend in turn also on the accurate description of the exchange processes that link the atmosphere to the biosphere (Huntingford et al., 2009). For this, one needs robust and reliable dynamic ecosystem models, i.e. models that are able to describe and predict the dynamic development of ecosystems.

Requirements for the use of ecosystem experiments for building, testing ecosystem models and to use these for predictions of future ecosystem responses to changes in the external drivers such as the climate are several:

0. *INCREASE Knowledge on ecosystem structure and functions*

1a. *Availability of data to setup and drive the models*

1b. *Availability of data to calibrate the models to the site*

1c. *Availability of data to validate the results and responses.*

2 *Iteratively INCREASE the quality of experimental infrastructure through collaboration with modellers*

These requirements have to be judged in order to evaluate the suitability of terrestrial experimental research infrastructures to provide data for predictive modelling. The evaluation here is based on the experience from the INCREASE research infrastructure.

Ad. 0: INCREASE knowledge on ecosystem structure and functions.

Predicting the dynamic development of ecosystems over relevant time periods, e.g. 100 years and longer, is by far not trivial, because of the large magnitude of matter and energy flows through ecosystems compared to the small magnitude of the long-term *net* gains or losses. The latter are, however, the material and fuel that is available to build up new biomass or soil organic matter. Process based models simulate the *gross* fluxes with growing accuracy, but even if the accuracy is close to +-10% of a gross flux, this small error is comparably large, e.g. 100% and more of the net flux. The model applications within INCREASE and others have shown that models are successful to simulate the physical and some physiological processes in ecosystems with generally applicable theory, but we are still far from understanding quantitatively some of the key processes, such as the allocation of carbon in the vegetation, laws that describe the formation of functional structures, the mechanisms that stabilize organic matter in the soil, the processes that stabilize plant metabolism under extreme environmental conditions, to mention at least some of the most important ones. Because of the large likelihood for introducing systematic errors in models and the extremely high requirements for accuracy and precision when determining the gross fluxes, the assumption to end up with a mechanistic model in which the so far unknown ecosystem properties and responses simply emerge, is naïve. Confronting models to data and especially to experimental data is therefore vital to develop and evaluate models. Experimental data allow to force ecosystems to more extreme ecosystem states and to compare them with initially equal systems that exist under different conditions. These experiments are key elements to demonstrate alternative ecosystem trajectories forced by well-defined and known alterations of the environment. Ecosystem manipulation experiments produce in the best case data that contains information on cause-effect relationships. Proven or hypothetic cause-effect relationships are the core elements of ecosystem model structures. By providing this new quality of ecosystem response data, the INCREASE infrastructure has a unique potential to develop more realistic, dynamic ecosystem models through intensive scientific collaboration between model developers and empirical scientists, or in other words by confronting theory with novel empirical facts with large relevant information content.

Ad.1a: Availability of data to setup and drive the models

In order to set up and run models, various types of data are required. The data includes basic site information to initialize the model (initial state variables) and climatic data to drive the model runs (driver data). The site characteristics include parameters, i.e. constants that enable 'customizing' the model structure to the special case, on key soil and vegetation characteristics. The quality and number of parameters and initial state variables depend on the accuracy with which the model is to represent the ecosystem complexity and their non-destructive measurement is often a challenge because accurate modelling demands typically more detailed information than the field experiments can provide. However, some parameters are generic and universal parameters from other sites and studies can be used.

Driving variables to run the models are typically climatic variables such as hourly air temperature, precipitation, solar radiation, wind speed etc.. These require measurements at the site by a meteorological station. This is normally not a problem anymore, since the development of commercially available, high quality, automated weather stations; and experimental infrastructures can thus be expected to be able to provide such data. A challenge remains, however, still to assure the representativeness of such measurements. This is especially important in complex terrain, i.e. in hilly landscapes or close to natural and cultural barriers or strong micro climatic gradients. In these cases the wind speed and the radiation components and thus the entire energy exchange with the atmosphere can considerably vary locally. A solution is to run more than one climate station, which will also open the opportunity to fill un-avoidable data gaps with comparable measured data. The constantly high quality of measurements requires robust sensors and constant high quality maintenance and recalibration. Errors from drifting, damaged or dirty sensors propagate directly in model simulation results and model parameter estimates.

Successful representation of the ecosystems' complexity requires detailed and accurate information. The more accurate the measured parameters and the initial state variables are, the more realistic is the model simulation. A key element of scientifically reasonable modelling is the estimation of the uncertainty of the simulation. Both for analytical and numerical uncertainty estimation, the probability distributions of the parameters are essential. This imposes another significant challenge to the experimental field work. The concentration of experimental efforts in research infrastructures increases the density and quality of data and leads therefore to the, from a modeller's perspective desirable situation to increase the number and quality of measured parameters and decrease the demand for parameter estimation from calibration.

Ad.1b: Availability of data to calibrate the models to the site

Calibration is the estimation of un-measured parameter values that are constrained by their theoretical quantitative relationship to measured data. Putting individual data into an ecosystem context is the creative semi empirical aspect of modelling, or in other words the means how models generate more information than the sum of the single data streams contains. This extra information is utilized to constrain unmeasured parameters. The power of model calibration is however limited by the inevitable relationship between system complexity and information content of the test data. If the complexity of the model, e.g., the number of parameters, is much higher than the information on the system, parameter values that are generated from calibrations can easily reach unphysical magnitudes. This phenomenon is called equifinality and is discussed in various modelling studies (Franks et al, 1997, Ibrom et al, 2006, Wu et al, 2012). Equifinality is directly linked to model over-parameterisation. Reducing the number of un-determined parameters enables using more complex model structures and increases the power of model calibration to generate meaningful and accurate parameter values.

Calibration data includes measured responses of key soil, water and vegetation processes. Preferably these data should cover all main ecosystem compartments and processes in order to constrain the model as effectively as possible. Of particular interest here is also response data from periods with strong dynamic changes such as drying/rewetting periods. This is because modelling such periods will demonstrate if the model is able to describe the dynamic changes.

Such data is generally available from ecosystem experiments as these are the key focus of most experiments. However, it can often provide a particular challenge to get sufficient data and as well as data structured in a way that fits the structure of the ecosystem and thus the model.

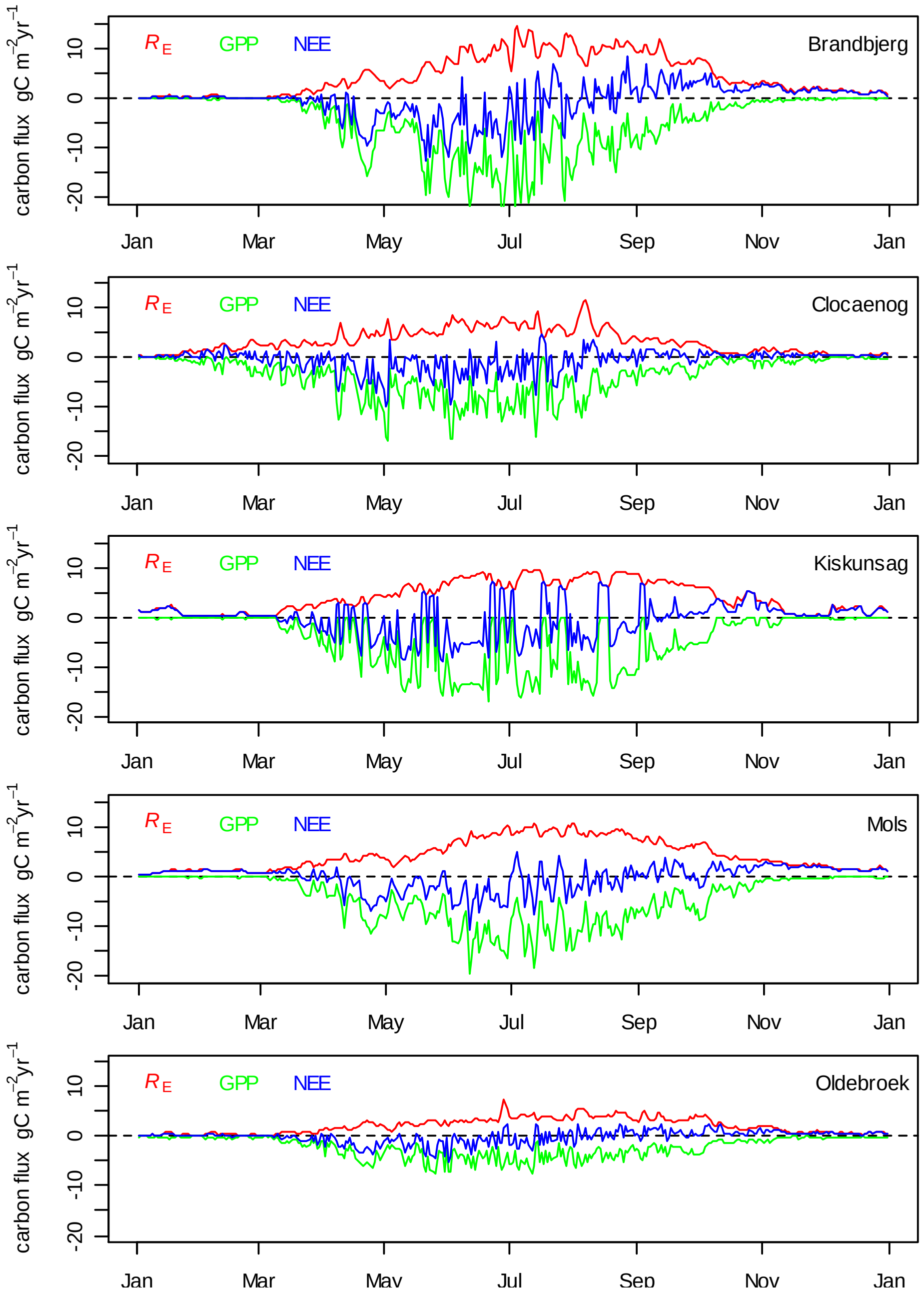
Ad.1c: Availability of data to validate the results and responses

Validation data have the same characteristics as the calibration data being response data from relevant ecosystem compartments and processes. These must on the other hand be independent from the data used for calibration in order to assure that the validation will be independent of the calibration. In order to test, whether the model has predictive properties the validation data also need to be qualitatively different from the calibration data. This requirement is often overlooked, when performing so-called cross-validation studies. Ecosystem experiment data are an excellent example for comparable but independent and qualitatively different data. Further, the validation should preferably cover the process types of particular interest for the up-scaling and predictions. Again, such data are generally available from the experimental infrastructures. However, data may often not be available in optimal structure and/or spatial and temporal resolution needed by the model in question.

Ad.2: Iteratively INCREASE the quality of experimental infrastructure through collaboration with modellers

The quality of the INCREASE infrastructure has benefited in various ways from the collaboration between modellers and empirical scientists. Modellers look in a way on field experiments that is demand driven, e.g. asking which information is needed to understand the system more completely? Field experimentators are forced to look at field experiments in a supply driven way, i.e. asking which information is feasible to collect within fixed economic and physical constraints. Both aspects are important to generate novel and meaningful information with ecosystem experiments. As none of the infrastructures in INCREASE has been built up by the project, the experiments were not optimally set up from a modelling perspective. This can most likely be improved, if modellers are part of the team when creating a field experiment.

Figure 16 : Simulated carbon budgets (NEE), gross-primary productivity (GPP) and ecosystem respiration from 5 INCREASE sites (upward fluxes are positive). The simulations have been performed with the dynamic ecosystem, model COUP (Jansson, 2012).



But even if this was not possible, modelling has improved the data quality and thus the research infrastructure. The internal use of data for modelling helped to develop and test the data base facilities and, even more importantly, revealed a number of data quality issues, when looking at them together with other data streams. This data has now been corrected or flagged.

Generally spoken, models are able and useful to combine different data streams and evaluate their quality on the basis of ecosystem theory and general physical laws. However lack of information and knowledge on ecosystem processes cannot be easily compensated for by modelling. More detailed and diverse parameter and validation data are needed to improve the capacity to accurately simulate the processes in these ecosystems and thus to estimate their vulnerability to the changing climate. The INCREASE project has shown that collaboration between modelers and empirical scientists can trigger an iterative process to improve research infrastructures and thus scientific progress.

1.3.9 Further research needs

One of the main outcome of the tests was that our experimental set-up with warming and drought is still valid and among the very best. The reflectance properties of the alu-roof material was not the best in test but among the best materials. The major drawback is the sensitivity of the material to weather extremes. Although the manipulations are within the lower end for temperature increase, they are realistic and have a significant effect on ecosystem processes. However, what we did not mimic was the combination of extreme events followed by moderate changes in climate. Our cross site syntheses emphasize the need for this combination. Further, there is a need for more advanced experiments than the presence-absence of treatment, e.g. applying several levels as a response surface. This will enable inclusion of natural variation among plots and overcome some of the statistical problems. This aspect was discussed thoroughly during the final workshop and a scientific paper in progress.

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1.4 Additional material

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2 The potential impact and the main dissemination activities and exploitation of results

2.1 Potential impact

The summed effects of anticipated atmospheric and climate changes on ecosystem functioning, and thereby also on human welfare is a significant issue of global proportion. In order to gain an improved understanding on the environmental controls of biological processes, a large number of experimental manipulation studies have been initiated for measurements of subsequent biological changes. The manipulations include elevated CO2, increased temperature or changes in precipitation amounts or patterns. These manipulations have, however, involved a number of unintended and undesirable changes and there has been a need for more sophisticated techniques to mimic climate change, which has been a main task in the INCREASE project. The mean surface temperature is predicted to increase more in northern latitudes. Therefore, most climate change studies have been conducted in the arctic and sub-arctic regions with focus on warming. This geographic bias has led to problems in up-scaling results from climate change studies to a larger scale. Furthermore, extended drought may affect the southern latitudes to a greater extent than northern latitudes, and render ecosystems more vulnerable to risks, such as fire.

Manipulation experiments are often restricted in land area due to methodological and economic reasons so the second task has been to document and further improve non-destructive or less intrusive methods for measurements of ecosystem pools and processes increasing the sustainability of the infrastructures and providing documented tools for similar infrastructures. As long term responses to climate change may be different or even opposite to short term effects, it is necessary to use facilities, which have been running for longer time. The long term sustainability of experimental field sites depends on the use of non-destructive techniques and methodologies for sampling.

The seven large scale field manipulation experiments have been running since 1998 (2001) and a large amount of data are available so a major task has been to gather and synthesize the data. There is a need for long-term response data, which the INCREASE network of infrastructures substantially has contributed to. The combination of the measurements performed during the first 4-10 years of the experiment and the long term responses measured during the project provides a unique possibility to relate short- and long term responses and evaluate to what extent short term experiments provide sufficient and useful information about the long term consequences of climate change. Data have been gathered in a comprehensive data-base and used for water balance model, improved fire risk assessment tools and phenological model and for development and testing of dynamic ecosystem simulation model, on the specific issue of projecting long term responses based on short term experiments.

The socio-economic relevance of the project can be divided into several categories i) the feedbacks to society as better experiments, models and methods produce more realistic results of the climate change impact on shrublands (e.g. changes in soil erosion, fire risk, water chemistry, carbon sequestration, etc) and ii) the value of shrublands as habitats to biodiversity and species persistence and iii) providing the scientific community with documented and optimized designs of realistic climate change manipulation experiments and iv) providing access to eight installations for studies of climate change impact.

2.2 Main dissemination activities – Annex 1 revisited

The distribution of the results obtained in INCREASE has high priority. Originally, the dissemination plan operated at different levels serving three purposes: progress assessment, scientific quality assurance and results sharing. The dissemination activities of results of INCREASE have been and will be distributed according to the table below.

A major effort has been put into papers for peer-reviewed international journals as well as presentations at national and international scientific conferences regarding the technological and scientific achievements.

We have specifically addressed dissemination of good practice. A broad range of target groups have been identified e.g. students, technicians, and scientists.

Expected /Achieved	Results	Target group	Dissemination activity and exploitation of results
Expected and achieved	**INCREASE home-page** A project web-site was produced within the first months and has been regularly updated. Description of the network, the infrastructures, contact info and outreach. Further, results, workshops and papers are available.	Mostly the scientific community, students and to a lesser extend policy makers	The site has been available for all groups at http://increase.ku.dk/ since the beginning of the project and will be updated and available in the future as well.
Expected and achieved	**Portal for transnational access** was provided at the web-site within the first months of the project including	European scientist	The portal has been available and calls for proposals announced since the

	all relevant information about the infrastructures, contacts, application form, reimbursement form etc		beginning of the project. We still invite visiting scientists but we can't provide the same service without funding
Expected and achieved	**INCREASE project folder** with description of challenges, objectives and methodology as well as transnational access and contact info was produced within the first months	Broad range of target groups	Handed out during classes, workshops, meetings to communicate the project idea and transnational access possibilities
Expected and achieved	**INCREASE database** INCREASE databases and data sharing: Existing databases from climate change manipulation experiments are typically fragmented and difficult to access. The dissemination of the database was a main objectives during the project and results are described in details below	Scientific community	Database with background and foreground, reports for i) documentation of design, ii) tutorial for internal and external use of the database. The database will be available in the future.
Expected and achieved	We prioritized **scientific papers** and expected >3 annually and have produced more than 30 and a number of cross site synthesis papers are in progress.	Scientific community	High production and more papers are expected within the next year. This will simultaneously serve as a quality control on the scientific results
Expected and partly achieved	We expected one national and international **popular science paper** per country per year. We have published fewer papers but participated in many national workshops with oral and poster presentations.	National scientific communities, land managers, politicians,	The dissemination of results on workshops either as oral or poster presentation has been a good way to get in contact with a broad range of target groups.
MS-Excel application was written and circulated for providing a new tool for simulation	MS-Excel application was written and circulated for providing a new tool for simulation and estimation of the water balance of shrubland ecosystems for the internal and external users of the research infrastructure network	MS-Excel application was written and circulated for providing a new tool for simulation and estimation of the water balance	MS-Excel application was written and circulated for providing a new tool for simulation and estimation of the water balance of shrubland ecosystems for the internal and external users of the research infrastructure

and estimation of the water balance of shrubland ecosystems for the internal and external users of the research infrastructure network		of shrubland ecosystems for the internal and external users of the research infrastructure network	network
Expected and achieved	**Tested improved manipulation methodology** for realistic climate manipulation experiments for i) elevated temperature, ii) extended drought periods, iii) irrigation systems, iv) elevated CO_2 and interactions,	experimentalists	Peer review paper and test reports dealing with different aspects of the technology. Further, we have provided guidance to the European climate manipulation community with respect to setting-up and running experiments, choosing scenarios, and minimising artefacts.
Expected and Achieved	Providing **transnational access** to the European scientific community. TA has stimulated cross site research and resulted in a high number of publications on a wide range of topics well beyond the disciplins we cover within the network ; some printed but most of them in draft versions	Scientific community including young scientists	WE provided almost 2000 user days. We have established good contacts to many research teams, which will be valuable also in the future for both the scientific community and society.
Expected and achieved	**Water balance prediction tool.** Modelling tools for assessment of the water balance in shrubland ecosystems.	Scientific community and land managers	We have released a beta version. MS-Excel application was written and circulated for providing a new tool for simulation and estimation of the water balance of shrubland ecosystems for the internal

			and external users of the research infrastructure network.
Not achieved	A project **news-letter** was planned to inform about the project, the results and the progress. We decided early that the web page and activities at target workshops and meetings were a better way to communicate results	Broad range of target groups	National leaflets, posters, oral presentations and visits by laymen at the installations have replaced the newsletter
Expected and achieved	**Ecosystem model for shrublands**. The work with the CoupModel has significantly broadened the number of ecosystem types that may be modelled by the CoupModel , which was originally developed for monoculture forest ecosystems and now has been adapted also to shrubland ecosystems with more than one plant functional types. The model has been successfully parameterized across sites within INCREASE	Scientific community	The model application is documented by parameter files, meteorological driver data and model output. A manuscript on the cross-site model application is in preparation. The CoupModel application across sites is documented as parameter files and model application files within the CoupModel and described in detail in a report
Expected and achieved	**Automated camara observation system** for phenological observations. The prototype of the APOS - Automated Phenological Observation System has been developed and documented. Optimization of the camera-plot focus distance and parameters values of the APOS system for the specific visual coverage of the experimental site was obtained using a specifically developed custom software.	Scientific community	Report documenting the design and communication of results at workshops
Expected and achieved	The IFI, **Integrated Fire Danger Index**, was applied in the Italian and Hungarian site using historical and current data. The main objective of this research activity was to evaluate	Scientific community and land managers	The test results are documented in a report and available at the web site and has further been communicated at workshops.

	the skill of IFI to detect changes in the water status of the vegetation/soil at treatment level and quantify the impacts on the fire danger. The results allowed to quantify the effects and impact on fire danger of the climate manipulations in the shrubland ecosystems.		
Expected and achieved	**Prototype chamber for NEE** measurement has been produced, tested and documented under different environmental conditions. Further a script has been optimized for fast data evaluation and handling.	Scientific community	Report documenting the design and the communication at workshops. Scientific papers are in progress dealing with different aspects of net ecostsrem exchange assessment by chamber methods.
Expected and achieved	**An automatic NEE chamber system** has been developed to be compatible with a LICOR 8150 multiplexer system which makes it flexible to potential users because the chamber can be used together with standard LICOR chambers for measurements of soil respiration. The chamber is unique by its ability to be darkened as well as other novel features (e.g. non-intrusive chamber base). The possibility of measurements both with light and without light, i.e. with active photosynthesis + respiration or just with respiration enables gross photosynthesis rates and ecosystem respiration to be estimated.	Scientific community	Report documenting the design and the communication at workshops. We expect a certain interests from other groups for the test reports and design details as it solved a number of problems with available systems.
Expected and achieved	**Education of a new generation of scientists in climate change research.** The network has been an excellent platform for training of young scientists through workshops, meetings and summer schools. In total, we have produced 10 PhD-candidates and a few more is on the	Students within environmental science etc.	Courses, supervision, experimental facilities

	way. Further a number of MSc and Bc-projects have been provided		
Expected and achieved	**Contacts and collaboration with similar networks**. We have extensive collaboration and exchange of knowledge between INCREASE and a number of other infrastructures/platforms such as Climmani, Expeer, InterAct, InterFace, ANAEE. The networks have been used for gathering and synthesising scientific results and findings and channelling the results to relevant areas of policy making.	Scientific community in Europe and abroad – especially US	Cross site synthesis papers, generalization of results, upscaling of results.
	Overall results The research within these infrastructures provided and will provide important knowledge and information and a better understanding of implications of ecosystem responses to climate change Indirectly, the work of INCREASE will be of interest and relevant for national and international policy makers and policy oriented organisations with a focus on "ecosystem services" provided by terrestrial ecosystems Potentially also organisations providing data on environmental status and impacts will be interested in the work, such as European Environment Agency (EEA).		

2.3 Exploitation of foreground

2.3.1 The INCREASE Database

Exploitation activities are intended to help ensuring a consistent and successful deployment of the INCREASE database (DB) implementation, and check feasibility, technical and scientific aspects. The purpose of this section is to show activities already done or to be planned in the future to foster the exploitation of information, knowledge and experience gained from the INCREASE DB project.

We provided a comprehensive integrated database (the INCREASE DB project) of information and data from experiments on the potential effects of climate change on shrubland ecosystems in Europe. Data have been collected at six research infrastructures with eight installations for a period of time ranging from 4 to 12 years. Data included experimental observations and scientific results on the effects of climatic treatments on vegetation and soil. These data represent a relevant source of knowledge for research studies on ecology, ecophysiology, and climate change impact studies. The main objectives were:

- to improve capacities in the protection, management and storage of data and results from the research infrastructures network, with the implementation of an integrated database system, and
- to provide a Web-based access to data and results from the infrastructure network for a larger research community at a European and international level.

During the lifetime of the project, dissemination activities have mainly focused on making the INCREASE DB project visible and accessible in the research community, and spreading information on the vision and the high level objectives of the project. The INCREASE DB project took great advantages from past European projects, whose experiences and knowledge were integrated into the INCREASE DB design. In particular, significant benefits derived from the exchange of knowledge, information, and data with NitroEurope, a large European Integrated Project (2006-2011). The NitroEurope DB, which provides easy upload and extraction of data for analysis, interpretation and modelling to research community, has represented a good, relevant benchmark in designing, developing and implementing the INCREASE DB.

No applications for patents, trademarks, registered designs, etc. have been made by the INCREASE DB project.

The exploitable foreground can be broadly categorized as 1) data standardization, 2) data protection, 3) data management and storage relevant tools, 4) synthesized information, and 5) data accessibility. information are general available to all users (from the science community to education at all levels, from local stakeholders to regional and global stakeholders, and decision makers).

The public web site of the INCREASE DB, located at https://increase.ss.ibimet.cnr.it, is the main online hub for making the dataset collection visible and to publish results to the public. The web site was launched as planned in February 2011, and will remain online after the project end according to the overall agreement. The knowledge and tools developed in INCREASE DB project will be exploited in a number of ways within the framework of the INCREASE Infrastructure Intellectual Property Policy for Database Access Agreement. It is anticipated that the exploitation for foreground will be primarily for future research.

One specific avenue the INCREASE DB project is exploiting, in coordination with the overall partnership, is complementing and cooperating with national, EU, JPI, and international programs related to climate change experiments in terrestrial ecosystems. In particular, with two relevant European initiatives 1) the COST Action *ClimMani: Climate Change Manipulation Experiments in Terrestrial Ecosystems: Networking and Outreach*, which intends to provide progress in data sharing through creation of meta databases and guidelines for data bases and data sharing and 2) the ESFRI project AnaEE (Analysis and experimentation on ecosystems), a pan-European long-term experimental platforms network for the study of ecosystems, which includes also databases and model platforms.

The visits and stats presented in this section covers the period from May 2012 to, and partially including, January 2014. A summary of the period is captured in Figure 2.3.1.

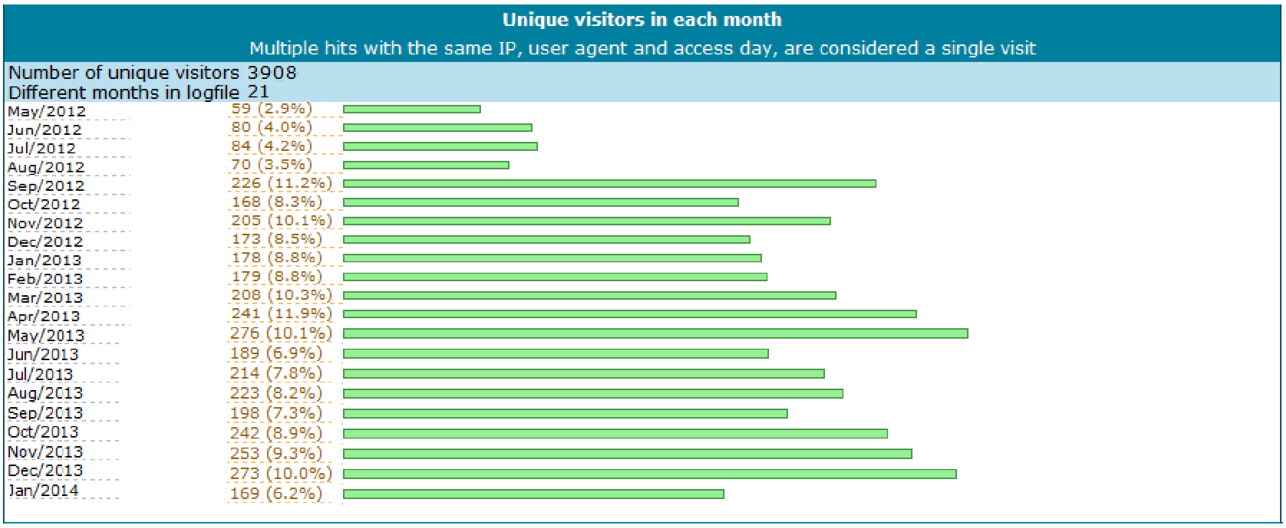


Figure 2.3.1: Overview of web site traffic.

The statistics of this period reports almost more than 3.900 unique visitors (3.908), who in all have made close to 6.640 visits and almost 23 500 pageviews. The visitors are from across the world, with four non-EU countries represented on the top-10 list.

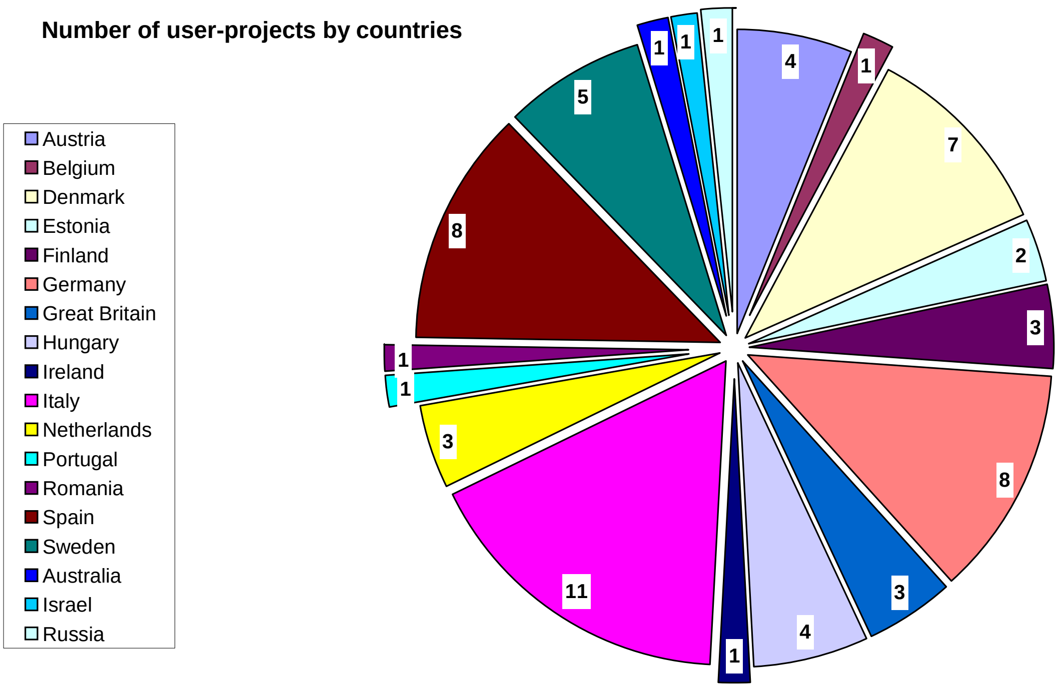
In conclusion, the INCREASE partners, as a consortium or individually, have guaranteed a wide dissemination and therefore visibility of the INCREASE DB project objectives and technical solutions through several activities and initiatives. The exploitation of the INCREASE DB results has been and will be pursued by the partners, both at individual partner level and at overall consortium level, to better promote the INCREASE DB results and their suitability to contribute and to match the requirements of the ongoing and future actions of the experimental climate change research community.

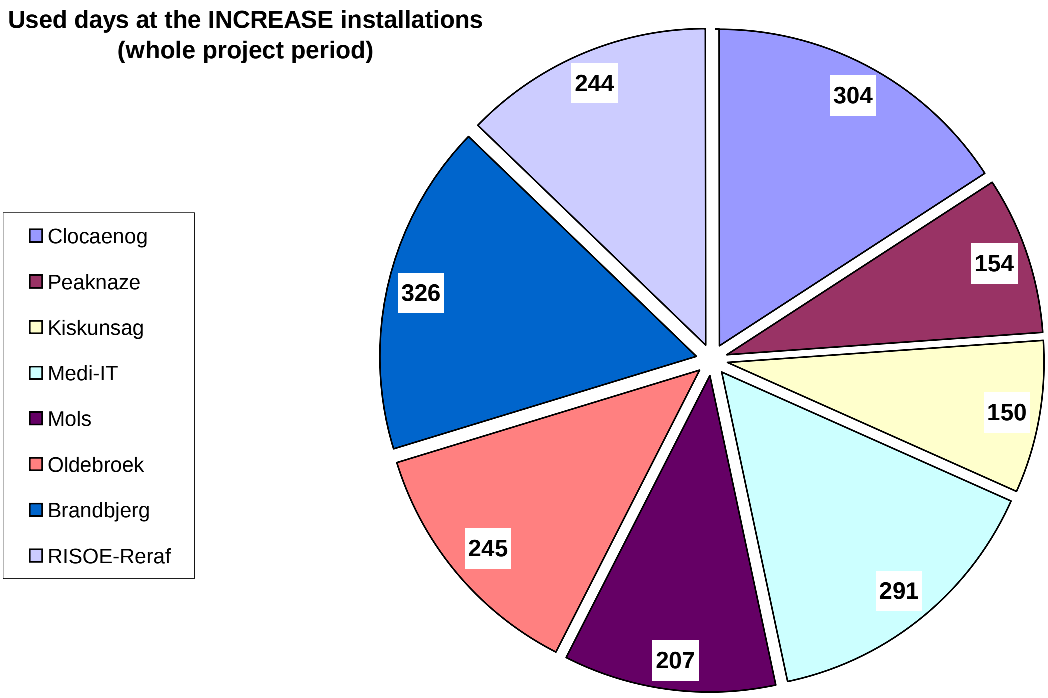
2.3.2 Transnational Access (TA)

WE see the transnational access as an integrated part of our dissemination activities. During the period of duration of the INCREASE programme, the eight installations hosted 65 Transnational Access projects, for a total of 1921 user days and 111 scientists involved. Considering the nationality of the lead scientist, 15 EU countries were represented and 3 non-EU.

During the project we have had almost 2000 days with visiting scientists working in the infrastructures. To support their research, we have discussed the non-intrusive design and sampling methodology with standard protocols and further provided the visiting scientists with background and foreground data from the infrastructures. This has been a major dissemination pathway and contributed to the structuring of European climate change research. We hope to be able to continue the provision of transnational access although the contribution from the Commission to both access providers and users has been important. We are worried that the discontinuous funding will reduce the number of visits by young scientists and groups without means.

The distribution of the user days among the installation as well as the distribution of the user projects among the countries are reported in the following figures.





2.4 Summary of dissemination activities

Within the duration of INCREASE the dissemination list includes:

- 35 scientific publications printed and about 20 in prep
- 16 workshops
- 1 conference
- 24 technical reports
- 5 Training courses
- 10 PhD-degrees
- 48 oral presentation at workshops and conferences
- 43 poster presentations