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Assessing the impacts of site characteristics, management, disturbance and lateral fluxes on greenhouse gas dynamics.

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Abstract

There are many factors that influence ecosystem scale carbon (C), nitrogen (N) and greenhouse gas (GHG) dynamics, including the inherent heterogeneity of soils and vegetation, anthropogenic management interventions, biotic interactions and abiotic disturbance events. It is important therefore, to document the characteristics of the soils and vegetation and to accurately report all management activities, biotic interactions or abiotic disturbance events in order to aid the interpretation of the collected data, and to determine whether the ecosystem has a positive or negative impact on climate change. This paper outlines the procedure to assess both the spatial and temporal variability of soils and vegetation and to report all management events, lateral fluxes of C or N and the occurrence of biotic/abiotic interactions at ecosystem stations of the Integrated Carbon Observation System (ICOS), a pan-European research infrastructure.

Keywords

Protocol, characterisation, management, disturbance, lateral flux.

Introduction

The key components and infrastructure that are required to assess carbon (C), nitrogen (N) and greenhouse gas (GHG) budgets at the ecosystem scale are well documented (Ciais et al., 2010; Neftel et al., 2006; Osborne et al., 2010; Schulze et al., 2010; Smith et al., 2010) and have been determined through experimental research networks. While the predominant C stocks and GHG fluxes such as the atmosphere-biosphere exchange of C and GHGs, soil organic C stocks (SOCs) or lateral losses through harvest events are generally well accounted for in many ecosystem scale studies, some emissions and lateral C and N losses associated with land management, biotic interventions and abiotic disturbance events are not. These are often neglected due to logistical, technical or financial constraints, or because they are perceived to represent a small proportion of the net ecosystem C, N or water budgets. However, these lateral fluxes often constitute fundamental drivers of the ecosystem C and N balance and are therefore required to provide a more comprehensive understanding of ecosystem scale biogeochemical cycles and therefore warrant inclusion in the experimental protocols undertaken at these long-term GHG observational stations (Lal, 2004; Osborne et al., 2010), including the Integrated Carbon Observation System (ICOS) a pan-European research infrastructure (Franz et al., this issue).

Key management and disturbance events include tillage (Davis et al., 2010; Eugster et al., 2010; Kutsch et al., 2010; Willems et al., 2011; Merbold et al., 2014), fertilisation (Fuβ et al., 2011; Jassal et al., 2010; Snyder et al., 2009; Ventera et al., 2005), irrigation (Chamizo et al., 2017; Falloon and Betts, 2010; Verma et al., 2005) a change in the cropping system (Aubinet et al., 2009; Petersen et al., 2011) or biomass removal during grazing or harvest (Allard et al., 2007; Ceschia et al., 2010; Zanotelli et al., 2013); in addition to both abiotic disturbance events and biotic interactions such as extremes of temperature, hydrological changes and increased frequency of storm events (Ciais et al., 2005; Dahal et al., 2014; Hawkins et al., 2013; Hussain et al., 2011; Reichstein et al., 2013), pest infestations (Jimoh et al., 2013; Kurz et al., 2008; Straw et al., 2002), windthrow (Lindauer et al., 2014; Thürig et al., 2005; Ulanov, 2000), or fire (Amiro et al., 1999; Powers et al., 2013). These events may alter C and N dynamics within the ecosystem (e.g. windthrow or extremes of temperature) or may act both within and outside the ecosystem (e.g. grazing which will alter the plant canopy dynamics and also lateral losses of C and N). Measuring the effects of these events on ecosystem scale GHG emissions will help to explain the overall spatial and temporal changes of the associated C and N losses. Additionally, it is also important to consider the effects of land management practices on C and N dynamics where, for example, plant biomass or soil is removed from the ecosystem due to grazing management, herbivory or the removal of harvested products in croplands, grasslands and forests, as this can represent a significant lateral export of C and N from the ecosystem (Serrano-Ortiz et al., 2011). Further consideration should be given to sites that are actively managed, as the C and N consumed by grazing animals is ultimately transformed into carbon dioxide (CO_2), methane (CH_4), excreta or animal biomass. Harvesting and grazing also modify the plant canopy which can have further implications for the canopy microclimate, soil chemistry, soil properties and soil microbial activity, nutrient distribution, water table and potential soil erosion by wind and water. All of these factors influence the Net Biome Productivity (NBP) and associated components of an ecosystem, and warrant adequate assessment in order to better understand both the short and long-term storage of C and N within an ecosystem.

Furthermore, many flux sites exhibit significant heterogeneity in the structure and composition of both soil and vegetation, which will condition the measurement techniques used, the interpretation of flux data and the extent and assessment of uncertainties in net ecosystem C budgets (Göckede et al., 2004). It is therefore imperative to establish a spatially representative assessment of the particular characteristics at each ICOS ecosystem station. The target area of interest at each station can be defined at its maximum as the physical boundary or delimitation of the land use class or ecosystem on which the flux measurements are undertaken. The site characterisation is required to determine the spatial variability in soil or vegetation characteristics across an ICOS ecosystem station to determine whether this variability influences the measured flux parameters either directly, by changing the seasonal or annual flux footprints or by creating indistinct footprint boundaries, or indirectly by altering canopy characteristics. An example of this is the occurrence of windthrow in forests which may influence microclimatic conditions within, or advection from, an adjacent area within the flux footprint (Knohl et al., 2002).

If the characterisation process is undertaken prior to the establishment of a new site, it will also aid in both the site selection process and the determination of the most suitable location for the flux tower, soil climate and ancillary vegetation measurement locations (see Rebmann et al., Op de Beeck et al., Gielen et al., and Loustau et al., this issue). When applied to an existing experimental site, the characterisation process may assist the interpretation and analysis of primary flux data by aligning any modifications within the site to the predominant flux footprint.

The objectives of this paper are to provide the guidelines required to describe and report the soil characteristics and vegetation composition at each ICOS ecosystem station. The guidelines will ensure that any C and N losses or GHG emissions associated with relevant management interventions, biotic interactions, abiotic disturbance or lateral export are identified and accounted for in a standardised manner at each flux station.

Methodology

Site Characterisation

Description of ecosystem stations

Descriptive information on the site, defined as the target area of the eddy covariance (EC) system that is delimited by the boundaries of the land cover/site of interest, are provided using a standardised template. Within ICOS, all relevant parameters are reported using the Biological, Ancillary, Disturbance and Metadata (BADM) template. The basic information includes the ecosystem type, the ecosystem boundaries of the ICOS station and the representative area covered by the footprint of the EC system, vegetation composition including species cover and distribution, geographic location and key climatic parameters (mean annual temperature, precipitation, wind direction, radiation). A description of the site history is provided for as long as records are available and should include information on any previous land uses or land use change events, the occurrence of historical abiotic disturbance events or biotic interactions, as well as current management practices. Management interventions need to be reported, including any soil or land management activities prior to planting (e.g. drainage or tillage), the sowing or planting date, species mixture, sowing rate or tree density, and any management interventions (e.g. thinning, pruning, grazing or harvesting) or amendments that have either taken place prior to the establishment of the measurement station or which take place on a regular basis (e.g. liming, fertilization, pesticides, irrigation).

Soil and vegetation sampling and assessment

The soil characteristics, vegetation composition, cover, distribution and biomass across the site should be assessed when setting up a new station. Existing stations that have collected such information previously should report this as part of the site description and under the guidance of the Ecosystem Thematic Centre (ETC), the ICOS central facility coordinating the ecosystem network, and should evaluate the information generated during previous sampling techniques to ensure it meets the requirements and recommendations of ICOS protocols. The sampling strategy used to characterise the ecosystem and target area of interest on which an ICOS station is installed, is outlined in the ICOS Ecosystem Instructions. Using this approach the station Principle Investigator (PI) will initially map the boundaries of the ecosystem and will identify areas where the allocation of sampling points should be avoided, such as roads or other infrastructure for example (Figure 1). This information is submitted to the ETC who will then partition the target area into ten geographically compact, randomly generated sub-areas of equal proportion (Figure 2 a). The ETC will also provide coordinates to assign two first order sparse measurement plots (SP-I-order) to each of the ten sub-areas (to identify 20 SP-I-order plots in total across the target area of interest) using a stratified random scheme, which is scale-independent (Figure 2 b). In addition, twenty second order (SP-II-order) sampling locations are assigned randomly within a 10 m circumference of each SP-I-order sampling point (Figure 2 c and d). Five of the SP-II-order points are used for the characterisation of vegetation at each ecosystem station, while the remaining SP-II-order points are held in reserve (SP-II-order-R) and are re-sampled after a 10 year period or when a disturbance event has occurred (Figure 2 d.). The SP-I-order points should be separated by a distance of 30 m from the next adjacent SP-I-order point and 10 m from the boundary of the target area of interest. If such spatial separation does not occur during the randomised allocation of sampling points or a SP should fall on an exclusion area, an additional SP-I-order point is randomly assigned. In addition to the SPs, two to five Continuous Plots (CP) are also assigned to the station in forest and cropland systems, which are used for continuous measurements of soil-meteorological parameters and repeated measurements of ancillary vegetation traits (forests only) (see Gielen et al., and Op de Beeck et al., this issue). CPs are not assigned to grassland stations, while the number of CPs assigned to mire ecosystems is variable and depends on the number of plant communities and associated ecotypes identified as part of the vegetation characterisation process. An example of the distribution of both SPs and CPs at an ICOS station is illustrated in Figure 3. Should a SP plot fall within a CP location and the station PI considers that any such overlap could negatively impact on the measurements made, there are two possible options. Firstly, the CP locations are defined once the location of the SPs have been determined and provided to the PI by the ETC, secondly, the area covered by the planned CP are considered as exclusion areas and are not used in the characterisation sampling design, however this request has to be submitted directly to the ETC. Once the station PI has been provided with the coordinates for each of the SP sampling points, these form the centre of the SP plots used for vegetation and soil characterisation and should be located with an accuracy of ≤ 2 m and ≤ 1 m in forest and sparse-vegetation ecosystems, respectively. The exact corresponding coordinates should then be recorded, detailing up to the fifth digit of degree decimal format of the geographic coordinates using the WGS84 geodesic system, with a GPS or other topographical tool with a precision of 1 m in forests and 0.5 m in low-stature canopies. Where possible, these points should be permanently marked to facilitate the subsequent identification of sampling points when required. The coordinates of the SP-I-order points located at each station must be reported to the ICOS ETC at the time of the site characterisation exercise, while the SP-II-order points only need to be reported when they are sampled. The submission of information is undertaken using the BADM data template. This information is then validated by the ETC and the spatial sampling scheme for site characterisation and subsequent repeated measurement campaigns is complete. The workflow associated with this process is summarised in Figure 4. The plot type and related measurements are summarised in Table 1 (see also Arrouays et al., Gielen et al., Loustau et al., and Op de Beeck et al., this issue for specific measurement methodologies). The main objective of the vegetation assessment is to characterise the plant community structure, composition and relative health, and if repeated, to allow the detection of any long-term changes and to identify the mechanisms of change. This will require a census survey of plant species abundance in each of the SPs, based on the relative frequency of each species. The reference nomenclature for plant species classification should follow the Plant List Database (http://www.theplantlist.org). Further information can be found in the ICOS Ecosystem Instructions for Plant Species Reporting. The visual assessment procedure is also important for the identification of the occurrence of biotic interactions or abiotic disturbance events, such as the presence of pests or diseased material within the plant canopy as well as recording changes to the canopy structure due to harvest (e.g. thinning of forest canopies) or the influence of wind (e.g. windthrow or flattened crops). If management operations such as forest thinning are planned either before or during the site characterisation process or in the initial measurement year, it is recommended to sample the vegetation in the year prior to the operations in addition to the year after disturbance (if known). The characterisation of vegetation at grassland, forest and mire ecosystem stations is described below, for cropland systems it is required to report the primary crop species only. All information should be reported using the BADM template:

Grassland ecosystems:

The assessment of species composition is carried out at each of the five SP-II-order plots located around each of the 20 SP-I-order plots within the target area (100 sampling locations in total), during the first year of ICOS measurements. This assessment should be carried out close to the peak biomass, and should consider the timing of flowering to aid identification. The plants present must be identified at the species level. If identification at species level proves to be very difficult or impossible, identification at genus level may be sufficient, this however has to be discussed with the ETC. Measurements of aboveground biomass (AGB) for characterisation purposes are made at two of the SP-II-order plots located around each of the 20 SP-I-order plots within the target area. This measurement should also be conducted when the standing biomass is at its peak. Full instructions can be found in the ICOS Ecosystem Instructions for Grassland characterisation.

Forest Ecosystems:

At each SP-I-order location a 15 m radius circular plot is defined with the centre coinciding exactly with the SP-I-order point. In forest plantations, where the trees are spaced at regular intervals, the area to be considered around each SP-I-order location is not a circular plot but must instead be a square plot of 700 m^2, centered on the SP-I-order location. The corners should always be located between the rows of trees and thus the square shape may therefore be adapted to a rectangle if needed. A minimum of four rows of trees should be included. For each tree with a diameter at breast height (DBH) > 5 cm growing inside the circular or rectangular plot, its species and health status are noted, and the DBH and height is measured following the methodology described in the Instructions for Ancillary Vegetation Measurements in Forests. The AGB of the forest overstorey is determined by the use of allometric relations using DBH and tree height. The understorey aboveground biomass is not included in the site characterisation. All measured trees have to be either marked or precisely mapped in order to ensure that the same trees will be considered in the next measurement campaign.

The Green Area Index (GAI) of the overstorey is determined by means of digital hemispherical photography if seasonal max GAI < 6 $m^2\ m^{-2}$, and by means of linear ceptometry if seasonal max GAI > 6 $m^2\ m^{-2}$. Full instructions can be found in the ICOS Ecosystem Instructions for Forest characterisation.

Mire Ecosystems:

If the target area is entirely accessible, the vegetation survey is carried out at at each of the five SP-II-order plots located around each of the twenty SP-I-order plots within the target area (100 sampling locations in total), during the middle of the first growing season of the ICOS station operation. If access to the target area is difficult and can only be accessed using boardwalks, the site characterisation has to be undertaken based on a vegetation survey at a number of locations along the installed boardwalks, combined with aerial imagery of the target area. The spectral quality of the survey locations of the aerial image is linked with the plant community types into which they are categorised through statistical classification using Two Way Indicator Species Analysis (TWINSPAN) (Chahouki., 2012). With this information, the aerial image can be converted to a map of the distribution of the plant community types. This map is then used to derive the fraction of the target area that each of the community types occupies. The vegetation survey must be performed at a total number of 100 sampling locations along both sides of the installed boardwalks. The position and total length of the boardwalks must be communicated to the ETC. The distance between the centers of adjacent sampling locations has to be such that the 100 sampling locations are equally spaced along the boardwalk network and alternated on both sides of the entire boardwalks. The center of each sampling location must be 50 cm away from the boardwalk edge. The plants present must be identified at the species level. If identification at species level proves to be very difficult or impossible, identification at genus level may be sufficient or may be based on the main strata or the microtopographical features that support the distinct community types (e.g. hummock/strings, lawn, hollow/flarks). This however has to be discussed with the ETC. The percentage species cover should be estimated and recorded, and if a sampling location falls on a pool system it should be classified as such. Full instructions can be found in the ICOS Ecosystem Instructions for Mire characterisation.

The initial soil description at the ecosystem stations should be undertaken by taking a soil core (for non-stony/coherent soils) or digging a soil pit (for stony/incoherent soils) at each SP-I-order point. Should access to each of the SP-I-order plots become difficult, the total number of SP-I-order points sampled can be reduced in discussion with the ETC. Following this five SP-II-order plots located around each of the 20 SP-I-order plots are sampled by taking soil cores to a depth of 100 cm in non-stony/coherent soils. For soils where coring is problematic, soil pits are dug to a depth of 100 cm at three SP-II-order plots located around each of the 20 SP-I-order plots. Full details on the sampling methodology used to assess soil characteristics (type, texture, depth, and chemical composition) for all ecosystems can be found in Arrouays et al. (this issue).

Lateral export of C and N in vegetation and soils

The determination of lateral export of C and N out of the target area of interest at ICOS stations occurs when C or N that is non-gaseous or dissolved, held in plant biomass or soil is removed or lost from the site. In certain ecosystems, such as grasslands, additional consideration should be given to the transformation of C and N by grazing animals, where material consumed can either be emitted as CO_2 or CH_4, returned to the soil in excreta, transformed into animal biomass and exported from the ecosystem. The main components of the lateral export of biomass and C and N that need to be reported to the ETC are the harvest products from production systems (e.g. grain, silage, fruits, timber, grazing) which should be recorded using the BADM template. Similarly, the management or removal of harvest residues should be reported.

The station PI can then independently investigate the lateral export of C and N further by assessing soil C and N that adheres to and is removed with the below ground component of some crops, as well as through wind or water erosion (in both particulate or dissolved form). Other aspects including the conversion of grassland biomass to animal biomass can be assessed according to reporting guidelines (IPCC, 2003), and recording the live weight and stocking density of animals that graze the target area of interest. It is important, however, to ensure that losses through grazing are not double-counted. As for losses via enteric fermentation, these fluxes may either be measured at the ecosystem scale (EC-techniques) or at the animal scale by using the sulphur hexafluoride tracer technique (Pinares-Patino et al., 2007). While these latter techniques provide greater detail on lateral C exports, only the biometric assessment of harvest removal are required to be reported to the ETC (see Gielen et al., this issue).

Site amendments

Site amendments refer to any material that is added to or incorporated into the soil to enhance ecosystem productivity or agronomic condition. These amendments are applied to improve soil physical and chemical properties such as nutrient status, water retention, permeability, infiltration, aeration or structure. Soil amendments vary in origin and composition and may consist of either organic or inorganic constituents. Typical soil amendments include mineral and/or organic fertilisers, soil conditioners (e.g. compost or organic residues), cover crops as a green manure, liming, pesticides and irrigation. It is important to report the C and N content of amendments, the timing and rates of application (Table 2), the application methodology, any spatial variability in application and the occurrence of any conditions that require repeated or amended applications (e.g. pest/pathogen outbreak or limited water availability). Additionally, including an estimation of the fossil fuel consumption derived from these management practices will benefit the accuracy of the NBP estimates of these ecosystems, especially in case of agricultural stations.

Biotic interactions and abiotic disturbance events

Biotic interactions can have both positive (e.g. symbiotic associations such as the mycorrhizal or rhizobial associations) and negative impacts (e.g. pests) on the primary productivity of plant species. Depending on the intensity of the biotic interaction some organisms can have a negative impact on plant growth, and are the focus in this instance. They include insects (which can be categorised by both feeding habit, e.g. chewing, sucking, rasping, and the parts of the plant eaten; e.g. roots and rhizomes or stems and foliage), pathogens (e.g. fungi, bacteria, viruses and mycoplasmas), nematodes and other animals (e.g. birds, deer, rabbits and rodents). They can influence different components of the C and N cycles (e.g. gross primary production, ecosystem respiration, net primary production and net ecosystem production) and may impact different plant organs at different physical locations within the plant system (roots, trunk, branches or foliage) or within the soil. Given the complexity of interactions between the main plant type(s), the associated organism responsible for the interaction, across different ecosystem compartments and time scales, the quantification of their activity is not straightforward. It is also prudent to consider the interactions between biotic and abiotic disturbance events, as the prevalence of a biotic pest may enhance the vulnerability of the ecosystem to other pests and pathogens or to adverse environmental conditions and vice versa.

Abiotic disturbance events are caused by non-living factors and are considered extreme when they occur outside of their common range of variability. Moore and Allard (2010) categorised these events under five key headings: meteorological (cyclones, storms [wind, snow, ice/hail, dust/sand]), climatological (drought, heat stress), hydrological (floods), geophysical (tsunamis, earthquakes and volcanic eruptions) and anthropogenic (fires, oil spills, air pollution and radioactive contamination). Many of these events however, do not occur in isolation and are closely linked. The occurrence, size, intensity, severity, spatial distribution, frequency, return interval and rotation period all need to be considered in the detection and description of such events. The occurrence of such disturbance events should be identifiable from the ICOS station meteorological data when compared to the long-term (e.g. 30 year mean) climatological data. This information can be used for example to identify storm events (e.g. based on maximum wind speed and precipitation regimes), drought events, and temperature extremes (e.g. heat waves, frost). Site-specific thresholds for such conditions should be defined based on long-term (30 year), regional scale meteorological records in order to detect a potential disturbance event which can then be reported within the meta-data. The meteorological data can also be used to identify periods where there is an increase in the potential probability of an abiotic disturbance event (e.g. the possibility of flooding or fire). Where such possibilities exist, changes in site conditions can be assessed using both remote means (e.g. webcams), but also by regular manual/visual site assessments. The detection of such events requires the ICOS station PI to consult other key ICOS measurement protocols (e.g. EC data acquisition/processing, chamber methodologies and ancillary vegetation measurements, see Rebmann et al., Sabbatini et al., Pavelka et al. and Gielen et al., this issue) to ensure that they adequately capture the impact of any disturbance on C, N and other GHG emissions.

The methodological techniques that can be utilised to assess the impacts of biotic and abiotic disturbances on the aboveground biomass component of terrestrial ecosystems include the use of hemispherical imagery, inclined phenocams, ceptometer measurements of light interception and an assessment of foliar characteristics. Further details on these methodologies are described in Gielen et al., Wingate et al., and Loustau et al., in this issue.

Results and Discussion

A good understanding of the C, N and GHG dynamics of terrestrial ecosystems is needed to determine, under current climatic conditions and management interventions, whether they have a positive or negative impact on climate change (Lin et al., 2017; Prescher et al., 2010). Through the development and coordination of a global network of experimental and observation platforms (e.g. Fluxnet), the scientific community has been able to capture the impacts of management, climatic variability (including inter-annual variability and climatic extremes) and biotic interactions on net ecosystem C, N and GHG budgets (Baldocchi et al., 2001; Dolman et al., 2008). Furthermore, by maintaining these networks and standardising the experimental approaches used, which is a key objective of the ICOS network, there is the potential capability to capture how short-term climatological or anthropogenic changes influence C and N dynamics at the site-scale (Richardson et al., 2007) or even ecosystem resilience (Holling, 1973), and how this information translates across larger spatial and temporal scales (Beer et al., 2012; Ciais et al., 2005; Montagnani et al., 2017).

The characterisation of the soils and vegetation of eddy covariance sites, particularly within the target area of interest, is required for a comprehensive assessment of the drivers underpinning the measured fluxes. This is particularly important in ecosystems where natural spatial variability influences net ecosystem C, N and GHG exchange, such as in the arctic tundra (Pirk et al., 2017) or in forest ecosystems for example (de Araujo et al., 2010). However, even in relatively homogenous canopies, such as croplands, intensively managed grasslands and mono-culture forest plantations, spatial variations will be significant. Ecosystem scale C and N dynamics will, in addition, always be influenced by nutrient limitation, pests and diseases or wind damage (Niu et al., 2010; Hou et al., 2016; Sjögersten et al., 2011; Thürig et al., 2005). Therefore, regular assessments of canopy structure are necessary when investigating the drivers of atmosphere-biosphere GHG exchange. Furthermore, it is also important to consider how heterogeneity in the wider landscape might influence the turbulent exchange of trace gases at the site-scale (Stoy et al., 2013). Characterisation of the heterogeneity of soil properties across the target area of interest is also crucial, as key physical and chemical soil properties, such as bulk density, mineralogy, porosity or pH, for example, can influence a range of parameters (e.g. water availability, cation exchange capacity, nutrient availability, C, N and organic matter) that directly influence plant productivity and soil microbial activity, and thus rates of gross primary productivity (GPP) and ecosystem respiration (R_{eco}). Such variability in physical characteristics could also have an impact on soil-meteorological parameters (Op de Beeck et al., this issue), or rates of soil-derived trace gas emissions (Pavelka et al., this issue; Stoyan et al., 2000) and therefore need to be quantified.

The influence of land use, vegetation type and management interventions can have a significant impact on the C, N and GHG dynamics of terrestrial ecosystems (Ceschia et al., 2010; Lal, 2004). For example, the prevalence of weed species have been shown to significantly increase the net C sink strength of irrigated olive orchards (Chamizo et al., 2017), while soil disturbance through tillage is widely considered to result in a decrease in SOCs (Baker et al., 2007). Increases in rates of soil CO_2 efflux have been observed in different cropping systems during tillage events (Reicosky et al., 1997), while the ploughing of grassland ecosystems has been shown to result in a short-term increase in soil CO_2 efflux (Willems et al., 2011). The application of soil amendments to enhance plant productivity in agricultural systems can have both a positive and negative atmospheric feedback. The addition of organic matter to grazed grasslands ecosystems has been shown to increase rates of soil respiration and have little or no impact on CH_4 and nitrous oxide (N_2O) emissions, while enhancing net ecosystem productivity (Ryals and Silver, 2013). However, the application of inorganic nitrogen-based fertilisers has been shown to increase the rate of N_2O emissions from agricultural soils (Abdalla et al., 2010; Hyde et al., 2006). The magnitude of these N_2O emissions depend on substrate supply, the rate and form of N application, soil water content, pH and temperature (Baggs, 2010; Hörtnagl and Wohlfahrt., 2014; Skiba et al., 1999). Furthermore, soil-derived N_2O emissions show significant spatial and temporal variability, being characterised by both emissions at "hot-spots" or during "hot-moments"

(Butterbach-Bahl et al., 2013). This highlights the importance of characterising the soils and vegetation and reporting the management practices at ICOS ecosystem stations, and aligning this information with both the application of chamber-based measurements and the up-scaling and interpretation of all flux data at the ecosystem scale. Moreover, it is important to report the timing and magnitude of any agricultural amendments such as pesticides and herbicides in order to assess any potential impacts on the measured GHG fluxes.

Abiotic disturbance and biotic interactions caused by climatic extremes such as droughts, temperature anomalies and precipitation events or by insect or pathogen infestation can have a significant impact on the plant and soil microbial physiological functions and therefore on C and N dynamics of terrestrial ecosystems (Frank et al., 2015; Hicke et al., 2012). The impacts of such events are manifested in both short-term and long-term alterations of the net ecosystem productivity of terrestrial ecosystems. For example, extreme precipitation events during the growing season had a negative effect on annual forest GPP, whilst exceptional/extreme low-temperature events during winter had negligible long term effects but were associated with significant short term reductions in GPP (Saunders et al., 2014). Stand-replacing disturbance events (e.g. fire and insect infestation) have been shown to result in long-term C losses (10-20 years) from forest ecosystems in North America (Amiro et al., 2010), while soil CO_2 emissions and post-fire forest management have been shown to influence the recovery of the C sink strength of these ecosystems (Marañón-Jiménez et al., 2011; Serrano-Ortiz et al., 2011). Furthermore, the utility of long-term observational and experimental platforms across Europe has been highlighted in the detection of a pan-European reduction in primary productivity following extreme periods of heat and drought (Ciais et al., 2005). Again, this underlines the need for the regular assessment and characterisation of the vegetation at ICOS flux stations in order to detect both small and large scale disturbance events, and to align this with the ancillary vegetation and meteorological protocols utilised within the network.

Theoretically, the lateral flux of C and N from an ecosystem occurs when C and N in plant or animal biomass, soil or water is removed across the boundary of the ecosystem of interest. At ICOS stations the removal of biomass in harvested products needs to be reported, however it is perhaps worthwhile to also highlight here other lateral exports of C and N that may have a significant impact on net ecosystem C and N budgets. For example, losses of biogenic C through leaching at grassland and cropland stations across Europe equated to approximately 22% and 25% of the measured net ecosystem exchange (NEE) at these sites (Kindler et al., 2011). Dissolved losses from forest systems have been shown to exhibit greater variability with negligible losses at some sites, possibly due to soil related factors and the significant NEE of these ecosystems (Kindler et al., 2011), while other unproductive sites have reported losses up to 10% of NEE (Gielen et al., 2011). Furthermore, it has been estimated that up to 30 Mg ha^{-1} of soil can be removed from agricultural soil during the harvest of crops such as sugar beet, which can have significant implications for soil based C stocks (Osborne et al., 2010; Ruysschaert et al., 2005). The information generated from ICOS stations that assess lateral fluxes in more detail, will provide further evidence of the key factors that influence such fluxes and the relevance for each ecosystem type.

Conclusions

1. The standardisation of methodologies to characterise ICOS ecosystem stations and to report on the impacts of management and disturbance on C, N and GHG emissions are essential to develop a coherent pan-European flux network.
2. The characterisation of soils and vegetation at the ICOS research stations will allow a better account of the site-specific spatial variability of these ecosystem components and the impact they may have on net ecosystem C, N and GHG dynamics. This will assist in the appropriate allocation of new EC stations.
3. Initial measurements at the SP-I-order and SP-II-order points and the long-term assessment of SP-II sampling locations in ICOS ecosystem stations will provide useful information for the identification and potential quantification of the impact of disturbance events on C, N and GHG dynamics.
4. A close collaboration between the station PI and ETC is essential to report any management related events that might imply ecosystem disturbance or site amendments that may be relevant for the interpretation of flux data.
5. To ensure the robust calculation of net ecosystem C and N stocks it is required to report any lateral C and N losses that occur with harvest events. It is also important to assess other lateral fluxes, such as leached biogenic C that might represent a substantial loss of C and or N from the ecosystem; however the latter is not mandatory within the ICOS measurement guidelines.

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Table 1: The presence of SPs and CPs in different ecosystem types and the required measurements that are made at each of the plots. Table derived from the ICOS spatial sampling instructions.

Ecosystem	Sparse Measurement Plots (SP)	Continuous Measurement Plots (CP)
Forest	Vegetation species Green Area Index Diameter at Breast Height Tree height Soil characteristics	Repeated ancillary vegetation measurements (green area index, aboveground biomass, litter, foliar sampling for chemical analysis) Continuous soil-meteorological parameters
Cropland	Biomass and crop yield at harvest Soil characteristics	Repeated ancillary vegetation measurements (green area index, aboveground biomass, litter, foliar analysis) Continuous soil-meteorological parameters
Grassland	Vegetation species Periodic ancillary vegetation measurements (green area index, aboveground biomass, litter foliar sampling for chemical analysis) Soil characteristics	Not present[1]
Mire	Vegetation species[2]	Assessment of station heterogeneity Repeated ancillary vegetation measurements (green area index, aboveground biomass, foliar sampling for chemical analysis) Continuous soil-meteorological parameters

[1] Grassland ecosystems do not need to use CPs.
[2] Mire ecosystems do not always need to use SPs where access to the entire target are of interest might be difficult. This is reviewed by the ETC on a case-specific basis.

Table 2: The common units for various site amendments.

Amendment	Units
Fertiliser Inorganic	kg N m^{-2}, kg P m^{-2}, kg K m^{-2}
Fertiliser Organic	m^3 m^{-2} (liquid manure), Mg m^{-2} (solid manure)
Pesticide/Herbicide	g or L (active matter) m^{-2}
Irrigation	L m^{-2}

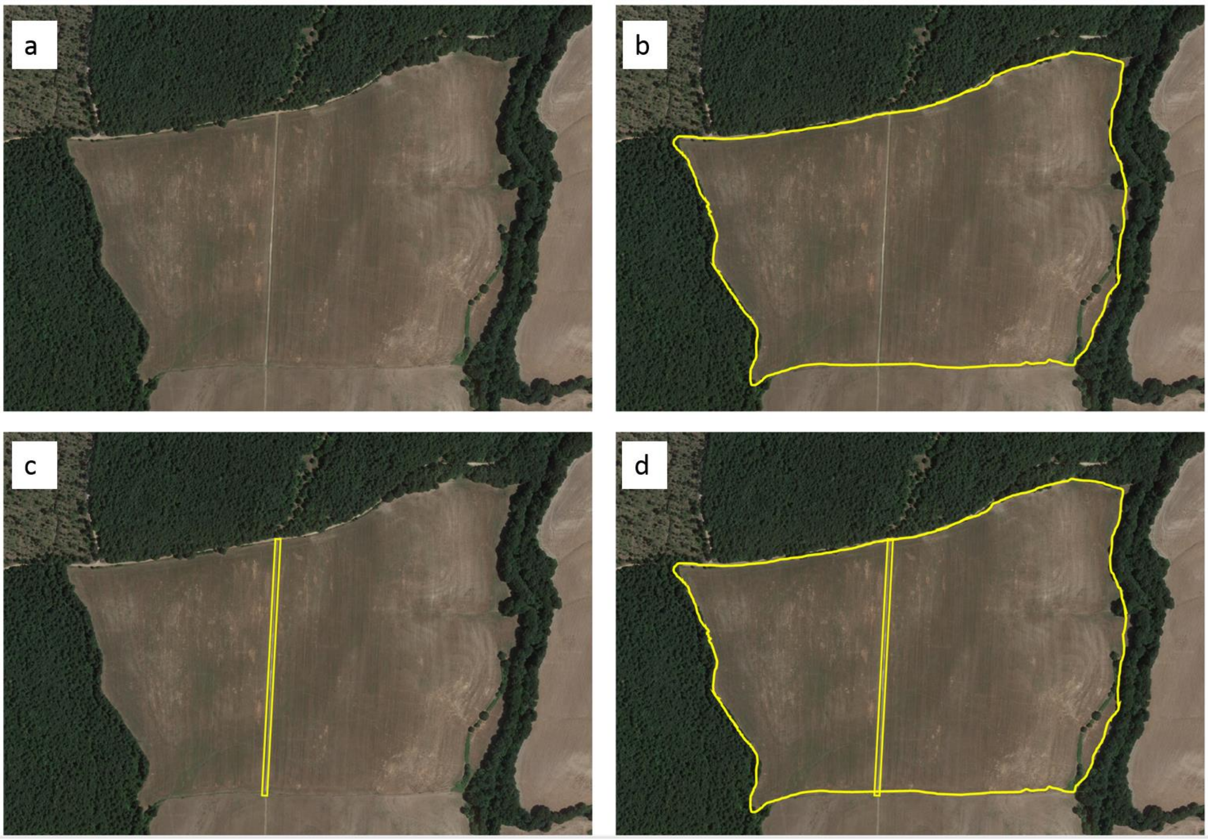
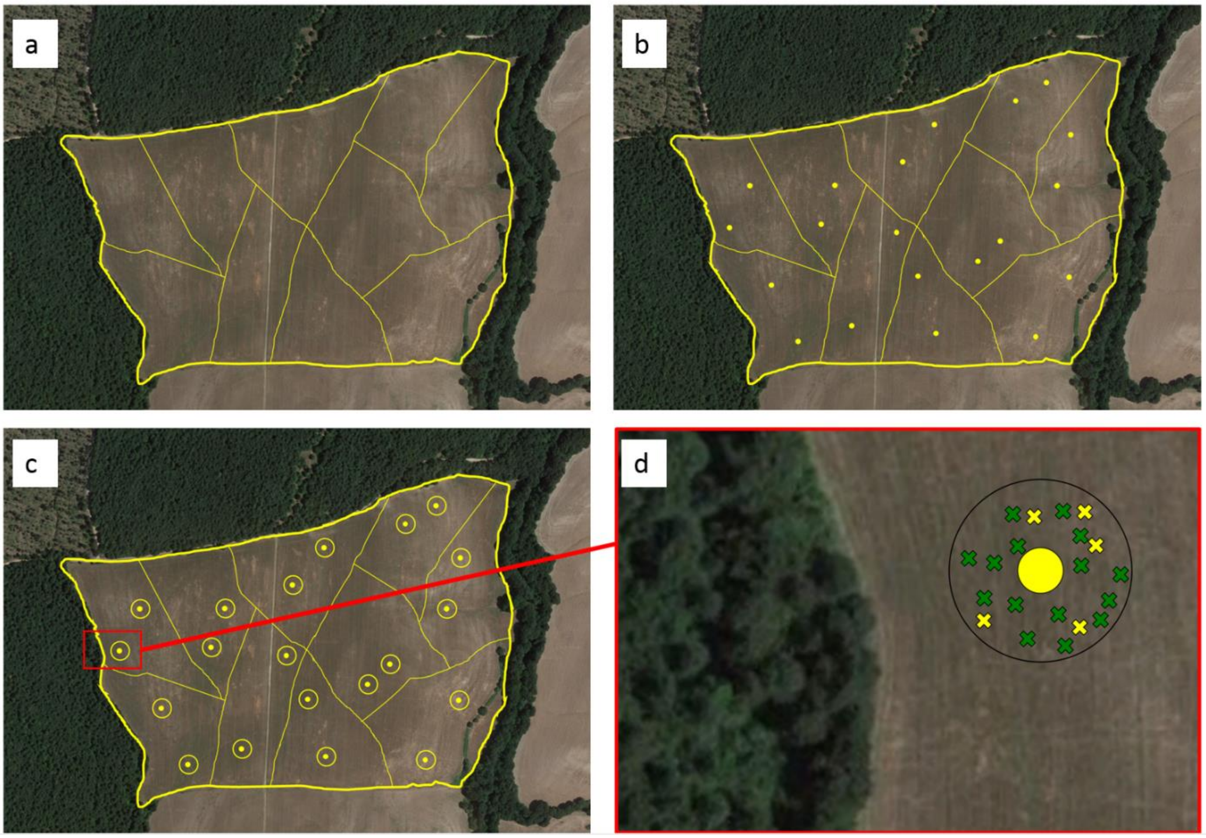


Fig. 1. (Figure produced by D. Papale).



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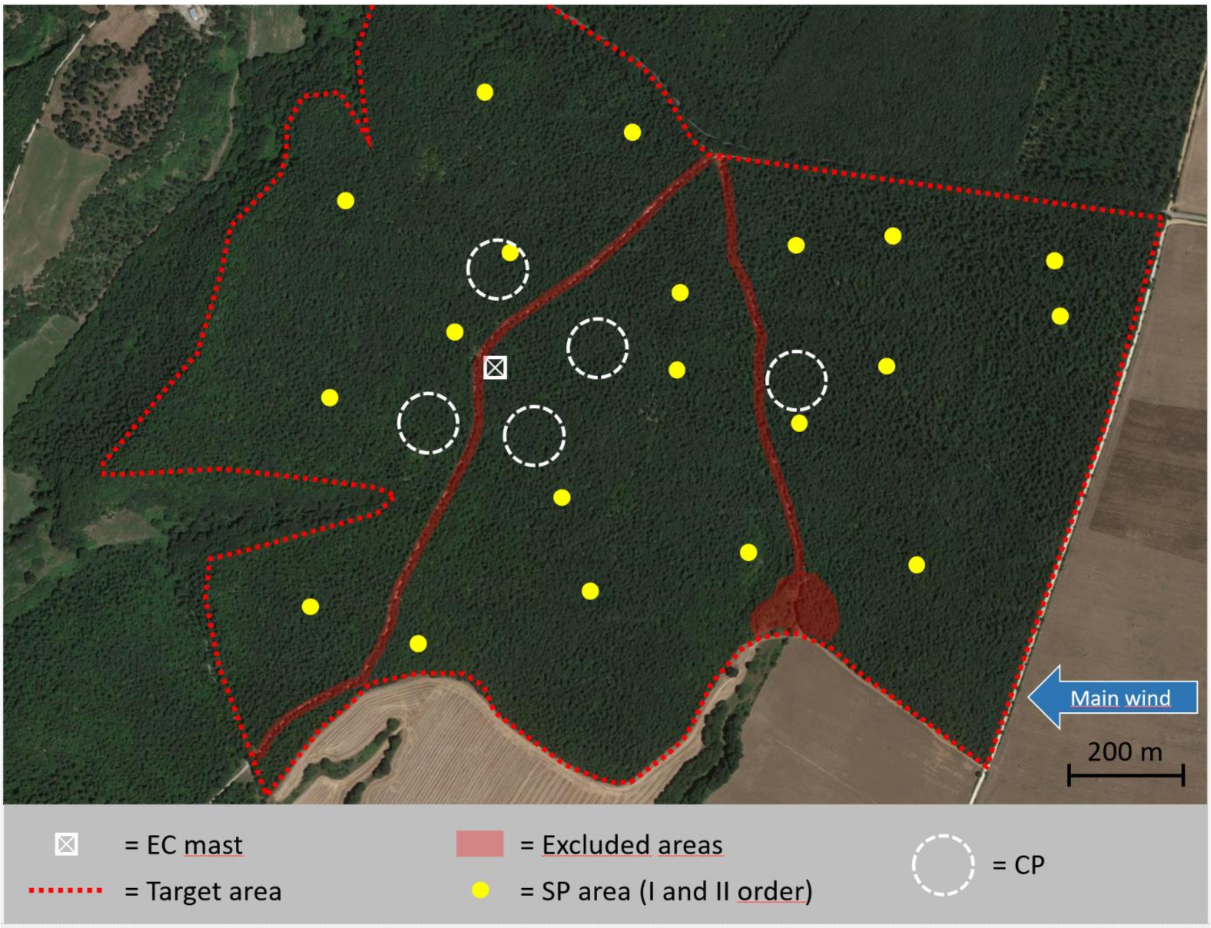

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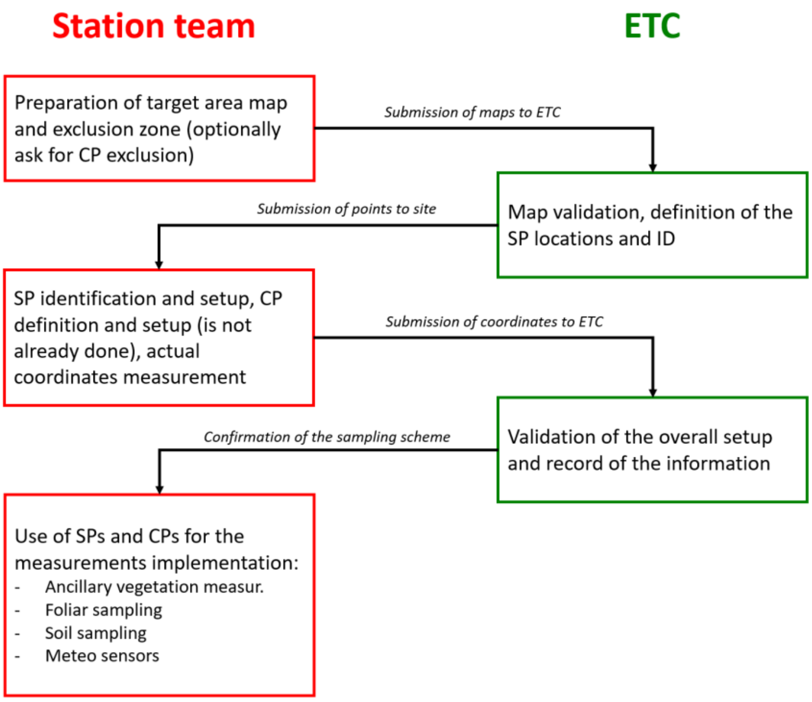

Fig. 4. (Figure produced by D. Papale).

List of Figures.

Fig 1: An example of the determination of the target area for an ICOS station; a. the ecosystem area of interest; b. the identification of the target area delineated by the boundaries of the ecosystem, c. identification of area to exclude from the sampling design (e.g. roads), d. merging of polygons to identify the overall area for assessment. Figure produced by D. Papale.

Fig 2: Illustrative example showing the ecosystem of interest and the location of both SP-I-order and SP-II-order sampling locations; a. the target area is sub-divided into ten equal compartments; b. the random location of two SP-I-order sampling points in each cell; c. the area around each SP-I-order point where the additional 20 SP-II-order points will be randomly allocated; d. an example of one SP-1-order point showing the location of the additional SP-II-order points used for the site characterisation process (yellow) and the location of the SP-II-order-R points for subsequent assessment (green). Figure produced by D. Papale.

Fig 3: An example of the overall sampling scheme for ICOS stations, showing the location of both SP-I-order and CP plots in addition to areas that have been excluded as part of the characterisation sampling regime. Figure produced by D. Papale.

Fig 4: Summary of the workflow for the development of a spatial sampling scheme at ICOS ecosystem stations for site characterisation and repeated measurement campaigns. Figure produced by D. Papale.

- The standardisation of methodologies are required for site characterise and to report on the impacts of management and disturbance on C, N and GHG emissions.
- The characterisation of soils and vegetation provides greater understanding of the site-specific spatial variability and the impact on net ecosystem C, N and GHG dynamics.
- Initial measurements and the long-term assessments of pre-defined sampling locations will provide useful information for the identification and potential quantification of the impact of disturbance events on C, N and GHG dynamics.
- It is essential to report any management related events that might imply ecosystem disturbance or site amendments that may be relevant for the interpretation of flux data.
- To ensure the robust calculation of net ecosystem C and N stocks it is required to report any lateral C and N losses that occur with harvest events, and other lateral fluxes, such as leached biogenic C that might represent a substantial loss of C and or N from an ecosystem.

Figure 1

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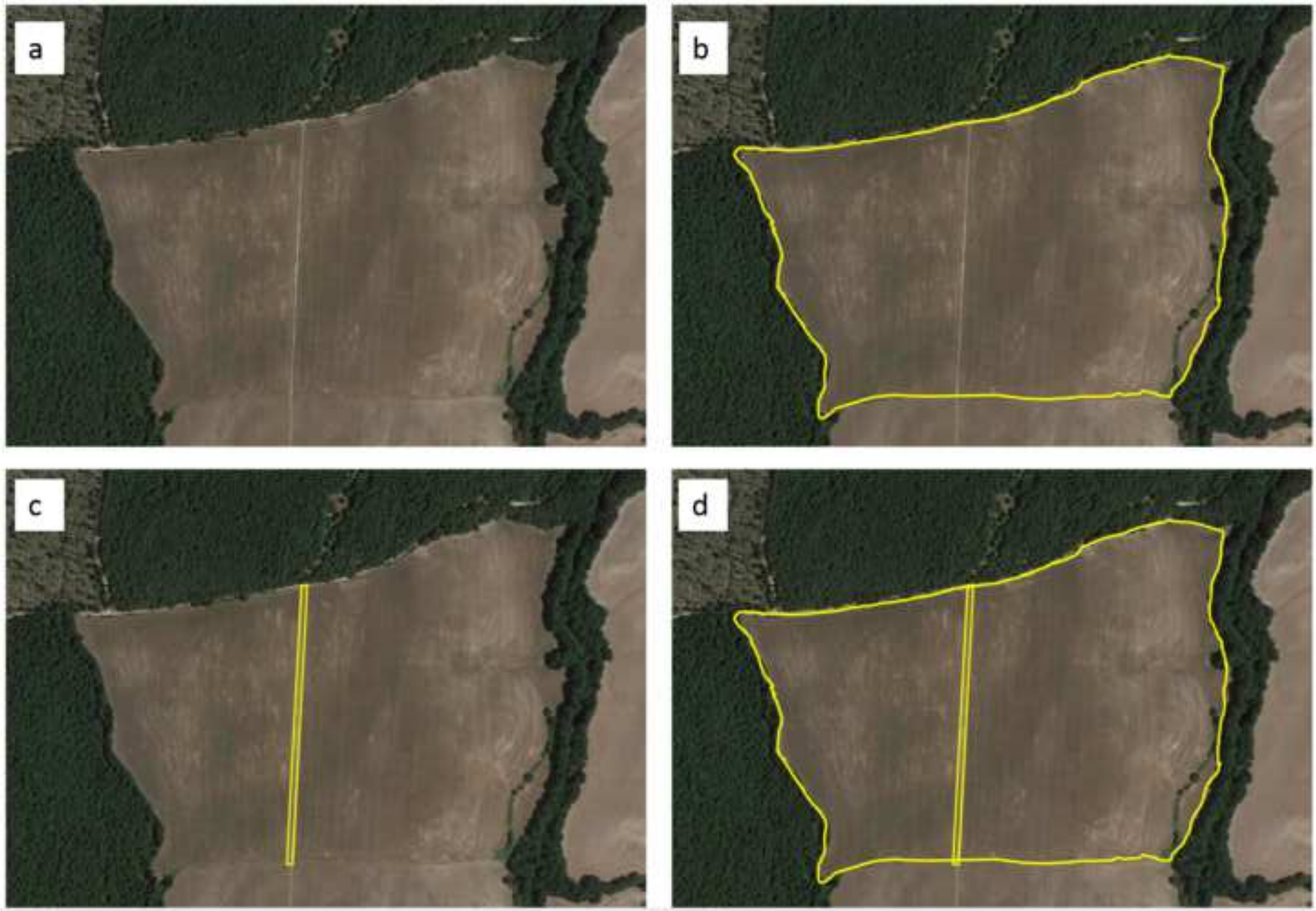

Figure 2

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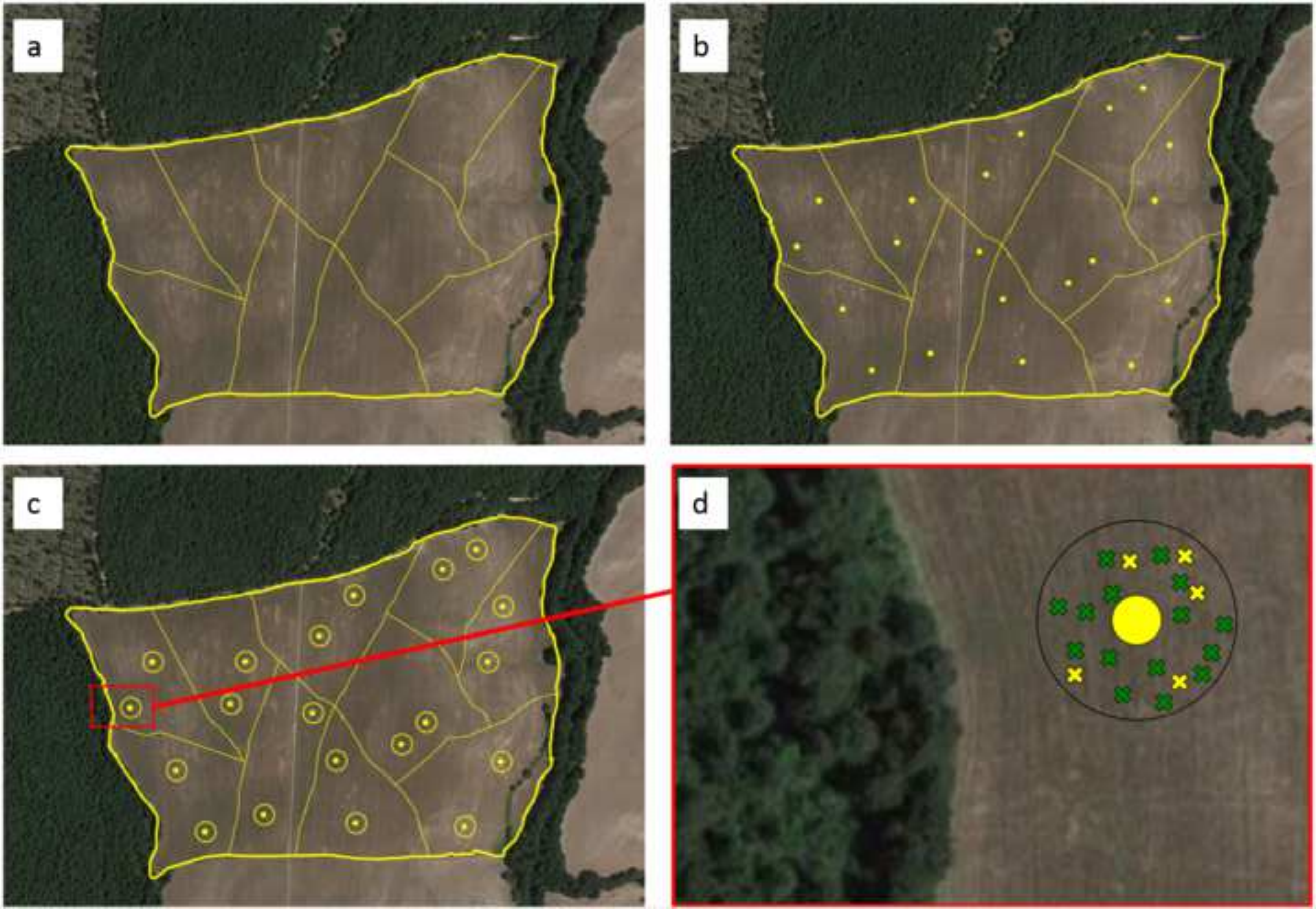

Figure 3

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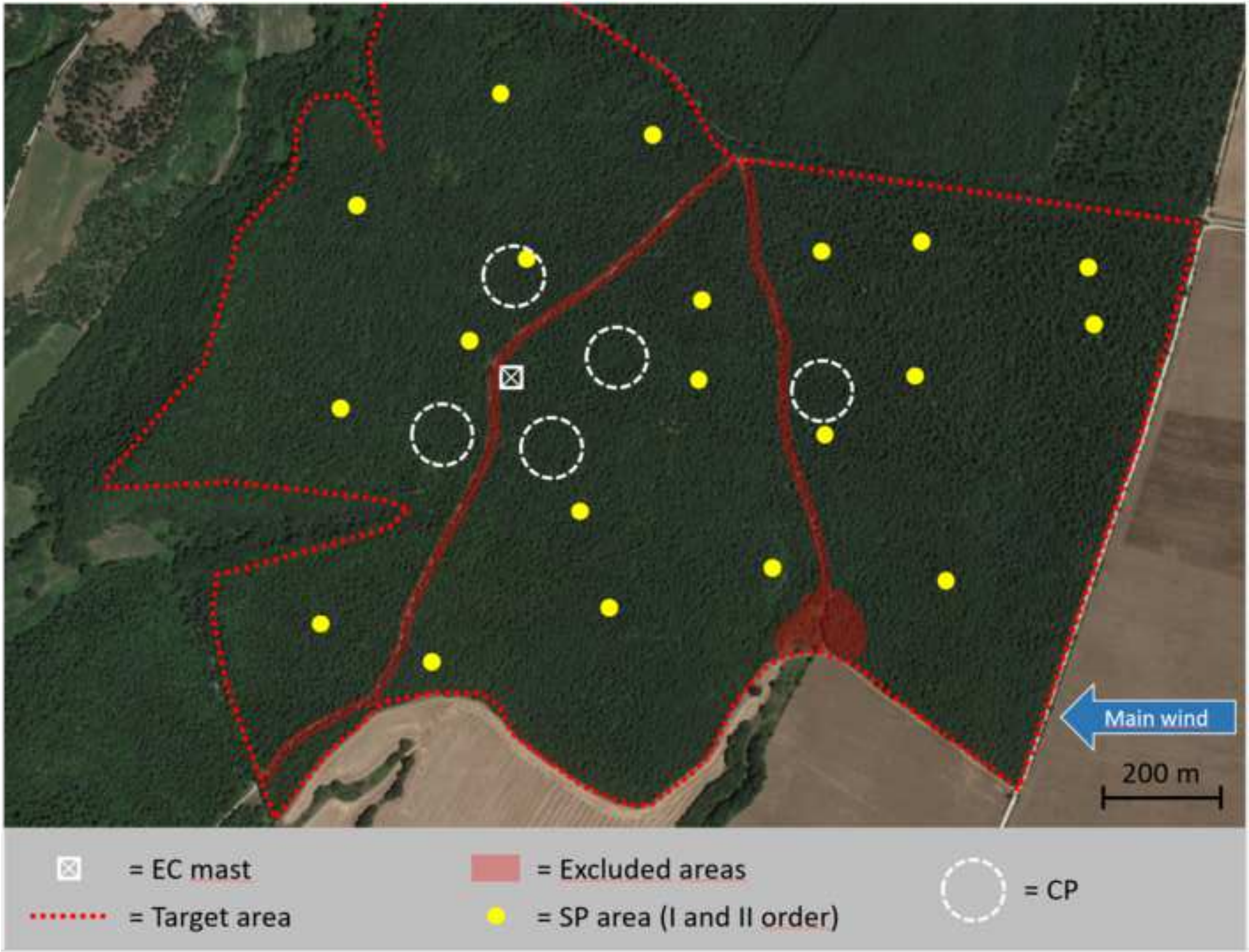

Figure 4

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