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Action 3 – ECo
Report n. 3 (2014-02)
(Action ECo IT & ECo SI)

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1 Brief summary of contents

1.1 Contents from Sub-action 2 – Activities in Italy

In Reports n. 2 (2013_February) of Action ECo-Italy were presented results of Phase-1.

The activities performed in Phase-1 were mainly focused on characterising the forest landscape spatial pattern of areas subjected to forest management actions (analysed as small area) on the basis of the landscape context, including surrounding forest areas and/or other natural or semi-natural ecosystems in which they appear (analysed as large areas). The complete descriptions of activities and achieved results have been widely described within Report n. 2.

Within the future estimation of planned Action's objectives of Report n. 2 was also supposed to analyse timber harvesting impacts on forest landscape sites by application of forest landscape simulation models (FLSMs).

The objectives that Action ECo-Italy must pursue within the project are: to use remote sensing techniques and mapping tools to assess the landscape patterns and the ecological connectivity of the test areas with the neighbouring ecosystems/landscape. Furthermore the Action will deal with the evaluation of potential remote-sensing indexes related to Sustainable Forest Management (SFM) indicators such those connected to carbon stocks/sequestration and structural biodiversity and to check how the management operations may influence ecological connectivity.

The main goal of Action ECo Phase 2 is to analyse and quantify the potential disturbances due to forest management application on forest ecosystems, evaluating the potential increasing or decreasing of both landscape and fauna biodiversity in order to identify best forest practices.

In Phase 2 the monitoring of forest landscape post-application of forest treatments is based mainly on the acquisition of remote sensing images after cutting activities and in the use of mapping tools to assess the landscape patterns after forest management activities.

The development of this phase is closely related to the performance of other activities of the project and in particular at the cutting activities within site areas.

The remote sensing monitoring from optical passive multispectral sensors has been widely used in forestry research. Different multispectral sensors at medium and high resolution have been used to produce landscape thematic maps of different phenomena in several environmental contexts (Chirici and Corona, 2006). Several correlation methods have been also used to correlate forest attributes collected in field surveys within sampling points and auxiliary remote sensing variables in correspondence of the same sampling points (Chirici and Corona, 2006). Remote sensing data have been also used as information source of different models inputs and in the quantitative data spatialization with parametric and non-parametric methods (Chirici and Corona, 2006).

The high potentiality of the remote sensing techniques in the forest monitoring field is widely used and tested. In the Action ECo-Italy, the forest landscape spatial pattern of sites in the pre-treatments situation will be analysed and compared with that post-treatments using remote sensing data acquired in the date before and post forest management application.

To monitor the potential disturbance of forest management activities application on the forest landscape through the use of remotely sensed data, is necessary to acquire these data at the end of all the cutting activities.

The potential delay in the application of timber harvesting activities within site results in a potential delay in Action ECo activities.

Furthermore, the better reflectance indexes of vegetation which can be observed in the near infrared (NIR) (about 0.7-0.3 μm) and better in the medium-infrared (MWIR) (about 1.35-6 μm) wavelengths of the electromagnetic radiation is closely depend on the leaf water content and for this reason, the time of acquisition of data should be in the growing season (mainly in summer months).

During the acquisition process of data from remotely multispectral sensors, especially if high resolution sensors, often occur that data of the area of interest are not available or, if available, they cannot be used because the image have too much cloud cover. Data searching and selection of best data is an important procedure to be performed and oftetn does not provide the expected results.

Simulation of timber harvesting impacts in forest landscape may be a possible alternative solution to overcome certain kinds of problems. Furthermore, predicted scenarios may allow evaluating the potential forest management disturbance on forest landscape over time.

For these reasons two FLSMs were tested on a site area of the project and in particular, two timber harvesting simulation models (THSMs) in order to evaluate the feasibility of their application in the project context to reach the expected results in case the potential obstacles discussed above occur.

The feasibility of application of timber harvesting simulation models were tested in the small area (as spatially defined in Phase 1 of 10 km^2 size) of Cansiglio site. The tests aims were: 1) to evaluate the feasibility of THSMs application using as inputs for models the available and collected data for project test sites; 2) to compare two different THSMs approaches; 3) to evaluate the necessary time for the application of models in order to be able to respect the project deadlines.

The two forest management alternatives actuated within Cansiglio site were tested.

Present report is mainly focused on: *i)* to describe the tested models: *static community* and *dynamic community*; *ii)* to simulate the two FM alternatives applied in Cansiglio site with both tested models; *iii)* to present resulting scenarios of tested simulation models; *iv)* to discuss the feasibility of application of models in the project context.

1.2 Contents from Sub-action 2 – Activities in Slovenia

This report refers to the annual progress report of Action ECo-SI, the Slovenian part of the ECo action, which differs somewhat in methods from the Italian part.

The main objective of Action ECo-SI is to use remote sensing techniques and GIS tools to compare different forest management regimes at the forest stand level (i.e., at the selected forest test sites) and to assess their impacts on forest structures, carbon balance and biodiversity. Another objective is to analyse the forest landscape processes at the regional scale, employing landscape classification by means of metrics such as percent of forest cover, forest core area statistics, land-use pattern, landscape fragmentation, etc.

The analyses of land use changes and landscape metrics at the landscape level were done with the forest maps from 2012 and 1975. Socio-demographic trends were evaluated using statistical data provided by Statistical Office of the Republic of Slovenia.

At the forest stand level there was the second (post treatment) lidar data acquisition performed in 2013 over the three Slovenian test sites in order to be able to compare the stands with the 2011 lidar data and thus to glean immediate 3-D structural effects of sylvicultural treatments. Multitemporal lidar data were processed and several metrics were analysed in order to glean the change in the lidar-based indicators.

2 Report on performed activities

2.1 Performed activity from Sub-action 1 – Activities in Italy

2.1.1 General presentation of forest landscape simulation models (FLSMs)

FLSMs were designed specifically to address management or research questions about spatially extensive landscapes (Scheller & Mladenoff, 2007).

All FLSMs are spatially explicit: landscape elements have map coordinates and are placed within their geographic context. Landscape elements must be assigned values before simulating a landscape, i.e., the landscape must have an initial configuration. A geographic information system (GIS) is typically used to input, store, and display data (Scheller & Mladenoff, 2007). FLSMs may also be spatially interactive, i.e., simulate lateral (horizontal) fluxes or processes that spread across the landscape (Reiners and Driese, 2001; Mladenoff, 2004; Peters et al., 2004; Gustafson and Crow, 1998; Gustafson et al., 2000).

Because of the emphasis on broad-scale change, FLSMs are typically used to simulate landscape change for multiple decades (50–500 years) (Scheller & Mladenoff, 2007).

FLSMs vary widely in their algorithms, complexity, and input requirements (Scheller & Mladenoff, 2007). In particular, the main approach is the object oriented design (OOD) producing simulation models with multi-purpose and multi-scale applications built from modular components (Maxwell and Costanza, 1997). As a result, a single model may represent different processes using a combination of rules, continuous mathematics, probability theory, and both deterministic and stochastic algorithms (Scheller & Mladenoff, 2007).

FLSMs are typically used to compare alternative ecological assumptions or management options. The suite of conditions simulated is typically referred to as scenarios. Scenarios define the assumptions and parameters necessary to estimate potential future conditions, identify key processes, or reveal important interactions among simulated processes. Multiple scenarios form a suite of hypothetical circumstances, the results of which are compared against each other. Scenarios enable an experimental approach to landscape change by allowing alternative hypotheses that would otherwise not be possible (Mladenoff and Baker, 1999a; Mladenoff, 2004).

Operationally, a scenario may begin either with empirical landscape data as input or with an artificially generated initial state, such as a random or fractal arrangement of spatial locations (Gardner et al., 1987).

FLSMs can be classified from an ecological perspective in models considering: spatial interactions, ecosystem processes, and community dynamics (Scheller & Mladenoff, 2007).

We tested two models considering spatial interactions excluding ecosystem processes and in particular two kinds of models considering: a *static community* and a *dynamic community.*

Spatially interactive (also 'landscape' or 'contagious') processes transfer energy, matter, or information across the landscape (Reiners and Driese, 2001). Spatial interactions across landscapes produce emergent behaviour and spatial patterning at multiple scales and therefore contribute to the evolution of landscape pattern and changes in spatial heterogeneity. Examples of spatial interactions include the dispersal of seeds, a fire spreading, the movement of herbivores, and neighbouring trees competing for light (Scheller & Mladenoff, 2007).

A landscape can also be broken into a grid of equal sized, typically square or hexagonal, cells. Spatial interactions among cells can be defined by either neighbourhoods (e.g., the 4, 8, or 12 nearest neighbours) and/or can be a function of the distance between cell centre points (Mladenoff and He 1999; Mladenoff and Baker, 1999b).

All FLSMs include spatial and temporal change of tree species composition-forests change over time. The principle difference among FLSMs is whether the community itself is static or dynamic (Scheller & Mladenoff, 2007).

For a *static community*, tree species composition and associated characters are defined a priori and do not evolve during a simulation, although the spatial distribution of the community will change over time. A *dynamic community* is not fixed and the composition and character of simulated communities will evolve over time (Scheller & Mladenoff, 2007).

Forest communities can be represented as successional stages or 'serial community types' (Cattelino et al., 1979). The terms 'community state', 'vegetation classification', and 'land cover type' also apply (Yemshanov and Perera, 2002). A successional stage is associated with species, age, and/or biogeochemical information. Successional pathways are typical, likely, or potential transitions among successional stages. Without disturbance, these pathways will converge on a single "climax" community or potential vegetation type (Keane and Long, 1998; Logofet and Lesnaya, 2000). Transitions occur after a certain time passes or disturbance occurs (Klenner et al., 2000; Keane et al., 2002). Alternatively, time dependent transitions probabilities (Markov chain) can be used (Balzter et al., 1998; Logofet and Lesnaya, 2000; Yemshanov and Perera, 2002).

Since successional stage models have static communities, their application is limited to stable ecosystems or short time horizons. For example, climate change or species invasion will likely alter successional processes and cannot be modelled with static communities. Another critical assumption is that all successional pathways are known and that novel combinations of species will not occur. Finally, the use of static communities typically assumes that all species propagules are universally available (Scheller & Mladenoff, 2007).

Other FLSMs explicitly include discrete tree species and their life history traits (Mladenoff et al. 1996; Roberts 1996a). Species can be recorded as present or absent, stratified into classes (diameter and age classes being the most common), or recorded as individual trees. The inclusion of discrete species implicitly assumes that forest change can only be adequately predicted by considering individual species life history attributes, physiology, behaviour, and/or biochemistry. Communities represented by multiple species, each individually responding to changing environmental drivers, are dynamic and will evolve over time. Although apparently more flexible, dynamic communities require that a greater number of demographic processes be parameterized and simulated, including at least birth, ageing, and death. The duration of the model simulation and the estimated stability of community types will determine whether simulating a dynamic community is justified, given the additional parameterization required.

2.1.2 Timber harvesting simulations in Site-1 (Cansiglio) forest landscape (small area of 10 km^2 size)

We tested the models within the small area (10 km^2 size as defined in Phase-1) (orange line in Fig. 1) of Site-1 (Cansiglio). In this site, forest treatments were applied within the about 30 hectares area (yellow line in Fig. 1) by the Italian National Forest Service.

In the small areas of Italian sites were available (description of acquired data can be found in Report 2 of Action ECo). Forests in small area cover about 754 ha. The main forest type is the even-aged beech forest with a cover of 71 % of total small area. It is the main managed forest type. A small percentage of coniferous forests (mainly Norway spruce plantations) are present.

Within the site of about 30 hectares size (yellow line in Fig. 1), forest management activities are implemented into smaller areas of about 3 hectares size. In particular, forest harvesting activities were developed according two different criteria of application indicated as: *traditional* and *innovative* criterion. Both criteria involve the application of "selection cutting" ('single tree selection', 'group selection' or a combination of the two).

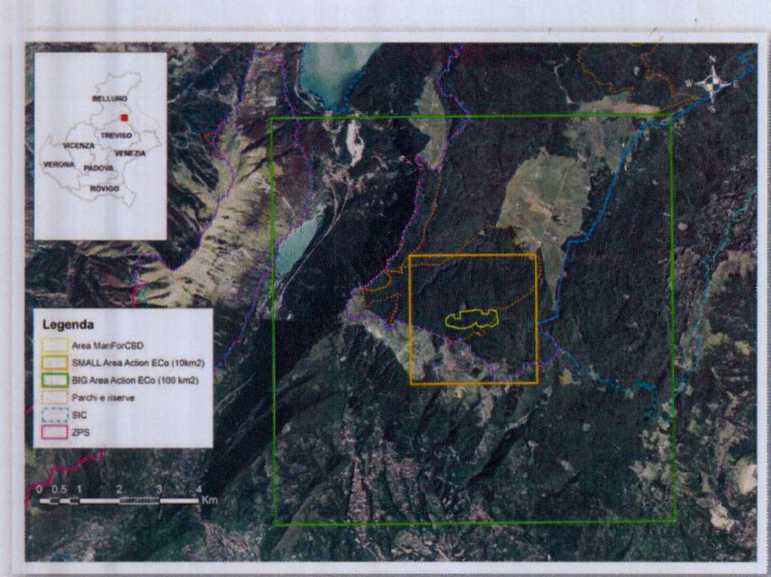


Figure 1: Cansiglio test site 1. Yellow fine defines the area where forest management actions are developed. Orange and green lines demark respectively small (10 km^2) and big (100km^2) areas as defined in the Phase 1 of the Action ECo activities.

As defined by the Italian National Forest Service, the aim of the "*traditional*" forest management (FM) criterion is mainly to reduce the level of competition and to optimize the distribution in the growth space for the best select species within the forest population (Fig. 2a). The main aim of the "innovative" criterion is to create a greater structural diversity within forest stands (Fig. 2b).

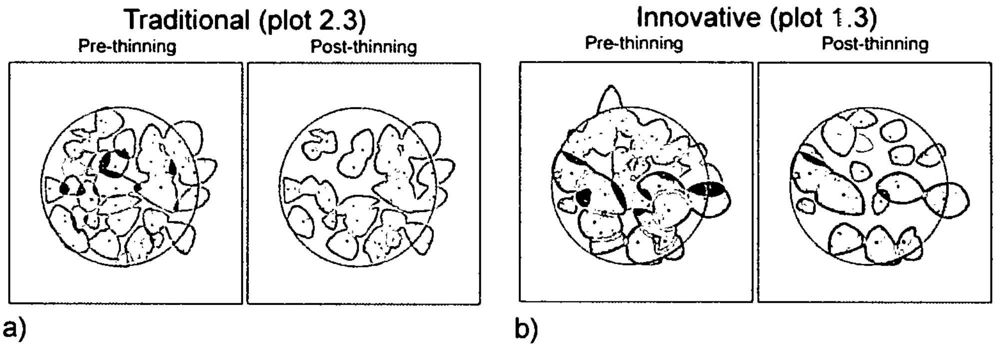


Figure 2: scheme of resulting forest stand pattern following the two forest management criteria applied in two Cansiglio site plots.

In the feasibility tests we simulated the forest harvesting disturbance due to the two forest management alternatives without include ecosystem processes.

Ecosystem processes encompass a broad range of biophysical and biological processes that mediate the exchange of energy and matter between biotic pools and the abiotic environment (Scheller & Mladenoff, 2007). FLSMs that explicitly include ecosystem processes typically simulate the net growth of trees (photosynthetic carbon fixation minus autotrophic respiration) at a minimum.

In the below paragraphs the two tested FLSMs types will be described. Both FLSMs excludes ecosystem processes ad will be distinguished as:

- THSM-1: simulation model including spatial interactions; static communities; excluding ecosystem processes;

- THSM-2: simulation model including spatial interactions; dynamic communities; excluding ecosystem processes.

In the simulation of timber harvesting activities by the different FLSMs, several assumptions were made.

2.1.3 THSM-1: simulation model including spatial interactions; static communities; excluding ecosystem processes

Among FLSMs including interaction, static communities and excluding ecosystem processes which include simulation of timber harvesting activities, the timber harvest simulation model HARVEST (Gustafson and Crow, 1998) was tested in Italian Site-1.

- *General description of the HARVEST timber harvest simulator*

The HARVEST timber harvest simulator (Gustafson and Rasmussen, 2005) was rested is well suited to predict the spatial effects of strategic forest management actions (Gustafson, 1999). By providing control over timber harvest parameters that represent strategic management components, HARVEST can be used to conduct virtual experiments to provide insight into the relative effects of these components on landscape wide patterns (Gustafson, 2007). Experience has shown that conducting such experiments using real landscape patterns are confounded because the initial stand conditions reflect past management actions of the various owners (Gustafson and Loehle, 2006) and such patterns can persist for a long time (Wallin et al., 1994). Neutral model landscapes provide an ideal solution to this problem by using algorithms to produce patterns that are neutral (random) relative to all spatial processes except the ones being experimentally manipulated (Gardner et al., 1987; Gustafson and Parker, 1992). By generating neutral stand maps that are independent of past management, the response of stand conditions to experimental variation of management component will not be confounded by the initial conditions.

HARVEST operates on a grid-cell (raster) representation of the landscape. The model is well suited to evaluate alternative strategies by providing comparable predictions about how the alternatives affect the age (or successional stage) distribution of the forest, the spatial distribution of forest interior and edge habitats, and the patch structure of the resulting forest landscape.

HARVEST is a rule-based stochastic model that simulates the timber management of forested landscapes by applying silvicultural techniques to maps of forest mosaics. The silvicultural techniques applied can vary among forest types and spatial units (e.g., ownership blocks). The model mimics the process of selecting stands for silvicultural treatment in space and time, and these treatments change either stand age, forest type, or both, depending on the silvicultural technique or process (e.g., type conversion) being simulated. Silvicultural techniques are targeted to specific forest types and are specified by several parameters: cut block size, stand age constraints, rotation length, spatial dispersion of cut blocks, effect of cutting on stand age and forest type, adjacency constraints, and total area to be cut. Stands are stochastically selected and harvested to satisfy the criteria of the parameters.

With HARVEST, the object is not to find a scheduling solution (i.e., determining the sequence of harvest activities to optimize the achievement of a specific objective), but to predict the expected spatial pattern of the forest mosaic under a specific management strategy. It has been verified that HARVEST can mimic patterns produced by past timber management activity (Gustafson and Crow 1999).

HARVEST simulates harvest practices that reset the age of forested sites to a specific age. This includes even-aged timber harvest techniques (e.g., clear-cutting, shelter wood, seed tree techniques) and uneven aged group selection. Version 6.1 has some capability to simulate other uneven-aged techniques where such treatments predictably change stand structure, by using stand age as a surrogate for stand structure.

HARVEST allows the user to interactively simulate harvest activities that are targeted to forest type and management area (MA). Management areas are relatively large, multi-stand areas that are to be managed by specific objectives. The user specifies harvest parameters (such as harvest size, rotation age, green-up interval), for a management area and forest type. The process may be repeated for multiple management area/forest type combinations and time steps.

HARVEST allows the user to specify any combination of two treatment effects when a harvest is implemented: 1) the age to which the treated cells are set and 2) whether the forest type will be converted upon cutting (e.g., planting). This is useful to simulate planting (or under-planting), or other silvicultural techniques that convert forest type and/or reset stand age. These combined effects can be used to simulate simple, deterministic succession or disturbances by converting the forest type of cells that are above a specified age without resetting the age.

HARVEST can conduct several analyses of the spatial pattern of the landscape both before and after simulated harvest. The patch structure (patches defined by stand age or forest type) can be analysed for the entire mapped area or by individual management areas. The amount of forest interior and edge habitat can be calculated and displayed according to the definition of interior given by the user. Version 6.1 adds calculation of the fragmentation index GISfrag (Ripple et al., 1991).

Application of HARVEST simulator in the Italian Site-1

HARVEST simulator requires a set of four input map files to simulate harvest activity: forest age map, forest type map, management area map, and a stand identification number (ID) map.

For Cansiglio small area test site medium and high resolution geographic datasets were acquired in the last Phase-1 and available.

The landscape of test site was represented by 10 by 10 meters grid cell size as the spatial resolution of the available territory data.

We simulated the FM criteria (traditional and innovative) within the small area (10 km^2) over 200 years.

- *Inputs maps used in the simulation*

Forest Age Map for Cansiglio

This is a grid map contains cells whose values represent the age (in years) of the forest on each cell and is used by HARVEST to determine if cells meet the age constraints for harvest (Gustafson and Rasmussen, 2005).

The available forest types map (1:10000) for small area test site contained also information of dominant forest structure. This map was rasterised at the defined pixel resolution (10 by 10 m) and used as basis to classify the forest landscape in dominant forest age per types on the basis also of acquired forest managers opinions (Fig. 3a). The classified map has a dominant forest age ranging from 56 to126 years.

Forest Type Map for Cansiglio

The above rasterized forest types map (1:10000) was used. In this map, each cell in contains a assigned integer code value denoting a specific forest type.

This map is used by HARVEST to apply harvest rules to the correct forest type. HARVEST also uses this map when leaving uncut buffers (typically riparian buffers), and to identify the non-forest land when calculating the amount of forest interior and edge habitats (Gustafson and Rasmussen, 2005).

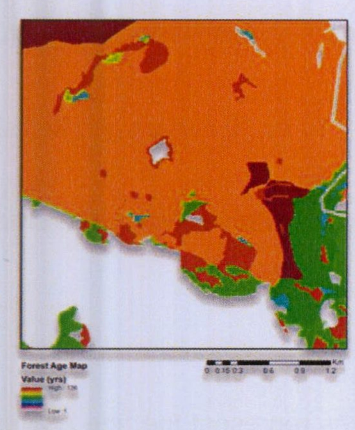
In the small area test site the forest landscape is dominated by beech forests types (Fig. 3b).

Management area for Cansiglio

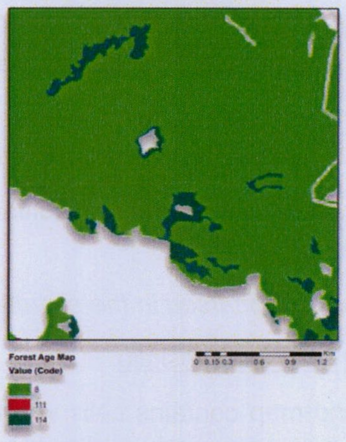
Each cell in this map contains an assigned integer code value denoting the management area in which that cell falls. A management area is considered as a multiple-stand area in which all the stands will be treated with similar, specific management practices.

This map is used by HARVEST to apply the specified harvest strategies to the correct management area. This map of MAs remains constant throughout a simulation of multiple time periods (Gustafson and Rasmussen, 2005).

For Cansiglio small site the forest stand map of the Biogenetic Nature Reserve was first acquired in digital format, implemented in GIS and georeferenced. The forest stand geographic dataset was produced by visual digitalization of stands boundaries. The 30 ha size area boundaries subjected to the FM activities was included ad the layer was then rasterised at the 10 x 10 m resolution (Fig. 3c and Fig. 4). A total number of 29 MAs was maintained.

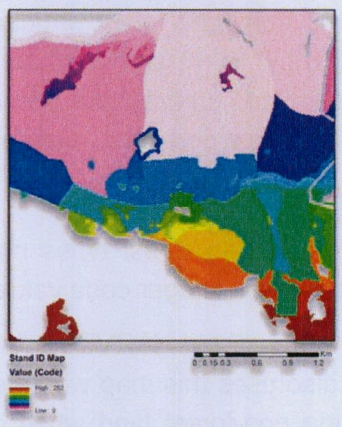


a) Forest Age map



b) Forest Types map

c) Management Area map (MA)



d) Stand ID map

Figure 3: input maps for Cansiglio HARVEST model.

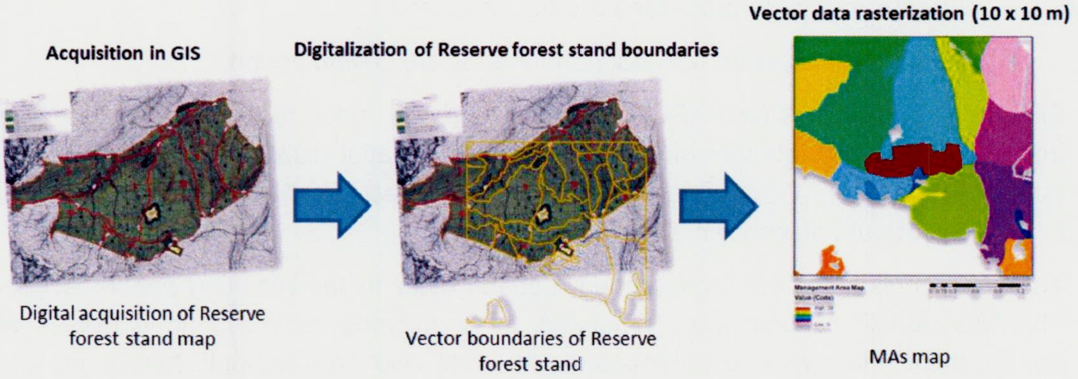


Figure 4: Flow chart of creation of MAs map input for simulation by HARVEST in Cansiglio small area test site.

Stand ID for Cansiglio

This is a map of stand ID numbers, where each stand ID value is a unique integer <64,535. This map is used by HARVEST to track harvest activity in stands. This map of stand IDs remains constant throughout a simulation of multiple time periods.

The stand ID map for Cansiglio was made by intersecting forest type, age, and MA maps (Fig. 3d). Stand ID ranges from 1 to 252. In all maps zero value defines the non-forested areas and is not considered by HARVEST.

- *Description of spatial timber harvest simulation by HARVEST in Cansiglio*

In order to simulate the timber harvesting activities by HARVEST in Cansiglio site we assumed that:

1. The forest cover was uniform at the simulation time zero (assumed to be the year 2011);
2. Were no other forest management activities within the small area site before the timber harvest simulation;
3. The forest type does not change during the simulation.

In addition to these assumptions the assumption of HARVEST simulator are the follows:

- Forest age is used as a surrogate for merchantability. It is assumed that the likelihood of harvest of a stand of a given forest type within a management area is related solely to the age of the stand although is know that stocking density, size class, site conditions, accessibility and operability are all factors that influence stand growth and harvest decisions in reality.
- HARVEST randomly selects suitable stands from those stands that satisfy age and adjacency constraints. Over a time period of a decade or more, this mimics the pattern found on real managed forests (Gustafson and Crow 1999). For shorter time periods this may not be the case.
- Forest type of a stand is assigned based on the type that is most abundant within the stand.

- Forest succession processes are not simulated.
- Stand boundaries do not change along the simulation period.

Simulation parameters for HARVEST are specified for each forest type/MA combination and include size distribution of harvest openings, spatial dispersion method for placing openings within an MA, minimum stand age for harvest, total area to be harvested, and information about adjacency constraints.

The two simulated forest management options differ in the resulting pattern scenarios. The “traditional” criterion was simulated by a thinning regime that increases stand development (more mature within-stand structure) over time without creates gaps inside the forest canopy. The “innovative” criterion instead, was simulated by creation of little opening inside forest canopy.

The cutting activities were simulated into the beech forest (code 8) which resides within five MAs. Treatments are simulated every 25 years over 250 years. The prescription simulated harvesting activities in 1/10 of stands with a target harvest size of 30.5 hectares each time step of 25 years (Table 1).

Table 1: parameters used simulation by HARVEST simulator in Cansiglio small test area.

Mas (n. ID)	*Forest management option*	*Mean Size (m^2)*	*Minimum Size (m^2)*	*Maximum Size (m^2)*	*Min Age (yrs)*	*Max Age (yrs)*	*Dispersion method*			*Cut target (ha)*	*GU* Int. (yrs)*
								Group Prop	*Reset forest Age*		
19, 20, 23, 24, 29	Traditional	100	200	400	80	160	Group	0.1	Minus 10 years	30.47	40
	Innovative	100	200	400	80	160	Group	0.1	-	30.47	40

(*) Green-up interval. The green-up interval typically is understood to be the length of time it takes for a stand to regenerate sufficiently to no longer be considered a newly harvested opening.

We run three replicates for each forest management option.

- *Description of spatial pattern analysis after timber harvest simulation in Cansiglio*

We used HARVEST to calculate area of forest edge and interior habitat from scenarios of age forest maps. We calculated the amount of interior habitat based on the assumption that edge effects penetrate 100 m into the forest and we assumed that harvested areas persist as openings for 25 years before canopy closure. We analysed the amount of interior (forest <100 m from harvested openings <25 years old).

2.2 Results from Sub-action 1 – Activities in Italy

2.2.1 Results of THSM-1: HARVEST simulator

Examples of resulting forest age pattern scenarios taken from the Cansiglio simulation for both “traditional” and “innovative” options after 25, 85 and 125 years of timber harvest simulation can be found in Figure 5. Examples of edge and interior habitats scenarios for both simulated FM alternatives at the same simulation periods are reported in Figure 6.

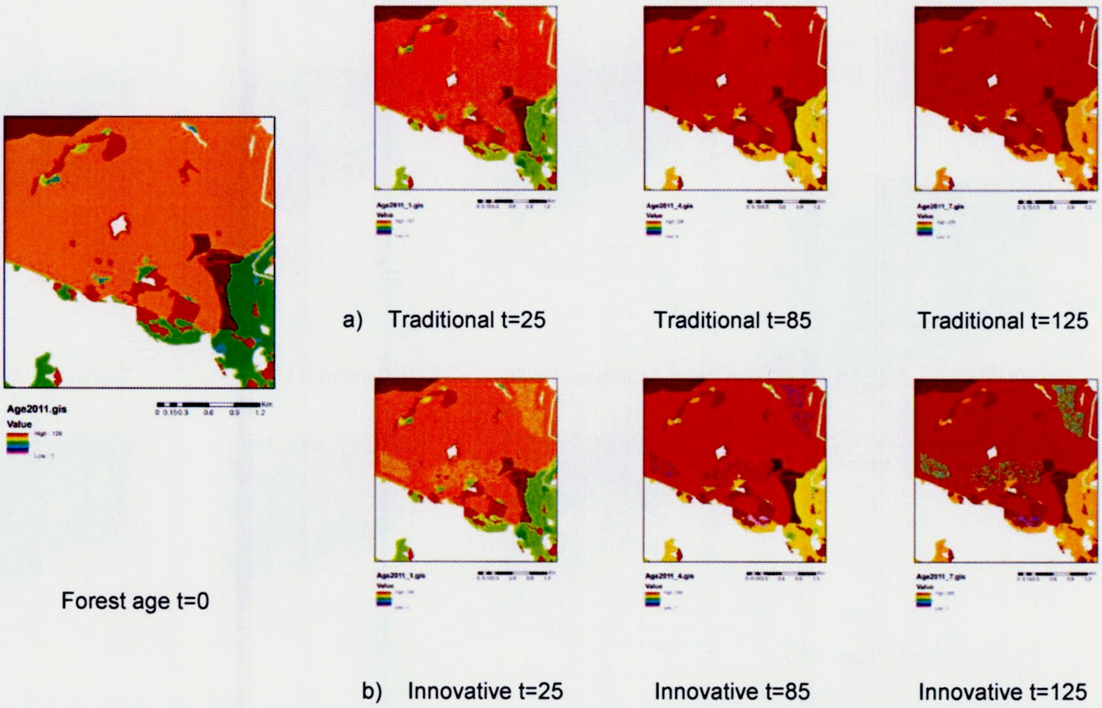
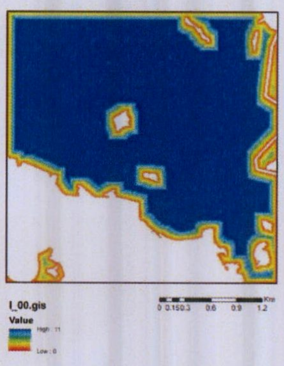
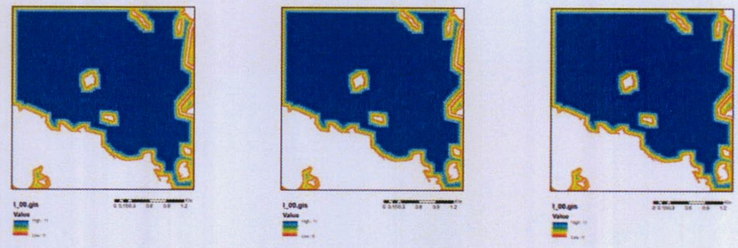


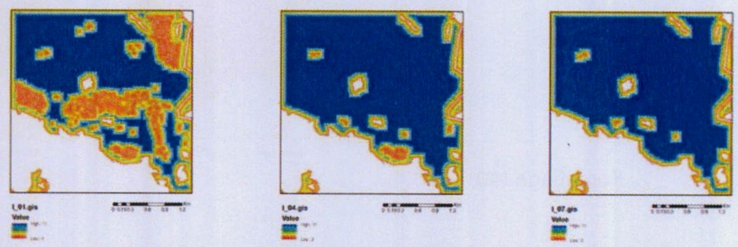
Figure 5: examples of a forest age scenario maps for a) “traditional” and b) “innovative” forest management of the Cansiglio site at years 25, 85 and 125 of simulation.



Forest spatial pattern t=0



c) Traditional t=25 Traditional t=85 Traditional t=125



d) Innovative t=25 Innovative t=85 Innovative t=125

Figure 6: examples of interior and edge scenario maps for a) "traditional" and b) "innovative" forest management of the Cansiglio site at years 25, 85 and 125 of simulation. Open habitat includes both non forested and recently harvested (<25 years) areas. Edge habitat was defined as forest within 100 m of open habitat.

The analysis of forest area amount treated each time steps (25 years) over the simulation period for both "traditional" and "innovative" forest management (Fig. 7) shows as after the fourth simulation time, a drastic reduction of the surface treated occur for both alternatives since the cutting target amount was achieved.

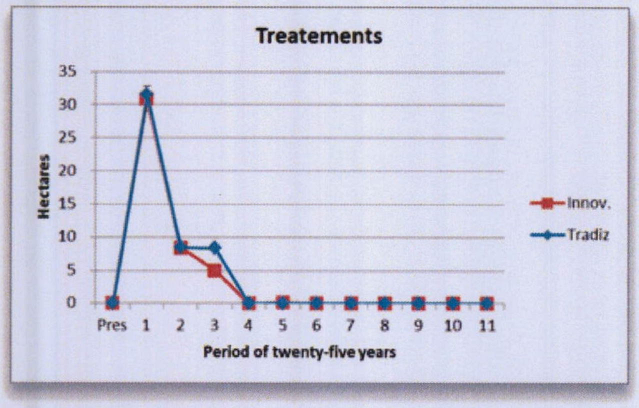


Figure 7: amount of treated forest area for each forest management option over the simulation period. Values express averages of three simulation replicates.

Simulated forest ages were grouped within four classes: regeneration (1-25 years old); young (26-80 years old); mature (81-150 years old); old growth (>150 years old).

At time zero of simulation (Fig. 8) the forest landscape is dominated by the mature age classes (81-150 years old).

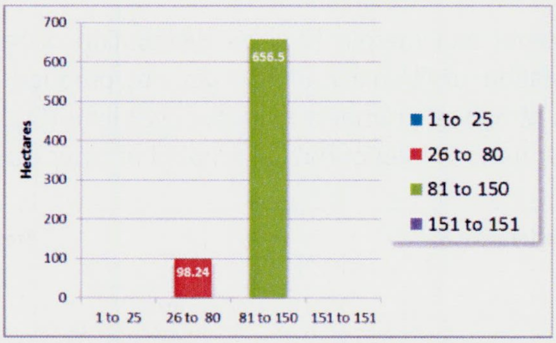
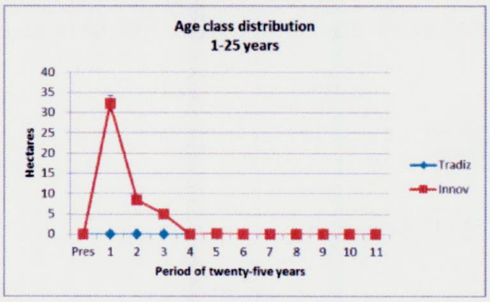


Figure 8: initial amount of forest age classes into Cansiglio small area forest landscape.

The analysis of resulting scenarios of forest age classes (Fig. 9) shows as the regeneration class (1-25 years old) appears after the first simulated treatment, since it was not present at the time zero of simulation. As see above, the "traditional" forest management simulates the increasing of average age into the stands. For both different criteria distribution of young classes (26-80 years old) initially decreases for the transition of stands in the class of more than 25 years old. In the second period, treated stands in the first cutting activities transit in this class causing the increment until the next simulated cut. The mature class (80-150 years old) is the class within which model simulates the first cutting activities and it decreases until the target size is reached. When all stand in scenarios have over 150 years old, all stands are old growth and the age class distribution remain constant over time.



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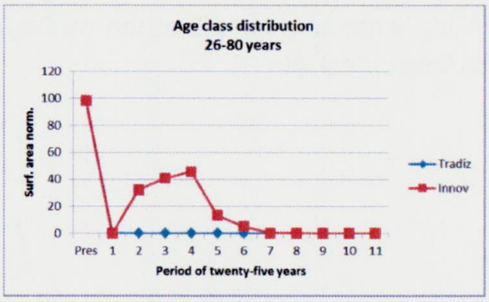

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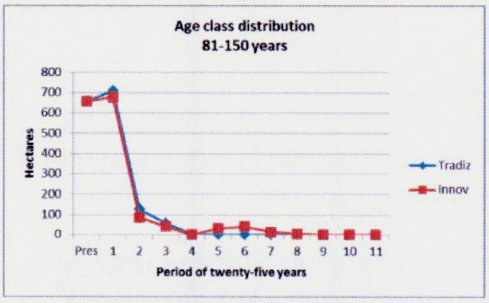

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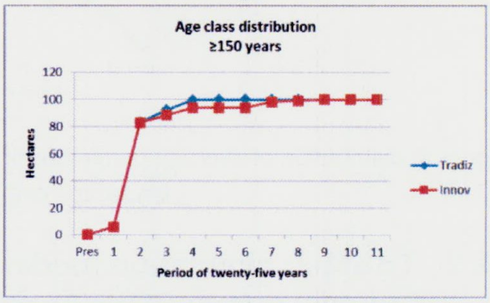
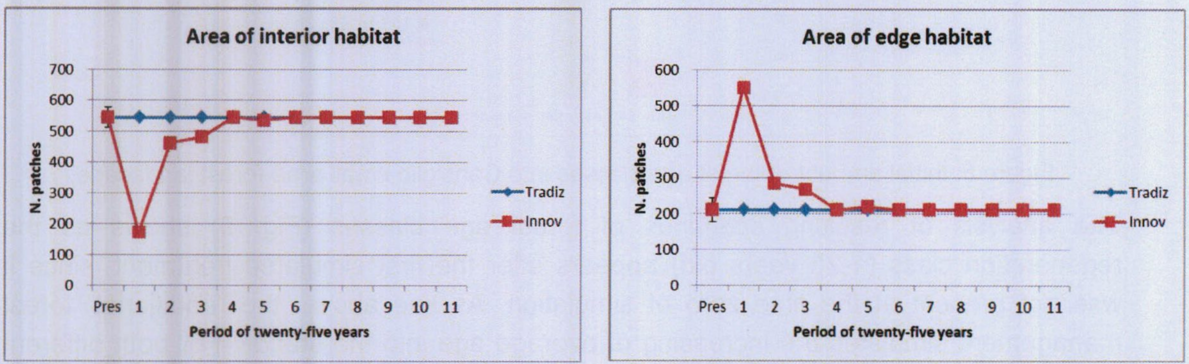


d

Figure 7: distribution of forest age classes within small landscape in simulated scenarios for Cansiglio. a) area of regeneration class (1-25 years old); b) young class (26-80 years old); c) mature class (80-150 years old); d) old growth class (>150 years old).

- ***Results of landscape pattern analysis***

The analysis of internal and margin habitats distribution of resulting pattern scenarios shows as the simulation of "traditional" FM did not produce openings into the forest canopy. The pattern of habitats remains constant over time (Fig. 8a). The "innovative" FM produced an irregular trend in interior habitat amount of older classes (> 150 years old).



a b

Figure 8: distribution patches number of interior (a) and edges (b) habitats within Cansiglio small area landscape over the period of simulation.

The simulation of "innovative" FM produced a regular trend of average patch area distribution every four simulation time (Fig. 9). At this time, stands cut in the initial simulated treatment reach the right age to be cut again. This trend shows some similarity with the expected trend that the real application of the "innovative" FM should produce over time in test site.

Figure 9: distribution of average patch size of old growth forest classes within Cansiglio small area landscape over the simulation period.

2.2.2 THSM-2: simulation model including spatial interaction; dynamic communities; excluding ecosystem processes

Among these kinds of FLSMs we used the timber harvest disturbance simulation module within LANDIS-II simulator (He, Mladenoff and Boeder, 1999).

LANDIS is a forest landscape model that simulates the interaction of large landscape processes and forest successional dynamics at tree species level. LANDIS simulates large-scale landscape processes as well as fine-scale, species-level vegetation dynamics.

- **General description of LANDIS model**

LANDIS is able to simulate successional dynamics, seed dispersal and different disturbance regimes (fire, wind and timber harvest). Its design is object-oriented (OOD) and it is a raster-based model, optimized for greater spatial complexity (He, Mladenoff and Boeder, 1999).

From the model's perspective, a landscape is a grid of equal-sized cells or sites, each having unique coordinates. Thus, site (*i, j*) is the place on the ground at column *i* and row *j* in the grid (Fig. 10). The cell size can be varied to accommodate studies at different scales. At each site, one or multiple species is present, similar to observations in the field. Furthermore, existing species may have single or multiple age-cohorts, which are divided into 10-year intervals.

Each site (*i, j*) resides on a certain land type or *ecoregion* (a spatial landscape input, processed from other GIS layers, that may correspond to homogeneous soils, slope, or other physical characteristics) and a *disturbance regime* type (for ex. harvest) and includes a unique *list of species* present and their associated *age cohorts* divided into 10-year intervals from age 10 to the average longevity of that species. The species/age cohort information varies with establishment, succession, and seed dispersal, and interacts with disturbances (Fig. 10).

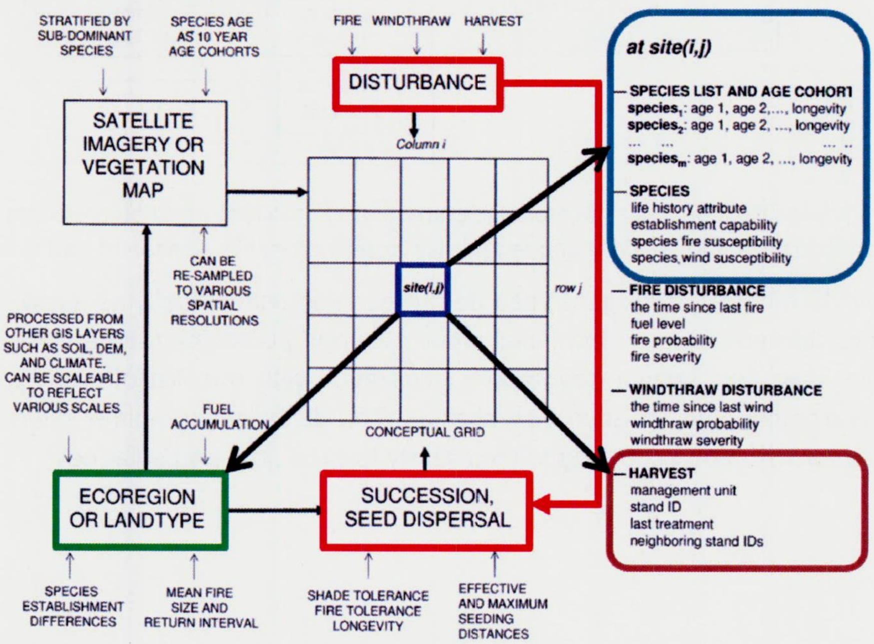


Figure 10: Specifications in LANDIS model design. The image was modified by (He, Mladenoff and Boeder, 1999). A landscape can be conceptualized as a grid of equal-sized individual cells or sites, e.g, site (*i, j*) and is stratified into environmentally homogeneous units as landtypes or ecoregions. Each site (i, j on a certain landtype, records a unique species list and age cohorts of

species. These species data change via establishment, succession and seed dispersal and interact with disturbances.

The essence of OOD is modularity, to where a complex problem is broken into multiple small and simple modules. In LANDIS the modules are the various ecological processes identified during model specification. Ecological processes differ in terms of the spatial and temporal scales at which they operate. For example, species life history attributes are static, independent of both spatial and temporal scales. Land type, which may vary with spatial scales, is independent of temporal scale. Processes such as succession are constantly occurring on every site as long as a species exists. Seeding or seed dispersal also occurs constantly but operates at spatial extents larger than a single site. Other ecological processes such as fire, wind and harvest occur at landscape scales with strong temporal variations. Therefore in abstraction in LANDIS, ecological processes can be described as modules or objects from the spatially and temporally constant to the spatially and temporally explicit (Figure 11)

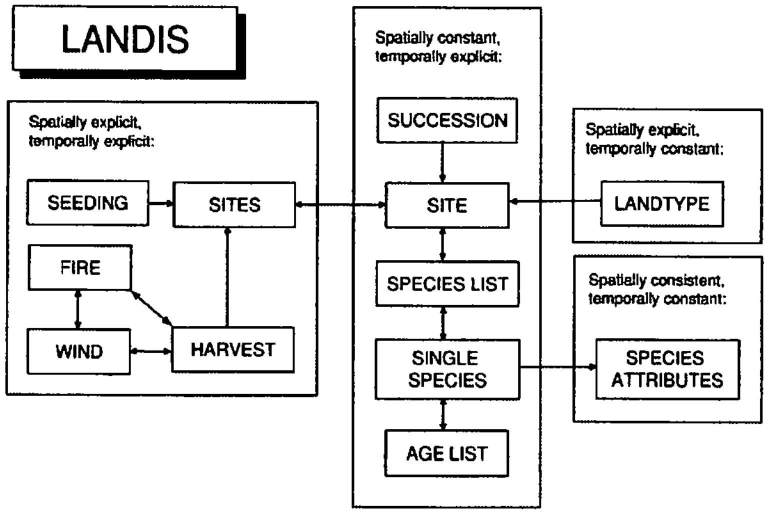


Figure 11: LANDIS Modules. The modules correspond to the real world objects from spatially and temporally constant to spatially and temporally explicit (from He, Mladenoff and Boeder, 1999).

The LANDIS model core (Fig. 12) can be represented conceptually as a repeating cycle of processes that operates on the initial input map and subsequent time steps of 10 years. Each site have own spatial geographic localization with own list of species age cohorts and physiological data for each tree species. The disturbance regime influences the tree species establishment according to their ability to exist on a particular cell.

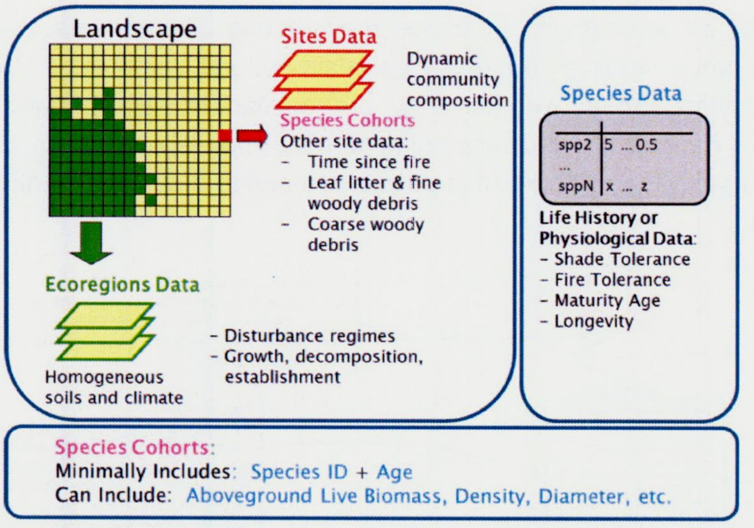


Figure 12: LANDIS Model core structure (modified from LANDIS-II workshop 04_2006).

Considering the succession module basic in LANDIS (Fig. 13), the succession process is simulated at site level according to the tree species vital attributes and their ability to exist on a particular cell based on propagule availability (seed or sprouting ability) in relation to the ecoregion type. The succession is simulated by aging the existing cohorts, by removing the old cohorts, by calculating the side shade and by simulating the reproduction adding new cohorts.

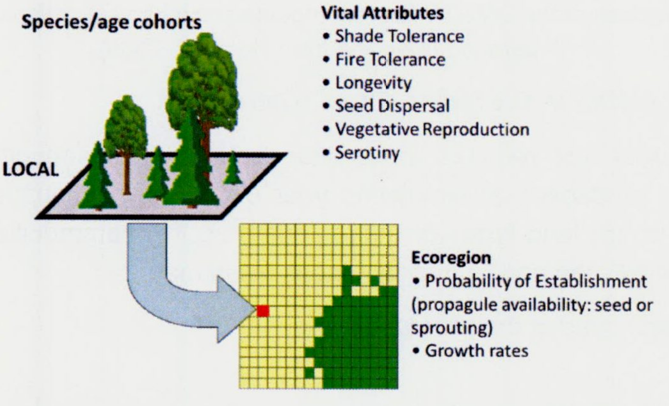


Figure 13: Scheme of succession model simulation in LANDIS Model (modified from LANDIS-II workshop 04_2006).

- *General description of the timber harvest disturbance module simulator of LANDIS -II*

The flowchart of the module basic simulating disturbance by timber harvest activities called HARVEST in LANDIS-II simulator (Gustafson et al., 2000) is shown in Figure 14.

Timber harvests are implemented within a specific hierarchical management structure. The overall landscape is divided into MAs, each to be treated with specific harvest regimes at specific intensities. Within MAs that are to be harvested, LANDIS expects to find the land base delineated into stands.

Harvests are implemented by removing specific cohorts of specific species on sites selected for harvest. The sites selected for harvest are determined by one of the different "harvest regimes" among which the user may choose. These harvest regimes vary in the number of entries required to complete the silvicultural treatment, in the intensity of the harvest activities and in whether they are applied to. Within each MA, stands are prioritized for harvest (ranked) according to rules that reflect criteria of a specific forest management activity. And here, it is possible to define a series of ranking algorithms (He et al., 2005).

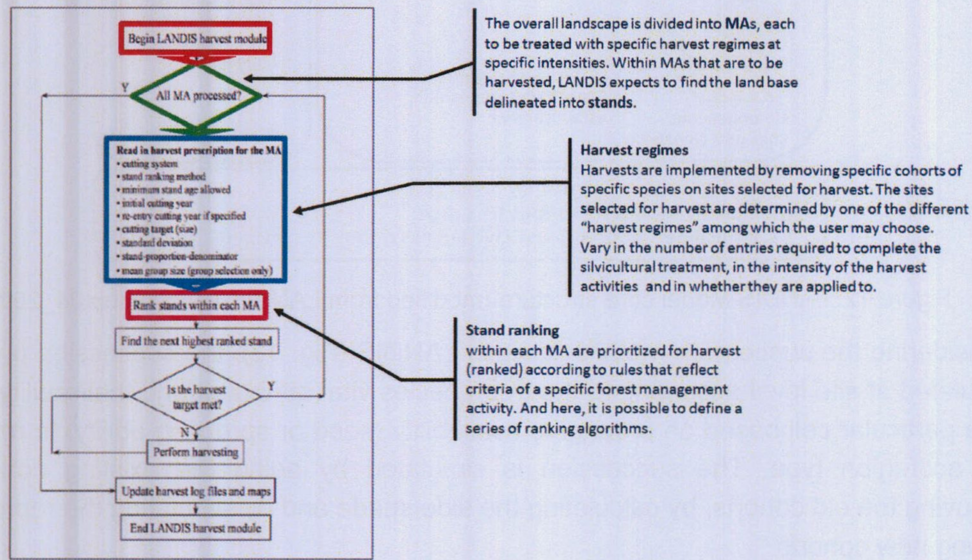


Figure 14: Flow chart of the LANDIS harvest module show harvest actions with one LANDIS iteration (modified from He et al., 2005).

Application of LANDIS in the Italian Site-1 (Cansiglio)

The LANDIS model first requires information on the "initial conditions" for each site (cell/pixel) of the landscape at simulation year 0. These are spatially defined by four raster input layers: (a) land types or ecoregions map; (b) communities localization map; (c) stand boundaries map and (d) management areas map.

- *Inputs maps used in the simulation*

<u>Ecoregion map</u>

In LANDIS the environmental condition of each site (cell/pixel) is defined by ecoregions or land types stratifying the landscape.

In Cansiglio small area test site medium resolution GIS vector layers of forest types and ecoregions at regional scale (1:25000 and 1:50000 respectively) were available. The ecoregion layer contains information about topographic characteristics, soils and local climate conditions. This map was then rasterised at 10 by 10 meters (0.01 ha) pixel resolution and used as "ecoregion" input layer in LANDIS model (Fig. 19a).

<u>Initial communities localization map</u>

LANDIS requires the map of "initial localisation of communities" at simulation year 0 to link each site (cell/pixel) with a list of species, corresponding to the life history and phenological data of each forest community species and age cohort of 10 years.

Species age map are not available for the project study areas.

We derived the initial communities map and species-age cohorts list by several steps (Fig. 15):

1) We first grouped forest type map classes in two dominant species classes: beech forests and Norway spruce forests.
2) In the second step, we estimated the forest volume collected in the Italian National Forest Service inventory data (dependent variables) at landscape scale, by the non-parametric k-NN method implemented in K-NN FOREST software (Chirici et al, 2012; Chirici et al., 2008) using as correlated variables 4 multispectral bands of cloud free IRS LISS III imagery acquired in summer 2006 (resampled at 10 by 10 m resolution).
3) We then correlated the volume of each forest dominant species (beech and silver spruce forests) by allometric equations to estimate the age per sites of 10 by 10 m. Estimated age values per pixel were grouped in three initial forest size classes: pole (80-120 yr); sawlog (120-160 yr) and old growth (>160 yr).
4) We then spatially combined the age map, forest dominant species and ecoregion map to achieve 15 different combinations representing the initial localization of forest species communities (Fig. 19b).
5) Finally, we populated the "initial communities attribute table" of dominant species cohorts of 10-years classes by the distribution frequency of age of dominant species for each of the 15 combinations of the "initial communities localization map".

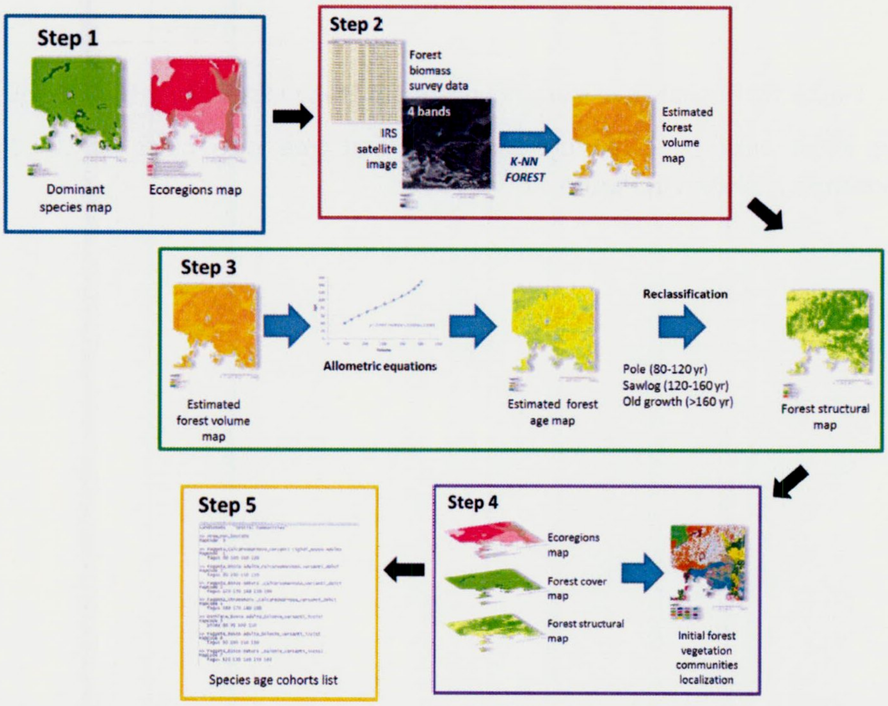


Figure 15: Flow chart of creation of initial communities information for Cansiglio small area. Step 1: Grouping forest types classes in two dominant species classes: beech forests and Norway spruce forests; Step 2: Spatialization at landscape scale of forest volume; Step 3: Estimation of age for dominant species; Step 4: Combine; Step 5: List of 10-years cohorts of dominants species.

- Stand boundaries and management areas (MAs) maps

In the simulation stand boundaries map is the same used in the HARVEST simulator.

The MAs map was produced by aggregating forest stand of same dominant forest species. The result was a map composed of two MAs respectively dominated by *Fagus* and *Picea abies* (Fig. 16 and Fig. 19d).

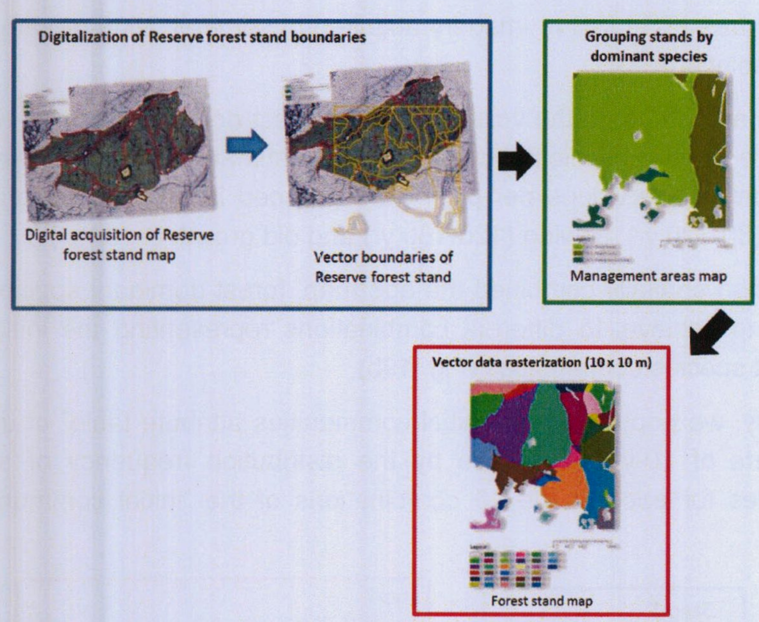


Figure 16: Flow chart of stand boundary and MAs maps creation for Cansiglio small area.

The initial area by MAs, by ecoregion and tree size class of Cansiglio small area landscape is shown in Figure 17.

Category	Amount (hectares)
Management area (MA 1)	744.19
Area of natural disturbance simulation only (MA 2)	36.73
Non forest area	219.08
Reserve area	500.93
Ecoregions	
Calcareomarnoso (900-1700 mslm) (precipitazioni 1400-2000 mm; t. medie annue 6°-12° C.) (suoli moderatamente profondi)	55.31
Calcareomarnoso (800/1000-1700 mslm) (precipitazioni 1000-2000 mm; 6-13° C.) (suoli moderatamente profondi)	382.21
Calcare con fenomeni carsici (700-2000 mslm; precipitazioni 1000-2000 mm; t. medie annue 6°-13° C.) (suoli sottili su roccia)	191.65
Dolomie (400-2000 mslm) (precipitazioni 900-2000 mm; t. medie annue 6-13° C.) (suoli moderatamente profondi)	151.75
Dominant size class	
Early Sawlog (80-120 yr)	60.13
Mature sawlog (120-160 yr)	402.67
Old growth (>160 yr)	318.12
Number of stands (n) and size range ()	57 (0.59-74.14 ha)

Figure 17: Initial landscape conditions for Cansiglio small area.

At simulation year 0 the forest landscape of Cansiglio small test area is dominated by three age classes (Figure 18). First class includes sites of age ranging between 120 to 160 years old; the second class includes sites greater than 160 years old and the third size class includes sites of age ranging between 80 to 120 years old.

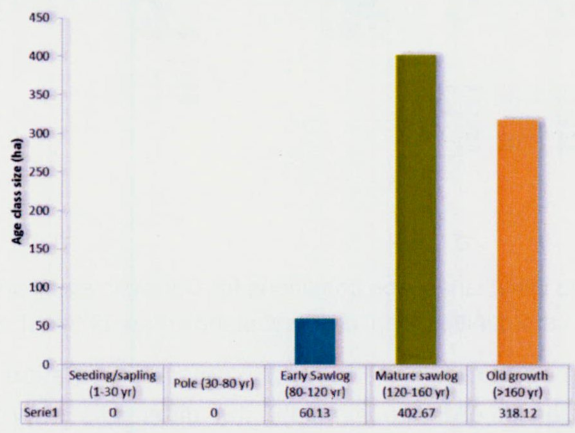
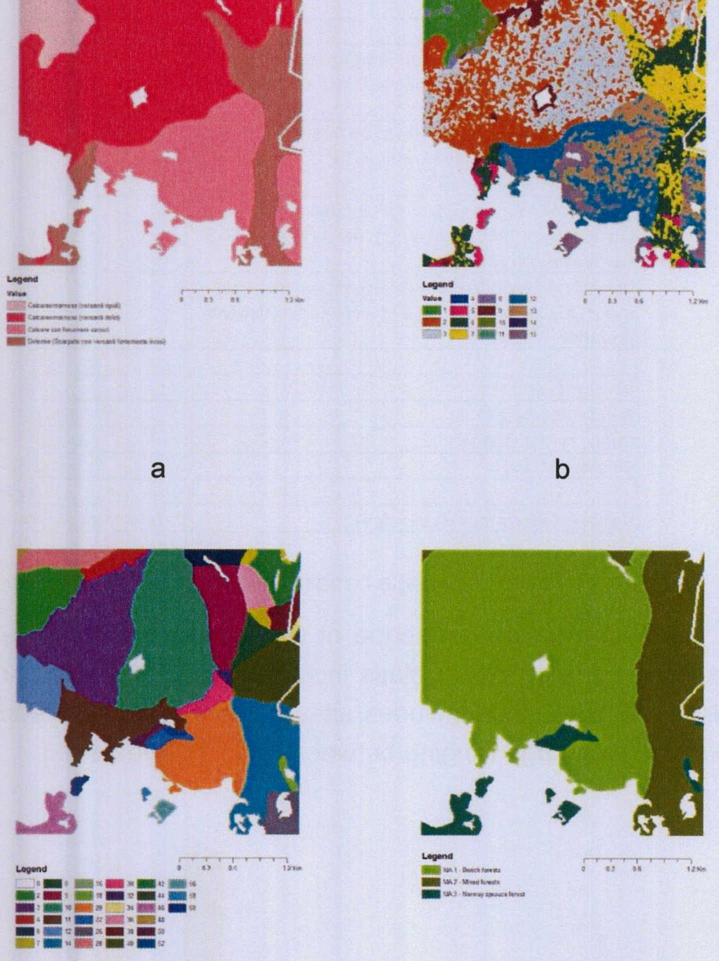


Figure 18: Initial tree species age classes in the Cansiglio small area landscape.

All input maps used in the simulation of timber harvesting by LANDIS in Cansiglio small test site are shown in Figure 19.



a b

c d

Figure 19: Maps of the initial landscape conditions for Cansiglio small area: a) ecoregions map; b) initial localization of communities map; d) forest stands map; c) forest management areas map.

LANDIS model also requires a list of phenological information and the establishment probability per species in order to simulate the differential reproduction, dispersal, and succession patterns by species and incorporating effects of disturbance and environmental heterogeneity across the landscape. These information were derived by literatures (Gellini and Grossoni, 1996). More difficult was to derive the establishment probability by species. Literature information (Vittoz and Engler, 2007) were linked with opinions of forest managers' and of experts' forestry and botanic researchers.

Application of LANDIS-II simulator in the Italian Site-1

In the LANDIS-II simulation test, we modeled three different scenarios over 400 years: 1) no harvest disturbance scenario; 2) harvest disturbance due to the "traditional" FM and 3) the harvest disturbance due to the "innovative" FM.

In LANDIS harvest prescription were assumed occur inside the MA dominated by *fagus sylvatica* (MA 1) (Table 20). The prescriptions differ for initial stand ranking, site selection and stand constraints. Both have equal rotation periods. Both are selective harvesting.

Table 2: harvest prescription in the LANDIS-II simulation test for Cansiglio small area.

Code	Mgmt. Area name	Management alternative	Harvested method
1	**"Innovative"** Selective thinning and **"Innovative"** Forest renovation cut	Harvest 40% of the MA each decade. patch cutting with opening of 1 ha size was simulated into 20% of a stand each decade, with a time rotation of 40 year and a regeneration of the area using patch cutting with opening of 1 ha size on 20% of the stand each decade with a rotation time of 120 years	Patch cutting are applied on stand random ranked ranging between a minimum age of 50 yr and a maxim age of 140 yr of half of the youngest cohorts of fagus species. Stands must be at least 20 years old prior to harvest. The renovation cutting was applied to all cohorts of fagus species. In this case stand must have a minimum age of 140 years to be cut and in addition, there must be close to it a stand of at least 30 years old. Stand are ranked to produce regulate distribution of ages classes.
2	**Cohorts aging**	**Not applied**	**Not applied**
1	**"Traditional"** Selective thinning and **"Traditional"** Forest renovation cut	Harvest 40% of the MA. Partial stand thinning on 12 ha of the stand each decade with a rotation of 40 years and regeneration of area using patch cutting with opening of 3 ha size on 50% of the stand each decade with a rotation of 120 years .	Thinning of stand random ranked ranging between a minimum age of 50 yr and a maxim age of 120 yr of the youngest cohorts of fagus and picea. Stands must be at least 20 years old prior to harvest. Renovation cutting of all cohorts of fagus and picea. In this case stand must have a minimum age of 140 years to be cut and in addition, there must be close to it a stand of at least 30 years old. Stand are ranked to produce regulate distribution of ages classes.
2	**Cohorts aging**	**Not applied**	**Not applied**
1	Not Managed	Not applied	Not applied
2	**Cohorts aging**	**Not applied**	**Not applied**

2.2.3 Results of THSM-2: LANDIS-II simulator

Examples of maps of forest age classes at simulation year 400 for the three different simulated LANDIS-II scenarios are shown in Figure 20.

Size classes modelled by LANDIS are grouped in the 10-year age classes. We distinguished five groups of age classes: seedling/sampling (1-30 years old); pole (30-80 years old); early sawlong (80-120 years old); mature sawlong (120-160 years old); old growth (> 160 years old) (Fig. 20a).

The no harvest disturbance scenario, shows a landscape mainly dominated by old growth age class (>160 years old) and abundant little patches of younger classes (1-30 years old) (Fig. 20b).

The simulation of "traditional" FM produced a landscape scenario mainly dominated by the pole age classes (30-80 years old) fragmented with little young patches (1-30 years old) and bigger islands of old growth forests (>160 years old) (Fig. 20 c).

The simulation of the "innovative" FM produced a diversified landscape scenario. Inside a matrix of old growth forests class (> 160 years old), medium size patches of pole classes (30-80 years old) and abundant smaller patches of young cohorts (1-30 years old) are presented (Fig. 20d).

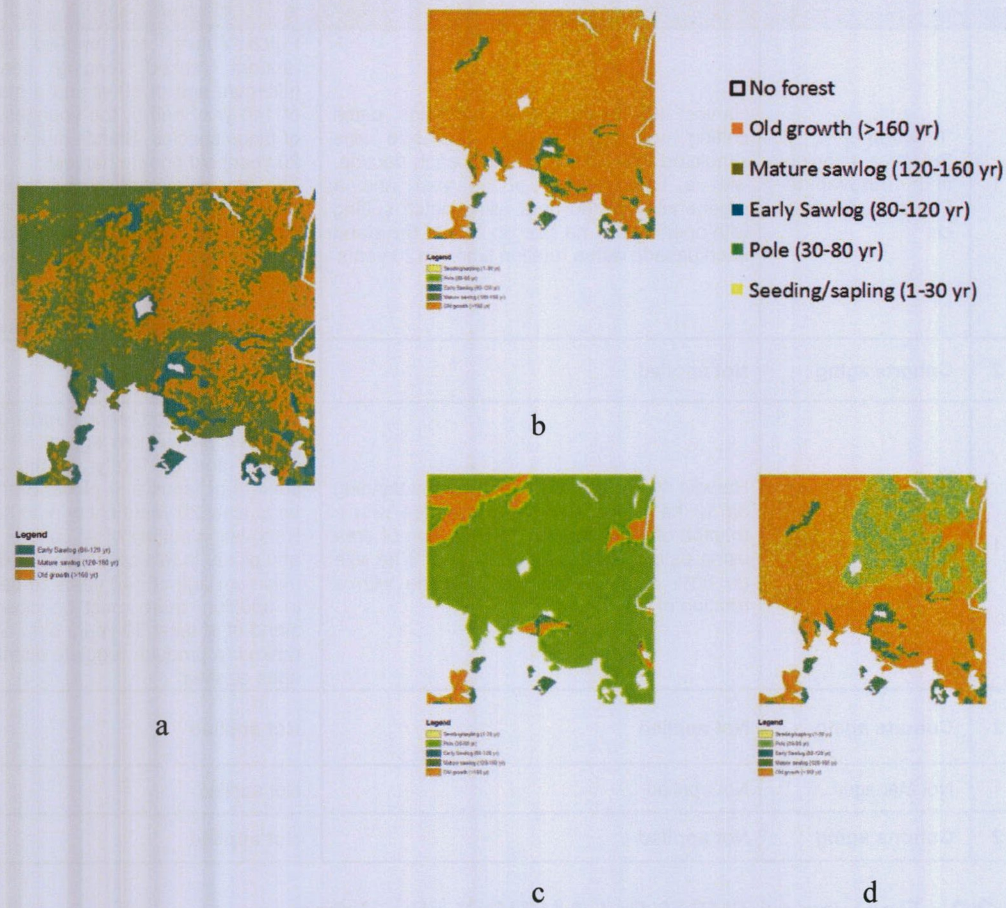


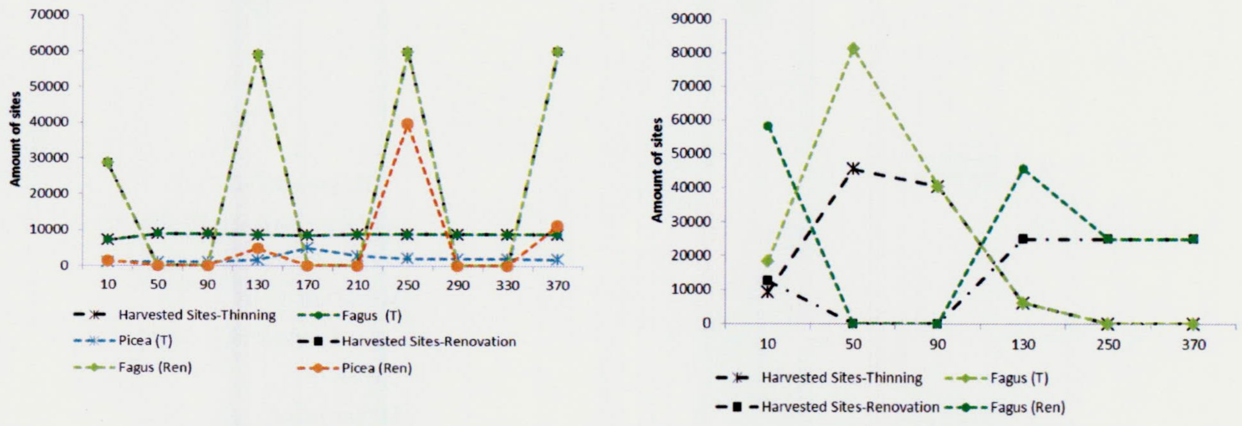
Figure 20: Spatial arrangement of forest size classes of the modelled scenarios for Cansiglio small area landscape at the simulation year 400. Size classes were grouped in the 10-year age classes modelled by LANDIS: a) spatial arrangement of age classes at simulation year 0; b) spatial arrangement of age classes without harvest disturbance; d) spatial arrangement of age classes scenario for the "traditional" forest management; d) spatial arrangement of age classes scenario for the "innovative" forest management.

The events trend by amount of harvested sites by typology of cutting and harvested species "innovative" and "traditional" FM is shown in Figure 21.

The thinning cut has a repetition time of 40 years. The regeneration cut is simulated every 120 years.

From year 90 of the simulated “innovative” alternative, removed sites by thinning cut are sites of beech forest. This occurs also in the regeneration cut at simulation year 250.

In the “traditional” alternative, the timber harvesting activities have a regular trend. For both types of cut, at each event time, total amount of harvested sites are beech forest sites.



Traditional FM Innovative FM

Figure 21: Trend of simulated harvest events for both “traditional” and “innovative” FM as amount of harvested sites for Cansiglio small landscape.

The tree size class distribution for all species by decade over 400 years of simulation for the all scenarios is shown in Figure 22.

Initial trends of the simulated “traditional” FM scenario and scenario without harvest disturbance are similar. The simulated harvest disturbance in the “traditional” FM produced the irregular distribution between age classes and the reduction of old growth forest classes (> 160 years old).

The simulation of the “innovative” FM produced a scenario with the initial diversification of age classes within landscape due to the implementation of patch cutting of 3 ha size. Sites cut aging until the second time rotation period. After 110 years of simulation, trend of the more mature classes (> 160 years old) becomes similar to the trend of the same classes in the no harvest disturbance scenarios.

All scenarios showed the increasing of young cohorts (1-30 and 30-80 years old) after the simulation year 120 due to the senescence of *Fagus sylatica* cohorts.

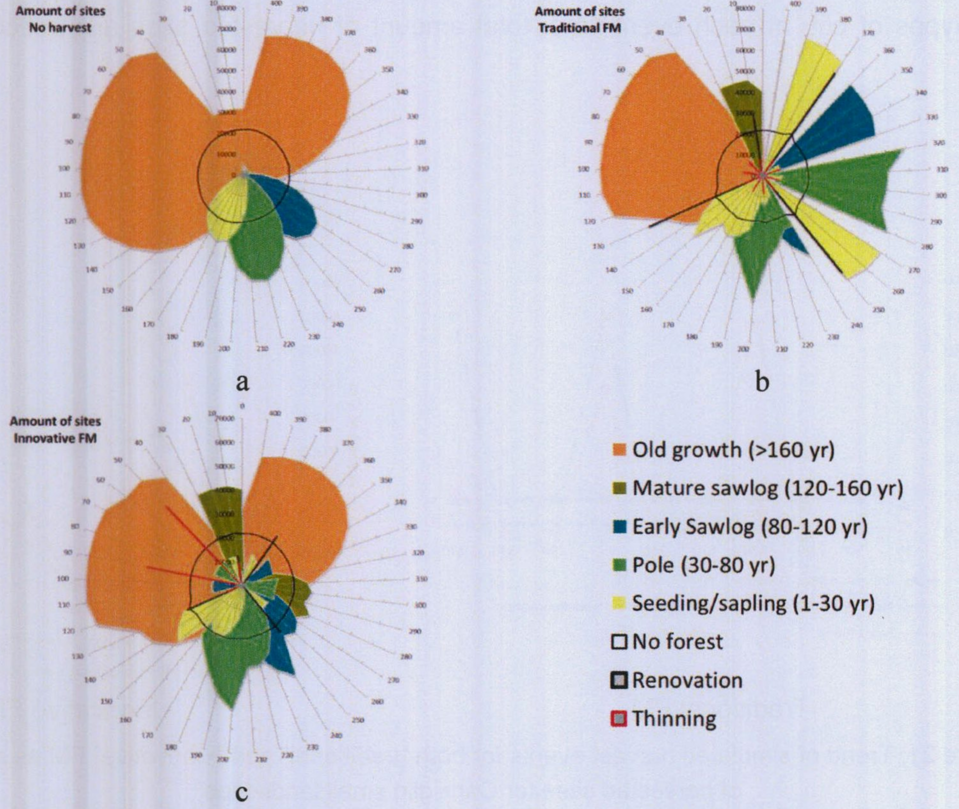


Figure 22: Trend of tree size class distribution by decade over 400 years or Cansiglio small landscape: a) no harvested scenarios; b) "traditional" FM scenarios; c) "innovative" FM scenarios. Graphs reports cuts events also (thinning and regeneration cuttings).

2.2.4 General conclusions on tested THSMs

The tested models made it possible to assess the feasibility of their application in the context of the project to address potential barriers at the achieving of Action ECo objectives previously discussed.

A model based on static communities (THSM-1) developed by HARVEST simulator and a model based on dynamic communities developed by LANDIS-II (THSM-2) were compared.

The HARVEST simulator is easier to apply respect to the LANDIS-II model. The first required few input data (§ 2.1.3) respect to the dynamic communities model developed by LANDIS-II (THSM-2) (§ 2.1.5). Because later model considers dynamic processes like succession, it requires more information.

The HARVEST simulator is able to simulate forest spatial pattern after timber harvesting in neutral landscape and it was able to simulate the "innovative" FM option. Because of the cell size of initial landscape, HARVEST was not able to simulating thinning cuts of the "traditional" FM. With higher cell resolution, small gaps can be simulate into the forest canopy.

The high simulating potentialities of the dynamic communities model LANDIS-II contrast to the greater difficulty of application of this model.

LANDIS includes many types of spatially interactive processes, each with its own neighborhood structure (He and Mladenoff 1999; Gustafson et al. 2000; Sturtevant et al., 2004). However, the emphasis on individual species behavior can introduce significant uncertainty. Studies demonstrated that mean and maximum seed dispersal distances for many tree species remains unresolved (Clark 1998; Higgins et al. 2003) and that assembling the necessary species data can be time consuming and may require significant estimation (Scheller & Mladenoff, 2007).

Tests also confirmed that the application of the LANDIS model needs a lot of time. This is mainly due to the data input preparation. Different GIS technics and remote sensing technics, in addition to a long literature review were needed (§ 2.1.5).

Models like HARVEST simulator including spatial interactions, static communities, excluding ecosystem processes, commonly serve as 'null' models for exploring interactions among landscape processes and a small number of state variables and have been used extensively to simulate the effects of harvesting on landscape pattern (Wallin et al. 1994; Gustafson and Crow 1998).

This latter model is easier to apply respect to the LANDIS-II model. This easier applicability is related to the numerous model assumptions (see above).

In conclusion, both models may be applied to simulate timber harvesting activities in project sites. The simulation model static is easier to apply than the dynamic one, even if the latter has a high potentiality, but it is also more difficult to calibrate because more dynamic processes are simulated.

Predicted scenarios of timber harvesting impacts on forest landscape may allow the potential forest management disturbance evaluation on forest landscape over the project time duration. Changes in landscape diversity may not be notice in this brief period. Dynamic communities models could be applied on test areas over the project time duration to better understand these potential disturbances.

For this reason as parallel activity of action ECo, the tested LANDIS-II model in Cansiglio site area will be refine and calibrated in order to a possible following application in other site areas over the project time duration.

To overcome the above discussed potential problems, timber harvesting activities may be simulated within a neutral forest landscape or considering the succession process, but in this latter case the application will need more time.

In both alternatives, simulated forest management activities will produce forest spatial pattern scenarios which may be analysed and compared with forest pattern mapped in the pre-treatments landscape situation.

Landscape ecology quantitative metrics could also be calculated in each simulated landscape and simulated layers analyse with a Multi-Criteria (MCE) approach.

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2.3 *Performed activity from Sub-action 2 – Activities in Slovenia*

The analyses were performed at two spatial level, at the forest stand level and at the landscape level.

Landscape level: In Manfor EcoSi Report n. 2 (2013) we reported that analyses at the landscape level were done in 3 sample squares measuring 100 km^2 each. The squares are centered around the test site's centers of gravity. After that we decided to expand our research also to wider area and get possibility for data comparison and more objective interpretation of results. Analyses at the landscape level were done at 5 spatial levels (Figure 1). First level represents country Slovenia as a whole. Relationship between country level and Manfor test squares represents Marušič (1998) classification of landscape types in Slovenia, which provides relative spatial homogenity (climate, geology, land use, macro-relief, landscape image) within units. It divides Slovenia into five broad landscape regions, among them we focused on the landscape region called "Kraške regije notranje Slovenije" (Karst regions of the inner Slovenia), where 3 Manfor test sites are located. The region is divided into 5 wider landcape units and further into 17 landscape units. Nearly all analyses were done for all five levels.

Land use and landscape metrics were analysed for two periods – for 2012 and 1975. For 2012 we used monotemporal Agricultural land use data at map scale 1:5000 (Ministry of Agriculture and Environment), containing the forest border as of 2012. For 1975 we used forest mask, taken from the topographical map scaled 1:50.000.

Socio-demographic analyses were based on statistical data collected by Statistical Office of the Republic of Slovenia. We were interested in long trends, which should be reflected also in land use changes. For this reason we analysed demographic data for 1869, 1931, 1961 and 2013. For years 1869, 1931 and 1961 we used Population censuses data, for 2013 we used up-to-date statistical data provided also by Statistical Office of the Republic of Slovenia. Demographic data are collected at the level of settlements, municipalities, statistical regions and country. For the country level we could directly use existing statistically analysed data. For other four levels, which borders are not consistent with statistical units, tremendous work was done with acquisiton, preparation and analysis of the data, especially for past periods, which are not in digital format. The procedure was very time consuming. We had to collect the data at the settlement level, for 1.396 settlements located in landscape region "Kraške regije notranje Slovenije". In further steps we combined these data at higher levels.

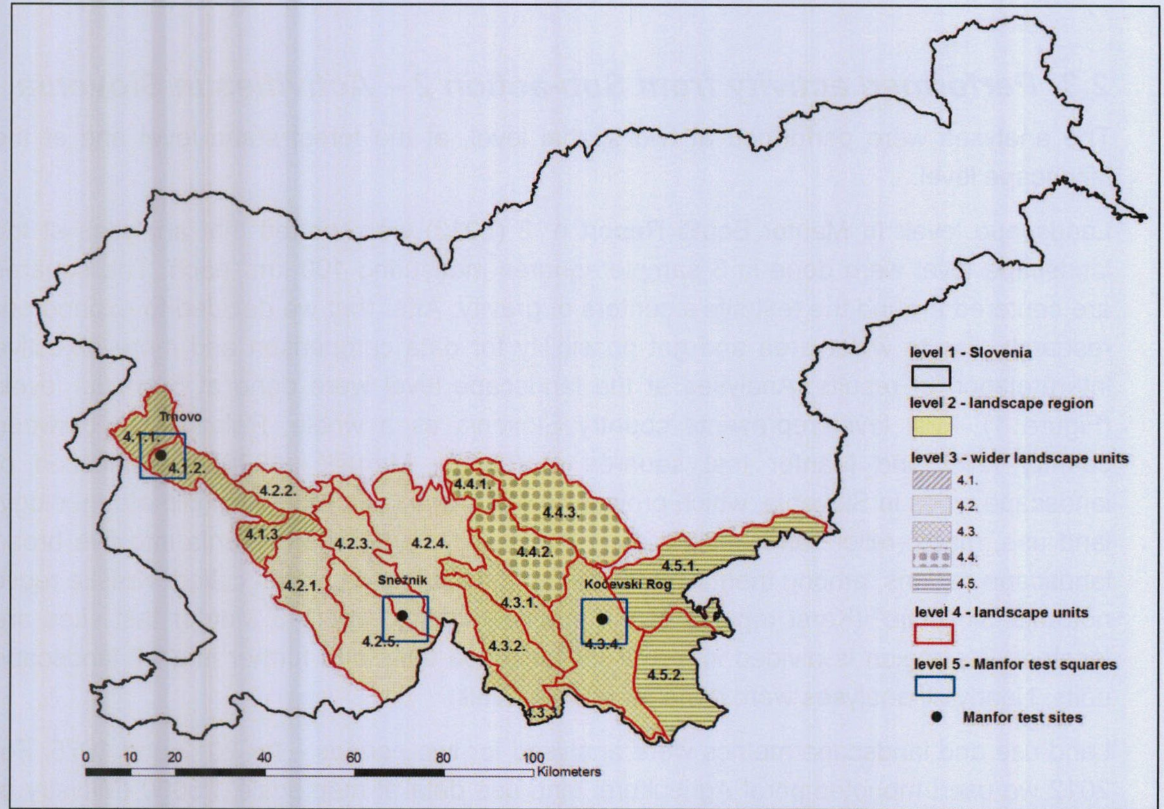

Figure 1: Spatial levels for analysing land use changes, forest landscape fragmentation metrics and socio-demographic trends

At the forest stand level there was the second (post treatment) lidar data acquisition performed in 2013 over the three Slovenian test sites in order to be able to compare the stands with the 2011 lidar data and thus to glean immediate 3-D structural effects of sylvicultural treatments. Multitemporal lidar data were processed and several metrics were analysed in order to glean the change in the lidar-based indicators.

From the newly acquired lidar data the digital canopy models (DCMs) were computed for the year 2013 and compared to 2011 as the basis for detecting the change of the spatial pattern of gaps in the forest stand canopy. Discontinuities (gaps) in forest canopy reaching to the ground are the centers of forest rejuvenation. Their areal percentage and spatial juxtaposition is an important indicator of forest stand developmental and ecological status.

The change of the Forest canopy cover indicator was detected based on lidar data for 2013 and 2011, since canopy cover regulates the light conditions in the stand and thus also the increment, rejuvenation, species composition etc. Lidar technology enables computing continuous gradients of this indicator over large areas, enabling more informed sylvicultural treatments.

Volume of photosyntheticaly active forest canopy indicator was measured from the 2013 data and compared to 2011. The amount of the photosyntheticaly active part of the forest stand canopy is a proxy for the stand productivity. As the canopy is a 3-D structure it can be gleaned from the lidar point cloud. The rectangular 3-D pixels (voxels) are classified into 'filled' (by lidar returns) and 'empty' voxels. The upper 65% of filled voxels in each column are considered the photosyntheticaly active part of the canopy, according to (Lefsky et al., 1999, Lidar remote sensing of the canopy structure ..., Remote Sening of Environment, 70: 339-361).

2.3.1 Analyses at the landscape level

Analysis of land use changes between 1975 and 2012

The basis of the analyses for the year 2012 was the Agricultural land use map at the scale of 1:5.000, as of 2012 (Ministry of Agriculture and Environment), containing also the forest edge. For 1975 we used forest mask, taken from the topographical map scaled 1:50.000. As we reported in last report the superfluous details i.e., apparent clearings due to the presence of forest roads in Agricultural land use map from 2012 have been filtered out using morphological closing. We repeated this procedure also for the map from 1975.

Spatial and temporal change of forest landscape fragmentation metrics

We evaluated:

- effective mesh size,
- forest patches,
- core areas.

Effective mesh size

Effective mesh size (meff) is an expression of the probability that any two randomly chosen points in a region may be connected,i.e., not separated by barriers such as transportation infrastructure or urban areas (Jaeger 2000). It expresses the possibility that any two randomly chosen points in the region under observation may or may not be connected. The more barriers (e.g., roads, railroads, urban areas) erected in the landscape, the less chance that the two points will be connected. It can also be interpreted as the ability of two animals of the same species – placed randomly in a region – to find each other. The encountering probability is converted into the size of an area called the effective mesh size. The more barriers in the landscape, the lower the probability that the two points will be connected, and the lower the effective mesh size. If a landscape is fragmented evenly into patches all of size *m*eff, then the probability of being connected is the same as for the fragmentation pattern under investigation (Girvetz et al. 2007).

Main problem with effective mesh size landscape metric, as pointed out by Moser et al. (2007), is that it assumes the unfragmented patches of land stop at the boundary of the planning unit (i.e. county, Caltrans district, or watershed), when in fact, the unfragmented area may extend far beyond the boundary of the planning unit. The effective mesh size described above uses the originally "CUT" (cutting out procedure) procedure. An alternative implementation of the effective mesh size calculation to account for this is the effective mesh size based on the cross boundary connection (CBC) procedure, which accounts for the area of connected unfragmented areas that extend beyond the boundaries of a given planning unit that the effective mesh size is being calculated for (Girvetz et al. 2007).

To analyze landscape fragmentation it is first necessary to specify which landscape elements are important (Jaeger et al. 2008). It is actually an ecological question because different landscape elements, which act as a barrier, have a different impact on the object being studied, usually wildlife populations or their habitats. Several studies showed that landscape fragmentation due to transportation infrastructure and urban sprawl is known to be a major cause of the alarming decrease of many wildlife populations in Europe and North America (Jaeger et al. 2008, after different authors).

We calculated effective mesh size landscape metric for 5 spatial levels for years 1975 and 2012. We used both procedures - CUT and CBC.

Forest patches

Large habitat reserves are superior to small reserves for the long-term persistence of area-sensitive forest species and low-mobility habitat specialists (e.g., Cottam et al. 2009; Keller and Yahner 2007; Price et al. 2007 cit. after How much... 2013). As well, it is increasingly recognized that high enough numbers of smaller patches in a landscape can also help support overall landscape biodiversity, at least for forest birds and amphibians. Forest patch size remains a vital metric for forest species that are particularly area-sensitive or intolerant of human disturbances, or both (How much... 2013).

Even though small patches can and do provide habitat for some species, preservation of some larger patches in the landscape is required for the long-term survival of forest populations as a whole. Larger patches of forest also tend to have a greater diversity of habitat niches and area, and therefore are more likely to support a greater richness or diversity of both plant and wildlife species. For forest plants that do not disperse broadly or quickly, preservation of some relatively undisturbed large forest patches is needed to sustain them because of their restricted dispersal abilities and specialized habitat requirements, and to ensure continued seed or propagation sources for restored or regenerating areas nearby (Honnay et al. 2002; Jacquemyn et al. 2003; Taki et al. 2008 cit. after How much... 2013).

We analysed area and number of forest patches, especially area of largest forest patches for 5 spatial units for years 1975 and 2012.

Core areas

The forest core area is the internal area of large forest patches, that is sufficiently far from the forest edge, so that nonforest disturbances are not felt. The cores of the forest patches are at least 300 m inside of the forest edge, according to Hladnik (Hladnik D., 2005, Spatial structure of disturbed landscapes in Slovenia, Ecological Engineering 24 (2005) 17–27). Hladnik has proposed this distance in accordance with Forman (Forman, R.T.T., 1995. Land Mosaics: The Ecology of Landscapes and Regions. Cambridge University Press, Cambridge, p. 632), who examined how the number of different bird species depended on the size of forest remnants.

We analysed core areas for 5 spatial units for years 1975 and 2012.

Analysis of socio-demographic trends

In the first step, for better understanding of underlying socio-economic changes and their impact on the forested landscape, the historical sources on past economy, population, way of life etc. in wider area of Manfor test sites were reviewed.

In the second step we analysed basic several socio-demographic data:

- number of settlements in 2013 at 5 spatial levels,
- number of population in 1869, 1931, 1961 and 2013 and at
- population density in 1869, 1931, 1961 and 2013 and at 5 spatial levels,
- age structure in 1961 and 2013 at the level of Manfor test squares,
- employment structure in 1961 and 2013 at the level of Manfor test squares.

We analysed demographic data for 3 periods: longest period between first population census in 1869 and 2013 with the latest available data, period between 1931and 1961, which is interesting because of the impacts of Second World War on population and last period between 1961 and 2013.

At the country level we used existing statistically analysed data. At spatial levels 2 (landscape region), 3 (wider landscape units) and 4 (landscape units) we analysed the demographic data for all settlements, which central points are located in landscape region "Kraške regije notranje Slovenije". At the level of Manfor test squares we analysed the demographic data for all settlements, which administrative borders at least partly stretches into Manfor test squares, also those, of which central points are not inside the test squares. By that we increased the number od data and representativeness of results.

Definitions and indicators

Population are persons with registered permanent and/or temporary residence in Slovenia who live or intend to live in Slovenia for one year or more and are not temporarily absent from Slovenia for a year or more.

Population density is number of people per km^2.

Age structure of a population is the distribution of people among various ages. Age structure can be presented with different tools. For large number of population we usually use population pyramids. More suitable for presentation of age structure of smaller groups of population is ratio between large age groups:

- 0-14 years – young population,
- 15- 64 – working age population,
- 65+ - older population.

We analysed also ageing index - the ratio between the old population (aged 65 and over) and the young population (aged 0–14) multiplied by 100.

Both indicators were compared with Slovenian average.

Employment structure

Employment structure is the percentage of active people employed in major groups of activities. According to the Statistical Office of the Republic of Slovenia and Standard classification of activities, we grouped activities into 3 groups:

- agricultural activities (agriculture, forestry and fishing),
- non-agricultural activities (mining and quarrying, manufacturing, water supply; sewerage, waste management and remediation activities, construction
- service activities (wholesale and retail trade; repair of motor vehicles and motorcycles, transportation and storage, accommodation and food service activities, information and communication, financial and insurance activities, real estate activities, professional, scientific and technical activities, administrative and support service activities, public administration and defence; compulsory social security, education, human health and social work activities, arts, entertainment and recreation, other service activities, activities of households as employers; undifferentiated goods- and services-producing activities of households for own use activities of extraterritorial organisations and bodies

2.3.2 Airborne lidar scanning

At the forest stand level there was the second (post treatment) lidar data acquisition performed in 2013 over the three Slovenian test sites in order to be able to compare the stands with the 2011 lidar data and thus to glean immediate 3-D structural effects of sylvicultural treatments. Multitemporal lidar data were processed and several metrics were analysed in order to glean the change in the lidar-based indicators.

The post-treatment lidar data acquisition for the three Slovenian test areas was done by the FLYCOM Company, Slovenia, the same company as with the first acquisition. The flights took place on November 28, at 3 PM, for Trnovo test site, and on November 29, at 10 AM - 1 PM, for the Snežnik and Kočevski Rog test sites. The laser scanner Riegl LMS Q780 was mounted onto a helicopter. The lidar data acquisition was done in clear weather with a flying height of 400 m above the terrain and at a ground speed of 80 km/h. Scanning angle was ±30° from nadir, beam divergence was 0.25 mrad and the footprint was 10 cm. The resulting average point cloud density over the three test areas is 188/m^2 (combined for the first, last, intermediate and only returns).

From the newly acquired lidar data the digital canopy models (DCMs) were computed for the year 2013 and compared to 2011 (Figure 22 - Figure 30) as the basis for detecting the change of the spatial pattern of gaps in the forest stand canopy. Discontinuities (gaps) in forest canopy reaching to the ground are the centers of forest rejuvenation. Their areal percentage and spatial juxtaposition is an important indicator of forest stand developmental and ecological status.

DCM vegetation heights were computed in a rectangular grid with the horizontal resolution of 1 m x 1 m. All types of lidar returns were taken into account. For each return its height above the bare ground was computed using bilinear interpolation from the neighbouring DTM grid points. The highest lidar return within each grid cell was considered as the vegetation height for this grid cell.

In order to mitigate any spatial displacement between the two lidar acquisitions a new digital terrain model (DTM) was computed from the 2013 data. Relative heights of the 2013 cloud points above bare ground were thus not affected by the slight displacements.

DCMs have been computed for all three Slovenian test areas. The gaps in forest stand canopy have been identified from DCM as those areas where vegetation heights do not exceed 1 m, i.e. discontinuities or gaps in the forest canopy cover.

The change of the Forest canopy cover indicator was detected based on lidar data for 2013 and 2011 (Figure 31 - Figure 39), since canopy cover regulates the light conditions in the stand and thus also the increment, rejuvenation, species composition etc. Lidar technology enables computing continuous gradients of this indicator over large areas, enabling more informed sylvicultural treatments.

Forest canopy cover (CC) is given as a numerical value between 0 and 1, computed for each cell in the 1 by 1 m grid as the ratio of ground-to-vegetation frequencies of different return types:

$$CC = 1 - [(N_{first,ground} + N_{intermediate,ground} + N_{last,ground} + N_{only,ground}) / N_{all}]$$

where:

CC ... canopy cover

$N_{first,ground}$, $N_{intermediate,ground}$, $N_{last,ground}$, $N_{only,ground}$... *frequencies of those first, intermediate, last and only returns in the cell, respectively, that are 1 m or less above bare ground*

N_{all} ... *total frequency of all first, intermediate, last and only returns in the cell*

CC maps have been computed for all three Slovenian test areas.

Volume of photosyntheticaly active forest canopy indicator was measured from the 2013 data and compared to 2011 (Figure 40 - Figure 48). The amount of the photosyntheticaly active part of the forest stand canopy is a proxy for the stand productivity. As the canopy is a 3-D structure it can be gleaned from the lidar point cloud. The rectangular 3-D pixels (voxels) are classified into 'filled' (by lidar returns) and 'empty' voxels. The upper 65% of filled voxels in each column are considered the photosyntheticaly active part of the canopy, according to (Lefsky et al., 1999, Lidar remote sensing of the canopy structure ..., Remote Sening of Environment, 70: 339-361).

2.4 Results from Sub-action 2 – Activities in Slovenia

2.4.1 Landscape level

Analysis of land use changes between 1975 and 2012

Slovenia is one of the most densely forested countries in the Europe, since forests cover more than a half of its total area over the last few decades. The major reasons of relatively well-preserved forests are sustainable forest management and a complete prohibition of clear-cutting by law. Analysis on the country level showed an increase of forest land by 7 percentage points in the period 1975-2012 (Table 1). Because many people moved from rural to urban areas abandoned agricultural land has been subjected to continuous natural expansion of forests, although it seems that so called spontaneous afforestation stabilized in recent years.

Table 1: Land use changes in Slovenia between 1975 and 2012

Area name	Area (km^2)	Area of forest in 1975 (km^2)	% of forest in 1975	Area of forest in 2012 (km^2)	% of forest in 2012
Slovenia	20,273	11,001	54	12,326	61

The landscape region »Kraške regije notranje Slovenije" covers majority of the southern half of the country area, where forest cover is even higher than on the country level (Table 2). This region includes mature forests with high growing stock and deadwood amount and also a diverse wildlife (bears, wolves...). The prevailing forests in the region that developed on limestone are mixed beech-fir forests.

Table 2: Land use changes in landscape region "Kraške regije notranje Slovenije" (level 2) between 1975 and 2012

Area code	Area name	Area (km^2)	Area of forest in 1975 (km^2)	% of forest in 1975	Area of forest in 2012 (km^2)	% of forest in 2012
4	Kraške regije notranje Slovenije	4,752	3,214	68	3,530	74

When considering the wider landscape units at level 3 the picture of the forest land is similar to that one at the region level (level 2). The share of forest area ranged between 57 and 81 % in 1975, and has increased in each landscape units by about 6 percentage points on average until 2012. The landscape units with the largest and the smallest forest area are "Pivško-Cerkniška planota" and "Trnovsko-Nanoška planota", respectively, while the share of forest is the largest in "Kočevska kotlina in Kočevski Rog" (

Table **3**).

Table 3: Land use changes in wider landscape units (level 3) between 1975 and 2012

Area code	Area name	Area (km^2)	Area of forest in 1975 (km^2)	% of forest in 1975	Area of forest in 2012 (km^2)	% of forest in 2012
4.1.	Trnovsko-Nanoška planota	442	325	74	374	85
4.2.	Pivško-Cerkniška planota	1,660	1,095	66	1,218	73
4.3.	Kočevska kotlina in Kočevski Rog	1,092	884	81	932	85
4.4.	Grosupeljska kotlina in Suha krajina	751	452	60	481	64
4.5.	Gorjanci z Belo krajino	808	457	57	525	65

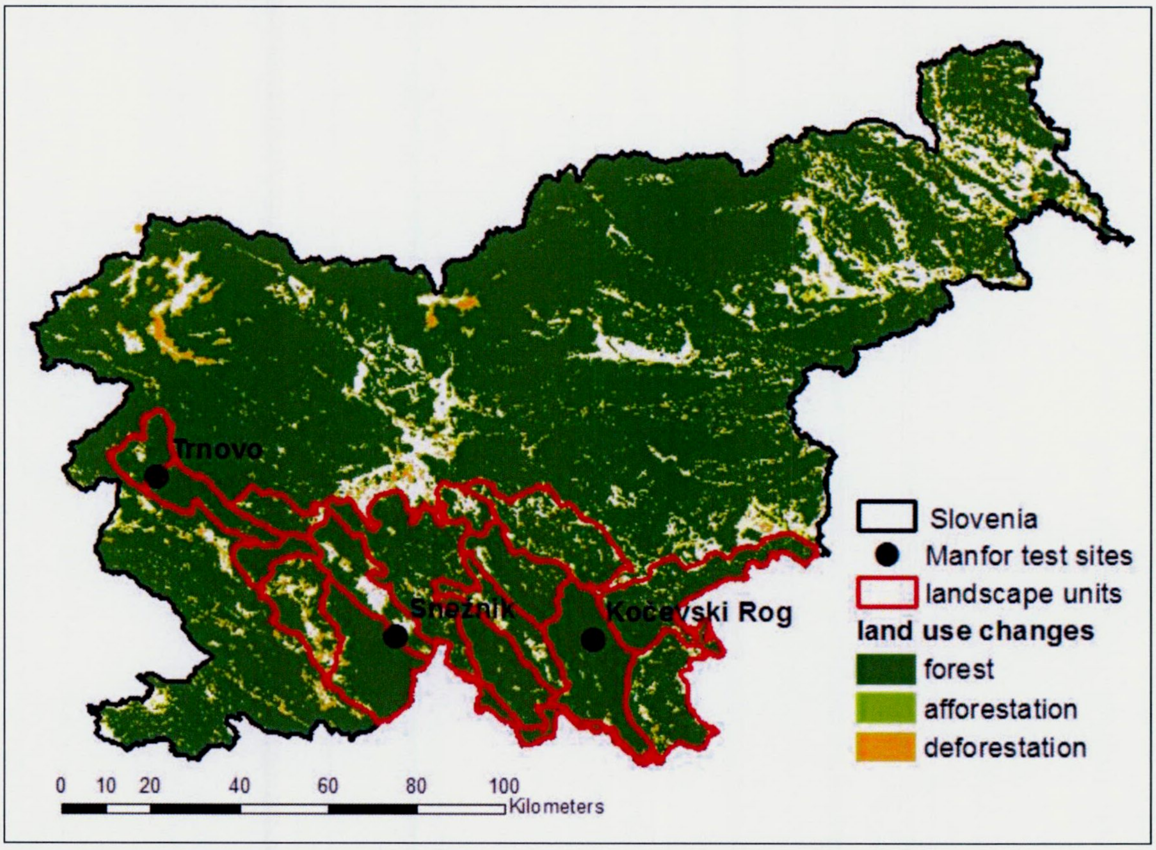

Figure 2: Land use changes between 1975 and 2012 in Slovenia and landscape units

In general, the spontaneous afforestation took place most obviously in the mountains, particularly in the Julian Alps within the northwestern part and in Kamnik-Savinja Alps in northern part of the country (Figure 2), where the process was most intense. In other parts of the country the pattern of the afforestation is more or less scattered, while deforestation is more frequent in the vicinity of urban areas than on countryside, typically around large cities.

The Manfor test squares are located within the following landscape units: “Trnovski gozd”, “Cerkniško območje” and “Kočevsko-Roško hribovje”. The share of forest cover in “Trnovski gozd” and “Kočevsko-Roško hribovje” is among the largest of all landscape units, while in “Cerkniško območje” it is below the average of all units at level 3 (**Table 4**). The results show that conversions to forest land in the period between 1975 and 2012 were largest in “Banjška planota” with forest cover difference of 21 percentage points, followed by “Pivška planota” with 13 percentage points and “Bela Krajina” with 10 percentage points (**Table 4**, Figure 3). On the other hand, units with the smallest land use changes regarding the forest cover difference over the last 37 years are “Kočevsko-Roško hribovje”, “Krajina severno od Krk”, and “Ribniško-Kočevska dolina”.

Table 4: Land use changes in landscape units (level 3) between 1975 and 2012

Area code	Area name	Area (km^2)	Area of forest in 1975 (km^2)	% of forest in 1975	Area of forest in 2012 (km^2)	% of forest in 2012
4.1.2.	Trnovski gozd	190	151	79	165	87
4.2.3.	Cerkniško območje	284	169	59	185	65
4.3.4.	Kočevsko –Roško hribovje	472	415	88	429	91
4.4.1.	Grosupeljska kotlina	92	41	45	44	48
4.4.2.	Suha krajina južno od Krke	267	198	74	212	80
4.4.3.	Krajina severno od Krke	393	213	54	224	57
4.5.1.	Gorjanci z Radoho	463	278	60	310	67
4.5.2.	Bela krajina	345	179	52	215	62

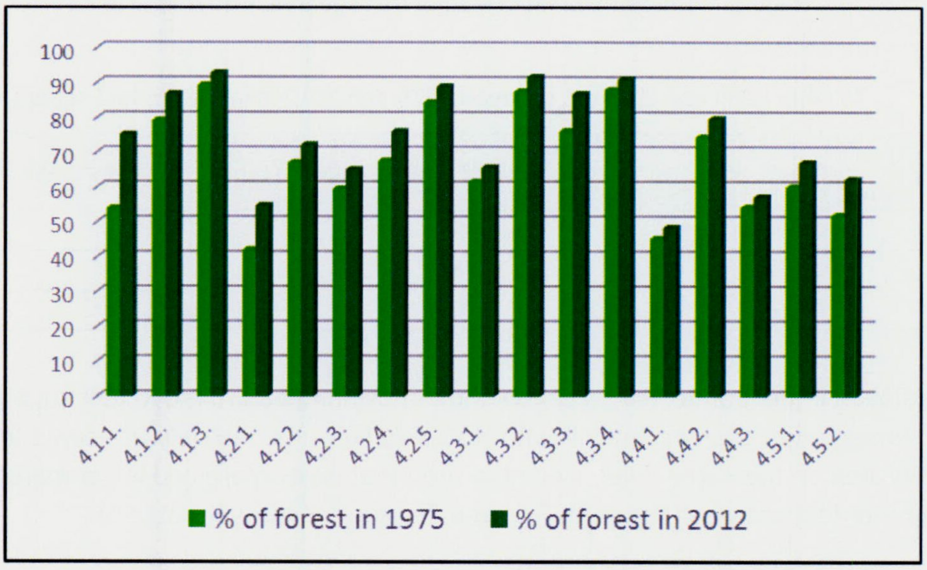

Figure 3: Share of forest in lanscape units in 1975 and 2012

Among the Manfor test squares in Slovenia in the period 1975-2012, forest area increased the most in Trnovo (Table 5, Figure 4), while the share of forest has remained largest until 2012 in "Kočevski Rog", which is one of the most heavily forested unit at level 4.

Table 5: Land use changes in Manfor test squares between 1975 and 2012

Area code	Area name	Area (km^2)	Area of forest in 1975 (km^2)	% of forest in 1975	Area of forest in 2012 (km^2)	% of forest in 2012
1	Trnovo	100	72	72	85	85
2	Snežnik	100	76	76	81	81
3	Kočevski Rog	100	94	94	95	95

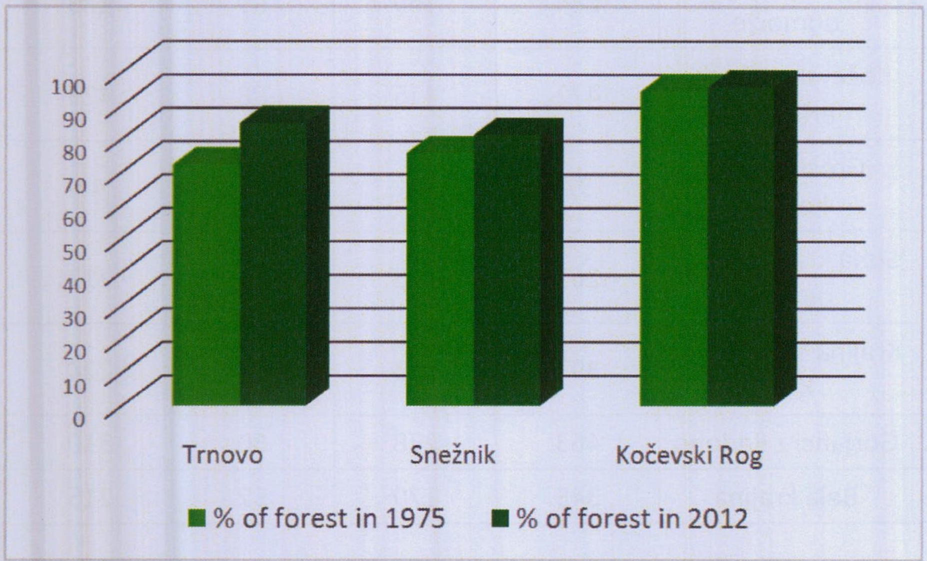

Figure 4: Share of forest in Manfor test squares in 1975 and 2012

Table 6: Land use changes between 1975 and 2012 in in Manfor test squares

Area code	Area name	Forest (km^2)	Afforestation (km^2)	Deforestation (km^2)
1	Kočevski Rog	93	2	2
2	Snežnik	74	6	2
3	Trnovo	70	13	2

Afforestation in the period 1975-2012 was the most intense in Trnovo test square and was 3 to 6-times larger than in Snežnik and Kočevski Rog, respectively. It seems that logging intensity was on the same level, since the area that was deforested is comparable among the ManFor test squares (Figure 5, Figure 6, Figure 7, Figure 8, Table 6) .

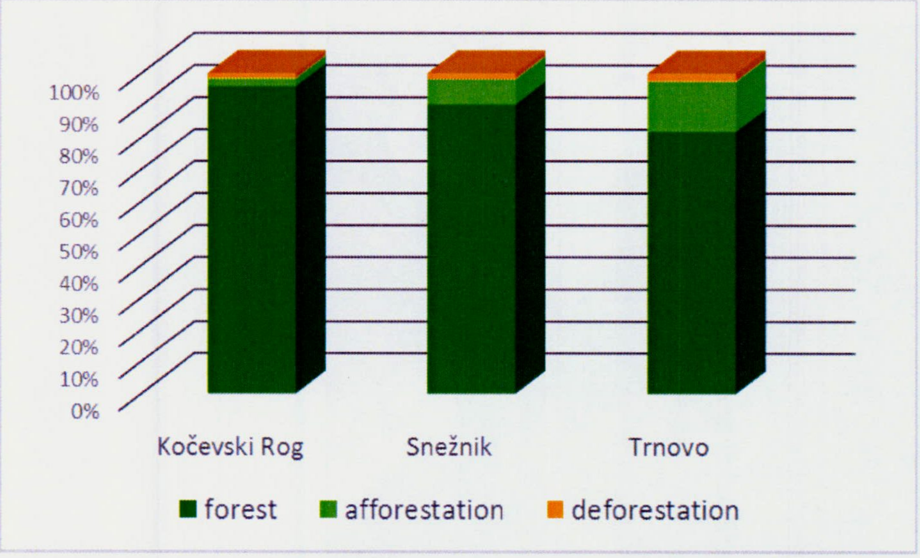

Figure 5: Land use changes between 1975 and 2012 in in ManFor test squares

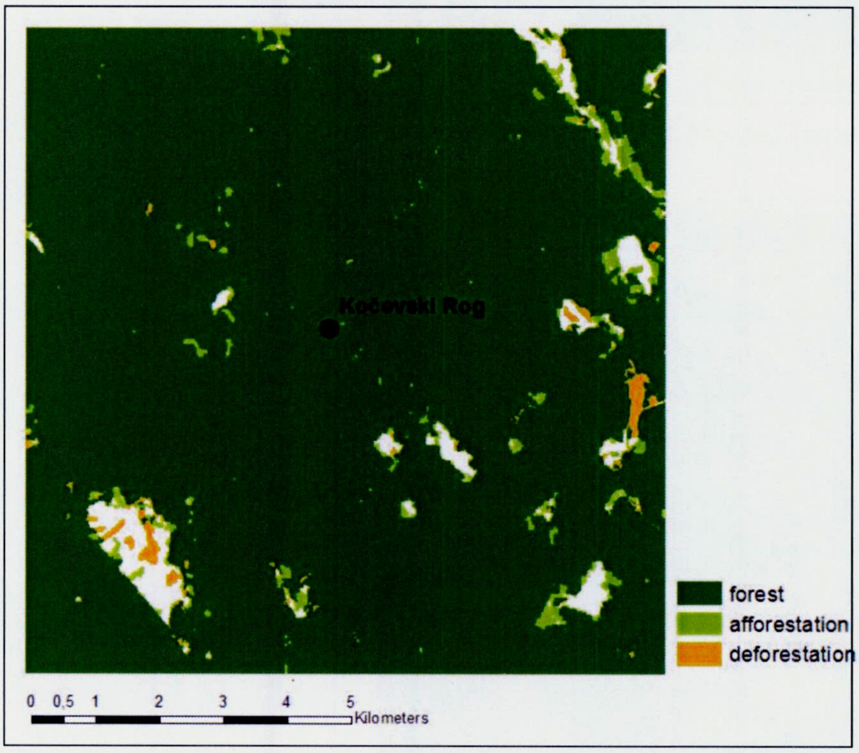

Figure 6: Land use changes between 1975 and 2012 in ManFor test square Kočevski Rog

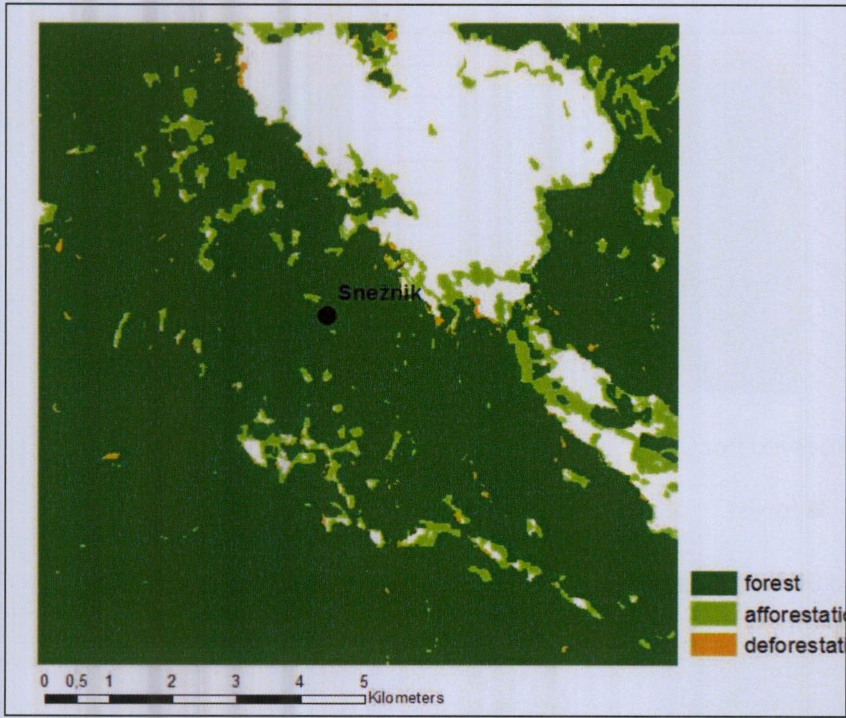

Figure 7: Land use changes between 1975 and 2012 in ManFor test square Snežnik

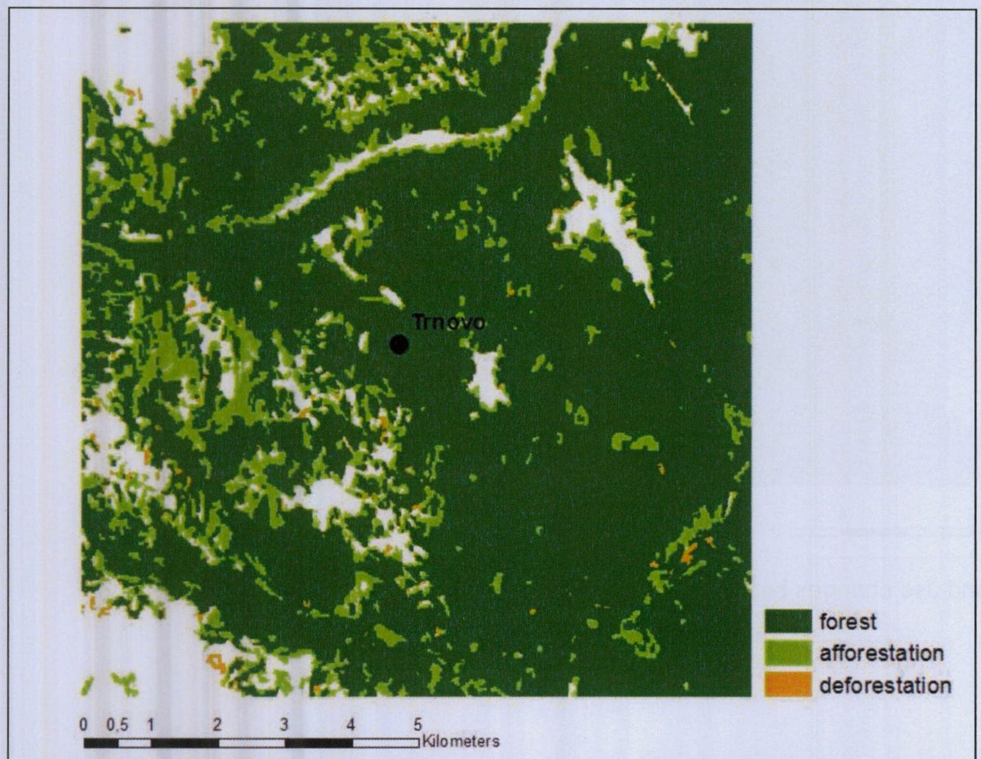

Figure 8: Land use changes between 1975 and 2012 in ManFor test square Trnovo

Spatial and temporal changes of forest landscape fragmentation metrics

Effective mesh size

The value of effective mesh size (meff) at the country level is the same regardless of the procedure used. From 1975 until 2012 the Meff increased by 30,8 %, which means on average of less than 1% per year. This would also mean the landscape at the country level became less fragmented or in other words the elements of landscape, such as forest patches, became more connected in the period 1975-2012. However, the difference in meff is not only the result of land use change occurring in the nature, but also of methodology used (see explanation in the beginning of the "Lansdscape level" section). In the last few decades lots of abandoned agricultural land was under the process of spontaneous afforestation in Slovenia, yet there was also a remarkable urbanization process including the construction of buildings in settlements, regional development of industrial zones and many projects by which a national road network was established. The latter are among the common fragmenting elements and their specific choice defines a so-called "fragmentation geometry" (Girvetz et al. 2008). The higher number of fragmenting elements implies the more complex fragmentation geometry, and therefore the lower value of meff.

Table 7: Effective mesh size within Slovenia in 1975 and 2012

	Shape lenght (km)		Shape area (km^2)		Meff_Cut (km^2)		Meff_CBC (km^2)	
Area name	1975	2012	1975	2012	1975	2012	1975	2012
Slovenia	82,122	135,249	10,999	12,114	684	895	684	895

At the level of landscape region, namely "Kraške regije notranje Slovenije" the meff after both procedures was more than 2-times larger as the one at the country level (Table 7, Table 8). This is most probably due to large forest patches, which are frequent in the region, rather than a larger number of the landscape barriers.

Table 8: Effective mesh size within landscape-ecological region "Kraške regije notranje Slovenije" in 1975 and 2012

Area code	Area name	Shape lenght (km)		Shape area (km^2)		Meff_Cut (km^2)		Meff_CBC (km^2)	
		1975	2012	1975	2012	1975	2012	1975	2012
4.	Kraške regije notranje Slovenije	13,454	24,926	3,214	3,484	1,246	1,477	1,457	1,975

In the period 1975-2012 the Meff increased also at level 3 units with noticeable difference between Cut and CBC procedure (Table 9). The Meff_Cut in the year 1975 ranged between 101 and 693 km^2, while Meff CBC between 829 and 1,929 km^2, what is in relative terms also true for the year 2012. The largest value of Meff is in the region "Kočevska kotlina in Kočevski Rog" and the smallest in "Gorjanci z Belo krajino". These results are in line with the share of forest area, meaning the larger share of forest area in the region the larger Meff and vice versa.

Table 9: Effective mesh size within wider landscape units in 1975 and 2012

Area code	Area name	Shape lenght (km)		Shape area (km^2)		Meff_Cut (km^2)		Meff_CBC (km^2)	
		1975	2012	1975	2012	1975	2012	1975	2012
4.1.	Trnovsko-Nanoška planota	1,929	2,845	325	368	225	297	1,672	1,873
4.2.	Pivško-Cerkniška planota	4,253	9,317	1,095	1,201	439	601	1,457	2,093
4.3.	Kočevska kotlina in Kočevski Rog	2,225	3,970	884	924	693	771	1,929	2,644
4.4.	Grosupeljska kotlina in Suha krajina	2,247	4,303	452	474	218	230	1,322	1,752
4.5.	Gorjanci z Belo krajino	3,140	4,852	457	518	101	109	829	1,093

Analysis showed similar trend also at the level 4 (Table 10). Generally, Meff increased in the period between 1975 and 2012 in all studied regions except the regions "Grosupeljska kotlina" and "Bela krajina", where the Meff_Cut decreased. The regions differ in their areas, however the Meff is suitable for comparing the fragmentation of regions with differing total areas and with differing proportions occupied by housing, industry, and transportation structures, which is one of the several advantages over other landscape indices (Jaeger et al. 2008).

Table 10: Effective mesh size within landscape units in 1975 and 2012

Area code	Area name	Shape lenght (km)		Shape area (km²)		Meff_Cut (km²)		Meff_CBC (km²)	
		1975	2012	1975	2012	1975	2012	1975	2012
4.1.1.	Banjška planota	1,015	1,245	76	103	35	73	1,162	1,643
4.1.2.	Trnovski gozd	737	1,216	151	163	114	134	1,813	1,915
4.1.3.	Nanos in Hrušica	205	417	99	102	87	93	2,079	2,095
4.2.1.	Pivška planota	805	2,106	113	144	12	35	521	1,389
4.2.2.	Planota Črni vrh-Logatec	461	938	87	92	57	60	1,550	1,561
4.2.3.	Cerkniško območje	638	1,428	169	182	66	75	1,417	1,837
4.2.4.	Velika notranjska planota	1,895	3,864	397	439	229	291	1,533	2,217
4.2.5.	Snežnik z Javorniki	667	1,211	329	344	262	300	1,987	2,756
4.3.1.	Ribniško-Kočevska dolina	547	1,064	142	149	76	92	1,394	1,992
4.3.2.	Kočevska gora z Moravsko planoto	457	798	242	252	209	229	2,107	2,858
4.3.3.	Dolina Zgornje Kolpe	479	736	86	96	62	82	1,794	2,673
4.3.4.	Kočevsko – Roško hribovje	941	1,588	415	426	361	382	2,118	2,829
4.4.1.	Grosupeljska kotlina	263	473	41	44	16	13	1,013	1,170
4.4.2.	Suha krajina južno od Krke	728	1.685	198	209	143	159	1,776	2,432
4.4.3.	Krajina severno od Krke	1,329	2,222	213	222	75	79	1,085	1,427
4.5.1.	Gorjanci z Radoho	1,882	2,828	278	306	41	121	594	1,602
4.5.2.	Bela Krajina	1,270	2,038	179	212	77	36	1,145	411

Considering the Manfor test squares, the trend is the same as at the higher landscape levels. The highest value of Meff in 1975 was calculated for the test square Kočevski Rog followed by Snežnik and Trnovo. The Meff in 2012 was again the highest in Kočevski Rog, but in Snežnik it was lower than in Trnovo, where the relative difference from 1975 to 2012 was the largest (Table 11). Besides, there is a significant difference in Meff between the Cut and CBC procedures, yet the trend stayed the same.

Table 11: Effective mesh size within Manfor test squares in 1975 and 2012

Area code	Area name	Shape lenght (km)		Shape area (km^2)		Meff_Cut (km^2)		Meff_CBC (km^2)	
		1975	2012	1975	2012	1975	2012	1975	2012
1	Kočevski Rog	146	259	94	95	89	90	2.280	2.981
2	Snežnik	207	362	76	80	56	64	1.817	2.517
3	Trnovo	503	630	72	83	50	68	1.652	1.881

Forest patches

The number of forest patches increased for more than 4-times and the largest forest patch at the country level increased by 30 % from 1975 until 2012 (Table 12). The number of forest patches increased mostly due to the methodological reasons. Particularly, in the period 2000-2012 the national land use/cover classification system became more accurate than the former one, which had broader and aggregated categories. Besides, the minimum area for delineating the polygons of land use including the forests had become smaller in recent years, and therefore more polygons.

Table 12: Number of forest patches and area of largest forest patch within Slovenia in 1975 and 2012

Area name	Number of forest patches		Area of largest forest patch (km^2)	
	1975	2012	1975	2012
Slovenia	21,425	89,601	2,422	3,146

Table 13: Number of forest patches and area of largest forest patch within landscape region "Kraške regije notranje Slovenije" in 1975 and 2012

Area code	Area name	Number of forest patches		Area of largest forest patch (km^2)	
		1975	2012	1975	2012
4.	Kraške regije notranje Slovenije	2,519	16,346	2,382	2,534

The number of forest patches at the level 2 was about 6.5-times larger in 2012 than in 1975, but the area of largest forest patch was smaller compared to the one at the country level. The largest forest patch in the studied region increased only by 6.4 % between 1975 and 2012 (Table 13).

The increase in number of forest patches at level 3 from 1975 to 2012 varied significantly among the units. The number of forest patches was larger in 2012 in the range between 2,8 and 14,5-times compared to the year 1975. The area of largest forest patch slightly increased in all landscape units except in the unit "Grosupeljska kotlina in Suha Krajina" (Table 14).

Table 14: Number and area of largest forest patches within wider landscape units in 1975 and 2012

Area code	Area name	Number of forest patches		Area of largest forest patch (km^2)	
		1975	2012	1975	2012
4.1.	Trnovsko-Nanoška planota	663	1,833	312	357
4.2.	Pivško-Cerkniška planota	505	7,320	824	924
4.3.	Kočevska kotlina in Kočevski rog	260	2,143	864	910
4.4.	Grosupeljska kotlina in Suha krajina	355	2,531	403	399
4.5.	Gorjanci z Belo krajino	858	2,733	272	277

The number of forest patches at the level 4 in 1975 varied between 47 and 524 and in 2012 between 312 and 2,645. The increase in patch number was the largest in "Cerkniško območje" (almost by 19-times) and the smallest in "Banjška planota" (by 2,4-times). Generally, the area of largest forest patch increased a bit from 1975 to 2012 excluding the four regions, in which it decreased in 2012 (Table 15, Figure 9).

Table 15: Number and area of largest forest patches within landscape units in 1975 and 2012

Area code	Area name	Number of forest patches		Area of largest forest patch (km²)	
		1975	2012	1975	2012
4.1.1.	Banjška planota	428	1,037	67	100
4.1.2.	Trnovski gozd	199	650	146	156
4.1.3.	Nanos in Hrušica	55	175	98	101
4.2.1.	Pivška planota	177	2,540	36	43
4.2.2.	Planota Črni vrh-Logatec	53	528	71	85
4.2.3.	Cerkniško območje	60	1,135	126	81
4.2.4.	Velika notranjska planota	217	2,645	353	401
4.2.5.	Snežnik z Javorniki	67	580	320	342
4.3.1.	Ribniško-Kočevska dolina	100	903	86	122
4.3.2.	Kočevska gora z Moravsko planoto	48	368	230	251
4.3.3.	Dolina Zgornje Kolpe	75	411	78	93
4.3.4.	Kočevsko –Roško hribovje	95	574	412	423
4.4.1.	Grosupeljska kotlina	47	312	23	18
4.4.2.	Suha krajina južno od Krke	55	1,010	196	194
4.4.3.	Krajina severno od Krke	274	1,266	155	166
4.5.1.	Gorjanci z Radoho	524	1,512	110	236
4.5.2.	Bela Krajina	349	1,247	132	96

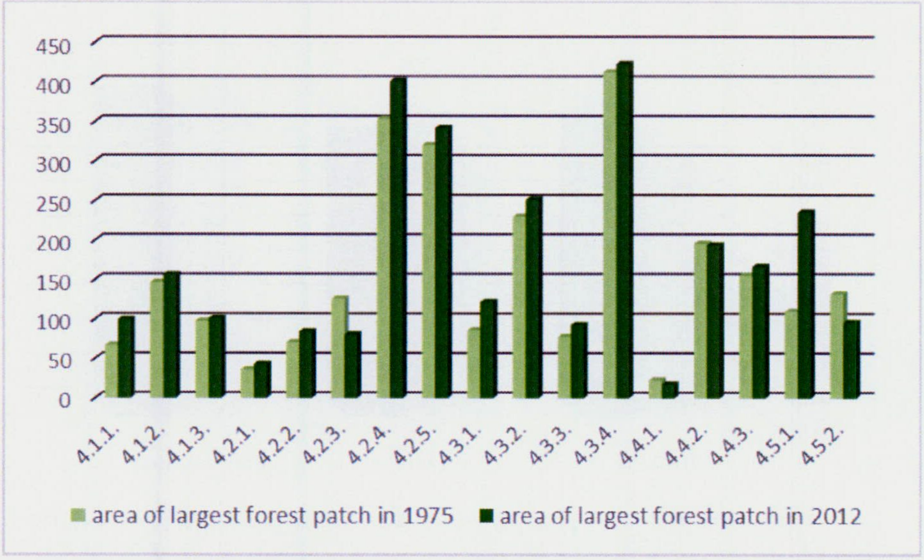

Figure 9: Area of largest forest patches within landscape units in 1975 and 2012

The difference in the number of forest patches among the Manfor test squares was relatively large between test square Kočevski Rog and other two squares in 1975, but it became smaller in 2012. The increase in number of forest patches was the largest in Snežnik (Table 16). It is obvious that the area of largest forest patch decreases with lowering the landscape level, which was expected, since the total studied area is also getting smaller. In general, the area of largest forest patch in all three Manfor test squares remained stable from 1975 to 2012 (Figure 10).

Table 16: Number and area of largest forest patches patch within ManFor test squares in 1975 and 2012

Area code	Area name	Number of forest patches		Area of largest forest patch (km^2)	
		1975	2012	1975	2012
1	Kočevski Rog	120	472	71	82
2	Snežnik	13	209	75	79
3	Trnovo	8	50	92	92

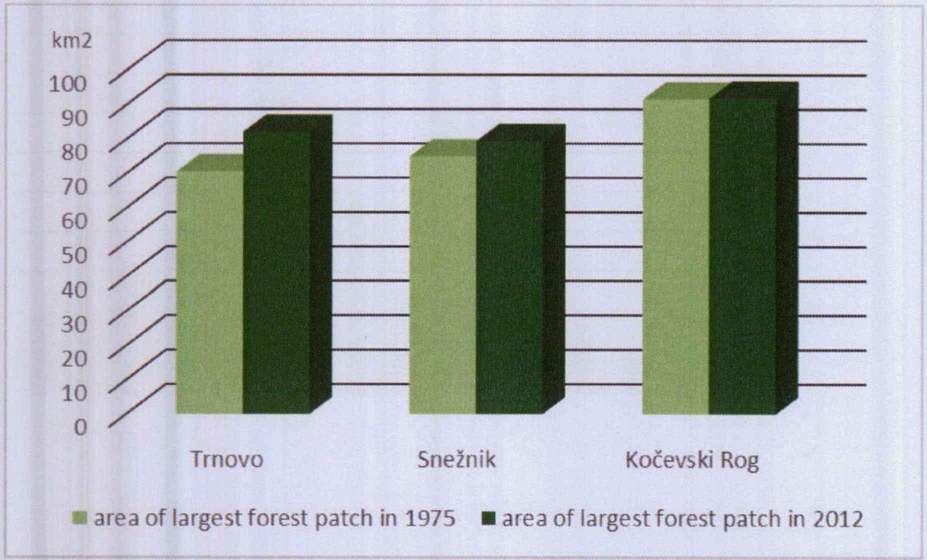

Figure 10: Area of largest forest patches within ManFor test squares in 1975 and 2012

Core areas

The results shows that the number and area of cores areas, the share of core areas of landscape and of forest, remained relatively stable from 1975 until 2012 almost at all landscape levels with a few exceptions (Table 17, Table 18,

Table 19, Table 20). The latter are significant at landscape level 4, where these parameters generally changed more in the units 4.1.1, 4.1.2, 4.3.4, 4.4.2 than in the others (Table 20, Figure 11 and Figure 12). On the other hand, area of the largest core area changed more than other parameters in the studied years at all landscape levels.

Table 17: Core areas within Slovenia in 1975 and 2012

Area name	Number of core areas		Area of core areas (km^2)		% of landscape		% of forest		Area of the largest core area (km^2)	
	1975	2012	1975	2012	1975	2012	1975	2012	1975	2012
Slovenia	4,285	4,454	2,356	2,831	12	14	21	23	281	334

Table 18: Core areas within landscape-ecological region "Kraške regije notranje Slovenije" in 1975 and 2012

Area code	Area name	Number of core areas		Area of core areas (km^2)		% of landscape		% of forest		Area of the largest core area (km^2)	
		1975	2012	1975	2012	1975	2012	1975	2012	1975	2012
4.	Kraške regije notranje Slovenije	920	991	1,312	1,462	28	31	41	41	281	334

Table 19: Core areas within wider landscape units in 1975 and 2012

Area code	Area name	Number of core areas		Area of core areas (km^2)		% of landscape		% of forest		Area of the largest core area (km^2)	
		1975	2012	1975	2012	1975	2012	1975	2012	1975	2012
4.1.	Trnovsko-Nanoška planota	112	124	122	174	28	39	37	46	69	75
4.2.	Pivško-Cerkniška planota	342	371	452	467	27	28	41	38	216	212
4.3.	Kočevska kotlina in Kočevski rog	143	177	482	533	44	49	55	57	233	252
4.4.	Grosupeljska kotlina in Suha krajina	196	213	136	126	18	17	30	26	34	19
4.5.	Gorjanci z Belo krajino	190	180	120	162	15	20	26	31	23	50

Table 20: Core areas within landscape units in 1975 and 2012

Area code	Area name	Number of core areas		Area of core areas (km^2)		% of landscape		% of forest		Area of the largest core area (km^2)	
		1975	2012	1975	2012	1975	2012	1975	2012	1975	2012
4.1.1.	Banjška planota	46	50	3	22	2	16	4	21	1	22
4.1.2.	Trnovski gozd	58	57	53	81	28	43	35	49	38	81
4.1.3.	Nanos in Hrušica	12	21	66	70	60	63	67	68	65	70
4.2.1.	Pivška planota	47	75	31	32	11	12	27	22	11	32
4.2.2.	Planota Črni vrh-Logatec	42	44	26	26	20	20	30	28	18	26
4.2.3.	Cerkniško območje	53	71	76	76	27	27	45	41	34	76
4.2.4.	Velika notranjska planota	177	154	128	148	22	25	32	33	36	148
4.2.5.	Snežnik z Javorniki	68	78	192	185	49	47	58	53	188	185
4.3.1.	Ribniško-Kočevska dolina	44	54	70	72	30	31	49	48	32	72
4.3.2.	Kočevska gora z Moravsko planoto	15	43	164	169	59	61	68	66	158	169
4.3.3.	Dolina Zgornje Kolpe	31	77	29	33	26	29	34	33	17	33
4.3.4.	Kočevsko – Roško hribovje	102	55	219	260	46	55	53	61	191	260
4.4.1.	Grosupeljska kotlina	32	31	8	9	9	10	20	20	3	9
4.4.2.	Suha krajina južno od Krke	67	90	82	65	31	24	42	30	32	65
4.4.3.	Krajina severno od Krke	112	110	46	52	12	13	22	23	12	52
4.5.1.	Gorjanci z Radoho	121	119	73	90	16	19	26	29	23	90
4.5.2.	Bela Krajina	69	63	47	72	14	21	26	33	8	72

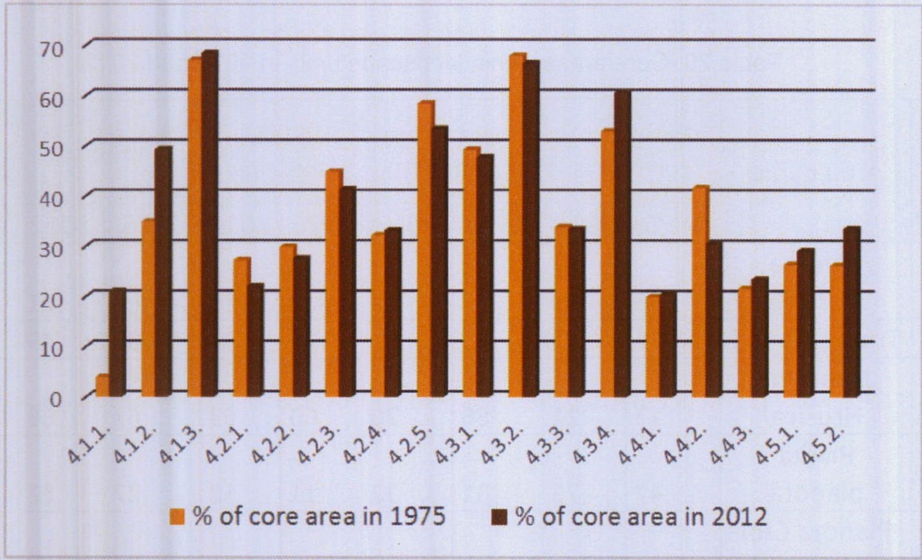

Figure 11: Share of core area in forest within landscape units in 1975 and 2012

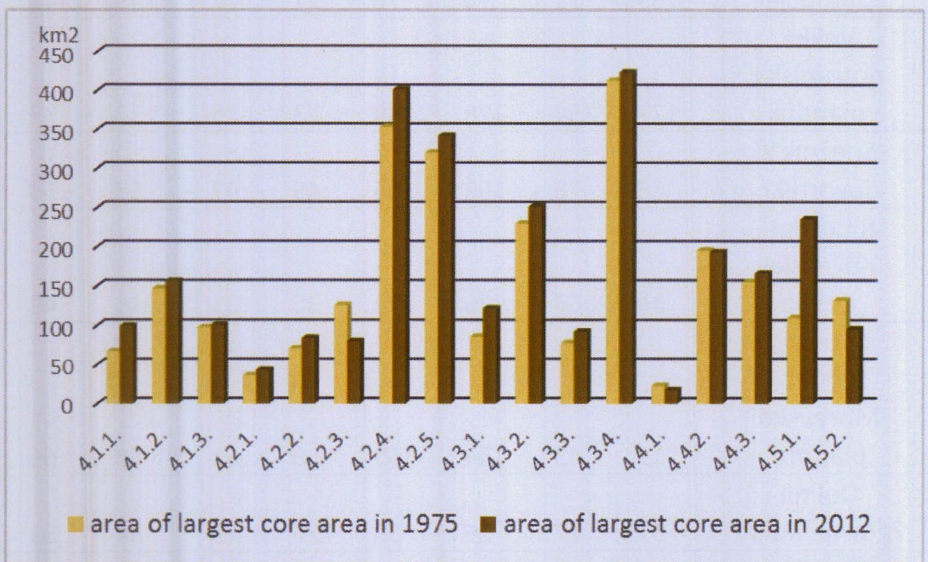

Figure 12: Area of largest core area within landscape units in 1975 and 2012

The trends of all landscape parameters (indicators) for the Manfor test squares are quite similar than at the higher landscape levels. Again, there were few exceptions also at this landscape level. For example, number of core areas in Trnovo decreased significantly from 1975 to 2012, whilst in other two test squares it did not. Besides, in Trnovo the share of core areas of landscape increased and the area of the largest core area decreased significantly between 1975 and 2012 (Table 21, Figure 13 and Figure 14).

Table 21: Core areas within ManFor test squares in 1975 and 2012

Area code	Area name	Number of core areas		Area of core areas (km^2)		% of landscape		% of forest		Area of the largest core area (km^2)	
		1975	2012	1975	2012	1975	2012	1975	2012	1975	2012
1	Kočevski Rog	12	16	62	68	62	68	66	72	61	66
2	Snežnik	22	23	35	39	35	39	46	51	28	36
3	Trnovo	45	14	14	19	5	45	14	14	19	5

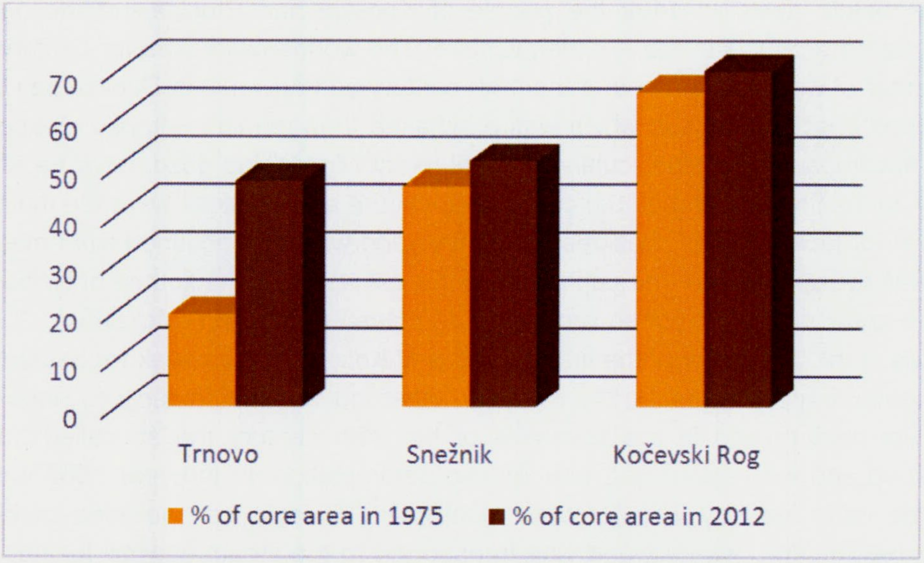

Figure 13: Share of core area in forest within Manfor test squares in 1975 and 2012

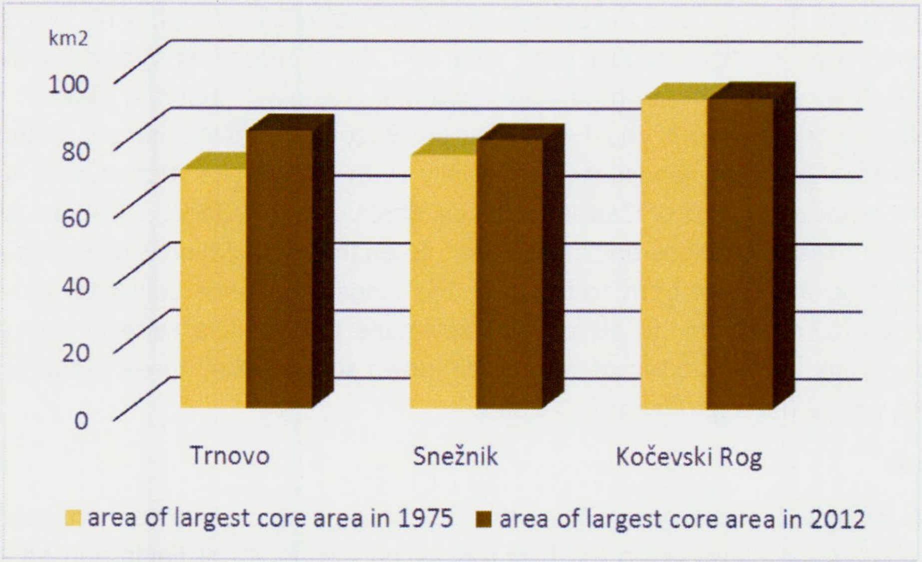

Figure 14: Area of largest core area within ManFor test squares in 1975 and 2012

Analysis of socio-demographic trends

ManFor test sites and their broader surrounding from historical point of view

Kočevski rog

In the beginning of the 10th century AD the first Slovenian settlers came to the Kočevsko area, followed by the German colonists (Zgodovina gozdarstva na Kočevskem, 2013). Migration with intense deforestation and slash and burn technic continued in to the higher hilly and wooded landscape between 12th and 15th century (Blaznik, 1970). At the end of the 15th century estate represented the main source of survival for the rural population (Makarovič, 2005). Due to the over-exploitation of forests, first forest regulation appeared in the middle ages. In 1492 the people of Kočevje and Ribnica got the right to sale handcrafted products to the Austrian Empire. The woodenware was for centuries a major consumer of wood. At the end of the 18th century an ironworks in Dvor began to operate. It needed a lot of charcoal, which was purchased from farmers. Intense charcoal burning were accompanied by clear-cutting of local forest (Zgodovina gozdarstva na Kočevskem, 2013). In the first half of the 19th century agriculture and livestock were the main source of survival for local families. Besides forest, firewood was also optioned from meadows and pastures overgrown with trees and bushes. Forest was also the source of timber, wood for boards and roof tops, wooden products and potash production (Makarovič, 2005). In the eighties of the 19th century the first residents of Kočevska area seek for better life namely in America. Except for milling there was no other industry in Črmošnjice. Since the end of the 19th century and in the seventies of the 20th century the so called "furmanstvo" flourished and was associated with intense deforestation. In the year 1937 it was stated that the main industry was forestry. Municipality Črmošnjice consisted of large forest complexes in Rog, where wood was transported to the steam sawmill located in Ribnik, Srednja vas, Straža and Semič (Makarovič, 2005). Roška saw or "Saw Rog" was of great importance for the survival of the population in Črmošnjiška - Poljanska valley. It began to operate in late 1895 up until the beginning of the First World War in 1914. With the closure of many sawmills workers lost their jobs and the surrounding villages were severely affected. New employment opportunity opened in 1932 with a steam sawmill, which was successfully operating until the 1941. After the Second World War strong changes can be seen in the Slovenian landscape, especially in the Kočevska area due to the political reasons (sudden exodus of German families, destruction of villages...). A decade later the biggest landscape changes become evident. Even the colonization with Slovenian families couldn't stop the forest from taking back the landscape, once cultivated by the people known as Kočevarji. In the sixties and seventies the families were buying agricultural machinery and farmers often decided to cut down some of their forests to afford the new, modern way of farming (Makarovič, 2005).

Snežnik

People inhabited Loška dolina since the prehistoric times. Slovenian colonization in the early middle ages stopped in the hilly region, on the edges of fields and on the natural shelves where there was no danger of flooding (Loka - Dolina.net..., 2013). Turkish incursions represent a breaking stone in the history of the Loška dolina, not only because of the fear and devastation, but also because it affected social and spiritual life of Loška dolina population. Restoration of farms after the Turkish incursions took years to help local people, they got more rights in the forest and also in trade of wood products (Loka - Dolina.net ..., 2013). In some districts, for example in the Loška dolina and Notranjska there was a manufacture of a large scale according to the privileges from the 16th century of wooden bowls, wooden rings, woodenware etc. The wood for this purpose was obtained from the nearby forests. In general, the consumption of wood for wood products did not significantly affect the extent of forest exploitation (Blaznik, 1970).

The strongest mark on the Snežnik forests gave the last pre-war owners Schönburg. The Schönburg property was visited by guests of the monarchy, interested in hunting (Sterle, 2000). Besides hunting in the old Snežnik land registers and archives the main forest products are listed: beechnuts, dormice hunting, flint fungi and beech potash. Beech wood had almost no value but at that time the property Snežnik was the size of five square miles and it yearly needed three hundred carts of firewood. A few fir wood was taken by farmers with servitude against a minimum compensation called "Waldstellung". Farmers were also allowed to convert forest to meadows and in this way the forest also represented an important source of income (Sterle, 2000). Even forest grazing was profitable if there was no servitude. In all parts of the estate forest grazing was mainly leased by shepherds from Istria and Karst region. Over the summer they herded hundreds of sheep in to the forest and in autumn they gradually moved their herds toward the sea. For better grazing conditions the shepherds offend burned forest areas. Even today the evidence of burning can be found in every forest district. Even the local names remind us of the forest burning in the past and it is still possible to recognize large burned areas Vratca - Obramec and on the hill Pogorelček near Leskova dolina. Related local names can be also found in the forest district Mašun: Sežgani klanec, Pogoreli vrh and Škornje. In the forest fire on the slope called Javornik, the local farmers were recruited to dig ditches to prevent fire from spreading. Today the area is known as Prekopavnik. According to tradition the whole valley called Leskov grm (today known as Škorenj) was in flames. Also in the district Gomance we can find names as Zgorina or Paleš.

The history of Leskova dolina is also closely related to the fate of factory of wooden derivatives (Sterle, 2000). The agricultural crisis in the 90 of the 19. century also affected the area of Notranjska. Increasing industrialization along with the loss of income from home handcrafting, high taxes, old debts, loss of land claimed by large landowners and extortion destroyed the farmers and they were force to move to the city or leave the country. They often left to America (Loška-Dolina.net..., 2013). The first water saw on the stream Obrh were built in the 80s for the purpose of sawing wooden. The saw on Marof started to work around the years 1906-1907. At that time lot of mills were working for the needs of local people. There was also a brickyard established in Podcerkev. The agriculture was still the main source of survival (Loška-Dolina.net..., 2013). After the Second World War thousand kilometres of forest roads and skidding roads were built making the forest more profitable and valuable. Today the forest of Snežnik have an important historical, ecological and economical value (Sterle, 2000).

Trnovo

Based on the research and development in Smrečje on Predmeja it is assumed that the first dwellers of Trnovski gozd were the Illyrians and Celts. Their main occupation was livestock rising. The organized forest service can be traced back in the Roman times.

There is no data on Trnovski gozd up until the year 1001, when the Cesar Oton III give his half of castle Solkan and half of village Gorica together with forest, water, hunting, grazing and fishing rights in valley of Soča and Vipava to the patriarch of Oglej. The Trnovo plateau was also in the hands of Oglej patriarchs for several hundred years. Up until the fire, caused by the shepherds in 1540, the forest extended all the way to the valley and represented the source of survival for the first settlers who were namely foresters, hunters and shepherds. During the Isonzo Front forest also represented a refuge for solders and deserters.

From the year 1873 on, the forest of Trnovo was divided in the district of Trnovo, Lokve, Dolina, Nemci, Mrzla draga, Poncala, Mala Lazna, Krnica, Selovc, Čaven, Predmeja and Otlica. In each district a forest station was established with district foresters. The oldest village named Trnovo can be found on the edge of Trnovo forest. The name originates from pomegranate, the plant with thorns that surrounds the village where there is very little water springs. So the local people built drinking ponds from clay for their livestock. In the near vicinity of Trnovo, precisely in Mojska and Mrzla draga the quartz sand can be found. In the old days it was used for making glass products. The people of Trnovo were dealing with agricultural and livestock rising but the main source of income was forest. As forest workers and drivers they were also known in other parts. They were also woodcutters, charcoal-makers, sawyers, sellers of firewood and gatherers of forest fruits.

The livestock farming in the village was very well developed. Rich families breed draft animals, especially horses for bringing wood from the forest. Agriculture was poorly developed because of high altitude and extreme climate conditions. In the time of Habsburg monarchy, the people of Voglarje were known as excellent charcoal-makers, selling charcoal to Trieste for cooking and heating. During the war Trnovo forrest had a crucial role as the natural forge. Its high altitude (1000-1200 m) made him almost impossible to conquer.

In the year 1947 a saw started to work in Trnovo. During the Italian occupation the forest was already devastated and additional devastation was made by people of Voglarji with extensive cutting. At that time local people were cutting very vital young forest. The section for agriculture and forestry put an end to it with the supervision of Local People's Committee with forest saints (Terčič, 2011). In 1947 Primorska became a part of Yugoslavia. With the assignment of city of Gorica to Italy, Primorska region lost an important economic, cultural and administrative centre. This led in to a building of the new city called Nova Gorica.

Analyses of population changes

LEVEL 1 – SLOVENIA

Number of population

According to the Statistical Office of the Republic of Slovenia, at the beginning of 2013 Slovenia had a population of 2,058,821. From 1869 population increased by 931.079 (Table 22) due to natural increase and specially in last period also due to net migration. It has 6032 settlements. Every other settlement had fewer than 100 residents. Altogether the population of such settlements equalled half of population of the largest settlemet – Ljubljana (The demographic portrait... 2008).

Table 22: Number of settlements and population in Slovenia in 1869, 1931, 1961 and 2013

Area name	Number of settlements	Number of population			
		1869	1931	1961	2013
Slovenia	6032	1,127,742	1,388,772	1,591,523	2,058,821

From 1869 to 2013 number of population increased by 82 % (Table 23), in next period between 1931 and 1961 the population growth was even smaller due to Second World War (+14,6 %). In last period (1961-2013) population increased by nearly 30 %. It means that population slowly but constantly increased during all observed period.

Table 23: Population changes in Slovenia (1869-2013, 1931-1961 and 1961-2013)

Area name	Index of the number of population 1869/2013	Change of the number of population 1869/2013 (%)	Annual change of the number of population 1869/2013 v %	Index of the number of population 1931/1961	Change of the number of population 1931/1961 v %	Annual change of the number of population 1931/1961 v %	Index of the number of population 1961/2013	Change of the number of population 1961/2013 v %	Annual change of the number of population 1961/2013 v %
Slovenia	182.56	82.56	0.57	114.60	14.60	0.49	129.36	29.36	0.56

Population density

The average population density was 101.6 people per km^2 (Table 24). Slovenia due to its great landscape diversity is settled unevenly. A sixth of the country has an above-average of population population density, mostly in altitude belts below 400 meters where four fifth of the population lives or in the areas around Slovenia's largest settlements (Kladnik 2004). In the study period population density slowly but continuously increased and is almost twice as high at it was in 1869 – 55.6 people per square km^2.

Table 24: Population density in Slovenia in 1869, 1931, 1961 and 2013

Area name	Area (km^2)	Population density (number of people/km^2)			
		1869	1931	1961	2013
Slovenia	20,273	55.6	68.5	78.5	101.6

LEVEL 2 – LANDSCAPE REGION

Number of population

In 2013 "Kraške regije notranje Slovenije" had 202,930 of population (Table 25). Number of population between 1869 and 2013 increased only for 19 % (Table 26), what was far below country average. We can explain this with unfouvarable natural conditions of landscape region: karst surface, lack of water resources, steep slopes, unfouvarable conditions for agriculture...), which influence also on social conditions. Some parts of observed region are far away from bigger settlements, don't have sufficiently developed infrastructure, opportunities for employment... Between 1931 and 1961 number of population even decreased, what was consequence of historical events during Second World War (exodus in Kočevska region...). In last observed period the population change was slighly more positive, number of population namely increased by quarter.

Table 25 : Number of settlements and population in landscape region »Kraške regije notranje Slovenije« in 1869, 1931, 1961 and 2013

Area code	Area name	Number of settlements	Number of population			
			1869	1931	1961	2013
4.	Kraške regije notranje Slovenije	1,396	170,104	179,591	162,043	202,930

Table 26: Population changes in region "Kraške regije notranje Slovenije" (1869-2013, 1931-1961 and 1961-2013)

Area name	Index of the number of population 1869/2013	Change of the number of population 1869/2013 (%)	Annual change of the number of population 1869/2013 v %	Index of the number of population 1931/1961	Change of the number of population 1931/1961 (%)	Annual change of the number of population 1931/1961 (%)	Index of the number of population 1961/2013	Change of the number of population 1961/2013 (%)	Annual change of the number of population 1961/2013 (%)
Kraške regije notranje Slovenije	119.30	19.30	0.13	90.23	-9.77	-0.33	125.23	25.23	0.49

Population density

Nowadays population density in "Kraške regije notranje Slovenije" is very low with only 42.7 people per km^2 (Table 27). In the past was even lower and it was relatively stable. In the first observed period it slightly increased, in the second it slightly decreased due to Second World War.

Table 27: Population density in landscape region Kraške regije notranje Slovenije in 1869, 1931, 1961 and 2013

Area code	Area name	Area (km^2)	Population density (number of people/km^2)			
			1869	1931	1961	2013
4.	Kraške regije notranje Slovenije	4,753	35.8	37.8	34.1	42.7

LEVEL 3 – WIDER LANDSCAPE UNITS

Number of population

There are great differences in demographic trends between wider landscape units. "Trnovsko-Nanoška planota", where also Manfor test site Trnovo is located, has only 5,500, while "Pivško-Cerkniška planota" and "Grosupeljska kotlina in Suha Krajina" have more than 50,000 inhabitants (Table 28). "Trnovsko Nanoška planota" is the only wider landscape unit, where the number of population strongly decreased during all observed periods (**Table 29**). Between 1869 and 2013 number of population decreased by half, in second and third observed period by approximately 30 %. Between 1869 and 2013 number of population slightly decreased (- 4%) also in "Kočevska kotlina in Kočevski Rog", where Manfor test site Kočevski Rog is located. Between 1931 and 1961 number of population decreased in all wider landscape units. In the last period (1961-2013) all wider landscape units with the exception of previous mentioned "Trnovsko Nanoška planota" had population growth. In "Grosupeljska kotlina in Suha Krajina" number of population increased by 44.6%, followed by "Pivško-Cerkniška planota" (35.8%). These are lowland wider landscape units with favourable geographic location in vicinity of Ljubljana basin with capital Ljubljana.

Table 28: Number of settlements and population in wider landscape units in 1869, 1931, 1961 and 2013

Area code	Area name	Number of settlements	Number of population			
			1869	1931	1961	2013
4.1.	Trnovsko-Nanoška planota	33	11,308	11,856	8,376	5,562
4.2.	Pivško-Cerkniška planota	366	49,133	55,972	49,990	67,904
4.3.	Kočevska kotlina in Kočevski rog	262	31,341	30,847	27,767	30,130
4.4.	Grosupeljska kotlina in Suha krajina	367	37,300	39,884	37,374	54,068
4.5.	Gorjanci z Belo krajino	368	41,022	41,032	38,536	45,266
Total		1396	170,104	179,591	162,043	202,930

Table 29: Population changes in wider landscape units (1869-2013, 1931-1961 and 1961-2013)

Area code	Area name	Index of the number of population 1869/2013	Change of the number of population 1869/2013 (%)	Annual change of the number of population 1869/2013 v %	Index of the number of population 1931/1961	Change of the number of population 1931/1961 v %	Annual change of the number of population 1931/1961 v %	Index of the number of population 1961/2013	Change of the number of population 1961/2013 v %	Annual change of the number of population 1961/2013 v %
4.1.	Trnovsko-Nanoška planota	49.19	-50.81	-0.35	70.65	-29.35	-0.98	66.40	-33.60	-0,65
4.2.	Pivško-Cerkniška planota	138.20	38.20	0.27	89.31	-10.69	-0.36	135.84	35.84	0,69
4.3.	Kočevska kotlina in Kočevski rog	96.14	-3.86	-0.03	90.02	-9.98	-0.33	108.51	8.51	0,16
4.4.	Grosupeljska kotlina in Suha krajina	144.95	44.95	0.31	93.71	-6.29	-0.21	144.67	44.67	0,86
4.5.	Gorjanci z Belo krajino	110.35	10.35	0.07	93.92	-6.08	-0.20	117.46	17.46	0,34
SKUPAJ		119.30	19.30	0.13	90.23	-9.77	-0.33	125.23	25.23	0.49

Population density

In 2013 population density ranged between 12.59 people per km^2 in "Trnovsko-Nanoška planota" and 72,0 people per km^2 in "Grosupeljska kotlina in Suha Krajina" (Table 30). According to changes in number of population, population density strongly decreased (by half) in "Trnovsko-Nanoška planota", slightly in "Kočevska kotlina in Kočevski Rog" and contrary strongly increased in "Grosupeljska kotlina in Suha Krajina" (+22,3 people per km^2) and in Pivško-Cerkniška planota (+11,3 people per km^2).

Table 30: Population density in wider landscape units in 1869, 1931, 1961 and 2013

Area code	Area name	Area (km^2)	Population density (number of people/km^2)			
			1869	1931	1961	2013
4.1.	Trnovsko-Nanoška planota	441.71	25.60	26.84	18.96	12,59
4.2.	Pivško-Cerkniška planota	1,659.63	29.60	33.73	30.12	40,92
4.3.	Kočevska kotlina in Kočevski rog	1,091.76	28.71	28.25	25.43	27,60
4.4.	Grosupeljska kotlina in Suha krajina	751.08	49.66	53.10	49.76	71,99
4.5.	Gorjanci z Belo krajino	808.32	50.75	50.76	47.67	56,00
SKUPAJ		4,752.50	35.79	37.79	34.10	42.70

LEVEL 4 – LANDSCAPE UNITS

Number of population

There are large differences also between landscape units, even larger than in case of wider landscape units. Number of settlements ranges between 1 in landscape unit "Nanos in Hrušica" with only 15 inhabitants in 2013 and 259 in landscape unit "Krajina severno od Krke" with more than 30,000 inhabitants (Table 31).

Table 31 : Number of settlements and population in landscape units in 1869, 1931, 1961 and 2013

Area code	Area name	Number of settlements	Number of population			
			1869	1931	1961	2013
4.1.1.	Banjška planota	15	6,860	6,406	4,482	2.812
4.1.2.	Trnovski gozd	17	4,391	5,388	3,821	2.735
4.1.3.	Nanos in Hrušica	1	57	62	73	15
4.2.1.	Pivška planota	53	13,804	16,032	16,064	19,853
4.2.2.	Planota Črni vrh-Logatec	12	5,091	6,179	6,330	12,633
4.2.3.	Cerkniško območje	49	12,090	13,338	12,030	15,138
4.2.4.	Velika notranjska planota	250	17,949	20,096	15,318	20,118
4.2.5.	Snežnik z Javorniki	2	199	327	248	162
4.3.1.	Ribniško-Kočevska dolina	76	13,363	15,878	19,119	25,372
4.3.2.	Kočevska gora z Moravsko planoto	35	3,210	3,087	1,969	1,268
4.3.3.	Dolina Zgornje Kolpe	92	5,948	5,444	3,846	1,550
4.3.4.	Kočevsko –Roško hribovje	59	8,820	6,438	2,833	1,940
4.4.1.	Grosupeljska kotlina	50	5,278	6,040	7,403	18,294
4.4.2.	Suha krajina južno od Krke	58	9,937	9,726	7,174	5,478
4.4.3.	Krajina severno od Krke	259	22,085	24,118	22,797	30,296
4.5.1.	Gorjanci z Radoho	221	21,959	23,916	21,325	23,680
4.5.2.	Bela Krajina	147	19,063	17,116	17,211	21,586
SKUPAJ		1,396	170,104	179,591	162,043	202,930

Between 1869 and 2013 approximately half of the landscape units had population growth and other half population decline (Table 32, Figure 15). Number of population strongly increased in landscape "Grosupeljska kotlina", located in vicinity of the capital (+246.61 %), followed by "Planota Črni vrh-Logatec" (+148.14 %) and "Ribniško-Kočevska dolina" (+89.87%). On the contrary landscape units "Kočevsko–Roško hribovje", "Dolina Zgornje Kolpe" and "Nanos in Hrušica" had a strong population decline (number of population decreased by more than 70 %). Between 1931 and 1961 number of population increased only in four landscape units. Between 1961 and 2013 the population changes were similar like in longest period, what means that number of population increased approximately in half landscape units, other half had population decline.

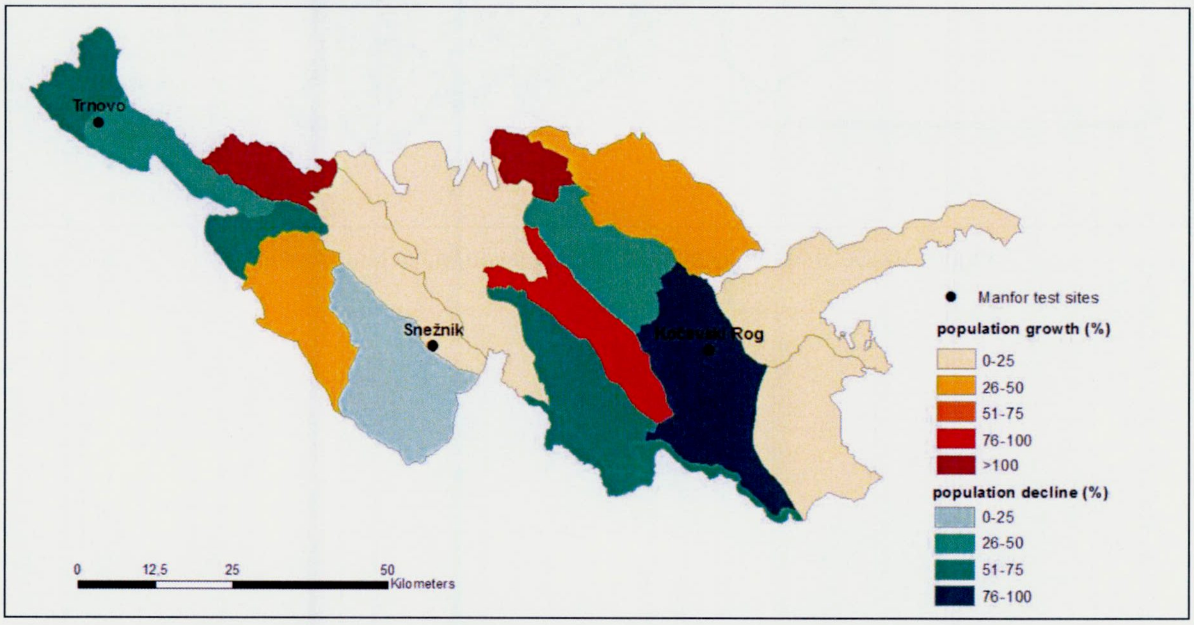

Figure 15: Population change between 1869 and 2013 inside landscape units

1,396 settlements in observed area are very unevenly distributed across the landscape units (Figure 16). Two hilly landscape units (»Nanos in Hrušica« and »Snežnik z Javorniki«) has only 1 or 2 small setlements and very low population density, which is below 1 people per square kilometre. One the other hand, there are 3 landscape units landcape units with more than 200 settlements.

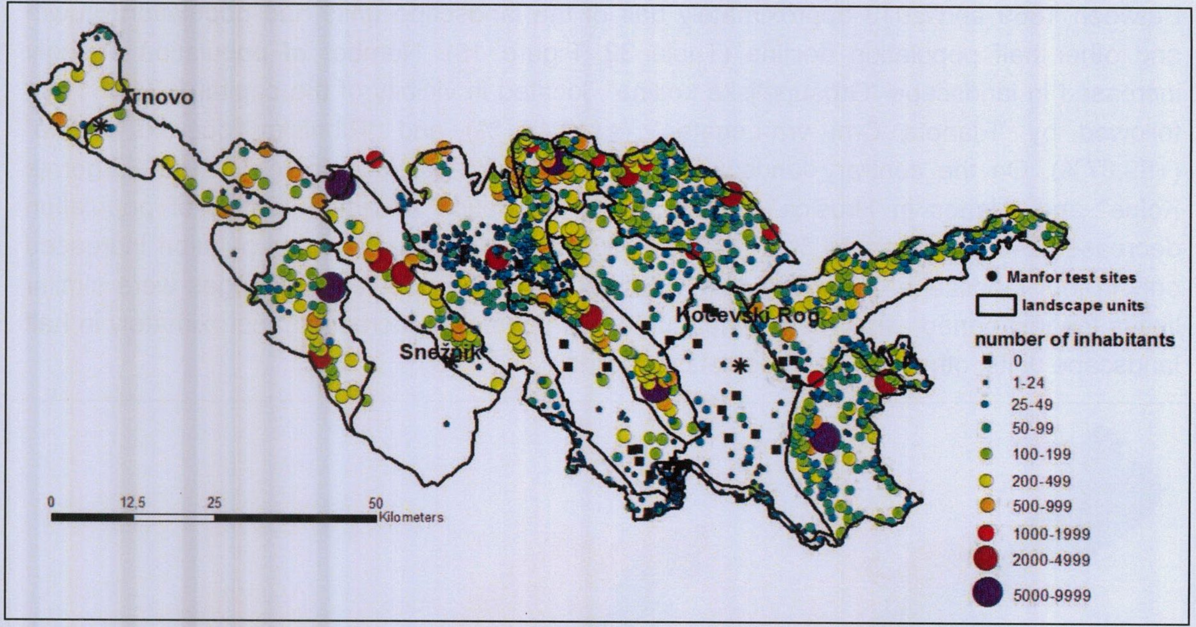

Figure 16: Setlements by number of population within landscape units

Table 32: Population changes in landscape units (1869-2013, 1931-1961 and 1961-2013)

Area code	Area name	Index of the number of population 1869/2013	Change of the number of population 1869/2013 (%)	Annual change of the number of population 1869/2013 v %	Index of the number of population 1931/1961	Change of the number of population 1931/1961 v %	Annual change of the number of population 1931/1961 v %	Index of the number of population 1961/2013	Change of the number of population 1961/2013 v %	Annual change of the number of population 1961/2013 v %
4.1.1.	Banjška planota	40.99	-59.01	-0.41	69.97	-30.03	-1.00	62.74	-37.26	-0.72
4.1.2.	Trnovski gozd	62.29	-37.71	-0.26	70.92	-29.08	-0.97	71.58	-28.42	-0.55
4.1.3.	Nanos in Hrušica	26.32	-73.68	-0.51	117.74	17.74	0.59	20.55	-79.45	-1.53
4.2.1.	Pivška planota	143.82	43.82	0.30	100.20	0.20	0.01	123.59	23.59	0.45
4.2.2.	Planota Črni vrh-Logatec	248.14	148.14	1.03	102.44	2.44	0.08	199.57	99.57	1.91
4.2.3.	Cerkniško območje	125.21	25.21	0.18	90.19	-9.81	-0.33	125.84	25.84	0.50
4.2.4.	Velika notranjska planota	112.08	12.08	0.08	76.22	-23.78	-0.79	131.34	31.34	0.60
4.2.5.	Snežnik z Javorniki	81.41	-18.59	-0.13	75.84	-24.16	-0.81	65.32	-34.68	-0.67
4.3.1.		189.87	89.87	0.62	120.41	20.41	0.68	132.71	32.71	0.63
4.3.2.	Kočevska gora z Moravsko planoto	39.50	-60.50	-0.42	63.78	-36.22	-1.21	64.40	-35.60	-0.68
4.3.3.	Dolina Zgornje Kolpe	26.06	-73.94	-0.51	70.65	-29.35	-0.98	40.30	-59.70	-1.15
4.3.4.	Kočevsko –Roško hribovje	22.00	-78.00	-0.54	44.00	-56.00	-1.87	68.48	-31.52	-0.61
4.4.1.	Grosupeljska kotlina	346.61	246.61	1.71	122.57	22.57	0.75	247.12	147.12	2.83
4.4.2.	Suha krajina južno od Krke	55.13	-44.87	-0.31	73.76	-26.24	-0.87	76.36	-23.64	-0.45
4.4.3.	Krajina severno od Krke	137.18	37.18	0.26	94.52	-5.48	-0.18	132.89	32.89	0.63
4.5.1.	Gorjanci z Radoho	107.84	7.84	0.05	89.17	-10.83	-0.36	111.04	11.04	0.21
4.5.2.	Bela Krajina	113.24	13.24	0.09	100.56	0.56	0.02	125.42	25.42	0.49
	SKUPAJ	119.30	19.30	0.13	90.23	-9.77	-0.33	125.23	25.23	0.49

Population density

Landscape units "Nanos in Hrušica" and "Snežnik z Javorniki" had the lowest population density in 2013 which was less than 0.5 people per km^2, that means that these landscape units are nearly unpopulated (Table 33). Landscape with far largest population density was "Grosupeljska kotlina" with 199.4 people per km^2, followed by "Ribniško-Kočevska dolina" (110.3 people per km^2). Country average (101.6 people per km^2) nearly reached also landscape unit "Planota Črni vrh-Logatec" with 97.6 people per km^2.

Table 33: Population density in landscape units in 1869, 1931, 1961 and 2013

Area code	Area name	Area (km^2)	Population density (people/km^2)			
			1869	1931	1961	2013
4.1.1.	Banjška planota	140.72	48.75	45.52	31.85	19.98
4.1.2.	Trnovski gozd	190.49	23.05	28.28	20.06	14.36
4.1.3.	Nanos in Hrušica	110.50	0.52	0.56	0.66	0.14
4.2.1.	Pivška planota	269.23	51.27	59.55	59.67	73.74
4.2.2.	Planota Črni vrh-Logatec	129.49	39.32	47.72	48.88	97.56
4.2.3.	Cerkniško območje	283.51	42.64	47.05	42.43	53.39
4.2.4.	Velika notranjska planota	587.11	30.57	34.23	26.09	34.27
4.2.5.	Snežnik z Javorniki	390.30	0.51	0.84	0.64	0.42
4.3.1.	Ribniško-Kočevska dolina	229.94	58.12	69.05	83.15	110.34
4.3.2.	Kočevska gora z Moravsko planoto	276.88	11.59	11.15	7.11	4.58
4.3.3.	Dolina Zgornje Kolpe	112.95	52.66	48.20	34.05	13.72
4.3.4.	Kočevsko –Roško hribovje	471.99	18.69	13.64	6.00	4.11
4.4.1.	Grosupeljska kotlina	91.73	57.54	65.85	80.70	199.43
4.4.2.	Suha krajina južno od Krke	266.75	37.25	36.46	26.89	20.54
4.4.3.	Krajina severno od Krke	392.60	56.25	61.43	58.07	77.17
4.5.1.	Gorjanci z Radoho	462.96	47.43	51.66	46.06	51.15
4.5.2.	Bela Krajina	345,36	55,20	49,56	49,83	62,50
SKUPAJ		4752,50	35,79	37,79	34,10	42,70

Figure 17 shows changes in population density between 1869 and 2013. Changes in population density between 1869 and 1931 were small. Population density increased only in two landscape units ("Trnovski gozd" and "Dolina Zgornje Kolpe") by one class (from < 25 people per km^2 to 26-50 people per km^2). Between 1931 and 1961 population density decreased in 2 landscape units ("Trnovski gozd" from 26-50 to < 25 people per km^2 and "Gorjanci z Radoho" from 51-75 to 26-50 people per km^2) and increased also in two landscape units ("Grosupeljska kotlina" and "Ribniško-Kočevska dolina", both from 51-75 to 76-100 people per km^2). Between 1961 to 2013 population density decreased in two landscape units ("Banjša planota" and "Dolina Zgornje Kolpe", both from 26-50 to < 25 people per km^2). On the other hand there were 7 landscape units, where population density increased by one ("Cerkniško območje", "Gorjanci z Radoho" and "Bela Krajina" from 26-50 to 51-77 people per km^2; "Krajina severno od Krke" from 51-75 to 76-100 people per km^2; "Grosupeljska kotlina" and "Ribniško-Kočevska dolina" from 76-100 to > 100 people per km^2 or even by two classes ("Planota Črni vrh-Logatec" from 26-50 to 76-100 people per km^2. Results show a general trend: landscape units that have low population density are faced with further depopulation, while population is concentrated in the landscape units with already higher density. These are especially those landscape units, which are located in lowlands, majority also in vicinity of the capital and have good transport links with bigger cities.

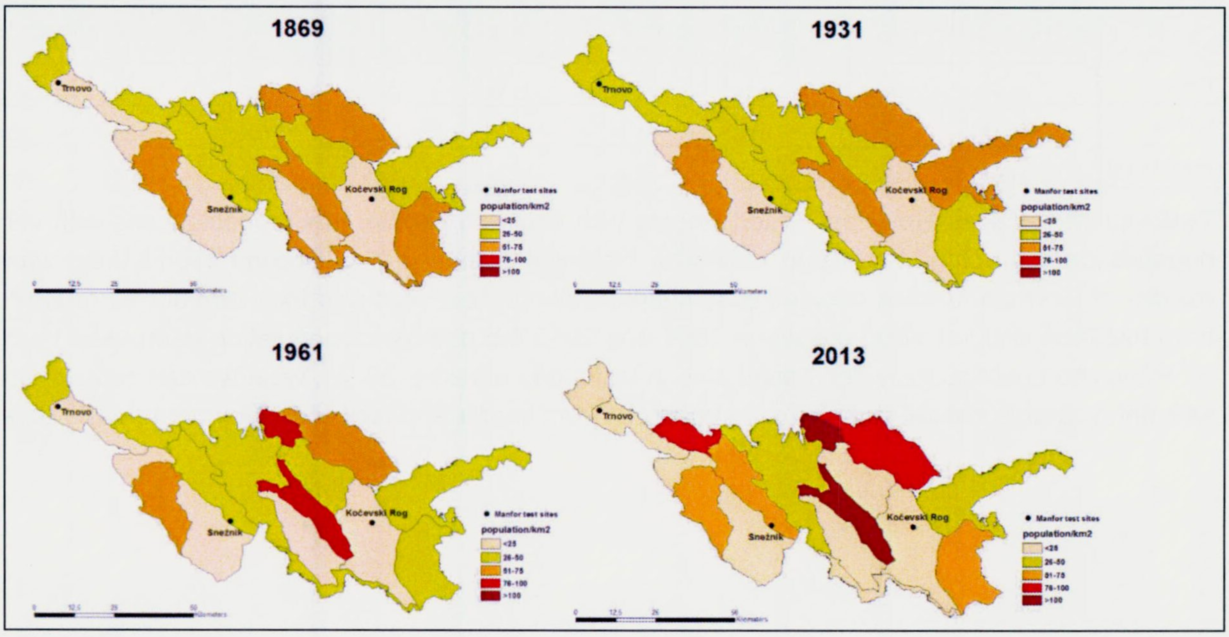

Figure 17: Population density within landscape units in 1869, 1931, 1961 and 2013

LEVEL 5 - MANFOR TEST SQUARES

Number of population

In Trnovo test square there are 21 of settlements with 7,684 inhabitants (**Table 34**). Between 1869 and 2013 population decreased by one fourth (Table 35, Figure 18). The greatest decline of population was between 1931 and 1961, what was the consequence of human lives loss in Second World War. In last period between 1961 and 2013 the number of population stagnated. Snežnik test site has 23 settlements with 4,116 residents. Demographic trends were similar like in Trnovo test square with one difference – the decline of population in longest study period was smaller – one tenth.

Table 34 : Number of settlements and population in ManFor test squares

Area code	Area name	Number of settlements	Number of population			
			1869	1931	1961	2013
1	Trnovo	21	9,494	9,332	7,317	7,684
2	Snežnik	23	4,500	4,923	3,996	4,116
3	Kočevski Rog	19	4,342	3,555	1,150	766

Table 35: Population changes (1869-2013, 1931-1961 and 1961-2013) in ManFor test squares

Area name	Index of the number of population 1869/2013	Change of the number of population 1869/2013 (%)	Annual change of the number of population 1869/2013 v %	Index of the number of population 1931/1961	Change of the number of population 1931/1961 v %	Annual change of the number of population 1931/1961 v %	Index of the number of population 1961/2013	Change of the number of population 1961/2013 v %	Annual change of the number of population 1961/2013 v %
Trnovo	80.94	-19.06	-0.13	78.41	-21.59	-0.72	105.02	5.02	0.10
Snežnik	91.47	-8.53	-0.06	81.17	-18.83	-0.63	103.00	3.00	0.06
Kočevski Rog	17.64	-82.36	-0.57	32.35	-67.65	-2.26	66.61	-33.39	-0.64

Test square Kočevski Rog has 19 settlements with only 766 people. It is a special case with very negative demographic trends due mainly to historical events during Second World War, when exodus of German families occured (see chapter: Manfor test sites and their broader surrounding from historical point of view). Between 1869 and 2013 the number of population decreased by 80 %. Population continuously decreased also in last study period (- 33 %), what we can explain also with unfavourable natural conditions, remoteness from capital and lack of employment possibilities.

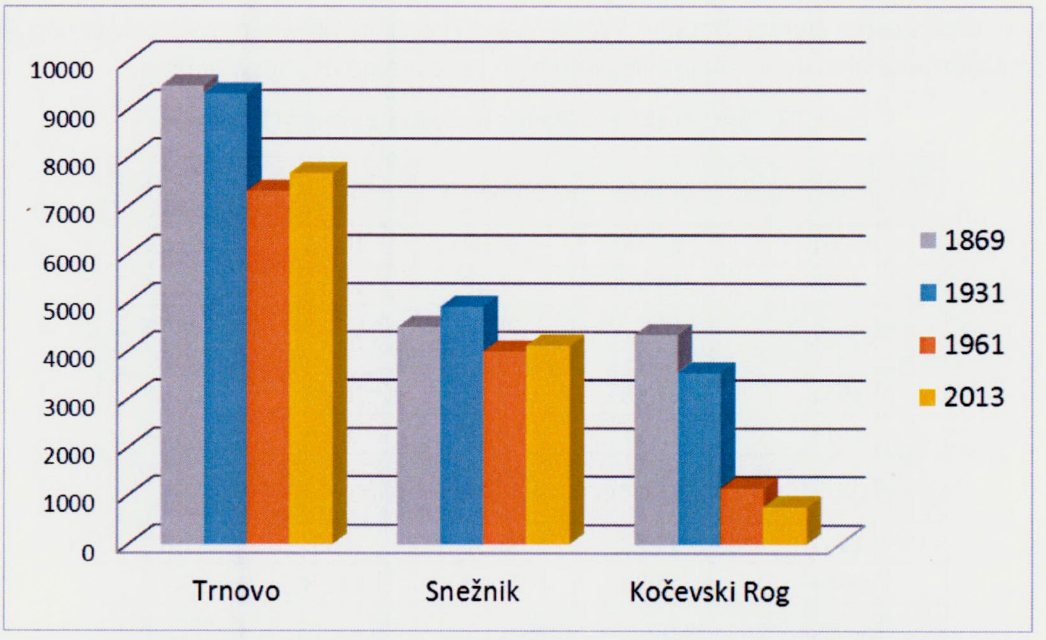

Figure 18: Change of population in Manfor test squares between 1869 and 2013

Population density

Population density in all 3 test squares sites is very low and far below the country average, which is 101.6 people per km^2. In 2013 population density ranged between 3.5 people per km^2 in test square site Kočevski Rog and 34.6 people per km^2 in Trnovo test square (Table 36). Very low population density is a consequence of uneven distribution of population in Slovenia, with concentrations in lowlands, in or in surrounding of bigger cities and with depopulation in hilly, mountain and other peripheral areas with unfavourable natural (steep slopes, lack of water resources...), and social conditions (poor infrastructure, lack of employment possibilities...). Population density decreased all the time due to incline of population number.

Table 36: Population density in Manfor test squares in 1869, 1931, 1961 and 2013

Area code	Area name	Population density (number of people/km^2)			
		1869	1931	1961	2013
1	Trnovo	42,80	42,07	32,98	34,64
2	Snežnik	14,48	15,84	12,86	13,24
3	Kočevski Rog	19,89	16,28	5,27	3,51

Age structure

Analysis of age structure (Table 37) showed the great differences between 2013 and 1961, when all 3 test squares had favourable age structure. If the demographic development should be ideal, the ageing index is expected to be around 40. When the ageing index is higher than 80, you can expect a reduction in the number of inhabitants (Jakoš et al., 1998). The test squares Snežnik and Trnovo had still ideal demographic trend, even they were both above country average, which was 28.5. Ageing index in test square Kočevski Rog was extremely low (11.8), what was probably consequence of events during Second World War. The ratio between young, working age and older population was also very favourable, with high percentage of young people.

Table 37: Age structure in Manfor test squares and in Slovenia

Trnovo	0-14 let	15-64 let	65 + let	Ageing index
1961	25.16	64.68	10.16	40.35
2013	15.20	67.48	17.32	113.95
Snežnik	0-14 let	15-64 let	65 + let	Ageing index
1961	22.98	66.54	10.49	45.64
2013	15.57	65.06	19.36	124.34
Kočevski Rog	0-14 let	15-64 let	65 + let	Ageing index
1961	39.50	55.82	4.69	11.87
2013	14.23	72.19	13.58	95.41
Slovenia	0-14 let	15-64 let	65 + let	Ageing index
1961	27.34	64.85	7.81	28.5
2013	14.48	68.42	17.10	118.1

In 2013 the main demographic trend in Manfor test squares as well as in Slovenia is population ageing, what means relative increase in the proportion of elderly and old people in the total population. Ageing index ranged between 95.4 in Kočevski Rog and 124.3 in Snežnik, country average was 118.1. That means that we can expect further reduction in population in both 3 test squares. The population of Slovenia was and still is growing very slowly (Slovenia's population... 2009). Such population development is a result of lower or negative natural increase and net migration (the positive difference of immigrants and emigrants).

Between 1961 and 2013 the share of young population (0-14) strongly decreased in all test squares and in Slovenia (**Figure 19**). The largest difference in age structure was noticed in test square Kočevski Rog, where the share of young population decreased from 39.5% to 14.2% and the share of older increased from 4.7 % to 13.58 %. Due to very favourable age structure in 1961, Kočevski Rog also in 2013 had a slightly lower share of older population than young population, while other two test squares and Slovenia had more older than young population. Figure 19 shows age structure in test square Snežnik, where the share of young people in study period decreased from 22.9 % to 15.5%, while the share of older increased from 10.4 % to 19.3 %, what means that in 2013 there were 3.8 % more older than young people.

Population ageing is a serious social problem in many aspects, also in terms of impact on land use. In all three Manfor test squares with already very high share of forest we can expect further depopulation, abandonment of agriculture, afforestation and ruin of cultural landscape.

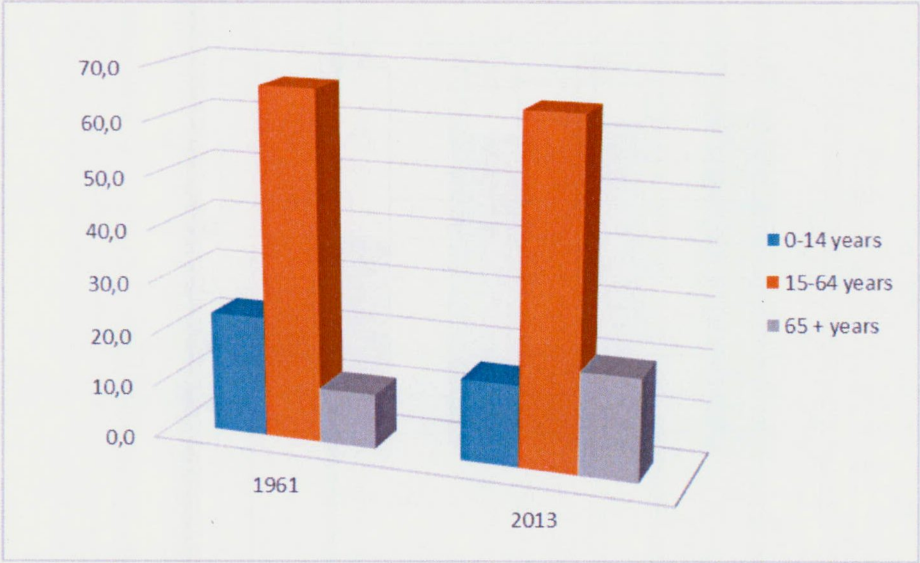

Figure 19: Ratio between major groups of population in Manfor test square Snežnik in 1961 and 2013

Employment structure

In 1961 (Figure 20) agricultural activities had a very important economic role in all three test squares, especially in Kočevski Rog, where more than ¾ of active people worked in this sector. Agricultural activities prevailed also in test square Trnovo (55%). In test site Snežnik nearly half of active people worked in non-agricultural activities. Share of active people who worked in service activities were low in all three test squares (around one tenth). Slovenia had considerably different employment structure with prevail of service activities (44.2%), followed by non-agricultural (41.6 %) and agricultural activities (13.6%).

The 2013 data show (Figure 21) that from the economic point of view the agricultural activities totally lost its significance. The share of economically active population employed in agricultural activities was under 5% in test sites Snežnik, Trnovo and in Slovenia. In test site Kočevski Rog agricultural activities still have important role (11.3%), even though the reduction of the share of the economically active population employed in agricultural activities was here the largest (from 78.7 % in 1961 to 11.3% in 2013). With the exception of test site Snežnik with 57,7% of economically active population employed in non-agricultural activities, in all studied areas prevail service activities, where it was employed more than half of economically active population.

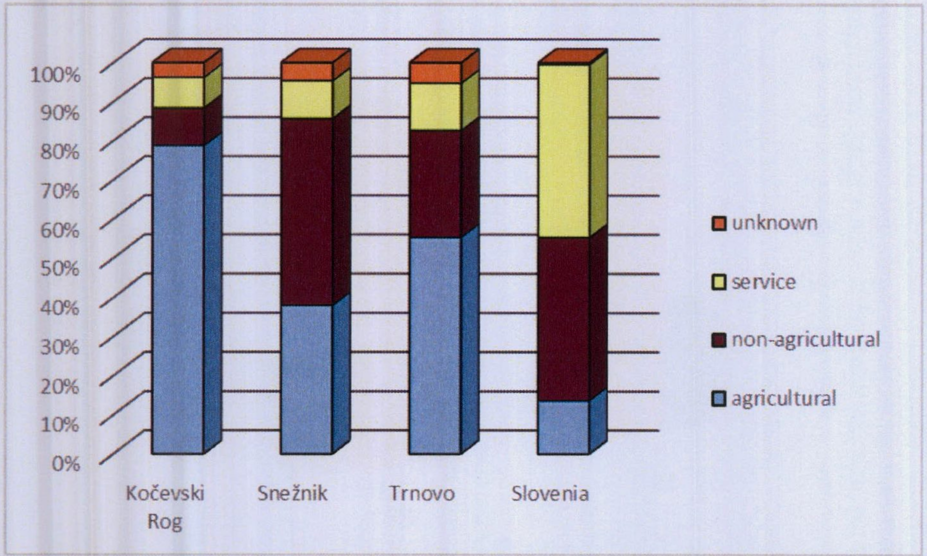

Figure 20: Employment structure in Manfor test squares and in Slovenia in 1961

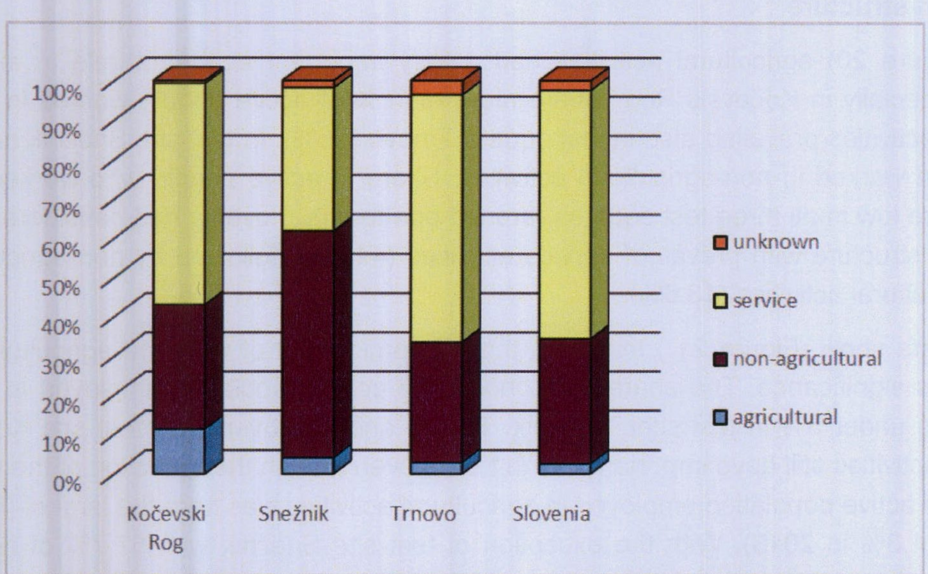

Figure 21: Employment structure in Manfor test squares and in Slovenia in 2013

2.4.2 Airborne lidar scanning

From the newly acquired lidar data the digital canopy models (DCMs) were computed for the year 2013 and compared to 2011 (Figure 22 - Figure 30) as the basis for detecting the change of the spatial pattern of gaps in the forest stand canopy. Discontinuities (gaps) in forest canopy reaching to the ground are the centers of forest rejuvenation. Their areal percentage and spatial juxtaposition is an important indicator of forest stand developmental and ecological status.

DCM vegetation heights were computed in a rectangular grid with the horizontal resolution of 1 m x 1 m. All types of lidar returns were taken into account. For each return its height above the bare ground was computed using bilinear interpolation from the neighbouring DTM grid points. The highest lidar return within each grid cell was considered as the vegetation height for this grid cell.

In order to mitigate any spatial displacement between the two lidar acquisitions a new digital terrain model (DTM) was computed from the 2013 data. Relative heights of the 2013 cloud points above bare ground were thus not affected by the slight displacements.

DCMs have been computed for all three Slovenian test areas. The gaps in forest stand canopy have been identified from DCM as those areas where vegetation heights do not exceed 1 m, i.e. discontinuities or gaps in the forest canopy cover.

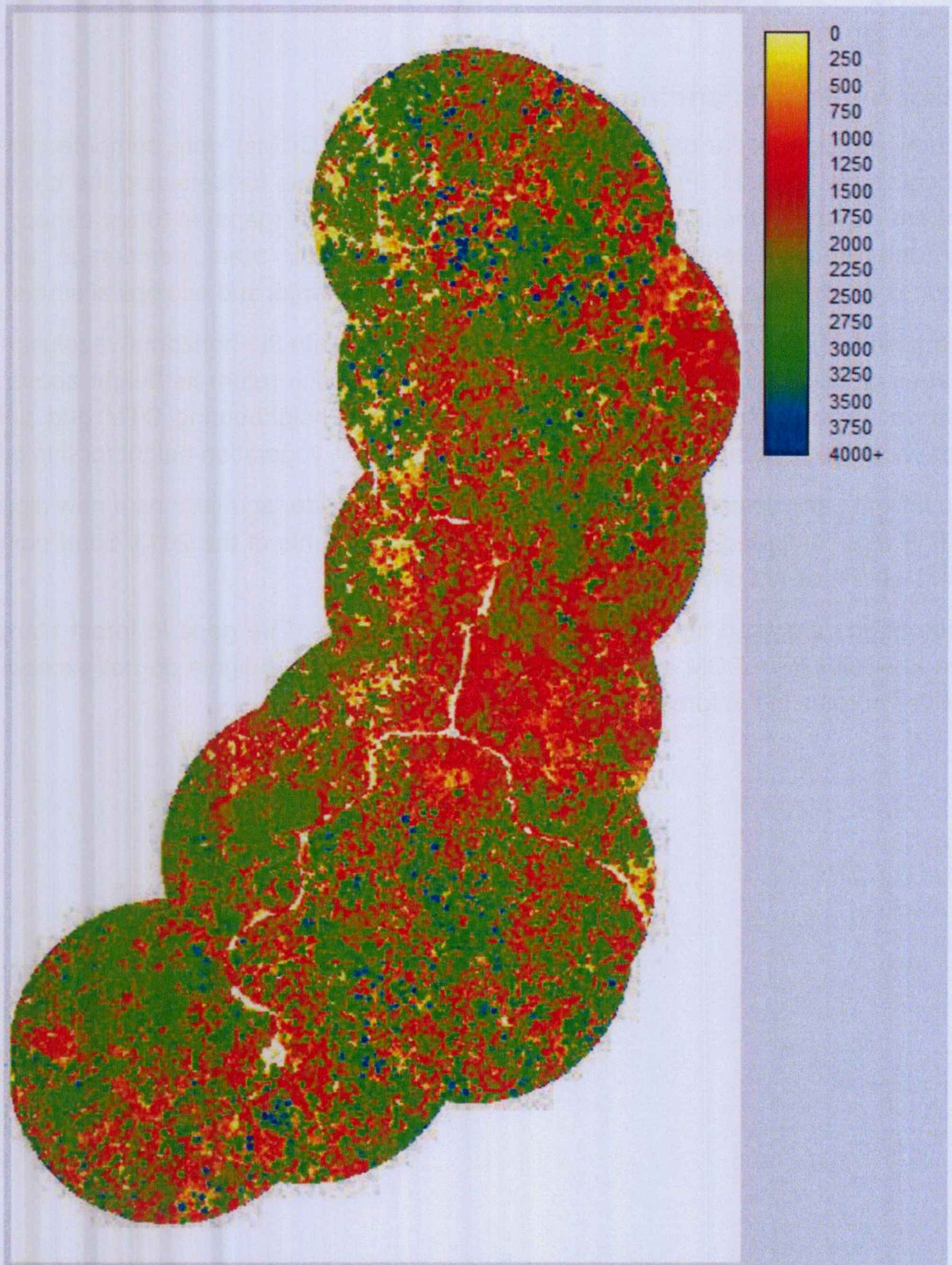

Figure 22: Kočevski Rog test site. The digital canopy model (i.e., forest vegetation heights) for the year 2011 (before treatment), vegetation heights given in centimeters, horizontal resolution 1 m. DCM is the basis for computing the change of the indicator "Spatial pattern of gaps in the forest stand canopy".

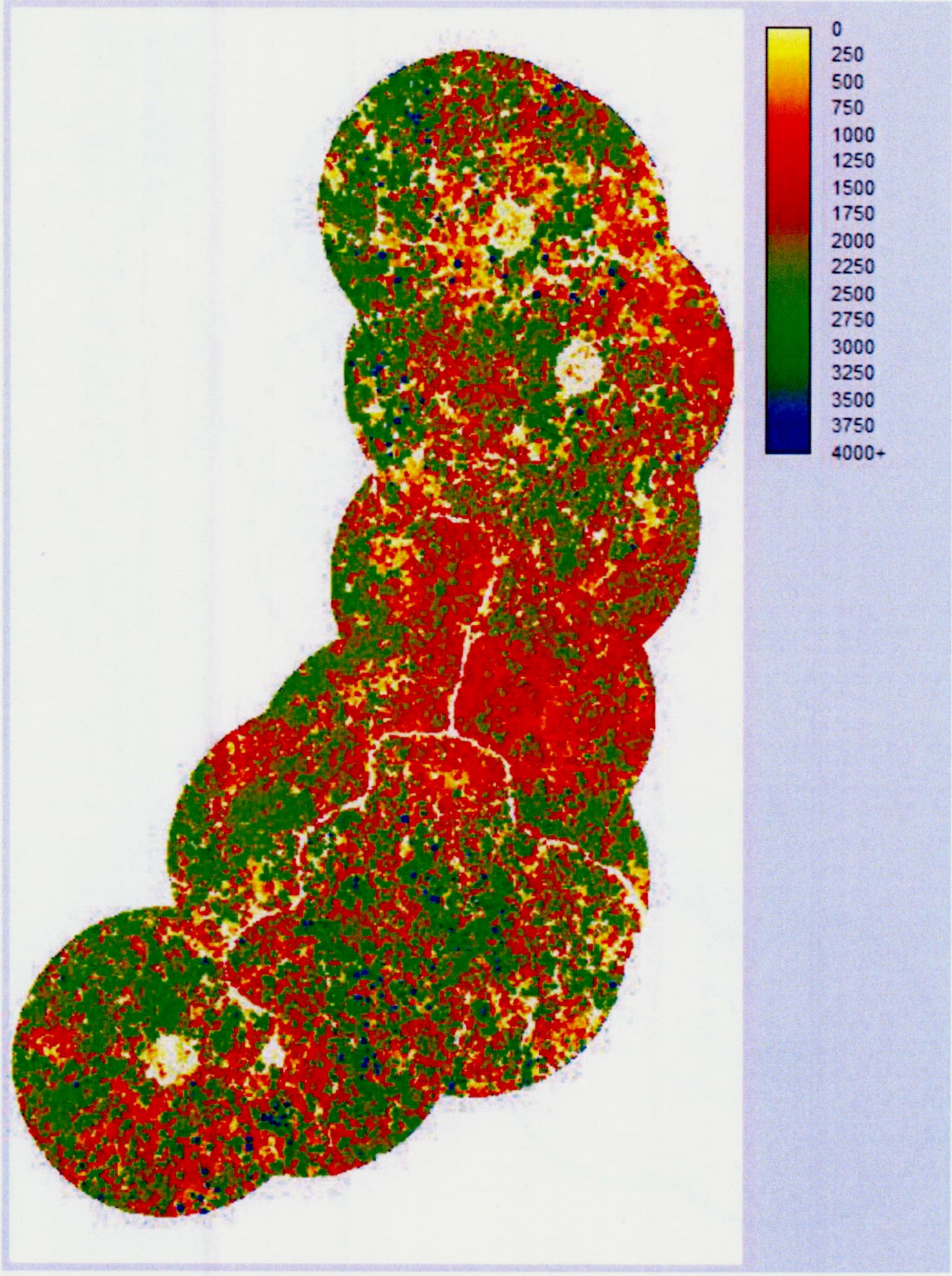

Figure 23: Kočevski Rog test site. The digital canopy model (i.e., forest vegetation heights) for the year 2013 (after treatment), vegetation heights given in centimeters, horizontal resolution 1 m. DCM is the basis for computing the change of the indicator “Spatial pattern of gaps in the forest stand canopy”.

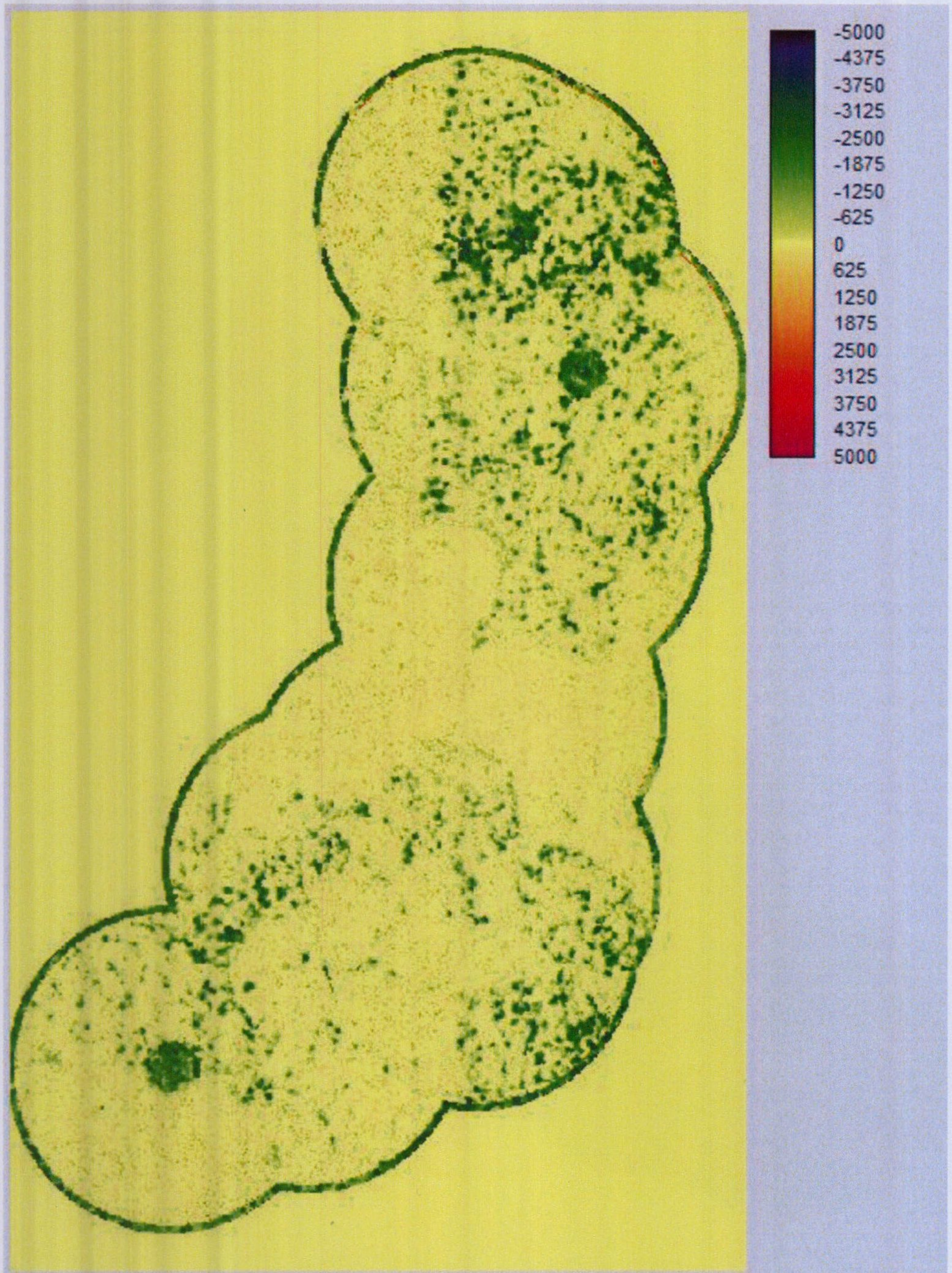

Figure 24: Kočevski Rog test site. The difference in forest vegetation heights between the year 2011 (before treatment) and 2013 (after treatment), vegetation heights given in centimeters, horizontal resolution 1 m.

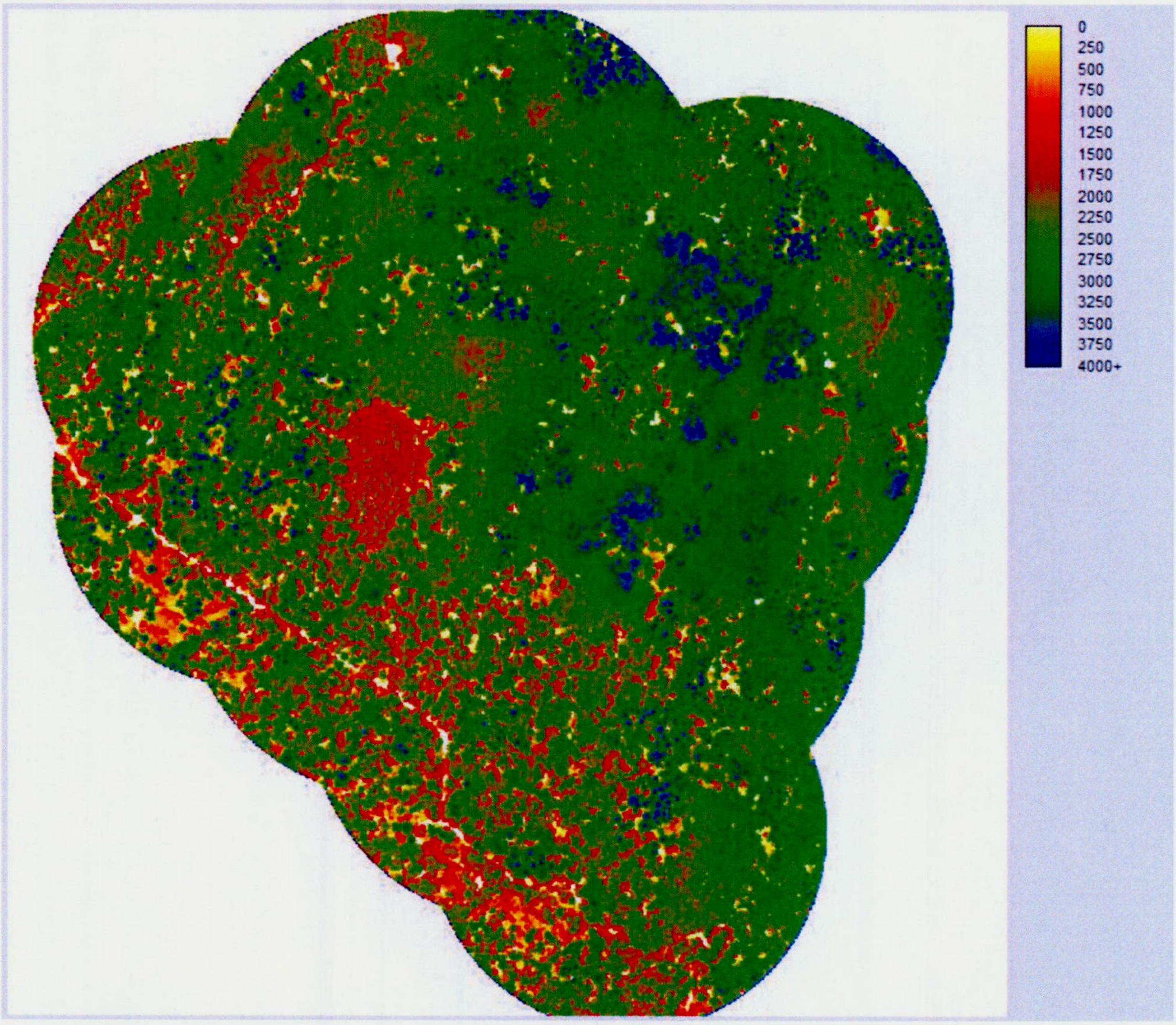

Figure 25: Snežnik test site. The digital canopy model (i.e., forest vegetation heights) for the year 2011 (before treatment), vegetation heights given in centimeters, horizontal resolution 1 m. DCM is the basis for computing the change of the indicator "Spatial pattern of gaps in the forest stand canopy".

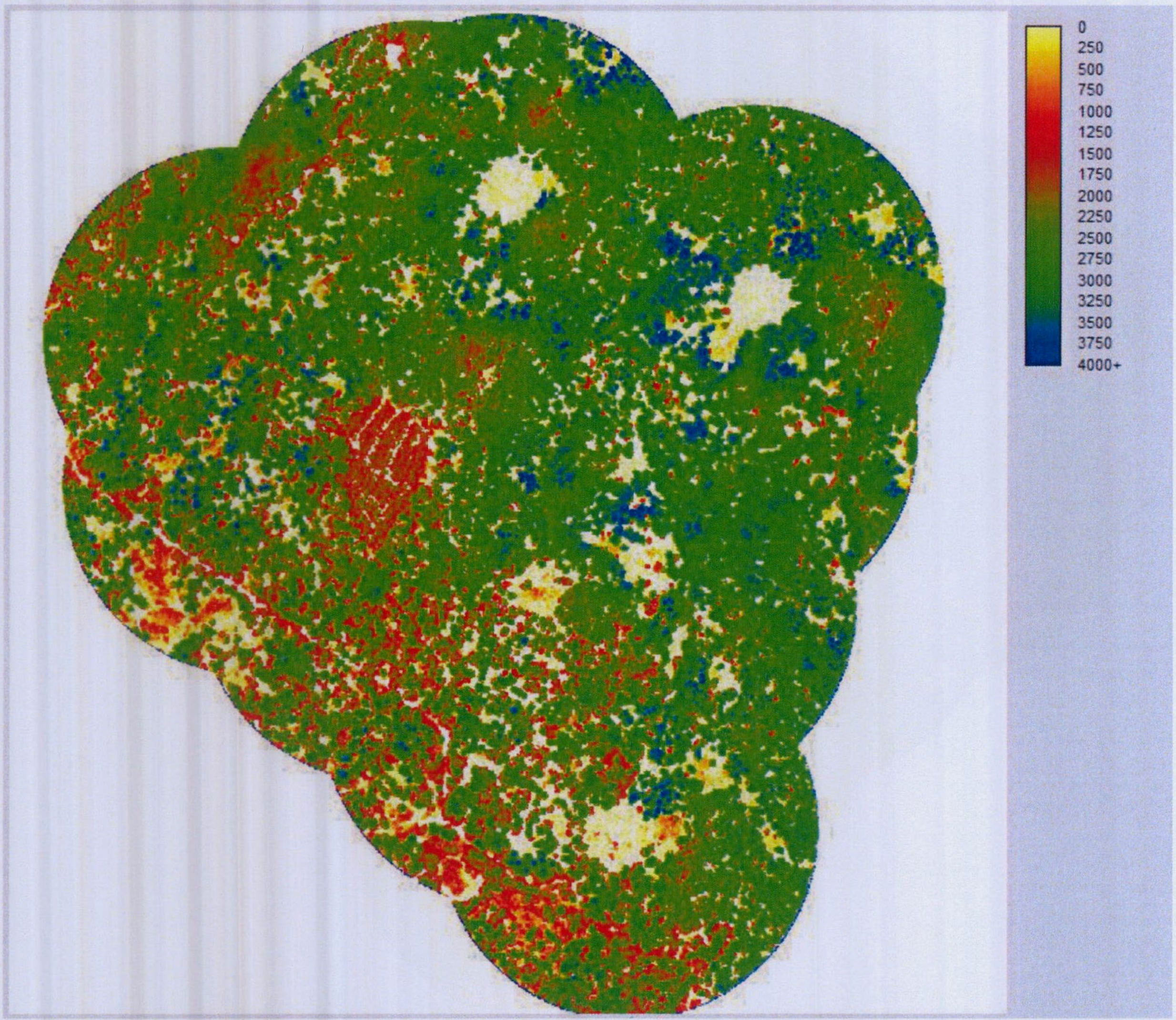

Figure 26: Snežnik test site. The digital canopy model (i.e., forest vegetation heights) for the year 2013 (after treatment), vegetation heights given in centimeters, horizontal resolution 1 m. DCM is the basis for computing the change of the indicator "Spatial pattern of gaps in the forest stand canopy".

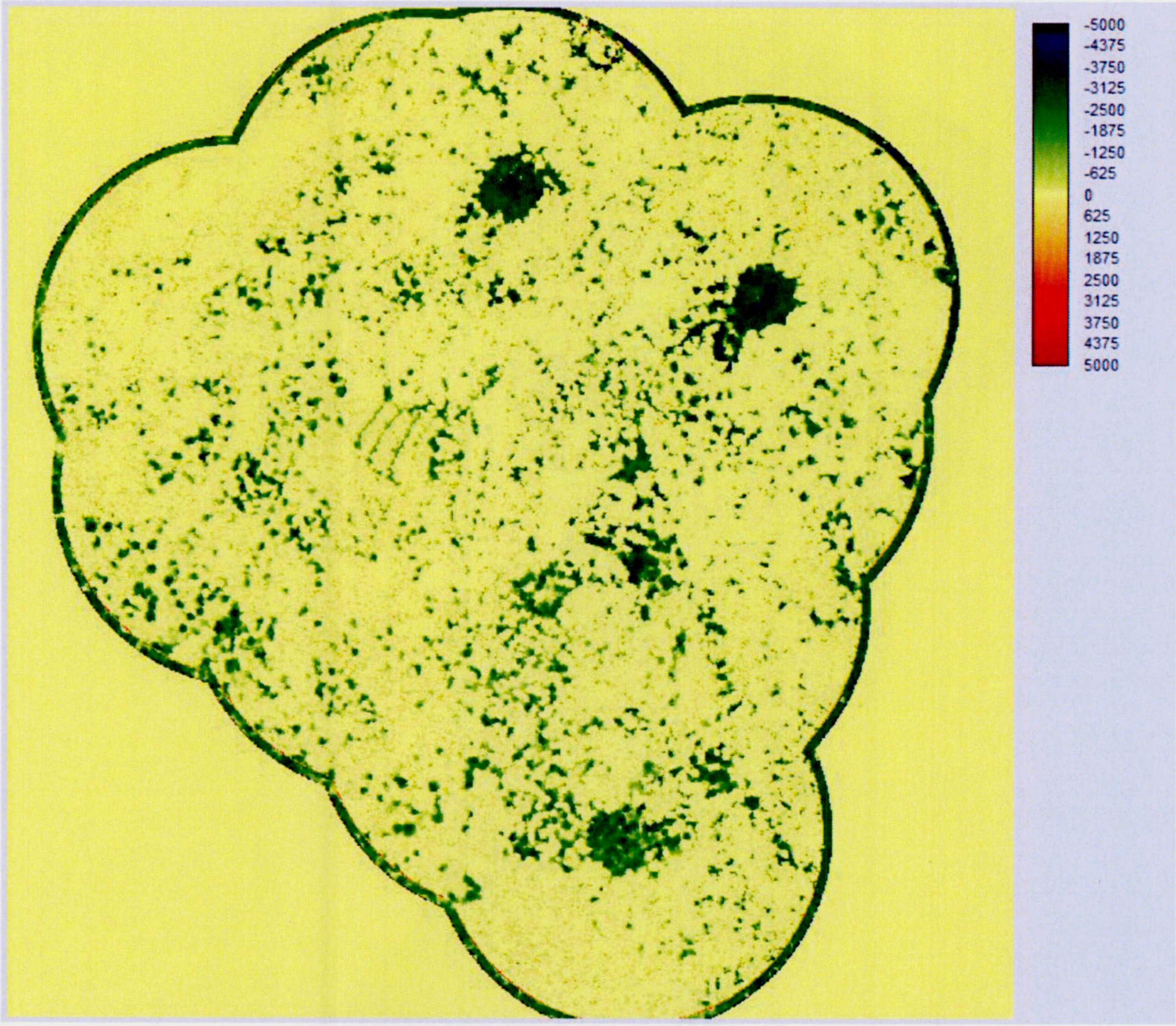

Figure 27: Snežnik test site. The difference in forest vegetation heights between the year 2011 (before treatment) and 2013 (after treatment), vegetation heights given in centimeters, horizontal resolution 1 m.

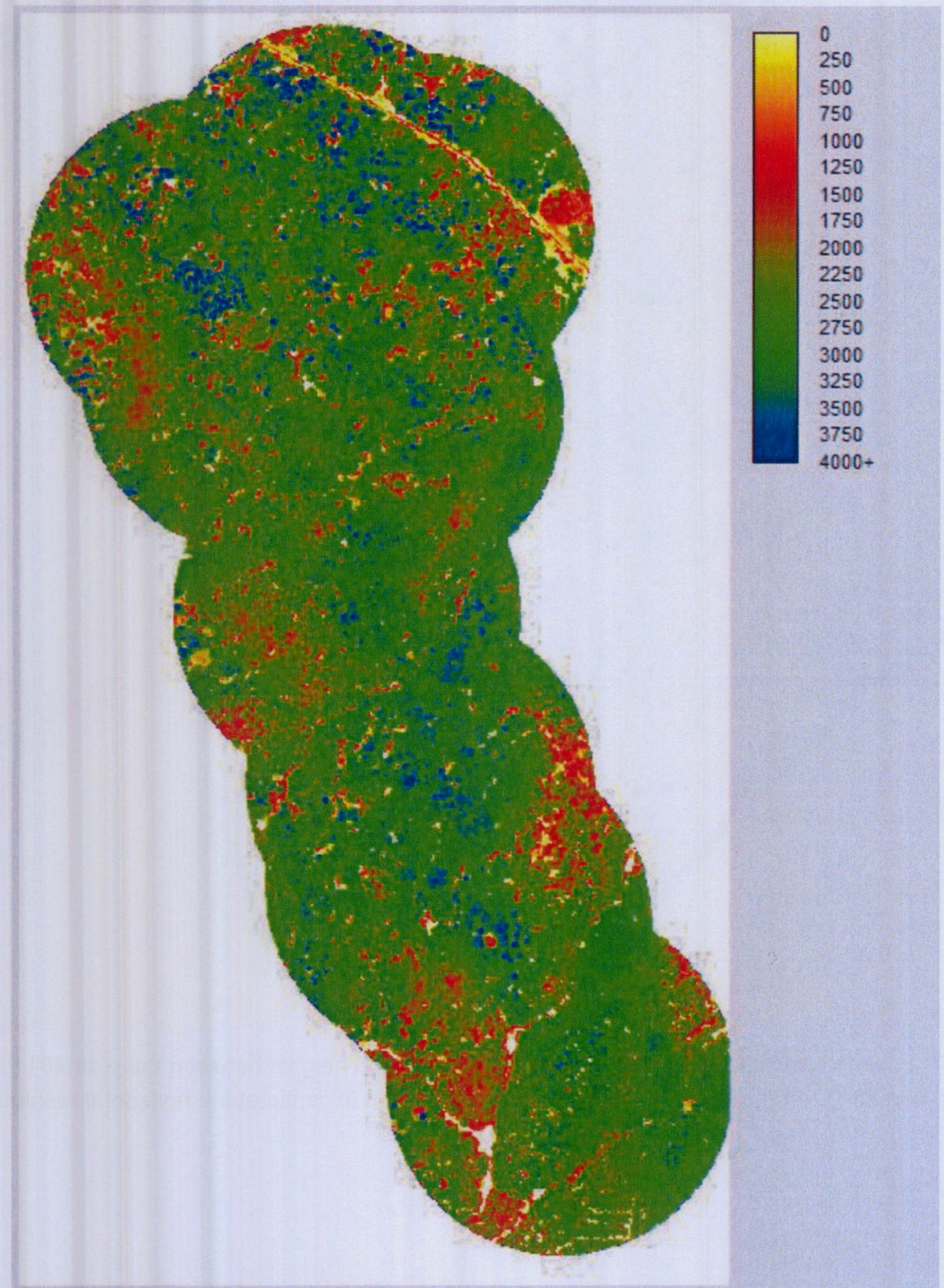

Figure 28: Trnovo test site. The digital canopy model (i.e., forest vegetation heights) for the year 2011 (before treatment), vegetation heights given in centimeters, horizontal resolution 1 m. DCM is the basis for computing the change of the indicator “Spatial pattern of gaps in the forest stand canopy”.

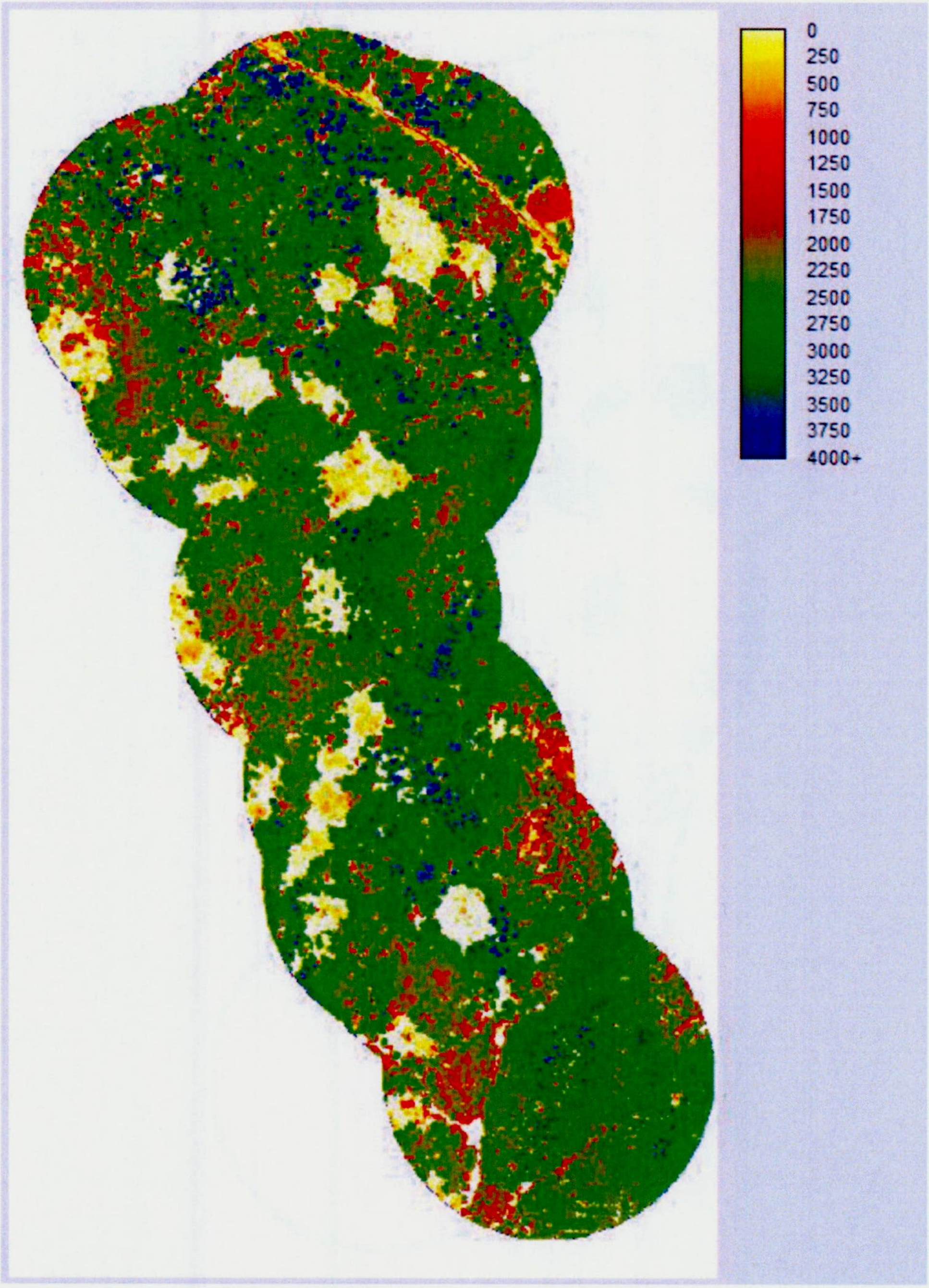

Figure 29: Trnovo test site. The digital canopy model (i.e., forest vegetation heights) for the year 2013 (after treatment), vegetation heights given in centimeters, horizontal resolution 1 m. DCM is the basis for computing the change of the indicator “Spatial pattern of gaps in the forest stand canopy”.

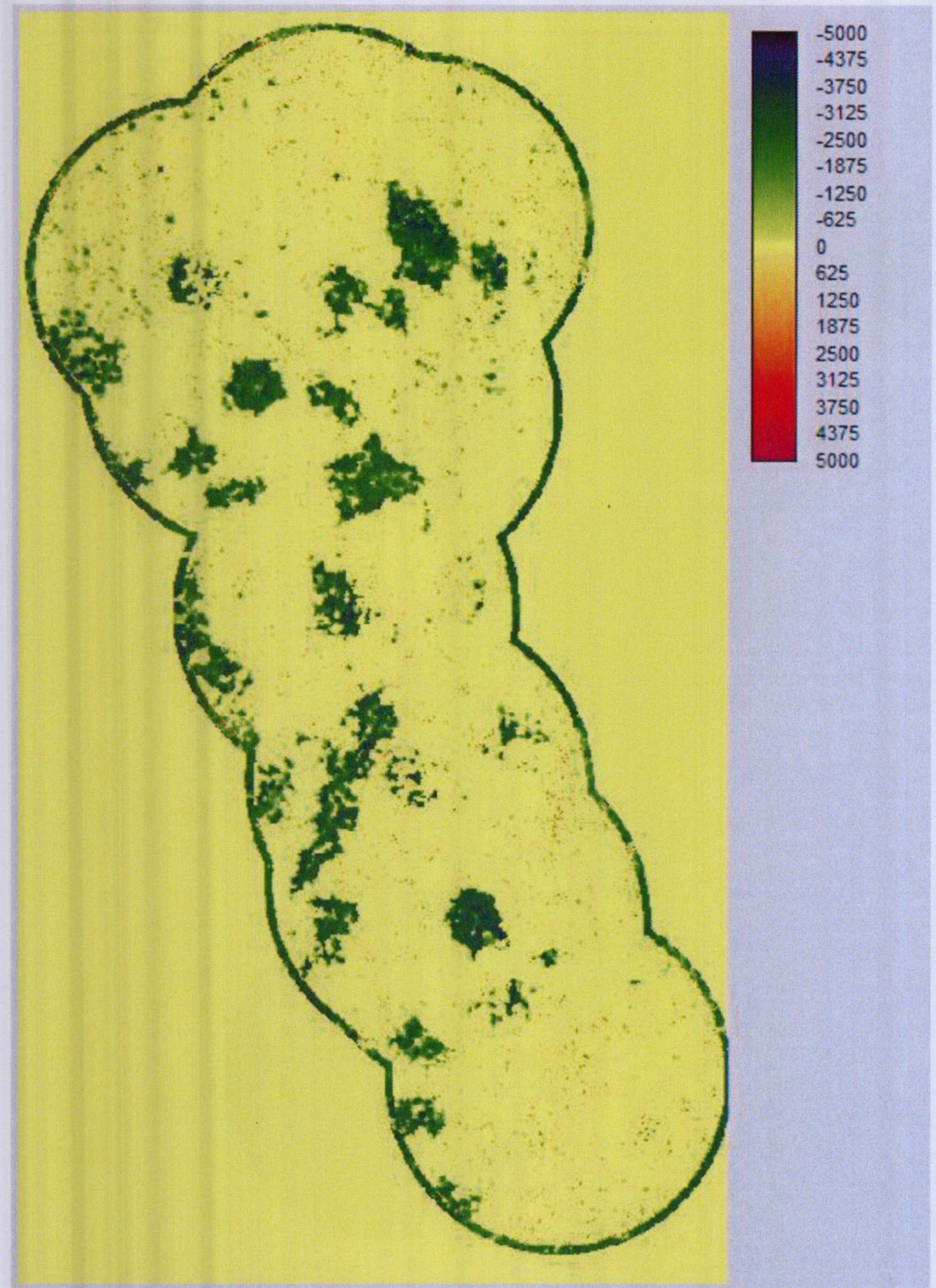

Figure 30: Trnovo test site. The difference in forest vegetation heights between the year 2011 (before treatment) and 2013 (after treatment), vegetation heights given in centimeters, horizontal resolution 1 m.

Forest canopy cover (CC) is given as a numerical value between 0 and 1, computed for each cell in the 1 by 1 m grid as the ratio of ground-to-vegetation frequencies of different return types:

$$CC = 1 - [(N_{first,ground} + N_{intermediate,ground} + N_{last,ground} + N_{only,ground}) / N_{all}]$$

where:

CC ... canopy cover

$N_{first,ground}$, $N_{intermediate,ground}$, $N_{last,ground}$, $N_{only,ground}$ ... *frequencies of those first, intermediate, last and only returns in the cell, respectively, that are 1 m or less above bare ground*

N_{all} ... *total frequency of all first, intermediate, last and only returns in the cell*

CC maps have been computed for all three Slovenian test areas.

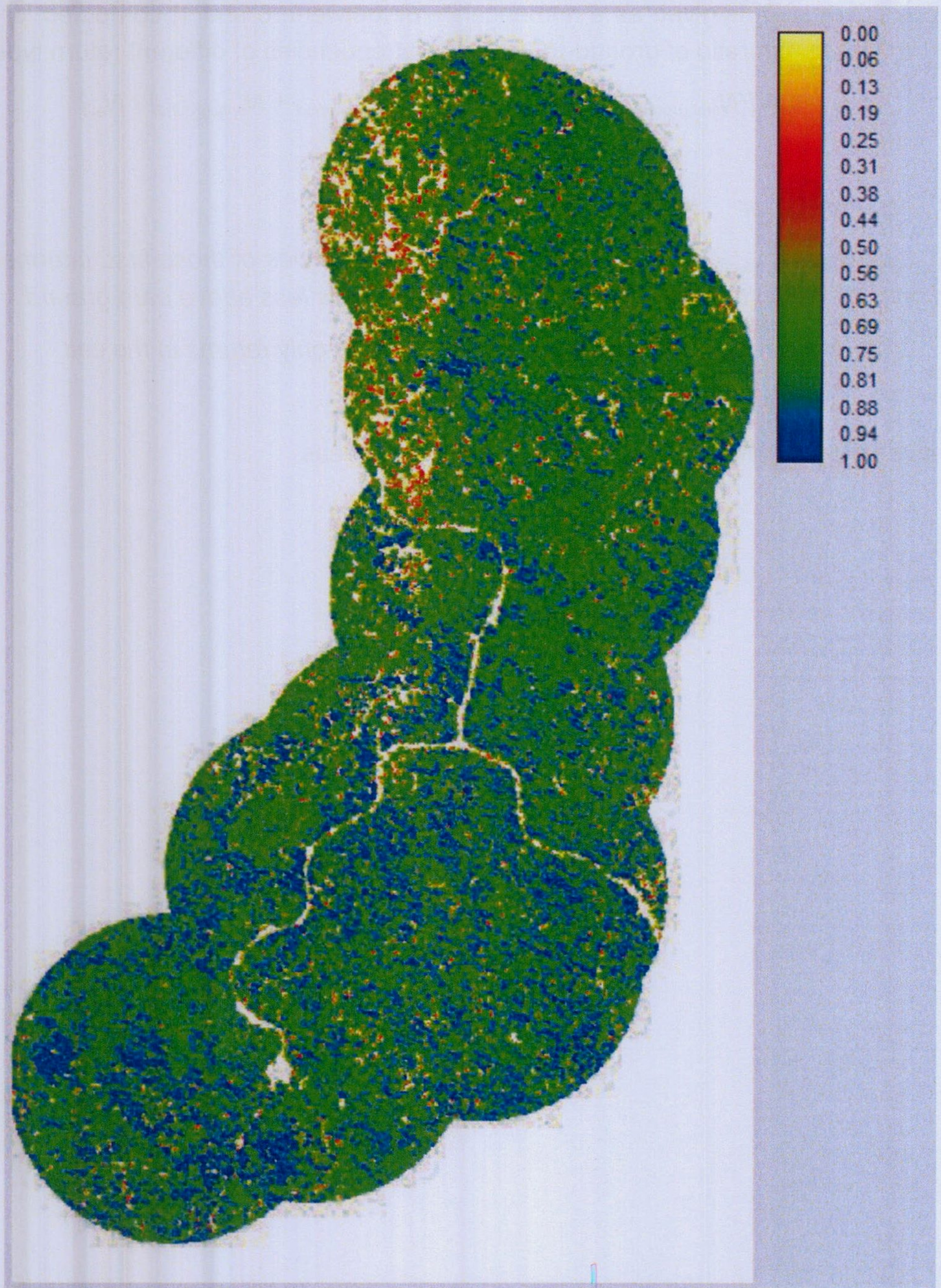

Figure 31: Kočevski Rog test site. The amount of forest canopy cover in the year 2011, i.e., before treatment (0.0 meaning no forest canopy cover and 1.0 meaning 100% cover), horizontal resolution 1 m. The amount of forest canopy cover is the basis for computing the change of the indicator “Forest canopy cover pattern”.

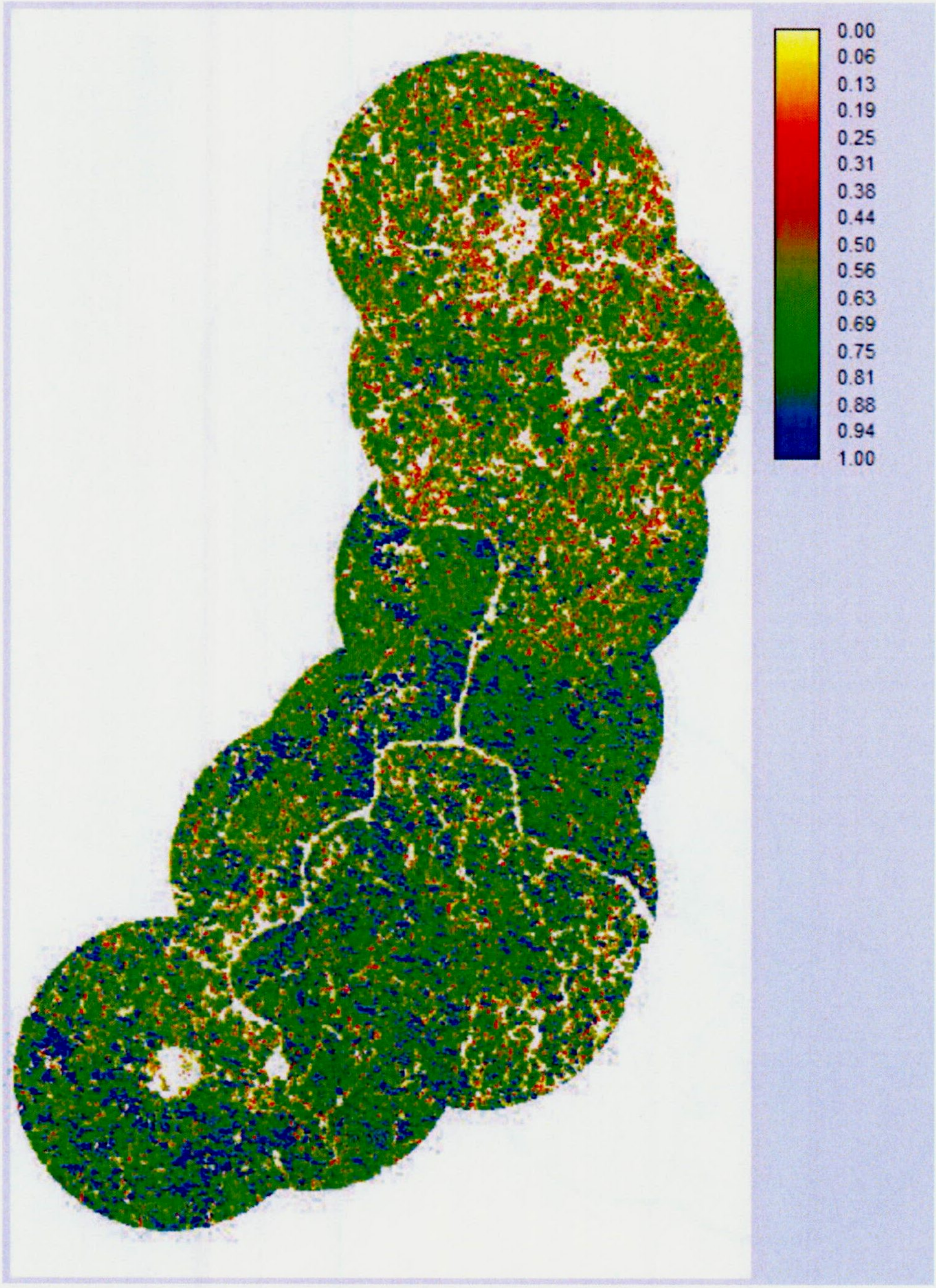

Figure 32: Kočevski Rog test site. The amount of forest canopy cover in the year 2013, i.e., post treatment (0.0 meaning no forest canopy cover and 1.0 meaning 100% cover), horizontal resolution 1 m. The amount of forest canopy cover is the basis for computing the change of the indicator "Forest canopy cover pattern".

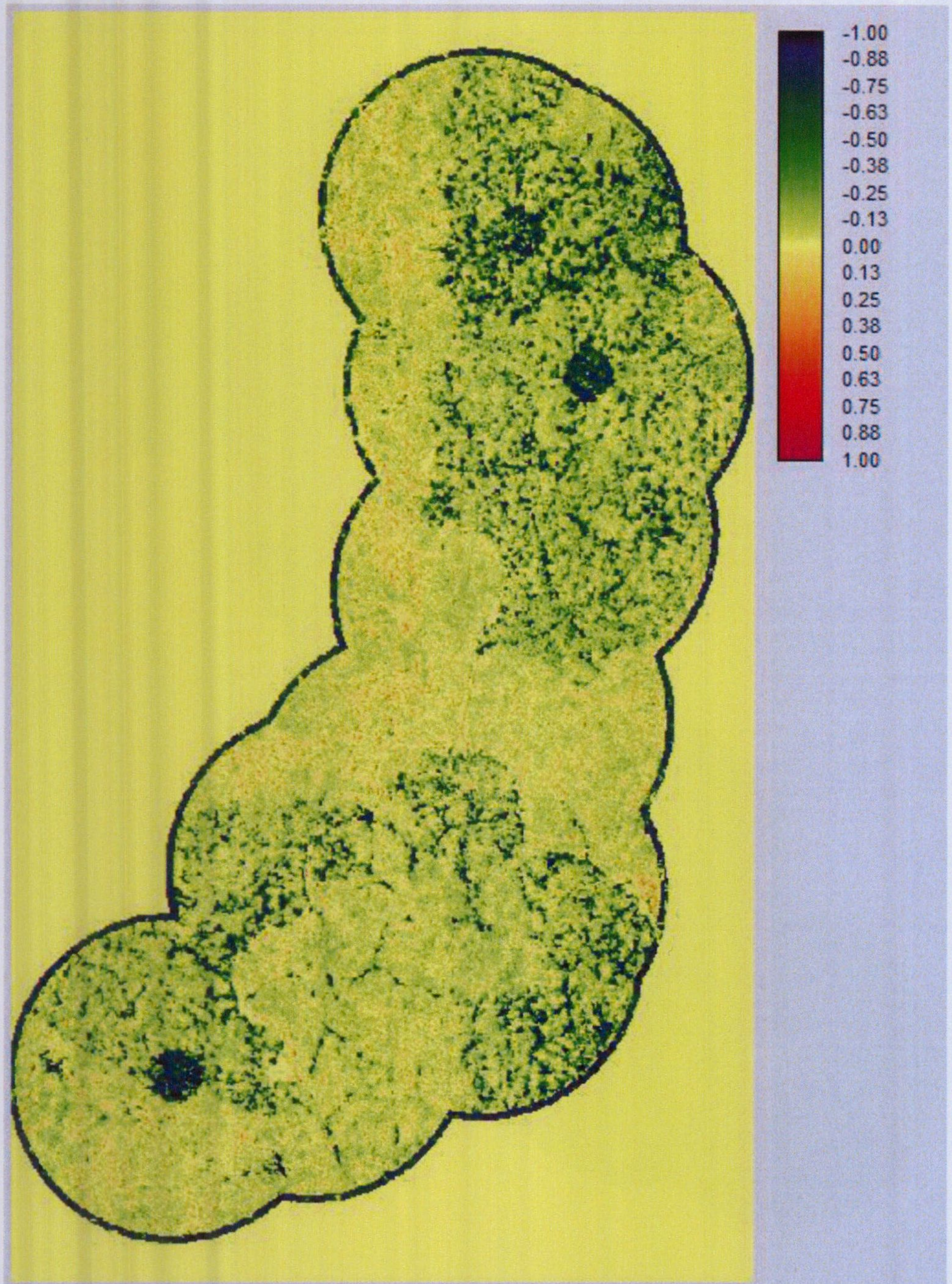

Figure 33: Kočevski Rog test site. The spatial representation of Forest canopy cover pattern indicator change. This is the difference between the forest canopy cover in the year 2011, i.e., before treatment, and 2013, i.e., post treatment (-1.0 meaning complete loss of forest canopy cover and 1.0 meaning complete gain of forest canopy cover in the respective period), horizontal resolution 1 m.

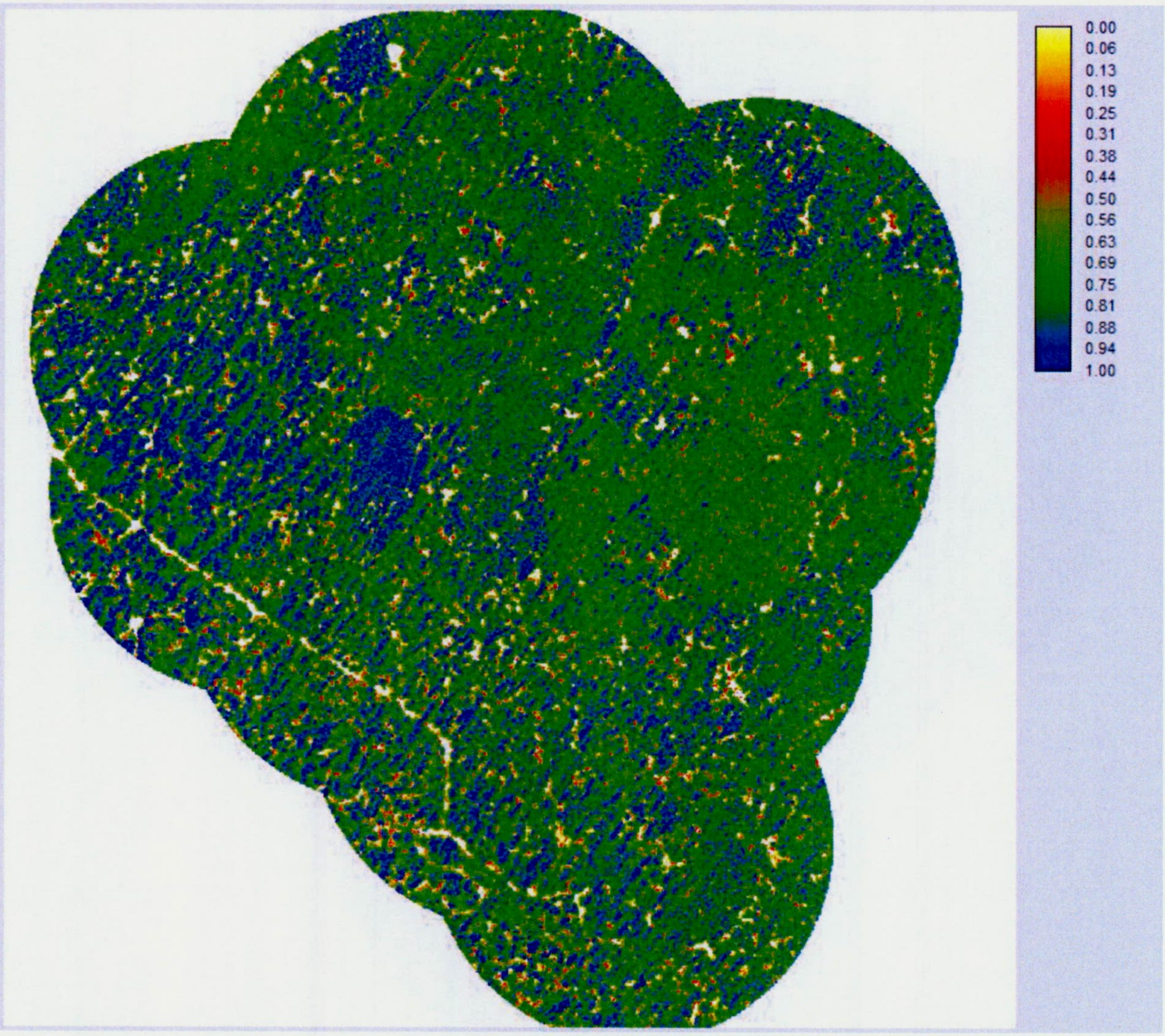

Figure 34: Snežnik test site. The amount of forest canopy cover in the year 2011, i.e., before treatment (0.0 meaning no forest canopy cover and 1.0 meaning 100% cover), horizontal resolution 1 m. The amount of forest canopy cover is the basis for computing the change of the indicator "Forest canopy cover pattern".

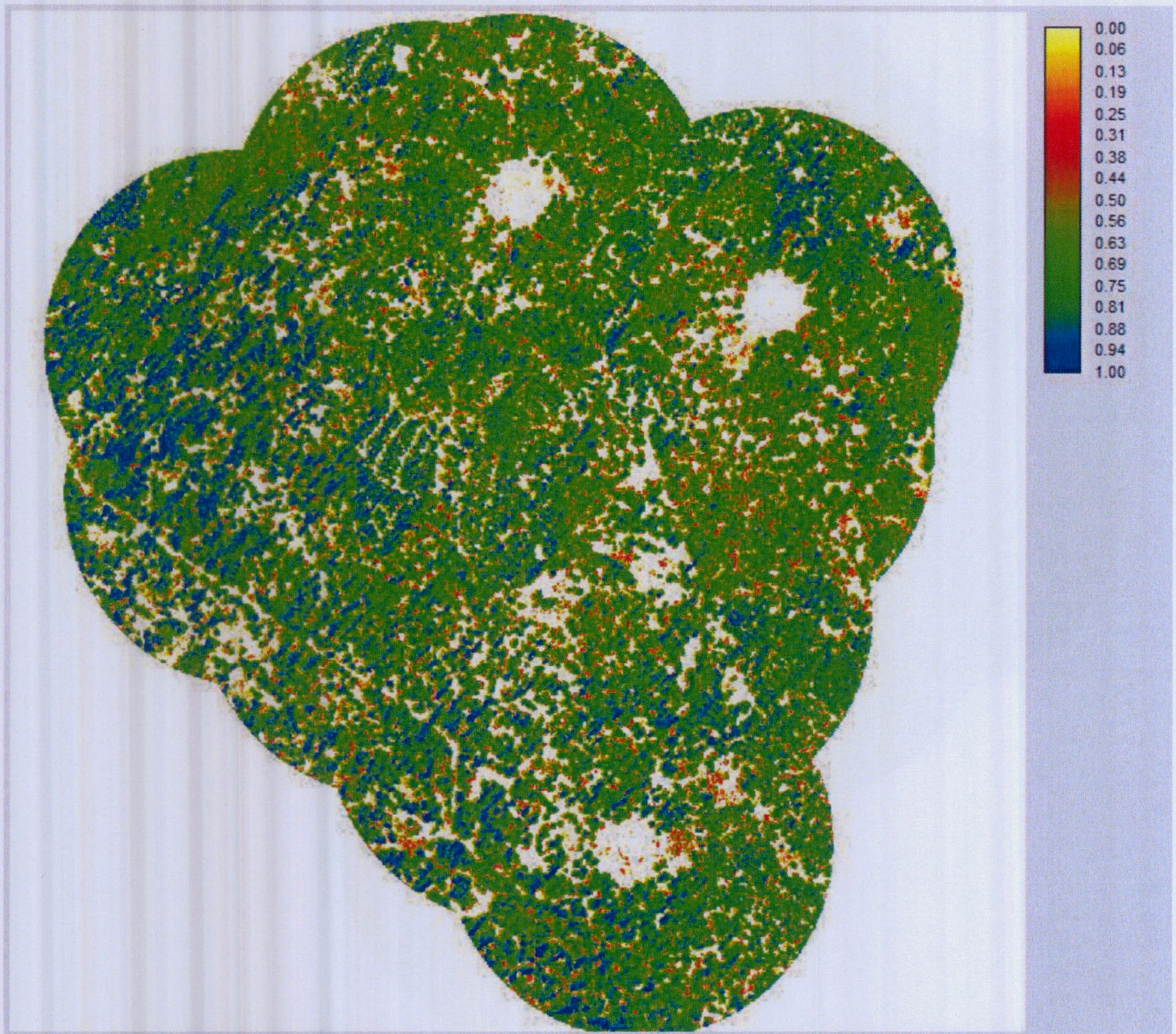

Figure 35: Snežnik test site. The amount of forest canopy cover in the year 2013, i.e., post treatment (0.0 meaning no forest canopy cover and 1.0 meaning 100% cover), horizontal resolution 1 m. The amount of forest canopy cover is the basis for computing the change of the indicator “Forest canopy cover pattern”.

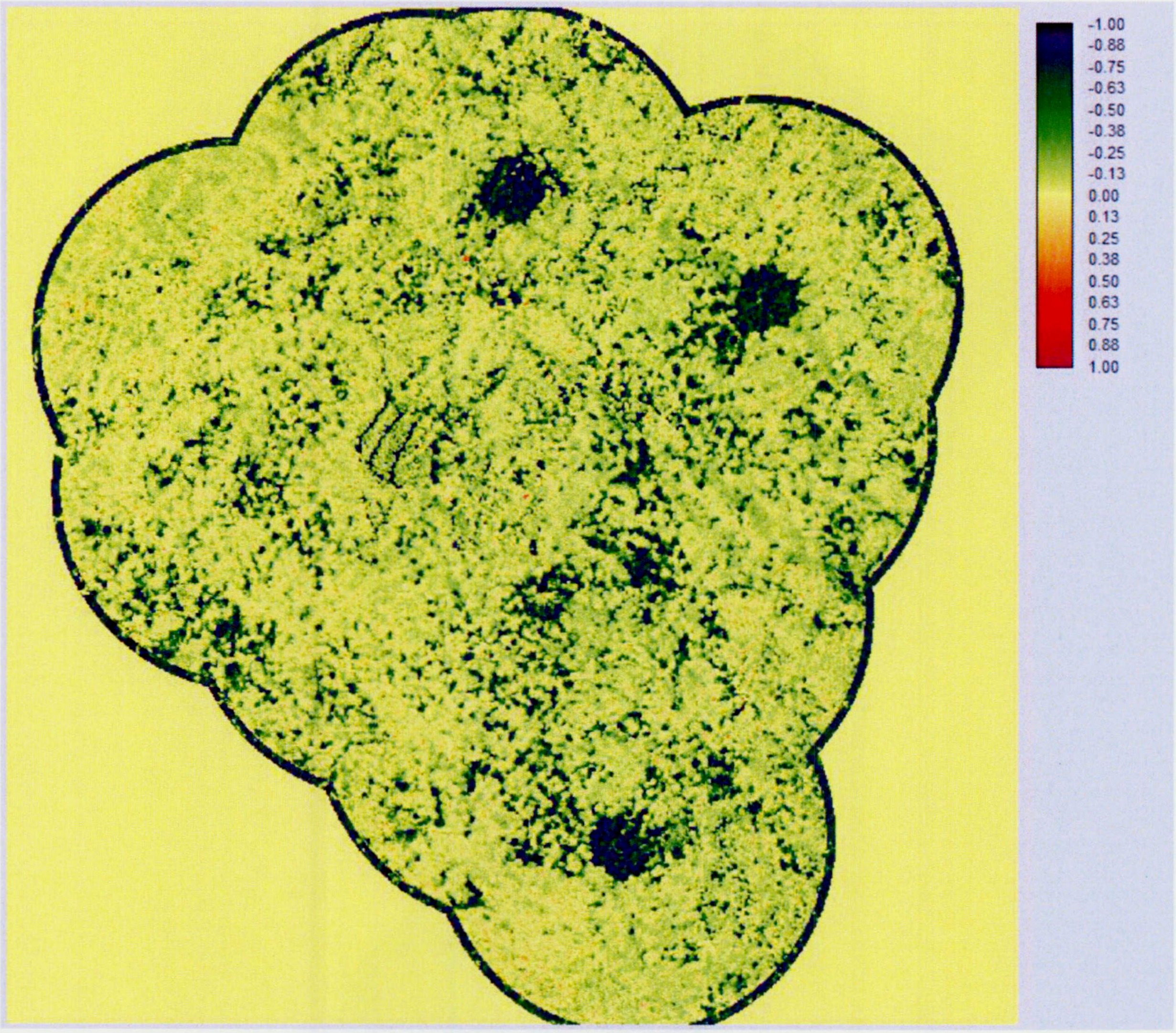

Figure 36: Snežnik test site. The spatial representation of Forest canopy cover pattern indicator change. This is the difference between the forest canopy cover in the year 2011, i.e., before treatment, and 2013, i.e., post treatment (-1.0 meaning complete loss of forest canopy cover and 1.0 meaning complete gain of forest canopy cover in the respective period), horizontal resolution 1 m.

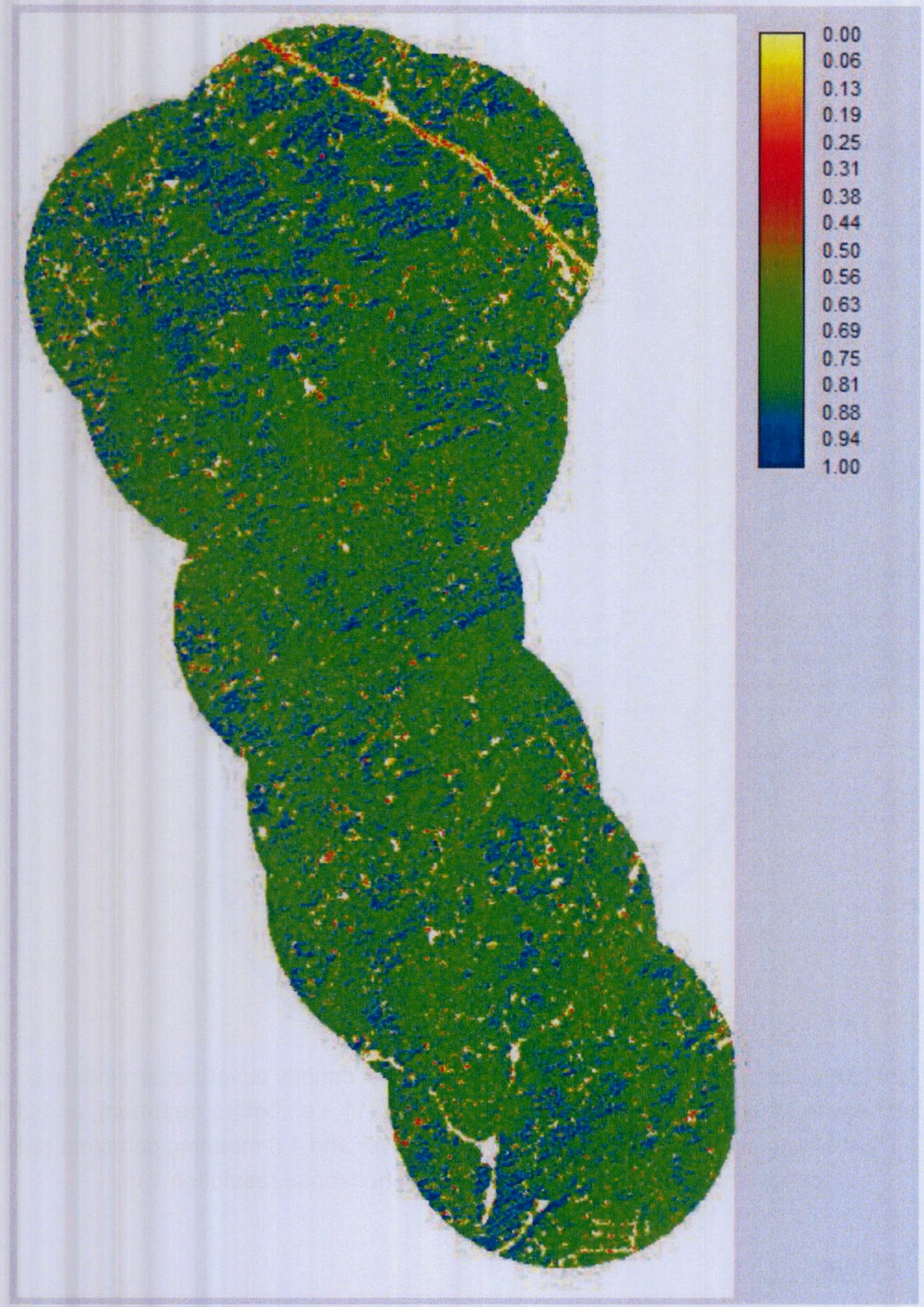

Figure 37: Trnovo test site. The amount of forest canopy cover in the year 2011, i.e., before treatment (0.0 meaning no forest canopy cover and 1.0 meaning 100% cover), horizontal resolution 1 m. The amount of forest canopy cover is the basis for computing the change of the indicator "Forest canopy cover pattern".

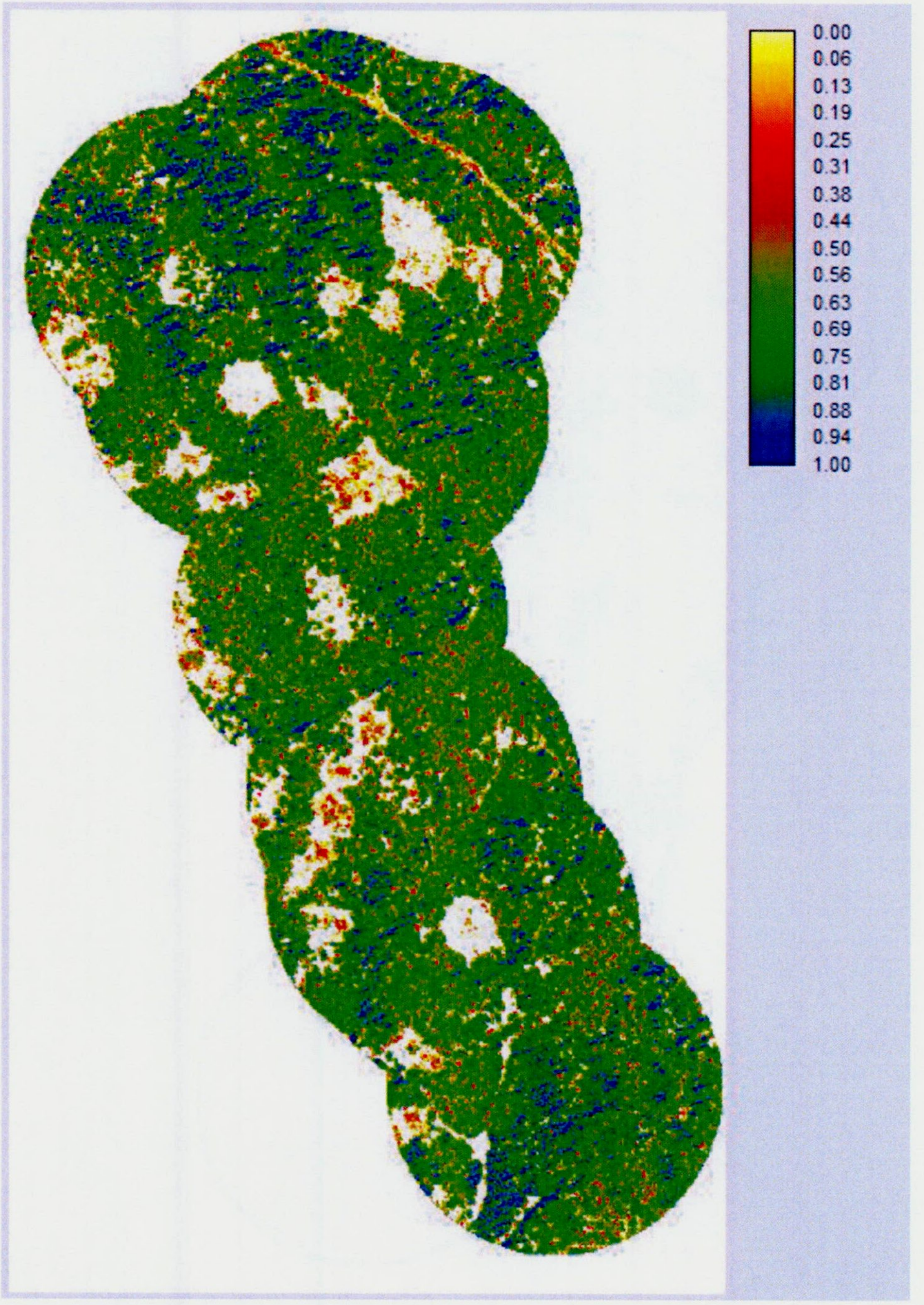

Figure 38: Trnovo test site. The amount of forest canopy cover in the year 2013, i.e., post treatment (0.0 meaning no forest canopy cover and 1.0 meaning 100% cover), horizontal resolution 1 m. The amount of forest canopy cover is the basis for computing the change of the indicator "Forest canopy cover pattern".

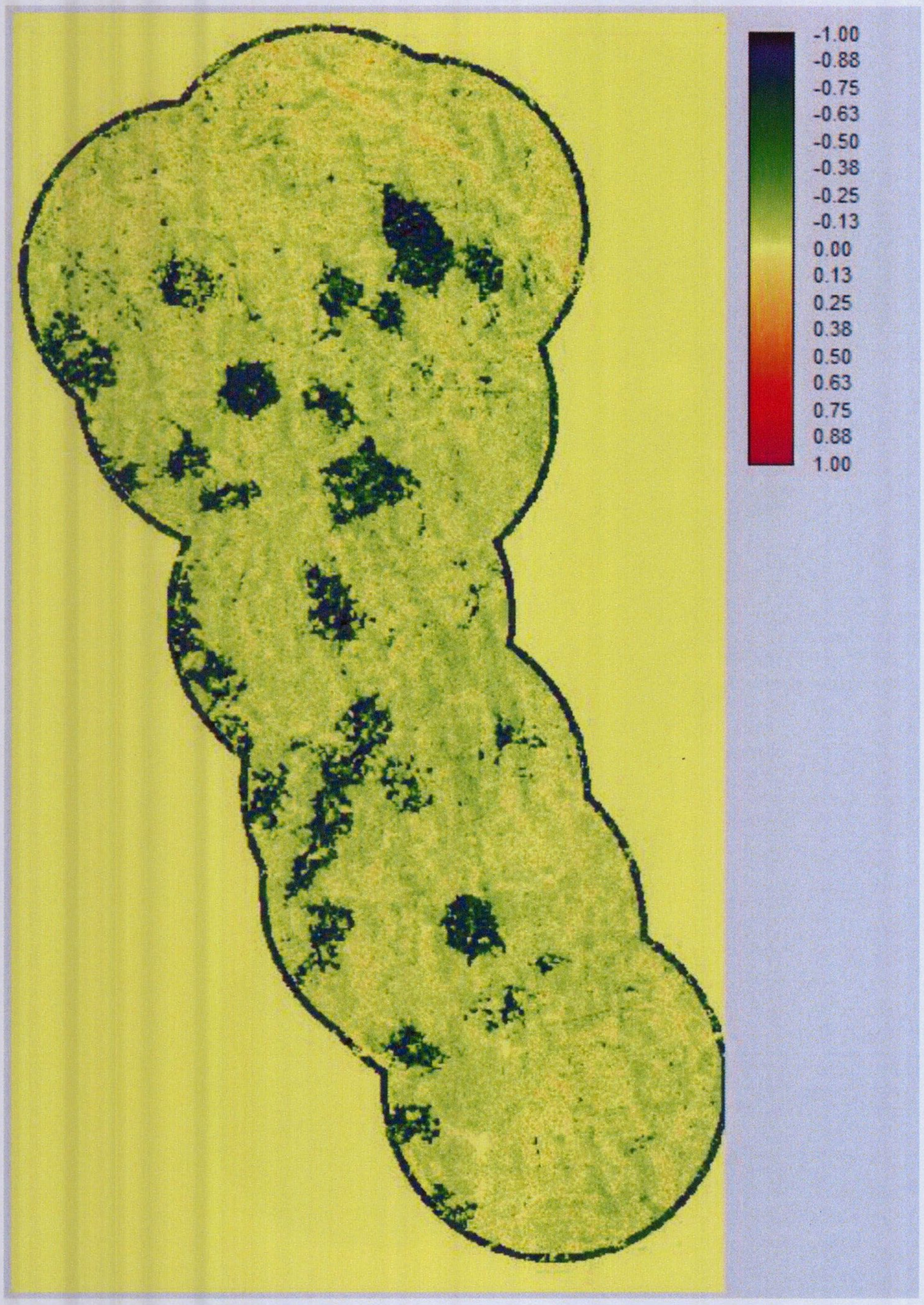

Figure 39: Trnovo test site. The spatial representation of Forest canopy cover pattern indicator change. This is the difference between the forest canopy cover in the year 2011, i.e., before treatment, and 2013, i.e., post treatment (-1.0 meaning complete loss of forest canopy cover and 1.0 meaning complete gain of forest canopy cover in the respective period), horizontal resolution 1 m.

Volume of photosyntheticaly active forest canopy indicator was measured from the 2013 data and compared to 2011 (Figure 40 - Figure 48). The amount of the photosyntheticaly active part of the forest stand canopy is a proxy for the stand productivity. As the canopy is a 3-D structure it can be gleaned from the lidar point cloud. The rectangular 3-D pixels (voxels) are classified into 'filled' (by lidar returns) and 'empty' voxels. The upper 65% of filled voxels in each column are considered the photosyntheticaly active part of the canopy, according to (Lefsky et al., 1999, Lidar remote sensing of the canopy structure ..., Remote Sening of Environment, 70: 339-361).

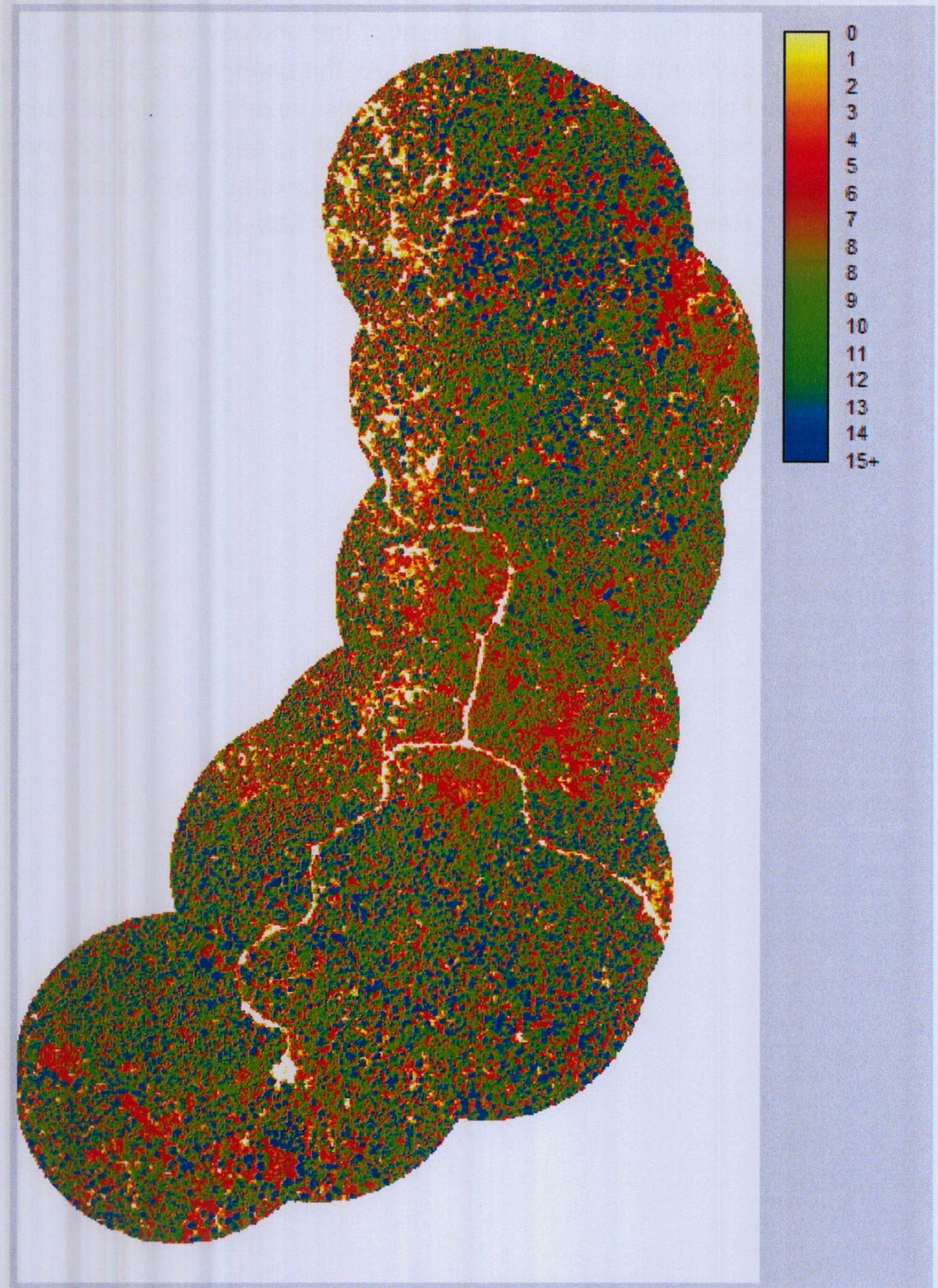

Figure 40: Kočevski Rog test site. The amount of photosinthetically active canopy volume in the year 2011 (before treatment), horizontal resolution 1 m. According to Lefsky et al. (1999) the amount of photosinthetically active canopy is defined as the upper 65% of the total canopy volume. It is given in cubic meters of canopy volume per square meter of forest area.

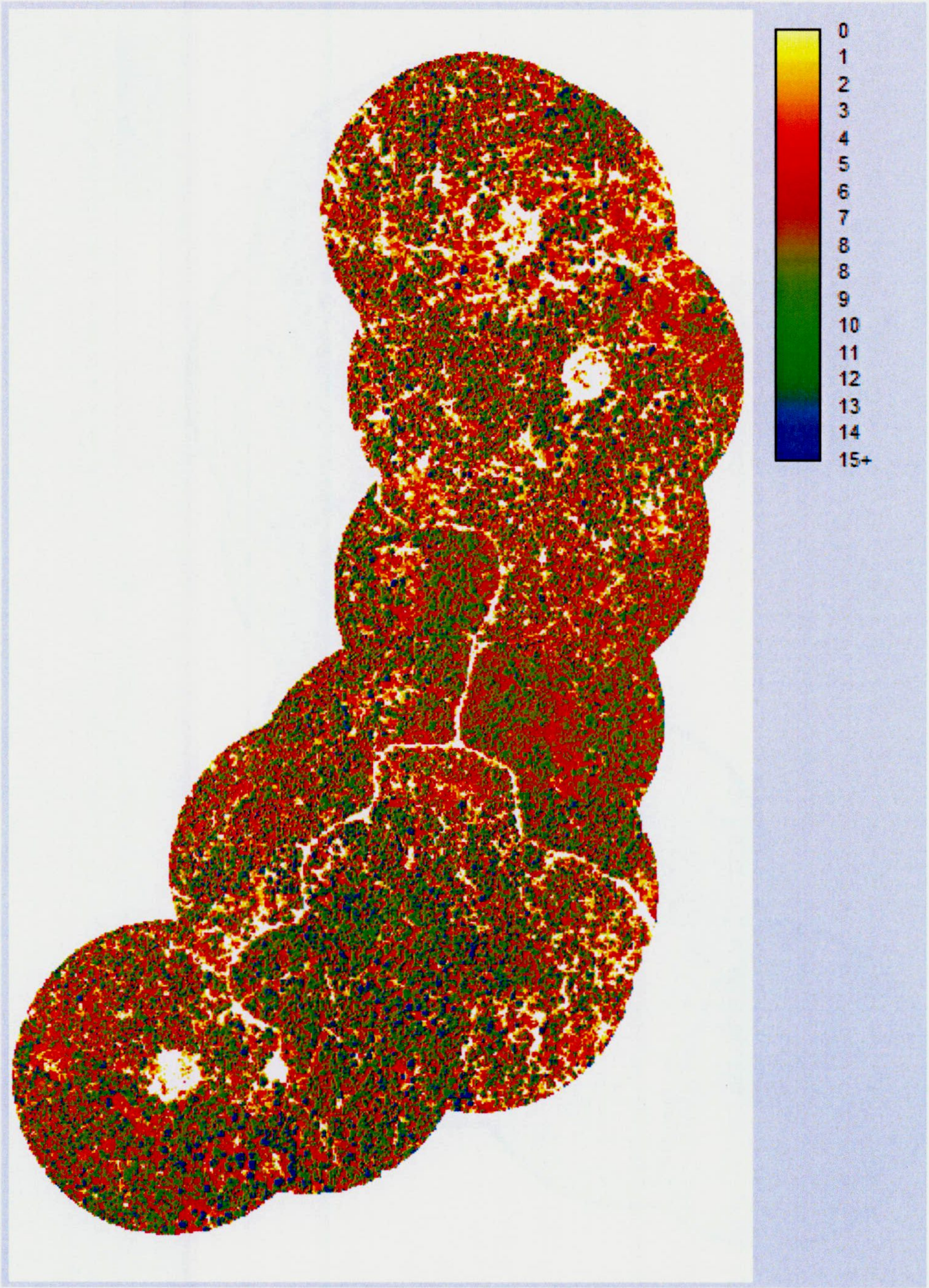

Figure 41: Kočevski Rog test site. The amount of photosinthetically active canopy volume in the year 2013 (after treatment), horizontal resolution 1 m. According to Lefsky et al. (1999) the amount of photosinthetically active canopy is defined as the upper 65% of the total canopy volume. It is given in cubic meters of canopy volume per square meter of forest area.

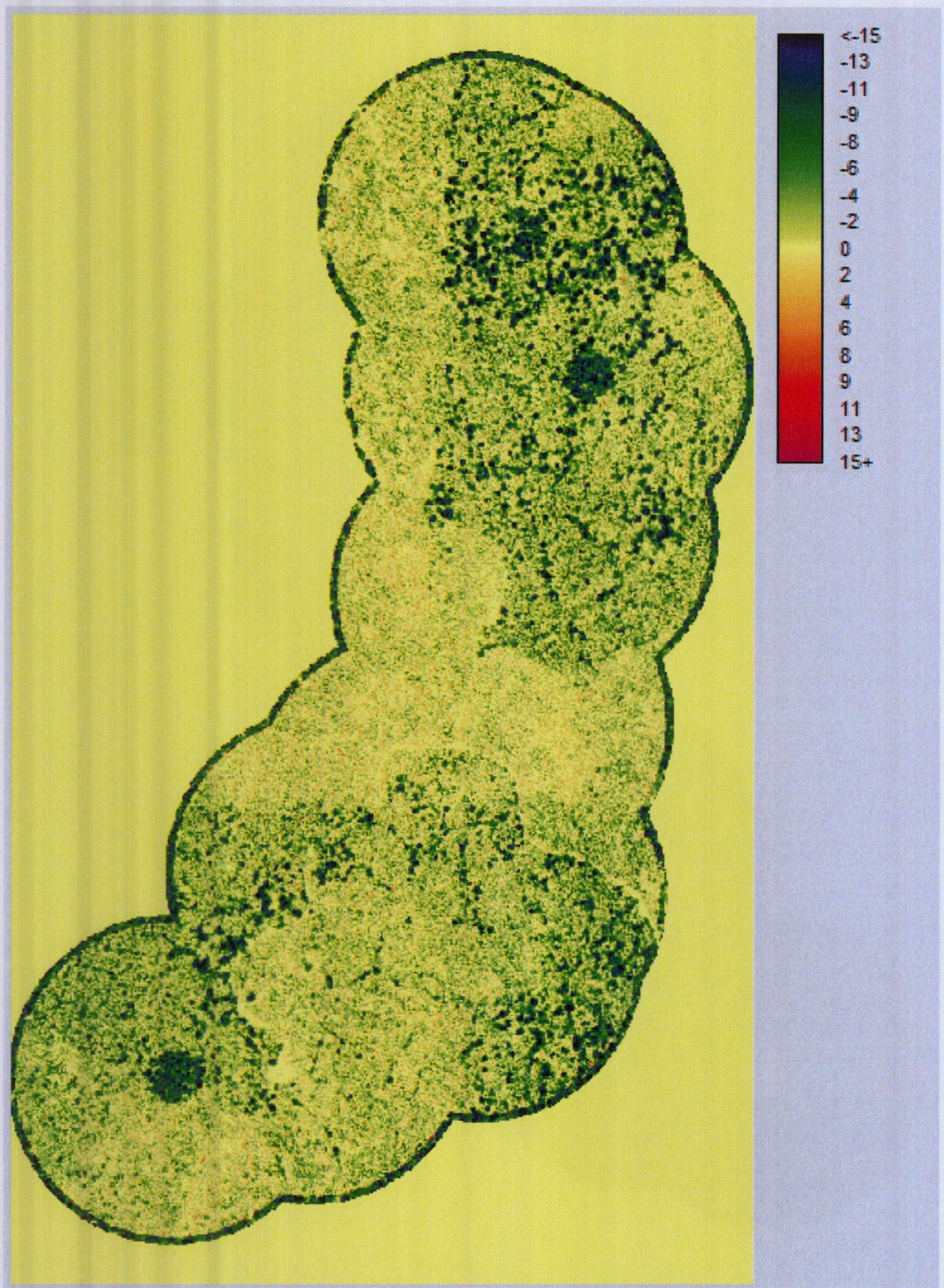

Figure 42: Kočevski Rog test site. The change of photosinthetically active canopy volume between the year 2011 (before treatment) and 2013 (after treatment), horizontal resolution 1 m. Positive and negative values indicate a gain and loss, respectively, of photosinthetically active canopy volume. According to Lefsky et al. (1999) the amount of photosinthetically active canopy is defined as the upper 65% of the total canopy volume. It is given in cubic meters of canopy volume per square meter of forest area.

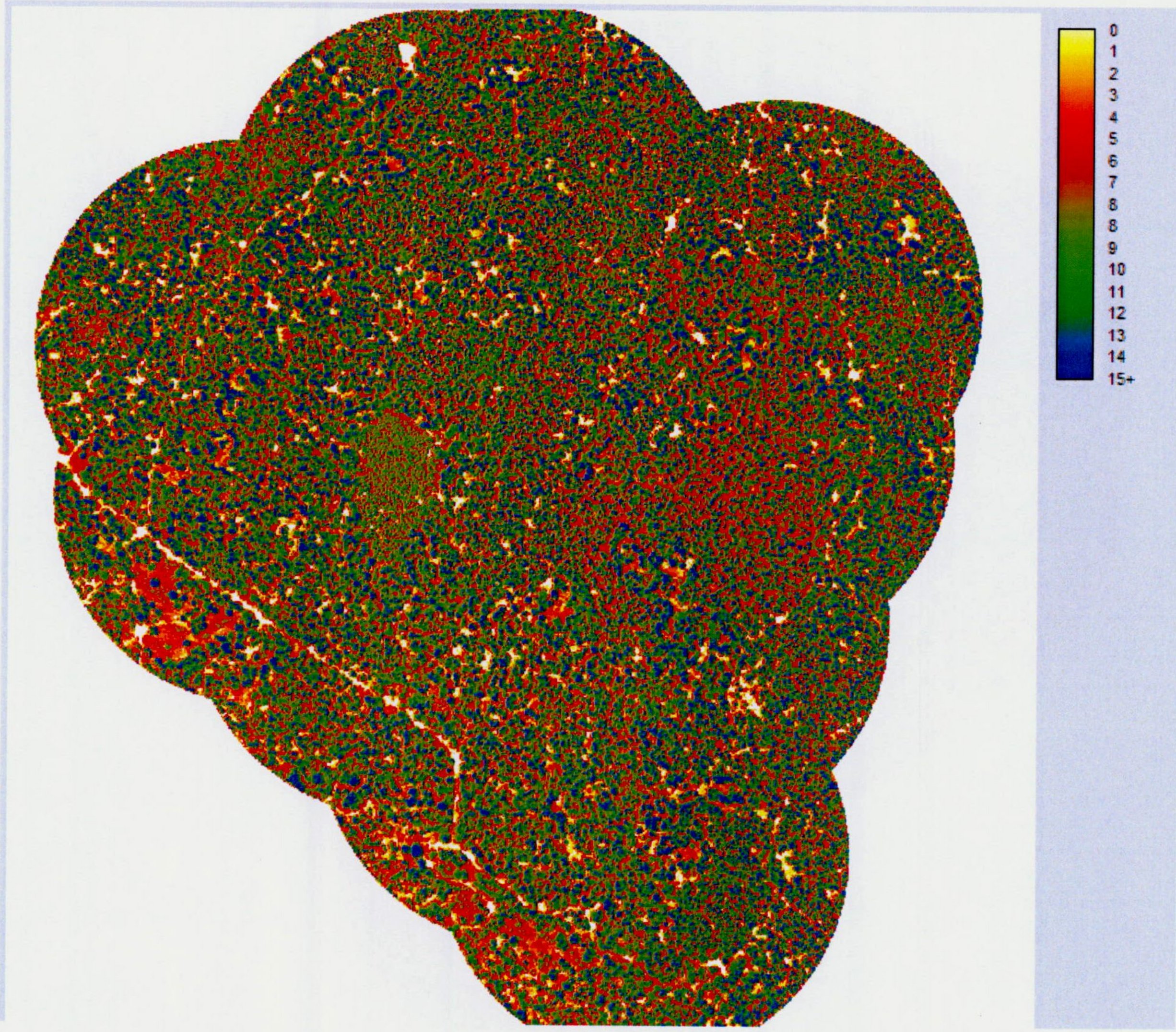

Figure 43: Snežnik test site. The amount of photosinthetically active canopy volume in the year 2011 (before treatment), horizontal resolution 1 m. According to Lefsky et al. (1999) the amount of photosinthetically active canopy is defined as the upper 65% of the total canopy volume. It is given in cubic meters of canopy volume per square meter of forest area.

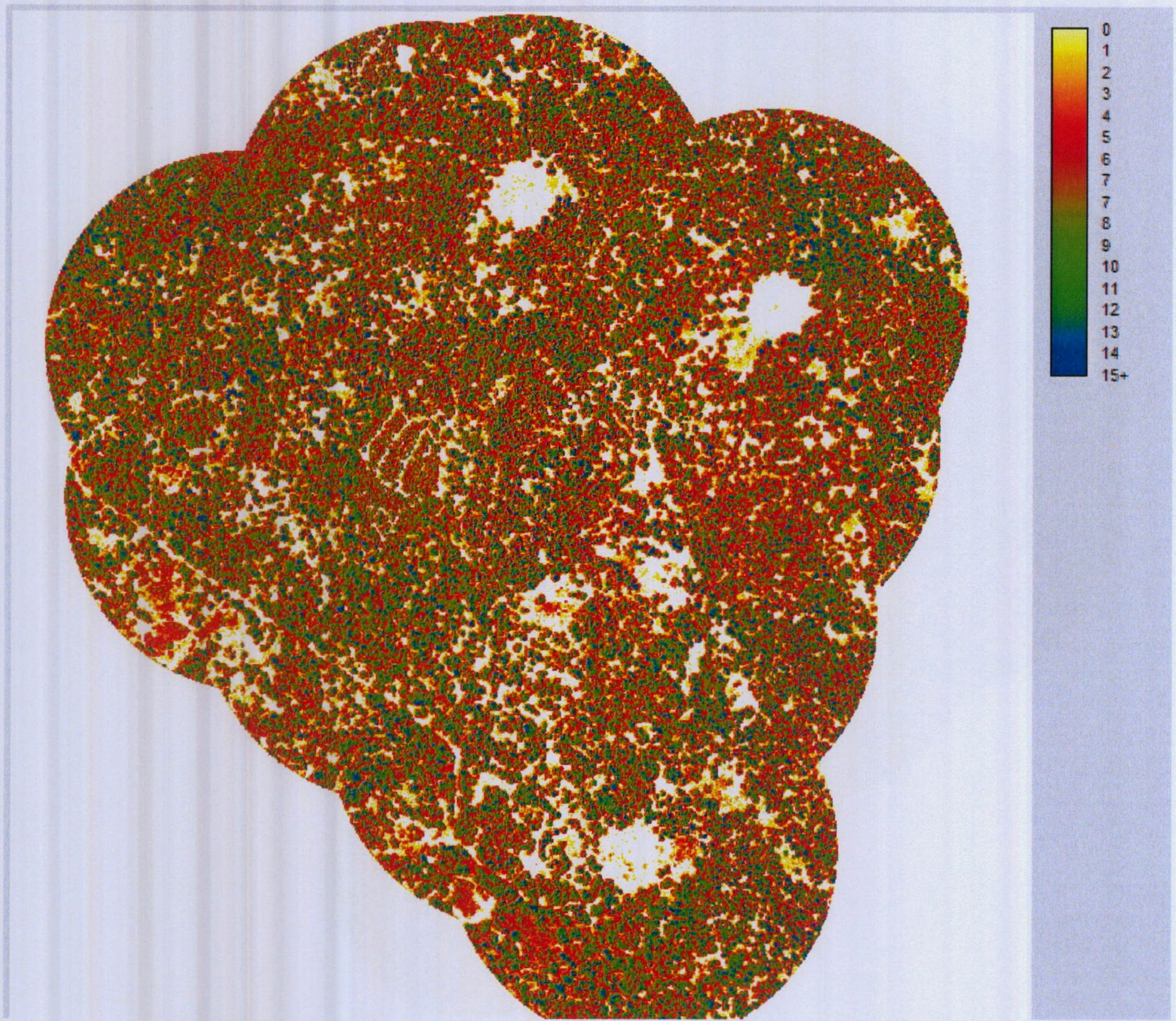

Figure 44: Snežnik test site. The amount of photosinthetically active canopy volume in the year 2013 (after treatment), horizontal resolution 1 m. According to Lefsky et al. (1999) the amount of photosinthetically active canopy is defined as the upper 65% of the total canopy volume. It is given in cubic meters of canopy volume per square meter of forest area.

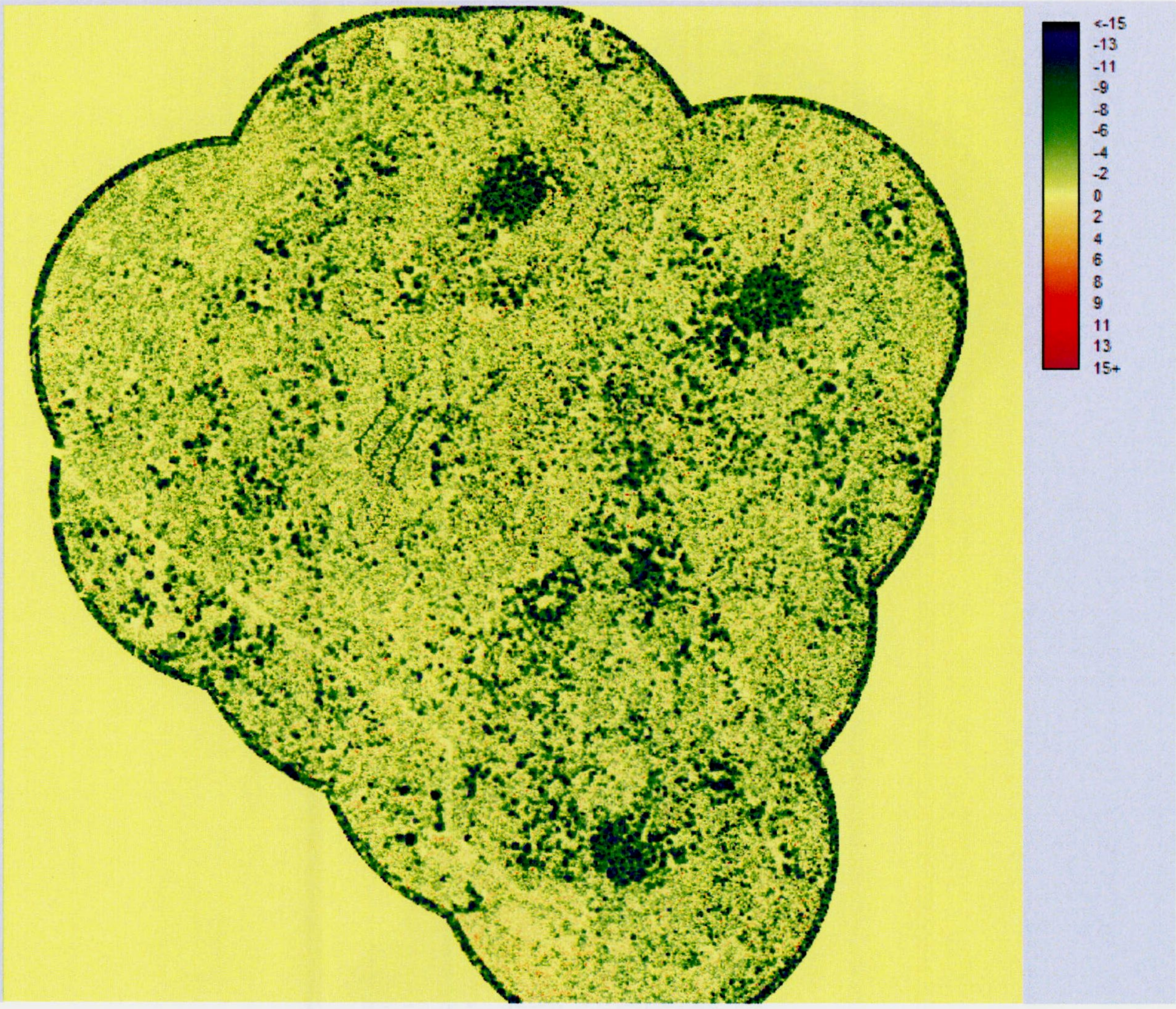

Figure 45: Snežnik test site. The change of photosinthetically active canopy volume between the year 2011 (before treatment) and 2013 (after treatment), horizontal resolution 1 m. Positive and negative values indicate a gain and loss, respectively, of photosinthetically active canopy volume. According to Lefsky et al. (1999) the amount of photosinthetically active canopy is defined as the upper 65% of the total canopy volume. It is given in cubic meters of canopy volume per square meter of forest area.

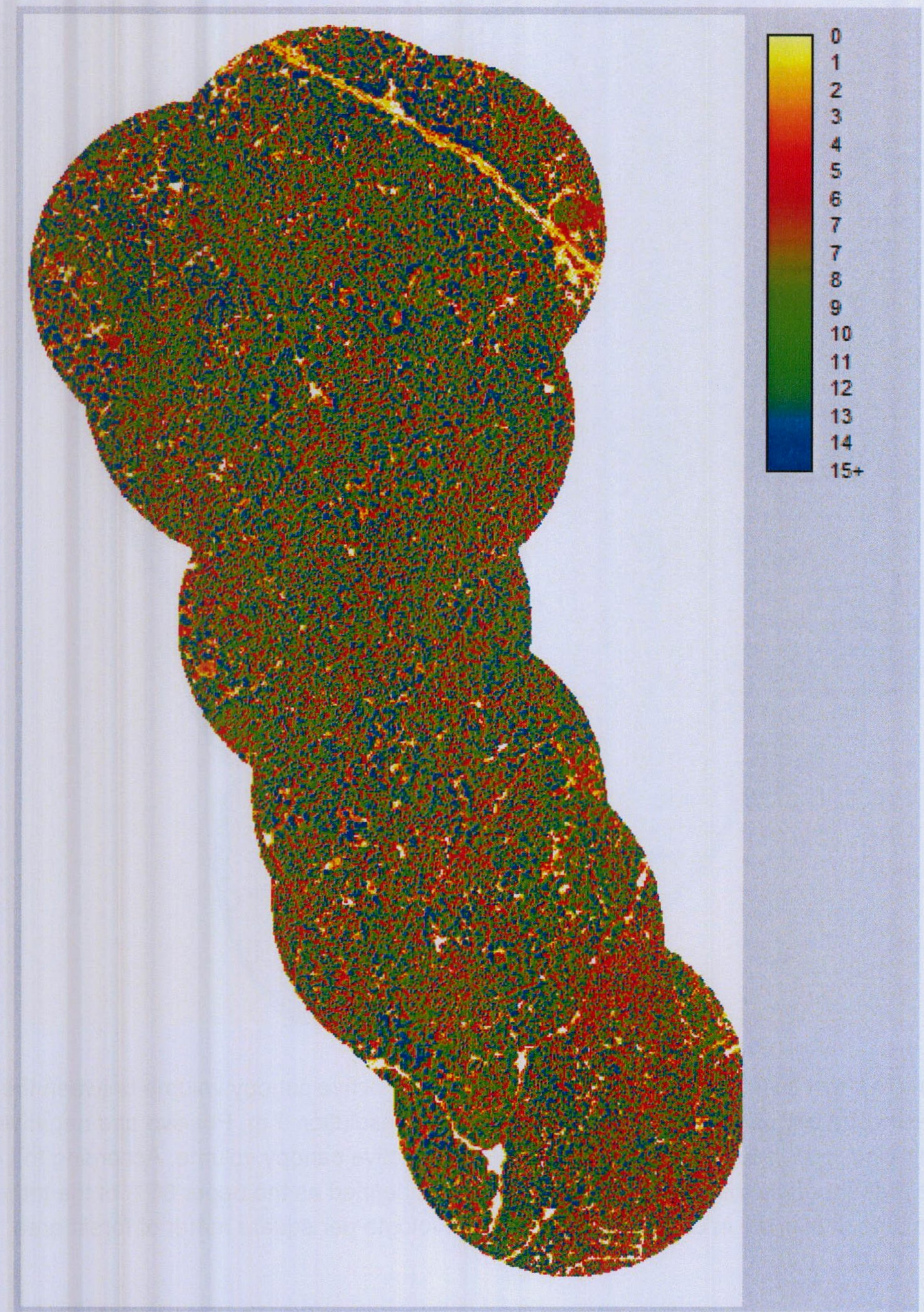

Figure 46: Trnovo test site. The amount of photosinthetically active canopy volume in the year 2011 (before treatment), horizontal resolution 1 m. According to Lefsky et al. (1999) the amount of photosinthetically active canopy is defined as the upper 65% of the total canopy volume. It is given in cubic meters of canopy volume per square meter of forest area.

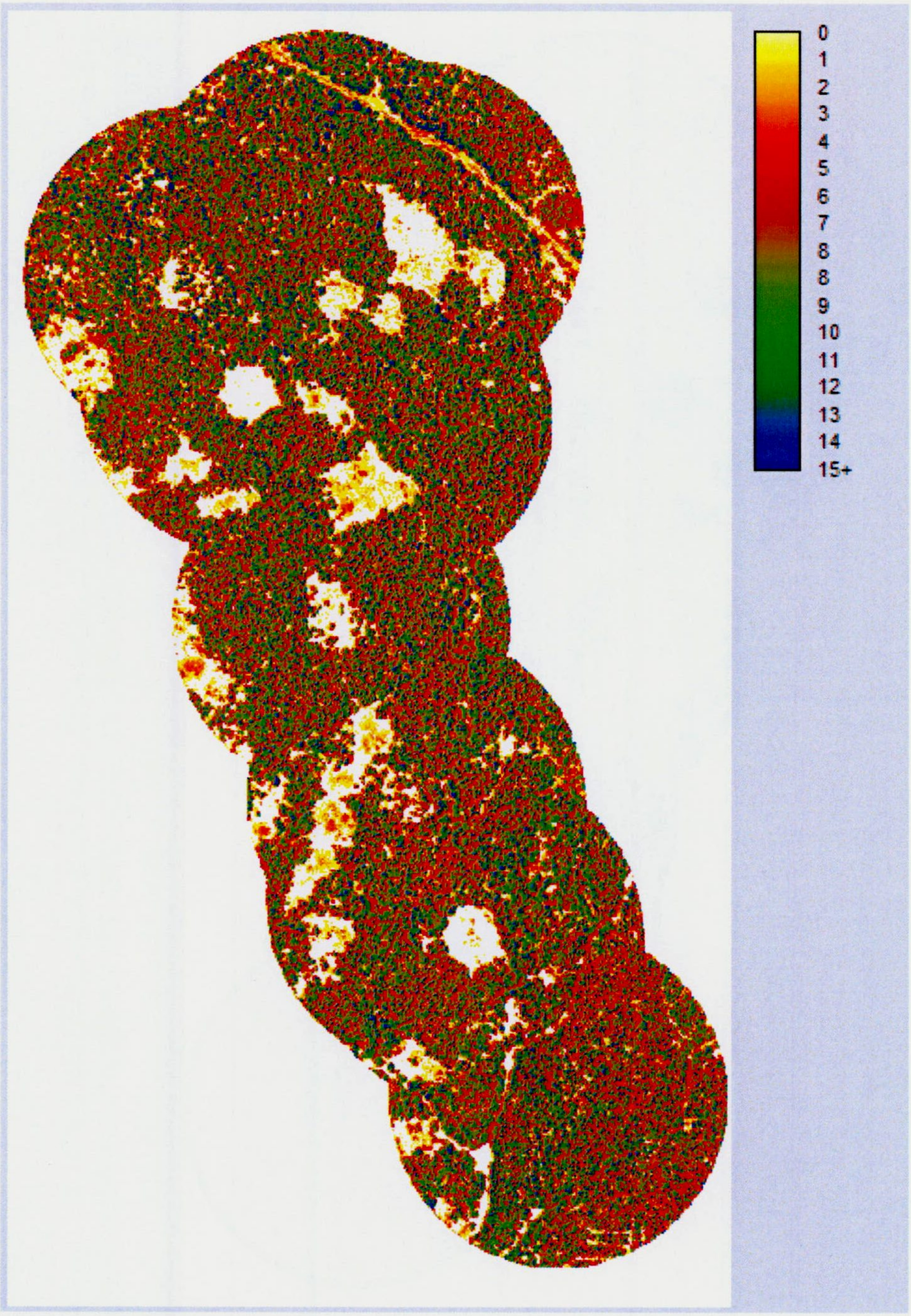

Figure 47: Trnovo test site. The amount of photosinthetically active canopy volume in the year 2013 (after treatment), horizontal resolution 1 m. According to Lefsky et al. (1999) the amount of photosinthetically active canopy is defined as the upper 65% of the total canopy volume. It is given in cubic meters of canopy volume per square meter of forest area.

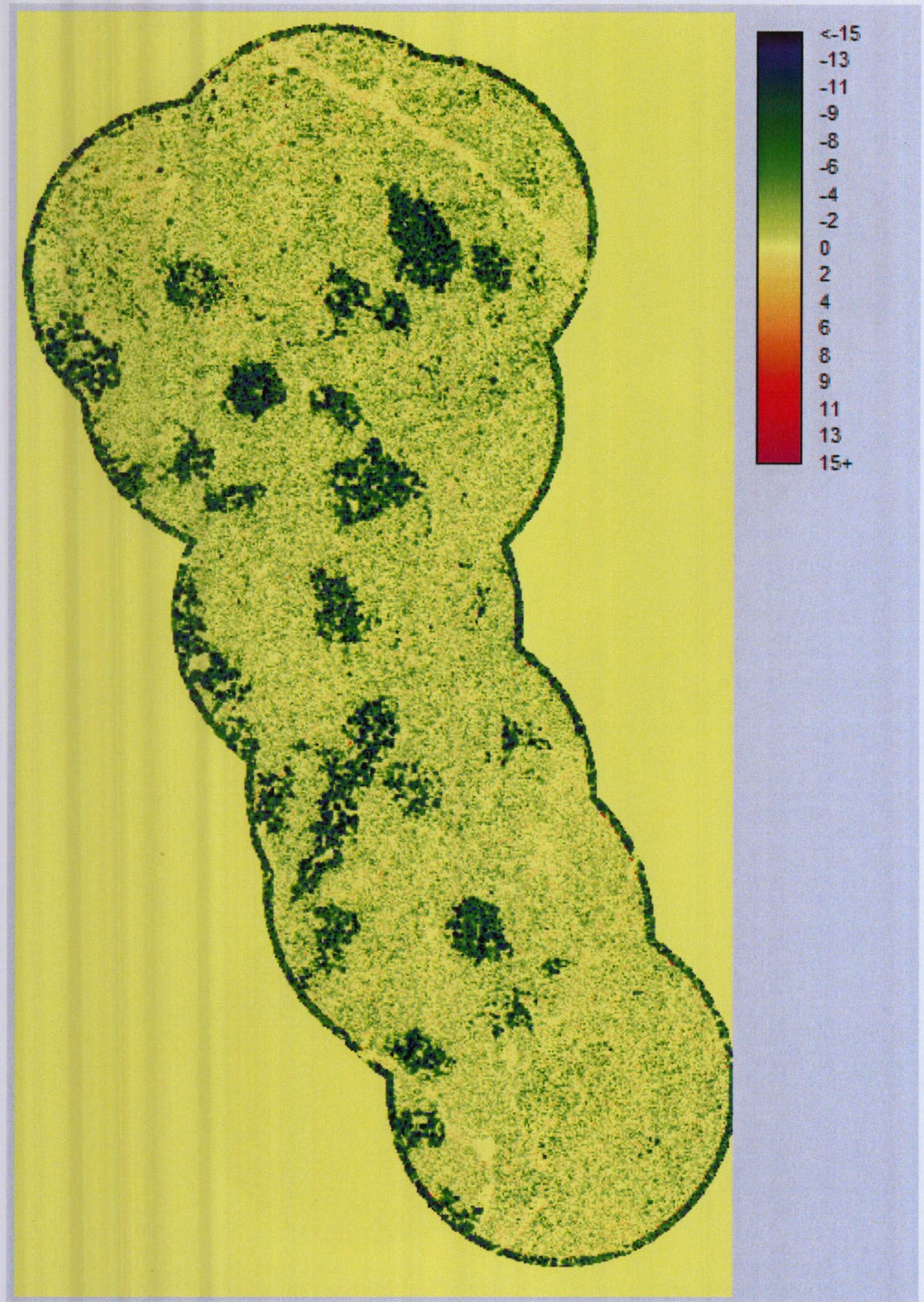

Figure 48: Trnovo test site. The change of photosinthetically active canopy volume between the year 2011 (before treatment) and 2013 (after treatment), horizontal resolution 1 m. Positive and negative values indicate a gain and loss, respectively, of photosinthetically active canopy volume. According to Lefsky et al. (1999) the amount of photosinthetically active canopy is defined as the upper 65% of the total canopy volume. It is given in cubic meters of canopy volume per square meter of forest area.

3 Comparison of achieved vs. expected results

3.1. Expected results in the reporting period

3.1.1 From Sub-action 1 – Activities in Italy

The results achieved in this reporting period allowed assessing applicability of timber harvesting simulation models to solve potential barriers to achieving the Action goals.

This evaluation was crucial because has allowed testing the ability of selected models to simulate forest management activities really applied in one site area.

The expected results stated in the Phase 2 is to analyse and quantify the potential disturbances due to forest management application on forest ecosystems, evaluating the potential increasing or decreasing of both landscape and fauna biodiversity in order to identify best forest practices.

In this reporting period the time schedule set in the project paper to analyse by December 2013 50% of test areas in the post-treatment situation was not met.

The reasons are widely discussed in the present report. The main is the need to await the conclusion of cutting activities in site areas to proceed at the remote sensing data acquisition and analysis.

3.1.2 From Sub-action 2- Activities in Slovenia

The results achieved in the reporting period comply with the expected results stated in the project.

At the forest stand scale the 2013 post-treatment lidar data were processed into digital terrain models and digital canopy models for all Slovenian sites, enabling the estimation of relative heights of cloud points above the bare ground without adversary effects of slight spatial displacement between the acquisitions. Also the forest canopy cover and the volume of photosyntheticaly active forest canopy maps were computed for all sites. For all the lidar-based products the change of the metrics was detected between the years 2013 (post-treatment) and 2011 (pre-treatment), enabling us to glean the impact of the silvicultural treatments upon the 3-D forest stand structure.

At the landscape level we performed all planned activities. Previous analyses regarding landscape fragmentation we upgraded with additional landscape metrics and with another research year - 1975, necessary for land use changes analyses. We put a lot of effort into socio-demographic analysis.

3.2 Evaluation of performance during the reporting period

3.2.1 From Sub-action 1 – Activities in Italy

Although it was not possible to meet the deadlines in the project with regard to the percentage of areas to be analysed in Phase 2, the activities carried out during this reporting period were very important and achieved results will support the future course of the Action.

3.2.2 From Sub-action 2 – Activities in Slovenia

The performance of actions pursues the time schedule set in the project paper. No delays have been detected.

At the landscape level we analysed land use changes and several landscape metrics (effective mesh size, forest patches and core areas) for 1975 and 2012. We analysed demographic data for 1869, 1931, 1961 and 2013. Nearly all analyses at the landscape level were done at 5 spatial levels (country Slovenia as a whole, landscape region "Kraške regije notranje Slovenije", where 3 Manfor test sites are located, 5 wider landcape units and 17 landscape units).

At the forest stand scale all three test sites (70 hectares each) in Slovenia have been scanned for the second time by lidar and a number of lidar-based maps of pre-treatment forest stand structure have been computed for the post-treatment stage. Also the change detection of lidar-based metrics for the Slovenian test sites was performed.

3.3 Overall future estimation of planned Action's objectives

3.3.1 From Sub-action 1 – Activities in Italy

Until the end of the project the focus will be: 1) the acquisition of high resolution images from multispectral optical sensors on the small area (10 km^2) of sites where the cutting activities have been concluded; 2) the application of different remote sensing technics for the change detections; 3) the identification, analysis and evaluation of treatment impacts within small areas; 4) the identification of the best silvicultural practices connected to carbon stocks/sequestration, landscape biodiversity and ecological connectivity.

3.3.2 From Sub-action 2 – Activities in Slovenia

At the landscape scale we'll try to find and explain correlations between socio-demographic indicators and land use changes. Causal relationship between them will be good basis for prediction of future development and landscape appearance.

Until the end of the project the focus at the forest stand level will be (1) the lidar-based change detection of the proposed forest stand structure indicators due to sylvicultural treatments and (2) the identification, analysis and evaluation of treatment impacts, based on these lidar indicators.

4 Indicators of progress

4.1 Planned indicators

4.1.1 From Sub-action 1 – Activities in Italy

Images of small (10 km^2) site areas are acquiring at the earliest available date and before forest management applications and in a date post-treatments where these have been concluded. As soon as they become available it will be elaborated.

4.1.2 From Sub-action 2 – Activities in Slovenia

At the landscape level we analysed planned landscape fragmentation metrics, land use changes (1975-2012) and socio-demographic trends (1869-2013). In next period we'll expand our research by adding demographic data from 1971 and improve effective mesh size by detailed barriers layers. In the final step we'll analyse correlations between landscape metrics, land use changes and socio-demographic indicators.

At the forest stand scale all test sites in Slovenia have been scanned by lidar for the second time and a number of lidar-based maps of post-treatment forest stand structure have been computed. Also change detection was done by comparing those maps between the years 2011 (pre-treatment) and 2013 (post-treatment).

4.2 Additional indicators

4.2.1 From Sub-action 1 – Activities in Italy

No additional indicators are defined at the moment.

4.2.2 From Sub-action 2 – Activities in Slovenia

No additional indicators are defined at the moment.

5 Envisaged progress until next report

5.1 From Sub-action 1 – Activities in Italy

By March 2014 the image acquisition procedure should be completed and second phase of Action ECo will be performed.

The next Action report will be produced by December 2014 and will be the last Action report. Until this date all sites will be analysed to report on spatial analysis of forest management and ecological connectivity.

5.2 From Sub-action 2 – Activities in Slovenia

Landscape scale

Regarding effective mesh size we will improve analysis with including more accurate layers presenting barriers for wildlife like railways, regional, local roads etc. At first we'll have to specify critical widht of corridors, landscape elements that act as barriers... We'll add demographic data from population census from 1971, corresponded to land use data from 1975. We will correlate land use changes and landscape fragmentation metrics (effective mesh size, area and number of patches, patch density, core areas etc.) with socio-demographic trends (number of population, population density, age and employment structure) and analyse statistical/causual relationship between them.

Forest stand scale

At the forest stand scale we will correlate the lidar-based metrics / indicators with field measurements of some forest stand parameters in order to develop local empirical models for spatial extrapolation of those parameters.