Universitatea
Transilvania
din Brașov

# HABILITATION THESIS

## Long-term monitoring of human interventions to forest ecosystems using multi-source geospatial data

Domain: Forestry

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BRAŞOV, 2018

## Cuprins

## (A) Rezumat

Teza de abilitare prezintă o parte din rezultatele activității de cercetare desfășurate în domeniul fundamental Ştiințe Inginereşti, subdomeniul Silvicultură, după susținerea publică a tezei de doctorat intitulate "Posibilități de îmbunătățire a metodologiei de prognoza a debitului maxim al viiturilor torențiale în bazine mici, predominant Forestiere", în anul 2011, în cadrul Universității Transilvania din Brașov. Teza de abilitare este structurată după cum urmează: rezumat, realizările profesionale și științifice, planul de dezvoltare a carierei și bibliografie.

Managementul forestier din trecut poate afecta puternic gestionarea și conservarea pădurilor în zilele noastre și mai ales activitatea de amenajare a bazinelor hidrografice torențiale. Cu toate acestea, se cunosc relativ puține schimbări în ceea ce privește acoperirea pădurilor de-a lungul secolelor, ceea ce limitează înțelegerea modului în care gestionarea anterioară afectează practica forestieră actuală și conservarea ecosistemelor. Din punct de vedere al funcției hidrologice și de protecție a solului îndeplinită de păduri, cunoașterea perturbărilor ecosistemelor forestiere pe termen lung oferă cuantificarea fenomenului de histerezis, ce definește diminuarea funcțiilor de protecție ale pădurilor afectate în trecut de perturbări. Astfel, o cunoaștere a distribuției spațiale a pădurilor afectate de histerezis ar conduce la o mai bună gestionare a resursei în domeniul amenajării bazinelor hidrografice torențiale.

Conținutul tezei de abilitare este format în jurul ideii cuantificării pe termen lung a influenței antropice asupra ecosistemelor forestiere și asupra dinamicii văilor torențiale montane. Sunt prezentate 4 direcții de cercetare care au la baza articole publicate în calitate de autor principal (prim autor sau autor corespondent) in reviste internaționale de prestigiu, indexate ISI WOS. Aceste 4 direcții de cercetare sunt dezvoltate pe verticală, pornesc de la un nivel macro – cuantificarea influenței antropice la nivel național, și ajung un nivel micro – cuatificarea influenței antropice la nivelul unei văi torențiale după cum urmează:

- Monitorizarea influenței antropice pe termen lung asupra ecosistemelor forestiere
- Dinamica pădurilor în bazinele montane folosind imagini satelitare și date climatice
- Managementul pădurilor și impactul asupra resurselor de apă utilizând analiza geospațială

- Dinamica pe termen lung a albiei într-o vale torențială amenajată

Rezultatele celor 6 ani de cercetări aduc în lumină folosirea metodelor geospațiale precum și a datelor din mai multe surse, de mai multe tipuri și sunt redate pe parcursul a 4 capitole.

În capitolul 2 se prezintă un studiu care acoperă o perioadă de 100 de ani și se bazează pe 2 lucrări publicate în reviste internaționale de presitigiu din domeniul Silviculturii și al Teledetecției satelitare, Forest Ecology and Management respectiv Remote Sensing of Environment. Studiul din capitolul 2 prezintă cum anume au evoluat perturbările la nivelul fondului forestier în 4 puncte importante din istoria Romaniei: 1920 perioada de început a Romaniei Mari, 1955-1965 perioada plății despagubirii daunelor de război catre Uniunea Sovietica, 1965 – 1990 perioada socialistă și 1990 – 2016 perioada postdecembristă. Am constatat că suprafața pădurilor a crescut în România din 1924 cu 5% și că rata anuală de recoltare a pădurilor între 2000 și -2013 a fost jumătate din rata anuală între 1912 și 1922. Pentru perioada postbelică, mai exact din 1955-1965, au fost cuantificate pădurile afectate de tăieri rase și definitve. Aceast perioadă este cunoscută ca fiind o etapă în care economia României a revenit din război, a stabilit legături economice strânse cu Uniunea Sovietică și a plătit prin exporturi de lemn către Uniunea Sovietică. Pentru a realiza acest lucru, am dezvoltat o metodă precisă și rapidă de orthorectificare a fotografiilor sateliților spion americani, Corona, de înaltă rezoluție care au survolat întreaga planeta în perioada 1962-1972. Am identificat 530.000 ha de tăieri rase și definitive, care sunt de trei ori mai mari decât suprafețele parcurse cu tăieri în zilele noastre. Cercetările oferă dovezi cantitative că războaiele pot provoca efecte pe termen lung asupra mediului. Abordarea prezentată în studiu facilitează extinderea înregistrării datelor privind observarea spațială a pământului cu unul până la două decenii mai devreme decât este posibil cu seturile de date prin satelit, iar datele Corona sunt disponibile la nivel global.

În capitolul 3 este prezentată dezvoltarea altitudinală și latitudinală a limitei pădurii în bazinele hidrografice montane, acest aspect fiind în directă legătură cu activitatea de amenajare a bazinelor hidrografice mici, predominant forestiere, studiu publicat în revista internațională Climate Research. Intensitatea și viteza avansării limitei pădurii depind și de numeroși factori fizici, biologici și umani care sunt specifici regiunii. Am selectat patru zone de studiu pentru a analiza comportamentul temporal și spațial al liniei de pădure și al pădurii pe baza criteriilor de selecție, cum ar fi interferența minimă la nivel uman și reprezentativitatea maximă la nivel european. Au fost utilizate patru intervale de timp pentru evaluarea comportamentului de acoperire a pădurilor în raport cu suprafețele ne-împădurite: 1971-1980, 1981-1990, 1991-2000 și 2001-2014. De asemenea, în acest studiu au fost incluse date privind clima și topografia, cum ar fi tendințele de temperatură și caracteristicile topografice locale, factori care au permis compararea și calcularea relațiilor de dependență. Rezultatele noastre indică diferențe semnificative între zonele analizate. De exemplu, pentru aceeași perioadă de referință (1981-1990), cele mai mari diferențe în ceea ce privește schimbarea acoperirii pădurilor au fost de +28%. În urma analizei datelor climatice tendința de temperatură a influențat în mod semnificativ evoluția pădurii în zona montană, fapt ce are implicații directe în modul de management al bazinelor hidrografice montane, predominant forestiere.

În capitolul 4 sunt prezentate aspecte referitoare la influența perturbărilor apărute în ultimii 10 ani în pădurile romanești asupra îndeplinirii funcției hidrologice și antierozionale. Este prezentată o metodă geomatică de cuantificare a perturbarilor și se realizează un studiu național privitor la distribuția spațială și tiparele acestor perturbări la nivelul fondului forestier.

În capitolul 5 se prezintă un studiu în profunzime a efectelor antropice asupra unei văi torențiale, mai exact asupra dinamicii morfometriei albiei minore. Studiul a fost publicat în revista indexată ISI – Environmental Engineering and Management Journal. Folosind tehnici geomatice complexe și date de surse si formate diferite s-a putut reconsitui evoluția albiei minore a unei văi torențiale după amplasarea unor construcții hidrotehnice transversale.

Partea finală a lucrării prezintă planul de dezvoltare a carierei universitare (în cercetare, în activitatea didactică și relația cu mediul economic). Teza de abilitare se încheie cu lista referințelor bibliografice menționate în cuprinsul ei.

(B) Scientific and professional achievements and the evolution and development plans for career development

## (B-i) Scientific and professional achievements

## 1. Introduction

### *1.1. Human interventions on forests structure and services*

*"Forests have so many roles in the universe, and so many benefits can be drawn by themselves but the care that is given by a Nation to forests can be taken as a criterion for the degree of its civilization"* (Hepites, 1899).

Hepites' statement was to highlight the state of the art of the specialists, namely the awareness that the forest is more than a renewable economic resource. Influenced by the recent deforestations aiming to prepare land for agriculture (Giurgiu, 2010; Munteanu et al., 2016), this perception on forests would establish two categories with protective functions on the 1910 Forest Code (Botez, 2014).

*a) "Particularly protected forests, that is, those found in torrent reception basins, those whose existence is necessary to prevent rupture, land movements, erosion, rock and rock dislocation, those situated on rapid slopes, intended to ensure the safety of traffic on the railways and on the roads, as well as those which prevent the formation of moving sands; "*

*b) "Forests or parts of forests the maintenance of which is necessary to protect the banks of rivers against breakage and water disasters, as well as those which provide the regular water course and the conservation of springs;"*

Whether we call them the benefits of the forests or, more recently, ecosystem services, forest functions manifest themselves in the form of favorable influences or useful services in the area where the forest is located and surroundings (Leahu, 2001; Rucareanu and Leahu, 1982).

Over time there has been an evolution of the perception of the forest, so that their protection could be detected in the following services:

a) water protection service;

b) soils protection service;

c) protective service against climatic hazards and industrial factors;

d) recreation service;

e) service of scientific interest and preservation of the genetic - forest fund.

In terms of main services performed by forests, those with special protection service (functional group I) represent 53.1% (Adorjani et al., 2008). Used as biological solutions against soil degradation and pollution of water sources, wooded areas play an important role in stopping and preventing land degradation and torrential phenomena (Clinciu et al., 2012; Constandache and Nistor, 2006; Davidescu et al., 2012). Of the total of these forests, 24.1% are forests mainly for the protection of land and soils, and 14.5% are forests with water protection functions.

From the hydrological point of view, Romania's forests are grouped in stands with high hydrological efficiency 28.2%, stands with average hydrological efficiency 53.8%, stands with low hydrological efficiency 15.6% and stands with very low hydrological efficiency 2.4% (Adorjani et al. 2008).

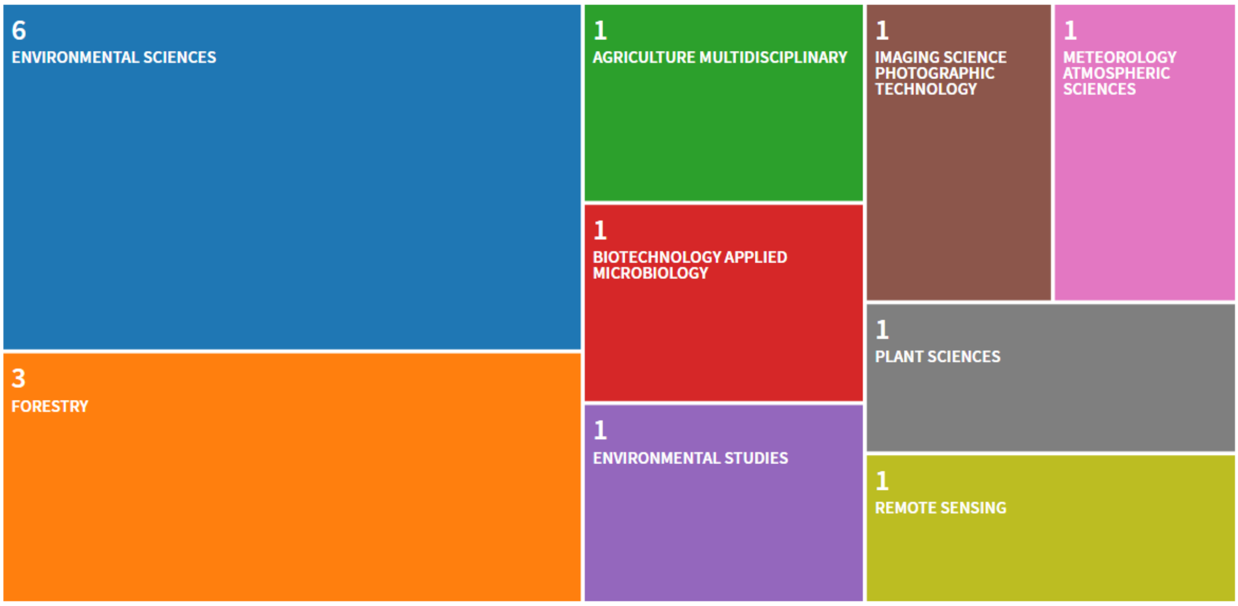
The hydrological state of the stands is dynamic, expressing in real time the influences of biotic and abiotic factors. The state of the stands directly influences the hydrological balance within a hydrographic basin and "spontaneously based on the law of links between of objects and phenomena in nature, triggers the entire mechanism of modification of the other components" (Munteanu et al., 1991).

### *1.2. Research articles that are at the base of the habilitation thesis*

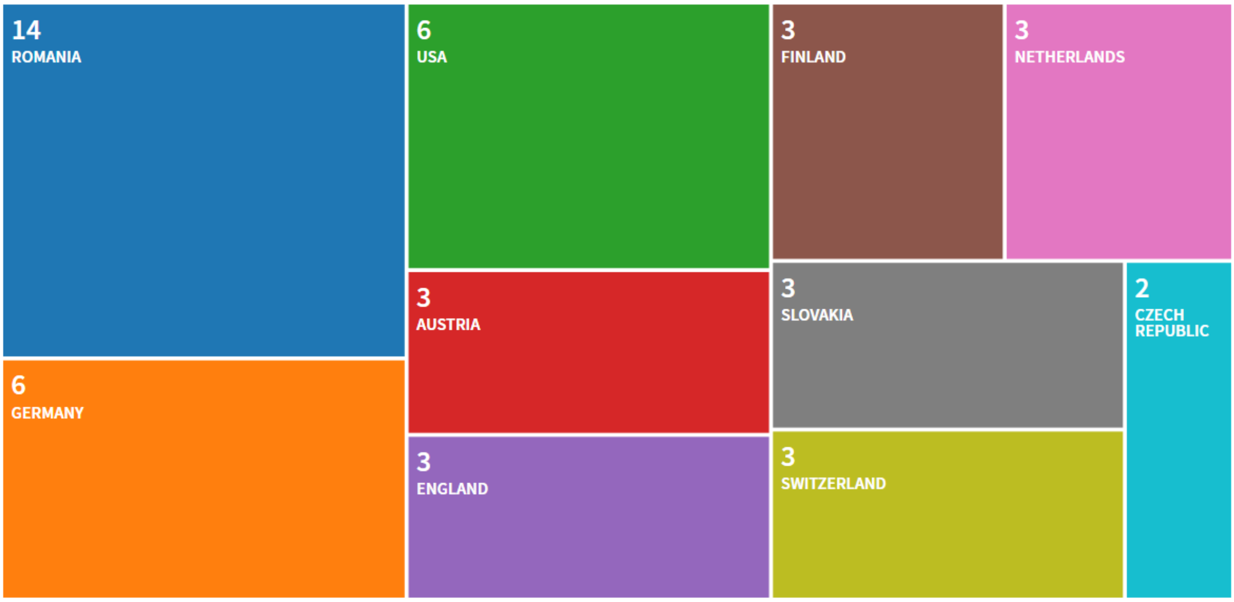
| Article | Journal | Ranking |
|---|---|---|
| Widespread forest cutting in the aftermath of World War II captured by broad-scale historical Corona spy satellite photography<br>Nita MD, Munteanu C, Gutman G et al. | Remote Sensing of Environment (2017) 1-11 | Q1 – No.1 in Remote Sensing |

| Article | Journal | Ranking |
|---|---|---|
| Forestland connectivity in Romania—Implications for policy and management<br>Stăncioiu P, Niță M, Lazăr G | Land Use Policy (2018) 1-0 | Q1 |
| Forests dynamics in the montane-alpine boundary: A comparative study using satellite imagery and climate data<br>Dinca L, Nita M, Hofgaard A, et al. | Climate Research (2017) 73(1-2) | Q1 |
| Evaluation of stream bed dynamics from vidas torrential valley using terrestrial measurements and gis techniques<br>Niță M, Clinciu I, Popa B | Environmental Engineering and Management Journal (2016) 15(6) | Q3 – No.3 in Forestry |
| Historical forest management in Romania is imposing strong legacies on contemporary forests and their management<br>Munteanu C, Nita M, Abrudan I et al. | Forest Ecology and Management (2016) 361 179-193 | Q1 |
| Monitoring status of forest hydrological and erosional protection service using geospatial analysis.<br>Niță MD, Candrea-Bozga B, Clinciu I | Revista Pădurilor 130 (5/6), 66-73 | Cabi – Forest Science database |
| Magnitude of damage events on hydrotechnical torrent control structures<br>I Clinciu, IC Petrițan, MD Niță | Environmental Engineering and Management Journal | Q3 |
| Research on spatial distribution of soil moisture in a small, forested watershed from the mountainous area of Brașov.<br>C Badea, I Clinciu, MD Niță | Revista Pădurilor | Cabi – Forest Science database |

The distribution and impact of the research article that are the base of the habilitation thesis are illustrated in the next figures.



Articles distribution on major categories



Citation distribution on countries

# 2. Monitoring the long-term influence of humans to forest ecosystems

## *2.1. Introduction*

Historic forest management can heavily affect contemporary forest management and conservation. Yet, relatively little is known about century-long changes in forest cover, and that limits the understanding of how past management are affecting current forestry practice and ecosystem conservation.

Land use dynamics have transformed the Earth's ecosystems to an unprecedented extent (J. A. Foley et al., 2005). Long-term forest changes, in particular, have major consequences for ecosystem functioning, carbon storage, climate regulation and biodiversity (DeFries et al., 2004; Newbold et al., 2015). Globally, forest cover loss increased from roughly 7% in 1700 to over 21% in 1990 (Ellis et al., 2013; Goldewijk, 2001) although several countries in Europe and Asia experienced forest transition (Mather, 1998) only in late 19th and early 20th century (Meyfroidt and Lambin, 2011) and are currently increasing in forest cover, and carbon sequestration (Erb et al., 2013; Rautiainen et al., 2010). Even though deforestation is declining in some countries (Gold et al., 2006), forest loss due to harvesting and natural disturbances remain high in many areas of the globe (Hansen et al., 2013; Potapov et al., 2014). Forest change is clearly related to socio-economic, political, institutional and environmental drivers (Lambin et al., 2001) but uncertainty about the role of past land uses, also referred to as path dependency, remains a concern for land change assessments. Long term human influence on forests can create legacies that may affect ecosystem functioning, structure and management of ecosystems for centuries (Foster et al., 2003; Munteanu et al., 2015a), but the link between past and contemporary land management practices is still poorly understood.

Historical land management decisions affect contemporary landscape patterns across the globe (Foster et al., 2003) and land use legacies can manifest themselves in many aspects of forest ecosystems such as occurrence of disturbance, composition or age patterns. In Eastern Europe, forest disturbance occurs more frequently in areas that were not forested a century ago, indicating that disturbance patterns are affected by past land management (Munteanu et al., 2015a). Past forest fires and harvests diminish the coniferous forests in the Russian Far East (Cushman and Wallin, 2000) and historically farmed forests in Western

Europe show a higher abundance of species that colonize abandoned land, and fewer poor dispersers (Dupouey et al., 2002; Plue et al., 2009). Furthermore, the intensity of historic farming affects forest species composition (Atkinson and Marín-Spiotta, 2015; Plieninger et al., 2010), indicating that effects of past management may persist for a long time into the future. Finally, age structure can also be a reflection of past land management, because age-patterns established by harvesting can persist for multiple rotation cycles, even under different management practices (Wallin et al., 1994). In summary, this highlights the persistence of land use legacies even after changes in land use type (Munteanu et al., 2015a; Thompson et al., 2013) indicating that past land management may constrain forest management for centuries thereafter.

According to a 35 years analysis of satellite data and provide a comprehensive record of global land-change dynamics during the period 1982–2016 it is shown that contrary to the general idea that forest area has declined globally tree cover has increased by 7.1% relative to the 1982 level (Song et al., 2018). According to Song, of all land changes 60% are associated with direct human activities and 40% with indirect drivers such as climate change. Land-use change exhibits regional dominance, including tropical deforestation and agricultural expansion, temperate reforestation or afforestation, cropland intensification and urbanization.

Although forested areas have increased in Europe in the 20th century (Fuchs et al., 2014; Gold et al., 2006; Munteanu et al., 2014), forest disturbance in the past decades is high in Eastern Europe (Griffiths et al., 2014; Hansen et al., 2013) and the forest composition and age structure are changed (Munteanu et al., 2015a; Vilén et al., 2012). Contemporary patterns of forest harvesting in Europe vary across countries and have been explained by a suite of factors including site conditions, forest resource availability (Levers et al., 2014), institutional and political context (Baumann et al., 2011; Kuemmerle et al., 2007), ownership structures (Kuemmerle et al., 2009b) and level of protection (Butsic et al., 2015; Knorn et al., 2012c).

However, most of these factors can act at different spatial and temporal scales and their effects can change over time, so that the links between past drivers and contemporary change remain widely unexplored.

Eastern Europe represents a particularly interesting natural experiment for studying the relationship between past and contemporary forest change in relation to land tenure, political systems and conservation efforts because the region has a long history of human use (Giosan et al., 2012), very good data records starting as early as the 18th century (Timár et al.,

2010) and experienced multiple shifts in institutions, land tenure, and socio-economic pressures both in time and space (Munteanu et al., 2014). Furthermore, current rates of forest harvesting are high (Griffiths et al., 2014) and controversial (Knorn et al., 2012a; Kuemmerle et al., 2009a), but their relationship to past forest management is still largely unexplored.

Another fact is that in the last century Romania was affected by two major conflicts, and from the forest ecosystem was affected especially by lag effect of these conflicts which affected the socio-economical environment. Wars have major economic, political and human implications, and they can strong affect environment and land use, not only during the conflicts, but also afterwards. However, data on the land use effects of wars is sparse, especially for World War II, the largest war in history. Land use change is a major aspect of global change (J. a Foley et al., 2005; Vorovencii, 2014) but land use change is typically gradual (Lucian Dinca et al., 2017; Geist and Lambin, 2004; Kozak et al., 2007; Müller et al., 2013). However, when shocks - such as wars - occur, land use and land cover changes can be rapid and unpredictable (Baumann and Kuemmerle, 2016; Bouma et al., 1998; Lambin et al., 2003). The immediate effects of wars on the environment can be substantial (Baumann et al., 2014; Rudel et al., 2005), but there are likely also time-lagged and long-term land use effects of wars, which remain largely unknown (Robinson and Sutherland, 2002). Time-lagged effects of wars can be due to, for example, reparation payments following conflict, or rebounding economies following a war, a phenomenon known as the Phoenix factor (Humphreys, 2005; Organski and Kugler, 1977), which occurs typically about 15-20 years after major conflicts (Kim et al., 2014; Organski and Kugler, 1977). However, a given country's economical and socio-political development may affect this timing, where the least developed societies are likely to deteriorate for long periods after wars (Fisunoglu, 2014; Hasic, 2004), whereas more developed countries rebound faster. Given this, it is important to increase the understanding of the time-lagged effects of wars on land use and the environment (Baumann et al., 2014; Burgess et al., 2015).

The largest war in history was the Second World War (WWII, 1939-1945), which had major economic, political and human implications, both during the conflict, and afterwards. The economic and fiscal collapse of many countries immediately following the war (Bakacsi et al., 2002; Brenner, 2003; Eichengreen, 1945) was due to the loss of human capital, lack of education for young children, and reduced earnings (Ichino and Winter-Ebmer, 2004). Military actions during WWII also caused widespread environmental effects, including soil compaction and vegetation changes (Machlis and Hanson, 2011), contamination of marine life (Martins et al., 2006) and introduction of invasive species (Fritts and Rodda, 1998; Kim, 1997).

In the post-war period (1947-1956), the Soviet Union government secured large reparation payments from East Germany and much of Eastern Europe, which likely even exceeded the $10 billion dollars that it had negotiated at Yalta (DeConde, 1978; Herman, 1951; Parrini and Matray, 2002). Many of the reparation payments were made in form of natural resources, such as timber, which may have had long-lasting environmental and land use effects beyond the immediate harvests, because the infrastructural developments facilitated further resource use even after reparations have been fully paid, and because historical land use can cause land use legacies that persist until today (C. Munteanu et al., 2016; Munteanu et al., 2015b). Furthermore, as the main actor of the economic development of Eastern Europe, the Soviet Union implemented the Stalinist strategy of industrialization and central planning, especially in the "allied" countries (Czechoslovakia, Poland, Yugoslavia), and they established either fully Soviet-owned companies (Hungary, Bulgaria), or joint companies (Romania) that delivered their profits to the Soviet Union (Banu, 2004; Bekes et al., 2015; Ben-ner and Montias, 2015; Gibianskii and Naimark, 2006; Tamas, 1987).

Unfortunately, there is limited data on the environmental effects of WWII, partly because remote sensing data for broad scale analysis only became available with the launch of the first Landsat satellites in 1972 (Roy et al., 2014). The US government did collect space borne photography globally for strategic intelligence decades prior to the first Landsat satellite, these data remained classified until 1996 (Galiatsatos et al., 2004; McDonald, 1995). Corona images provide space borne photography for the decades immediately following the WWII (Song et al., 2014) and are well suited for land use mapping (Beck et al., 2007; Challis et al., 2002; Day, 2015). Prior studies using Corona images have monitored boreal forest decline (Rigina, 2003), vegetation dynamics (Kadmon and Harari-Kremer, 1999), land use change (Tappan et al., 2000), carbon emissions from forest fires (Isaev et al., 2002), ice sheet change (Bindschadler and Vornberger, 1998; Grosse et al., 2005), and archaeological features (Beck et al., 2007; Casana and Cothren, 2008; Challis et al., 2002). However, because ortho-rectifying Corona images is complex and time-consuming (Sohn et al., 2004; Song et al., 2014; Tappan et al., 2000), and due to the lack of information about a given mission's sensor (Hamandawana et al., 2007; Peebles, 1997; Sohn et al., 2004; Zhou et al., 2003), high level of spatial distortion (Cassana and Cothren, 2008; Sohn et al., 2004; Song et al., 2014), and scanning errors (Gheyle et al., 2011), there have been relatively few land use studies using Corona photographs, and they have typically been limited in their spatial extent.

After all, the responsibility of forsters in the field of torrential watershed management has the argument that the ecological reconstruction of forests is integrated into watershed management which reconstructs the damaged environment or prevents its degradation. In Romania the forestry is based on the idea of "efficient control of water and soil "(Munteanu, 1976), which can materialize only through the essential input of the forest, especially through its hydrological function of anti-erosion. Therefore, knowing long-term influences of humans to forest ecosystems leads to a better identification of hysteresis phenomena. This phenomenon describes that the curative force of the reinstalled forest on the slopes basins is important but not sufficient to remove, in the short term, the remanence erosion at the level of the hydrographic network.

### *2.2. Using multi-source data to quantify influence of humans to forest ecosystems*

Data on how human activities affected forest ecosystems is scarce and the further you go in history the higher inaccuracy and inconsistency of data. Besides, datasets like censuses have a high level of accuracy and representativeness but a low update frequency, usually being renewed once every five or ten years. Statistical data aggregated into administrative boundaries are unable to reveal the accurate distribution of human activity below the administrative division level. Using multi-source data (statistical, cartographic, satellite, field data) improves process of quantifying and mapping the way humans influence forest ecosystems.

#### *2.2.1 Use of historical and contemporary data in quantifying forest disturbance*

Historic forest management can heavily affect contemporary forest management and conservation. Yet, relatively little is known about century-long changes in forest cover, and that limits the understanding of how past management and land tenure are affecting current forestry practice and ecosystem conservation. Our goal here was to assess forest condition as indicator of forest management since the early 20th century in Romania, and quantify how historical forestry affects current age, composition and disturbance patterns.

We analyzed long term forest dynamics for Romania in relation to major socio-economic shifts and ownership changes based on an extensive literature review and national level statistics. We relied on forest cover statistics about major forest types (coniferous, beech, oak, others) for the years 1924, 1954, 1964, 1980, 1985,1994, 2006 and 2010 (Directia Centrala de Statistica, 1985, 1980, 1964; Directiunea Statisticei Generale, 1954; Institutul National de Statistica, 2010, 2006, 1994; Ministerul Agriculturii şi Domeniilor, 1924). We used average disturbance data from the 1924 forestry statistic for the decade 1912-1922 and used age structure to reconstruct average disturbance for the decade 1902-1912. We only extrapolated the age structure for young forest classes only because this method is related to uncertainties for mature forests. The disturbance value for 1870 is based on literature estimates (Nicolau-Barlad, 1944). For the years 1960 to 2014 we calculated disturbed areas based on FAO harvest volume data (FAO (United Nations Food and Agriculture Programme), 2015) which we converted to area estimates (ha) using an average volume/ha value of 400 cubic meters. The conversion factor was chosen based on average dendrometric values for forests of harvestable age in Romania (80 years or older) (Rusu and Cojinovschi, 2014) and is comparable to timber volumes for clear-cuts in other parts of the world (Masek et al., 2011). We cross validated these estimates with annual disturbance rates reported in remote sensing analysis (Griffiths et al., 2014; Potapov et al., 2014) and found differences of only 1-2% in disturbance of forest areas for the overlapping years. Our estimation is rather conservative and assumes that harvest volumes have stayed constant over time for the period 1960-2014. Recent studies have shown that volume density may have increased in recent years (Rautiainen et al., 2010; Vliet et al., 2015) and for our study this may mean that our estimates of disturbance may in fact underestimate the amount of historic harvest.

We analyzed national ownership patterns based on 1924 statistical data at county level (Ministerul Agriculturii şi Domeniilor, 1924) and national statistics for 2010 and 2014 (Curtea de Conturi a Romaniei, 2013). We relied on bibliographical sources on ownership data for 1940 and for the socialist period (1948-1990) (Bouriaud and Popa, 2008; Giurescu, 1981; Nicolau-Barlad, 1944). We compared the proportions of three ownership types in each time periods: public (state owned), institutional, and private.

Since the mid 19th century Romania experienced five major land privatization events in relation to socio-economic and political shifts such as wars and revolutions. In 1872 serfs were liberated and received land for farming and in 1921 WWI soldiers received land as war compensation. After WWII all land was nationalized and managed by the state. Following the collapse of the Soviet Union in 1990, three restitution laws, ensured that forest passed back into private ownership in in 1991, 2000 and 2007 (Ioras and Abrudan, 2006) (Figure 2).

Our spatial analysis was largely based on forest inventory data, spanned two scales (country level and forest management unit) and focused on two time periods: early 20th century when the study region was under influence of the Habsburg and the Ottoman Empire (hereafter historic) and following the collapse of the Soviet Union and EU accession (hereafter contemporary). In order to analyze forest extent, composition, age classes and disturbances we relied on county level forest inventory statistics for the historic period (Ministerul Agriculturii şi Domeniilor, 1924) and aggregated spatial and statistical data at county level for the contemporary time period. We digitized forest statistics on age classes, forest composition, and yearly forest disturbance for the decade 1912-1922. Data was available for the 60 historic counties of Romania according to the 1930 administrative boundaries (Max Planck Institute for Demographic Research and Chair for Geodesy and Geoinformatics, 2015).

For the contemporary time period, we integrated four major data sources: two national statistics (Institutul de Cercetări şi Amenajări Silvice Bucureşti, 2015; Institutul National de Statistica, 2015) and two spatial broad scale data sets, one on forest disturbance (Hansen et al., 2013) and one on forest composition (Brus et al., 2011). We aggregated these data at county level using administrative boundaries of the 42 Romanian counties of 2014 (Tab 1). In order to limit effects of inconsistencies in our data sources and ensure comparability, we used the baseline of national statistics, to which we assigned disturbance rates and species composition from the spatial datasets.

Table 1. Data sources for forest extent, composition, age classes and disturbances for three time periods and at two spatial scales >>>

| | Historic (1924-1945) | Contemporary (2000-2014) |
|---|---|---|
| Spatial scale: Romania, at county level | | |
| Disturbance occurrence | (Ministerul Agriculturii şi Domeniilor, 1924) | (Hansen et al., 2013; Institutul National de Statistica, 2015) |

| | | |
|---|---|---|
| Forest ownership | (Ministerul Agriculturii şi Domeniilor, 1924) | (Institutul de Cercetări şi Amenajări Silvice Bucureşti, 2015) |
| Age class distribution | (Ministerul Agriculturii şi Domeniilor, 1924)(Nicolau-Barlad, 1938) | (Institutul de Cercetări şi Amenajări Silvice Bucureşti, 2015) |
| Species composition | (Ministerul Agriculturii şi Domeniilor, 1924) | (Brus et al., 2011; Institutul de Cercetări şi Amenajări Silvice Bucureşti, 2015) |

At the forest management unit level, we obtained forest extent, composition, age and disturbance from forest management plans dated between 1926 to 1945 (Tab 2). Contemporary forest management plans for the years 2008 to 2014 were available in GIS format and we compared them with digitized historical records to assess shifts in composition, disturbance and age structure.

For our analysis, we define disturbance as loss of forest cover due to forest harvest and natural disturbances (which are most commonly followed by salvage logging in Romania). At national level we relied on historic disturbances between 1912 and 1922 from forestry statistics (Ministerul Agriculturii şi Domeniilor, 1924). Historic data on forest harvest was collected by forest rangers in the field and subsequently centralized for each county, and we expect that this data could underestimate the amount of historical harvest. For the contemporary period (2000-2013) we mapped disturbance at county level using remote sensing data (Hansen et al., 2013) complemented with county level statistics for selective and shelterwood logging, because remote sensing data does usually not capture fine-scale disturbances (Kittredge et al., 2003). At the forest management unit level, we compared the historic and contemporary occurrence of disturbance based on the forest management plans.

For all of Romania, we compared historic and contemporary extent of four major tree species (beech, oak, fir, spruce) at county level using the 1924 and 2014 statistics and reported change as percentage of the total forested area. 1924 data was summarized by 1930 administrative regions. For the contemporary dataset we compiled two data-sources of species distribution: statistical data on the area covered by major forest type (coniferous, deciduous and mixed) at the county level (Institutul National de Statistica, 2015) and spatial information on the distribution of tree species groups in Europe at 1 km × 1 km (Brus et al., 2011). We calculated percentage of tree species per county and assigned them to major forest types. We finally summarized tree species areas by county to obtain more detailed statistics. At the forest management unit level, composition is reported as percentage species in each stand. For the three case studies, we compared historic and contemporary extent and percentage of species for each forest management unit.

Across Romania, statistical data on age class distribution was available only at regional level for 2014 (Institutul de Cercetări şi Amenajări Silvice Bucureşti, 2015), and at the country level for 1964 (Directia Centrala de Statistica, 1964) and 1924 (Ministerul Agriculturii şi Domeniilor, 1924). We aggregated all data at the national scale and analyzed changes over time. At forest management unit level, we compared shifts in age distribution between the historic and contemporary time periods at the stand level.

### *2.2.2. Use of Corona spy satellite in quantifying forest disturbance*

Romania experienced severe shocks due to WWII, both economically and environmentally. After WWII, the country had to make reparation payments to the Soviet Union in the form of natural resources such as petroleum, mineral and timber (Bancila, 2016; Bekes et al., 2015; Ben-ner and Montias, 2015; Giurescu, 1976). Furthermore, until 1958, the Soviet Union imposed polices that put pressure on natural resources (Bekes et al., 2015). Under joint Soviet-Romanian economic ventures (SOVROM), Romania was to provide 1 million cubic meters of timber annually to the Soviet Union (Banu, 2004; Bekes et al., 2015), plus other natural resources (e.g. petroleum, natural gas, and uranium), in exchange for knowledge and infrastructure development (Bancila, 2016; Ben-ner and Montias, 2015; Constantinescu, 1953).

Romania had extensive forest resources at the end of WWII. In 1946, approximately 26% of the country was forested, with a high proportion of coniferous forests in the mountains (*Picea abies*- spruce and *Abies alba* fir) as well as ecologically valuable deciduous forests (e.g., oak) (C. Munteanu et al., 2016). Furthermore, based on Soviet reports, Romania had approximately 1 million ha of so-far inaccessible old-growth forests that might become available for harvesting with additional road construction (Banu, 2004; Ivanescu, 1972). As a result, anecdotal evidence suggests that much of the country's mature forest cover was harvested in the aftermath of WWII (Marea Adunare Nationala, 1976), but a detailed assessment of post-war harvesting has been lacking.

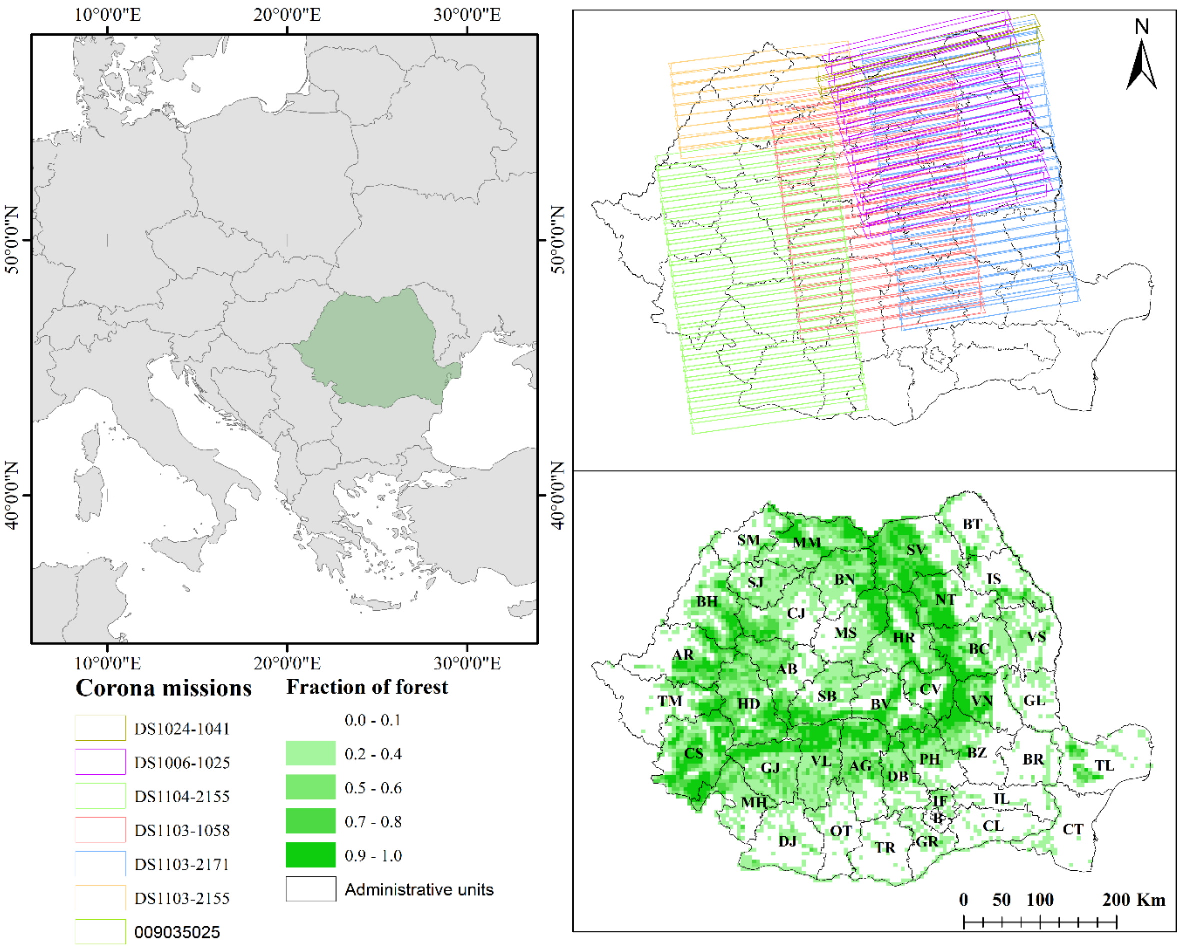


Figure 1: Location of Romania within Europe (left), coverage of the 208 Corona spy satellite photographs (104 stereo pairs) of seven different mission (top right), and percent forest cover in 1970 (5-km resolution, bottom right) (Nita et al., 2018)

We obtained declassified photographic data acquired by six Corona missions (Song et al., 2014) from 1962 to 1968 from the U.S. Geological Survey (Figure 1). Specifically, we analyzed 208 scanned, panchromatic, medium and high stereographic coverage Corona images, grouped in 104 stereo pairs (Table 2). Each scanned film strip covers approximately 17 x 230 km on the ground (Sohn et al., 2004).

Table 2: Corona mission data and observations (Nita et al., 2018)

| Mission ID | Launch date | Number of images | Camera type | Comments[1] |
|---|---|---|---|---|
| 009035025 | 30 May 1962 | 4 | Stereo medium | Slight Corona static on film |
| 1006-1025 | 04 Jun 1964 | 30 | Stereo medium | Highest-quality imagery attained to date from the KH-4 system |
| 1024-1041 | 22 Sep 1965 | 4 | Stereo medium | All cameras operated satisfactorily |
| 1103-2155 | 01 May 1968 | 18 | Stereo high | |
| 1103-2171 | 01 May 1968 | 54 | Stereo high | Out-of-focus imagery is present on both main camera records |
| 1103-1058 | 01 May 1968 | 46 | Stereo high | Out-of-focus imagery is present on both main camera records |
| 1104-2155 | 07 Aug 1968 | 52 | Stereo high | Best imagery to date on any KH-4 systems |
| | Total | 208 | | |

[1] (National Reconnaissance Office, 2005)

These 208 images provide a nearly-full coverage of Romania's forests with 1.83–2.74 m resolution (Figure 2). For areas that were out-of-focus or partially cloud covered, we used more than one image pair.

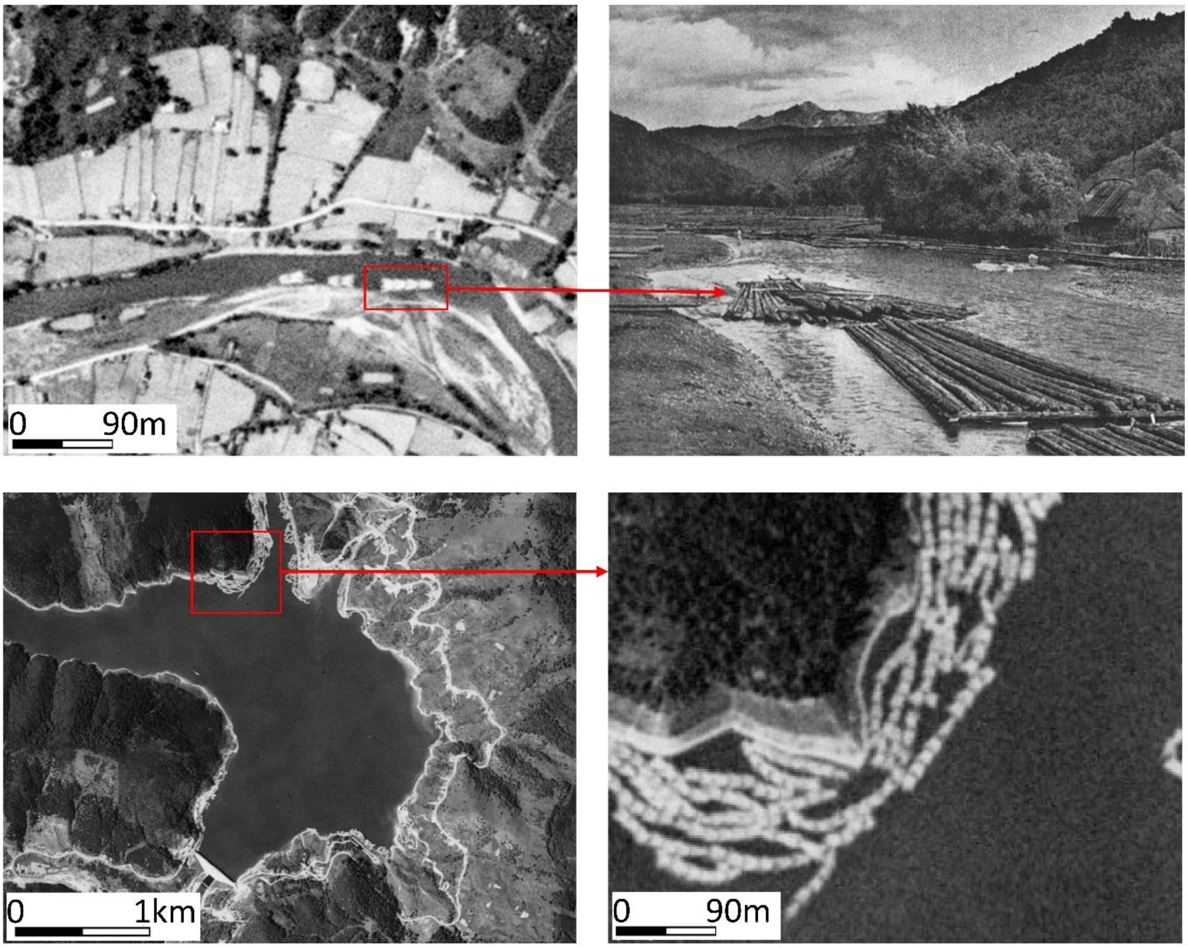


Figure 2: Example of Corona photographs showing timber rafts on the Bistrita River (top left) and on Izvorul Muntelui Lake (bottom right and left) in DS1006-1025DA077 Corona Image (2-m resolution) from June 4th 1964. Historic photography of timber rafts from the same period show the typical shape of the rafts (top right, image source: http://www.carpati.org). (Nita et al., 2018)

For the geo-rectification of the stereo-pairs we employed Structure from Motion (SfM) bundle adjustment as implemented in AgiSoft Photoscan (Figure 3). We divided the process into four steps: 1) aligning photos, 2) point cloud georeferencing, 3) digital surface model extraction, and 4) orthophoto generation (Agisoft LLC, 2011).

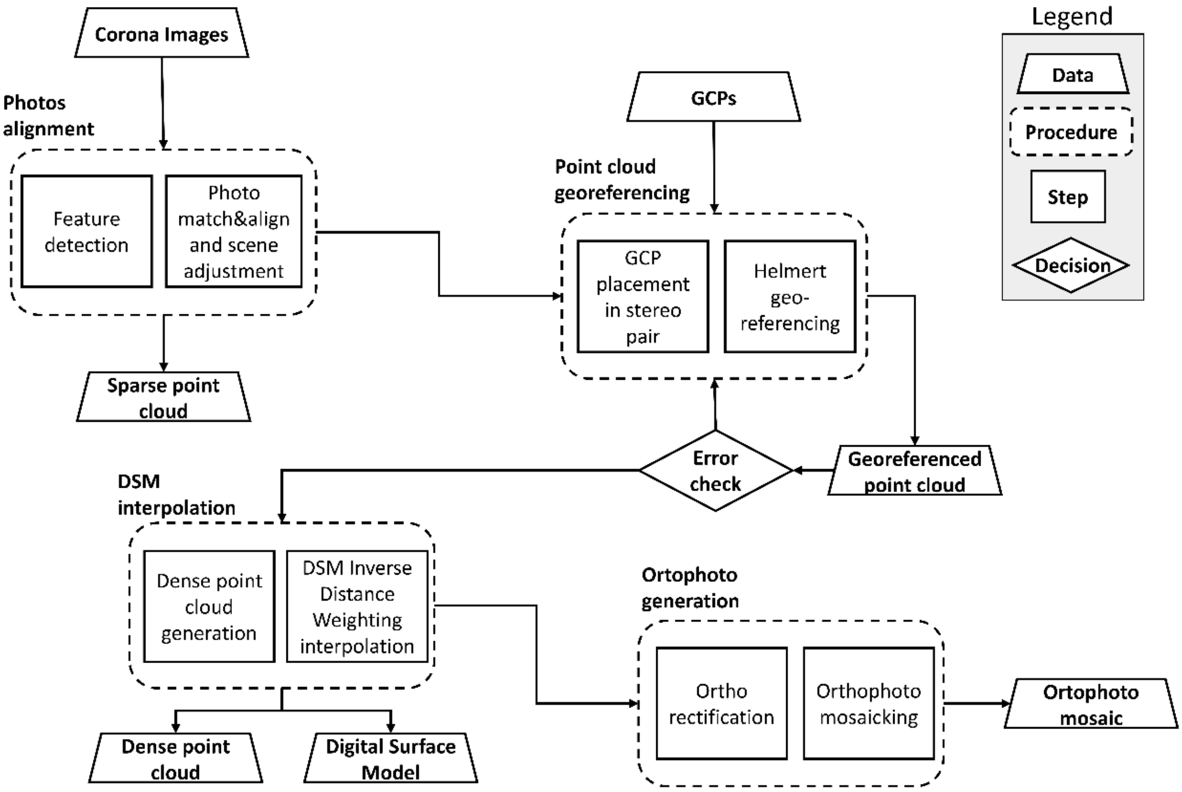


Figure 3: Corona image ortho-geo-rectification workflow using Structure from Motion algorithms, including four major work steps: photo alignment, point cloud referencing, digital surface model interpolation and orthophoto generation. (Nita et al., 2018)

In the first step, we used a procedure based on detecting and matching image features to align the photos. The algorithm estimates camera parameters such as focal length in x,y dimensions, principal point coordinates, skew transformation coefficient, and radial and tangential distortion coefficients, using only the relation between the images (Agisoft LLC, 2011; Heikkila and Silven, 1997; Lucchese, 2005; Slama et al., 1980). SfM matches individual pixels between the images independent of geometric transformations and instead based on information from neighboring pixels (Apollonio et al., 2014; Harris, 1993; Lowe, 2004), . The algorithm detects points in both source photos that are stable under different viewpoint and lighting conditions, depending on the camera position (Agisoft LLC, 2011; Ouédraogo et al., 2014) and identifies tie points (TP) between images. Because data about flight, camera, image and film parameters were either unavailable or incomplete for Corona photographs (Dashora et al., 2007; Galiatsatos et al., 2004; Kim et al., 2007), we utilized the Agisoft Photoscan algorithm, and the derived tie points to estimate the intrinsic camera parameters. Based on the tie points and the intrinsic camera parameters, we computed the 3D points in a synthetic coordinate system that was not connected to a real-world coordinate system (Agisoft LLC, 2011).

In the second step we assigned real-world coordinates to the point-cloud, by calculating the extrinsic orientation parameters of the camera using the relation between the point cloud coordinates and ground control points (GCPs). To calculate this relation, we used the Helmert 3D transformation (Watson, 2006). We selected GCPs for each stereographic pair and distributed 20-30 points per pair evenly across the area and at different altitudes (Figure 3). The ground x,y and z coordinates for GCPs were derived from an aerial image mosaic from 2010 provided as WMS (Web Map Service) from National Cadaster Agency, and from the Shuttle Radar Topographic Mission (SRTM) data for elevation (ANCPI, 2010; USGS, 2004). We aimed for an average locational error of 15 m for the entire scene. If the error was higher, we added more GCPs and recalculated the extrinsic orientation parameter (Figure 3).

In the third step, we extracted the digital surface model, which is important for the orthorectification of the Corona images. The precision and resolution of the digital surface model greatly affects the accuracy of the final product, especially in mountainous areas (Altmaier and Kany, 2002; Popescu et al., 2003; Verhoeven et al., 2012). To extract a precise digital surface model from the point cloud, we used the exact smooth method, which is based on pair-wise depth map computation (Agisoft LLC, 2011). To extract a high-resolution digital surface model, we calculated the depth information for each camera and combined it into a single dense point-cloud. We built the digital surface model by interpolating the dense points with an Inverse Distance Weighting interpolation (Agisoft LLC, 2011; Henley, 2012).

In the fourth and final step, we generated the orthophotos based on the relation between original Corona images and the digital surface model and compiled a full area coverage orthophoto mosaic. (Agisoft LLC, 2011; Lerma et al., 2006).

We quantified the processing time for each stereographic pair that we analyzed and tested the positional accuracy after georectification for the horizontal axes x and y, and the total 3D error, using the previously selected Ground Control Points (GCP). To assess what affected georectification accuracy, we summarized the total error by camera type, image quality, major morphological classes, and slope. For continuous variables, we calculated their correlation with the overall error. For categorical variables, we ran two-sample T-tests, and Tukey multiple comparisons of means to test if certain categories had higher overall error.

Additionally, we created an independent and random validation point dataset containing 400 random points distributed across the different Corona missions.

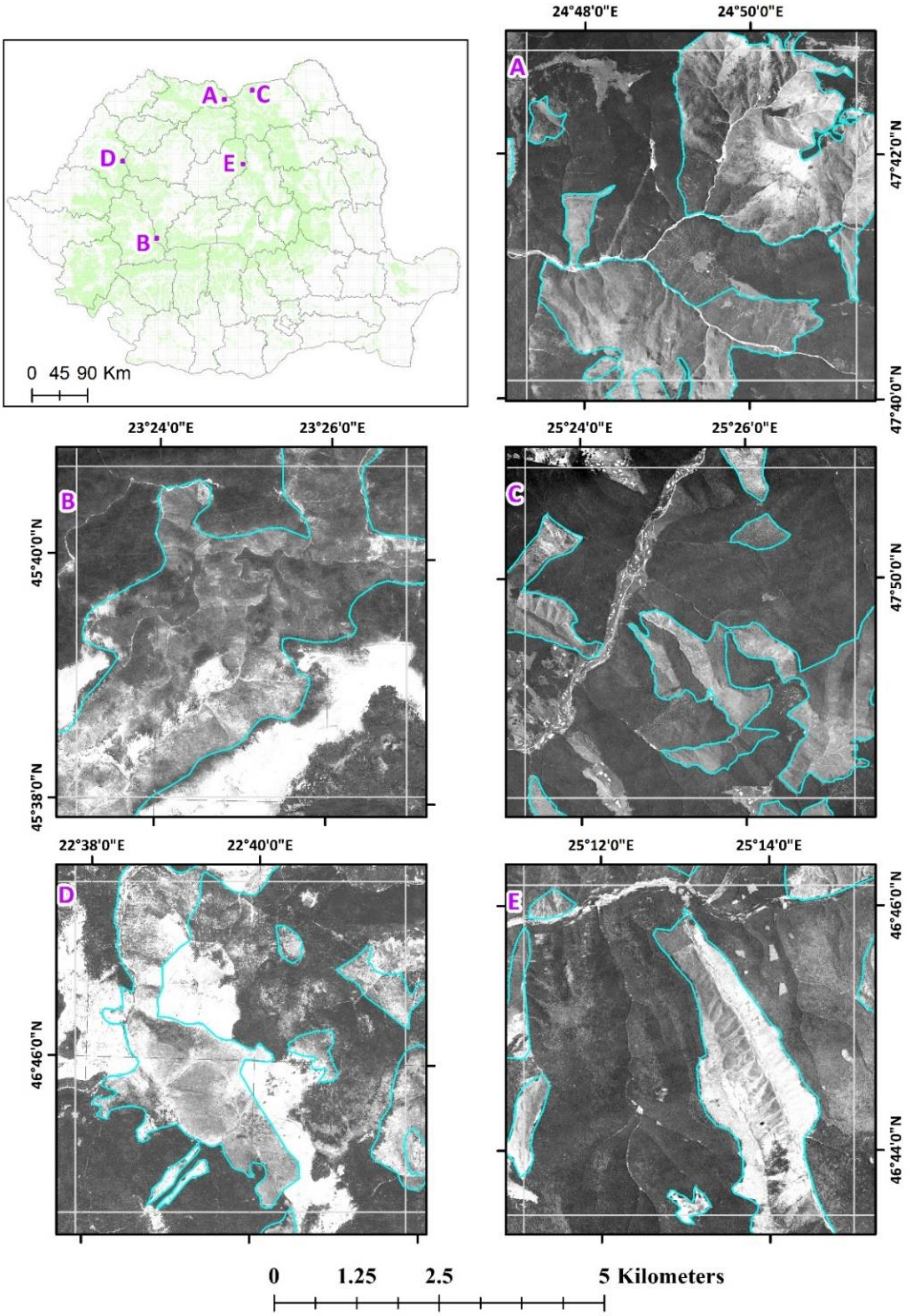


Figure 4: Forest cover in Romania in year 1970 (top left), and five 5x5 km cell examples of forest disturbance in Corona photographs. A: Maramures (1964), B: Hunedoara (1968), C:

Suceava (1964), D: Bihor (1968), E: Mures (1964). Blue lines represent the digitized disturbed areas and grey lines represent the cell limit (Nita et al., 2018)

For the forest harvest analysis, we mosaicked the 104 orthophotos and digitized all forest disturbances using standard visual interpretation techniques. We defined forest disturbance as loss of forest cover, including clear-cuts, final-cuts in shelterwood systems, windthrows, and insect attacks that were visually apparent in the pan-chromatic image mosaics due to differences in image texture, gray level and patch size (Figure 4). To differentiate the disturbances from pastures or other visually similar areas we used a forest cover mask extracted from the 1970 topographic map of Romania (Directia Topografica Militara, 1975). Based on our estimate, visible disturbances in the Corona mosaic stemmed from forest disturbances from 1955-1965. We chose this 10 year period based on forest regeneration rates observed in other remote sensing studies in the Carpathians (Hansen et al., 2013; Potapov et al., 2015). Additionally, we tested the rate of forest regeneration in terms of how texture and grayscales changed over time, by examining Corona images from successive years (i.e., 1962, 1964, 1968) for selected areas.

### *2.3. Results*

### *2.3.1. Long term evolution of Romanian forests 1920 – 2016*

Historic forest management (particularly extensive forest harvest) is reflected in contemporary age structure, composition and disturbance patterns across Romania. Overall, forest area increased in Romania by roughly 308.000 ha since 1924, and the country experienced forest transition (shift from decreasing to increasing forest area) in the first half of the 20th century. The lowest forest cover occurred sometime between 1920s, when disturbance was particularly high (93000ha) and 1955 when forest inventory area was as its minimum (5735000ha). Forest harvest reached its highest point in the late 19th century (with over 100000ha being harvested in one year, Figure 5). The contemporary Romanian forest inventory reports 6.3 mil ha of forest, which does not include shrub encroachment and forest succession on abandoned lands (estimated at 2.2 mil ha Hansen et al., 2013). Overall, yearly forest disturbance decreased from 1.40 % of the total forest cover in 1924 to 0.71% in 2013.

Forest composition also changed substantially in Romania, with the proportion of deciduous forests decreasing since 1924, when beech accounted for 39% and oak for 22% of the total forest cover. The maximum coniferous cover was reached in Romania in the mid 1980s (31%).

Forest ownership changed drastically during several historical land reforms and post-socialist privatization. Our data indicated that in Romania in 1924 land ownership was divided between private land owners (3 298 000 ha), state (1 556 000 ha) and other institutions (1 217 000 ha) i.e., roughly 54, 26 and 20% respectively. Privately owned land decreased by 1940 to 48% of the total forest area. In 1948 all forest was passed into state ownership (Ioras and Abrudan, 2006). Total state ownership lasted until 1991 when following the collapse of the socialism land started being privatised. Post socialist statistics report a shift in ownership to 30% private, 53% state and 17% other institutions, with a higher percentage of publicly owned forests than before WWII (Figure 5). In 2014, private forests represented roughly one third of the private forest in 1924. The cross-tabulation of forest disturbance and ownership patterns showed that in 1924 54% of the forests were privately owned, but as much as 66% of the disturbances occurred in privately owned forests and only 20% in state forests. Spatial information on disturbance by ownership type for 2010 was not available to us.

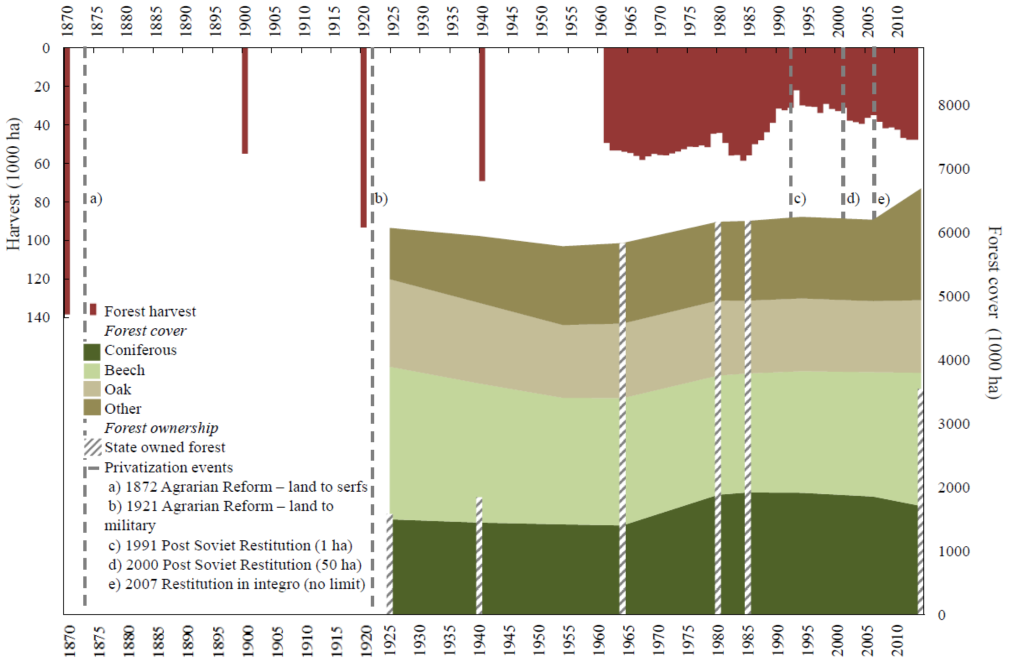


Figure 5: The evolution of forest cover, species composition, disturbance and ownership patterns in Romania between 1870s and 2010, in the context of major land tenure changes (C. Munteanu et al., 2016)

Forest area increased in Romania since 1924 (when it covered 6072000 ha) by 5% and the total amount of forest harvested (clear cuts and final cuts) between 2000-2013 dropped by 30% (amounting a total of 250000 ha) compared to 1912-1922. Historically, forest harvest was concentrated in the more accessible, lowland areas of Romania, especially in the south and east of the country, where individual counties had annual harvesting rates between 4-6% of their forest cover (Constanta, Ilfov, Vlasca, Olt and Covurlui). Contemporary forest harvesting is concentrated mostly in Northern Carpathians and the northern half of Transylvania (Suceava, Bistrita-Nasaud, Harghita, Covasna, Cluj, Mures, Neamt, Bacau), as well as in the south-east of the country (Calarasi, Ialomita), where forest cover was low to begin with (10% of the county territory). In contrast to overall lower harvesting rates across Romania, in some of the Eastern Carpathian counties, contemporary forest disturbance was higher than historic forest disturbance (Figure 6).

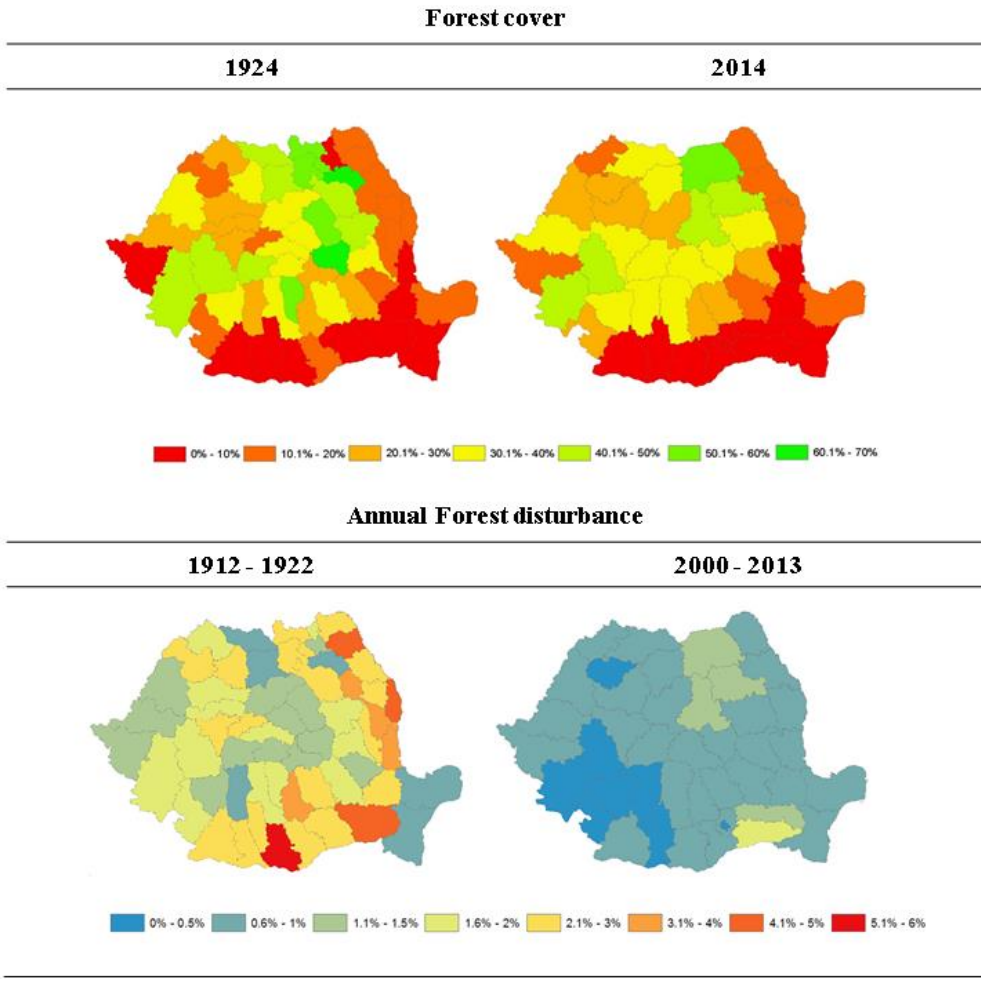


Figure 6: Percentage forest cover and forest disturbance in Romania historically (n= 58 counties) and contemporary (n=42 counties) (C. Munteanu et al., 2016)

We found that the total area, proportion and spatial distribution of main tree species changed drastically across Romania since 1924. Forest composition shifted towards higher coniferous (Picea sp, Pinus sp, Larix decidua and Pseudotsuga menziesii) and other softwood species (Tilia cordata, Populus sp, Betula sp, Alnus sp) which are now more homogenously distributed in space. Norway spruce increased in area since 1924 (by 6.75%), currently covering an area of 1 590 000 ha in Romania. Spruce was mostly concentrated at higher elevations and in the northern part of the Carpathians, but its area was extended to lower elevations more recently. Beech and fir decreased in area (by 14.66% and 1.05% respectively), losing a total of 861000 ha, mostly to spruce plantations. For both species, we found a more spatially homogeneous distribution amongst most counties of Romania: beech declined in the southern Carpathians and the west of Romania and increased slightly in the south of the country. Oaks cover now roughly the same area in Romania as in 1924 (ca.1 400 000 ha, amounting 22% of the forest cover) but the abundance and spatial distribution shifted greatly from southern Transylvania and the western part of the country towards the southern and eastern regions. We recorded highest loss of oak from the historical regions of Alba de Jos, Tarnava Mica and Tarnava Mare where oak comprised between 30-50% of all forests in 1924 to only 10-20% in 2010 (Figure 7).

In contemporary Romania, more forests are even-aged and the area of old forests decreased compared to the historic time period. Age structure data was available only at regional level for 2014, and at the county level for 1924. We complemented this dataset with national level statistics for 1964 and aggregated all data to the national level. Old forests (over 80 years) had a higher percentage ( 25 % of all forests) in 1924 compared to 2014 (21% of all forests). In 1924 as much as 49% of all forests were in age classes below 40 years old, with a total of 1887000 ha being younger than 20 years old. Overall, we observed an equalization of age structure over time, with roughly 10-17% forest in each age class. Between 1924 and 2014, forests over 100 years declined from 14% to 9% and forests between 80-100 increased by 1% (Figure 8).

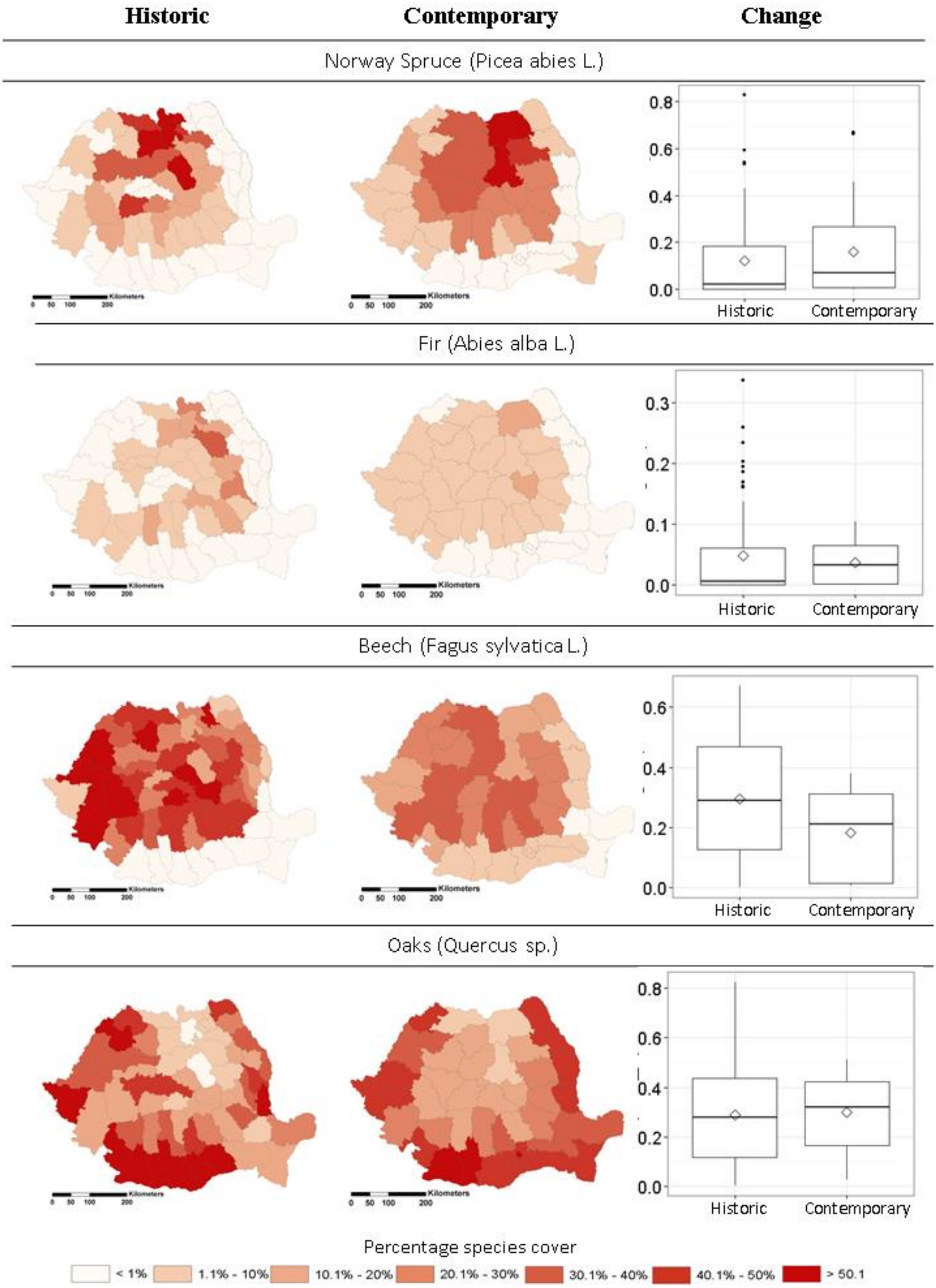


Figure 7: Percentage of major coniferous species (Picea abies, Abies alba) and major deciduous species (Fagus sylvatica, Quercus sp) within forest cover of Romanian regions in 1924 (n= 58 regions) and in 2014 (n=42 regions) (C. Munteanu et al., 2016)

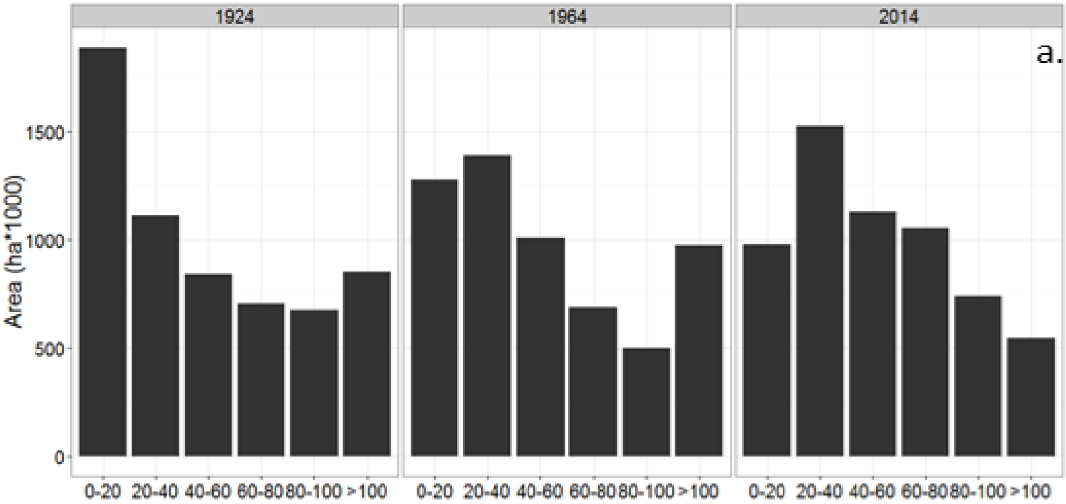


Figure 8. Forest age distribution in Romania in at (a) national level for the years 1924, 1964 and 2014 (C. Munteanu et al., 2016)

### 2.3.2. Influence of WWII to Romanian forests in 1954-1964

We found that out of the total 6,100,000 ha of forest cover in 1950 (C. Munteanu et al., 2016), 530,000 ha were harvested from 1955 to 1965. We mapped 10,505 harvest patches, most of them in spruce, beech and mixed beech-spruce forests. The forest harvests covered 8.7% of the total forest area. Most of the disturbances were concentrated in the northern part of the Eastern Romanian Carpathians (Figure ), but large harvests also occurred in the western Southern Carpathians, and in the central part of the Western Romanian Carpathians. The average size of harvested patches was 50.5 hectares, but at elevations higher than 500 meters, the average patch size was 123 ha, and individual cuts were as large as 11,700 ha (Table3).

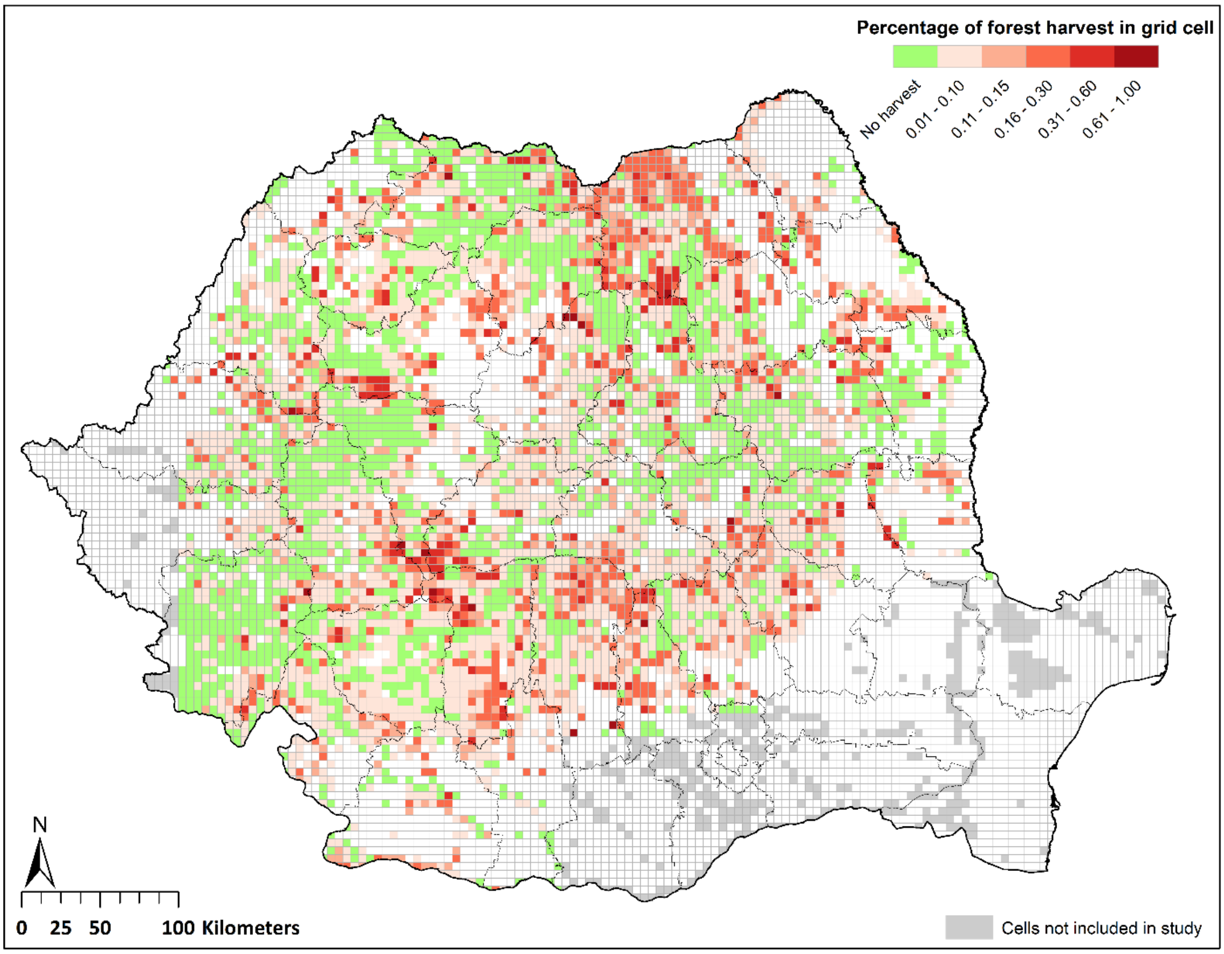


Figure 9: Forest disturbances patterns summarized for 5-km grid cells (based on 1962-1966 photographs).

We found that the largest harvests were concentrated in mountain areas and affected mostly mixed beech and spruce forests, with smaller (average 43 ha) and clustered patches in hilly areas. Most the harvests occurred on steep slopes (>10 degrees). Spruce, mixed beech-spruce and beech forests were generally targeted for harvest, with a total of 35% of the harvest (190,000 ha) occurring in beech forests, and another 35% in mixed beech and spruce forests (Table 1).

When we cross-checked our disturbance data versus contemporary forest age according to the forest management plans of selected areas, we found that for 98% of the areas, the age distribution data coincided with disturbances mapped from Corona (Figure ). The average forest management year for cross-checking the disturbance data was 1959.5.

Table 1: Forest disturbance patch summaries

| | No of patches | Harvested area (ha) | Average patch size (ha) | Std. dev | Min patch size | Max patch size |
|---|---|---|---|---|---|---|
| **TOTAL** | 10505 | 530901.5 | 50.5 | 176.2 | <0.01 | 11731.8 |
| **Major relief units** | | | | | | |
| Plains | 598 | 13071.0 | 21.9 | 31.5 | <0.01 | 373.8 |
| Hills | 5642 | 147255.6 | 26.1 | 43.4 | <0.01 | 836.6 |
| Mountains | 4260 | 370536.4 | 87.0 | 267.7 | <0.01 | 11731.8 |
| **Main forest types** | | | | | | |
| Beech | 3792 | 190179.9 | 50.2 | 108.6 | <0.01 | 3186.2 |
| Spruce | 767 | 63427.2 | 82.7 | 206.0 | <0.01 | 2770.8 |
| Spruce- Beech Mix | 1544 | 187919.5 | 121.7 | 388.1 | <0.01 | 11731.8 |
| Others | 1417 | 19359.7 | 13.7 | 15.8 | <0.01 | 187.2 |
| Oak | 2985 | 70015.3 | 23.5 | 33.2 | <0.01 | 481.6 |
| **Elevation (m)** | | | | | | |
| <500 | 5704 | 148278.6 | 26.0 | 43.0 | <0.01 | 836.6 |
| 500-1000 | 201 | 24794.6 | 123.4 | 339.9 | <0.01 | 3186.2 |
| 1000-1500 | 1612 | 182578.3 | 113.3 | 381.4 | <0.01 | 11731.8 |
| >1500 | 2988 | 175250.1 | 58.7 | 125.3 | <0.01 | 2125.6 |
| **Slope (degrees)** | | | | | | |
| <5 | 1449 | 30777.7 | 21.2 | 31.5 | <0.01 | 481.6 |
| 5-15 | 5261 | 200203.8 | 38.1 | 99.6 | <0.01 | 3186.2 |
| 15-30 | 3668 | 296137.9 | 80.7 | 269.7 | <0.01 | 11731.8 |
| >30 | 127 | 3782.0 | 29.8 | 32.5 | <0.01 | 222.5 |

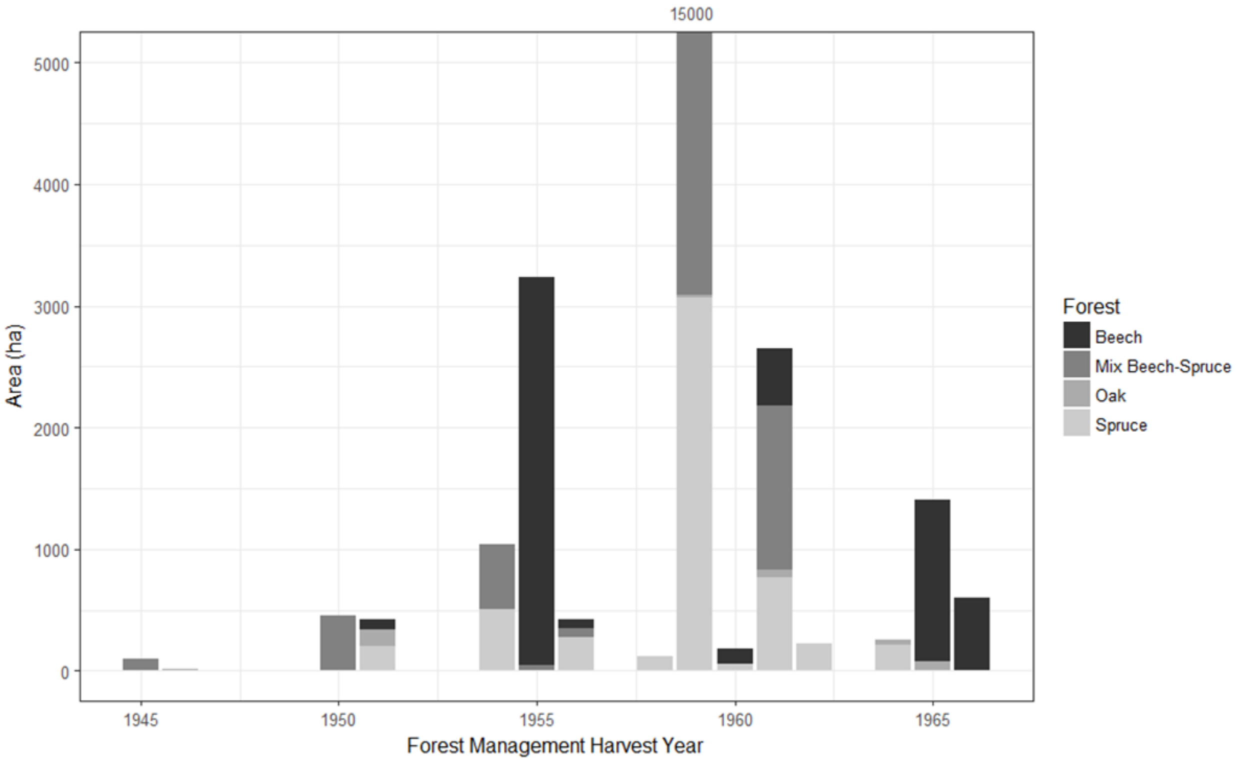


Figure 10: Forest harvest year distribution based on forest management plans within the cross-checked disturbance polygons that we digitized based on Corona images. Forest types are indicated based on forest types following Corona mapped disturbance. (Nita et al., 2018)

Last but not least, when we investigated the potential long term effects of historic harvests by cross-tabulating harvests in the 1960s with contemporary forest composition based on Corine Land Cover 2012 and pre-harvest forest composition (Catalina Munteanu et al., 2016), we found that of all the 1960s harvests, 32% were contemporary spruce monocultures

In order to assess the long term effects of historic land harvests on contemporary land cover data we cross-tabulated harvest information with contemporary CORINE Land Cover 2012 data and national statistics on pre-SOV-ROM, described in (C. Munteanu et al., 2016). We found that of the historically harvested areas, 32% are spruce monoculture in the CORINE data. Furthermore, 49% of the mixed beech forests and 9% of pure beech forests present in Romania in 1920s were harvested and transitioned to spruce monocultures until 2012, which is > 107.000ha (figure 11).

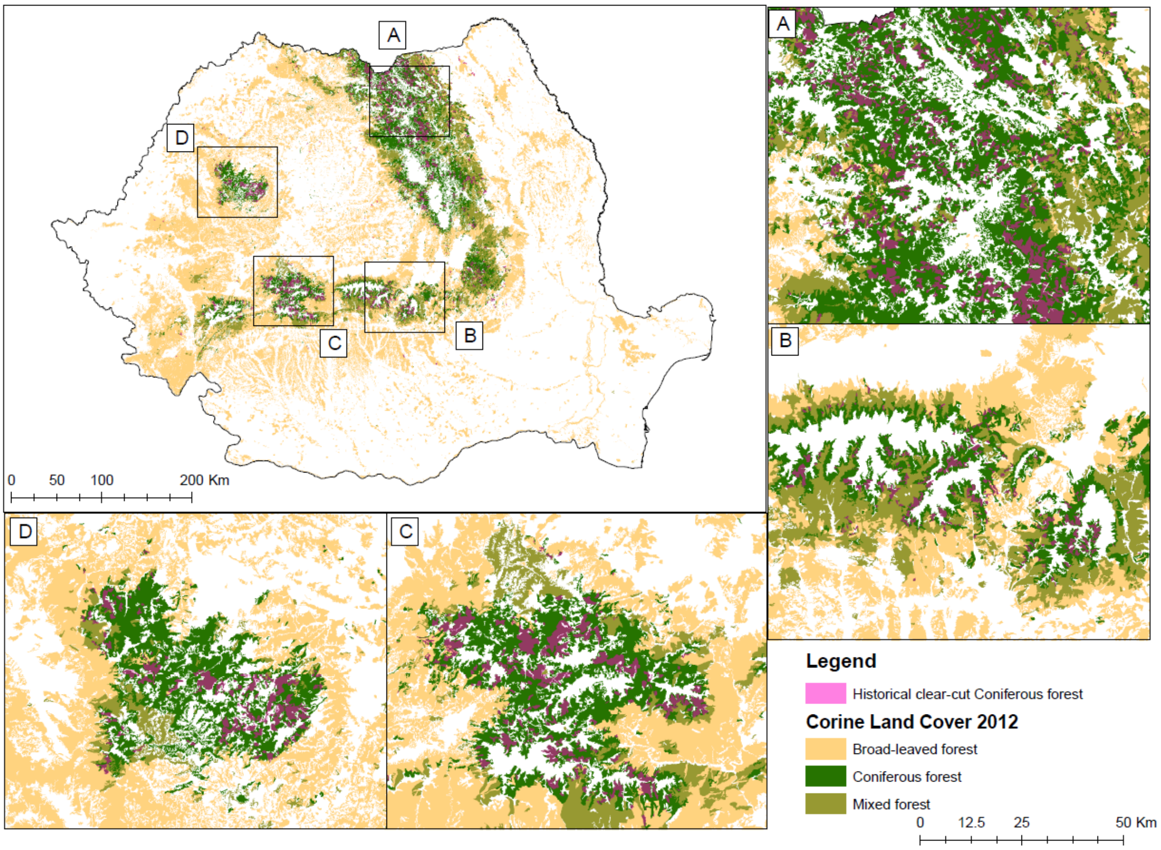


Figure 11. Spatial patterns of historical clear-cut Coniferous forests

### *2.4. Discussions*

We present here a substantial methodological advancement by developing an accurate, robust and fast method to orthorectify Corona photographs, which allowed us to extend the time horizon of space borne earth observation by over a decade prior to the first Landsat images. By applying this methodology, we were able to map post-WWII forest harvests across Romania for a total area of 212,000 km$^2$.We identified widespread forest cutting, with rates that were three times higher than the contemporary harvest rates. Our results suggest that time-lagged environmental effects of WWII were substantial in Romania. We attribute these effects to post-war socio-economic and political decisions such as reparation payments and related infrastructural development. Our results suggest that effects of wars on ecosystems may persist much longer than the wars themselves and that effects may have time-lags, particularly in cases where policies such as war reparations affect ecosystems for decades after the conflict ended (Fisunoglu, 2014; Kim et al., 2014; Organski and Kugler, 1977).

To quantify the environmental effects of WWII on Romania's forests, we developed an accurate and time-efficient method to orthorectify historical declassified satellite photography. Our new method is relevant to many disciplines concerned with land monitoring because Corona high-resolution data is available worldwide (Song et al., 2014), and our approach enables researchers and practitioners to extend the time-horizon of broad-scale analyses using satellite data from 1972, when the first Landsat was launched, to the early 1960s. The method is user-friendly, robust, time-efficient compared to photogrammetry methods (Galiatsatos et al., 2004; Sohn et al., 2004; Tappan et al., 2000) , and it does not require ancillary information regarding camera position and conditions, (Beck et al., 2007; Cassana and Cothren, 2008; Hamandawana et al., 2007; Ouédraogo et al., 2014; Peebles, 1997; Sohn et al., 2004; Zhou et al., 2003). Our method resulted in an average horizontal positional error of only 14.3 m, comparable to previous studies that employed photogrammetric approaches for rectification of Corona, and the number of ground control points that were required for the rectification was only 20-30 points per image strip, compared with 35-250 points for photogrammetric approaches (Casana and Cothren, 2013, 2008; Fowler, 2004; Grosse et al., 2005; Hamandawana et al., 2007; Sohn et al., 2004; Zhou et al., 2003).

Corona photographs have high spatial resolution (up to 2m), good spatial and temporal coverage, and are affordable. One image strip covers 3900 km$^2$ (Day, 2015; Sohn et al., 2004) and multiple images were typically recorded on the same day, making it possible to map large areas with high resolution data that is temporally consistent (Perry, 1973). The cost and the amount of data to be processed are lower when working with Corona (30$ per image strip) than when working with historic aerial photography. Furthermore, this approach can be easily applied to other aerial or satellite imagery with stereographic capabilities and could therefore represent a valuable tool for historic land monitoring.

Our methodological advancement allowed us to quantify the time-lagged effect of WWII on Romania's forests. Countries of the former Eastern Bloc that were relatively undeveloped (Fisunoglu, 2014; Kim et al., 2014), such as Romania, likely experienced a delay in the Phoenix factor after WWII (Organski and Kugler, 1977). Our results show that effects of WWII lasted at least two decades, likely due to war reparation payments and related infrastructural development effects (Bereziuc, 2004; Ivanescu, 1972). Indeed, war reparations in form of natural resources are common in many parts of the world following conflict events

(Parrini and Matray, 2002) and here we provide for the first time a solid estimate how this affected forest harvests.

In the context of Romanian forestry, our results highlighted the magnitude of forest harvesting after WWII partly due to war reparation agreement between Russia and Romania (Banu, 2004; Bekes et al., 2015; Ben-ner and Montias, 2015). This represents the first spatially explicit account of Cold War forest harvest for the region, and we mapped a total amount of 530,000 ha harvested forests. Prior reports suggested that Romania had agreed to pay war reparations to Russia by harvesting 256,000 ha of forest (Banu, 2004), but our results highlight that actual harvests may have been twice as much and continued even after Romania war reparations were paid in full in 1956. Furthermore, official reports from 1974 confirmed broad scale harvests between 1949 and 1964, when forest harvesting exceeded the sustainable thresholds by up to 47% countrywide (Marea Adunare Nationala, 1976). Most of those harvests were reported to have occurred in coniferous stands, which were harvested by as much as 104% above the sustainable level (Marea Adunare Nationala, 1976). Our results are consistent with reports that highlight major harvests in the regions of Neamt, Suceava and Bacau (Marea Adunare Nationala, 1976) but in addition to these regions, we found logging hotspots in Cluj, Hunedoara, Alba, Sibiu, Arges and Gorj.

We highlight that the majority of the harvests were clear cuts or final-cuts in shelterwood systems, and that mixed forest of spruce and beech were particularly affected by large-scale harvests, suggesting that the most valuable timber was especially targeted (Giurescu, 1976; Ivanescu, 1972). However, we caution that our analysis may have also captured wind throws or other natural disturbances, that we could not distinguish from harvests. Most of the disturbed forests were located in mountainous areas and in previously inaccessible valleys, which required new forest roads and narrow gage railways (Giurescu, 1976). This infrastructure development likely caused continued large-scale harvesting in areas that became newly accessible for forestry, even after the war reparation agreements between Russia and Romania ended (Giurgiu, 2010; Ivanescu, 1972). Our data capture these processes up to 1965 when a major political regime shift occurred in Romania, accompanied by changes in forest management (Tamas, 1987). In Romania, prior to the WWII, old forests (over 80 years) made up over 25% of all forests, but by 2010, this value had decreased to 21% (C. Munteanu et al., 2016). These reported decreases in old forests in Romania during the Socialist period may be related to the broad scale harvests that we show here. Furthermore, our analysis revealed one of the largest continuous disturbed areas (11,700 ha) ever identified in Romanian forestry.

More broadly, our findings make two major contributions to land-use science and remote sensing. We demonstrated the magnitude of time-lagged environmental effects of wars, which in Romania were also caused by war reparations and resulted in substantial changes in forest harvest and forest cover. This may also affect contemporary land management, land use change and conservation (Abrudan et al., 2009; Knorn et al., 2012b). Historic land use and disturbance events can impact contemporary soils (Foster et al., 2003; Plue et al., 2008), vegetation patterns (Morris et al., 2011; Rhemtulla et al., 2009), and subsequent rates of forest change (Munteanu et al., 2017, 2015b). In Romania, historic forest cover and historic deforestation affected both contemporary harvesting rates and forest composition (Munteanu et al., 2017, 2015b). Although most of the historically harvested areas have returned to forest cover, the composition and structure of differs greatly, with potentially major implications for management and conservation (C. Munteanu et al., 2016). A back-of-the envelope calculation of contemporary forest composition of historically harvested patches (based on Corine Land Cover data 2012) shows that as much as 14% contemporary spruce cover was actually harvested during our researched time period, and likely replanted with monocultures, despite the fact that as much as 67% as the harvested areas were historically deciduous or mixed forests. Furthermore, of the historic harvests, 163.307 ha (32%) are currently spruce monocultures (also see Supplementary Figure No 1). Monoculture are prone to natural disturbances such as windthrows and bark beetle infestations. More broadly, we provide evidence for the broad-scale effects of political and economic shocks on natural resources at multiple temporal scales.

Overall, our methodological contribution to the field of remote sensing is that we developed a fast and efficient approach to extend satellite-based land-use analyses into the past, based on Corona spy satellite photographs. Here, we used the case of Romanian forestry to show the time-lag effects of WWII on forest ecosystems in Romania, which may have long-term legacies up to today. We suggest that Corona photography, especially due to the stereoscopic capabilities (Galiatsatos et al., 2004) can be used for scientific inquiry in multiple fields such as geology, archeology, water and ice monitoring or vegetation monitoring . Our method unlocks the potential of such analysis at broad scales and for answering further remote sensing and ecological questions.

# 3. Forests dynamics in the montane watersheds using satellite imagery and climate data

## *3.1. Introduction*

Mountain water courses are distinct flowing ecosystems, which provide at the same time both an important source of clean water and a natural habitat for unique biological communities (Munteanu, 1979, Meyer et al, 2007, Richardson & Danehy, 2007). These streams are the interface between terrestrial and riparian ecosystems, providing hydrological connectivity between highlands and downstream waters (Clinciu, 2001; Freeman et al., 2007).

In international literature, small river basins have been defined as watercourses that either do not have tributaries (Strahler, 1957) or have fewer than three tributaries (Vannote et al, 1980, Freeman et al., 2007) (Peterson et al., 2001) or areas of less than 100 hectares (Gomi et al., 2002).

In the last decades, the altitudinal and latitudinal advancement of forest lines has increased due to global warming and the abandonment of less productive areas previously subject to agricultural activities. The intensity and speed of the forest line advancement depend also on numerous physical, biological and human factors that are region-specific. It is important to fully understand the mechanisms that stand behind such behaviours, since existing studies do not report global figures. The advancement of forest line is producing important changes in the montane watersheds leading to unknown changes in their hydrological system.

In Romania, because of the morphological particularities of the mountain area, "the basins are often torrential being represented by natural water courses characterized by relatively small areas of the order of hundreds or more than several thousand hectares with fast and irregular slopes and even with low flow, but which, due to the violent rains or sudden melting of the snow), show a large, rapid and short-term increase of the liquid flow, usually accompanied by intense erosion, transport and sedimentation " (Munteanu, 1968, 1975, 1979, Clinciu, 2001). For these reasons, the small hydrographic basins located in the mountainous area have been called torrential streams, that is courses which, although morphologically (surface, slopes of the slopes and the hydrographic network, etc.) resemble the actual torrents.

Small river basins cover large areas across the globe. In the world, torrential streams include some two-thirds authors (Leopold et al, 1964; Freeman et al, 2007) to over 80% after others (Sidle et al, 2000; 2002, Naiman et al, 2005) of the total length of watercourses. In our country, about 60% of Romania's hydrographic network has a strong torrential character, pluvial erosion affects over 6 million hectares (of which over 900 000 hectares with very strong and excessive erosion) and land slides expand to about 700 000 hectares (Gh. Mihaiu, 1998; V. Giurgiu, 1998).

A defining characteristic of torrential streams is specific hydrology. This affects the very perception of these basins. That is why the basins are no longer identified as simple land areas from which a hydrological formation collects their waters, but they are a part of the ecosystem that provides a specific environment, a habitat to both river vegetation and aquatic fauna.

The definition of small river basins in the mountain range varies from case to case depending on the field of activity and the scale at which they work. For example, at macro and regional level, small basins become slopes, the rapid floods that form on this narrow valley become "floodplains". Instead, at micro level, they become habitats for various plant and animal species, become river beds that transport alluviums into storage lakes, and examples can continue.

In conclusion a small hydrographic basin in the mountainous area is an open system, subject to reciprocal relations with internal and external factors, which are in close interdependence with the environment following the principle of action and reaction. It presents a very well-defined hydrological cycle with the components organized vertically (geology, morphology, etc.) and horizontally (vegetation, climate etc), which are interdependently hierarchical according to natural laws.

In montainous watersheds forested areas are increasing, especially in developed countries due to the combined effects of more intensive agriculture, abandonment of less productive areas and increasing awareness regarding the environmental importance of forests (Mueller et al. 2009, Kozak 2010, Lambin & Meyfroidt 2010, Baumann et al. 2011). In mountainous afforested areas, the dynamics in the montane-alpine belts, namely in the tree and forest lines, are particularly relevant. Here, climate influences ecological processes governing dynamics in forest stands, but human land-use has also been a control factor for centuries (Gehrig-Fasel et al. 2007). Due to the climatic influence on the tree and forest lines, they are regarded as environmental change descriptors. In Europe, changes in these boundaries have been observed (Gehrig-Fasel et al. 2007) and the discussion whether these changes are related to human land-use or climate is still open. Therefore, to monitor forest changes within the montane-alpine belts and evaluate their relationship with altered climatic features is of public interest, particularly if multiple sites are considered, allowing comparisons on a continental scale.

### *3.2. Using satellite imagery and climate data to monitor changes in mountain watersheds*

#### *3.2.1. Study areas*

We selected four study areas to analyse the temporal and spatial behaviour of the forest line and forest cover based on selection criteria such as minimal human interference and maximal representativeness at the European level. The sites were located in National Parks that were evently spread across Europe in some of the dominant European mountain ranges such as the Pyrenees, Alps and Carpathians, at comparable altitudes and latitudes and with similar land cover proportions in the year 1970.

The areas shared homogeneous minimum human influence and protected status (in the core areas of National Parks) and were located in the Austrian Alps, Slovak and Romanian Carpathians and Spanish Pyrenees at similar altitudes comparable un-forested surfaces in 1970 (pastures, alpine hollows, etc.): 19.945 ha (Ordesa, Spain), 18.945 ha (Nockberge, Austria), 10.436 ha (Tatra, Slovakia) and 15.175 ha (Retezat, Romania). The latitudinal range for selected areas was $4^0$ (between 43° and 47° N), while the general aspect (orientation) was Eastern-Western.

The treeline was defined in this study as the pixels classified as forest near the non-forest pixels located in the upper area of the massif. Assessing the expansion of forest line over time is a typical problem of change detection, and many approaches can be found in the literature (Singh 1989, Almutairi &and Warner 2010, Canty 2010; Hecheltjen et al. 2014, Singh 1989), each with specific advantages and disadvantages.

Change detection methods can be grouped into six categories (Lu et al. 2004): algebra (which includes image differencing, vegetation indexes, change vector analysis), transformation (e.g., principal components analysis), classification, advanced models (where image reflectance values are often converted to physically based parameters), GIS approaches and visual analysis. Generally, it is not possible to establish a priori which method of change detection is the most convenient, so the choice is often made on a pragmatic and application-driven basis (Coppin et al. 2004).

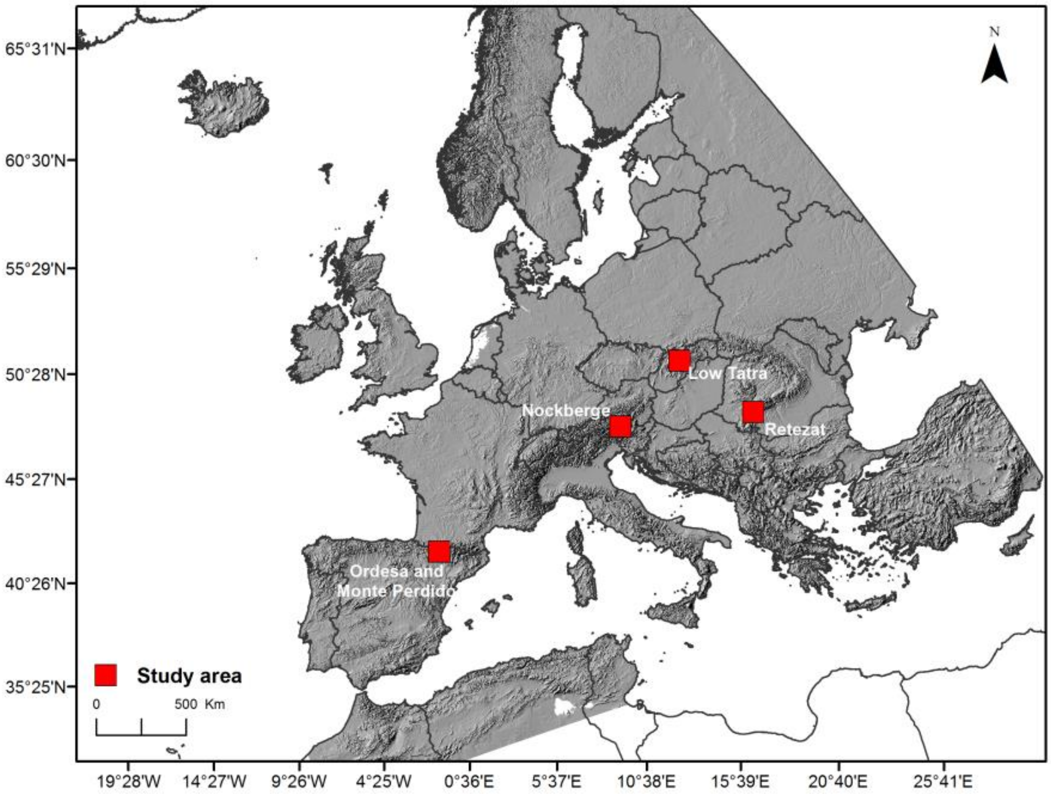


Figure 1. Location of the mountain study sites considered in this study: Ordesa and Monte Perdido, Spanish Pyrenees; Nockberge, Austrian Alps; Low Tatra and Retezat in the Slovak and Romanian Carpathians. (L. Dinca et al., 2017)

*3.2.2. Imagery pre-processing*

The Landsat Data Continuity Mission (LDCM) and the launch of the Landsat 8 platform in 2013 offer a unique opportunity to perform monitoring by remote sensing on a regional scale (Mandanici &and Bitelli 2015). Due to the large temporal extent (1972–2014), remote sensing data was obtained from different Landsat sensors: Landsat Multispectral Scanner (MSS) sensor for 1972 and 1980, Landsat Thematic Mapper (TM) sensor for 1990, Landsat Enhanced Thematic Mapper Plus (ETM+) for 2000, Operational Land Imager (OLI) for 2014.

Sixteen Landsat scenes acquired during the vegetation season (May–September between 1973 and 2014) were used to evaluate temporal dynamics in forest lines and forest covers across the study sites. The scenes were obtained from the USGS repository http://earthexplorer.usgs.gov/. To reduce noise caused by different acquisition angles, seasons and reflectance features, scenes captured in different years, but within the same vegetation season, were chosen for each study area. This is a useful procedure in multi-temporal studies with satellite data. In this study, we used L1T products which, according to producer, provides a high radiometric and geodetic accuracy by incorporating ground control points while employing a Digital Elevation Model (DEM) for topographic displacement (Table 1). The spectral coverageresolution of band images is (in micrometers) OLI 0.42 – 2.29, ETM 0.45 – 2.35, TM 0.45 – 2.35, MSS 0.5 – 1.1.

As reference cartographic material we used the Soviet Topographic Map, a declassified map which was created based on intelligence information gathered in the Cold War period (Oberman and Mazhitova, 2003). The maps were georeferenced based on the original Gauss-Kruger grid reprojected in UTM, WGS84 projection, with an average RMSE of 5 m.

Table 1 Summary of satellite data used forconsidered to multi-temporal mapping of forest dynamics in the mountain study sites. Data is given by site and date. NIR and SWIR refers to Near-Infrared and Shortwave Infrared bands, respectively. (L. Dinca et al., 2017)

| | Site | | | | Metadata | |
|---|---|---|---|---|---|---|
| Year | Ordesa | Nockberge | Low Tatra | Retezat | Band-to-band registration accuracy | Geometric accuracy and registration succes* |
| 1970 | Soviet Topographic Map | Soviet Topographic Map | Soviet Topographic Map | Soviet Topographic Map | - | 5 m |
| 1980 | 1975-07-26 Landsat 1 (GLS 1975) | 1979-05-22 Landsat 2 | 1979-09-03 Landsat 2 | 1980-09-21 Landsat 3 | 0.2 pixel (90%) | Less than 40 m (average 30.6) |
| 1990 | 1989-07-17 GLS 1990 | 1988-08-07 Landsat 5 | 1990-07-16 Landsat 5 | 1988-08-29 Landsat 5 | 0.2 pixel (90%) | Less than 30 m (average 22 m) |

| | Site | | | | Metadata | |
|---|---|---|---|---|---|---|
| 2000 | 2001-08-1 Landsat 7 | 2003-06-30 Landsat 7 | 2001-05-26 Landsat 7 | 2000-08-22 Landsat 7 | 0.2 pixel (90%) | Less than 30 m (average 4.6) |
| 2014 | 2014-07-22 Landsat 8 | 2014-09-18 Landsat 8 | 2014-08-03 Landsat 8 | 2014-07-04 Landsat 8 | 0.2 pixel (90%) | Less than 30 m<br>(average 8.3 m) |
| Spatial resolution (m) | 30 | 30 | 30 | 30 | | |
| Spectral resolution (μm) | Visible and NIR | Visible, NIR, SWIR | Visible, NIR, SWIR | Visible, NIR, SWIR | | |

*According to Landsat metadata files

### *3.2.3. Image processing*

To remove the relief effects, images were normalised using the SRTM digital terrain model downloaded from http://earthexplorer.usgs.gov/. SRTM (Shuttle Radar Topographic Mission) is a key breakthrough in digital mapping and provides a major advance in the accessibility of high quality elevation data worldwide.

The SCS topographic correction method was used to remove the topographic effects. SCS correction (Gu and Gillespie, 1998) is based on sun-canopy-senor geometry, and it can be expressed as:

$$L_m = L \cdot \left(\frac{\cos\theta \cdot \cos\alpha}{\cos i}\right)$$

where Lm is the normalized radiance, L is the uncorrected radiance, $\theta$ is the solar zenith angle, i is the incident angle, $\alpha$ is the slope of the surface.

All images have been thus co-registered to Universal Transverse Mercator (UTM) - WGS 84, and the accuracy of image registration was assessed using topographic plans and local cartographic products based on terrestrial measurements and aerial surveys, according to the acquisition period (figure 2).

Due to the different characteristics of spectral sensors (i.e. TM and ETM+) in the Landsat image series, we also corrected the spectral reflectance between images acquired by different sensors (MSS, TM, ETM+, OLI8). The empirical line approach for reflectance factor retrieval from Landsat-5 TM and Landsat-7 ETM+ was used for this purpose (Moran et al. 2001). All operations were performed in ENVI 5.0.

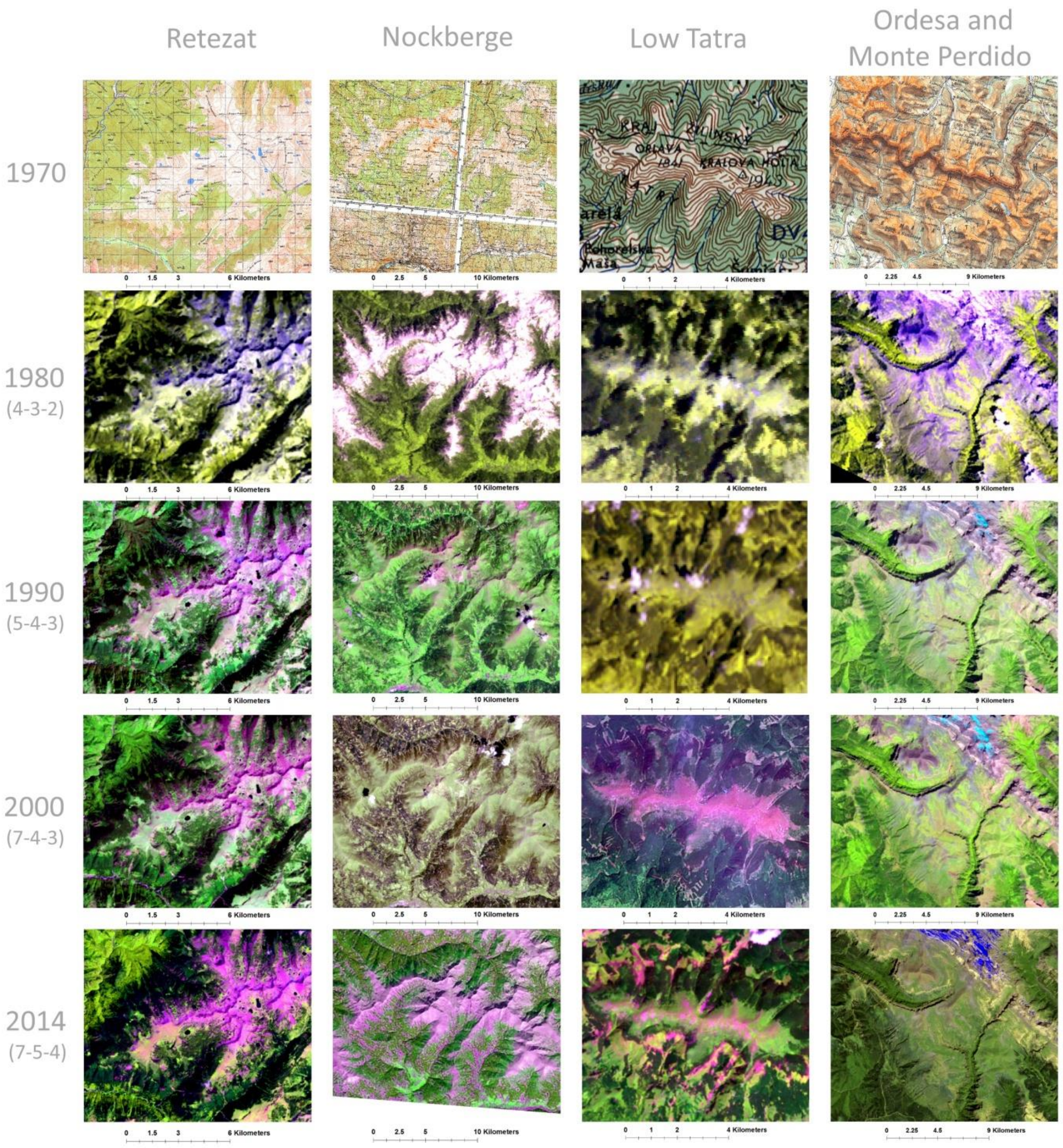


Figure 2. Illustration of topographic maps (1970) and Landsat imagery used in the supervised mapping of forest with false-color composites: 1980 (Landsat MSS 4-3-2), 1990 (Landsat TM 5-4-3), 2000 (Landsat ETM+ 7-4-3) and 2014 (Landsat OLI 7-5-4). (L. Dinca et al., 2017)

### *3.2.4. Mapping and change detection in forest line and cover*

Temporal and spatial dynamics in forest covers and lines within the montane-alpine elevation belts (> 900 m) were measured using post-classification comparison (PCC) change detection with independently classified images. This method compares pixel by pixel two independent classified images acquired onat different dates, using a change detection matrix (Jensen 2004). Here, PCC minimizes the influence of sensor variation in the detection of change. Results depend on the accuracy of initial classifications (Coppin et al. 1996). The method locates changes and provides "from-to" change information. Here, the source for PCC change detection was land cover data created for each Landsat scene. Land cover classification was performed using a supervised classification with maximum likelihood algorithm supported by. We used forest management data which provided information on the spatial distribution of forest spatial distribution and other additional variables (e.g. information like stand age, height or diameter). Two land cover classes were considered (forest and pasture), and all bands were used for classification, except the thermal band. The approach included the three stepsmethod consisted of choosing training sites selection, classification and assessment of results (Lillesand et al. 2008).

Reference data for training and validation was collected based on high resolution satellite images or air photos available in Google Earth that cover the complete study area (Baudron et al. 2011; Knorn et al. 2009). We sampled 200 random training areas and classified those as either forest or non-forest, based on visual interpretation. Areas were considered forested if tree cover exceeded 60% and forest patches were larger than one Landsat pixel (900 m2) (Kuemmerle et al. 2009).

Classification accuracy was evaluated through a confusion matrix based on a minimum of 100 ground-truths sites for each image established through random samplings strategy, other than the training sites, based on field recommendations (Congalton &and Green 2009, Vorovencii 2016). In order to emphasise the changes in land cover classes over the 1970–2014 period, the classified images were compared by cross-tabulation, which resulted in the change matrix that estimates quantitative change (Figure 3). Using theseis data, forest line and forest cover dynamics were quantified.

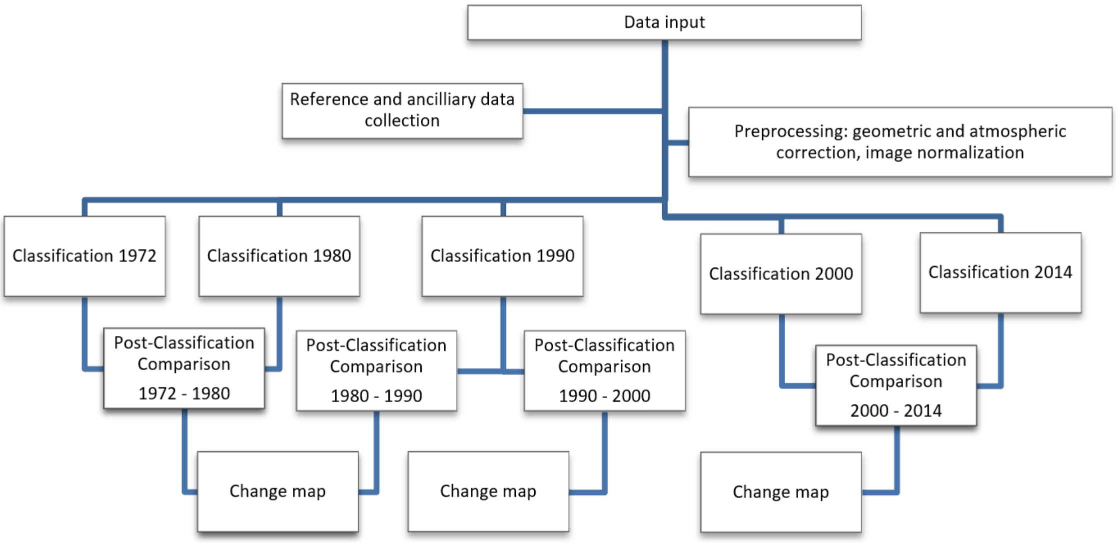


Figure 3. Analytical framework used for multi-temporal land cover analysis across the study sites with Landsat satellite scenes. (L. Dinca et al., 2017)

### 3.2.4. Historical climate data

Climate data retrieved from Climate Explorer Utility (http://climexp.knmi.nl) were used to pattern climate conditions across each study area from 1900 until 2014 (we took monthly station data, introducing the coordinates of the National Parks, from 10 nearest meteorological stations near that point). To reconstruct climate conditions trends during the analysed tree line period (1970-2014), climate data between 1901 and 1970 were taken as a baseline. Climate conditions were represented by average temperature, precipitation and deMartonne aridity index (de Martonne E, 1926). However, preliminary correlation analysis showed an insignificant statistical relationship between growth in forest area and the last two variables, which led to their exclusion from the analysis. This was expected, as precipitation in forest line ecosystems is not a limiting factor (Leal et al. 2007, Grytnes et al. 2014; Leal et al. 2007).

### 3.2.5. Statistical analysis

Temperature evolution was analysed by using simple graphical trends for the studied regions. The reference mean temperature values calculated as simple arithmetic means of periods covering 10 to 15 years each were used to plot the trends. A clear growth trend was observed, so further analyses were carried out to estimate the dependence between temperature growths and the percentage of forested cover growth, and thethe altitudinal forest line migration. The percentage of forested cover growth and the forest line altitudinal migration were plotted versus the relative temperature increment during the studied period. Furthermore, the dependence between the percentage of forest cover growth and forest line altitude migration, with respect to temperature variation in the studied period, were modelled using least square simple regression.

### *3.3. Results*

All study sites showed changes in forest line and forest cover. Large and lower change in elevation of the upper forest limit (altitude growing) occurred in the Alps (Nockberge) and Pyrenees (Ordesa), respectively. Surface forest growths indicated differences between sites. The largest forest expansion was registered in the Alps (28%; Nockberge) and the lowest in the Pyrenees (1%; Ordesa) for the period 1981-1990. Largest forest line advance was recorded in the Alps (Nockberge) and the Carpathians (Retezat), while the lowest was found for the Pyrenees (Ordesa) (Table 3).

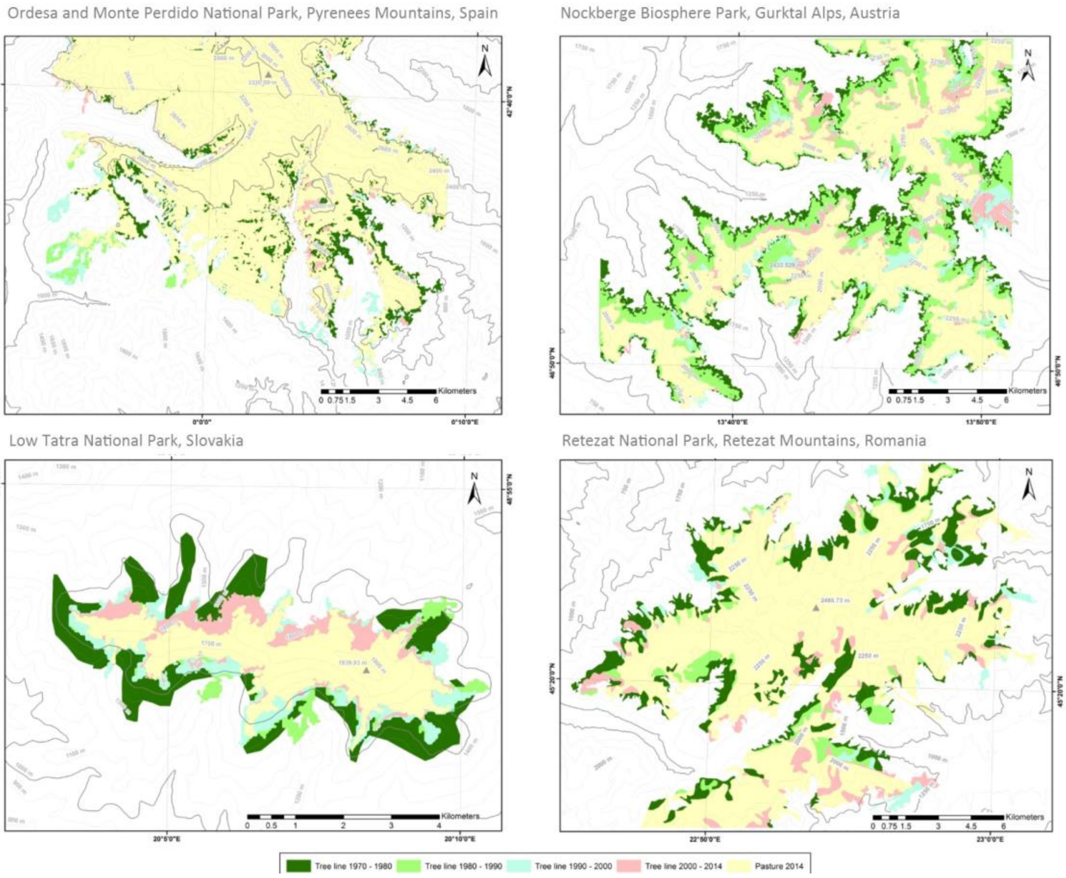


Figure 4. Spatial and temporal dynamics of forest line and cover in four European mountain sites obtained from supervised land cover classification of Landsat satellite data between 1970 and 2015. Dynamics are represented using a ten-year time-step interval for:

(a) Ordesa and Monte Perdido National Park, Spain; (b) Nockberge Biopshere Park, Austria; (c) Low Tatra Park, Slovakia and (d) Retezat National Park, Romania. (L. Dinca et al., 2017)

**Table 3.** Summary of changes in forest line and forest cover across the study areas between 1970 and 2014 and average annual temperatures registered during this period. (L. Dinca et al., 2017)

| Site | Years | 1901-1970 | 1971-1980 | 1981-1990 | 1991-2000 | 2001-2014 |
|---|---|---|---|---|---|---|
| Ordesa | Forest line surface growing (ha) | 0 | 243 | 195 | 874 | 3034 |
| | Forest line surface growing (%) | | 1.22 | 0.99 | 0.48 | 1.28 |
| | Altitude growing (m) | 0 | 5 | 4 | 18 | 5 |
| | Temperature (°C) | 4.45 | 4.63 | 5.25 | 5.79 | 6.00 |
| Nockberge | Forest line surface growing (ha) | 0 | 3204 | 4430 | 1601 | 1539 |
| | Forest line surface growing (%) | | 16.91 | 28.14 | 14.15 | 10.03 |
| | Altitude growing (m) | 0 | 90 | 44 | 34 | 2 |
| | Temperature (°C) | 4.10 | 4.29 | 4.73 | 5.29 | 5.51 |
| Low Tatra | Forest line surface growing (ha) | 0 | 181 | 5 | 271 | 183 |
| | Forest line surface growing (%) | | 12.6 | 0.4 | 21.68 | 18.69 |
| | Altitude growing (m) | 0 | 43 | 10 | 40 | 1 |
| | Temperature (°C) | 2.22 | 2.41 | 2.81 | 2.91 | 3.62 |
| Retezat | Forest line surface growing (ha) | 0 | 1997 | 737 | 414 | 962 |
| | Forest line surface growing (%) | | 13.16 | 5.67 | 3.38 | 8.12 |
| | Altitude growing (m) | 0 | 61 | 13 | 5 | 17 |
| | Temperature (°C) | 4.36 | 4.08 | 4.24 | 4.54 | 5.25 |

Forest expansion varied also across exposure classes and study sites. In the Austrian alps (Nockberge) and the Romanian Carpathians (Retezat), expansion was strongly skewed to northerly slopes, while in the Slovakian Carpathians (Low Tatra), it occurred mostly on southerly slopes.

**Table 4.** Spatial distribution of the expansion in forest cover (%) across topographic exposure classes in the study areas. (L. Dinca et al., 2017)

| Exposition | Forest area growth (%) | | |
|---|---|---|---|
| | Nockberge | Retezat | Low Tatra |

| | | | |
|---|---|---|---|
| N | 18 | 14 | 15 |
| NE | 18 | 12 | 12 |
| E | 11 | 10 | 7 |
| SE | 6 | 11 | 20 |
| S | 5 | 9 | 22 |
| SW | 8 | 11 | 10 |
| W | 16 | 14 | 3 |
| NW | 19 | 20 | 9 |

### *3.4. Discussion*

In this study, we combined multi-temporal satellite image analysis and observed the impacts of climate on forest cover and forest line dynamics in the montane-alpine boundary across European mountains between 1970-2014. Four protected areas, distributed along a west-east longitudinal gradient and enclosed in three emblematic European mountain ranges (Pyrenees, Alps and Carpathians), were considered. These areas were in National Parks created before the oldest satellite images considered for analysis. Therefore, human influence (cattle grazing, tree cutting, etc.) in the period of analysis was minimized, and changes in forest cover and line were mostly driven by natural processes. The influence of natural disruptive factors (windfalls, fires, insect attacks, etc.) was not accounted in this study. The accuracy values of imagery classification were predominantly above the average standard (85%) suggested by the USGS classification scheme (Anderson et al. 1976) and in line with previous studies using Landsat data in mountain regions (Doren et al. 2003; Kharuk et al. 2010). Lower accuracy values in some scenes, which can slightly influence the estimations, are related to common factors influencing multi-temporal satellite studies in mountain areas (e.g. spatial resolution, atmospheric anomalies and cloud cover), including in tree line studies (Zhang et al. 2008).

Forest change analysis revealed a considerable expansion in forest cover and altitudinal migration of forest lines in the montane-alpine boundary across all sites, particularly in the central eastern mountains. The expansion of the forest cover and increase in altitude of the upper forest line were two common patterns for northern hemisphere mountains in the last decades (Bolli et al. 2006, Gehring-Fasel et al. 2007, Harsh et al. 2009, Sckickhoff et al. 2015). Both forest cover and forest line were below their potential ranges (Gehring-Fasel et al. 2007), especially in mountains where humans have social and economic interests (Motta et al. 2006), as in the case of our study sites. The combination of atmospheric warming and decreased human activities at high altitudes promoted forest cover expansion and forest line shifts (Motta et al. 2006, Gehring-Fasel et al. 2007, Leonelli et al. 2011). Our patterns of upward shifts of the forest line were not uniform and varied across sites (Harsch et al. 2009). Registered upward shifts of forest lines were below (Low Tatra), in line (Retezat) or above (Nockberge) the 70-100 m belt previously proposed (Moiseev et al., 2010). Forest cover expansion also differed among sites and topographic exposure. While the western forest (Pyrenees) was slightly altered, central-eastern sites showed a considerable forest cover expansion of up to 28%. Dynamics in forests of central-eastern Europe have been widely discussed during the last few years (e.g. Gherig-Fasel et al. 2007, Hartl-Meier et al. 2014, Pretzsch et al. 2014, Munteanu et al. 2016).

The anthropogenic effect on forest expansion is reinforced by asymmetric historical distributions of the largest expansion periods across the study areas. While in the Romanian Carpathians (Retezat), large expansion occurred until the 1980s, in the Austrian Alps (Nockberg) and the Slovak Carpathians (Low Tatra), the hottest periods were registered within and after the 1990s. Moreover, large tree line upward shifts occurred in the early 1980s. This asymmetry within study sites under the same trend (increasing average temperatures during the last century) suggests that average temperature is not the only factor impacting forest and forest line expansion. Indeed, anthropogenic activity determined European mountain tree lines (Dirnböck et al. 2003, Kuemmerlee et al. 2008).

Several alpine treeline studies have documented altitudinal shifts and tree-density increase during the 20th century (Kullman, 1979, MacDonald et al. 1998), although only 51% out of 166 sites reviewed by Harsch et al. (2009) showed tree line advance. The main factors responsible for those changes were climate warming and land-use modification. In the Pyrenees, increases in temperatures between 1882 and 1970 were observed at the Pic du Midi meteorological station (Bücher & Dessens, 1991). In parallel, grazing pressure has been declining drastically since the 1950s (Alados et al. 2014). In spite of these changes, we did not observe the expected treeline upward shift. Previous studies (Camarero & Gutierrez 2004, Camarero et al. 2015) also showed that the treeline remained static in the central Pyrenees, while tree density increased within the ecotone.

In conclusion, rising mean annual temperatures in mountainous European areas have influenced tree line advancement, especially in areas with reduced human intervention

(National Parks). This mechanism was stronger in the mountainous areas located in Central Europe (Alps, Carpathians) and weaker in the warmer European areas (Pyrenees). Though, uncertainty in the definition of the line's position suggests careful interpretations. The accuracy with which the location of forest lines can be measured in historical data is influenced by the georeferencing accuracy of the data sources and the accuracy of the mapping technique in the definition of the line's position (Hofgaard et al. 2013). Our data include estimated uncertainties of 0.2 pixels band-to-band, which indicate a relative misregistration of less than 1/3 pixel in the position of forest lines due to misresgistration of Landsat imagery. In addition, uncertainty due to misclassification of forest class have also occurred. Mean uncertainty due to misclassification amounted to 11.2%, with Pyrenees (Ordesa) presenting the higher values. Interpretation in sites with limited change in forest line (e.g. Ordesa) and high uncertainty requires therefore caution.

Overall, open-access to historical forest maps and multispectral satellite imagery archives combined to accurate pre-processing and classification is well suited to multi-site comparative analysis on forest line and forest cover dynamics. Comparative analysis of forest lines in protected areas can be a good strategy to better understand the response of natural system to changes in climate conditions. The considering of novel variables can further enhance the benefits to mountain forest line understanding.

# 4. Forest management and the impact on water resources using geospatial analysis

## *4.1. Introduction*

The Romanian forests have a very interesting history due to the influences of different policies of the neighboring empires (Austrian-Hungarian, Ottoman, and Russian). Since 1864 until First World War, the increasing agricultural business in Romania put pressure on forests, causing losses up to 25% of forest cover. This decrease led to increasing of desertification phenomena in South of Romania.

Total forest area in Romania consists of 6.339.000 hectares from which 6.245.000 hectares covered with forest vegetation (27% of total land area of the country). In terms of tree cover the area is higher (approximately 8 million hectares), the difference is given mostly by reforestation of abandoned agricultural land, showing that the forest is gaining back his territories.

With a current population of 20.2 million, the average water availability in Romania amounts to 2000 cubic meters per capita per year, value which is above the thresholds generally defined for water stress (1700 cubic meter per capita per year), but lower than the average value for Europe (approx. 4500 cubic meters per capita per year).

The research in forest hydrology started in 1969 when several representative basins have been equipped with a minimum of facilities specific to the study: pairs of rain gauges or pluviograph, in the open and under the canopy of trees to study the canopy retention of part of the fallen precipitation, devices for determining sap tree flow and evaporation. The main goal of past research was to determine the factors and how much they influence the water balance in forested basins.

The legislation in Romania offers a good framework for increasing water yield and quality by increasing forest cover and quality. Another legal support is FSC certification of approximately 50% which regulates forest harvesting aiming to usage of non-invasive modern technologies.

Nowadays the future research and management practices that should be incorporated in the management of forest to improve water quality and water yield is to increase the forest cover especially in Southern and Easter counties, due to the increasing desertification phenomena. The research activity should concentrate on the needs of forest managers which converge into one point: increasing the forest cover by maintaining the harmony between economic needs and ecological demands

Romania's relief is split threefold: 31% mountainous; 36% hills/plateaus; 33% plains. The Carpathian ring is part of the Alpine chain, connected to the Alps in the west and the Balkans in the south. Beyond this are the Transylvanian Depression, which fills the Carpathian ring, hills, plains and the Dobrogea Plateau, plus the plains of the Lower Danube and Banat–Crisana.

Romania's climate is mild, temperate-continental with four distinct seasons, most precipitation in the warm season and some Mediterranean influence to the south. Mean annual precipitation is 400-800 mm in the main agricultural area and over 1200 mm in the Carpathians. Severe drought occurs every 15–25 years, especially in the plains.

Total forest area in Romania consists of 6.339.000 hectares from which 6.245.000 hectares covered with forest vegetation (27% of total land area of the country). Forest composition is varied. Conifers make up 31% (23% spruce, 5% fir-tree and other conifers 3%), beech 31%, oaks l8%, other hard broad-leaves 15% and soft broad-leaves 5% (Giurgiu, 2010). In terms of tree cover the area is higher (approximately 8 million hectares), the difference is given mostly by reforestation of abandoned agricultural land.

The Romanian forests have a very interesting history due to the influences of different policies of the neighboring empires (Austrian-Hungarian, Ottoman, and Russian). This history revealed drastically changes in landscape, especially in the part of forest loss for agricultural land (fig.1). Cutting age research results showed that *"Over the last century* **humans have altered the export of fluvial materials** *leading to significant changes in morphology, chemistry, and biology of the coastal ocean. Here we present sedimentary, paleoenvironmental and paleogenetic evidence to show that the Black Sea, a nearly enclosed marine basin, was affected by land use long before the changes of the Industrial Era. Although watershed hydroclimate was spatially and temporally variable over the last ~3000 years, surface salinity dropped systematically in the Black Sea.* **Sediment loads** *delivered by Danube River, the main tributary of the Black Sea,* **significantly increased as land use intensified in the last two millennia, which led to a rapid expansion of its delta**. *Lastly, proliferation of diatoms and dinoflagellates over the last five to six centuries, when intensive deforestation occurred in Eastern Europe, points to an anthropogenic pulse of river-borne nutrients that radically transformed the food web structure in the Black Sea."* (Giosan et al., 2012)

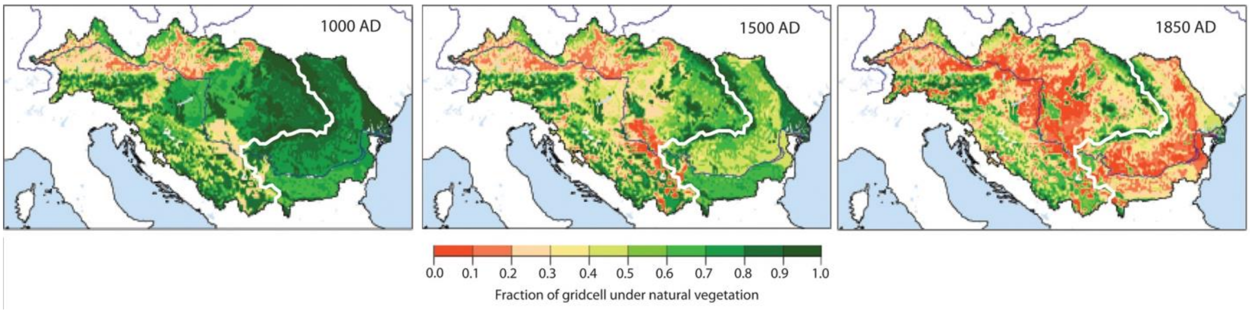


Fig.1. Forest cover evolution (Giosan et al., 2012)

Since 1864 until First World War, the increasing agricultural business in Romania put pressure on forests, causing losses up to 25% of forest cover (Nicolau-Barlad, 1944). Due to this drastically change of land use, the period between the two world wars is dominated by "Land Reclamation Law" (1930), which governed the legal framework for inventory of degraded lands, establishing the perimeters for afforestation of degraded lands and torrents.

Based on this law, Romania polices focused on increasing the forest cover, but due to the lack of finance and focus and constant pressure from societal needs, the approximate increase of forest cover with planted forests was of 100 000 hectares, meaning 2% increase.

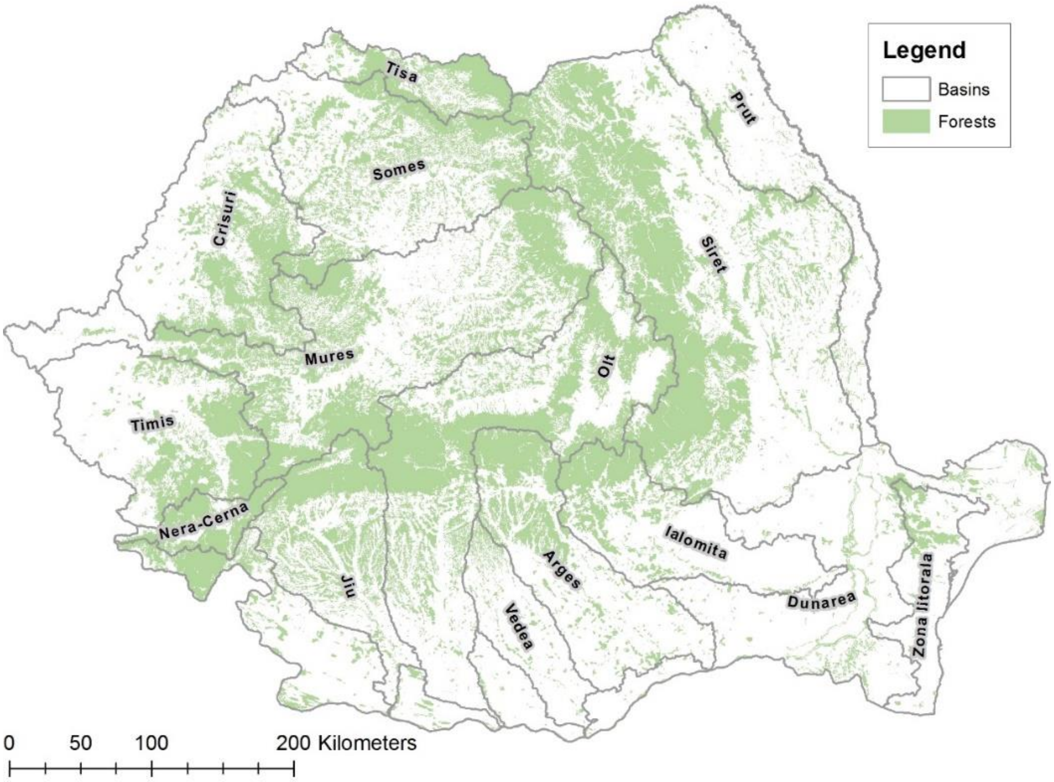


Fig.2. Forest cover distribution on major basins

In terms of priority functions performed by forests, according to forest management plans drawn up in recent years, forests coverage with special protection functions (functional group I) is 53.1%. The forests in this category are assigned with an important role in stopping and, especially, preventing degradation phenomena and occurrence of torrential floods. Managed as living shields against soil degradation and pollution of water sources, 24.1% of the forests are primarily managed for soil protection, and 14.5% are designed with water protection functions (table 1).

The main forest products in Romania remains the roundwood, which increased up to 18 million cubic meters in 2013. This increasing wood production produced a higher demand in the market putting pressure on forest resources.

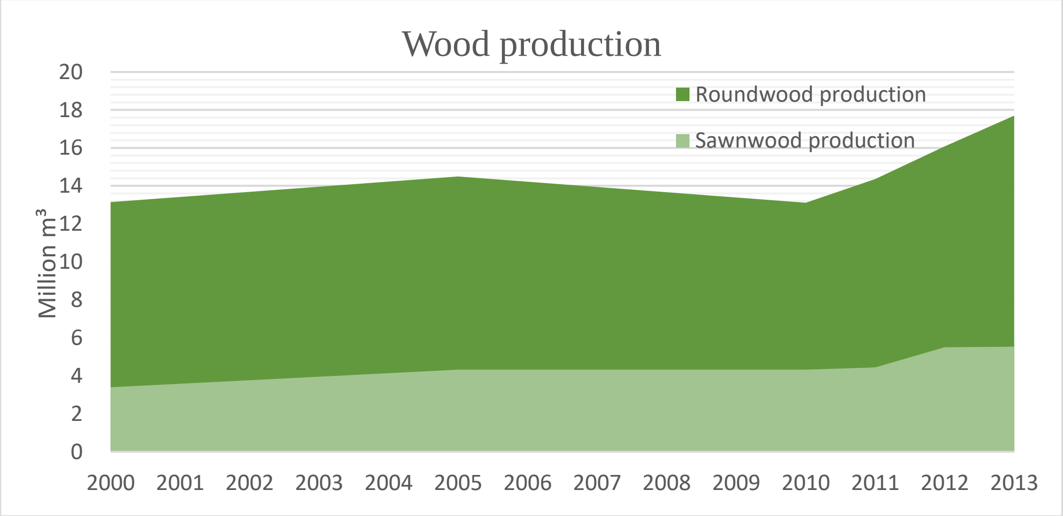


Fig.3. Wood production (Source: Eurostat)

Forest protection functions on basins and utilizable water resources

Table 1

| Basin Name | Protection Forests (%) | | | | Utilizable Water Resources (BCM/year) |
|---|---|---|---|---|---|
| | Water protection | Soil protection | Other protection | Total | |
| Tisa | 9.4 | 22.6 | 10.6 | 42.6 | 6.24 |
| Someş | 7.4 | 13.5 | 14.3 | 35.2 | |
| Crişuri | 11.5 | 13.8 | 8.1 | 33.4 | 2.87 |
| Mureş | 8.2 | 21.3 | 16.9 | 46.4 | 5.77 |
| Timiş | 9.7 | 19.4 | 16.7 | 45.8 | 3.56 |

| | | | | | |
|---|---|---|---|---|---|
| Nera - Cerna | 7.5 | 32.8 | 29.6 | 69.9 | |
| Jiu | 9.5 | 34.8 | 9.4 | 53.7 | 3.47 |
| Olt | 26.9 | 22.8 | 10.6 | 60.3 | 5.30 |
| Vedea | 2.5 | 52.4 | 15.3 | 70.2 | 2.39 |
| Argeş | 19.0 | 44.2 | 21.1 | 84.3 | |
| Ialomita | 18.9 | 28.4 | 32.6 | 79.9 | 1.39 |
| Siret | 13.9 | 23.6 | 11.4 | 48.9 | 7.54 |
| Prut | 5.3 | 11.5 | 8.0 | 24.8 | 1.76 |
| Dunăre | 34.8 | 30.2 | 25.7 | 90.7 | - |
| Litoral | 0.0 | 19.6 | 20.0 | 39.6 | 0.11 |
| **Total** | **14.5** | **24.1** | **14.5** | **53.1** | **40.41** |

Romania's surface water endowment consists of internal river basins as well as the Danube, which is a trans-boundary river basin shared by 19 countries. The natural surface water potential of Romania amounts to 127 Billion Cubic Meters (BCM)/year, with the internal river basins contributing 40 BCM and the Danube contributing 87 BCM per year. The groundwater endowment is estimated at 10 BCM/year (Stanciu, P., Oprisan, E., Tecuci, 2011).

**Water resources**:

Reservoirs: 1,449 from which 400 are very important

Accumulated volume: 13,070 million cubic meters

**Main water uses**

3,110 drinking water intakes with an installed flow of 171.26 cubic meters/second, from which 67.26 cubic meters/second ground sources intakes;

3,838 industrial water intakes with an installed flow of 1082.3 cubic meters/second, from which 49.5 cubic meters/second intakes from ground sources;

363 hydro-electric power stations in function, with 692 power groups.

With a current population of 20.2 million, the average water availability in Romania amounts to 2000 cubic meters per capita per year. While this value is above the thresholds generally defined for water stress (1700 cubic meter per capita per year) (Falkenmark, 1989), it is lower than the average value for Europe (approx. 4500 cubic meters per capita per year), and underscores the need for good management to ensure resource conservation and sustainability.

The water demands have steadily decreased in Romania since the 1990s, mainly due to structural changes in the economy:

Economically unviable irrigation schemes have closed.

Industrial production has reduced, and the remaining industries have significantly reduced water consumption in production processes.

Utilities have reduced losses and introduced tariffs, which have helped reduced water consumption in the domestic sector, even though the provision of water supply and sanitation services has expanded to an increasing fraction of the population.

Water resource key issues directly related to the forest changes:

**Flash Floods**: The high-intensity and short-duration floods (flash floods) are also becoming increasingly common in the mountain areas, mainly due to increasing frequency of high-intensity precipitation events, but also exacerbated by land use changes, especially forest loss and gain on high slopes. Even though the National Meteorological Administration and Institute of Hydrology developed new waring systems for floods, the warning time for small mountainous catchments which are prone to flash floods is about 2 hours, leaving the communities in these areas highly vulnerable to risk.

**Drought**: Due to increasing temperature and decreasing river flows (see the following section on climate change) the frequency of droughts is increasing in Romania.

**Climate change**: regional and local studies revealed that the climate is shifting. It is not sure if the climate heads to a warming or cooling, but what is observable is the fact that the amplitude of the floods and droughts is increasing and is correlated to the

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Using these basins, the researchers from National Institute of Hidrology and Watershed Management determined flow coefficients values in many river basins, with varying degrees of afforestation. Fund data accumulated through time created the possibility of determining the maximum flow of such probability rates which led to the development of a relation between specific discharge and watershed area (Giurgiu and Clinciu, 2008).

Figure 5 shows this type of relationship to the river Moldavian Central Plateau; they were based, for small areas, especially in peak flow values 1% exceedance probability, determined within the representative basin Tinoasa-Ciurea (no. 13 in fig. 4).

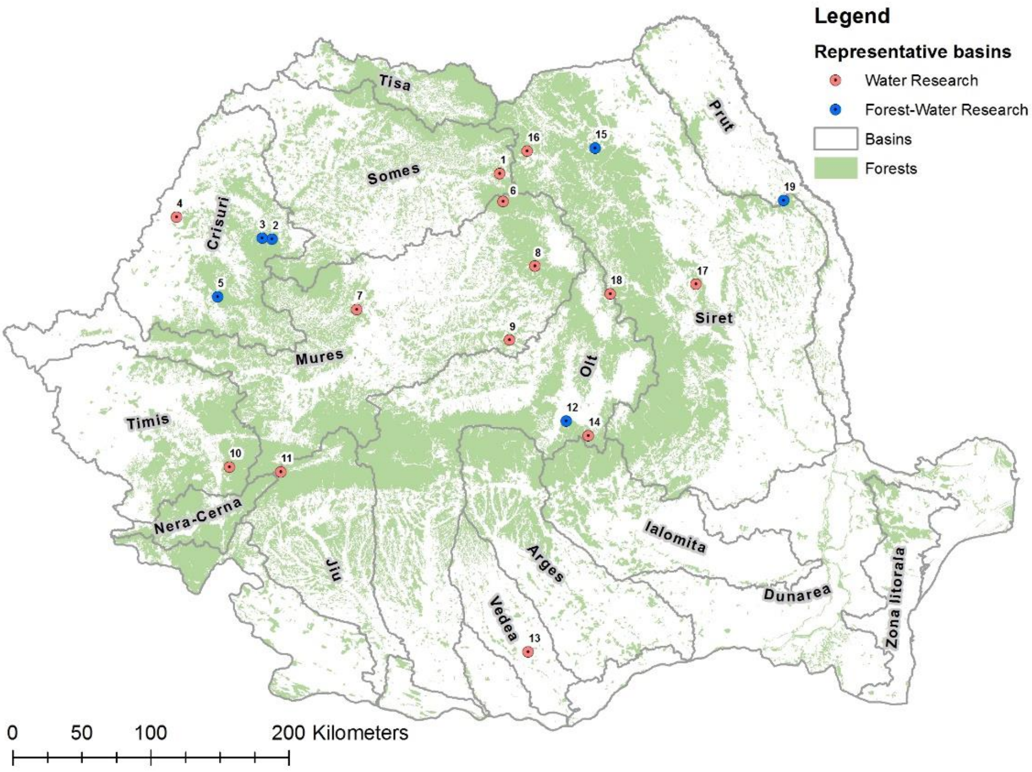

Fig.4. Geographic distribution of representative basins

Due to the forest hydrology research in Romania is emphasized that maximum flow calculation at probability 1% in small watershed can be done using a flow coefficient. The coefficient is based on data from representative basins, values depending on the variation of coefficient of afforestation: 0% to 100%, in accordance with the amount of rainfall corresponding to various parts of the country, for this probability. These values were included in a summary table which is particularly useful in the practice of hydrology.

An important work for increasing water yield and improving water quality was the implication of forestry specialists in managing torrential valleys, where massive deforestation produced in the past. At the beginning of the XIX-th century more and more scientists demonstrated the benefits of forests for water and for floods regulation. Starting with that period, the Romanian forest engineers begun their campaign in developing and putting into practice mapping and restoring degraded lands and managing torrential valleys (Giurgiu and

Clinciu, 2008). The benefits of that period can be seen nowadays in several watersheds like Bogdan Valley (Ialomita Basin) or Sării Valley (Siret Basin).

Flow coefficient (1% probability) based on Forest Coeficient (Cp) and Watershed slope (Ib)

Table 2

| Ib(%) | Cp(%) | | | | |
|---|---|---|---|---|---|
| | 0-20 | 20-40 | 40-60 | 60-80 | 80-100 |
| 5-10 | 0,55 | 0,53 | 0,51 | 0,49 | 0,47 |
| 10-20 | 0,57 | 0,55 | 0,53 | 0,51 | 0,49 |
| 20-30 | 0,59 | 0,57 | 0,55 | 0,53 | 0,51 |
| 30-40 | 0,62 | 0,60 | 0,58 | 0,55 | 0,53 |
| 40-50 | 0,64 | 0,62 | 0,60 | 0,57 | 0,55 |

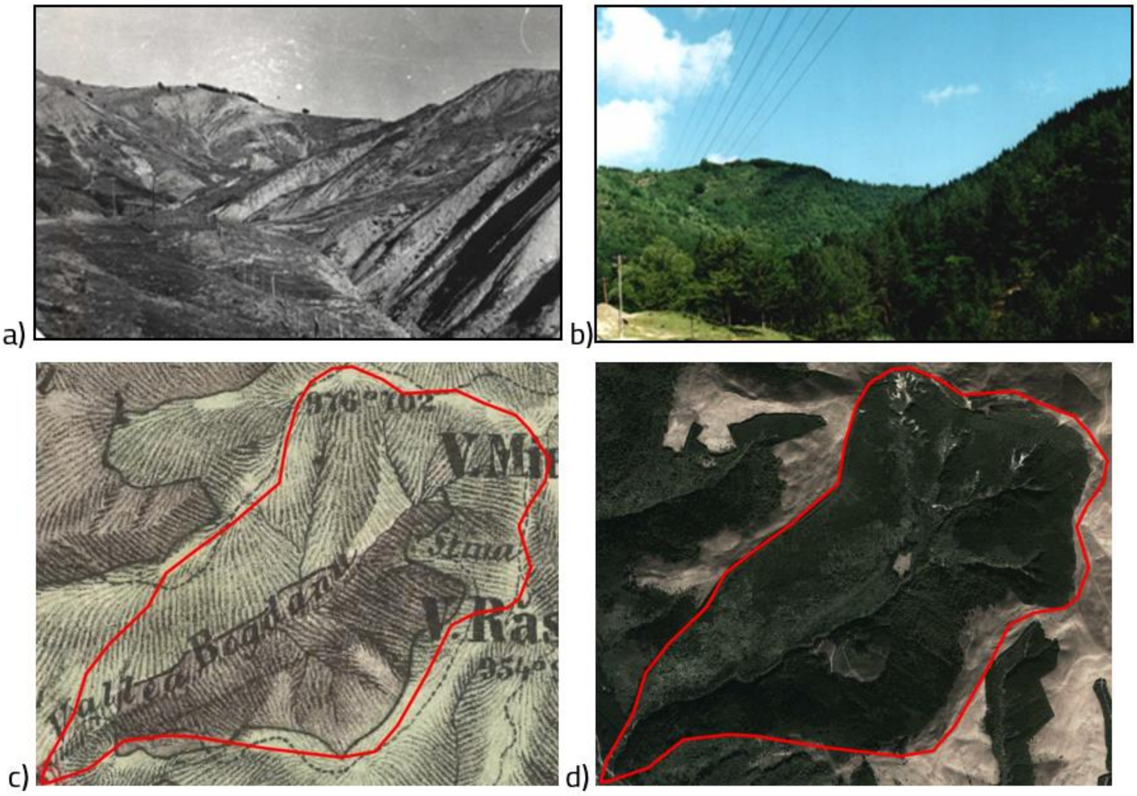

Fig.6. Increasing water yield and quality by reforestation and watershed management **Sării Valley** – a) In 1954 (Photo: Costin); b) In 1997 (Photo: Untaru) and **Bogdan Valley** – c) Map of Romania 1864; d) GeoEye image 2014

In Romania, environmental laws are established through Acts of Parliament. These Acts provide the general framework for:

- regulation of economical and social activities having an environmental impact;
- protection of natural resources and conservation of biodiversity;
- pollution control.

The responsibility for preparing more detailed requirements, regulations and standards belongs to the Ministry of Waters, Forests and Environmental Protection. The environmental legislative system has been revised according to the European legal system. It provides laws for different parts of the environment: air, water and soil. It also provides laws related to these environments: dangerous substances, the fight against floods, forestry, food and nuclear activity.

Today the Romanian environmental legislation is based on two fundamental laws that guide the whole environmental protection at the national level: The Environmental Protection Law (EPL) and the Water Law (WL). Both laws provide an excelent legislative frame for applying strong strategies for improving water yield and water quality. According to the Water Law all rivers have a buffer zone from 20 m to 100 m for protection. The protection of waters can be found in EPL and the same in Forest Law which defines that category of forests that should remain in basins stabilizing soil erosion and maintaining a constant water flow.

But from legal frame to facts is a very long way with a lot of issues like:

- Illegal extraction of sediments from river bed
- River contamination with garbage or industrial waste
- Intensive harvesting near large water storages
- Extracting logs using the watershed valley network
- Intensive grazing

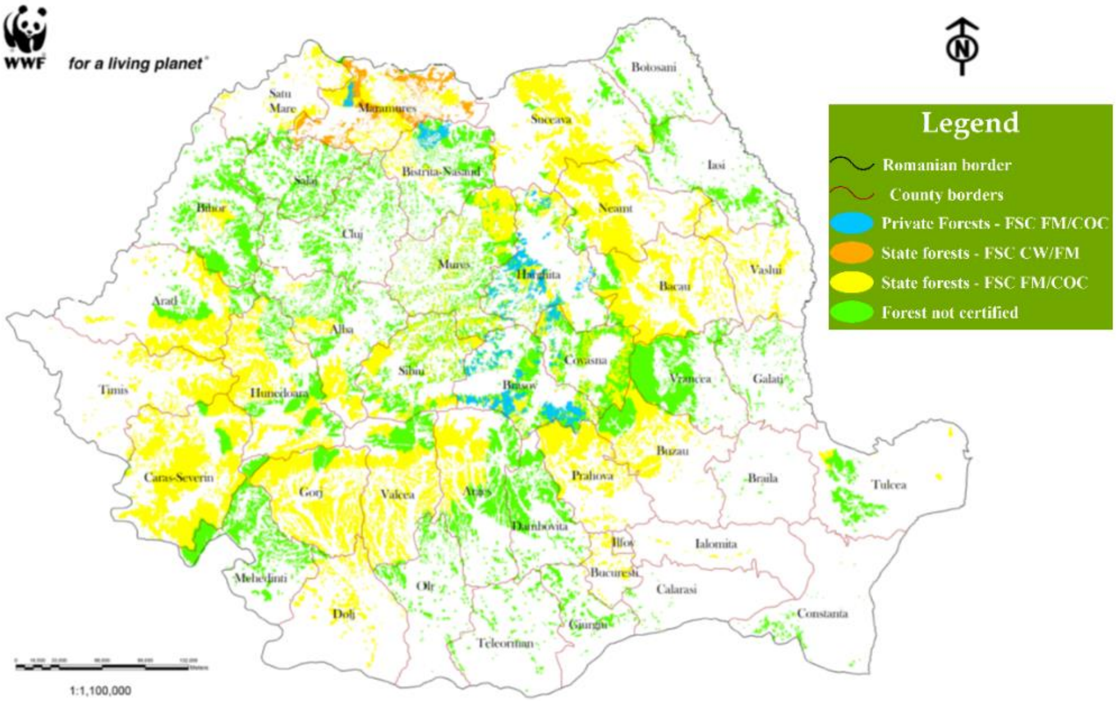

Fig.7. FSC Certified Forests in Romania (source: http://www.certificareforestiera.ro)

Another important legal frame for protecting waters through forests is FSC standard implementation. Logging directly disturbs forests and waters, but the FSC standard requires operators to minimize forest damage during harvesting and road construction, as well as to protect forest ecosystems (Macicuca and Diaconescu, 2013). Romania has good implementation of FSC standards, approximately 50% of Romanian forests are certified (fig.7.).

Related to climate change there are quantitative estimates for Romania which come from two categories of sources (World Bank, 1999):

- climate change studies of Europe;
- local studies aimed at assessing climate change impacts for specific selected river basins of Romania.

The results of the continental-scale studies include relevant findings for Romania. The observed changes in climate over Europe in the 20th century show that Southern and South-Eastern Europe has experienced decreases in annual precipitation of up to 20%. Precipitation has decreased at a rate of about 30 mm per decade in Romania, between 1961 and 2006. Annual mean precipitation is projected to decrease by 5-20% in southern Europe and the Mediterranean in the period 2071-2100, compared to the period 1961-1990 (Fig.8.).

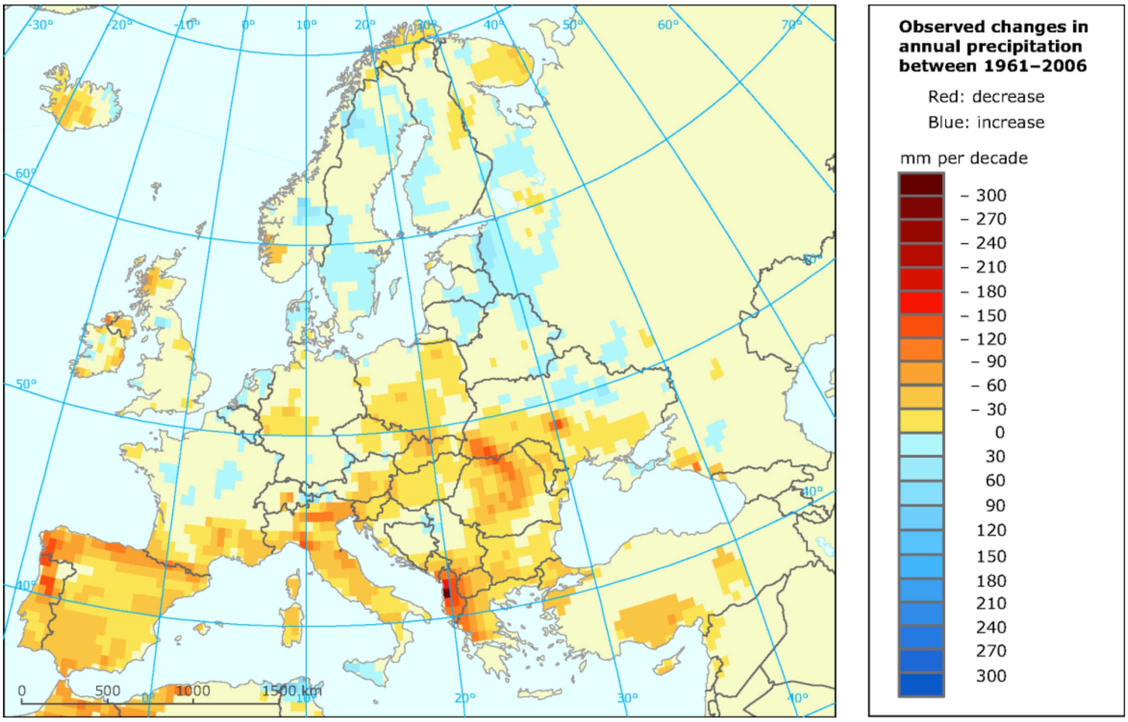

Fig.8. Trends in annual precipitation across Europe between Jan 1960 and Jan 2012 (source: http://www.eea.europa.eu/data-and-maps/figures/observed-changes-in-annual-precipitation-1961-2006)

In line with the precipitation changes, annual river flows are increasing in the north and decreasing in the south, and this trend is projected to increase in the future. Large changes in seasonality are also projected, with lower flows in summer and higher flows in winter for Romania. Therefore, droughts and water stress are expected to increase, particularly in summer. Flood events are projected to occur more frequently in many river basins, particularly in winter and spring, although estimates of changes in flood frequency and magnitude remain uncertain. In general, the range of climate change impacts across Romania includes a likely increase in cold spells, heat waves, heavy floods, landslides, formation of ice-dams on watercourses, damaging frost, and avalanches (World Bank, 1999).

Related to climate change the area occupied by forest plantations is slowly increasing especially in the southern part of Romania. These are the efforts of community to stop the increase of desertification phenomena. The process is still slow due to the lack of funds and bureaucracy.

The future research and management practices that should be incorporated in the management of forest to improve water quality and water yield is to increase the forest cover especially in Southern and Easter counties. The research activity should concentrate on the needs of forest managers which converge into one point: increasing the forest cover by maintaining the harmony between economic needs and ecological demands.

### *4.2. Monitoring the status of hydrological and anti-erosion protection functions through geo-spatial analysis*

The state of the stands is dynamic, expressing in real time the influences of biotic and abiotic factors (Clinciu, 2003). It directly influences the hydrological balance within a hydrographic basin and "spontaneously triggers the law of the connection of objects and phenomena in nature, the entire mechanism of alteration of the other components" (Munteanu et al., 1991).

The aim was to carry out a geo-spatial analysis of the status of hydrological and anti-erosion protection functions, focusing on the identification of races and definitive cuttings of more than 5 hectares in the early autumn of 2015. The term "forest" in the land cover category and not in the land use category, unless explicitly mentioned such as "forest land".

To make the most relevant analysis, the whole area covered with forests in Romania was chosen as the study area. The collection and processing of data was done at county level.

The applied method involved the extraction of forest areas affected by disturbances through clear-cuts or definitive cuts occurring on surfaces larger than 5 hectares. To obtain this cartographic product we used:

- The results of global mapping from Landsat images of a world-wide project, totaling 128.8 million square kilometers, equivalent to 143 million pixels Landsat with a 30-m space resolution (Hansen et al., 2013).
- False color mosaic image with 30 m spatial resolution, taken with the Landsat OLI8 sensor.

In the Hansen study, disturbances were defined as disturbances occurring at tree level, the results being broken down by degree of coverage with trees, expressed per cent and yearly (eg from more than 50% crown coverage to about 0% crown coverage) starting with 2000. The forestry works based on selective extraction (cleaning, shortening, progressive cuts, successive cuts, etc.) within the stands, which did not lead to their final cutting, were not included in the analysis of the study.

The Hansen product operates in two categories: forest gain through natural or artificial regeneration and forest loss resulting from forestry or calamities (Hansen et al., 2013).

The method was based on a cartographic process using Landsat scenario validation areas that were derived using satellite-based remote sensing. For mapping the gain / loss categories, high spatial resolution data such as Quickbird images (Hansen et al., 2013; Potapov et al., 2015) was used.

Since the Hansen product does not provide disturbing information until 2014, the disturbance was identified using a mosaic of fake color composites, combining the 6,5 and 4 bands of Landsat OLI8 satellite imagery.

Following Hansen's (2014) data analysis, they were validated on Landsat images in September 2015, as between 2014 and 2015 they were naturally regenerated or planted. For these reasons, validation on the mosaic of September 2015 led to the updating of the Hansen product by eliminating the regenerated areas and adding new areas affected by cutting and definitive cutting (fig. 9). In Figure 9, pink nuances can be seen that have not regenerated (delineated with red line), and with green shades the regenerated surfaces that have been extracted from the analysis (delineated with the green line).

Fig.9. Updating Hansen product

The final product, represented by a polygon file, was used to analyze the spatial distribution of disturbed land according to: the relief unit, the altitude, the soil texture, the territorial administrative unit.

Following the application of the methodology described above resulted in an area affected by disturbances of about 42,000 hectares, largely disposed in the Carpathian arc and its surrounding areas (Figure 3). 88% of all disturbances were found at altitudes above 1000 m.

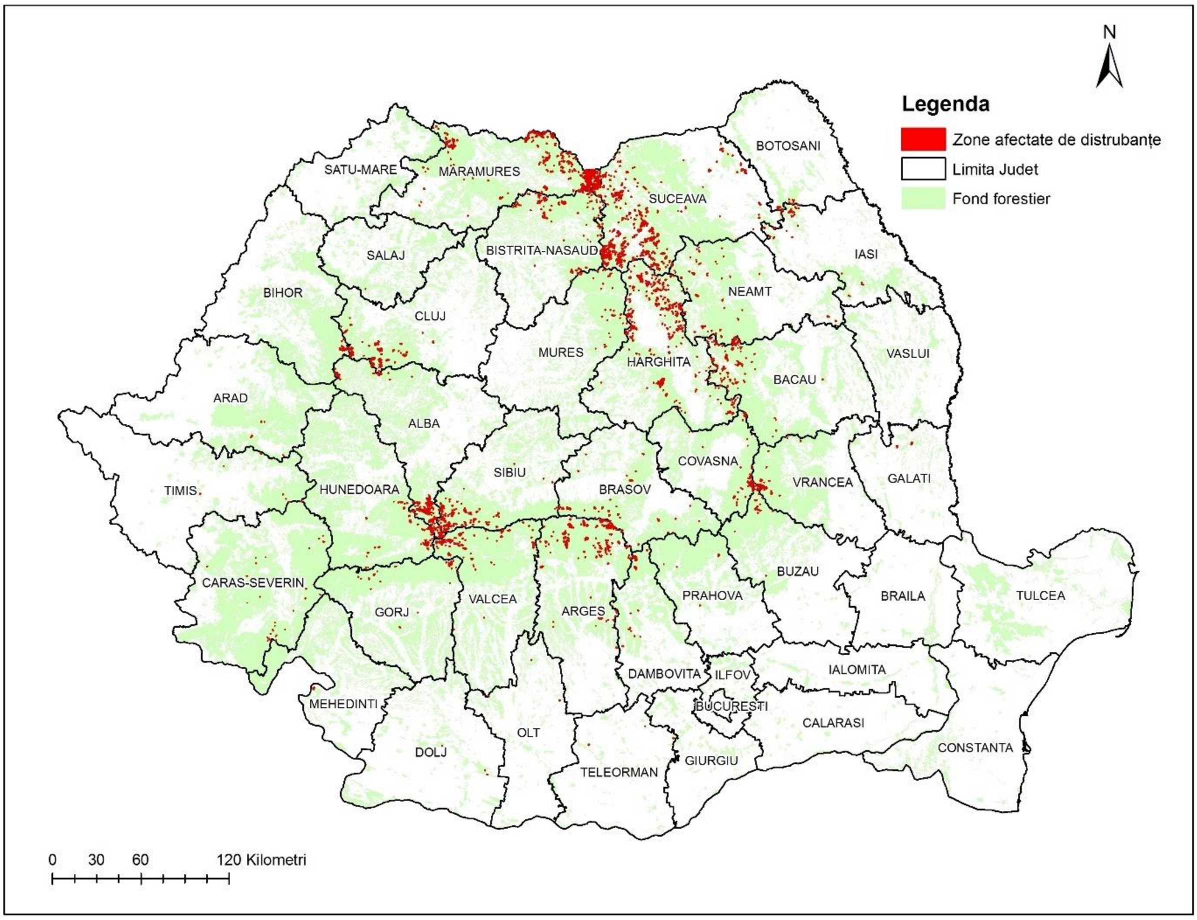

Fig.10. Spatial distribution of disturbed forests

From the distribution point of view on the relief units (Posea and Badea, 1984) it can be seen in Table 1 that 60% of the total disturbances are located in the Eastern Carpathians, and the latter with the Meridionali sums over 3 quarters of the total disturbances.

Table 3

Percentage distribution of disturbances per unit of relief

| *Morphometric Unit* | *Disturbance percentage* |
|---|---|
| *Carpații Orientali* | 60% |
| *Carpații Meridionali* | 24% |
| *Carpații Apuseni* | 7% |
| *Carpații de Curbură* | 4% |
| *Podişul Moldovei* | 4% |
| *Piemontul Getic (Podişul Getic)* | 1% |
| *Subcarpații* | 1% |

After the texture of the soil where the disturbances are located, more than 80% of the areas have textures with a medium to high drainage potential. Once they do not have woody vegetation to maintain their porosity, soils reduce their infiltration rate and favor the formation of surface leakage during torrential rains

More than 80% of the areas have textures with a medium to high drainage potential. Once they have no wood vegetation to maintain their porosity, soils reduce their infiltration rate and favor the formation of surface leakage during torrential rain

Table 4

Distribuția procentuală a disturbanțelor pe clase de textură

| *Texture* | *Descriere* | *Disturbance percentage* |
|---|---|---|
| *Heavy Clay* | have the greatest drainage potential and a very low infiltration rate when completely wet | 2% |
| *Clay* | has a drain potential close to the average | 12% |
| *Clay - Sand* | has a drain potential close to the average - high | 80% |
| *Sandy - Clay* | have low drainage potential and high infiltration rates when completely wet; | 6% |

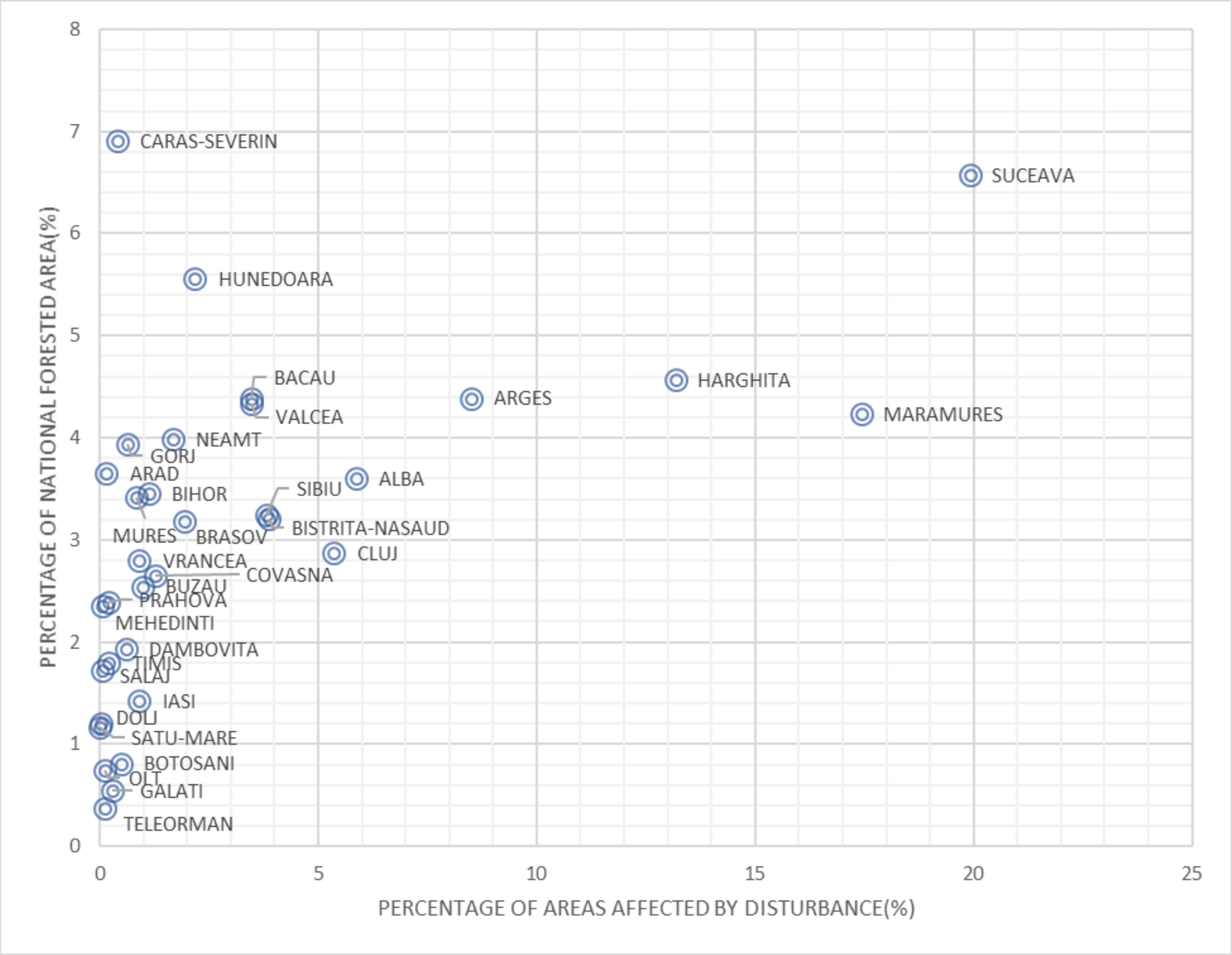

Figure 11. Distribution of counties according to the percentage of disturbed areas and the participation with forested areas at national level

The distribution of areas affected by disturbances at county level highlights certain areas that do not fit into the national pattern. As can be seen in Figure 11, in the counties of Cluj, Alba, Argeş, Harghita, Maramureş and Suceava, the percentage of disturbed areas is higher than 5% of the national value, having values higher than other counties similar as a percentage of the area wooded country. It also identifies certain situations that can be explained by the degree of afforestation of the county, the main species grown (resinous versus hardwood), accessibility, insect attacks or windbreaks / ruptures. For example, a concrete case can be found in counties with the largest forest area, Suceava and Caras-Severin, but with percentage of participation in diametrically opposed disturbances. It can be noticed that in these cases the resin culture is more "visible" from the hydrological point of view than in the case of decidous.

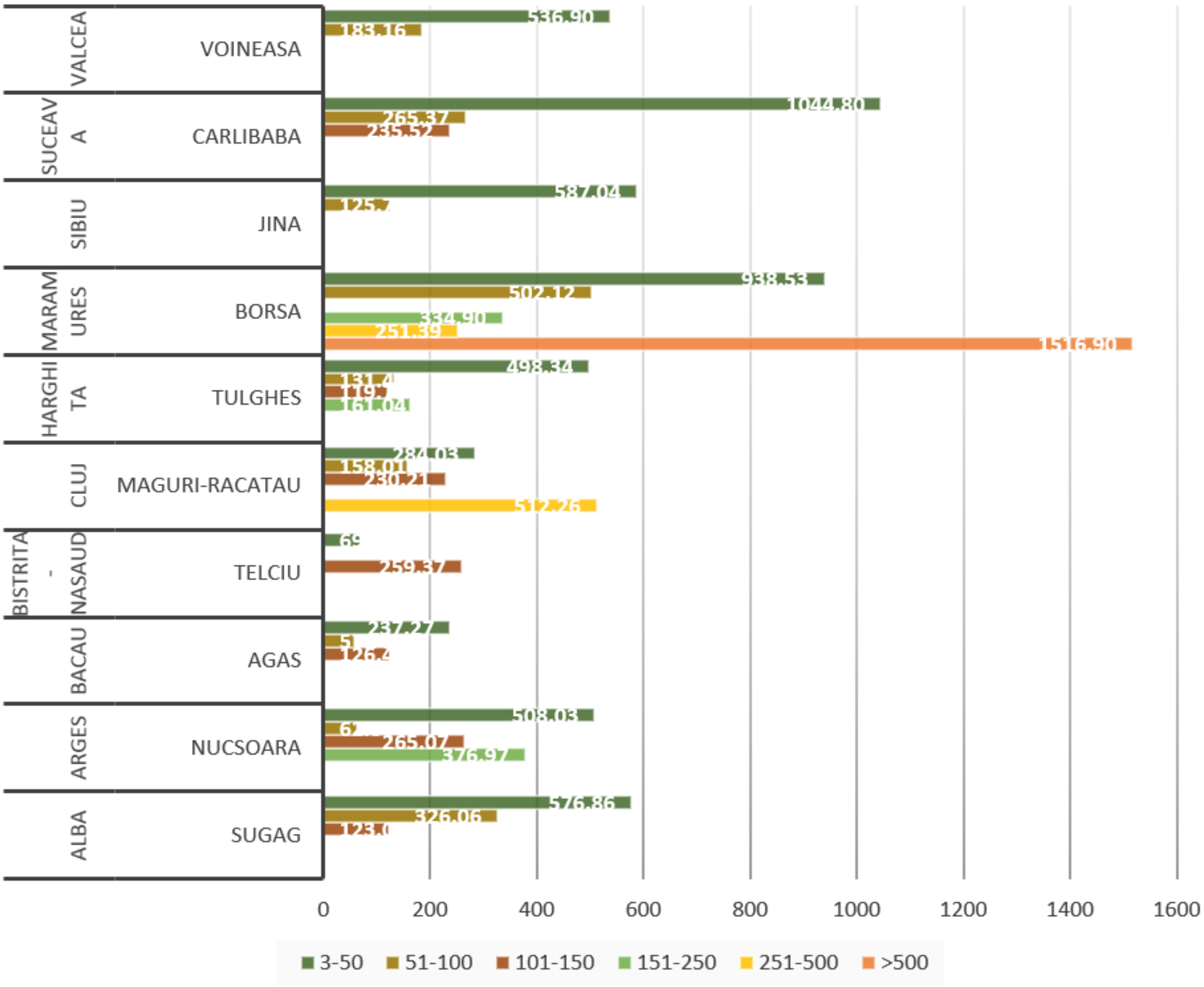

Figure 12. The distribution of the most affected territorial administrative units in the top 10 most affected counties,

Although only certain counties are affected by these disturbances, the phenomenon of geographical grouping of disturbances is even more pronounced at this level of territorial administrative units. Thus, most of the disturbed areas in a county (more than 90%) are usually located in a number of 5 localities at the level of each county. By joining the largest disturbance area in each of the 10 counties it is noted that the areas of disturbance are not mostly small, up to 50 ha, but there are areas where the areas over 50 ha are majority and even dominant, as in Borşa (MM), Măguri-Răcătău (CJ) or Nucşoara (AG) (fig.12).

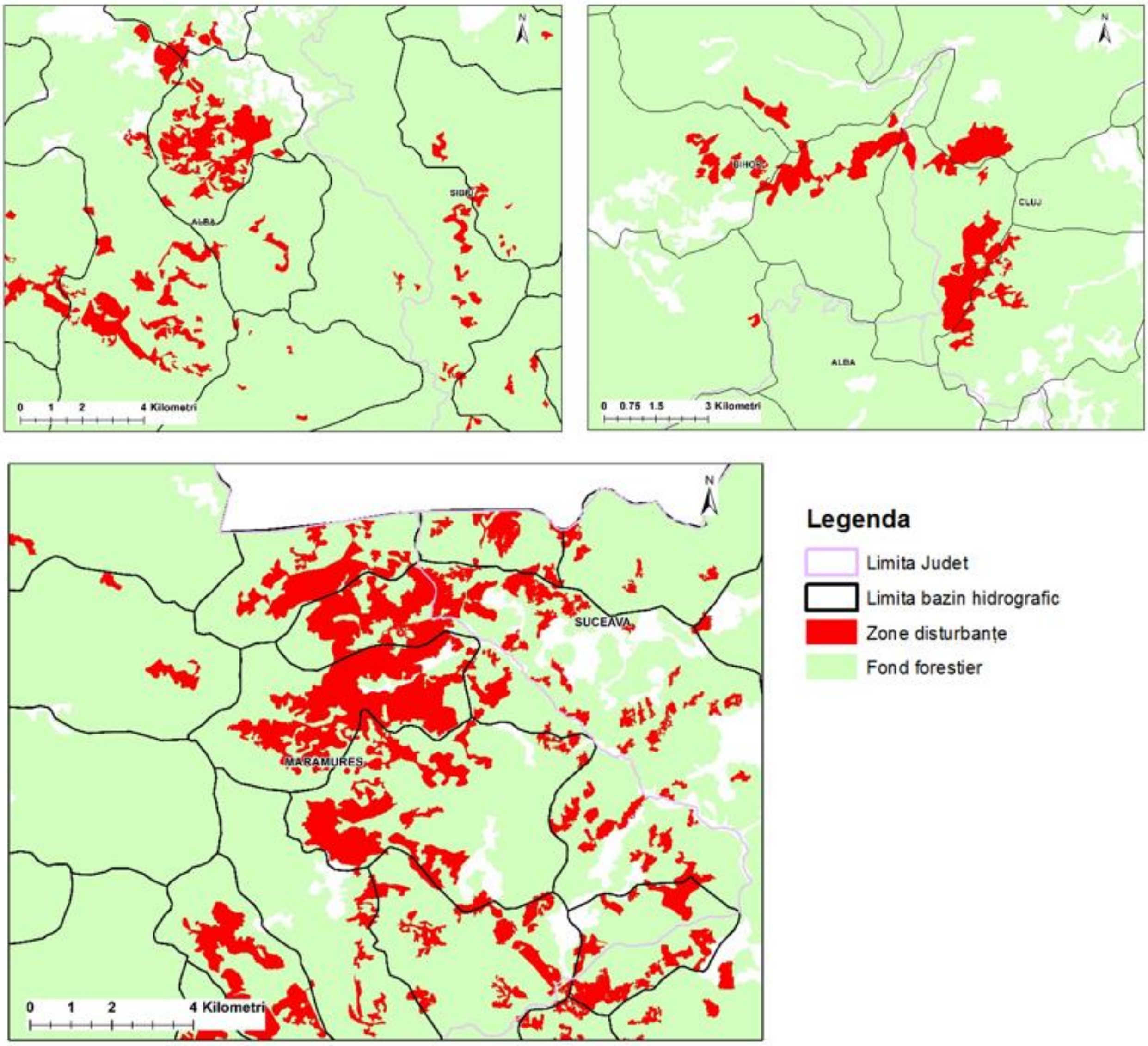

Figure 13. Example with grouping of disturbances on large surfaces in small, predominantly forest basin

The effect of grouping disturbances is major when they cover the surface of a whole small hydrographic basin having a major influence on the hydrological balance in the area.

### *4.3. Discussions*

The hydrological restoration of river basins, or rather the return to the hydrologic regime before the disturbances, involves complex and lasting processes. The restoration is mainly dependent on the return of the stands - reforestation, by restoring the crown to the previous level. As the forest canopy restores, the increase in erosion process performance is achieved over time.

In response to the question of the extent to which forest management influences the protective functions of the forest, especially on the protection of water, land and soils, the study showed that although the clear-cuts are limited to 3 hectares, however, the neighboring areas with final cuts, can affect considerable areas within a river basin.

On the other hand, the spatial disturbance provides a new perspective on how to design and apply forest managemnt in the current context of property. The study of disturbances has highlighted the pressure exerted on the forest, and, more importantly, has shown that there are certain "hot zones", without being able to claim that the phenomenon is a generalized one at national level. However, in the affected areas, the degradation of the protective functions of the forest can lead to major hydrological imbalances, followed by catastrophes with material damage and even human casualties.

The problem is tricky, almost all the affected areas are in the rural area and especially in the out-of-town areas, which does not alarm the dangers that can occur in the community and at the ecosystem level.

Therefore, an annual monitoring based on geospatial analysis is more than necessary in order to anticipate the occurrence of such phenomena and to base on a real fundament the measures required by the sustainable management of forests intended primarily to fulfill the functions of water and soil protection.

## 5. Streambed dynamics on torrential valleys

### *5.1. Introduction*

The activity of managing torrential valleys is in close relation with the dynamics of stream bed. As cited in literature, between torrent control check dams and the river bed will always be an action and a reaction, this fact being studied in Romania by different researchers in different conditions (Clinciu, 2001, 2005, 2006; Clinciu and Lazăr, 1992,1993; Clinciu, and Davidescu, 2000; Clinciu and Gaspar, 2005; Constandache and Nistor, 2006; Costin et al., 1975; Davidescu and Clinciu, 2005; Dinu, 1974; Gaspar, Clinciu, 2006; Gaspar, Abagiu, 1974; Giurgiu, 1998, 2006; Munteanu, 1975; Munteanu et al., 1991, 1993; Oprea et al., 1996; Traci, 1985; Traci, Untaru, 1986; Untaru, Traci,1989; Untaru, 1993, 2000).

Dynamics and effects of stream ecosystems and morphology from forested torrential watersheds based on mixed rock and wood debris have been scarcely considered by researchers until the 1980s, with some exceptions (Hack and Goodlett, 1960; Zimmerman et al.,1967; Heede, 1972; Beschta, 1979; Keller and Swanson, 1979; Keller and Tally, 1979; Untaru et al., 1994).

Quantification of geomorphological changes and rates of landscape evolution is a matter of primary importance, as much in natural hazards studies (Biali, 2009; Pasuto and Soldati, 2004) as in calibration of landscape evolution models (e.g., Hancock et al., 2002).

In this paper we investigate the influence of dams to morphological processes on a corrected torrential valley situated in mountainous area of Romania, called Vidas Valley. As a starting point we used a topographic survey taken on the valley before constructing the torrent control check dams (1979). This survey was the topographic base for designing the dams used in managing the torrential valley. Afterwards topographic surveys were made in 2008 on the entire length of the valley were torrent control check dams were constructed.

### *5.2. Site location and Methods*

Vidas valley is a small torrential watershed (105 hectares), a left tributary of the river Tărlung. Based on geomorphological map, the valley is in the northern side of the external curvature of the Eastern Carpathians, near the transition zone that delineates the Bucegi

Mountains. Because of this transition position, a number of morphological, hydrological, climatic, biogeographic processes characterize the studied watershed. The torrential valley underlayer is predominantly grafted on sedimentary rocks (lime and grit stones). The watershed lies from 730 m to 1875 m. The average annual precipitation is between 800 mm and 1800 mm.

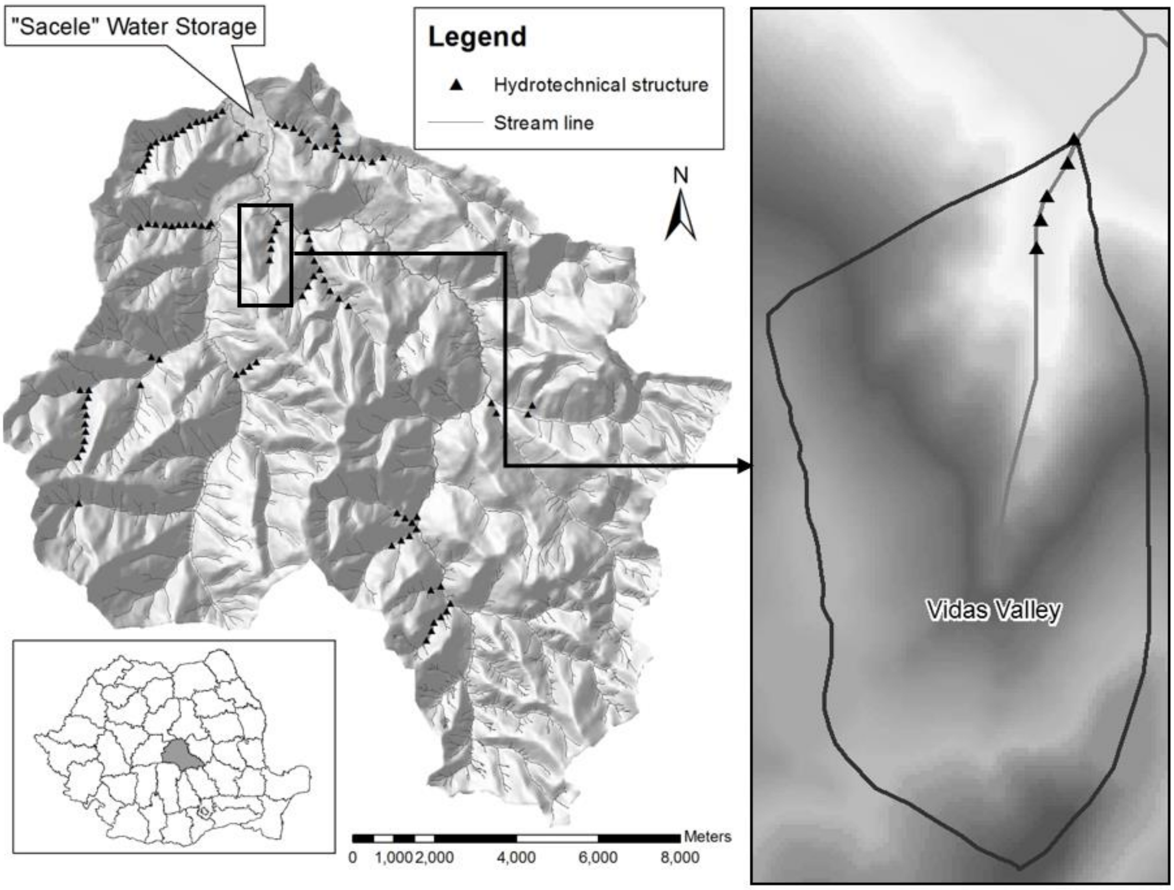

**Fig. 1.** Location of Vidas Valley

During 1980s several dams were constructed for protecting the national road DN1A from the torrential flash floods which occurred especially due to the abundant rains. For this case were used gravity dams made of prefabricated components (fig. 2). The components were 1x1 m length and wide. Since the valley was deep, the proposed solution was to construct 4 dams with a medium height of 3.5 m on a 700 m length of the valley.

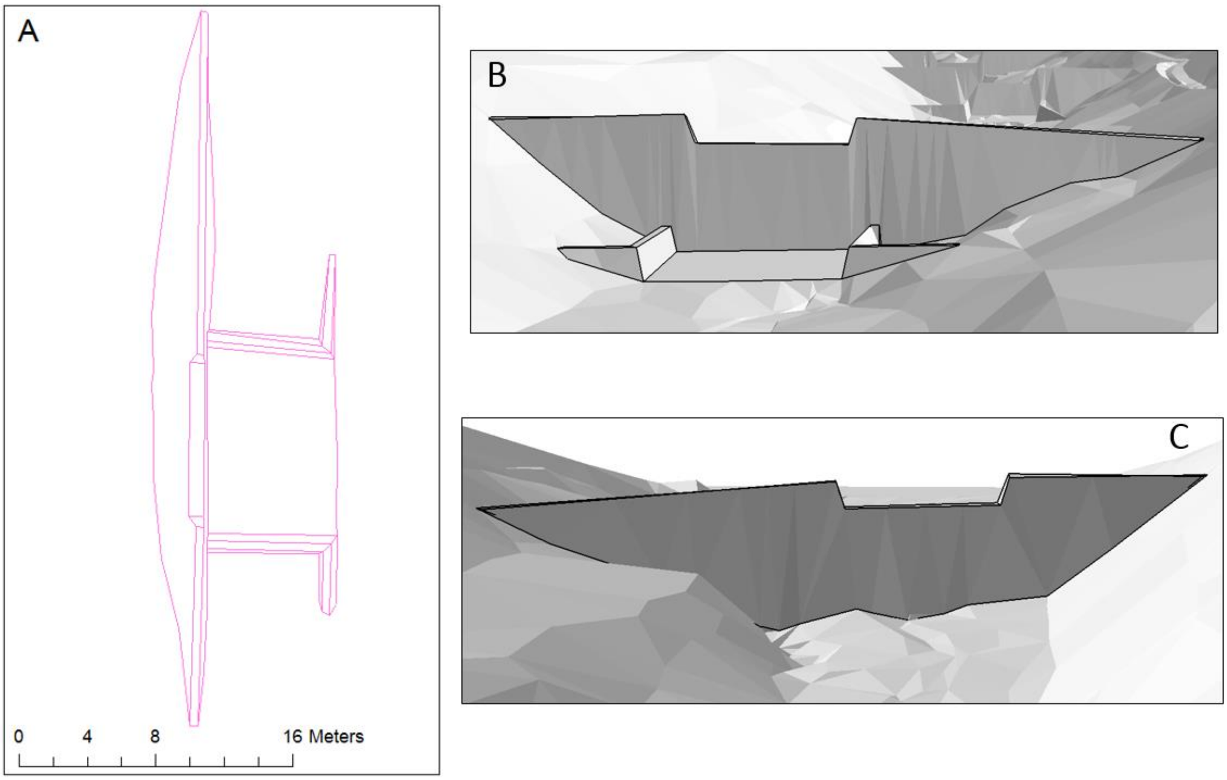

**Fig.2.** The morphology of the first dam A) Top view; B) Downstream view; C) Upstream view

In 1979 a project was prepared for elaborating the management of Vidas torrential valley of Tărlung Basin, Braşov County. This project was prepared by the Torrent Control joint team from Transylvania University, at the request of Forest Research and Management Institute ICAS Bucharest - Braşov branch.

To determine the exact location of the future dams and to estimate the total volume of siltation in 1979 a topographic survey was conducted. A special topographic plan (scale 1:250) was elaborated based on this topographic survey. This plan contains elevation contours delineated using the elevation profiles measured in the field (figure 3).

The topographic survey was done in 1980 using T2 universal theodolite with 28x telescope magnification and 29 meters diameter of field of view at 1000 meters. The shortest focusing distance of T2 is 1.4 meters.

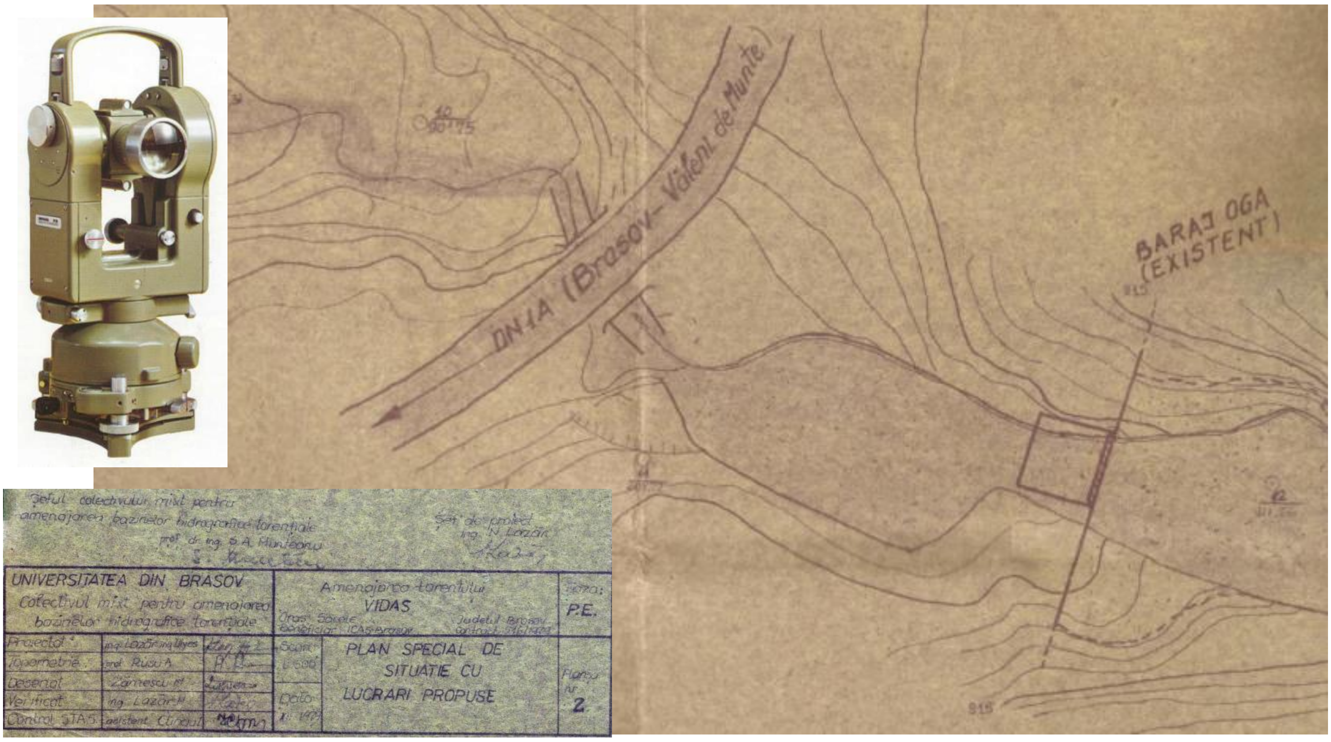

Fig. 3. Special topographic plan elaborated in 1979

To realize the digital elevation model of the valley, the existing graphic plan, stored in raster format, was turned into a digital plan by scanning and georeferencing. A vector layer containing elevation contours was made using ArcGIS 10.0 editing tools.

The digital elevation model of the valley was interpolated and stored in TIN (Triangle Irregular Network). The final product was referenced in national projection Stereographic 1970, S-42 Pulkovo datum, using ground control points identified on the map and measured in the field, due to the lack of original data of the measurements and the fact that the survey was done in local coordinates.

For creating DTM for 2008 a Leica TC407 total station and prism was used. The measurements were carried out using radio waves in the infrared region, with a length of 0.78 micrometers and a basic frequency of 100 MHz or 1.5 meters. The station is equipped with full rear 30x magnification, image right, diameter 40mm Minimum focusing distance of 1.7m. Field of view is 1 degree and 30 seconds and has an opening of 2.6m to 100m. Both spherical and the electronic level the precision of 2 mm.

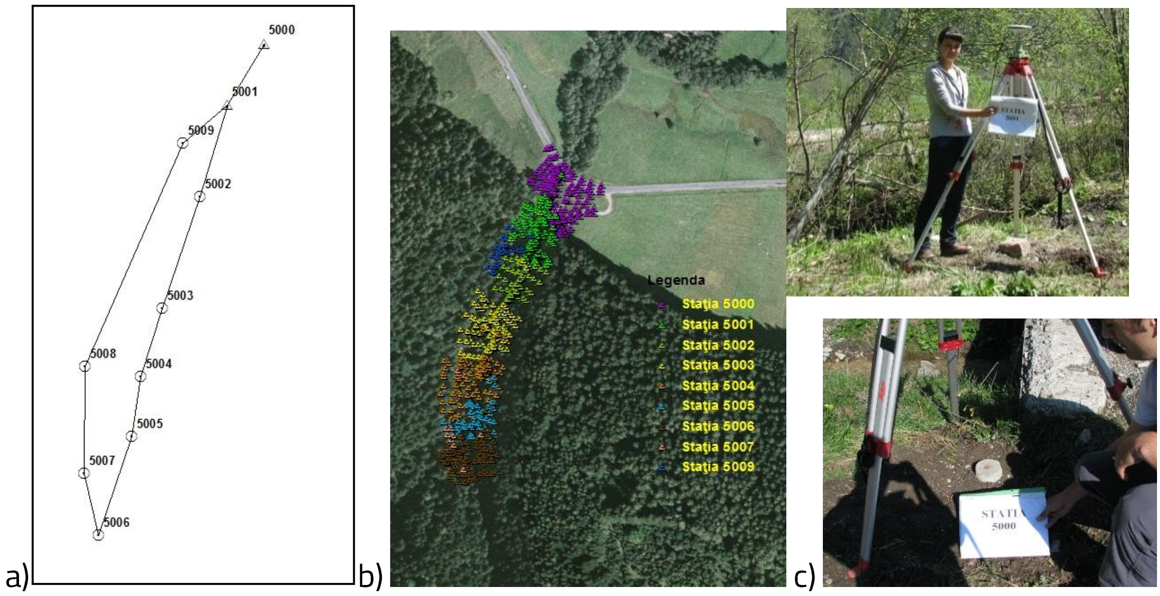

**Fig. 4.** a) Topographic survey schematics b) Measured points c) Station points

For positioning the survey in national projection two points were determined using GPS measurements with Leica 1200 GPS System (figure 4). For detailing measurements, a closed-loop traverse was made beginning and ending at the same 2 stations determined with GPS technique; this procedure allowed calculation and adjustment for closure error and use of interior and deflection angles.

### *5.3. Results*

Water erosion is the primary force determining the general shape of the landscape in a torrential valley. Processes and land degradation produced by rains create large disturbances and imbalances both to the environment and to human life and activity. The main determinant of the process is the torrential disruption of hydrological regime of Vidas River. This disruption alters the functions of protection against superficial flow and accelerated erosion. The torrentiality of the valley is also transforming the soil biological physical functions. Once triggered, the torrential processes accelerate over time and simultaneously the difficulty and cost of correcting them is increasing.

Knowing the influence of check dams to stream bed dynamics is therefore a useful monitoring tool for mitigation of these processes.

The evaluation of stream bed dynamics from Vidas torrential valley was done by comparing the two digital terrain models extracted from topographic surveys done in 1979 and in 2008. The digital elevation models used for extracting the results were derived from

TIN digital terrain models. The resolution of the models was 1 m/pixel (figure 5). This activity was done by monitoring the vertical and horizontal alteration of the riverbed profile. This monitoring was done in three approaches:

- by comparing the horizontal dynamics measured in different periods based on transversal profiles extracted from digital elevation models
- by comparing the vertical dynamics measured in different periods based on longitudinal profiles extracted from digital elevation models
- by monitoring of the degree of siltation behind the dams using raster calculator on digital elevation models

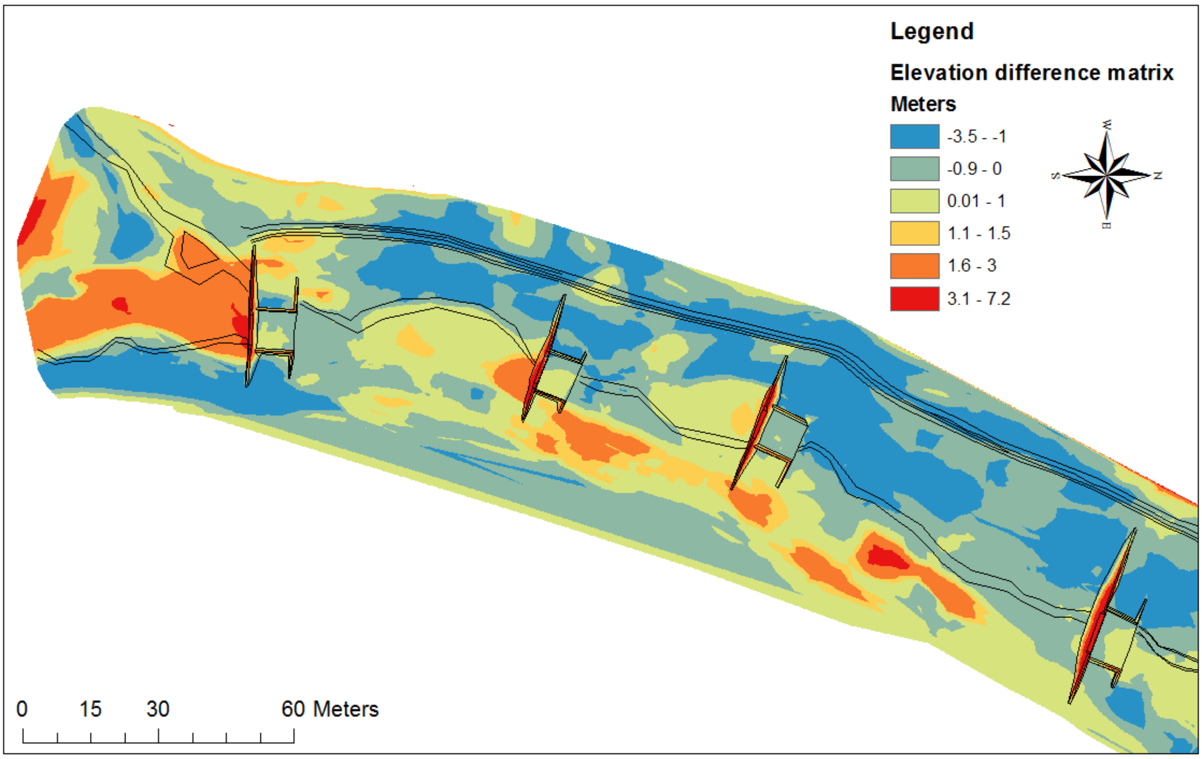

**Fig. 5.** Digital elevation differences from 1979 to 2008

#### *5.3.1. Horizontal dynamics*

To quantify the horizontal dynamics which occurred in period 1979-2008 we defined ten transversal profiles. Using a profile tool from ArcGIS environment it was extracted for each period the profile (figure 6).

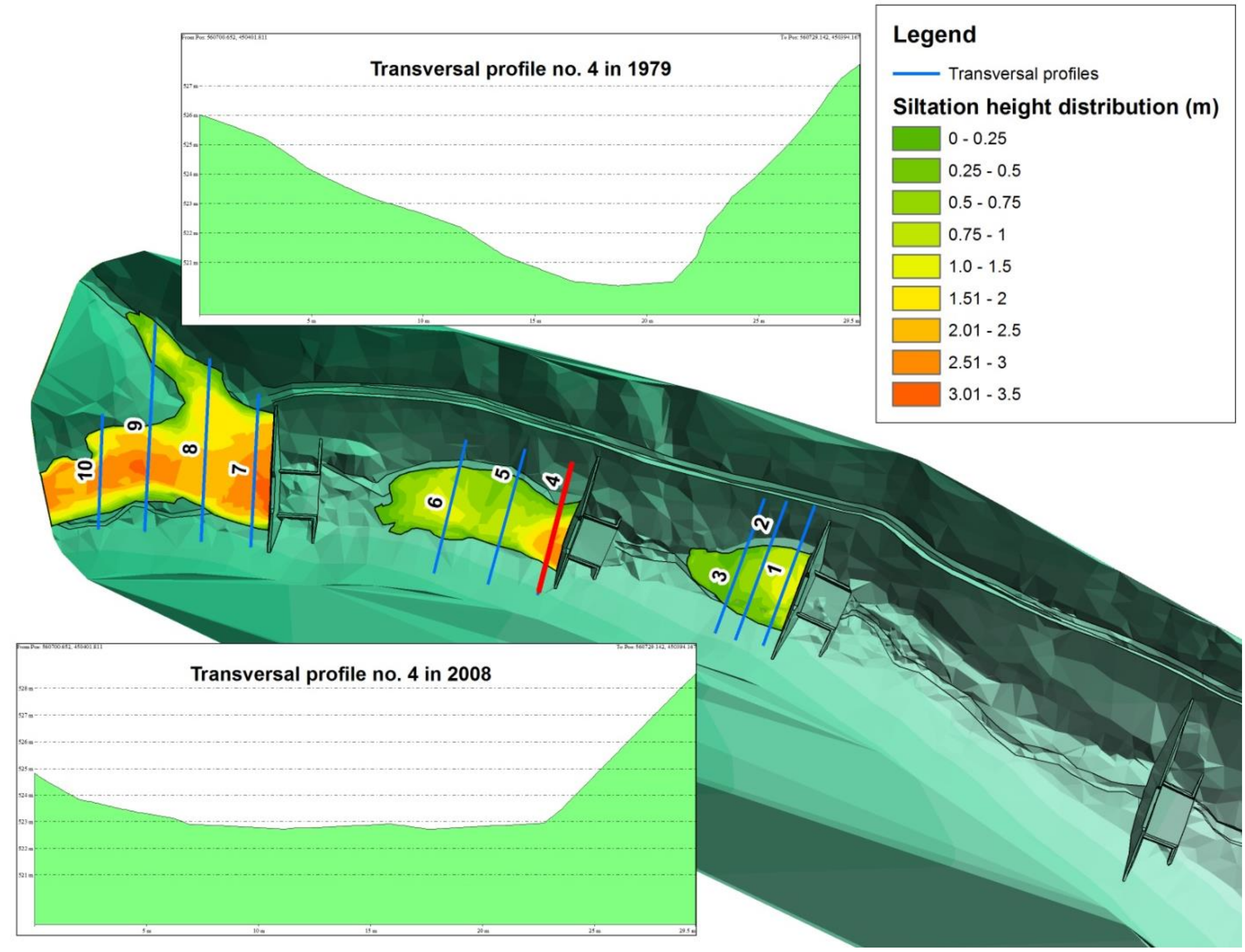

**Fig. 6.** Transversal profiles distribution with an example for profile number 4

Based on automated profile extracted from DEM for each case was extracted the length of the valley. For each profile a medium siltation height was determined using a line statistics tool. The results regarding morphological information about the profile were gathered in table 1.

Thereby it has been discovered that the valley width increased with a medium length of 7.19 m, this increase having the lowest value of 1 meter in profile number 3, and the highest value of 12.04 meters in profile number 9 (table 1).

As it was expected the horizontal dynamics of the valley occurred in increasing its width due to positioning transversal works which facilitated siltation. The width of the valley increase was major influenced by two major factors: the previous morphology of the valley and the height of the dam implicitly the height of siltation.

Table 1. Morphological data extracted from horizontal dynamics analysis

| *Profile number (1)* | *Valley width in 1979 (2)* | *Valley width in 2008 (3)* | *Valley width coefficient (3/2)* | *Valley width difference (3-2)* | *Siltation medium height on profile* |
|---|---|---|---|---|---|
| 1 | 14.86 | 18.46 | 1.24 | 3.60 | 1.30 |
| 2 | 11.33 | 16.95 | 1.50 | 5.62 | 1.37 |
| 3 | 12.70 | 13.76 | 1.08 | 1.06 | 1.38 |
| 4 | 4.60 | 15.87 | 3.45 | 11.27 | 2.57 |
| 5 | 14.90 | 17.65 | 1.18 | 2.75 | 0.80 |
| 6 | 10.70 | 15.99 | 1.49 | 5.29 | 1.14 |
| 7 | 12.90 | 24.29 | 1.88 | 11.39 | 3.00 |
| 8 | 9.30 | 18.73 | 2.01 | 9.43 | 2.28 |
| 9.1 | 6.30 | 11.38 | 1.81 | 5.08 | 3.06 |
| 9.2 | 4.20 | 16.24 | 3.87 | 12.04 | 3.06 |
| 10 | 4.00 | 15.57 | 3.89 | 11.57 | 2.84 |

The influence of siltation height can be observed by studying the regression equation between valley width coefficient and siltation medium height on profile (figure 7).

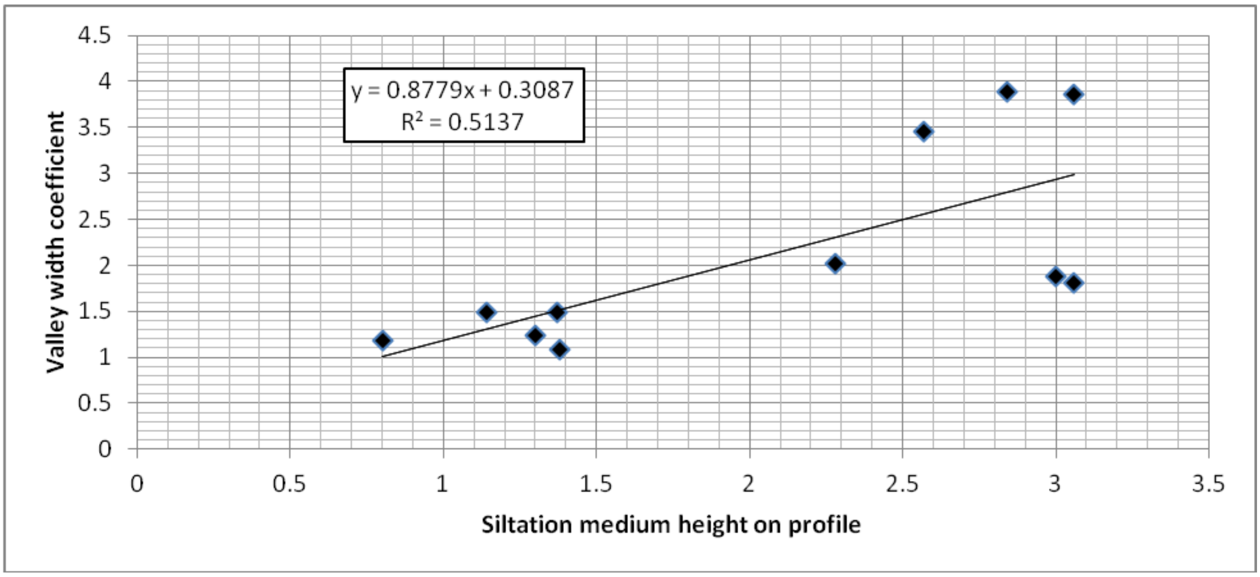

**Fig. 6** Regression equation between valley width coefficient and siltation medium height on profile

In case of analyzed population there are 10 degrees of freedom. Calculating the correlation coefficients between siltation medium height and valley width coefficient that make up the populations led, for existing degrees of freedom, to significant correlations r=0.717.

### *5.3.2. Vertical dynamics*

The approach in quantifying vertical dynamics was to define 5 sections of longitudinal profile and to calculate grid statistics for each period to each section. The sections were defined behind each torrent control check dam excepting the last construction where 2 valleys are meeting (figure 8).

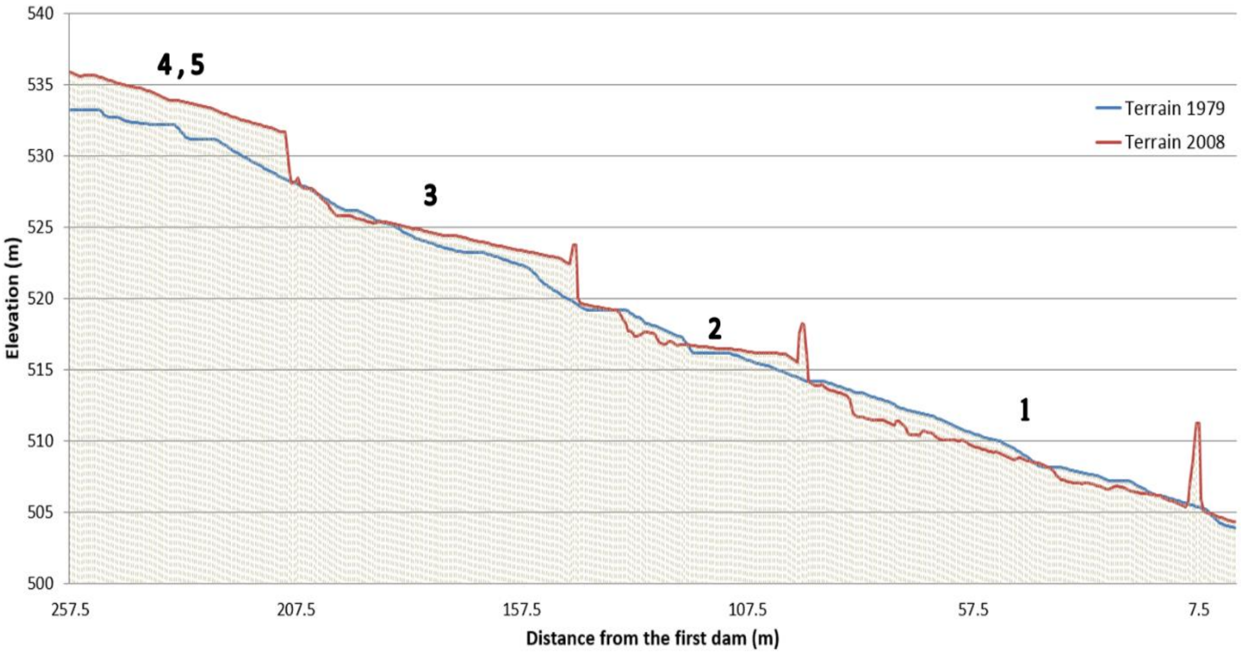

**Fig. 8.** Longitudinal profiles distribution on Vidas Valley

Regarding vertical dynamics, the slope decreased from 0.3 in section 2 to 4.4 degrees in section 5. It can be seen that in all sections the slope decreased with different percentages depending on factors like existing morphometry and underlayer (table 2).

Table 2. **Morphological data extracted from vertical dynamics analysis**

| *Profile number* | *Length (meters)* | *Slope – 1979 (degrees)* | *Slope – 2008 (degrees)* | *Slope difference (degrees)* |
|---|---|---|---|---|
| **1** | 72.6 | 5.9 | 4.8 | -1.1 |
| **2** | 38.8 | 7.0 | 6.7 | -0.3 |
| **3** | 50.6 | 6.6 | 4.7 | -1.9 |
| **4** | 39.3 | 7.4 | 6.2 | -1.2 |
| **5** | 42.7 | 10.8 | 6.4 | -4.4 |

Analyzing the slope values of siltation (table 2) offers a different perspective of what the technical project provided. It can be observed that in profile number 2,4 and 5 the slopes are much higher than expected (2-3 degrees). An explanation of these slopes can be the high percentage of wood debris in the siltation which increased the values to double or triple.

### *5.3.3. Spatial dynamics*

The facilities offered by a GIS environment and the digital elevation models made possible an analysis regarding spatial dynamics. Knowing the elevation distribution at cell level for each square meter it can be calculated the elevation difference between 1979 and 2008 (fig. 9).

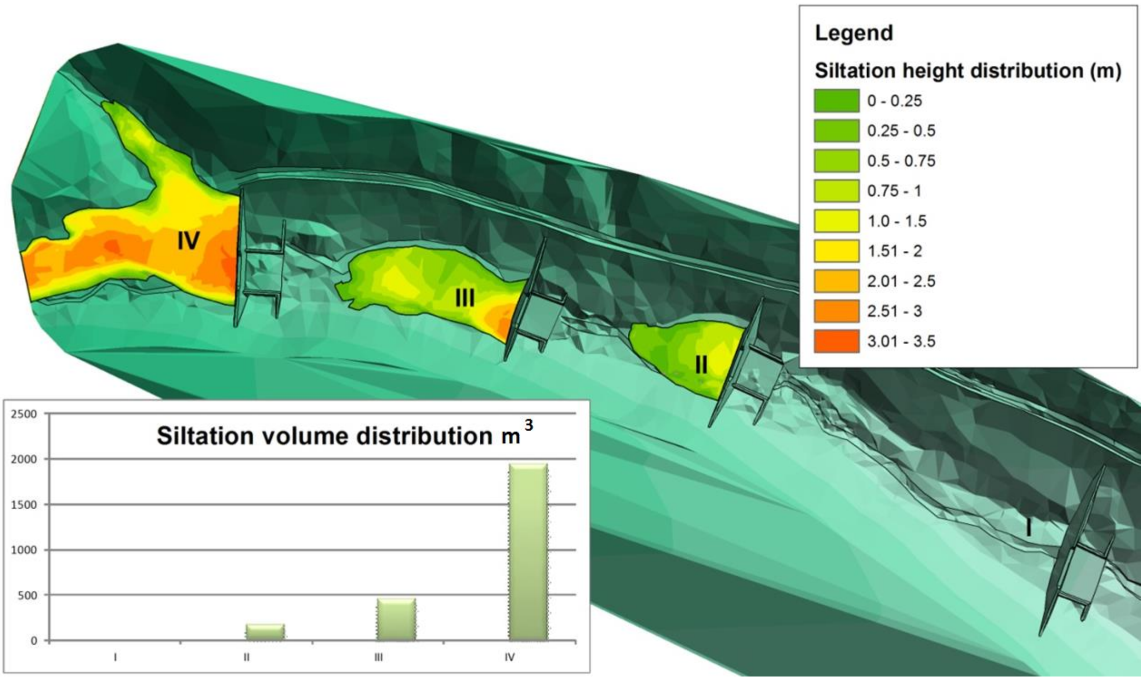

**Fig. 9.** Calculated sediment siltation for zones 1–4 formed during 1979 - 2008

For each polygon which delineated the siltation a total volume was calculated using a spatial statistics tool. The procedure was to determine which cells are composing the siltation and to calculate the exact volume by multiplying the elevation with the area of cell. Based on this procedure it was determined a total siltation volume of 2569.22 cubic meters deployed on a 1956.56 square meters area (table 3).

It can be observed in table 3 that the volume upstream the first dam is very low, taking into consideration that is the highest dam from all 4. This situation shows that even a long period passed from the construction of the dams, they stopped the siltation to go downstream into the lake.

**Table 3. The volume of siltation calculated on raster difference between digital elevation models**

| *Siltation number* | *Volume (cubic meters)* | *Upstream height of the dam (meters)* | *Perimeter (meters)* | *Area (square meters)* |
|---|---|---|---|---|
| **1** | 0.83 | 6 | 20.22 | 9.69 |
| **2** | 170.16 | 4 | 73.84 | 305.69 |
| **3** | 454.35 | 3.2 | 115.48 | 553.42 |
| **4** | 1943.88 | 3.2 | 192.26 | 1087.76 |
| | **Total volume - 2569.22** | | | **Total area - 1956.56** |

Based on the fact that the dams were constructed in 1980 it can be considered the hypothesis that the mean rate of siltation on Vidas Valley was of 91 cubic meters per year. Reporting this value to the total area determined in the research site the siltation grew with a medium value of 4.7 cm per year.

### 5.4. *Conclusions*

This activity of monitoring is developing in hard conditions and is conditioned by historical data which in most of cases are lost in time. As shown in the introduction there are few studies in our country and worldwide on torrential valleys to stream bed dynamics where torrent control check dams were placed. Within this study we wanted to identify any horizontal, vertical and spatial dynamics which occurred due to placing torrent control dams in 1980 on Vidas Valley. Some of the results demonstrated hypothesis easy to understand like: the direct correlation between increase of valley width and the height of siltation, or the reduction of valley longitudinal slope due to the siltation. There are still some results which shown that this kind of research needs to be continued and deepened like: relatively high slope of siltation or no siltation formation at the first dam.

From the presented study the situation of the first dam rises a question mark. Why this dam did not have siltation upstream? What were the causes? The research conducted so far reveals some aspects that can be emphasized as future research hypothesis.

One aspect is that the dam has no siltation due to the underestimation of siltation slope, especially to the last dam. This situation created the opportunity for a larger accumulation of siltation upstream the last dam and diminished the erosional force on the valley.

Another aspect it can be related to the river bank erosion. If the riverbanks, which were afforested for protection, did not produced to many sediments the situation lead to a missing siltation upstream the last dam.

This study shows how complex are the actions in nature, and how difficult is to predict which are the drivers in producing these siltation patterns.

## (B-ii) The evolution and development plans for career development

## 1. Professional evolution

### *1.1. Education*

2003 – 2008 – **Bachelor studies**. Forestry. Head of the class. Transilvania University of Brasov

2008 – 2011 – **Doctoral studies**: Possibilities of improving the peak discharge prognosis methodology in small torrential predominantly forested watershed. Transilvania University of Brasov

2016 - 2017 – **Postdoctoral studies**: Effect of World War II lingering in Romanian Forests. Univeristy of Wisconsin - Madison

### *1.2. Professional activity*

**Bachelor supervisor**: 40 projects. Since 2011 I was supervising bachelor projects in the field of Watershed management and Use of GIS, RS and Terrestrial Measurements in monitoring hydrotechnical structures

**Phd comittee supervisor**: 3

From professional point of view, I demonstrated the ability of being an independent researcher and managing groups of researchers as project manager or as group leader with satisfactory results:

**Project Manager:**

- Academic support services for Rectify and Mosaic 700 Corona Satellite images. University of Wisconsin – Madison. 2018-2019.
- Solutii ecologice pentru amenajarea albiilor torentiale din ariile naturale protejate ROSCI0207 Postavaru, ROSCI0195 Piatra Mare si ROSCI0038 Ciucas. UEFISCDI. 2014 - 2017
- Studiu privind inventarierea starii obiectivelor de corectare a torentilor din fondul forestier administrat de RNP-ROMSILVA si crearea unei baze de date pentru monitorizarea lucrarilor executate in acest scop. RNP-ROMSILVA 2015 - 2016

**Team member:**

- Sustainable networks for the energetic use of lignucellulosic biomass in South East Europe (FOROPA). 2013 - 2014
- European Islands Continue Education on Resources Efficiency Virtual Gateway (VIREG) - ERASMUS EQR. 2015-2016
- MSc Degree on Management of Sustainable and Ecological Tourism (MEST). 2014 - 2015
- European Research and Enterprise Alliance on Marketing and Economics of Ecosystems and Biodiversity - ECOSTAR - ERASMUS+, KA2. 2016 - 2018
- COREHABS - Coridoare ecologice pentru habitate si specii in Romania - M.SEE.2016 – 2017
- ENPI FLEG Consultant for conducting an analytical study on Forest Ecosystem Services (FES) in Moldova.2014
- Managing and conserving forests for multiple values.2013
- MsC Modules Programme in Environmental Security and Management-SEMP. 2013
- Estimating the available beech, Norway spruce and silver fir wood to be harvested in east Romania.2012
- Noi cercetari privind comportarea lucrarilor de amenajare a retelei hidrografice torentiale din bazinul superior al tarlungului (amonte de acumularea Sacele - judetul Brasov)
- Development of new products derived from satellite data adapted to users in the management of hydro-meteorological risk situations. (RISCASAT)
- " Improving the Financial Sustainability of the Carpathian System of Protected Areas" – Watershed protection in AP (soil stabilization, erosion control, water level fluctuation) and Disaster Risk Reduction value in AP
- Fundamente si solutii privind proiectarea si monitorizarea lucrarilor de amenajare a bazinelor hidrografice torentiale, predominant forestiere
- Studiu privind inventarierea starii retelei de drumuri forestiere administrate de Regia Nationala a padurilor-Romsilva si crearea unei baze de date pentru monitorizarea infrastructurii de transport forestier

- Cercetari privind managementul ariilor protejate Padurea Goroniste si Padurea Alparea din jud. Bihor. Elaborarea planurilor integrate de management a celor doua arii protejate

**International Talks:**

2007-Jesus College Oxford-UK;

2009-Faculty of Forestry Madrid-Spain;

2012-Faculty of Forest and Environmental Sciences Freiburg-Germany;

2014-Faculty of Forestry Krakow-Poland;

2015-Department of Forestry and Wildlife Ecology, University of Wisconsin-Madison-USA; Faculty of Forestry Madrid-Spain; Moldavian Forest Administration Chisinau-Moldova; -Department of Land, Environment, Agriculture and Forestry, University of Padova, Italy;

2016-NASA Goddard Space Flight Centre – Washington D.C., USA; Faculty of Forestry, Zvolen, Slovakia;

2017 – Humboldt University Berlin – Germany

2018 – Faculty of Geodesy, University of Zagreb, Croatia

International trainer: Zvolen, Zagreb, Bagkok, Vientiane

### *1.3. Research activity*

The research activity is based on a continous action starting as a young researcher gathering until present moment a participation in 18 research and technical projects, 10 international, and dissemination of research results in 32 research articles, 11 in ISI-WOS and 21 in international databases (e.g. CABI, Scopus, Springer). The most important contributions in the field of forestry are targeted to forest management and monitoring, on topics like LULUCF (land use, land-use change and forestry) using remote sensing and drone mapping, extensive expertise in historic land use change and historic forestry, evaluating Forest Ecosystem Services (FES), modelling habitat distributions for species and developing and managing GIS databases.

Related to international visibility, in 2016, I was selected through an international peer-reviewed competition, by the prestigious Fulbright Commission to be funded as Visiting Profesor Honorary fellow in Department of Wildlife and Forest Ecology, University of

Wisconsin-Madison, for 6 months 07/2016 – 03/2017. During that period, I was exploring the effect of wars and political conflict on forest ecosystems in Romania by assessing the forest disturbances during Soviet occupation (1945 - 1956) using a heuristic method based on SfM (Structure from Motion) and DISI (Declassified Intelligence Satellite Imagery). In January 2018 the research results were published in the most prestigious journal (ranked No.1 by Web of Science in Remote Sensing).

The scientific achievements can be categorised as highly interdisciplinary and combine different research areas such as forestry, remote sensing and social and economic history. Most notably, my research led to significantly incresing knowledge in the field of forestry and related areas, particularly the topic of historical forest management in Romania, long-term forest dynamics monitoring using satellite imagery or quantifying human long-term actions to natural ecosystems.

In the past I conducted a research on historical forest management in Romania and identified that past forestry measures were imposing strong legacies in contemporary forests. The study developed in SILVIS Laboratory from Department of Wildlife and Forest Ecology, University of Wisconsin-Madison (which was ranked by US National Research Council no. 1 forest science educational program in USA) was disseminated in the top journal in Forestry, Forest Ecology and Management. This article published in 2016 is already cited 16 times in ISI-WOS showing an important international visibility. This study was for the first time in Romania when were quantified the geo-spatial effects of historical forest management, which covered an extensive time frame of 100 years.

Another contribution on long-term forest monitoring is the research on forests dynamics using satellite imagery in collaboration with Sensitive Mountain Forest (SENSFOR) COST Action members. The paper published in a top journal in Environmental Sciences, Climate research, emphasize the quality of research in the field of quantifying the long-term effects of climate and humans to high elevation tree lines.

My contribution in quantifying human long-term actions to natural ecosystems is proven by the paper published in 2016 as first author in an ISI-WOS international journal in Environmental Sciences (Env Eng Manag J). The subject of quantifying riverbed dynamics improved the knowledge on long-term influence of human actions which altered the natural ecosystems in Romania. Within this research, I used a combined method of Terrestrial

Measurements, GIS and Historical Cartography to reconstruct the morphological changes caused by human riverbed correction.

Currently I am expanding my research on long-term human influence on ecosystem in Caucasus Mountains within a project financed by NASA and coordinated by University of Wisconsin – Madison.

## 2. Career development plan

### *2.1. Personal evaluation*

Since I start the research on my PhD ten years ago I continuously tried to harness every opportunity of development and accumulation in what concerns my technical capacity. Management of different organizations, international and national projects but also teaching abilities.

The focus of my career development was to become international in forest research, to be a part of high ranked research teams, to understand and learn the cutting-edge tehcnologies and methods in forestry, especially in GIS & Remote Sensing and Watershed Management and to improve the way I deliver this message to the students.

This focus gave me opportunities to study and work in different parts of the Globe (North America, South America, Asia, Europe) with different strong entities (NASA, ESA, IUFRO, more than 5 Top 100 ranked Universities). In 7 years after finishing my Phd, my research collaboration was disseminated in 35 research papers, 11 in Web of Science, 1 in the prestigious journal Remote Sensing of Environment (Ranked No.1 in Remote Sensing Sciences). My research was cited 77 times by other researchers and the trend is increasing.

My recent paper, "Widespread forest cutting in the aftermath of World War II captured by broad-scale historical Corona spy satellite photography" was for the 4 months in the top of the most downloaded papers in Remote Sensing of Environment.

Promoting and supporting collaborative approaches within the Faculty of Silviculture and Forest Engineering are important for me. I have been opened to actively involve in organizing (e.g. I was member of Organizing committee of our Faculty Biennial Session in 2008,2010, 2012,2014,2016 and continouing in 2018), planning and teaching activities and I intend to keep this openness for the future. I am an organized professional, ready to take responsibilities. All these qualities have been and will be offered in all possible collaborations with my colleagues. In my view, collaborations with colleagues, researchers and teachers, are the basis of getting to a synergic level of the whole activity in our Faculty and University.

Because of participating/coordinating in very important national and international scale projects I have continuously increased my knowledge and abilities, thus I think that stepping into the teaching and research field is a higher level for me, allowing to be able to assure an effective transfer of knowledge to younger generations.

During my career I have accumulated deep abilities in the field of applied remote sensing and innovative technology in the field of monitoring forest ecosystems and watershed management. My working approach is reliable, and I consider myself as being serious and responsible in achieving the intended goals, in close collaboration with all the members of the team. I like working in teams and I consider that the common effort is more valuable than the individual one. A have significant knowledges and capacities in integrating, at different level, of studies and research.

### *2.2. Areas of interest in research activities*

My areas of interest in research activities are related to forest management and monitoring, mainly in

- RS-GIS expert on topics like LULUCF (land use, land-use change and forestry) using remote sensing and drone mapping,
- modelling habitat distributions for species,
- evaluating Forest Ecosystem Services (FES),
- developing and managing GIS databases and WebGIS apps.

### *2.3. Opportunities regarding the involvement within the University and the Faculty*

### *2.4. Future development in the teaching activity*

As a member of the team of professors and researchers of the Faculty of Silviculture and Forestry Engineering I have imposed a series of objectives that will held a central position in my career development plans. Continuity in relationships with my colleagues is one of the objectives, and its achievement can be reached through an efficient transfer of knowledge and information. There are many specific organizational and institutional activities within the University and my plans, as a member of the organization, is to get as familiarized as possible with those specificities and get involved whenever my capabilities can be of use. In this context

I also plan to join professional associations or committees within the University, trying to make my contribution as valuable as possible.

I consider that participation in the events organized by the University is also important for any member of the organization. Another important aspect is the adoption of the highest level or morality and ethics in all University related activities. Involving in promotion at national and international level or the achievements of the University will also be an important point in my agenda, along with using and maintaining all collaborations and contacts between the University and other academic, research or production entities, in Romania or abroad.

In teaching, my concept is that the transfer of knowledge must reflect the professional experience of the teacher and therefore, my objectives are formulated around the idea of finding the best ways to transfer my professional experience to the students, of course in the limits of the disciplines I teach. My plans, in the immediate period, include:

- Facilitating better access to teaching materials for the students; using the elearning.unitbv.ro platform can be enriched with direct contact with students and encourage them to have a direct contact with the teacher;
- Permanent improvement of the teaching materials, keeping them topical and up to date;
- Elaboration and publication of brochures including courses notes for all the disciplines in my portfolio;
- Elaboration and publication of brochures including case studies for the seminars for Torrent Control;
- Permanent surveys for evaluating training needs of the students as well as their opinion on how good the knowledge transfer was; these approached are already implemented based on questionnaires, every year;
- Promoting the approaches based on guest speaking – inviting personalities of the sector to meet the students within the different courses.

I will continue the implementation of the modern and integrated teaching approaches, especially reflected in:

- Assuring the integration between the transferred information and the general study plan of the students;
- Promoting the use of specialized software, especially open-source

- Utilization of interactive communication methods and other interactive approaches for knowledge transfer (for instance using the Internet in an interactive way, using case studies during the seminars, direct teacher to student dialog, team working).

Another important component of my teaching career development plan is the interest I am willing to pay for the integration of the quality and quantity of the transferred information with other universities in Romania or in other countries, of course without sacrificing the local specificity or traditions. I intend to continue and improve the collaboration with teachers in the same areas from other universities in Romania or in other countries, promote students exchange, etc.

With the specific of the disciplines I teach in mind, an important part of my future preoccupation is the increase of applicability of the theoretical notions, especially implementation of the theoretical notions by students in their own businesses or organizations, or for their diploma works.

### *2.5. Future development in research and consultancy area*

The future development career plans in research will continue the way I already followed, being marked by the principle of improving the research performance, relevance and visibility. From this point of view, my operational plan of research career development will follow the main direction established at the level of the University, Faculty and Department. Main interest is to identify relevant areas of research, in close contact with the realities of the forestry sector in Romania, make efforts to find the most suitable financing opportunities for sustaining my own research and the research of the PhD students. The obtained results will be valorized in a way that can assure an effective visibility of the research, the Faculty and the University, especially publication in important, prestigious and recognized journals in forestry or related fields. Integrating students, PhD students, or master students in my research will be a priority, together with the integration of the research work with my colleagues in the Faculty. In my field of forest economics, my basic objectives for the research activity are subordinated to the idea of creating a research and consultancy team with the PhD students and other colleagues in the Faculty, the team being increasingly capable to continue or initiate synergic research direction in different research field:

- Continuation in the matter of attracting funds for different research projects as well as responding positively to different consultancy request from organizations in forestry or related fields in Romania and abroad;
- Promoting common projects with research and consultancy centers in Romanian or in other countries;
- Continuous publication of articles in relevant, recognized and prestigious journals (ISI Clarivate);
- Participation in international and national conferences;
- Elaboration of books or chapters of books and their publication at recognized publishing houses in Romania and abroad;
- Involvement in international collaborative projects (COST, IUFRO, SCERIN, etc.) in the areas of my specialization;
- Expanding the research directions that have been followed by now and promote cross disciplinary projects, in integrated teams including PhD students;
- Involvement in the development of the research center within the ICDT of our University;
- Supporting the efforts of the Faculty and University to organize different research events;
- Supporting and participating in different scientific international events, together with our international partners, in areas of my specialization;
- Organizing co-tutorial doctoral studies with relevant international Universities and research personalities;
- Promote connected and integrated doctoral areas of research for creating a synergic effect of the researches.
- Regarding the future research areas, they will have the basis in the directions that have been followed so far.

### *2.6. Career development framework*

The framework for my career development is built on general recognized values as: professionalism, transparency, excellence, openness to new, teamwork. These values are traditionally promoted also by my department of Forest Management and Forest Engineering, my Faculty of Silviculture and Forestry Engineering and my University – Transilvania University of Brasov.

The career development plan presented in the pages above corresponds with the mission and vision of Transilvania University of Brasov and The Faculty of Silviculture and Forestry Engineering and their strategic and operational plans.

I am also basing my plans on the continuation of logistic and material support that have been assured by the Department, the Faculty and the University.

In my view, the same importance should be attributed to collaborative approach. I will not be able to achieve the above stated objectives outside of the team functioning now under in the Faculty of Silviculture and Forestry Engineering. All my plans have, at the basis, the support and collaboration of my colleagues, mainly from our University but also from other partner organizations.

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