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Old-growth forest reserves in Slovenia: the past, present, and future

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Old-growth forest reserves in Slovenia: the past, present, and future

Slovenia has a small number of old-growth forest remnants, as well as many forest reserves approaching old-growth conditions. In this paper, we describe some of the basic characteristics of these old-growth remnants and the history of their protection in Slovenia. We then trace the long-term development of research in these old-growth remnants, with a focus on methodological changes. We also review some of the recent findings from old-growth research in Slovenia and discuss future research needs. The conceptual understanding of how these forests work has slowly evolved, from thinking of them in terms of stable systems to more dynamic and unpredictable ones due to the influence of natural disturbances and indirect human influences. In accordance with this thinking, the methods used to study old-growth forests have changed from descriptions of stand structure to studies that address natural processes and ecosystem functions.

Keywords: Balkan, Central Europe, primeval forest, virgin forest, old-growth forest

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By providing a reference for understanding natural pattern and process, old-growth forest ecosystems have long been valued by foresters and ecologists alike. In addition to scientific insight, the innate value of old-growth forests, including the ecosystem services they provide and the unique array of biodiversity they hold, raises significant challenges regarding their conservation and management. These issues are particularly important in the temperate zone of Europe, where silvicultural systems based on patterns and processes found in old-growth are still in need of quantitative information, yet very few old-growth ecosystems remain and extant remnants are often influenced by a number of indirect anthropogenic disturbances. Nevertheless, the remaining old-growth forests in the temperate zone of Europe have a long history of protection and have been thoroughly studied (e.g. Korpel' 1995, Peterken 1996, Splechtna & Gratzner 2005).

Similar to other countries in the Balkan region, Slovenia has several old-growth remnants that escaped historical logging, often due to the individual efforts of visionary foresters. These forests are at the heart of Slovenia's long tradition of ecologically based forest management, and have been a focal point of research for a half-century. During this time period, the view of how these forests work has slowly

evolved, from thinking of them in terms of stable systems to more dynamic and unpredictable ones (Splechtna & Gratzner 2005). In line with this thinking, the methods used to study old-growth forests have changed from descriptions of vegetation and stand structure (e.g. Hocevar et al 1980) to studies that address natural processes and ecosystem functions (e.g. Firm et al 2009).

The goal of this paper is to provide an overview of old-growth forest research in Slovenia. We begin the paper with a description of the historical development of old-growth forests in Slovenia. This is followed by a description of the extant network of old-growth forest reserves. We then trace the historical development of research methodologies used to study old-growth forests in the region. Finally, we provide a brief overview of more recent research findings from different old-growth forests in Slovenia, and conclude with a discussion of future research directions.

Historical development of old-growth forest reserves in Slovenia

There is a long tradition of old-growth forest protection and research in Slovenia. Already in 1892, an extensive area of old-growth forest in the Dinaric

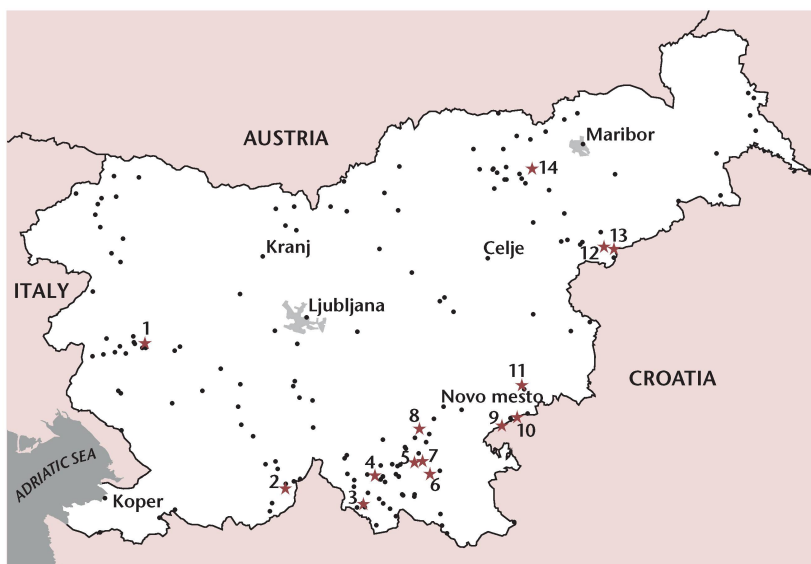


Fig 1 Locations of old-growth forests (stars) and forest reserves (black circles) in Slovenia. Numbered stars correspond to the list of reserves in Table 1.

Number in Figure 1	Old-growth reserve	Size (ha)*	Dominant tree species	Altitude (m a.s.l.)
1	Bukov vrh	8	<i>Fagus sylvatica</i>	1,250–1,314
2	Zdrocle	157	<i>F. sylvatica</i> , <i>Picea abies</i>	1,300–1,477
3	Krokar	75	<i>F. sylvatica</i> , <i>Abies alba</i>	750–1,190
4	Strmec	16	<i>A. alba</i> , <i>F. sylvatica</i>	820–940
5	Prelesnikova kolisevka	3	<i>P. abies</i>	425–475
6	Kopa	13	<i>F. sylvatica</i>	980–1,080
7	Rajhenavski Rog	51	<i>A. alba</i> , <i>F. sylvatica</i>	800–920
8	Pecka	60	<i>A. alba</i> , <i>F. sylvatica</i>	795–910
9	Gorjanci-Trdinov vrh	23	<i>F. sylvatica</i>	990–1,150
10	Ravna gora	16	<i>F. sylvatica</i>	890
11	Krakovo	40	<i>Quercus robur</i>	152–153
12	Donacka gora	28	<i>F. sylvatica</i>	600–800
13	Belinovec	4	<i>F. sylvatica</i>	600–700
14	Sumik	20	<i>F. sylvatica</i> , <i>A. alba</i> , <i>P. abies</i>	800–1,150
Total area		514		

Tab 1 Basic characteristics of old-growth forest reserves in Slovenia. * Approximate size of the old-growth area. The actual sizes of the reserves that contain the old-growth areas are often larger than the values reported here because they include buffer zones.

Mountains of southeastern Slovenia was protected under the forest management plan for the region (Hufnagel 1893). The first inventories of forest composition and structure were carried out at that time. During the 1950s, there was a lively discussion about the importance of nature reserves for life sciences in general and for the science and practice of forestry in particular (Wraber 1952). By 1973 the area of protected old-growth forest remnants encompassed 343 ha. In the same decade, a large project focused on the protection of new forest reserves – “old-growth forests for the future” – was started in Slovenia. It was led by Professor Dusan Mlinsek and inspired by the naturalistic movement of silviculture professors, especially Hans Leibundgut (Leibundgut 1959). The result of the project was a network of 173 protected

forest reserves covering an area of 9,040 ha, which included the previously protected old-growth reserves as well as several new ones, making a total of fourteen old-growth forest remnants with a cumulative area of approximately 500 ha (Mlinsek et al 1980). In the meantime, detailed guidelines for research and maintenance of forest reserves were developed (Anko et al 1976). Comprehensive studies of individual old-growth remnants were published as monographs (e.g. Hocevar et al 1985, Turk et al 1985, Hartman 1987). More recently, re-privatization of forests that followed the independence of Slovenia in 1991 introduced minor changes to the forest reserve network, but the network of old-growth forests remained unaffected. Today there are 170 forest reserves in Slovenia covering approximately 9,600 ha, which is about 0.8% of the total forest area in Slovenia (Figure 1).

Old-growth forests in Slovenia

Most of the old-growth reserves in Slovenia (officially referred to as “virgin forests” in Slovenia) are small (typically < 50 ha) remnants dominated by mixtures of *Abies alba* and *Fagus sylvatica*, but there are some exceptions (Table 1). Of the 14 old-growth reserves, most are located at upper elevations of the Dinaric Mountain range, predominantly on limestone parent material (Figure 1). In this region, *A. alba* and *F. sylvatica* are the dominant species, but less shade tolerant tree species, including *Acer pseudoplatanus*, *Ulmus glabra*, *Fraxinus excelsior*, and *Picea abies*, are also present depending on the site conditions and disturbance history. The largest and most researched old-growth remnants in the region are Rajhenavski Rog (Nr. 7 in figure 1), Pecka (Nr. 8), and Krokar (Nr. 3). Several smaller remnants (Strmec [Nr. 4], Kopa [Nr. 6], Gorjanci-Trdinov vrh [Nr. 9], Ravna gora [Nr. 10], and Bukov vrh [Nr. 1]) are mainly dominated by *F. sylvatica*. The only old-growth *P. abies* remnant in Slovenia, Prelesnikova kolisevka (Nr. 5), is located in a karst sinkhole at the foothills of the Dinaric region where a pool of cold-air (temperature inversion) is commonly formed. The Zdrocle reserve (Nr. 2), located on the southeastern side of Sneznik, the highest peak in the Dinaric Mountains of Slovenia, is the largest reserve on paper, but parts of the reserve were managed in the past, so stands with old-growth conditions form a smaller area. Zdrocle occurs on rather extreme karst geological conditions, characterized by abundant sinkholes and limestone outcroppings, where *F. sylvatica* is the most abundant species.

The remaining old-growth reserves occur outside the Dinaric Mountain region. They include two *F. sylvatica* dominated remnants in the Haloze region of eastern Slovenia, known as Donacka gora (Nr. 12) and Belinovec (Nr. 13), as well as Sumik

(Nr. 14), a mixed *Abies-Fagus-Picea* remnant in the Pohorje Mountain range in northeastern Slovenia and Krakovo (Nr. 11), a lowland *Quercus robur* dominated floodplain forest between the Krka and Sava rivers in southeastern Slovenia. In addition to the remnants under official protection, there are several old-growth remnants on state land that are currently unprotected, such as the Lucka Bela forest in the Kamniske Alps, as well as forest reserves that have old-growth conditions that are not on the list of old-growth remnants, such as the Menina-Strojnič forest reserve in the Kamniske Alps.

Methodological development of old-growth research

The methods used to study old-growth forests have changed over the past century in Slovenia, partly because of the paradigm shift in ecology emphasizing change over stability, but also because researchers are asking different types of questions today than they did fifty years ago. Additionally, modern research tools (i.e. remote sensing, lidar, light sensors, etc.) have opened up a world of new possibilities to forest researchers.

In Slovenia, much like other parts of Central Europe, early research in old-growth forests in the 20th century was focused on describing vegetation and stand structure. Many of the initial investigations in old-growth remnants consisted of very detailed inventories of site conditions, flora, fungi, and lichens (e.g. Hocevar et al 1980, Hocevar et al 1995). It is important to note that early forest researchers generally worked under the assumption that old-growth forests were stable ecosystems in terms of species composition and structure at a stand scale, whereby on a particular site type a specific climax forest would develop and reach a stable endpoint (Clements 1916). The basis of the climax concept, which originated in North America, was very similar to the phytosociological study of vegetation that developed in Europe (Braun-Blanquet 1964). Therefore, early researchers working in Slovene old-growth forests spent much time describing and mapping phytosociological associations, and this traditional approach is still carried on today (e.g. Accetto 2002, Marinček & Marinšek 2009).

Much effort was also invested in studying the dynamics of these old-growth remnants by mapping patches of forest in different development phases (e.g. Turk et al 1985, Hartman 1987, Kovac 1999, Boncina 2000). This development cycle approach encompassed all stages of development, from regeneration in gaps to senescence of old trees, and was generally thought to be driven by continuous, endogenous mortality of canopy trees. In most of the old-growth forests in Slovenia, developmental phases were mapped at least once during the past 30 years, and selected

reserves have been mapped several times. In addition to mapping development phases, full inventories of tree diameter, both living and dead, were carried out every 10 years since around 1980 in selected old-growth forests. Combined with repeated inventories of developmental phases, these “full callipering” datasets provide valuable insight into long-term changes in stand structure and composition (e.g. Diaci et al 2008b, Diaci et al 2010). Long-term monitoring of old-growth reserves is also carried out in a network of permanent research plots. These plots were established in most old-growth reserves about 30 years ago largely due to the forward thinking of professor Dušan Mlinšek. The plots generally range in size from 0.25 to 1 ha, and all trees > 5 cm dbh are tagged and numbered. Monitoring growth and mortality in the plots is carried out approximately every 10 years (e.g. Rozenbergar 2000). Mlinšek also initiated studies on regeneration ecology, including studies on sapling architecture and browsing impact (Mlinšek 1967, Mlinšek & Zupancič 1974).

More recently, research in old-growth forests in Slovenia has diversified and moved from descriptions of vegetation and stand structure toward research that examines various ecological processes and ecosystem functions. For example, many studies have focused on the role of coarse woody debris, including studies on quantity and quality (Kraigher et al 2002, Christensen et al 2005, Debeljak 2006) and the importance of dead wood for vascular plants (Kutnar et al 2002), bryophytes (Odor & Van Dort 2002), and fungi (Piltaver et al 2002, Grebenc et al 2004, Odor et al 2006). Research has also been done on the importance of old-growth structural conditions for fauna, especially birds (Perusek 1992, Boncina 2000) and insects (Floren & Gogala 2002). Another major research theme focuses on understanding the role of canopy openings in old-growth forests, including the influence of gaps on water balance (Vilhar et al 2005), mycorrhizal communities (Grebenc et al 2009), and tree regeneration (Rozenbergar et al 2007, Diaci et al 2008a, Mikac et al 2008). Finally, in order to move past the early ideas of stability in old-growth, recent studies have emphasized the role of disturbance processes in driving stand dynamics. This research has generally employed three different approaches, which include measuring characteristics of canopy gaps (Zeibig et al 2005), observations of recent higher intensity disturbance events (Marinšek & Diaci 2004, Nagel & Diaci 2006), and dendroecological investigations of disturbance history (Nagel et al 2007, Firm et al 2009).

Recent research findings

In the following section, we highlight some of the recent research findings on the dynamics of old-

Fig 2 Coarse woody debris and dense beech regeneration resulting from a storm in 1983 that caused intermediate severity damage to the Pecka old-growth forest in the Dinaric Mountains (left). Locations of windthrown trees from the two storm events in 1983 and 2004 in Pecka (right; original source: Nagel & Diaci 2006).



growth forests in Slovenia. A significant advancement in our understanding of old-growth dynamics in Slovenia has come from studies on natural disturbance. While traditional models of old-growth forest dynamics in Central Europe recognized that larger disturbances occurred, they generally underemphasized their role relative to continuous, small-scale endogenous mortality processes (Splechna & Gratzer 2005). Therefore, old-growth forests were thought to exist in a dynamic equilibrium, characterized by a shifting small-scale patchwork of different development stages (e.g. Korpel' 1995). One of the major findings that has emerged from research in old-growth *Fagus-Abies* forests in both the Alps and the Dinaric Mountains is that intermediate severity wind disturbances occur on top of the background of small-scale gap dynamics (Nagel & Diaci 2006, Nagel et al 2007, Firm et al 2009; Figure 2). These events may have a long-lasting influence on stand structure and composition, particularly with regard to maintaining less shade tolerant species (Marinsek & Diaci 2004, Nagel et al 2010). Consequently, this recent research has expanded the traditional site-controlled phytosociological view of forest composition toward a standpoint that highlights the interplay between site and disturbance in controlling species composition.

Another focus of recent research is the influence of novel disturbances related to anthropogenic activities on old-growth forest dynamics. These processes include high levels of browsing damage because

ungulate populations are maintained at a high density (through regulated hunting and supplemental feeding) and the decline of *A. alba* that occurred during the late 20th century in the Dinaric mountain region. These studies show that the interaction of these two processes has led to a shift from *A. alba* to *F. sylvatica* in some Slovene old-growth stands (Rozenberger et al 2007, Diaci et al 2010; Figure 3).

Finally, the last major research theme has focused on the influence of light on various aspects of tree regeneration. This body of work includes studies on stand level patterns of regeneration in relation to canopy structure (Nagel et al 2006), fine-scale patterns of light and regeneration within gaps (Diaci & Thormann 2002, Rozenberger et al 2007, Mikac et al 2008), and studies on the influence of light on architectural characteristics of regeneration (Debeljak & Mlinsek 1998, Diaci & Kozjek 2005, Rozenberger 2007). An interesting finding of the latter studies is that low levels of light (diffuse light < 5–10%) increase the probability of plagiotropic growth for *F. sylvatica* seedlings, but at later development stages, individuals either recover from this growth form or are outcompeted by individuals with straighter growth forms (Figure 4). Research has also compared the light conditions in gaps of similar size found within old-growth and managed forests (Diaci et al 2005). Generally, there is less light in old-growth forests, which may be attributed to taller trees, non thinned stands at gap borders, and the presence of a highly structured layer of advanced regeneration



Fig 3 An ongoing process in some old-growth *Fagus-Abies* reserves in Slovenia is a shift toward *F. sylvatica* dominance caused by the interaction of *A. alba* decline and intense deer browsing on *A. alba* regeneration. The photograph shows a typical stand in Rajhenavski Rog with standing dead *A. alba* trees and dense *F. sylvatica* regeneration.

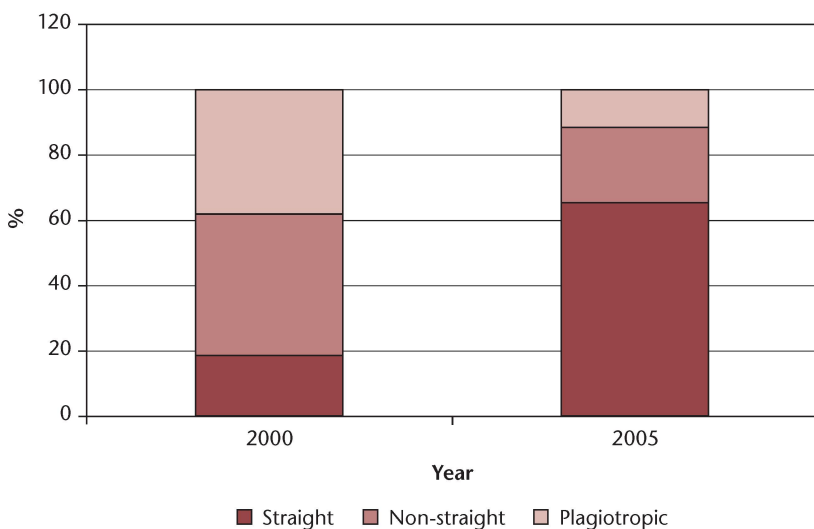


Fig 4 Proportion of plagiotropic, non-straight, and straight individuals of *F. sylvatica* measured on the same plots in 2000 and 2005 in the Rajhenavski Rog old-growth forest reserve. During this time period the average relative diffuse radiation increased from 6 to 10% and the height of individuals from 60 to 160 cm. Note the increase in the proportion of straight stems over the five-year period.

in old-growth. Taken together, these regeneration studies suggest that modern close-to-nature silviculture should not just mimic old-growth gap size distributions, but should pay close attention to the gap microclimate, particularly light conditions.

Future directions

Old growth forest ecosystems are undeniably important for preserving biodiversity and maintaining a variety of ecosystem functions. Likewise, they are also crucial for providing valuable insights into

natural functioning of forest ecosystems, which was recognized decades ago by forest scientists working in old-growth forests in Europe (Leibundgut 1978, Mlinsek 1986). The “reference” conditions provided by old growth are central for both developing ecologically based silvicultural systems and for assessing the long-term effects of forest management (Wraber 1952, Leibundgut 1959, Foster et al 1996, Frelich et al 2005). More recently, old-growth forests have received special attention because they serve as ideal test beds to examine subtle changes in forest dynamics caused by global climate change. There is increasing evidence that global climate change is causing widespread drought induced mortality in forests worldwide (van Mantgem et al 2009, Allen et al 2010). Long term monitoring of mortality in old-growth forests provides estimates of background rates of mortality, which if tracked over long time periods, can yield important information on changes in mortality rates.

A necessary prerequisite to using old-growth stands as reference conditions, however, is to evaluate their “old-growthness”, or the degree of old-growth attributes developed or maintained in a forest stand (Bauhus et al 2009). For example, some old-growth remnants in Slovenia have all the common structural attributes associated with old-growth forests and have very little evidence of past anthropogenic disturbance (e.g. Rajhenavski Rog, Pecka), while others still appear to be transitioning into the old-growth phase (e.g. Krakovo, Krokav). Although historic records show that no management occurred in these areas for the past century, it is very likely that they are still recovering from ancient land-use practices, such as timber harvesting or forest grazing. They may also be recovering from historical natural disturbances, as is the case in the Lucka bela old-growth remnant (Firm et al 2009). Therefore, it would be warranted to evaluate the naturalness or “old-growthness” of old-growth remnants and other non-managed forest reserves in Slovenia. Such an assessment would require an interdisciplinary approach, ranging from analysis of historical records to dendroecological and paleoecological analyses.

We also see a need for improved systematic monitoring of the current network of old-growth forests in Slovenia, particularly regarding the network of permanent research plots. Currently, many of the permanent research plots have not been monitored for more than 10 years and some old-growth remnants do not have sufficient plot coverage. Therefore, in collaboration with the Slovenian Forest Service, the Department of Forestry, University of Ljubljana, is currently setting up a system to monitor plots every 5 years, renovate old plots, and to establish new plots in several old-growth forest reserves. Along these same lines, it would be beneficial to unify monitoring strategies in old-growth forests across interna-

tional borders. If monitoring approaches would be consistent over a large network of permanent plots in old-growth remnants throughout the temperate zone of Europe, this would be a powerful tool to assess long-term changes in tree mortality and carbon storage in the context of global climate change.

Finally, research in old-growth forest reserves deserves more attention and recognition from within the forestry profession and the general public. In particular, despite the long history of “close-to-nature” silviculture in Slovenia, there is still a need for knowledge transfer from old-growth forest research to silvicultural practice (Brang 2005). This could be accomplished through various forms, such as publications in professional journals, involvement of professional foresters in old-growth research, and joint workshops. ■

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Urwaldreservate in Slowenien: gestern, heute und morgen

Slowenien verfügt über einige wenige Urwaldreste und über viele Waldreservate, die sich dem Urwaldzustand annähern. In diesem Aufsatz beschreiben wir einige Charakteristiken dieser Urwaldreste und die Geschichte ihrer Unterschutzstellung. Wir zeichnen dann die lange Entwicklung der Forschung in den Urwaldresten nach, wobei wir dabei ein Schwergewicht auf die methodischen Änderungen legen. Wir geben auch einen Überblick über neue Ergebnisse der Urwaldforschung in Slowenien und diskutieren den zukünftigen Forschungsbedarf. Das Verständnis, wie sich diese Wälder entwickeln, wandelte sich langsam; sie wurden zunächst als stabile, dann aber zunehmend als dynamische und unvorhersehbare Systeme angesehen, als Folge von natürlichen Störungen und indirekten menschlichen Einflüssen. Entsprechend haben sich die Methoden zur Erforschung der Urwälder gewandelt – von Beschreibungen der Bestandesstruktur zu Studien über natürliche Prozesse und Ökosystemfunktionen.

Les réserves de forêts vierges en Slovénie: le passé, le présent et l'avenir

La Slovénie a un nombre restreint de forêts vierges, cependant elle possède un grand nombre de réserves forestières qui s'approchent d'un état ancien. Dans cet article, nous décrivons certaines des caractéristiques fondamentales de ces forêts vierges et l'histoire de leur protection en Slovénie. Par la suite, nous retraçons le développement à long terme de la recherche dans ces forêts en mettant l'accent sur les changements méthodologiques. Nous examinons aussi quelques-unes des conclusions de recherches récentes portant sur ces forêts et discutons des besoins de recherche futurs. La compréhension conceptuelle de la façon dont ces écosystèmes forestiers fonctionnent a lentement évolué, passant de systèmes stables à plus dynamiques et imprévisibles, à cause notamment de l'influence des perturbations naturelles et des influences indirectes anthropiques. Conformément à cette pensée, les méthodes utilisées pour étudier les forêts vierges ont évolué, passant de descriptions générales de la structure du peuplement à des études plus poussées qui portent sur les processus naturels et sur les fonctions de l'écosystème.