Interreg
Alpine Space

EUROPEAN UNION

Links4Soils

EUROPEAN REGIONAL DEVELOPMENT FUND

# Forest site productivity assessment based on soil data

Slovenia Austria

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# IMPRINT

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# SUMMARY

Foresters are facing the question of the quality of their forest land since one of the main services forests are providing is sustainable production of wood. Soil productivity is defined as the capacity of soil, in its normal environment, to support plant growth. Soil productivity is reflected in the growth of forest vegetation or the volume of organic matter produced on site. In forest management, soil productivity is most often measured in volume of trees produced; however, other methods of determining productivity exist including forest community assessments.

Management systems and silvicultural options, such as site preparation, choice of tree species, provenance, spacing, thinning regimes, and regeneration method may affect forest site productivity by various impacts on the physical, chemical and biological characteristics of soils. The decrease in soil productivity affects the level of harvesting a forest can sustain. Moreover, a decrease of other forest services, such as wildlife habitat and populations, and biodiversity is possible as well.

Although there is no ˝perfect˝ or ˝best˝ method, an operational and low-cost measure or prediction of forest site productivity is most often used for forest management planning and it depends on forest structure characteristics, obviously less demanding methods for calculating forest site productivity are based on regular even-aged stands rather than on irregular uneven-aged ones.

Site productivity is an important characteristic of a stand and it is used in forest management for planning harvesting intensity, timesheet of measures and regeneration tactics. There is no "perfect" method for site productivity assessment, however it must be operational and low-cost. Most often methods using dominant three height of the stand are used. Other methods include total wood production assessments or phytosociological approach. Calculating forest site productivity is less demanding for even-aged stands than for uneven-aged ones.

The forest site productivity is presented on ten selected forest sites typical for Slovenia and Tyrol (Austria). Forest site types are based on the ecological and floristic similarity of forest plant communities. Forest site types were further divided into important syntax (phytosociological units), on the basis of which forest site productivity was evaluated. To this end both sides used different methods. Additionally, different examples of forest site productivity evaluations are explained in the report.

# 1 INTRODUCTION

One of the main services forests provide is sustainable production of wood (as the forestry sector depends on timber production), which is often evaluated through the site quality (Bontemps and Bouriaud 2014). **Site quality** is a combination of physical and biological factors that defines a particular geographic location or site, which may be influenced by management (Skovsgaard and Vanclay 2008). Meanwhile **site productivity** is the ability of a given phytocoenosis to produce biomass at a given site and it covers the entire production of biomass = net primary production (Kotar 2005, Kadunc 2013), regardless of how much of this potential is utilised by the vegetation. On the other hand, the production capacity of forest ecosystems is often used in more narrow sense as it takes into consideration timber production capacity only. The latter is defined as the maximum amount of timber (aboveground wood volume production) that is permanently achieved at a given site with suitable tree species and a suitable stand structure (Kotar 2005, Skovsgaard and Vanclay 2008, Kadunc 2013).

The inherent site productivity potential is determined largely by soil characteristics and climatic factors. At least in Slovenia, forest soils are characterised by high diversity of soil conditions and the conservation of natural soil horizons (Kobal 2013) in contrast to soils on cultivated agricultural land with mixed soil horizons. Foresters must be aware of the quality of their forestland to take proper measures in the forests since forest site productivity depends on both natural features of the site and on management-related factors. According to the Skovsgaard and Vanclay (2008), in forests the silvicultural options, such as site preparation, choice of tree species, provenance, spacing, thinning, and regeneration method may affect forest site productivity by various impacts on the physical, chemical and biological characteristics of soils. The decrease in soil productivity could affect the level of harvesting the forest can sustain. Moreover, there are also threats of decrease of other forest services, such as wildlife habitat and populations, and biodiversity. Therefore, it would be wrong to understand forest production capacity only from an economic point of view, but rather as an essential area of the production ecology of forest ecosystems. It is important both in the fundamental studies of ecosystems and in their management. Therefore, according to Kadunc (2013), knowledge of production potential is indispensable for forestry planning, forestry taxation and valuation and, more recently, for the calculation of potential $CO_2$ sinks in forests.

# 2 EVALUATING FOREST SITE PRODUCTIVITY

The site productivity assessment is an important issue in forestry (Zingg 2013). There is a variety of methods for determining the forest site productivity. According to the suggestions of Kadunc (2013), Skovsgaard and Vanclay (2008), these methods may be classified as either **geocentric**, i.e. site-based or **phytocentric**, i.e. vegetation-based. When we speak of forest stand productivity we often use phytocentric indicators. We take into consideration either forest stand, or the trees comprising the stand or components of the individual trees (dentrocentric or dendrometric) (Skovsgaard and Vanclay 2008).

An effective and low-cost measure or prediction of forest site productivity is needed for forest management planning (Pretzsch et al. 2008). Methodology depends on forest structure characteristics. Less demanding methods for calculating forest site productivity are based on regular even-aged stands rather than irregular uneven-aged ones. The most commonly used methods are thus vegetation-based. Commonly, permanent sampling plots are used to determine the aboveground wood volume production (Kadunc et al. 2013b). Later indirect indicators of production were researched, since the first method is time-consuming and demanding (Kotar 2005).

The purpose of this report is to evaluate forest site productivity on the basis of different examples using methodology that has been harmonised between project partners. The aim was to estimate the forest site productivity at the forest community level and to present some additional methods.

## 2.1 Methods

We designated ten forest site types (Table 1) that are typical both for Slovenia and Tyrol. Forest site types = a broader concept that describes the ecological and floristic similarity of forest plant communities. The forest site types were further divided into important syntax or forest community level (phytosociological units) for both, the Austrian (Tyrol) and the Slovenian example. Illustrations of different forest communities are shown in Figure 1. We evaluated forest site productivity for each forest community. The methods that were applied in Tyrol and in Slovenia are presented below.

*Figure 1: Spruce forest on Pokljuka plateau, beech forest in Radovna, Scots pine near Kranj Photo: A. Nève Repe*

## 2.2 Methodology that was applied in Tyrol

In the Tyrolian study, we used the parameters dgz (durchschnittlicher Gesamtzuwachs), SI (site index) and V/ha (stock volume/ha) to describe the estimated growth potential of a forest type (Waldtyp). The dgz stands for the average increase of tree growth. To get an overview at which age the dgz potentially culminates, we compared the dgz at the age of 100 and 150 years. The site index is a measure of the dominant height of a forest stand at the age of 100 years. We used the dominant height (Assmann 1961), which is defined by the medium height of the 100 thickest trees of a stand. The stock volume/ha is a calculated output of the tree growth sampling.

To determine the dgz, the site index and V/ha, we used two different types of tree growth sampling. The n-tree sampling was used in combination with the site sampling to estimate the forest type on the site. Therefore, the 6-tree sampling of Prodan (1965) was used. The angle count sampling of Bitterlich (1948) was used when the modelling of the forest type has already been finished. It was set up to get more data on tree growth for each forest type.

## 2.3 Methodology applied in Slovenia

For the study applied in Slovenia, we used the indirect indices. For most of the Slovene forests, the methodology of site index (SI) is appropriate although forests in Slovenia are not even-aged but are often structured as such. For the purpose of this report, we used SI and mean annual volume increment (MAI).

**Did you know?**

Production potential of Slovenian forests:

The average productivity measured by annual timber production totals 7-8 $m^3$ / ha

Current stand growth (increment) is 6.5 $m^3$ / ha.

The current harvesting is 3-4 $m^3$ / ha

### 2.3.1 Site index

SI describes the potential of forest trees to grow at a particular location or "site". The term site refers to a geographic location that is considered homogeneous in terms of its physical and biological environment. In forestry, a site is usually defined by the location's potential to sustain tree growth, often with a site-specific silviculture (Skovsgaard, Vanclay 2008). Most commonly, site indices are based on or derived from estimates of stand height at a given age and are species specific. Determination of the site index is achieved by measuring and averaging the total height and age of trees found on that site. Height is obtained from dominant or co-dominant trees (referred to as canopy position) in a stand at a base age such as 25, 50 and 100 years. It relies on the hypotheses that height growth correlates well with stand volume growth, that total volume production of a given tree species at a given stand height should be identical for all site classes and that stand volume growth is independent of thinning practice for a wide range of thinning grades (Skovsgaard, Vanclay 2008).

Slovenia has been establishing site indices since 1978. The SI in Slovenia is determined for syntaxonomic units for dominant tree species in a stand. They are mostly defined at the association level but are often also defined at lower units e.g. sub-associations (Kadunc et al. 2013b).

The SI directly determines only the upper height of the stand at the reference age. In order to know production capacity as the maximum amount that is permanently achievable, we need to interpret the SI with the help of appropriate and verified yield tables into $m^3$ per ha per year (average volume growth of stand at the time of culmination). In our case, according to Kotar (1994, 1995) or Kadunc et al. (2013b), the Slovak tables of Halaj et al. (1987) proved to be the most appropriate.

We provide SI for important syntax and dominant tree species. The required number of repetitions was provided for each site type (generally five) (Kadunc et al. 2013b).

### 2.3.2 Mean annual volume increment MAI max

Mean annual volume increment (MAI) is often considered a more useful measure of site productivity than an index based on stand height or height growth. The MAI refers to the average growth per year of a tree or stand (at a specified age) and represents volume production (i.e. $m^3$ per ha per year). MAI is calculated as $MAI=Y(t)/t$ where $Y(t)$ = yield at time t. Because the typical growth patterns of most trees are sigmoidal, the MAI is low at the beginning, increases to a maximum value as the tree matures and then slowly declines over the remainder of the tree's life. MAIs have high practical value since final felling is recommendable at the time of (relatively long lasting) MAI's culmination.

The data to present forest site productivity is based on Kadunc et al. (2013b).

# 3 RESULTS

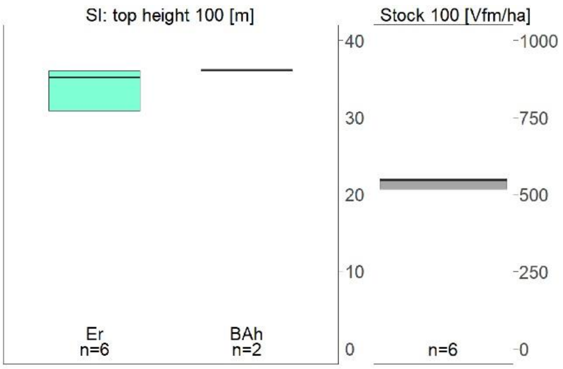
## 3.1 Comparison of the site production for Tyrol (Austria) and Slovenia based on forest site types

In Table 1, an evaluation of site productivity based on forest site types is shown: the left column presents the Tyrolean and the right column the Slovenian site production evaluations.

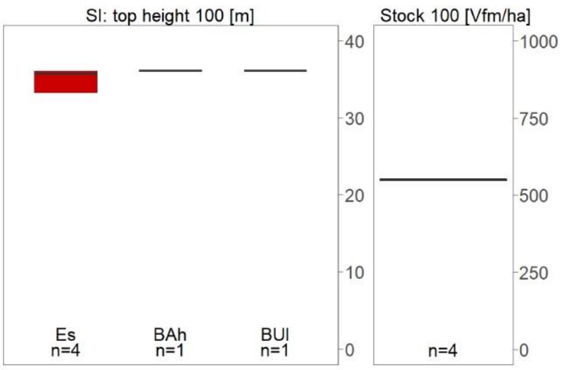
Table 1: Comparison of the site production based on forest site types (Tyrol, Slovenia)

| **Austria, Tyrol** | **Slovenia** |
|---|---|
| ***1. Riparian forest and fluvial forest (forests of Salix spp. with Populus spp., forests of Alnus glutinosa, and of Alnus incana and forests of Quercus robur and Carpinus betulus, and Ulmus laevis forests with Fraxinus angustifolia)*** | |
| *Er3 (Riparian forest)*<br>*Equiseto-Alnetum incanae*<br>*Lh14 (Fluvial forest)*<br>*Carici pendulae-Aceretum stachyetosum sylvatici* | *Alnetum glutinosae s. lat. Carici elongate – alnetum glutinosae* Koch ex Tüxen 1931<br>*Salicetum albae* Isslaer 1926<br>*Piceo abietis- Quercetum roboris* (M. Wraber 1966) Marinček 1994 *Querco roboris - Carpinetum* |

**Austria, Tyrol**

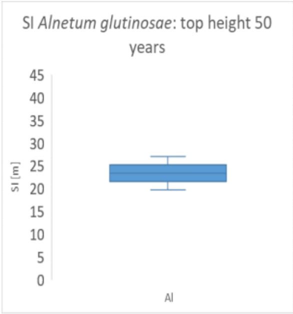


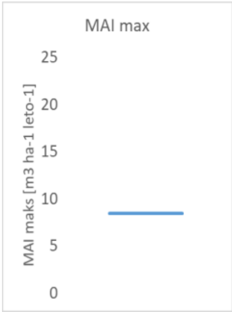

| Tree Species | dgz 100 [Vfm/ha] | dgz 150 [Vfm/ha] |
|---|---|---|
| Er | 11.7 | 10.3 |
| BAh | 12 | 10.7 |




| Tree Species | dgz 100 [Vfm/ha] | dgz 150 [Vfm/ha] |
|---|---|---|
| Es | 11.9 | 10.5 |
| BAh | 12 | 10.7 |
| BUl | 12 | 10.7 |

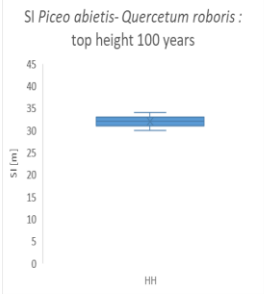
**Slovenia**

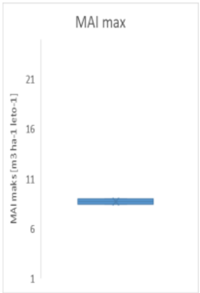



| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Al | 19,7 | 23,4 | 27 | 50 |

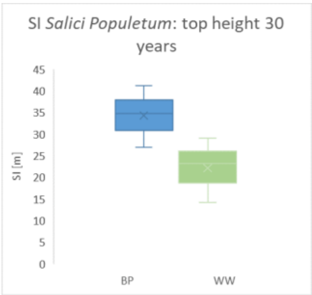
| MAI max average | MAI maks dominant species |
|---|---|
| 8,46 | 8,46 |

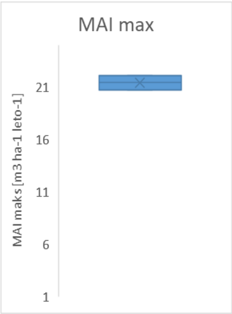



| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| HH | 30 | 32 | 34 | 100 |

| MAI max average | MAI maks dominant species |
|---|---|
| 8,96 | 8,44 |




| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| BP | 27 | 34,7 | 41,2 | 30 |
| WW | 14,2 | 23,2 | 29 | 30 |

| MAI max average | MAI maks dominant species |
|---|---|
| 22,09 | 20,67 |

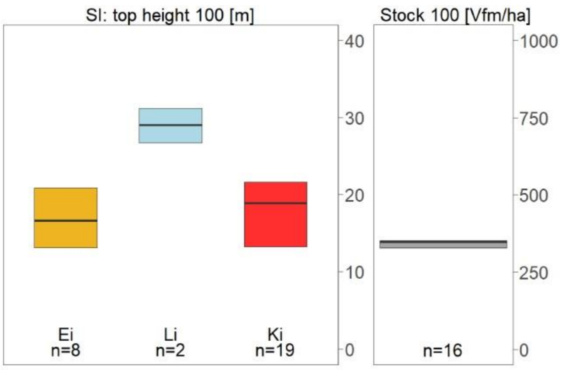
| **Austria, Tyrol** | **Slovenia** |
|---|---|

***2. Sessile oak – hornbeam forests (forests of Carpinus betulus and Quercus petraea)***

## Austria, Tyrol

*Ei4*

*Luzulo niveae-Quercetum petraeae brachypodietosum rupestre*

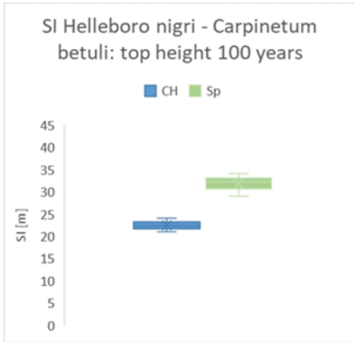


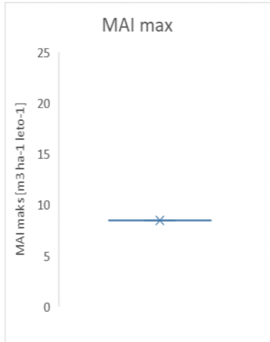

| Tree Species | dgz 100 [Vfm/ha] | dgz 150 [Vfm/ha] |
|---|---|---|
| Ei | 3 | |
| Li | 9.7 | 8.6 |
| Ki | 5.6 | 5.3 |

## Slovenia

*Helleboro nigri-Carpinetum betuli* Marinček in Wall., Mucina et Grass 1993

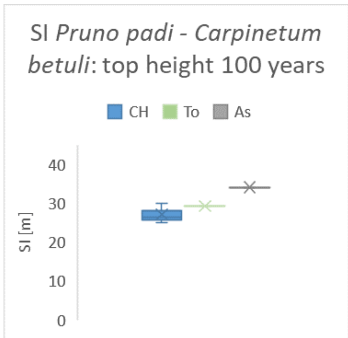
*Pruno padi-Carpinetum betuli* (Marinček et zupančič 1984) Marinček 1994

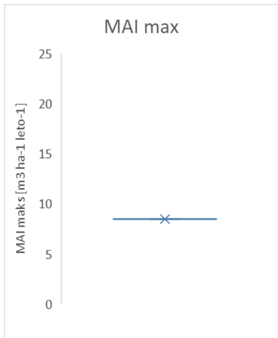



| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| CH | 21 | 22,3 | 24 | 100 |
| Sp | 29 | 32,3 | 34 | 100 |

| MAI max average | MAI maks dominant species |
|---|---|
| 8,46 | 8,46 |



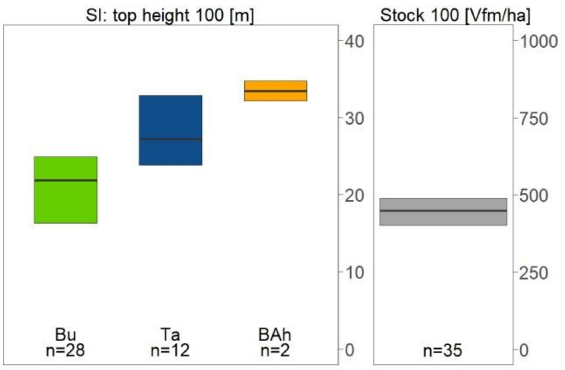




| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| CH | 25 | 26,3 | 30 | 100 |
| To | 29,3 | 29,3 | 29,3 | 100 |
| As | 34,1 | 34,1 | 34,1 | 100 |

| MAI max average | MAI maks dominant species |
|---|---|
| 8,46 | 8,46 |

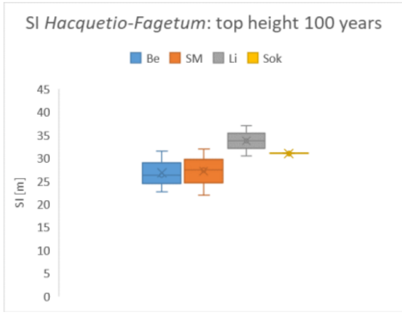
| **Austria, Tyrol** | **Slovenia** |
|---|---|
| ***3. Central European submontane beech forest*** | |
| *Bu1*<br>*Galio odorati-Fagetum typicum, luzuletosum; Tilio cordatae-Fagetum* | *Hacquetio-Fagetum* Košir 1962 var.geogr *Anemone trifolia* Košir (1979) |

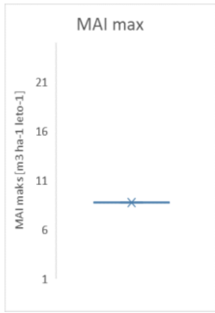
**Austria, Tyrol**




| Tree Species | dgz 100 [Vfm/ha] | dgz 150 [Vfm/ha] |
|---|---|---|
| Bu | 7.1 | 6.7 |
| Ta | 9.5 | 9.7 |
| BAh | 11.2 | 9.9 |

**Slovenia**

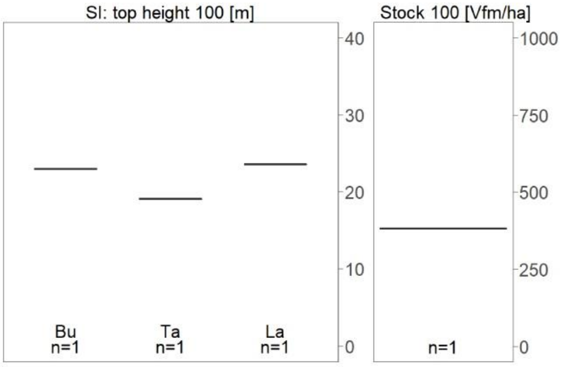


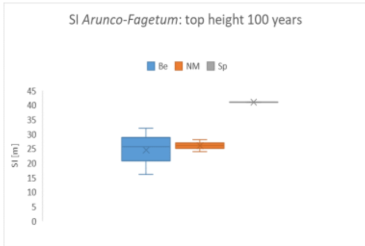

| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Be | 22,7 | 26,3 | 31,5 | 100 |
| SM | 22 | 27,4 | 32 | 100 |
| Li | 30,5 | 33,8 | 37 | 100 |

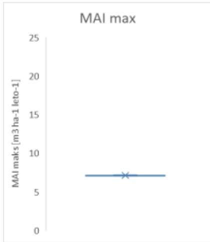
| MAI max average | MAI maks dominant species |
|---|---|
| 8,76 | 8,7 |

| Austria, Tyrol | Slovenia |
|---|---|
| **4. Montane, altimontane and subalpine Fagus sylvatica forests on carbonate and mixed bedrock (including also Forests of Acer spp., of Fraxinus excelsior and of Tilia spp.)** | |
| *Bu11*<br>*Saxifrago rotundifoliae-Fagetum polystichetosum aculeati* | *Arunco-Fagetum* Košir 1962<br>*Lamium orvale – Fagetum* (Hat. 1938) Borhidi *1963* var. geog. *Dentaria pentaphyllos* (Marinček 1981) Marinček 1995<br>*Rannunculu platanifolii-Fagetum* Marinček et al. 1993 var. geogr. *Hepatica nobilis* Marinček 1993 (sin. var. geogr. typica Marinček et Čarni 2010) |



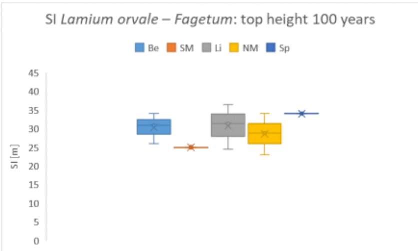

| Tree Species | dgz 100 [Vfm/ha] | dgz 150 [Vfm/ha] |
|---|---|---|
| Bu | 7.5 | 7 |
| Ta | 4.5 | 6.2 |
| La | 5.4 | 5.6 |

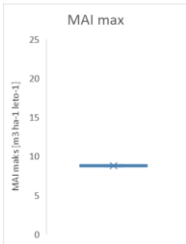



| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Be | 16 | 25,6 | 32 | 100 |
| NM | 24 | 26 | 28 | 100 |
| Sp | 41 | 41 | 41 | 100 |

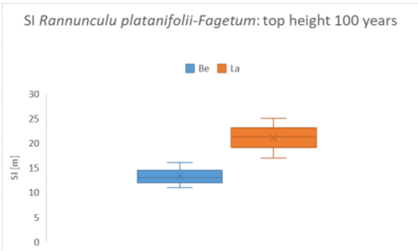
| MAI max average | MAI maks dominant species |
|---|---|
| 7,17 | 7,04 |

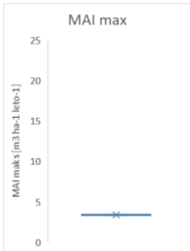



| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Be | 26 | 30,9 | 34 | 100 |
| SM | 25 | 25 | 25 | 100 |
| Li | 24,5 | 31,3 | 36,5 | 100 |
| NM | 23 | 28,8 | 34 | 100 |
| Sp | 34 | 34 | 34 | 100 |

| MAI max average | MAI maks dominant species |
|---|---|
| 8,67 | 8,89 |




| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Be | 11 | 13 | 16 | 100 |
| La | 16,9 | 21,2 | 25 | 100 |

| MAI max average | MAI maks dominant species |
|---|---|
| 3,45 | 3,3 |

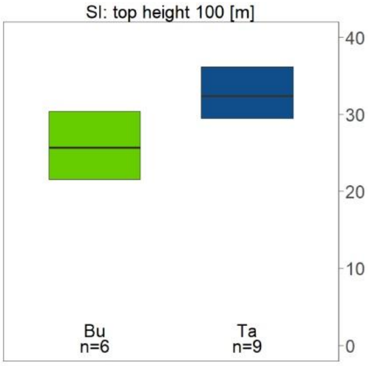
| **Austria, Tyrol** | **Slovenia** |
|---|---|

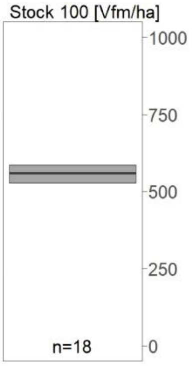
### *5. Montane and altimontane Fagus sylvatica forests on silicate bedrock*

**Austria, Tyrol**

*TB2*

*Luzulo-Fagetum typicum, athyrietosum*



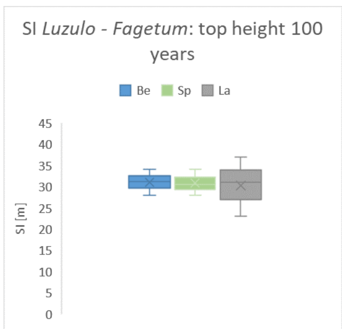



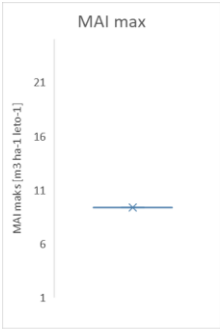

| Tree Species | dgz 100 [Vfm/ha] | dgz 150 [Vfm/ha] |
|---|---|---|
| Bu | 8.5 | 7.7 |
| Ta | 13.1 | 12.3 |

**Slovenia**

*Luzulo fagetum* Meusel 1937 var. geogr. *Cardamine trifolia Marinček et Zupančič 1995*

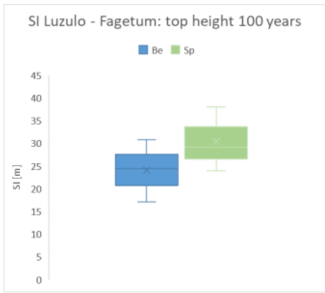
*Cardamini savensi – Fagetum* Košir 1962 var. geogr. *Abies alba* Košir 1979

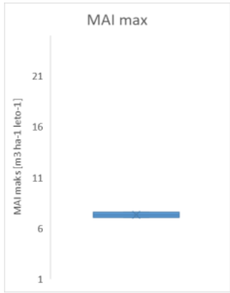



| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Be | 28 | 31,2 | 34 | 100 |
| Sp | 28 | 30,6 | 34 | 100 |
| La | 23 | 31 | 36,9 | 100 |

| MAI max average | MAI maks dominant species |
|---|---|
| 9,35 | 9,36 |



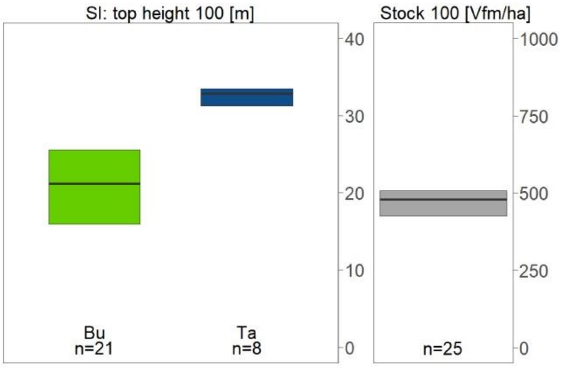




| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Be | 17,1 | 24,4 | 30,8 | 100 |
| Sp | 24 | 29,2 | 38 | 100 |

| MAI max average | MAI maks dominant species |
|---|---|
| 7,58 | 7,03 |

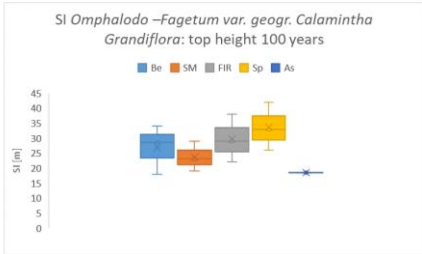
| **Austria, Tyrol** | **Slovenia** |
|---|---|
| ***6. Forests of Fagus sylvatica with Abies alba*** | |
| *TB1*<br>*Mercuriali-Fagetum typicum (incl. Galio odorati-Fagetum p.p.)* | *Omphalodo –Fagetum* (Tregubov 1957) Marinček et.al. 1993 var. geogr. *Calamintha grandiflora* Surina 2002 *Ophalodo-Fagetum* (Tregubov 1957) Marinček et. al. 1993 var. geogr. *Anemone trifolia*<br>*Homoggyno sylvestris-Fagetum* Marinčel et. al. 1993 |

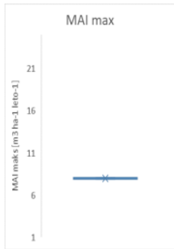
**Austria, Tyrol**




| Tree Species | dgz 100 [Vfm/ha] | dgz 150 [Vfm/ha] |
|---|---|---|
| Bu | 6.8 | 6.5 |
| Ta | 13.5 | 12.6 |

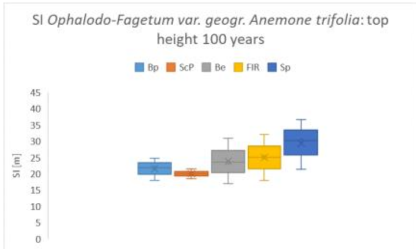
**Slovenia**

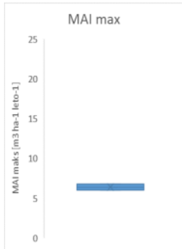



| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Be | 18 | 28,6 | 34 | 100 |
| SM | 19 | 23,1 | 29 | 100 |
| FIR | 22 | 29 | 38 | 100 |
| Sp | 26 | 32,9 | 42 | 100 |
| As | 18,5 | 18,5 | 18,5 | 70 |

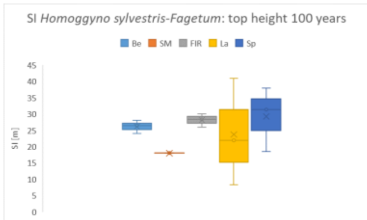
| MAI max average | MAI maks dominant species |
|---|---|
| 8,05 | 7,83 |

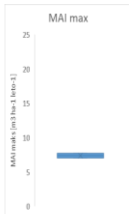



| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Bp | 17,9 | 21,9 | 24,8 | 100 |
| ScP | 18,5 | 20 | 21,5 | 100 |
| Be | 17 | 23,5 | 30,9 | 100 |
| FIR | 18 | 25,1 | 32 | 100 |
| Sp | 21,3 | 30,2 | 36,6 | 100 |

| MAI max average | MAI maks dominant species |
|---|---|
| 6,78 | 5,99 |




| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Be | 24 | 26,4 | 28 | 100 |
| SM | 18 | 18 | 18 | 100 |
| FIR | 26 | 28,4 | 30 | 100 |
| La | 8,4 | 21,9 | 40,9 | 100 |
| Sp | 18,5 | 38 | 31,4 | 100 |

| MAI max average | MAI maks dominant species |
|---|---|
| 7,72 | 7,04 |

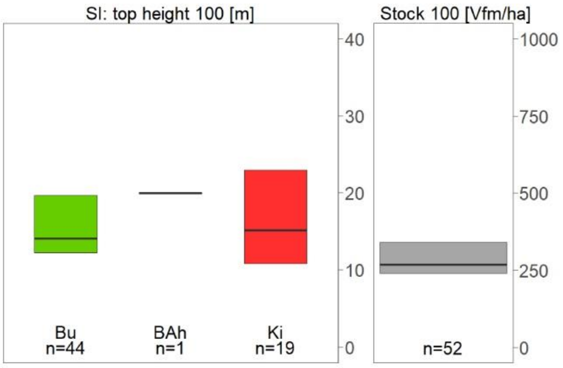
| Austria, Tyrol | Slovenia |
|---|---|

**7. Thermophious deciduous forests (Thermophilous *Fagus sylvatica* forests and Forests and woodlands of thermophilous broadleaves)**

## Austria, Tyrol

*Bu3*

*Carici albae-Fagetum s.l.; incl. Helleboro-Fagetum, Seslerio-Fagetum s.str.*



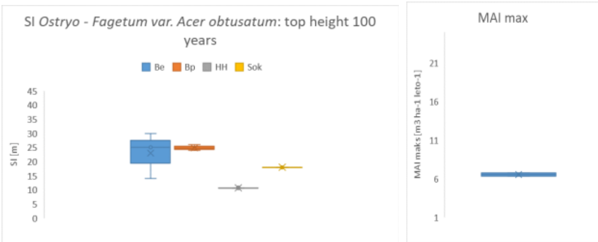

| Tree Species | dgz 100 [Vfm/ha] | dgz 150 [Vfm/ha] |
|---|---|---|
| Bu | 4 | 4 |
| BAh | 6.4 | 6.1 |
| Ki | 4.3 | 4.2 |

## Slovenia

*Ostryo-Fagetum* M. Wraberb ex Trinajstić 1972 var. gogr. *Acer obtusatum* Marinček, Puncer et Zupančič 1980

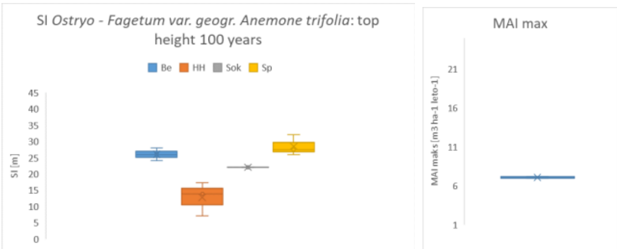
*Ostryo – Fagetum* M. Wraber ex Trinajstuić 1972 var. geogr. *Anemone trifolia* (Marinček, Puncewr et Zupančič 1980) Poldini 1982

*Seslerio autumnalis – Fagetum* M. Wraber ex Borhidi 1963



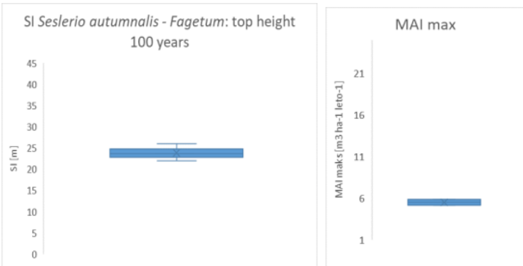

| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Be | 14 | 25 | 30 | 100 |
| Bp | 24 | 24,7 | 26 | 100 |
| HH | 10,7 | 10,7 | 10,7 | 40 |
| Sok | 18 | 18 | 18 | 100 |

| MAI max average | MAI maks dominant species |
|---|---|
| 6,35 | 6,75 |




| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Be | 24 | 26 | 28 | 100 |
| HH | 7,1 | 17,2 | 13,9 | 40 |
| Sok | 22 | 22 | 22 | 100 |
| Sp | 26 | 27,4 | 32 | 100 |

| MAI max average | MAI maks dominant species |
|---|---|
| 6,96 | 7,13 |

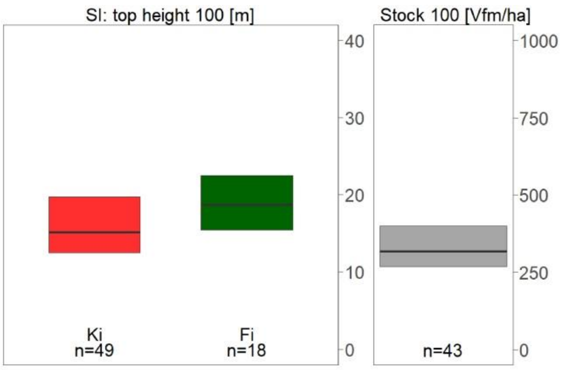



| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Be | 22 | 23,6 | 26 | 100 |

| MAI max average | MAI maks dominant species |
|---|---|
| 5,14 | 5,84 |

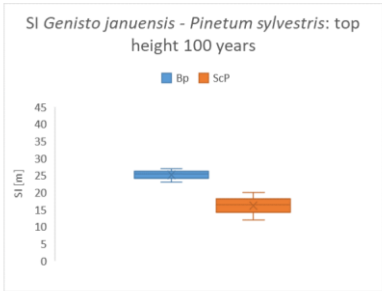
| Austria, Tyrol | Slovenia |
|---|---|
| ***8. Pinus sylvestris and Pinus nigra forests*** | |
| *Ki1*<br><br>*Erico-Pinetum sylvestris typicum* | *Genisto januensis – Pinetum silvestris* Tomažič 1940<br>*Brachypodio – Pinetum sylvestris* Zupančič et Žagar 1998<br>*Daphno alpinae – Pinetum nigrae* Accetto 2001<br>*Vaccinio myrtilli – Puinetum sylvestris* Jurasczek 1928 var. geogr. *Castanea sativa* (Tomažič 1942) Zupančič 1996 |

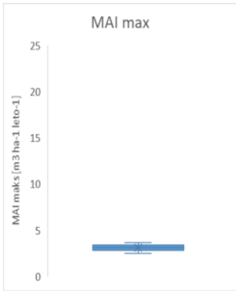
**Austria, Tyrol**




| Tree Species | dgz 100 [Vfm/ha] | dgz 150 [Vfm/ha] |
|---|---|---|
| Ki | 4.3 | 4.2 |
| Fi | 3.9 | 4.7 |

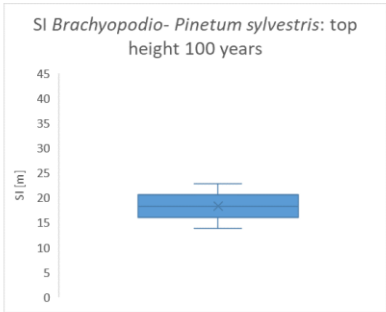
**Slovenia**

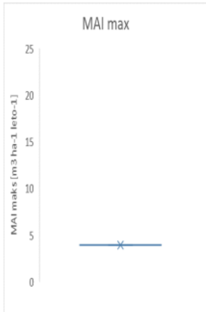



| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Bp | 23 | 25,4 | 27 | 100 |
| ScP | 12 | 16,4 | 20 | 100 |

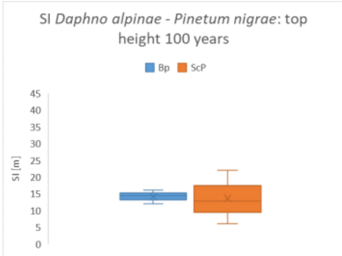
| MAI max average | MAI maks dominant species |
|---|---|
| 3,67 | 2,5 |

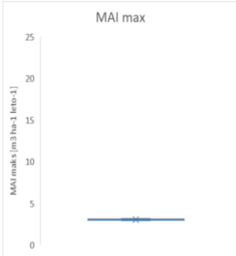


| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| ScP | 13,8 | 18,3 | 22,8 | 100 |

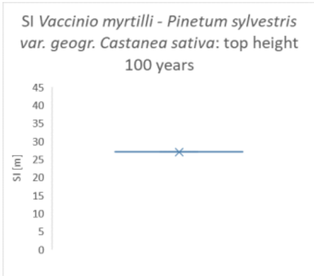
| MAI max average | MAI maks dominant species |
|---|---|
| 3,92 | 3,92 |

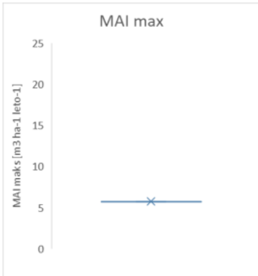



| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Bp | 12 | 14,3 | 16 | 100 |
| ScP | 6 | 12,8 | 22 | 100 |

| MAI max average | MAI maks dominant species |
|---|---|
| 2,92 | 3,18 |



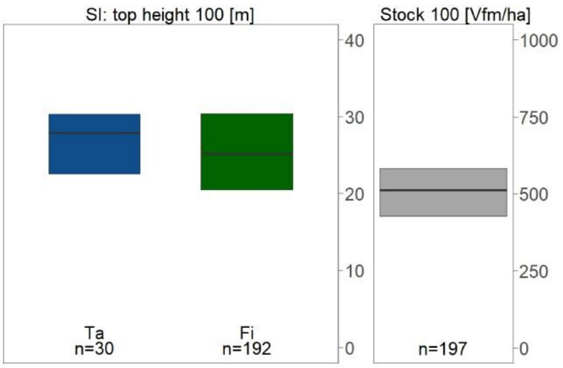




| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| ScP | 27 | 27 | 27 | 100 |

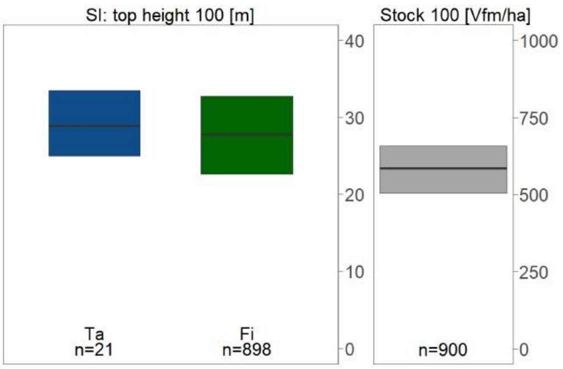
| MAI max average | MAI maks dominant species |
|---|---|
| 5,73 | 5,73 |

| Austria, Tyrol | Slovenia |
|---|---|
| ***9. Spruce and fir forest (forests of Abies alba, and of Picea abies on carbonate and mixed bedrock and forests of Abies alba, and of Picea abies on silicate bedrock)*** | |
| *FT3 (Carbonate bedrock)*<br>*Adenostylo glabrae-Abietetum, Carici albae-Abietetum typicum*<br>*FT1 (Silicate bedrock)*<br>*Calamagrostio villosae-Abietetum calamagrostietosum arundinaceae* | *Calamagrostio – Abietetum* Horvat (1950) 1962<br>*Homogyno sylvestris – Piceetum* Exner ex Poldini et Bressan 2007<br>*Paraleucobryo-Abietetum* Belec et al. ex Belec 2009<br>*Luzulo sylvaticae- Piceetum* M. Wraber 1963 corr. Zupančič 1999 |

**Austria, Tyrol**

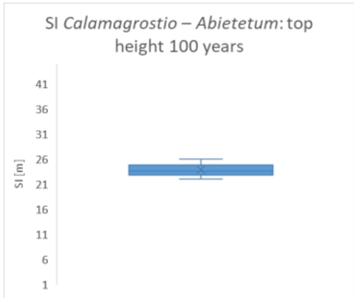


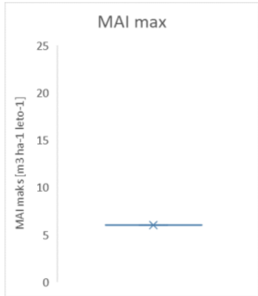

| Tree Species | dgz 100 [Vfm/ha] | dgz 150 [Vfm/ha] |
|---|---|---|
| Ta | 9.9 | 10 |
| Fi | 7.5 | 8.4 |




| Tree Species | dgz 100 [Vfm/ha] | dgz 150 [Vfm/ha] |
|---|---|---|
| Ta | 10.6 | 10.6 |
| Fi | 8.9 | 9.6 |

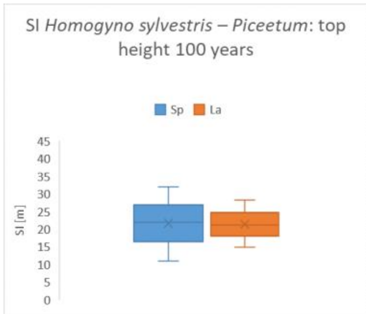
**Slovenia**

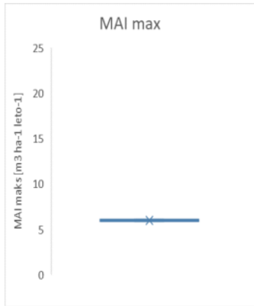



| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| FIR | 22 | 23,6 | 26 | 100 |

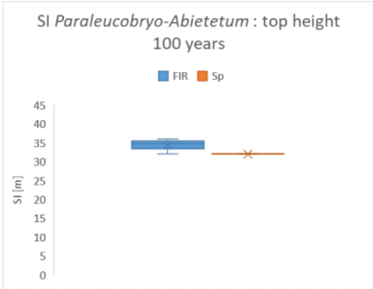
| MAI max average | MAI maks dominant species |
|---|---|
| 6,02 | 6,02 |

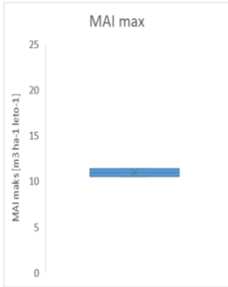



| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Sp | 11 | 21,9 | 32 | 100 |
| La | 14,8 | 21,1 | 28,3 | 100 |

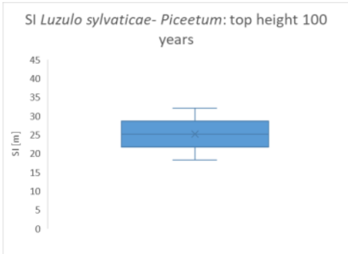
| MAI max average | MAI maks dominant species |
|---|---|
| 5,89 | 6,07 |

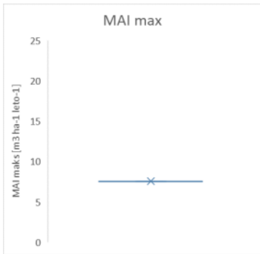



| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| FIR | 32 | 34,8 | 36 | 100 |
| Sp | 32 | 32 | 32 | 100 |

| MAI max average | MAI maks dominant species |
|---|---|
| 10,52 | 11,34 |



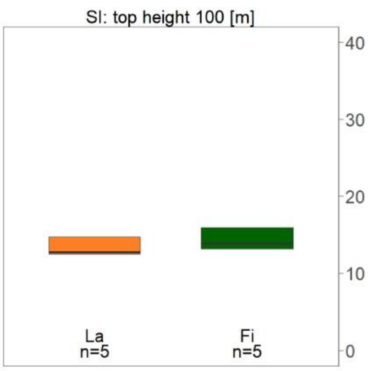



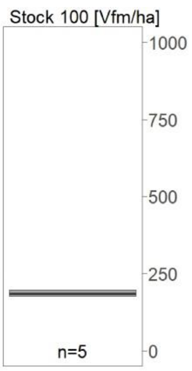

| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Sp | 18,3 | 25,1 | 32 | 100 |

| MAI max average | MAI maks dominant species |
|---|---|
| 7,55 | 7,55 |

| Austria, Tyrol | Slovenia |
|---|---|
| **_10. Other forests and woodlands (Bog woodlands of Picea abies, and of Pinus mugo, forests of Larix decidua, Woodlands of Pinus mugo)_** | |
| *La1*<br>*Adenostylo alliariae-Laricetum violetosum biflorae* | *Rhodothamno – Laricetum* (Zukigl 1973) Willner et Zukrigl 1999<br>*Rhodothamno – Pinetum mugo* Zupančič et Žagar 1980<br>*Sphagno-Piceetum Kouch 1954 corr. Zupančič 1982 var. geogr. Carex brizoides* Zupančič 1982 |

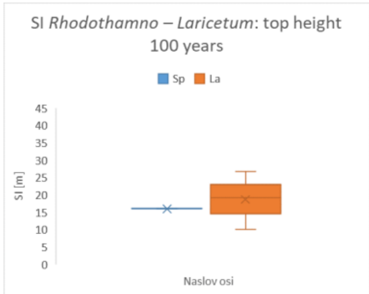
**Austria, Tyrol**

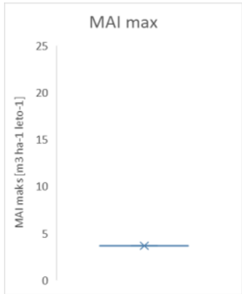



| Tree Species | dgz 100 [Vfm/ha] | dgz 150 [Vfm/ha] |
|---|---|---|
| La | 1.9 | 2.3 |
| Fi | 2.3 | 3.2 |

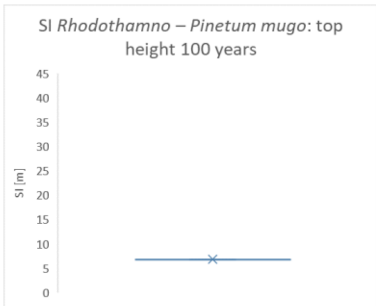
**Slovenia**

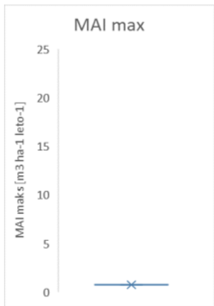



| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Sp | 16 | 16 | 16 | 100 |
| La | 10 | 19,2 | 26,8 | 100 |

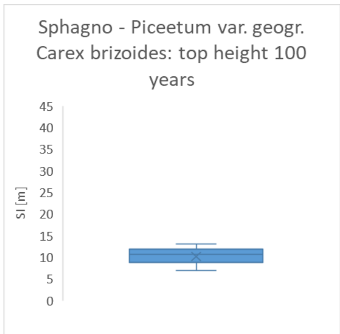
| MAI max average | MAI maks dominant species |
|---|---|
| 3,65 | 3,68 |

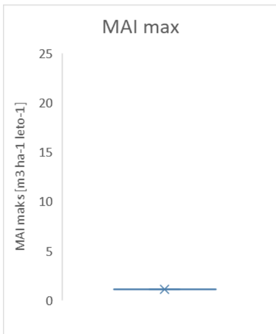



| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| La | 6,8 | 6,8 | 6,8 | 100 |

| MAI max average | MAI maks dominant species |
|---|---|
| 0,75 | 0,75 |




| Tree species | SI min | SI mean | Si Max | Refference age |
|---|---|---|---|---|
| Sp | 6,9 | 10,7 | 13 | 100 |

| MAI max average | MAI maks dominant species |
|---|---|
| 1,1 | 1,1 |

Table 2: Tree species and abbreviations

| **Tree species** | **Latin name** | **Abbreviation (EN)** | **Abbreviation (DE)** |
|---|---|---|---|
| Spruce | *Picea abies* | Sp | Fi |
| Fir | *Abies alba* | Fir | Ta |
| Beech | *Fagus sylvatica* | Be | Bu |
| Swiss stone pine | *Pinus cembra* | SwP | Zi |
| Larch | *Larix decidua* | La | La |
| Scots Pine | *Pinus sylvestris* | ScP | Ki |
| Black pine | *Pinus nigra* | Bp | Ki |
| Sessile Oak | *Quercus petraea* | SOk | TrEi (Ei) |
| Common oak | *Quercus robur* | COk | StEi (Ei) |
| Turkey oak | *Quercus cerris* | TO | Ei |
| Wild cherry | *Prunus avium* | WC | VKi |
| Ash | *Fraxinus excelsior* | As | Es |
| Wych Elm | *Ulms glabra* | WE | BUl |
| Rowan | *Sorbus aucuparia* | Ro | Vb |
| Mountain Pine | *Pinus uncinata* | MP | Spi |
| Lime | *Tilia platyphyllos/cordata* | Li | SLi (Li) |
| Alder | *Alnus incana/glutinosa* | Al | SEr (Er) |
| Manna ash | *Fraxinus ornus* | MA | MEs |
| Hop hornbeam | *Ostrya carpinifolia* | HH | HB |
| Whitebeam | *Sorbus aria* | Wh | MB |
| Dwarf pine | *Pinus mugo* | DP | Ki |
| Birch | *Betula pendula* | Bi | HBi (Bi) |
| Sycamore Mapel | *Acer pseudoplatanus* | SM | Bah |
| Norway maple | *Acer platanoides* | NM | SAh |
| Common hornbeam | *Carpinus betulus* | CH | HaBu |
| White willow | *Salix alba* | ww | SiWe (Wei) |
| Black poplar | *Populus nigra* | BP | Pa |

## 3.2 Assessing European beech (*Fagus sylvatica*) forest productivity in Slovenia

The second part of the study is assessing European beech (*Fagus sylvatica*) forest productivity using inventory data (Bončina et al. 2018). The results of this study were presented in the frame of Links4Soils project at IUFRO 11th International Beech Symposium: Natural and Managed Beech Forests as Reference Ecosystems for the Sustainable Management of Forest Resources and the Conservation of Biodiversity; Viterbo, Italy; September 2018.

What was the background of this study? Due to climate change, growing conditions, and thus growth, may change. Therefore, a question appears how to check and update values of site indices for the main tree species. One possibility is to use data gathered in forest inventories. Therefore, the main objective of our study was to estimate site index of European beech in different beech forest types by using data from permanent sampling plots (PSP) and to compare the results with those obtained with conventional methods for studying site index of tree species.

*Figure 2: Beech forest, Photo: A. Nève Repe*

### 3.2.1 Methods

The productivity of 18 beech forest types in the entire forest area of Slovenia (11,400 km$^2$) was studied based on the PSP (n = 14,719; 500 m$^2$ each) database of Slovenia Forest Service comprising data from two consecutive forest inventories (10 years in-between). In the analyses, only PSPs with ≥ 70 % of beech in growing stock were included. Stand age was estimated using radial growth of dominant trees, Figure 3.

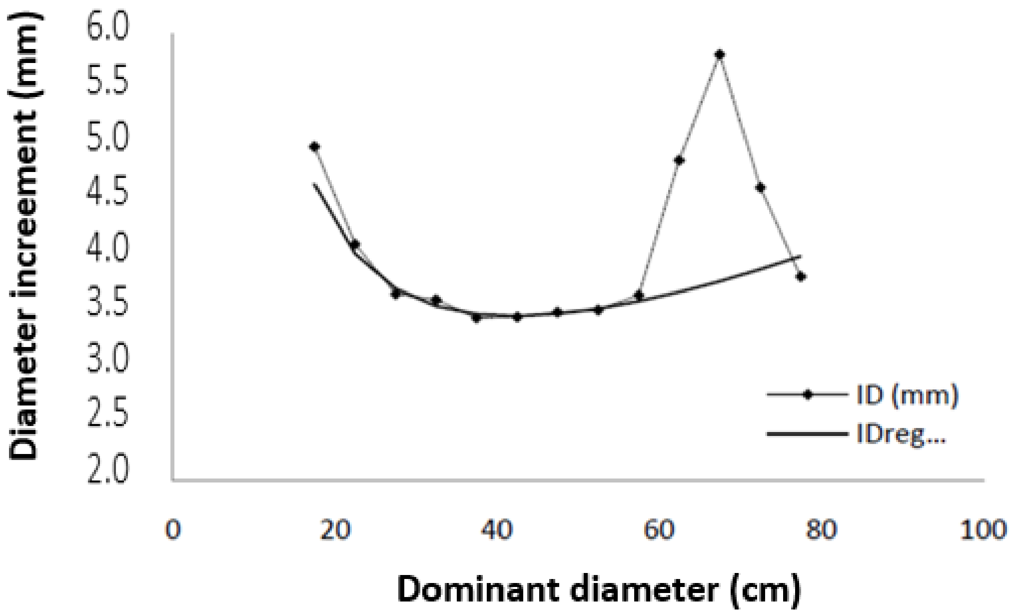



*Figure 3: Diameter growth of dominant trees in sub-mountain beech forests*

For each PSP, the dominant diameter at breast height (DBHdom) (cm), defined as quadratic mean of 5 largest trees per plot, and the average diameter increment Idom (mm) of 5 largest trees per plot was determined. Regression between DBHdom and Idom served to estimate the time needed for growth to reach a certain DBH and therefore the age of beech stands. Height growth of dominant trees (Hdom) for each forest type was calculated by using Chapman-Richards growth function (Figure 4). Site index of beech at the age of 100 years (SI100) was determined for each forest type.

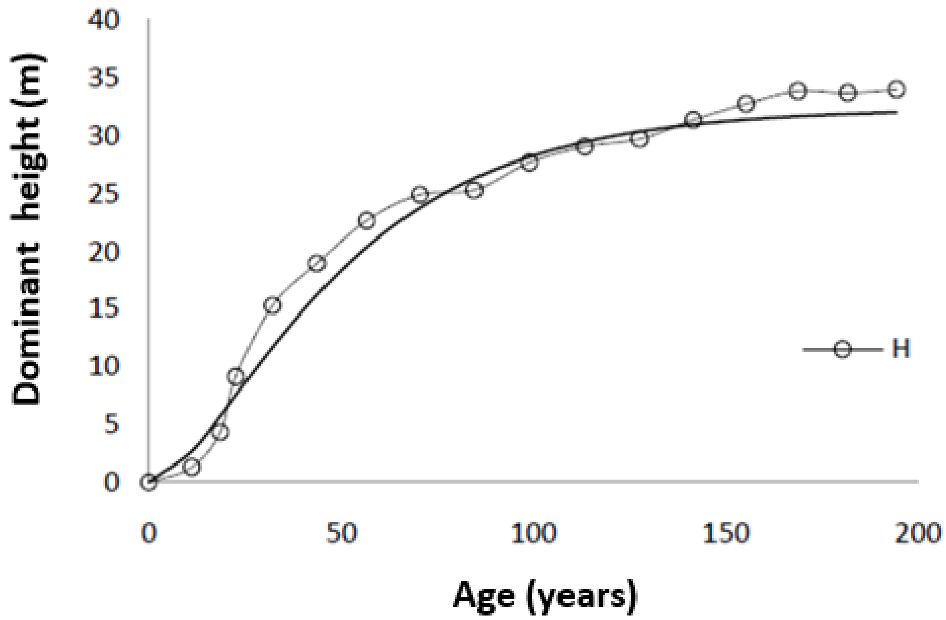



*Figure 4: Height growth of dominant trees in sub-mountain beech forests*

Productivity of beech forest types was estimated with the MAImax of forests. Based on Halaj et al. (1987) yield tables, the regression between SI of beech and MAImax of forest stands in the culmination period was calculated.

MAImax = - 1.4649 + 0.3166 * SI (R2 = 0.995)

### 3.2.2 Results and conclusions

The regression was used to estimate the site productivity of 18 beech forest types (Table 3).

Table 33: Estimation of SI and site productivity for beech forest types using inventory data and comparison to of SP estimations with conventional method (SI100)

| Forest types | Number of plots | SI (m) - inventory data | $MAI_{max}$ ($m^3$ha/year) – inventory data | Difference to SI – conventional methods (m) |
|---|---|---|---|---|
| Pre-Dinaric and Dinaric sub-mountain beech forest | 1565 | 29,1 | 8.00 | **1.4** |
| Pre-Alpine sub-mountain beech forest on calcareous bedrock | 524 | 27.2 | 7.38 | **0.9** |
| Oak-beech forest on leached soils | 1225 | 27.0 | 7.31 | **-4.7** |
| *Arunco-Fagetum* beech forest | 436 | 25.4 | 6.77 | **-0.2** |
| Pre-Dinaric and Dinaric thermophilous beech forest | 156 | 26.1 | 7.00 | **1.1** |
| Pre-Alpine and Alpine thermophilous beech forest | 210 | 25.1 | 6.66 | **-0.9** |
| Sub-Mediterranean beech forest | 408 | 17.5 | 4.13 | -6.1 |
| Pre-Dinaric mountain beech forest | 949 | 23.6 | 6.15 | -10.1 |
| Pre-Alpine mountain beech forest | 314 | 26.9 | 7.27 | **-4.0** |
| Alpine mountain beech forest | 739 | 21.2 | 5.38 | -7.8 |
| Dinaric fir-beech forest | 2489 | 27.2 | 7.38 | **-1.4** |
| Pre-Alpine fir, beech and spruce forest | 465 | 25.2 | 6.68 | **1.7** |
| Dinaric high mountain beech forest | 543 | 20.6 | 5.17 | -5.8 |
| Sub-alpine beech forest | 76 | 23.9 | 6.25 | 10.9 |
| Acidophilous oak-beech forest | 1051 | 29.4 | 8.10 | **-1.5** |
| Acidophilous beech forest | 638 | 27.1 | 7.34 | **0.6** |
| Acidophilous mountain beech forest (*Luzula luzuloides* type) | 1011 | 29.1 | 8.00 | **-2.1** |
| Acidophilous mountain beech forest (*Cardamine savensis* type) | 121 | 28.2 | 7.71 | **3.8** |

Most of the site indices for beech forest types lie within the confidence interval of the SI100 defined by conventional procedure. Thus, forest inventory data enable adequate estimation of site productivity. However, the method has some shortcomings: firstly precision of height measurements may be inadequate, secondly for minor forest types there is too small number of plots available. The main advantages of the method are that this is a non-destructive method, it is cost efficient in comparison to the conventional method, and it consists of systematically gathered data.

## 3.3 Productivity mapping

A hierarchical procedure for the estimation of forest site productivity including site mapping, unthinned reference stands (against which growth performance is measured) and adaptive modelling was suggested to be used by experts (Skovsgaard, Vanclay 2008). In 2014, the spatial estimation of forest site productivity was calculated by Bončina et al. on the basis of site indices of tree species per forest sites, defined by forest communities at the forest association level (Figure 5). The forest site productivity values were calculated per sub-compartments (n =54,156) based on portions of forest site types in every sub-compartment. 74 forest site types were used. Calculation of the mean value of forest site productivity per sub-compartments started with assessment of natural tree species composition of forest site types that was followed by an estimation of production capacity of individual natural tree species in each forest site type, and then the calculation of the mean value of forest site productivity at a sub-compartment level was conducted and finally a spatial overview of calculated values of forest site productivity per sub-compartments for the whole forest area of Slovenia. Production capacity of the 74 forest site types varies between 0 in 22.1 $m^3ha^{-1}$ $year^{-1}$, mean value totalled 7.5 $m^3ha^{-1}$ $year^{-1}$. In the 77 % of the whole forest area, the forest site productivity totals 6-10 $m^3ha^{-1}$ $year^{-1}$.

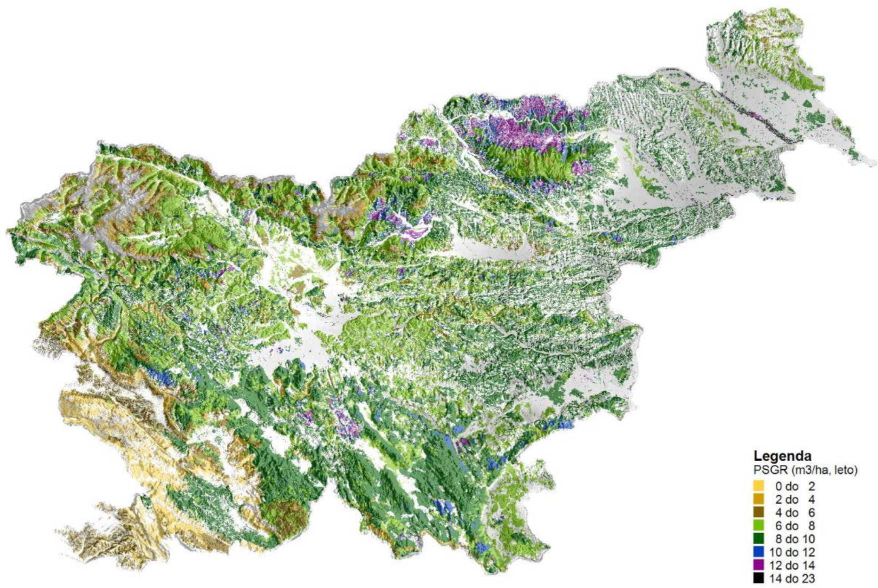


*Figure 5: Spatial representation of the production capacity of forest areas in Slovenia (Bončina et al. 2014).*

# 4 CONCLUSIONS

Forest site productivity is an important forestry topic. We are using different methods to estimate the productivity or its approximation. In most cases we are not measuring the site productivity itself, but the productivity of a given stand, in many cases in even-aged mono-species stands. Site productivity indicators also reflect site quality because productivity, or the realisable part of the site potential for volume growth, is related to the site quality.

In this report we presented different methods for evaluating forest site productivity. In the first part, a comparison of forestry types and forestry communities in Tyrol and Slovenia yielded interesting results. The values of forest site productivity based on forest types differ taking into consideration forest communities presented in both countries. Finally, this report shows that different methods may be efficient considering different types of forests.

Production capacity is not a static variable; the production capacity is changing mainly due to environmental changes. Maintaining soil productivity is critical to sustainable forest management. A decrease in soil productivity may affect many forest functions. Foresters are concerned about the level of harvesting the forest can sustain. However, with lowering productivity, other forest values are affected e.g. wildlife habitat, populations, and biodiversity. Sustainable forestry avoids disturbances that are produced by intensive forest management. This kind of management can have diverse impacts on the physical, chemical and biological characteristics of soils, which can, in turn, impact long-term productivity. To this end, it is important to increase awareness and understanding of soil impacts caused as a result of forest management activities among forest landowners, resource managers, loggers, equipment operators and others involved in forest management.

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