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EUROPEAN BEECH FORESTS UNDER Natura 2000 MANAGEMENT

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1 Introduction

1.1 Maintaining natural forest habitats throughout Europe and the place of the beech forests within European environmental strategy.

Forests host about 65% of the world's terrestrial taxa (World Commission on Forests and Sustainable Development, 1999). Big taxonomic groups like birds (Gill 1995), invertebrates (Erwin 1982; Majer et al. 1994) and microbes (Torsvik et al. 1990; Crozier et al. 1999) mainly depend on forest ecosystems. At the same time such forest ecosystems, like the European Beech Forests, deliver important natural resources, which are intensively used by the industry.

The sustainable management of those ecosystems is shifting to the center of a hotly contested debate around the conservation strategy. One of the key components of many national and international discussions around this matter is the conservation of biodiversity (e.g. Commonwealth of Australia 1998, 2001; Montre´al Process Liaison Office 2000; Food and Agriculture Organisation of the United Nations 2001). Most programs to sustain forest biodiversity have focused on the creation of protected areas (Lindenmayer et al. 2006). But reserves alone are insufficient to adequately conserve forest biodiversity (Sugal 1997; Daily et al. 2001; Lindenmayer et al., 2002).

The European Habitat Directive (1992) aims at creating a coherent European network of protected areas with the overall objective of maintaining biodiversity of natural habitats, fauna and flora throughout Europe. It highlights beech forests as one forest type of community importance. Member states are obliged to achieve and maintain favorable conservation status of target habitats within the protected beech forest areas.

1.2 Description of the project

The EU project "Beech Forest for the Future" (further mentioned as BeFoFu, see www.befofu.org) is carried out within the BiodivERsA network of the EU 7th Framework Programme for Research. The project combines ecological as well as social science analyses of the European beech forests with the focus on Natura 2000, assess the role of diverse types of knowledge and data (ecological, social science) at the science-policy interface in European beech forest conservation.

1.2.1 Research needs

The European beech, *Fagus sylvatica*, is one of the symbols for the European broadleaved forests and has at the same time a fundamental importance for European biodiversity. A diverse array of plants, animals and other organisms depend on it. Due to historical forest management, intensive utilization especially by replacement by other more “user-friendly” tree species, *Fagus sylvatica* cover only a small percentage of their former expanse in Europe. Even within this current distribution, the viability of large areas of remaining beech forests is threatened by environmental change as well as by changing socio-economic conditions (JNCC 2007), (Jantsch et al. 2014).

Especially today in the era of global climate change it is important to make forest management strategies more sustainable. The beech forests can play a vital role in contributing to mitigation of climate change. On the other side, climate change means for example drought stress or compositional changes. Currently, these potential compositional changes on the European beech forests have been directly investigated mainly in relation to local case studies (Burrascano et al. 2008).

Across the EU, the implementation process of Natura 2000 has been impaired by conflicts and diverging stakeholder interests regarding forest management. In order to make Natura 2000 working into a right ecological as well as socio-economical direction, it is necessary to proof and provide scientific data and methods for an appropriate assessment of beech forest conservation. To describe the success of the Natura 2000 strategy, it is necessary to include main ecological components like forest structure, microhabitats, deadwood and vegetation into the assessment.

1.2.2 Objectives of the project

The project itself and this research as a part of it, aims at “supporting of developing novel cross-national strategies for coherent beech forest conservation in Europe with a focus on Natura 2000“ *(BeFoFu project description, Appendix A, S.19, www.befofu.org)*.

The intention of this study is to detect and assess the actual effect of Natura 2000 on beech forest biodiversity and other ecosystem services, to collect relevant ecological data, to prepare and proof methods based on existing scientific practices. Primarily this will be done by assessment of specific structures on the tree- and stand level, as well as vegetation as described under the points Methods in terms of chapters 2 and 3.

1.3 Project structure of BeFoFu

Corresponding to the main objectives as described in Appendix A of the befofu project documentation (S.19-29), BeFoFu includes three major work packages conducted by three research groups. BeFoFu aims for a comparative research approach within and across multiple levels and jurisdictions. The summarized research will be conducted in a number of local case studies in several European countries such as Austria, France, Germany, Netherlands, Spain, UK, Italy and Denmark.

Work Package 1- "Biodiversity, conservation and management" (WP1) aims at analyzing the effects of different management and conservation strategies employed under Natura 2000 on beech forest biodiversity, and assessing the impacts of global climate change on beech forest ecosystems (regarding Appendix A of the befofu project documentation S.20). This work is a part of WP1. The research team belongs to the chair of Geobotany represented by Prof. Dr. A. Fischer (head of Geobotany TUM), Dr. Susanne Winter and MSc Alex Zharov. Other partners and institutions working on this part of the project are Dr. Axel Gruppe and Tobias Zehetmair (TU München, Chair of Animal Ecology), responding for faunistical studies as well as Dr. Alistair S. Jump, Jennifer Sjölund, Liam Cavin (University of Stirling), responding for dendrogenetical and intraspeciess differences research as well as climate impact on beech.

Work Package 2 – "Governance" (WP2) has two main goals:
(a) to analyze the institutional structures and processes of Natura 2000 implementation at different policy levels in order to understand the policy-relevant effects of the Directive and its effects on beech forest biodiversity conservation and (b) to analyze the potential of market-based instruments for beech forest conservation across Europe and derive proposals for innovative market-based instruments. These aims will be met by two Sub-Work Packages: Multi-level policy analysis (Sub WP-2a), and Ecosystem services and market-based mechanisms (Sub WP-2b) (regarding Appendix A, S. 23).

Work Package 3 – "Synthesis and Evaluation" (WP3) has the crucial task of synthesizing and inter- and transdisciplinarily evaluating the results of WP 1 and WP2 in order to develop overarching rationales and recommendations. It aims to create a new and comprehensive understanding of the present situation and to develop innovative management, conservation and governance strategies in order to ensure the survival of beech forests and associated biodiversity for future generations. Such an approach is obviously challenging. Therefore, WP 3 has been carefully designed to guarantee both, the truly interdisciplinary character of the project and an optimal approach towards knowledge dissemination, evaluation, and stakeholder engagement (regarding Appendix A, S. 26-27).

1.4 Dissertation structure

The presented study contains 2 main parts, which have own topics and own hypotheses:

- The first of it (see chapt. 2) deals with the effects of Natura 2000 on the ecological indicators in connection with the forest stand features, tree growth, deadwood and climatic conditions.
- The second part (see chapt. 3) deals with the effects of Natura 2000 on the vegetation.

1.5 Information regarding the data collection time

The collection of all field work data was done in the period from 2011 up to 2012. The vegetation data was collected during the summer field season, in terms of phenological conditions and regarding our south-north gradient.

2 Effects of Natura 2000 on microhabitats and specific tree structures in European beech forest stands

2.1 Introduction

2.1.1 Forest management and naturalness of the forest ecosystems

The naturalness of the European beech forests in central and western Europe can't be described as the original or virgin naturalness due to long management history and the high fragmentation (Winter et al., 2010). Throughout the literature there is a wide range of definitions of naturalness (Jonsson et al. 2011). Most of them can roughly be divided into three segments:

1) structure-based segment,
2) species-based segment,
3) process-based segment.

This Chapter mostly deal with the structural-based segment, because it gives a directly linkage to the mainly management effects related to the European beech forest biodiversity (Jonsson et al. 2011; Winter et al. 2010; Pommerening 2002).

In terms of the framework of the Ministerial Conference on the Protection of Forests in Europe (MCPFE, 2002) *"naturalness represents an indicator of sustainable forest management and belonging to the set of criteria and indicators for sustainable forest management"*.

As mentioned above, fragmentation of beech forests in Europe is very high due to historical background and becoming more abundant in many European regions because of the loss of forests arising from human activities, including settlement, agriculture, resource extraction, and timber harvesting (Harper et al., 2005). On the other side the timber requirement is growing once again since the 1970´s around the globe (Imhoff et al. 2004) as well as in Europe itself.

Because of such a dramatic increase of pressure on the forest ecosystems today, we have a special responsibility for maintenance of natural forest ecosystems and insure these existences for further generations. However, to find a way to provide a solution for this matter means to find a right balance between management and conservation. This kind of strategy is commonly described as "Sustainable Management".

Lindenmayer et al. (2006) define sustainable forest management as –
''... perpetuating ecosystem integrity while continuing to provide wood and non-wood values; where ecosystem integrity means the maintenance of forest structure, species composition, and the rate of ecological processes and functions within the bounds of normal disturbance regimes.''

The balance between management intensity and nature conservation in the European Union is regulated mainly by two directives, which build a network of designated sites, named Natura 2000 (Council Directive 79/409/EEC, Council Directive 92/43/EEC). Habitats and species for which Natura 2000 sites are designated must be maintained in a “favorable conservation status”, which is defined in the Habitats Directive. The guaranty of a “favorable conservation status” includes obligations for monitoring and reporting (Council Directive 92/43/EEC). However, most of the Natura 2000 sites still stay under some management pressure. Many of those sites need an appropriate management to maintain a favorable conservation status. This should often be based on low-intensity practices.

Regarding the abovementioned definition of sustainable forest management such components as forest structure and species composition should play the outstanding indication role for the assessment of the management impact on the forest ecosystems.

In earlier vegetation science the forest structure itself was often taken for the description of the forest vegetation and based on the assessment of the vegetation levels like trees, shrubs and herbs (Crozier & Boerner 1984). In the ecological issues of the last years, the term “forest structure” may cover a broad spectrum of further qualities like tree morphology, tree vitality, and presence of mature trees, basal area, abundance of microhabitats, forest development phases, deadwood volume etc. All the components will here be understood as structural parameters, which have a direct linkage to ecosystem services and biodiversity (Winter & Möller, 2008; Winter, 2005, 2010). Despite any efforts of the environmental science, further research is still needed to provide well-documented and scientifically-based quantitative methods and indicators to assess sustainable forest management (Barbier et al., 2009).

2.1.2 Importance of the microhabitats and specific forest structures for biodiversity of forest ecosystems.

As mentioned above, the main reasons for the implementation of the Natura 2000 network strategy is basically a loss of habitats and as a consequence a loss of species diversity, which propose the needs for an appropriate sustainable management.

What is the definition of biodiversity and what it depend on? Delong (1996) and Bunnell (1998) reviewed approximately 90 descriptions of “biodiversity”. The concept of biodiversity, which is regarded as the standard for environmental science, encompass genes, individuals, demes, populations, metapopulations, species, communities, ecosystems, and the interactions between these entities (Lindenmayer et al. 2006).

Well known that especially the structural features represent basic parameters to estimation of biodiversity within the forest ecosystems. Most beech forests in central and western Europe that escaped clearance and cultivation are managed for timber production with far-reaching effects on forest structure and biodiversity (Lonsdale et al. 2008).

The structural features on the stand level provide on the first place a possibility to assess the impact of management on the forest development. Such management strategies, which maintain more structurally complex multi-aged stands, represent the modern way into "the ecological forestry" (Hanson et al. 2012). A major objective is to create an ecological potential in form of the natural presence of dying trees, dead snags, and fallen logs as well as other kind of heterogeneous stand structures that may help promote biological diversity, critical ecosystem functions, and resilience to disturbances (Franklin et al., 2007).

In European beech forests and most of other temperate forests more than 20% of the amphibian, bird, and mammal species may rely on cavity trees or decaying logs for nesting sites, foraging sites, or escape cover (Evans & Connor, 1979; DeGraaf et al., 1992). As following, microhabitats perform a kind of basic ecological quality for the biodiversity. The heterogeneity of the stand structure and the tree growth provide important ecological qualities as well. As an example, the large living trees even without cavities and any microhabitats can provide important foraging sites because the thick, furrowed bark provides hiding places for insect prey (Jackson, 1979). The studies mentioned previously show not only lower populations of vertebrate species associated with structural elements within the intensively used forests (Winter 2005; Vuidot et al. 2011), but they also may have reduced populations of fungi, nitro- gen-fixing lichens, and other organisms important for ecosystem functions (Hanson et al. 2012).

As already known from earlier studies on managed and unmanaged forest stands, the species diversity is highly correlated with abundance of some types of microhabitats (Winter & Möller 2008; Winter 2005; McRoberts et al. 2008; Vuidot et al. 2011; Larrieu et al. 2011). That is the reason why the assessment of the microhabitats plays such an outstanding role in our research.

The term "microhabitat" describes several forest components, which vary among authors and cover different groups of substrates like ground, deadwood, living trees etc. The now commonly used definition of the microhabitat was implemented as - *"… small substrates used by certain species, or groups of species, to grow, nest or forage"* (Fenton and Bergeron, 2008). Based on this general definition, here we use a specific definition for the *microhabitats on the living trees as changes on the bark, stem or crown structure, which would weaken the tree recovery and make available for other organisms to grow, nest or forage* (Winter 2005). In this case we have a characteristic of living trees focused on elements like cavities, cracks, bark damages etc.

Many fungi, insects and vertebrates are adapted to the microclimatic conditions within deep stem cavities (Möller, 2005). Dietz and Frank (1994) give an example about 900 bats (*N. noctula*) found hibernating places in a huge cavity of a 140-year-old beech tree.

Cavities play an outstanding role for the faunistical biodiversity. For example cavities filled with mould in the lower half of the stem continuously receive mould and nutrients from the decay of the upper portion. Only such cavities may for example be used by the extremely rare, endangered, and protected beetle *Osmoderma eremita* (Appendix II European Union's Habitats Directive 1992) as well as by a large number of other insects (Ranius, 2002). In bark pockets, mould of decomposed bark mixes with remains of e.g. spiders, Hymenoptera, and beetles. This microhabitat is nutrient rich and is used, e.g. by the threatened mould beetles *Pseudocistela ceramboides* and *Prionychus melanarium* (Möller, 2005). Aside from that, bark pockets are used by nocturnal insects, e.g. *Aradus betulae*, which feeds exclusively on *F. fomentarius* during the night and uses bark pockets in daylight. Additionally, bark pockets are nesting substratum for birds (e.g. tree creepers *Certhia* spec.) and bats (e.g. Grindal, 1999; for *Barbastella barbastellus*: Meschede & Heller, 2000). Those kinds of microhabitats were grouped into the section - *"**closed microhabitats**"*, which typically have a closed microenvironment with specific conditions and most important indication value for biodiversity (Möller, 2005).

Another big group of microhabitats belongs to the *"**open**"* microhabitats. Bark losses is a typical example for this group. From the studies on German lowland beech forests it is known that both unmanaged and managed stands may have similar means of bark losses (Winter & Möller, 2008). But the nature of the arising wasn´t consider before. Most of such "open" damages in the European beech stands occurred due to management operating machinery, heavy foot traffic or even heavy vehicles driving between the tree stems as well as some natural factors like secondary damages after windfall and extreme climatic events.

One of the frequent groups of microhabitats are the ***crown breaks*** (Ihók et al. 2007). They can be divided into several categories (Winter & Möller 2008). All of them have quite a similar effect like open microhabitats regarding biodiversity. Additionally, significant crown breaks may influence the light condition on the ground, which is one of the key factors for vegetation diversity. Arising history of this kind of microhabitats are mostly similar to the open microhabitats with some exceptions. Most of them occur due to secondary damages after tree cutting or due to the wind. Some special cases were observed in UK. The most crown breakage cases, as well as some open microhabitats we observed in UK, were due to the gray squirrel *Sciurus carolinensis* (Gurnell 1996).

Figure 1. Gray squirrel damage (crown break), Oakley Wood, Cirencester, UK

Figure 2. Gray squirrel damage (bark loss), Lady Park Wood, UK

Dead branches are the next important microhabitat type, which basically have the function of the deadwood storage within the crown space, which is very important for a broad range of insects. The speed of decomposition of dead branches on the trees is significantly slower as on the ground. Aside from that, data about dead branches is an important and critical step in understanding C cycling of old-growth forests (Ishii & Kadotani 2006). This special feature can be used as an indicator for old-growth components of the stand, because only the big mature trees and big old dying trees have enough capacity to store a significant amount of the deadwood within the crown space (Grier et al. 1981; Gholz 1982; Sollins 1982; Harmon et al.1990).

Another group of microhabitats is the **bizarre growth**, which includes such types of microhabitats like trees with in minimum three forks, remarkable cancerous growth, heavy flow of resin etc. (Figure 3). Because of the higher structural heterogeneity due to this kind of microhabitats, they may be an important driver for the faunistical biodiversity as well. But the occurrence or presence of such structural features on the beech trees is not necessarily typical for the natural beech forests. However the bizarre growth was frequently observed within the stands, which have a long using history in the past as a traditional coppicing. And most of such finds where observed within the lowland beech forests in UK and eastern Austria.

Figure 3. Frequently observed types of bizarre growth

Species loss is predominantly driven by habitat loss (reviewed by Groombridge and Jenkins, 2002; Primack, 2001; Fahrig, 2003). In our case we have a nicely correlated relation between beech forest fauna and the microhabitats as an easy to observe ecological indicator (Michel & Winter 2009). On the other side the microhabitat provide a direct linkage to the stand structure as well as to the tree morphology (Winter 2005; Winter & Möller 2008; Vuidot et al. 2011; Winter 2010). And this fact allows using the microhabitats as a reliable link on the basis of the structural parameters to explain the ecological differences through the management strategies among all biogeographical regions. In our case, it will be done on the comparison of Natura 2000 and normal used forest areas.

2.2 Hypotheses

It is still difficult to identify tangible signs of the recovery of many threatened habitats and species in protected forests (Jones-Walters & Čivić 2013). Nevertheless the Natura 2000 implementation aims at conservation, supporting and complementing the natural habitat- and biodiversity. We build our hypotheses on this basis.

H1.1 - Microhabitat diversity within Natura 2000 is higher than outside
H1.2 - Individual tree structures differ according to forest management strategy
H1.3 - Structural diversity differs according to management strategy

2.3 Study design

The general design of the study was structured as following:
The actual part of the project includes three biogeographical regions, which are known as main regions for the European Beech Forests (Figure 4). Every biogeographical region is represented by two countries. In this way the study includes 6 European countries, which are ordered as follow (north to south):

- **Atlantic** biogeographical region: Denmark (DK), UK (UK)
- **Continental** biogeographical region: Germany (D), Austria (A)
- **Mediterranean** biogeographical region: France (F), Italy (I)

Each country contains, in the regular case, 3 paired study sites, which have the numeration 1-3 from north to south. By the selection of the study sites we were mostly depend on the support of our partner institutions in their countries, taking account of our selection criteria. The study site code consists of the country ID and study site number (Table 1).
We provided following selection criteria for the forest stands to our partner institutions in each country:

- stands are dominated by F. sylvatica
- stands have low percentage of coniferous trees within the top level
- stands host mainly *Asperulo-Fagetum* (Natura 2000 - Code: 9130) forest community

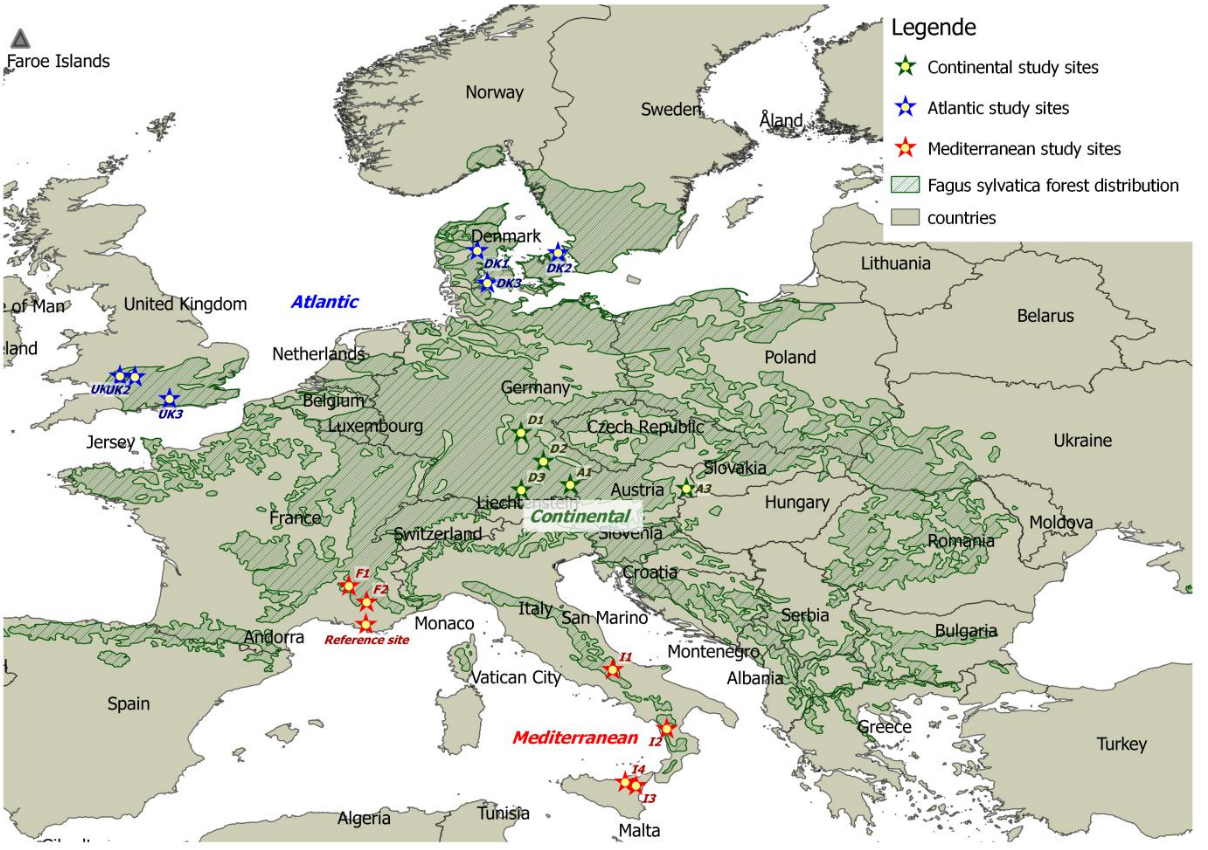

Figure 4. Locations of the study sites

Distribution of Beech (Fagus sylvatica), EUFORGEN 2009, www.euforgen.org

Each study site includes Natura 2000 and paired non Natura 2000 stands. The paired stands have the same forest community, age, management type.
We used 8 research plots per stand with following **plot requirements**:

1. *Fagus sylvatica* dominating
2. at least two *Fagus sylvatica* trees over 20 cm DBH
3. no conifers on the top level
4. exclude the edge area of the stand
5. the slope < 40°
6. plot radius = 17.84 m

In scope of this part of the study we evaluated 16 reference plots and 272 regular plots in total. The plot number we evaluated within each biogeographical region, listed in following:

- **Atlantic** biogeographical region: 96 plots
- **Mediterranean** biogeographical region: 96 plots
- **Continental** biogeographical region: 80 plots

Most of the Atlantic sites represent a special case according to the management history. Especially in UK, Natura 2000 beech forest stands were mostly under protection or have got a special status long before implementation of Natura 2000. The stand F3a located in the Massif de la Sainte Baume (FR9301606) was taken as a reference, cause of the naturalness and long low-management history.

For the establishment of the plots we prepared a preselection of points with help of Quantum GIS (Version 1.7.4.), which covered the suitable part of the stand according to the stand selection criteria. Each point of this layer has got a random ranking number. The distance between points was 50 meters. We observed the point locations in order of the ranking numbers and checked the suitability according to the plot requirements.

Table 1. Natura 2000 sites

Country	Site ID	Natura 2000 ID	Natura 2000 Name
Austria	A1	AT3110000	Ettenau
Austria	A3	AT1124823	Nordöstliches Leithagebirge
Germany	D1	DE6032371	Albtrauf von Dörnwasserlos bis Zeegendorf
Germany	D2	DE7036372	Hienheimer Forst östlich und westlich Schwaben
Germany	D3	DE8032372	Moore und Wälder westlich Dießen
Denmark	DK1	DK00DY262	Silkeborgskovene
Denmark	DK2	DK003X207	Gribskov
Denmark	DK3	DK009X271	Lilleskov og Troldsmose
UK	UK1	UK0012727	Wye Valley Woodlands/ Coetiroedd Dyffryn Gwy
UK	UK2	UK0013658	Cotswold Beechwoods
UK	UK3	UK0012723	East Hampshire Hangers
Italy	I1	IT7212124	Bosco Monte di Mezzo-Monte Miglio-Pennataro-Monte Capraro-Monte Cavallerizzo
Italy	I2	IT9310020	Fonte Cardillo
Italy	I3	ITA070010	Dammusi
Italy	I4	ITA030038	Serra del Re, Monte Soro e Biviere di Cesarò
France	F1	FR8212018	MASSIF DE SAOU ET CRETES DE LA TOUR
France	F2	FR9301537	MONTAGNE DE LURE
France	F3	FR9301606	Massife de la Sainte Baume

2.4 Data and Analyses

2.4.1 Climate and landscape

To compare the climatic conditions and landscape features of the selected study sites we used several parameters listed in Table 2.

Table 2. Parameters used to assess the Climate and Landscape futures

ID	**landscape & climate**	**description**
	3_1_Landscape	
1	coordinates	measured by Garmin Oregon 450t GPS device in decimal degree, WPS84
2	altitude	measured by Garmin Oregon 450t GPS device
3	aspect	measured by Suunto KB-14/360/R/D Compass, in degree
4	slope	measured by Vertex Laser VL402 device, in degree
	3_2_Climate	
1	average annual temperature	data from WorldClim
2	average annual precipitation	data from WorldClim

To analyze and compare the climatic favorability for *F. sylvatica* we used special modeled favorability index for *F. sylvatica*, based on the annual precipitation and temperature. For further information regarding the favorability index see (http://margins.ecoclimatology.com/).

2.4.2 Microhabitats and stand structure

On the basis of previously studies as described in chapter *2.1.1.and 2.1.2.*, we took the microhabitats as main indicators for the management impact to investigate the possible effects of Natura2000. We used 31 types of microhabitats, listed in Table 3. They build several "indicator blocks" described in the following. To explain the frequencies of the microhabitats we separated the structural parameters into blocks regarding these ecological values, and analyzed Natura 2000 impact on microhabitats in connection with each block.

Block1 - Stand level structures like: DBH mean, DBH maximum, basal tree area, maximum tree height, forest development phases, % top closure, sociability of the *F.sylvatica* seeds, bark defects due to nature, bark defects due to management
Block2 - Tree growth (or tree morphological) structures like: uprightness, branchiness, twisted growth, regularity, forked stems, number of partner stems after coppice, individual tree vitality (measured during winter field work, by observation of the stem and branches condition), etc. (detailed described under 0);
Block3 - The deadwood parameters: deadwood volume (in total, lying, standing, stumps) and decomposition classes (as described under 0).

Table 3. Types of microhabitats

ID	microhabitats	description
M1	Fomes conks	Trees with sporophores of *Fomes fomentarius* (L.ex Fr.) Fr.
M2	Fomitopsis conks	Trees with sporophores of *Fomitopsis pinicola* (Swartz ex Fr.) Kars.t
M3	other fungal trees	Long-lasting single sporophores with>5cm in diameter or cascades of smaller fruiting bodies of in minimum 10 cm.
M4	Broken tree crown	At least 50% of the crown broken off
M5	Partially broken crown	Less than 50% of the crown, including primary branches, broken off
M6	Broken fork	complete break-off of one of the two forking stemsresulting in a severe damage of the main stem
M7	Broken stem	The crown is totally absent. Underneath the fracture, some very small living twigs/epicormic branches have remained.
M8	Bayonet top	After stem breakage, creation of a new crown with an upturned leader
M9	Lightning scar	a crack caused by lightning at least 3 m long and exposing the sapwood
M10	Crack or other scars	Cracks or scars exposing the wood and at least 2 cm wide and 50 cm long
M11	Splintered stem after Stem breakage	Many splinters (in minimum 5) with a length of at least 50 cm each after stem breakage
M12	Small woodpecker cavity	Woodpecker hole in the wood that indicates a cavity of *Dendrocopus major* and *Picoides tridactylus*
M13	Large woodpecker cavity	Woodpecker hole in the wood that indicates a cavity of *Dryocopus martius*, *Picus viridis* and *P. canus*
M14	Cavity string	At least three woodpecker cavities in a stem with a maximum distance of two meters between two cavity entrances

M15	**Branch cavity**	Branch hole in the stem indicating a cavity (orifice/aperture in minimum 5 cm)
M16	**Stem cavity**	Cavity at the base of the tree or on the stem with few or no mould
M17	**Stem cavity with mould**	Cavity at the base of the tree or on the stem in an advanced decay stage and within minimum 8.000cm² mould
M18	**Bark pockets**	Space between loose bark of at least 5 cm in width and 2 cm deep
M19	**Bark pockets with decay**	Same as above but with mouldy substrate
M20	**Burls**	Cancerous growth at least 5 cm x 5 cm in size
M21	**Bark loss**	Loss of bark at least 5 cm x 5 cm in size
M22	**Uprooted stumps**	Fallen stumps or trees with a minimum height of 1.2 m of the vertical root plate
M23	**Heavy resinosis**	Fresh heavy flow of resin at least 1 m long
M24	**Rooted branches**	Branches which developed roots
M25	**Upright hanging trees**	Trees which are slightly being supported by neighbouring trees and inclinated, α ≥45°
M26	**Lying hanging trees**	Trees which are strongly crooked, α<45°
M27	**Bizarre growing tree**	Trees with in minimum three forks, crown starts in a minimum height of <5 m, spreading horizontal large branches with a minimum length of 10 m
M28	**Steep dead branches**	Dead steep branches with ≥10 cm in diameter
M29	**Epiphyte tree**	Stem of the standing tree with epiphytic vascular plants (*Viscum spec.*)
M30	**Mould fork**	Mould fork base with bryophytes, water and xylem stream at the stem
M31	**Dendrothelm**	Water filled tree hole

color codes for groups of microhabitats

color	group name
red	closed
blue	open
magenta	dead branches
green	crown breaks
cyan	bizarre
yellow	fungal trees
black	to less funds

The type of microhabitats, as described above, may have similar as well as different impact values regarding biodiversity, they can indicate close to nature condition as well as a management pressure or environmental influence (Michel & Winter 2009). In terms of ecological analysis we divided the types of microhabitats into six main groups by its ecological impact. The groups have got symbolic names as following: closed, open, dead branches, crown breakage, bizarre growth and fungal trees (Figure 5). Every group of microhabitats is especially important for a number of groups of organisms (as shown in Figure 5) and indicates a development processes or ecological features of the stand.

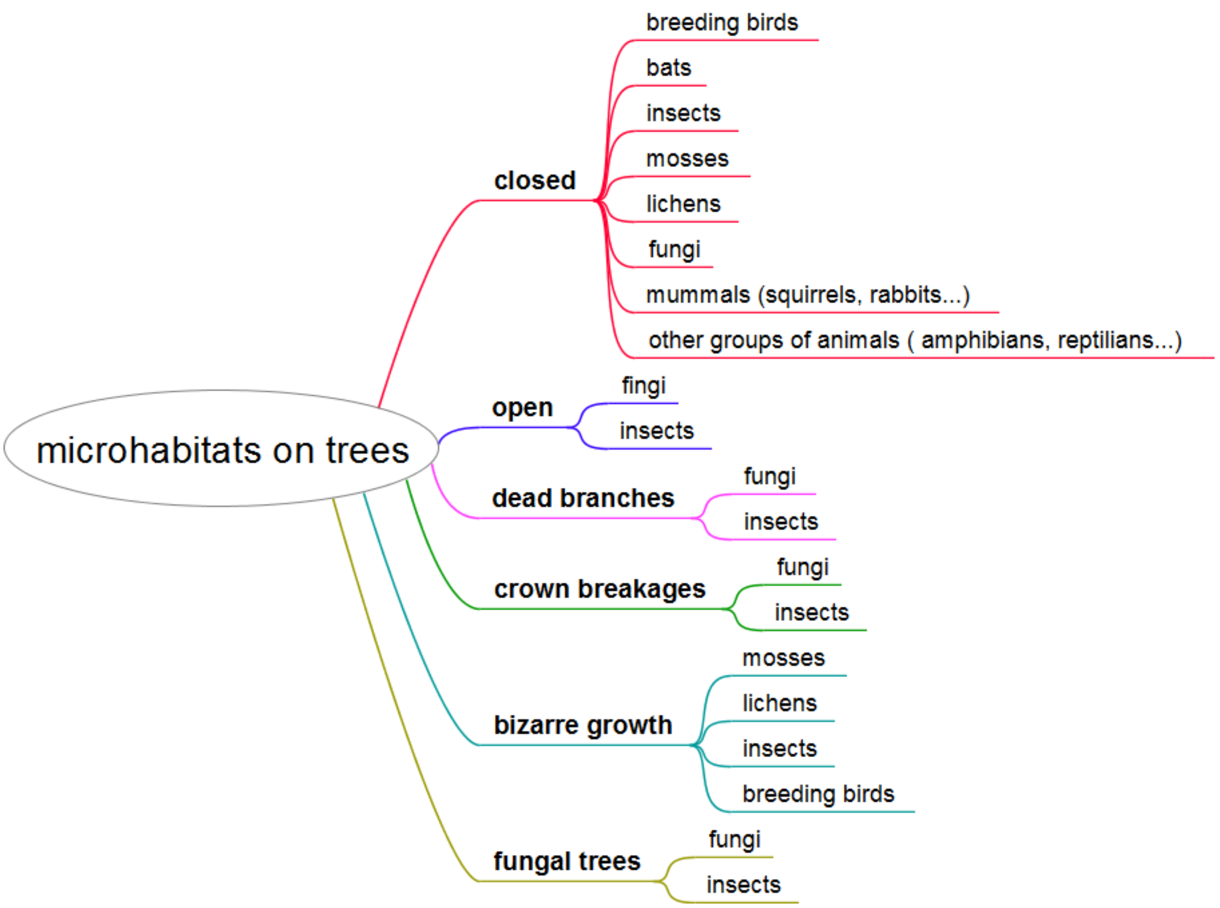

Figure 5. Groups of microhabitats and groups of organisms especially depend on microhabitats

2.4.3 Stand structure

Structural parameters used in connection with the microhabitats were selected regarding previously studies around the microhabitats and structural diversity (Winter & Möller 2008; Winter 2005; Vuidot et al. 2011; Müller 2005; Larrieu et al. 2011; Fritz & Heilmann-Clausen 2010; Winter 2010). As has been pointed out, this section of parameter includes two main blocks, which describe stand level structure and individual tree structure or tree growth. The used parameters of the stand structure are listed in the Table 4.

Table 4. Forest structures

ID	**Stand Structures**	Description
1	H max	maximal tree height of the plot
2	H min	the lowest tree over 5 m height
3	bark damages due to management	bark damages occurring due to the management activity and directly human impact: **absent** – no trees with signif. amount of damages **single funds** - up to 10% **frequently**- 10% to 30% **highly frequented** – 30% to 60% **massive** – clearly more than 60%
4	bark damages due to nature	bark damages occurring due to the natural factors: absent – no trees with signif. amount of damages single funds - up to 10% frequently- 10% to 30% highly frequented – 30% to 60% massive – clearly more than 60%
5	beech regeneration seeds	occurrence of the beech regeneration inside every single plot, on the basis of following classification: 0 - absent, 1 - single fund or less than 5 %, 2 - five to ten %, 3 - ten to 30 %, 4 - up to 50%, 5 - clear more than 50% of the plot area.
6	basal area	basal area with every single plot (m^2)
7	maximum DBH	maximum DBH of the plot (cm)
8	average DBH	average DBH of the plot (cm)
9	number of stems	number of all tree stems over 20 cm DBH and inside of the plot
10	Forest Development Phases	Cc = canopy cover of all trees with DBH >7cm on plot; DBH = diameter at breast height measured in 1.3 m; DBHmax = largest DBH on the plot; DBHø = mean DBH of trees >2m on the plot; Dw = Proportion of standing and lying deadwood on the total stock volume (DBH ≥7cm). Thresholds for the deadwood: diameter ≥7cm measured 1.3 m from the thicker end; decomposition stage 1-4 (Albrecht 1990), Hmax = Maximum tree height on the plot, Hpot= Maximum potential tree height on the plot; Reg = Percentage of the plot covered by tree regeneration. Regeneration includes all tree individuals after the seedlings stage and with DBH <7cm.
11	number of tree species	which represented by the number of the tree species within the tree layer

The actual research includes parameters to assess bark defects (Table 4, id 3,4), which describes the abundance of bark damages divided into “natural” and “unnatural”. This kind of damages are not a microhabitat like a bark loss or crack because of the small size, but the general frequency of such unnatural damages could be highly correlated with human activities like high tourist traffic and machinery activities within the forest (Vuidot et al. 2011). This may influence the potential microhabitat frequency significantly. For better handling of this kind of parameters we classified them into the five following classes according to the percentage of trees with bark damages:

- absent, no bark damages found
- single finds
- frequently but present on less than on 30 % of trees
- highly frequented but present on up to 60% of all trees
- massive occurrence, clearly over 60% of trees have significant bark damages

The used methodology for the determination of the forest development phases within the evaluation plots was based on the methods described by Tabacu (2000) and modified by Winter (2005) (see Figure 6). The phase determination has been associated with the plot area.

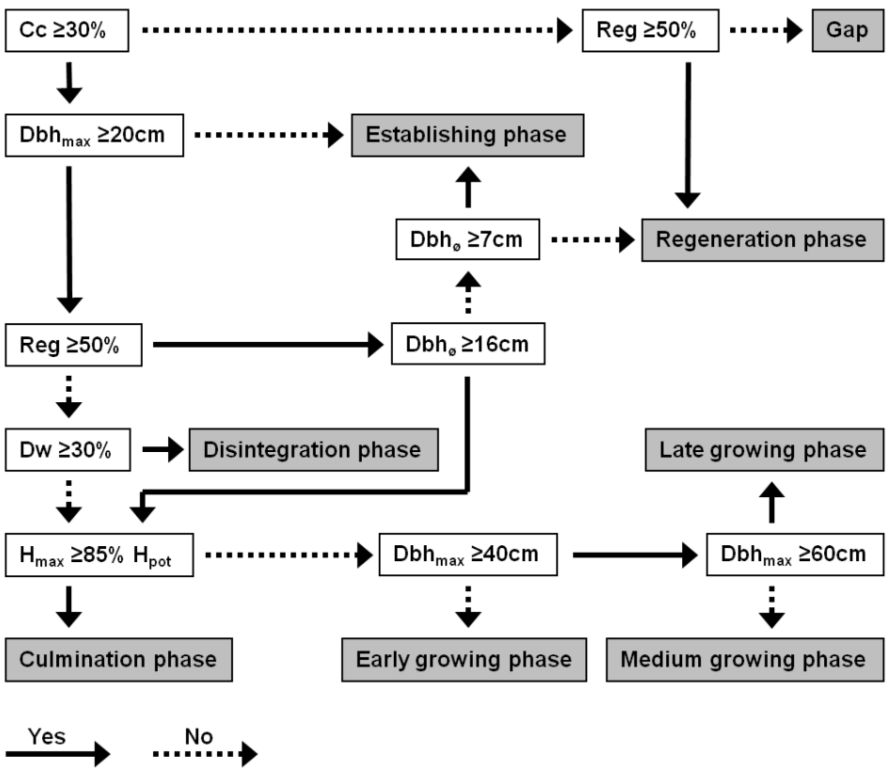

Figure 6. Forest development phases

Forest development phases (FDP) regarding Tabacu (2000) modified:

- Cc = canopy cover of all trees with DBH >7cm on plot;
- DBH = diameter at breast height measured in 1.3 m;
- DBHmax = largest DBH on the plot;
- DBHø = mean DBH of trees >2m on the plot;
- Dw = Proportion of standing and lying deadwood on the total stock volume (DBH ≥7cm).
  Thresholds for the deadwood: diameter ≥7cm measured 1.3 m from the thicker end; decomposition stage 1-4 (Albrecht 1990),
- Hmax = Maximum tree height on the plot,
- Hpot= Maximum potential tree height on the plot;
- Reg = Percentage of the plot covered by tree regeneration.
  Regeneration includes all tree individuals after the seedlings stage and with dbh <7cm.

2.4.4 Tree morphology and individual tree characteristics

To assess the individual tree characteristics we used nine main categories, which are commonly used to evaluate the vertical structure and individual conditions of trees regarding Winter (2005, 2008) (Table 5). Parameter 8 was originally used to record the occurrence of epiphytic and liana-like vascular plants. The only species we found within the evaluation plots was *Hedera helix* L. We observed low presence of *Clematis vitabla* within the stands of following study sites: A1, A3, F2, D3, UK3 and single finds of *Viscum spec*. within the stands of following study sites: F2, F3, I1, I4 (Table 1). But we didn´t find any of this two species on trees within the selected research plots.

Table 5. Individual tree characteristics

ID	**Tree Morphology and individual tree characteristics**	**Description**
1	forks	**occurrence of the stem forks** y, n
2	twisted growth	**occurrence of the twisted growth** y, n
3	uprightness	**uprightness of the stem:** 0 – crooked 1 – at least one dimension upright 2 – fully upright standing
4	branchiness	**occurrence of the branches** outside of the main tree crown: 0- no branchiness 1- low branchiness, 1-2 thin branches 2- medium branchiness, 3-10 middle branches (max. ca 6cm Ø) 3- strong branchiness, big branches or >10 middle branches
5	secondary shoots	**occurrence of the secondary shoots** on the tree stems, covering at least 1 % of the stem area y,n
6	partner stems	**number of the stems growing up from one mature root** (for example after traditional coppicing)
7	regularity of the stem crossectional area	0- regular (round) 1- low irregular(up to 2 cm difference) 2- medium irregularity of the cross section (>2 up to 5 cm) 3- strong irregularity >5 cm difference
8	H. helix occurrence on tree	y, n
9	tree vitality	1 – Top vitality and dominant tree without damages 2 – normal vitality with developed crown and without danger damages 3 – medium level of vitality, crown area is restricted by other trees, may have some damages. Is not in imminent danger of dying 4 - massive damages, is in imminent danger of dying 5 – short before dead tree

2.4.5 Deadwood parameters

Dead trees at different stages of decay have an important ecological role to play in conserving forest biodiversity. Forest deadwood is recognized as a Pan-European indicator of a sustainable forest management (Travaglini et al. 2007). Fallen dead wood and stumps provide nurse logs for the regeneration. Dead wood influences the forest microclimate and can be an important water-storing factor (Christensen et al. 2005).

Beside of that deadwood is one of the key indicators for the long term natural development history of the forest stand (Mountford 2002). It can be used an important indicator to identify forest stands with a long history with little or no management.

The deadwood parameters include 12 deadwood types as shown in the Table 6. Types 1 to 4 describe the standing deadwood, 5 to 10 lying deadwood and 11 to 12 stumps.

Table 6. Types of Deadwood

Type nr	Deadwood Types	Category
1	standing with fine branches	standing deadwood necromass
2	standing without fine branches middle branches are present	
3	standing with main branches	
4	stump without crown (including forks without crown); min. 1m length & 10 cm diameter	
5	lying with fine branches	lying deadwood necromass
6	lying without fine branches, middle branches are present	
7	lying with main branches	
8	lying stems or main branches	
9	deadwood with root plate	
10	cut stem part, min. 1m length & 10 cm diameter	
11	<30 cm ø	deadwood necromass of the tree stumps
12	≥30 cmø	

Further we selected information on the distribution and abundance of the decomposition classes as described below. Decomposition classes were defined regarding Albrecht (1990) as described and modified by Winter (2005):

- fresh dead totally with bark
- dead, with mainly present bark, wood still at least partially hard
- dead, advanced decomposition (bark is partially separated, wood soft or dry)
- dead, strongly decomposed (bark is not present, wood soft with holes)

The deadwood volume is the deadwood characteristic for the comparison between the stands. This parameter was calculated from the stem length and diameter regarding HUBER´s Formula as follow:

$$V = G * L$$

L - length
G - middle basal area

2.4.6 Statistical analyses

Applied statistical analyses contain following sections: differences (2.4.6.1), effects (2.4.6.2), ordinations (2.4.6.3) and classifications (2.4.6.4). The differences, effects and classifications were done with help of the *R version 2.15.2* (Copyright (C) 2012 The R Foundation for Statistical Computing) by applying of following external packages:

Package: coin
Title: Conditional Inference Procedures in a Permutation Test Framework
Version: 1.0-22

Package: stats.
Version: 2.15.2
Title: The R Stats Package

Package: effects
Version: 2.2-4

Package: vegan
Title: Community Ecology Package
Version: 2.0-8

Package: party
Title: A Laboratory for Recursive Partitioning
Version: 1.0-8

Package: partykit
Title: A Toolkit for Recursive Partitioning
Version: 0.1-5

Package: glmulti
Version: 1.0.7
Title: Model selection and multimodel inference made easy

Package: glm2
Type: Package
Title: Fitting Generalized Linear Models
Version: 1.1.1

Ordinations where done using PC-ORD 6.0:
McCune et al. 2011. PC-ORD.
Multivariate Analysis of Ecological Data.
Version 6.0
MjM Software, Gleneden Beach, Oregon, U.S.A.

2.4.6.1 Differences

Detecting differences and similarities of the ecological forest conditions regarding Natura 2000 status is the essential part of the actual research.
To see, whether some general trends regarding the most essential structural indicators (deadwood and microhabitats) could be already found or not, we created overview maps, which illustrate proportion between Natura 2000 and non Natura 2000 regarding those parameters. All geographic maps as well as additional analyses of data were done with help of geographic information system based on Quantum GIS software (version 2.0.1.) with python extensions for work with diagrams.
To get an impression of a situation regarding selected parameters and to compare the Natura 2000 and non Natura 2000 sites we did several non-parametrical tests. At the end we took the Wilcoxon rank sum test as the most robust and reliable one for this kind of data *(Wilcoxon-Mann-Whitney test, cf. Hollander & Wolfe 1999)*. The following sections of parameters were tested:

- total microhabitat frequency and groups of microhabitats
- microhabitat diversity
- tree morphology
- stand structures
- deadwood parameters

We prepared result tables with the tested significance of the differences between Natura 2000 and non Natura 2000 as well as the managed and not managed stands as a reference for the used parameters. The reference site (see chapt. 2.3) includes two paired forest stands with different management history. One site supposed to represent a semi-primeval beech forest with long natural development history and a

long term domination of beech. The other one is a regular managed stand, which must have similar as possible climate and soil characteristics as well as domination of beech. We have chosen the natural beech forest on the north slope of the Massive de Sainte Baume (southern France) as semi-primeval unmanaged stand. This stand in the past was subject of several researches about the management history and the formation (Delhon & Thiebault 2005), which confirm the suitability of this stand as a long-term natural beech forest.
We used the forest stand on the north slope of Montagne de Lure as the paired reference stand with similar landscape characteristics. This is a regularly used stand, which was traditionally managed as beech forest in the past and still be clearly dominated by beech trees.
By integration the reference site we used the opportunity to show the differences on the structural parameters of the natural and regular used forests in comparison with the differences between Natura 2000 and non Natura 2000 forests.

2.4.6.2 Effects

To describe the effects of the chosen parameters on the microhabitat frequencies we decided to apply bivariate and multivariate generalized linear models based on frequencies of the used microhabitat groups as *response*, because of the good suitability of GLM concept for multivariate as well as bivariate application for used data. To detect a possible general effect of Natura 2000 on microhabitat frequency we applied a bivariate generalized model according to following formula:

- microhabitat frequency ~ Natura 2000 status

Further we used multivariate poisson GLM´s to analyze the effects of Natura 2000 on microhabitat frequencies in connection with taken parameters, which were used as *terms* to specify a linear predictor for *response*.
To detect the effects of Natura 2000 status in connection with the significant number of different parameters we divided the GLM-structure into the following blocks:

- stand level
- tree morphology
- deadwood

The results show the modeled GLM-effects of Natura 2000 on microhabitat frequencies in connection with the stand parameters:

- maximal tree height
- minimal tree height
- average DBH
- maximal DBH
- basal area
- number of tree species within the tree layer
- bark defects due to management

Individual tree growth (tree morphology):

- stem vitality
- forked stems

- twisted growth
- uprightness
- branchiness
- secondary shoots
- partner stems
- regularity of the stem profile

Deadwood:

- volume of standing deadwood (m^3)
- volume of lying deadwood (m^3)
- volume of stamps (m^3)
- decomposition class 1
- decomposition class 2
- decomposition class 3
- decomposition class 4

Each section was analyzed by one multivariate poisson GLM with microhabitat frequency as “X” and the block of parameters in connection with Natura 2000 status as “Y”. The general effect of Natura 2000 on the microhabitats was analyzed by the bivariate models with microhabitat frequency as “X” and Natura 2000 status as “Y”. For the visualization of the effects we used the external package effects v.2.2-4. Chapter (2.5.3.) provides the visualization of the modeled effects of Natura 2000 on microhabitats regarding the multivariate section of parameters, as described above. Detailed effect plots of the single components within the sections added to the attachments.

2.4.6.3 Ordinations

Ordinations were done based on the PC-ORD software. The ordination was done for all Natura 2000 sites in total, as well as for each biogeographical region. For the ordination of the reference site we used 16 reference plots. The comparison of the differences regarding microhabitats between the paired forest stands usually indicates conditions of other important structural parameters (Müller 2005). Based on this assumption we prepare our ordination applied on references stands and paired Natura 2000-nonNATURA 2000 stands. Two suitable ordination methods were used for the visualization of the ordination results according to the final length of gradient. For the reference stands we used the PCA ordination method because the final length of gradient was significantly lower as 2. For all other sites it was acceptable to use the DCA because the final length of gradient was close to 2 or higher.
By the data, which was analyzed with help of the DCA method, the following additional parameters were used as the second matrix:

- individual tree vitality
- number of forked stems
- mean branchiness value on plot
- mean secondary shoots value on plot
- presence of *Hedera Helix* within the tree crown
- maximal number of the partner stems on plot
- deadwood volume
- *F.sylvatica* modelled favorability index
- percentage of the top closure
- sociability of the *F. sylvatica* seed on the ground
- basal area
- number of the tree species

2.4.6.4 Classifications

Classification process was used to test the classification possibilities into Natura 2000 – nonNATURA 2000 based on the groups of microhabitats as well as deadwood volume. The deadwood volume was chosen as an indicator for management before Natura 2000, which is well known and used for indication of the long term sustainable forest development (Lombardi et al. 2008). In this way we could indicate the density of stands, which were under protection long before Natura 2000. Classifications were done in R by using the *Toolkit for Recursive Partytioning* from the package "*partykit*".
The significance of the classifications was tested by *Monte Carlo Test*. As a result we provide the tree-plots with p-values for the classification. If the classification result for Natura 2000-nonNatura 2000 was not significant, so we have a single boxplot without a classification node on it.

2.5 Results

2.5.1 Climate and landscape conditions

The three encompassed biogeographical regions are well known as the core regions for the distribution of *Fagus sylvatica* (Habitats Directive Article 17 Reporting, 2009). Nevertheless all represented biogeographical regions have study sites located close to the edge area of beech forest distribution (see Figure 4). Especially the Mediterranean region has an outstanding position in terms of the nearness of the edge area for the beech dominated forests.

As mentioned above the European beech is distributed over different European biogeographical regions but the local climate within the core areas dominated by this species is usually not very different and especially the microclimate within beech forest stands indicates similar annual temperature allover beech forest stands of the same forest community (Bugmann 2013). In our case the core areas are concentrated within the Continental as well as the Atlantic biogeographical region. The differences of the annual temperature here are not as big as within the Mediterranean biogeographic region, which includes edges of the beech forest distribution. Indeed, the general influence of the climate seems to be a secondary factor for the forest development within the core area. Regarding locations of the forest stands, influences of the climate getting more significant on the edge of the distribution than within the core area of distribution (Ryan 2011). Indeed, the biggest climatic difference, regarding annual precipitation and temperature occur within the **Mediterranean** biogeographical region and not between the different biogeographical regions. Figure 7 shows the overview over the climatic conditions regarding temperature (T_yr) and precipitation (P_yr) among the biogeographical regions.

Our study sites detect the ombrothermic mean value of all forest stands by ca. 8.6 °C and 795 mm/yr. All 3 ombrothermic means are located within the intersection area of the data ellipses (see Figure 7). The modeled ellipses show the covariance area of 90 %, which should exclude outstanding statistical outliers.

Ombrothermic difference between Natura 2000 and non Natura 2000 sites wasn´t significant within each biogeographical region.

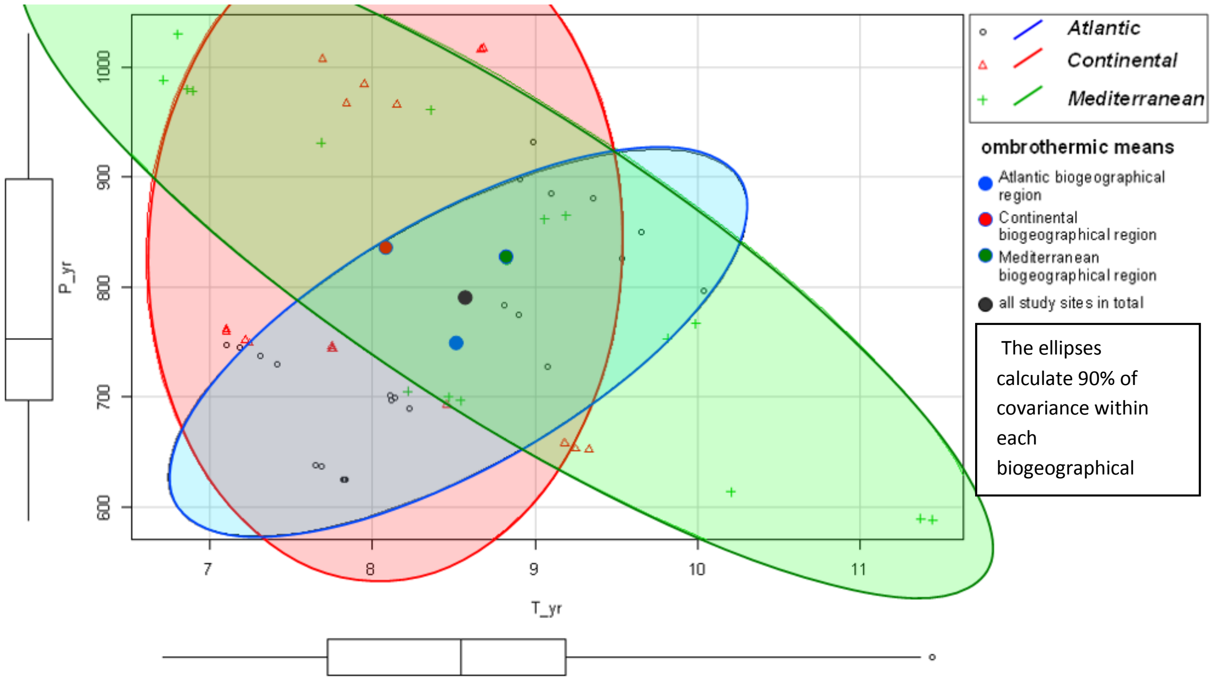

Figure 7. Overview over climatic conditions.

Annual precipitation (P_yr)

Annual temperature (T_yr)

Figure 8 gives an overview over the ombrothermic conditions among the study sites. Modeled ellipses show the scattering of the research plots within the study sites. We detect the smallest statistical scattering within the *Atlantic* biogeographical region. Significant climatic difference inside of the *Continental* biogeographical region has been detected on annual participation especially within the Austrian study sites. The highest scattering was found within the Mediterranean region. The Mediterranean region includes the wettest and coldest locations of the whole data set (represented by Massive de Saou and Montagne de Lure) as well as the driest and warmest one (represented by NP Nebrodi, Sicily) Figure 8.

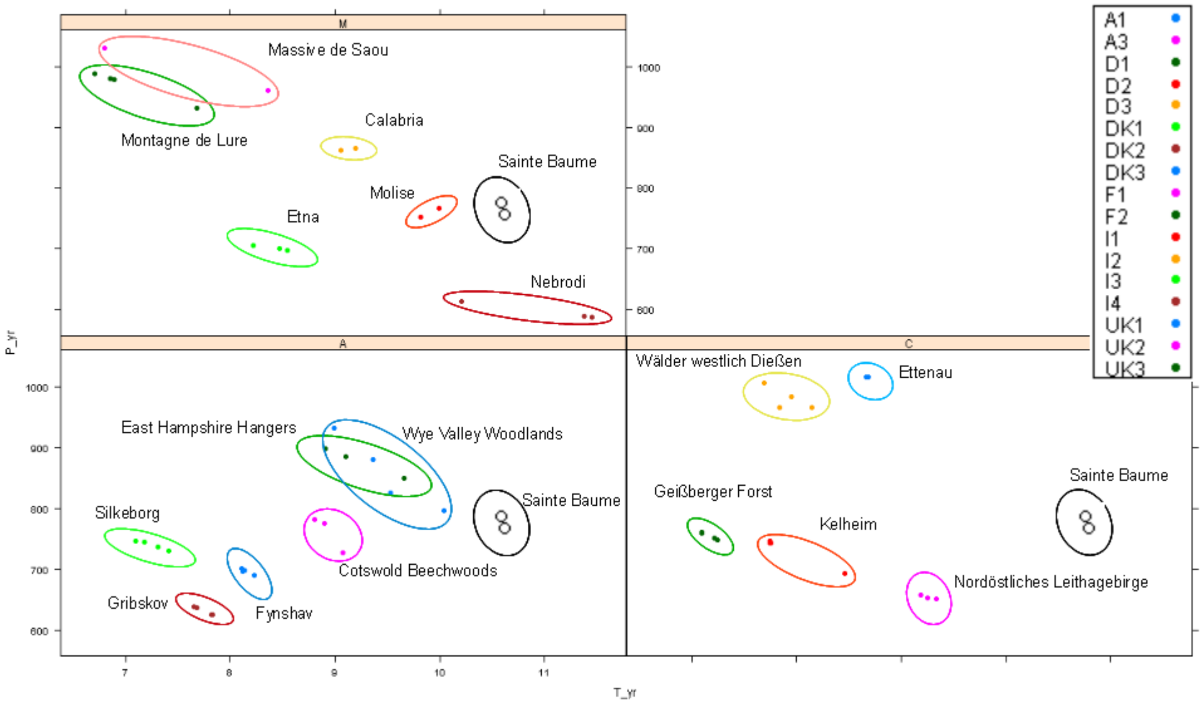

Figure 8. Climatic conditions among the study sites.

Annual precipitation (P_yr)

Annual temperature (T_yr)

Mediterranean sites - M

Atlantic sites - A

Continental sites - C

However, the altitude range of beech forests increases significantly from North to South. Contrary to annual temperature, altitude of the selected sites shows trendsetting characteristics (see Figure 9). The most southern stand has at the same time the highest altitude. The most northern sites (located in Denmark) indicate lowest altitudes (Figure 9).

The increasing slope may have an increasing influence on the microhabitat frequencies because of the tree damages due to the material dynamic on steep slopes (Larrieu et al. 2011).

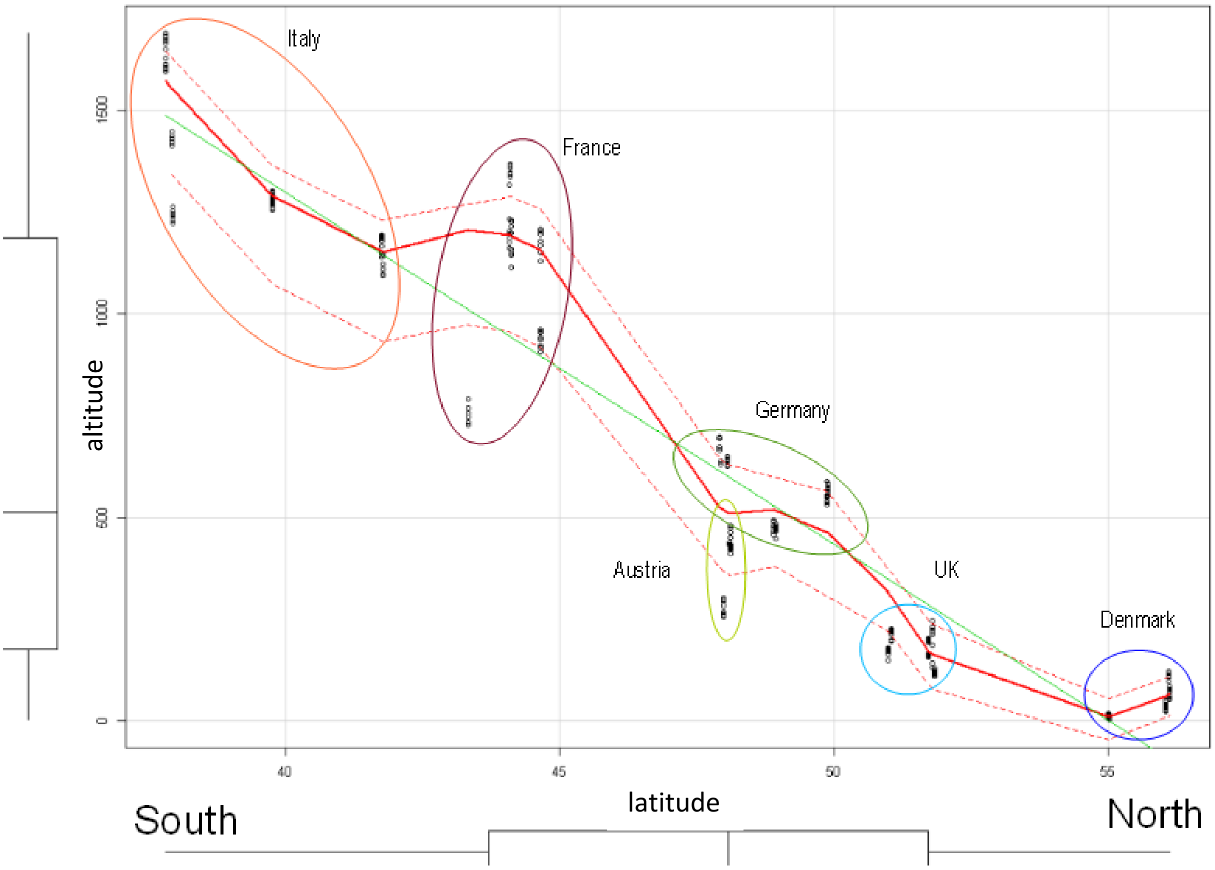

Figure 9. Altitude-Latitude relation among the evaluation plots.

The Figure 10 shows the classification of the closed microhabitats in connection with the slope variation in degrees. Presented classification results show a significant response by the closed microhabitats by the increasing of the slope over 11.6 degrees independent of the Natura 2000 status and management pressure (Figure 10, right diagram). The increase of the closed microhabitats was observed inside of stands with different climatic condition among all biogeographical regions and independent from the Natura 2000 status. The closed microhabitat frequency starts getting lower above the 22.1 slope degree, which was the case independent of Natura 2000 status and climate (Figure 10, left diagram). Nevertheless the described cases occurred mainly within the Mediterranean biogeographical region, due to the landscape characteristics (Figure 10, right diagram).

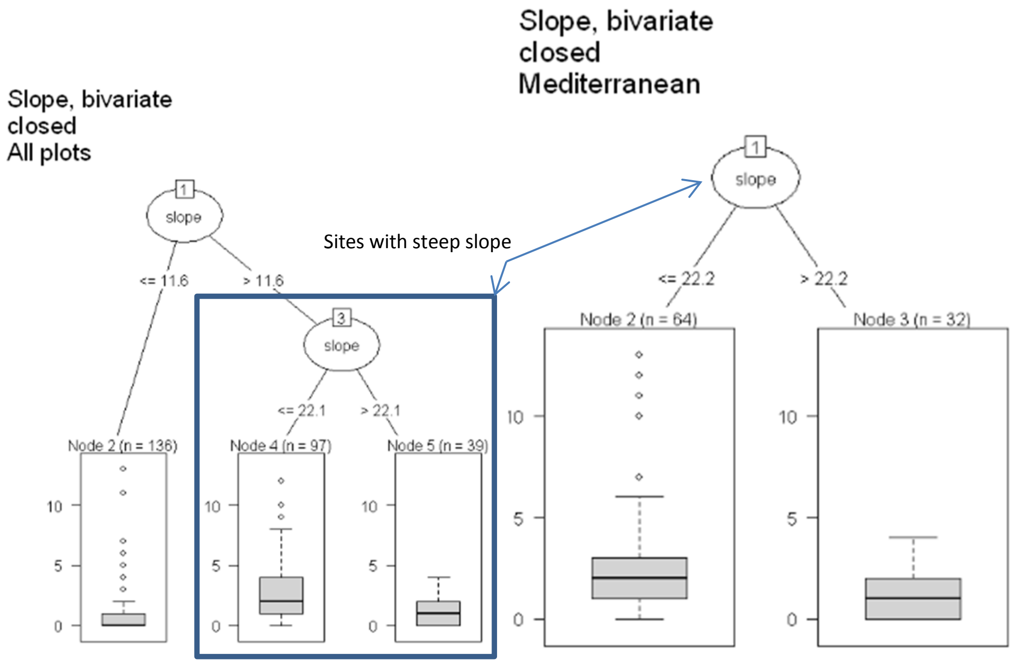

Figure 10. Classification of the microhabitat frequencies by the slope influence

The RDA on the basis of the favorability index for *F. sylvatica* shows the ordination of the 272 evaluation plots, grouped by the biogeographical region (Figure 11). Annual precipitation and annual temperature seem to be negatively correlated within the investigated study sites. According to our ombrothermic data, the coldest stand is in the same time the wettest as well as the warmest forest is also the driest. This RDA confirms that the biggest climatic variation occurs within the Mediterranean biogeographical region: the polygon area of the Mediterranean region, as shown on the Figure 11, is the biggest compared with others. The outstanding points of the Mediterranean biogeographical region are mainly located within the area of Massive *de Saou* as well as *Montagne de Lure* (bottom left) on the one side, and *Nebrodi* on Sicily (bottom right) and the other side.

The differences of climatic conditions between Atlantic sites were not significant. So the expectations to the variation of the favorability index of beech were the same. As expected the index values have the lowest variation within the Atlantic biogeographical region (0.60 to 0.67) and still very close to the Continental biogeographical region. The index values within Mediterranean stands start already by 0.47 and reach 0.67, which is the greatest variation compared to other biogeographical regions, but the significance regarding these differences between single biogeographical regions was statistically not confirmed (see Figure 11). The Continental biogeographical region shows the index variation between 0.59 and 0.67. The lowest favorability index of the whole dataset occurred within the Mediterranean non Natura 2000 stand, located on Sicily outside of Natura 2000 (I4b Nebrodi). Also the highest index value (0.6725) was detected within the Mediterranean biogeographical region inside of Natura 2000 stand, located in Calabria.

We used following parameters to overlay as the second matrix:

- maximal tree height
- tree vitality
- total deadwood volume
- top closure
- sociability of F. sylvatica regeneration seeds
- maximal DBH
- basal area

Only regeneration seeds of European beech trees indicate a significant vector regarding used data (Figure 11). *Sociability of F. sylvatica regeneration seeds* is a parameter, which describes occurrences as well as distribution of regeneration seeds (see Table 4, parameter 5). The detected vector was significant only according Axis 1.

Axis 1:

- r= -0.520, tau= -0.415

Axis 2:

- r=0, 120, tau= 0.113

This result confirms our observation regarding higher amount of the regeneration of the beech trees within the cold and wet stands in comparison to the warm and dry stands.

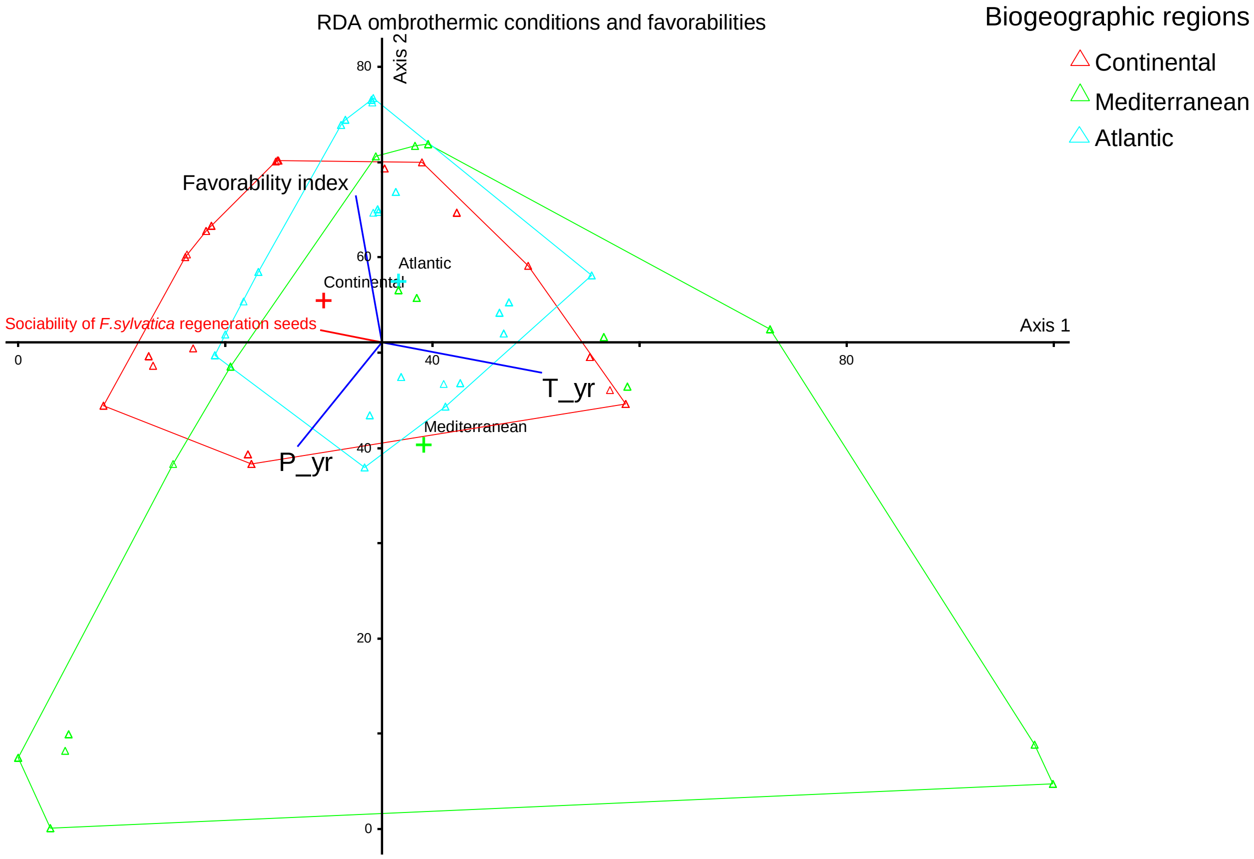

Figure 11. RDA ordination regarding annul temperature, precipitation as well as the modeled favorability index for *Fagus sylvatica* **(http://margins.ecoclimatology.com/).**

2.5.2 Detecting differences between Natura 2000 and non Natura 2000 sites in comparison with the reference site.

As has been mentioned by Merganičová & Merganič (2007) and Winter (2005), deadwood and microhabitat frequencies used to be the most efficient indicators for the forest naturalness and sustainable forest management. But the period of time, when indicators start to provide the significant results wasn´t defined up to now. That is why it is useful to take a look on deadwood volume and microhabitat frequency with help of geographic information system to see the general tendency in comparison between Natura 2000 and non Natura 2000 stands as well as the reference site.

Hereto we create maps, which illustrate the proportion of deadwood and microhabitat frequency regarding Natura 2000 status within each biogeographical region as well as the reference site.

The proportions between Natura 2000 and non Natura 2000 were calculated based on average values of Natura 2000 and non Natura 2000 stands. The results were illustrated in form of diagrams in the geographic map. We found that the frequency of the microhabitat (Figure 12) as well as the number of microhabitat types (Figure 13) show very similar proportions according to the Natura 2000 status. The measured microhabitat frequency of Natura 2000 stands was about 15 % higher than non Natura 2000 within the Atlantic biogeographical region. However, the reference site indicates the same trend but even more significant. Therefore our understanding is that a longer development is needed to make sustainable ecological effects on stand level clearly tangible for analyses.

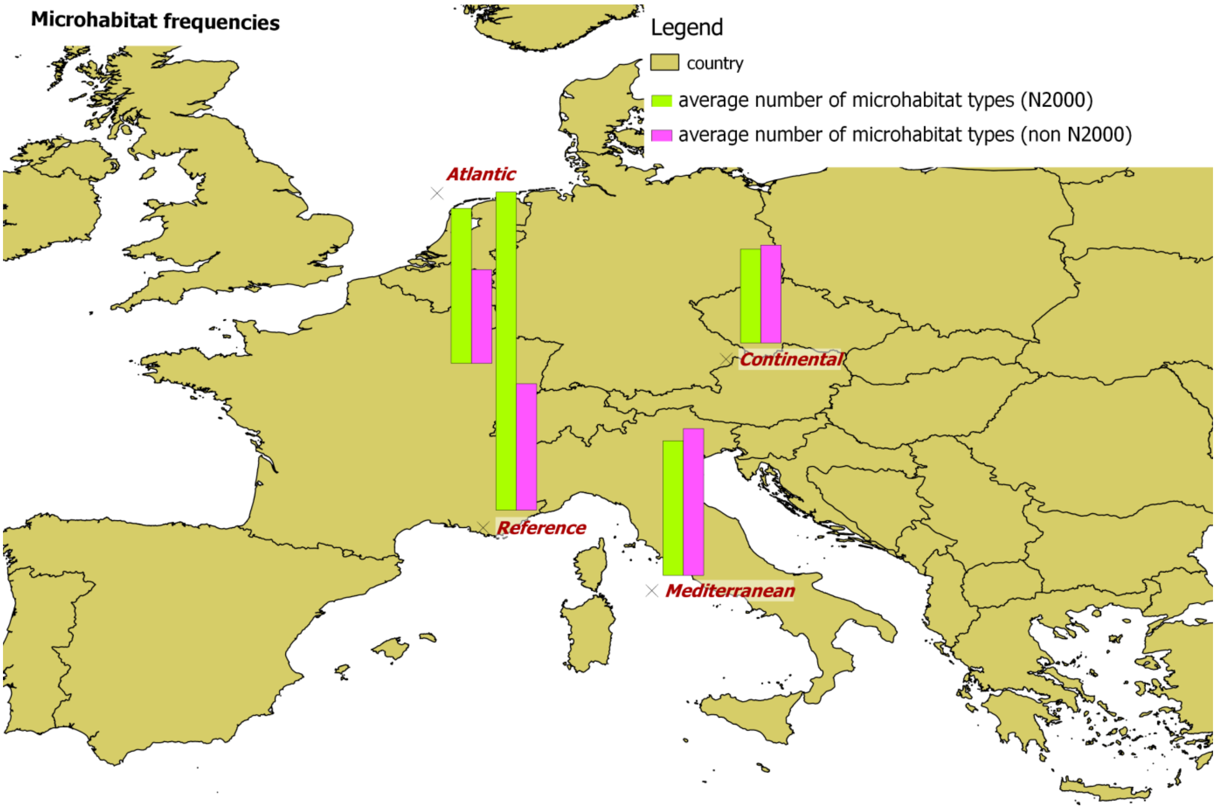

Figure 12. The average total microhabitat frequency within biogeographical regions

Our observations of the research sites show that a certain frequency of microhabitats can either occur due to the natural processes or due to intensive management and/or due to tourist activity within the forest stand.

To proof the trends indicated by microhabitat frequency is useful to get an overview over the microhabitat diversity (Vuidot et al. 2011). The number of microhabitat types (Figure 13) is one of diversity parameters we used for this purpose.

Once again, the trend indicated by the reference site has been confirmed only by the Atlantic biogeographical region. Other biogeographical regions don´t indicate clear differentiation trend between Natura 2000 and non Natura 2000. Here we see the proportion regarding Natura 2000 status close to 50% to 50%.

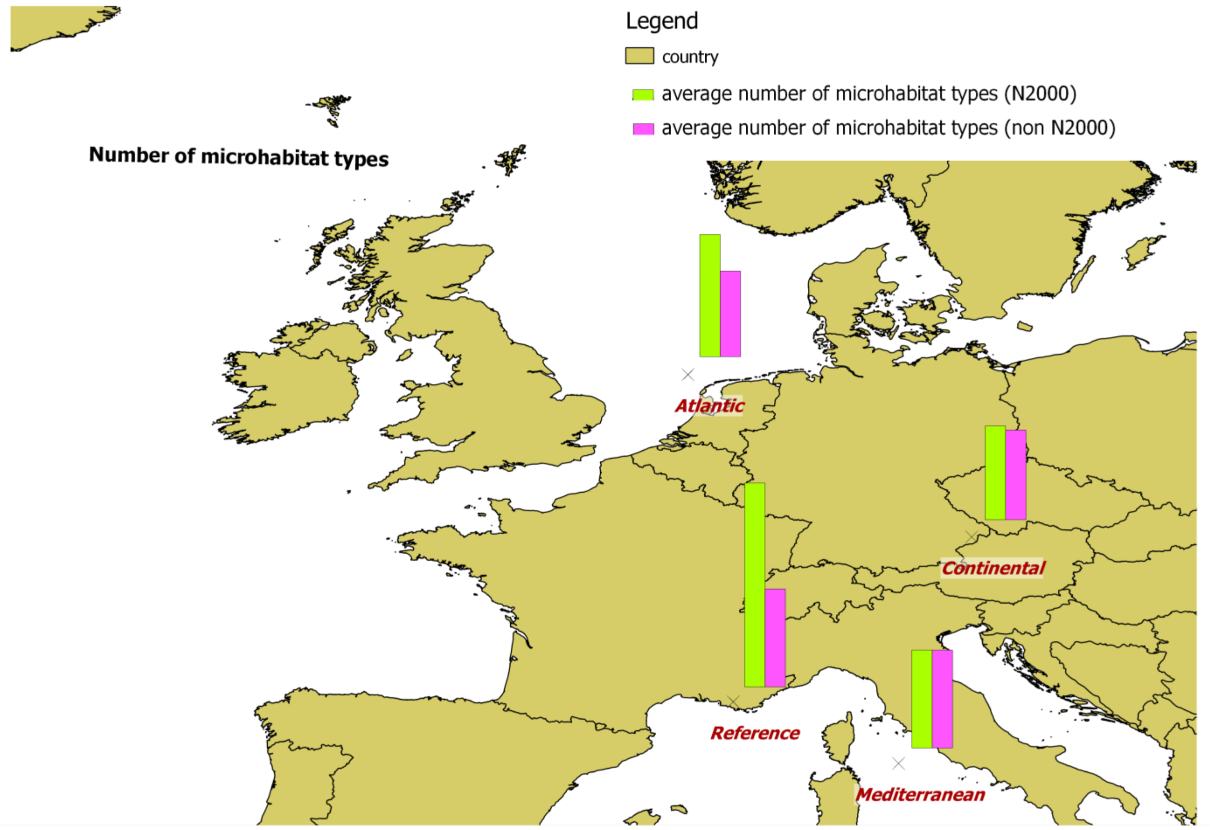

Figure 13. Comparison of Natura 2000 and non Natura 2000 stands regarding the number of microhabitat types

The Figure 14 illustrates the proportion between Natura 2000 and non Natura 2000 stands. As one can easily see, except the reference site, which indicates an outstanding difference between Natura 2000 and non Natura 2000 stands, only the Atlantic biogeographical region indicates higher amounts of deadwood within Natura 2000 stands, while neither the Continental nor the Mediterranean biogeographical region indicates such tendency. To have an impression how the deadwood differences would be we used the reference site by comparison of the long term forest reserve with the regular used forest (Massive de St. Baume) we found that the natural forest stand shows much higher deadwood volume than the managed forest (see Figure 14). It means that the deadwood volume recorded within the managed stand amounts just around 10 % of those within the unmanaged stand. And this difference is clearly more than even between Natura 2000 and non Natura 2000 within Atlantic sites.

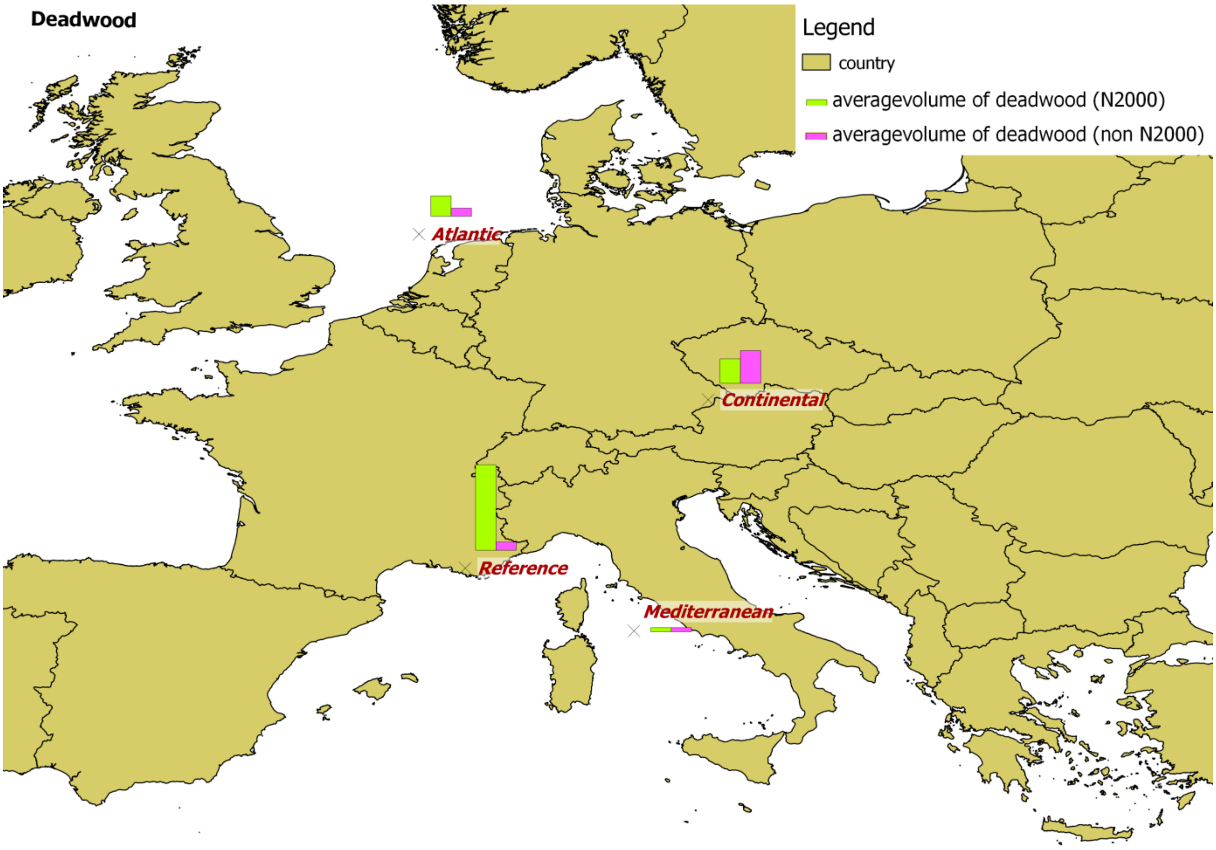

Figure 14. Average deadwood volume within biogeographical regions

Most essential results, which indicate **differences and similarities between Natura 2000 and non Natura 2000** stands, have been summarized in tables 7 to 11. Each of them builds a section of the test results according to the following blocks of parameters:

- microhabitat frequencies - table 7
- microhabitat diversity - table 8
- tree growth - table 9
- stand structures - table 10
- deadwood - table 11

The following abbreviations are listed in tables 7 to 11:

pRef - *p value of the reference site*, the test results for the differences between managed and semi primeval forest.

pTotal - *p value of all sites*, the test results for the differences between the Natura 2000 and non Natura 2000 evaluation plots in total.

pMed - *p value of Mediterranean sites*, the test results within the *Mediterranean* biogeographical region.

pAtl - *p value of Atlantic sites*, the test results within the *Atlantic* biogeographical region.

pCont - *p value of Continental sites*, the test results within the *Continental* biogeographical region.

The **arrow symbol up** - the values and frequencies within the Natura 2000 stands were higher numbered than nonNATURA 2000, otherwise – nonNATURA 2000 higher than Natura 2000.

The **arrow symbol down -** the values and frequencies within the Natura 2000 stands were lower numbered than nonNATURA 2000

The integration of the reference site allows the comparison of the current situation under Natura 2000 with the situation under long term low management regarding ecological indicators. As has been pointed out (Table 3), we used 31 types of microhabitat regarding Winter (2005), completed 2010. All types of microhabitats were sorted in 6 groups regarding the ecological impact and connectivity pattern *(*Figure 5*,* Table 3*)*.

Microhabitat frequency.

As can be seen in Table 7 the reference site shows significant differences on 3 of 6 groups of **microhabitats**. These are mostly natural microhabitats characterized by long formation time and high ecological value.

The regular sites in total show significant difference only on crown breakages. This result also shows that the crown breakages are higher numbered outside of Natura 2000 areas. The same trend we have within the *Mediterranean* biogeographical region. If we take a look on the other two biogeographical regions so we´ll see a clear different trend between Natura 2000 and non Natura 2000 stands inside of each of them. For example the Continental biogeographical region shows not any significant difference regarding the microhabitats between Natura 2000 and non Natura 2000 areas. By contrast, the Atlantic biogeographical region takes the outstanding position and shows significant differences on 2 of 6 groups (Table 7). The both groups represent the most important microhabitat types for the natural biodiversity (Vuidot et al. 2011). The frequencies of used microhabitat groups didn´t indicate any significant differences between Natura 2000 and non Natura 2000, which indicate a consistently trend within all biogeographical regions.

Table 7. Test results for the frequencies of microhabitat groups

Wilcoxon Test	Microhabitat frequency									
	Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05 (ns = not signif.)									
parameter	pRefeference		pTotal		pMed		pAtl		pCont	
(see Tab.3)	signif.	trend	signif.	trend	signif.	trend	signif.	trend	signif.	trend
Frequency of all Microhabitats	**	↑	ns		ns		ns		ns	
open microhabitats	ns		ns		ns		ns		ns	
closed microhabitats	**	↑	ns		ns		*	↑	ns	
crown breakage	**	↑	*	↓	*	↓	ns		ns	
dead branches	*	↑	ns		ns		*	↑	ns	
bizarre growth	ns		ns		ns		ns		ns	
fungal trees	ns		ns		ns		ns		ns	

Diversity of microhabitat types.

Also the **microhabitat diversity** shows clearly trends by comparison between the single biogeographical regions and the reference site (Table 8).

On the reference site the both used diversity indexes were highly significant by comparison of managed and unmanaged stands (Table 8). The p-value of the Inverse Simpson Index was even more significant as the Shannon Index. The number of microhabitat types was highly significant as well. No significance was detected for evenness of microhabitat types. All used diversity parameters show the higher values within the unmanaged forest stand.

In total no significant differences were detected between Natura 2000 and non Natura 2000 forest stands. But the trend indicates slightly increased diversity of microhabitats within the Natura 2000.

The Atlantic sites show significantly increased diversity of microhabitats within Natura 2000. Also the values of evenness were higher within the Natura 2000 sites.

No significances on the microhabitat diversity parameters regarding Natura 2000 status were detected within the Mediterranean as well as the Continental biogeographical regions. The number of microhabitat types was almost equal within the both regions. The other used parameters of this section detect slightly increased means of Continental Natura 2000 sites Table 8.

The trends go into the opposite direction within the Mediterranean sites. No statistical significances were detected in both cases.

To summarize, we didn´t found any significant difference between Natura 2000 and non Natura 2000 regarding microhabitat diversity, which occur consistently within all biogeographical regions.

Table 8. Diversity of microhabitats

Wilcoxon Test	Microhabitat Diversity									
Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05 (ns = not signif.) Trend codes: ↑ - higher value of Natura 2000, ↓ - higher value of nonNATURA 2000, ~ - equal										
Diversity parameter	pReference		pTotal		pMed		pAtl		pCont	
	signif.	trend	signif.	trend	signif.	trend	signif.	trend	signif.	trend
Inverse Simpson Index	***	↑	ns	↑	ns	↓	**	↑	ns	↑
Shannon Index	**	↑	ns	↑	ns	↓	*	↑	ns	↑
Number of microhabitat types	**	↑	ns	↑	ns	~	*	↑	ns	~
Evenness	ns	↑	ns	↑	ns	↓	**	↑	ns	↑

Tree morphology and vertical structures.

5 of 9 parameters on the reference site detect significant differences regarding **the tree morphology and vertical structure** (Table 9). Partner stems were higher within the managed stand. Twisted growth, secondary shoots and *Hedera* coverage were higher frequented within the unmanaged stand (Table 9).

Vertical structure and individual tree growth indicate a significant response according to the Natura 2000 status only on 1 of 11 used parameters in total. The frequency of the secondary shoots was significantly higher outside of Natura 2000 stands. The results of biogeographical regions were mostly not significant according to Natura 2000 status, but every of the regions indicate some few cases of significance listed below in the Table 9.

Atlantic sites have differences by the number of partner stems, which were higher inside of Natura 2000. And the frequency of the secondary shoots, which was significantly higher within the Natura 2000 stands. Occurrence of the partner stems has also significant differences within the *Mediterranean* biogeographical region. In contrast to the Atlantic sites, the frequency here was higher outside of the Natura 2000 stands. At the same time percentage of the trees with the partner stems wasn´t significantly different according Natura 2000 status. Continental region indicate only one case of significance, which is the coverage of stems by *Hedera helix*. This was significantly higher within the Natura 2000. Generally all significant differences between Natura 2000 and non Natura 2000 sites occur within the single biogeographical regions. But we couldn´t detect any difference, which occur consistently across all biogeographical regions.

Table 9. Differences of tree growth and vertical stand structure

Wilcoxon Test	Tree Morphology and vertical structure									
Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05 (ns = not signif.)										
Trend codes: ↑- higher value of Natura 2000, ↓- higher value of nonNATURA 2000										
Diversity parameter	pRef		pTotal		pMed		pAtl		pCont	
	signif.	trend	signif.	trend	signif.	trend	signif.	trend	signif.	trend
tree stem vitality	ns		ns		ns		ns		ns	
forked stems	ns		ns		ns		ns		ns	
uprightness	ns		ns		ns		ns		ns	
twisted growth	***	↑	ns		ns		ns		ns	
branchiness	ns		ns		*	↓	ns		ns	
secondary shoots	*	↑	**	↓	ns		**	↓	ns	
Hedera occurrence	***	↑	ns		ns		ns		*	↑
occurrence of partner stems	*	↓	ns		*	↓	*	↑	ns	
percentage of trees with partner stems	***	↓	ns		ns		**	↑	ns	
regularity of stem cross-section	ns		ns		ns		ns		ns	

Stand level parameters.

The **stand structure** was covered by 14 parameters as can be seen in the Table 10. These parameters have been used to detect differences between Natura 2000 and non Natura 2000 stands and compare these results with the reference site.
We found that 10 of 14 parameters show significant differences on the paired reference site. *Sociability of F. sylvatica seeds* and the *bark defects due to management* were less frequented within the natural old growth forest. All following parameters were higher within the natural forest:

- basal area
- maximum DBH
- average DBH
- forest Development Phases
- minimum tree height within the dominant tree level
- maximum tree height within the dominant tree level
- vegetation coverage of the herbal layer

The Natura 2000 paired sites in total show significant higher frequencies only on 3 following parameters (the frequencies of all 3 were higher inside of Natura 2000):

- basal area
- number of the tree stems over 20 cm DBH
- minimum tree height within the dominant tree level

The Natura 2000 paired sites within the *Mediterranean* biogeographical region show the significant difference only on the coverage by mineral soil, which was higher inside of Natura 2000.
The *Atlantic* biogeographical region indicates the outstanding position also according to the stand structure in comparison with two other biogeographical regions. The 3 following parameters were significant higher within the Natura 2000:

- average DBH
- natural bark damages
- coverage by organic matter

The coverage by vegetation of the herbal layer was significantly higher outside of Natura 2000. That was due to the high frequented occurrence of *Rubus spec.* as well as *Brachypodium spec.* within the non Natura 2000 Atlantic stands.

Continental sites indicate only two cases of significance. The basal area and the minimum tree height within the dominant tree level were significantly higher inside of Natura 2000 within the *Continental* biogeographical region.

We found no significant differences between Natura 2000 and non Natura 2000 according to the used stand parameters, which indicate consistently trends within all biogeographical regions.

Table 10. Test results for stand level parameters

Wlcoxon Test	Stand Structure									
wilcox_test(struct parameter ~ Natura 2000, alternative="two.sided", data=ref,total,med,atl,cont)										
Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05 (ns = not signif.)										
parameter	pRef		pTotal		pMed		pAtl		pCont	
	signif.	trend	signif.	trend	signif.	trend	signif.	trend	signif.	trend
Basal area	***	↑	**	↑	ns		ns		**	↑
number of stems	ns		*	↑	ns		ns		ns	
BHDmax	**	↑	ns		ns		ns		ns	
BHDmean	***	↑	ns		ns		*	↑	ns	
Forest Development Phases	**	↑	ns		ns		ns		ns	
Top Closure	ns		ns		ns		ns		ns	
Sociability of Beech Seedlings	***	↓	ns		ns		ns		ns	
Hmin	***	↑	*	↑	ns		ns		***	↑
Hmax	***	↑	ns		ns		ns		ns	
Bark damages by Nature	ns		ns		ns		*	↑	ns	
Bark damages by Management	***	↓	ns		ns		ns		ns	
Cover by Herb Layer	*	↑	ns		ns		***	↓	ns	
Cover by organic matter	**	↓	ns		ns		***	↑	ns	
Cover by mineral soil	ns		ns		*	↑	ns		ns	

Deadwood.

The **deadwood** represents an important indicator for the natural long term development (Mountford 2002). In Table 11 we provide 8 deadwood parameters, which include the volumes of different categories of deadwood and the volumes of the different decomposition classes.

6 of 8 following parameters were significantly higher within the natural forest:

- total volume of deadwood
- lying deadwood
- standing deadwood
- deadwood with the decomposition class 2
- deadwood with the decomposition class 3
- deadwood with the decomposition class 4

2 of 8 following parameters were significantly higher inside of Natura 2000 stands on all paired sites in total:

- lying deadwood
- volume of the deadwood with the decomposition class 1 (fresh deadwood)

Only *fresh deadwood volume* was significantly higher inside of Natura 2000 stands within the *Mediterranean* biogeographical region. The Continental biogeographical region shows no differences between Natura 2000 and non Natura 2000 regarding the deadwood.

At the same time the Atlantic biogeographical region shows the significant differences on 5 deadwood parameters. The volume of stumps is significantly higher outside of Natura 2000. The volume of the 4 following parameters is higher within the Natura 2000:

- lying deadwood
- standing deadwood
- deadwood with the decomposition class 2
- deadwood with the decomposition class 3

Consistently trends of differences regarding deadwood wasn't detected.

Table 11. Test results for the deadwood parameters

Wilcoxon Test	Deadwood									
parameter	pRef		pTotal		pMed		pAtl		pCont	
	signif.	trend	signif.	trend	signif.	trend	signif.	trend	signif.	trend
Total deadwood volume	**	↑	ns		ns		ns		ns	
lying deadwood	***	↑	**	↑	ns		***	↑	ns	
sanding deadwood	*	↑	ns		ns		***	↑	ns	
stumps	ns		ns		ns		**	↓	ns	
decomposition class 1	ns		*	↑	**	↑	ns		ns	
decomposition class 2	**	↑	ns		ns		*	↑	ns	
decomposition class 3	*	↑	ns		ns		**	↑	ns	
decomposition class 4	*	↑	ns		ns		ns		ns	

Supplementary tests of commonly used structural indicators.

On this point we´d like to take a look on **some details and additional information** around assessments of the structural conditions of the European beech forests. Some of used structural parameters like top closure or forest development phases are known as important indicators for forest conditions (Mountford 1997; Michel & Winter 2009; McRoberts et al. 2008; Ihók et al. 2007; Müller 2005).

Forest development phases:

One of the commonly used indicators for the natural processes is the heterogeneity of forest development phases (Burrascano et al. 2008).
We detected the following phases within the research plots:

1- regeneration
2- early growth
3- middle growth
4- late growth
5- culmination
6- disintegration

The difference of the forest development phases within the reference site was statistically highly significant according to the used tests. Middle and late growth as well as culmination phase was detected within the natural stand (Figure 15). The most common phase was the culmination phase. The unmanaged stand of the reference site indicated only 2 development phases, early and middle growth. The middle growth phase has been found most frequently within the managed stand.

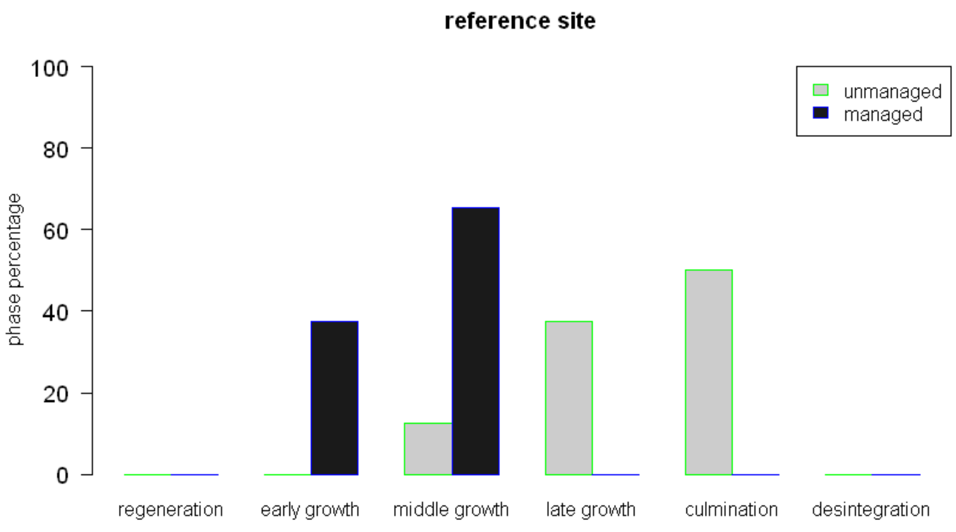

Figure 15. Forest development phases within the reference site

Figure 16 shows the percentage of the phases within the Natura 2000 and non Natura 2000 stands. Natura 2000 stands in total show no significant difference, in comparison with the non Natura 2000 stands, regarding the used statistical tests (Table 10). Disintegration phase was found only within the non Natura 2000 plots. Due to this fact non Natura 2000 stands indicate even slightly higher variance of the phases than Natura 2000.

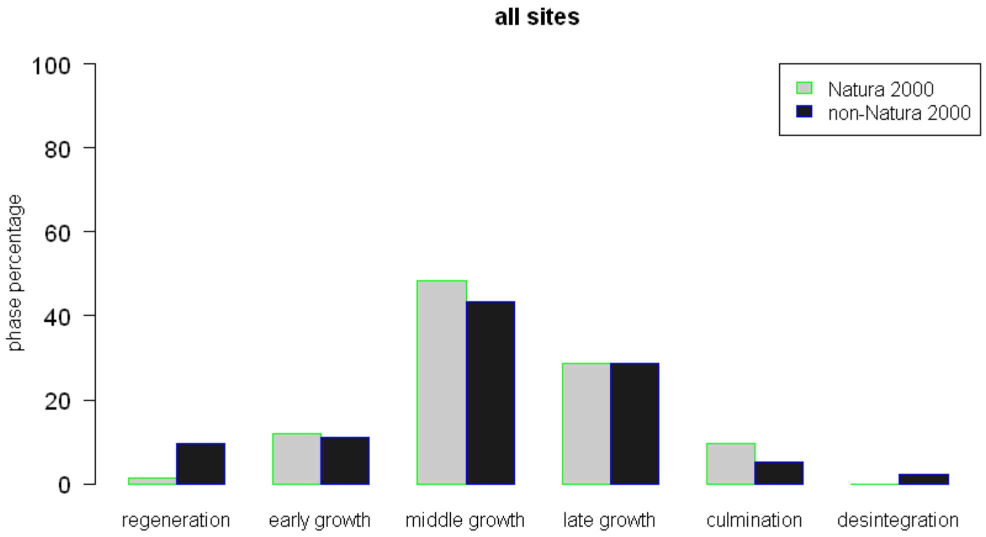

Figure 16. Frequencies of the forest development phases (all regular sites)

The variability of the forest development phases is similar within each biogeographical region. The used statistical tests indicated no significant difference of the phase's variability regarding the Natura 2000 status (see Table 10). We found that the middle growth phase is the most frequent forest development phase within all biogeographical regions independent of the Natura 2000 status (Figure 17). Nevertheless we found some differences according to the biogeographical locations:

Atlantic Biogeographical region: we didn´t detect the early growth phase outside of Natura 2000 sites as well as disintegration phase inside of Natura 2000. The late growth was here significantly higher outside of Atlantic Natura 2000 stands but the culmination phase was significantly higher frequented within the Atlantic Natura 2000 stands.

Mediterranean biogeographical region: we detected 4 development phases within the Mediterranean region (early, middle, late growth and culmination phase). The frequency of early and late growth was higher within the Natura 2000 stands. Middle growth and culmination phases were more frequent within the non Natura 2000 stands.

Continental biogeographical region: It shows a slight difference between Natura 2000 and non Natura 2000, mainly because of windthrow. The windthrow damages occur mainly within the non Natura 2000 sites. Due to this fact and the regular logging within the non Natura 2000 stands we detected a high percentage of the regeneration phases within the Continental region, which counts 27.5%. On this way we have a larger variation spectrum outside of Natura 2000, which encompass all development phases between regeneration and culmination phases. Inside of Natura 2000 we detected only 3 development phases, which are middle, late growth and culmination phases (Figure 17).

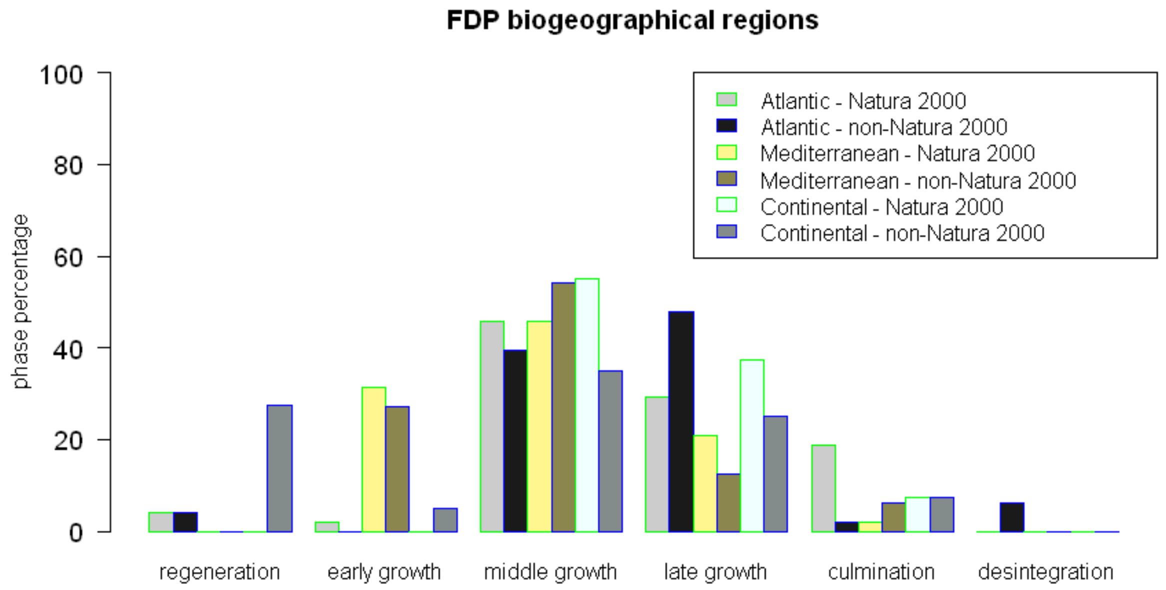

Figure 17. Forest development phases within each biogeographical region according to the Natura 2000 status

Canopy closure.

Another important aspect for the forest conditions is <u>the top closure</u>. We didn´t find any significant differences of the top closure between Natura 2000 and non Natura 2000 stands (see Table 10). Nevertheless, the general trend indicated slightly higher average percentage of top closure within the Natura 2000 stand (Figure 18).

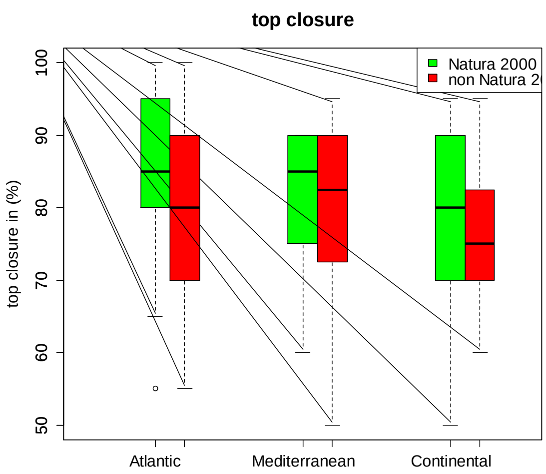

Figure 18. Average percentage of top closure within each biogeographical region

Detailed results of tests on microhabitat groups and stem conditions.

Bark defects.

Frequencies of the unnatural bark defects (bark defects due to management) were often used as the indicator of management pressure (Mountford 1997; Gurnell 1996). As has been pointed out in chapter 2.1.1 Forest management and naturalness of the forest ecosystems), we expected a close correlation between some kind of management activity and the frequencies of the mechanical bark defects. Indeed the reference site confirms our expectations by indicating extremely low frequency of such defects within the unmanaged forest (Figure 19, left diagram). The managed stand (reference site) shows abundance on the 20 up to 50 % of the trees, which is quite close to the regular results of Natura 2000 sites. The p-value of the difference between managed and unmanaged stand of the reference site was close to 0.0005 (Figure 19), which is much more significant than the difference between Natura 2000 and non Natura 2000 stands at this moment. All Natura 2000 stands together have no significant difference in comparison with the non Natura 2000 sites (Figure 19, right diagram). However the average of the frequency was slightly lower on the Natura 2000 in total (Figure 19, right diagram).

Even the situation within the single biogeographical regions doesn't show any significant differences between Natura 2000 and non Natura 2000 regarding this parameter (Figure 20). In general, the Continental biogeographical region indicated the lowest amount of this kind of bark damages compared with Atlantic and Mediterranean biogeographical regions. Also the percentage of plots without bark defects as well as single funds was higher within the Continental biogeographical region. Mediterranean sites have the highest total amount of damages compared with other biogeographical regions. Also the percentage of plots, classified as "*frequently*" and "*highly frequented*" (Table 4), was higher within the Mediterranean biogeographic region than in others. The conditions according to bark damages within the Atlantic biogeographical region seem to be closer to Continental than to Mediterranean biogeographical region. Evaluation plots with "*massive*" damage frequencies (clearly more than 60% of trees) wasn´t detected anywhere within used forest stands. As have been shown on Figure 20, main part of Atlantic and Mediterranean evaluation plots have 10% to 30% of trees with significant amount of such bark damages, which is defined as "frequently" (Table 4). The amount of Natura 2000 plots with the class "frequently" is slightly lower compared to non Natura 2000 within the both biogeographical regions. The main part of continental plots indicates 1% to 10% of evaluated trees with the damages, which was defined as "*single funds*". Thereby 62.5% of the continental Natura 2000 plots and 55% of the non Natura 2000 plots were classified as "*single funds*", which is significantly higher than inside of other biogeographical regions. The leader of the bark defects due to management is Mediterranean biogeographical region.

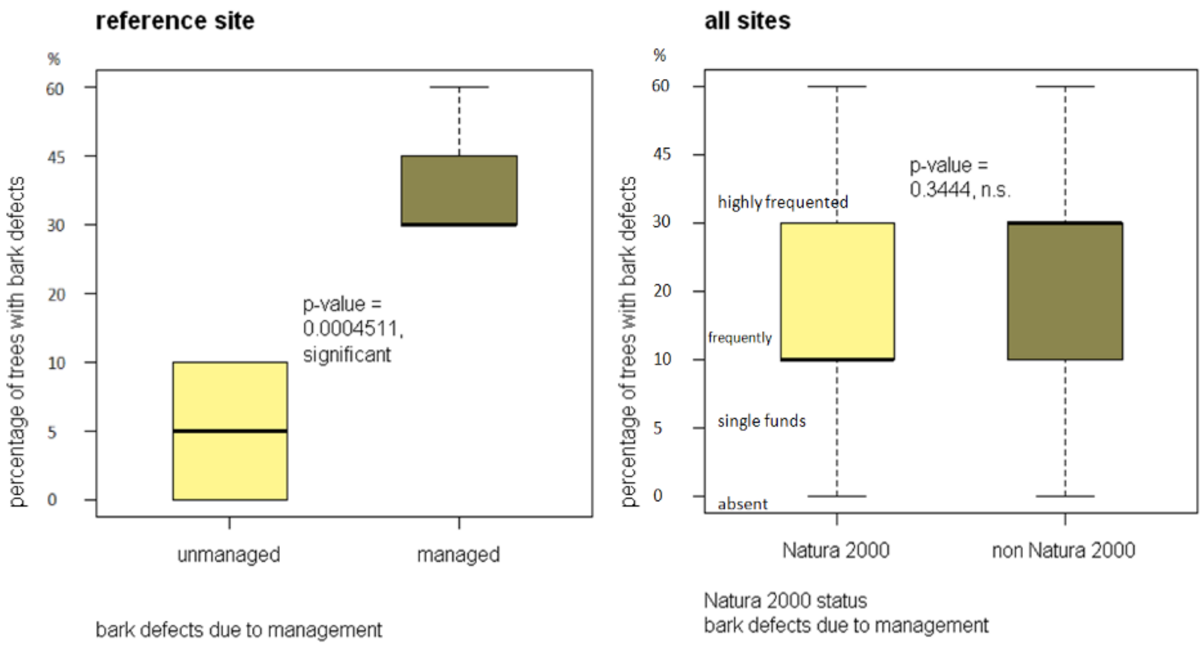

Figure 19. Percentage of trees with bark defects due to management (reference site, Natura 2000 paired sites in total)

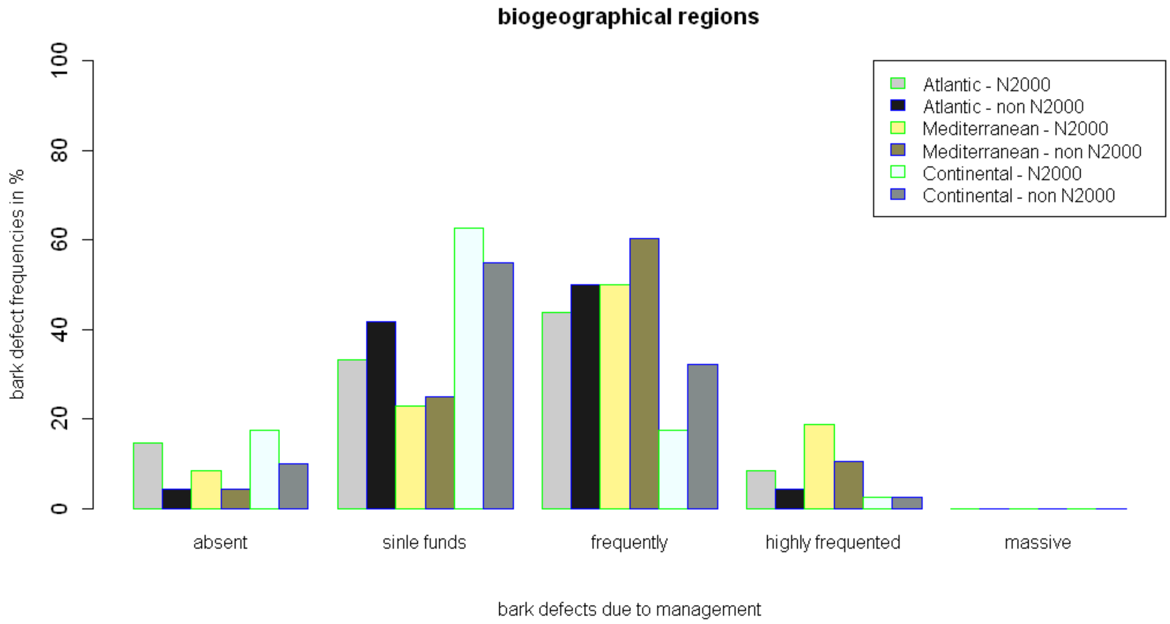

Figure 20. Unnatural bark defects within the biogeographical regions

Microhabitat frequency.

To assess total microhabitat frequencies in terms of ecological indication it may be not enough to make a comparison of the total microhabitat frequencies (Hanson et al. 2012). Following results show the detected total microhabitat frequency as well as the single groups of microhabitats. Figure 21 shows, that the total frequency of the microhabitats within the unmanaged stand was significantly higher than within the managed stand. On the other side the total microhabitat frequency within the Natura 2000 and non Natura 2000 areas wasn´t significantly different (Table 19, right diagram).

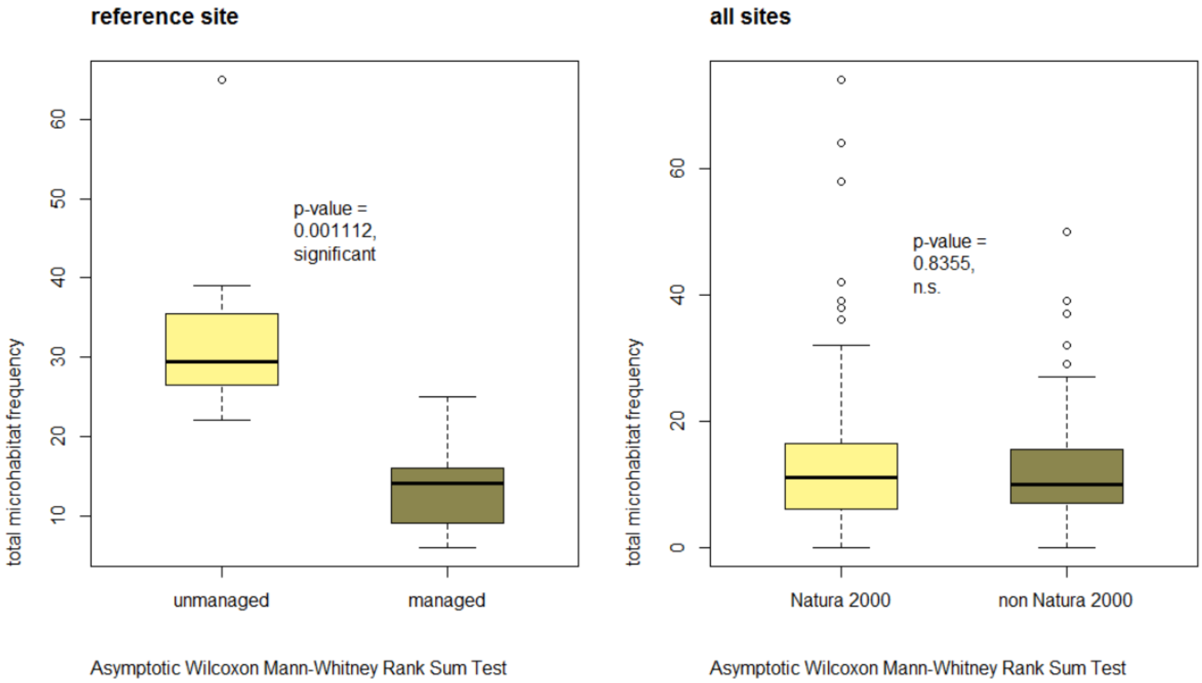

Figure 21. Total microhabitat frequency (Ref. site and all Natura 2000sites)

Closed microhabitats have the broadest connection to the beech forest natural fauna (Figure 5). We found highly significant differences of these kinds of microhabitats between the stands of the reference site. The frequency of these microhabitats was much higher within the unmanaged stand than the managed (Reference site Figure 22). On the other hand the frequency within the Natura 2000 sites was slightly higher than non Natura 2000. Nevertheless, the test results of all sites together give no significant difference regarding the Natura 2000 status. Also the situation within the Continental and the Mediterranean biogeographical region indicate similar test results. In contrast to this, the Atlantic biogeographical region indicates significant difference between Natura 2000 and non Natura 2000 regarding closed microhabitats. Especially the sites, which have been under protection for longer time period and still be now as a Natura 2000 stands, indicate significant higher closed microhabitat frequency in comparison with regular used stands. As a consequence, the frequency of closed microhabitats was significantly higher only within the Atlantic Natura 2000 stands compared to non Natura 2000.

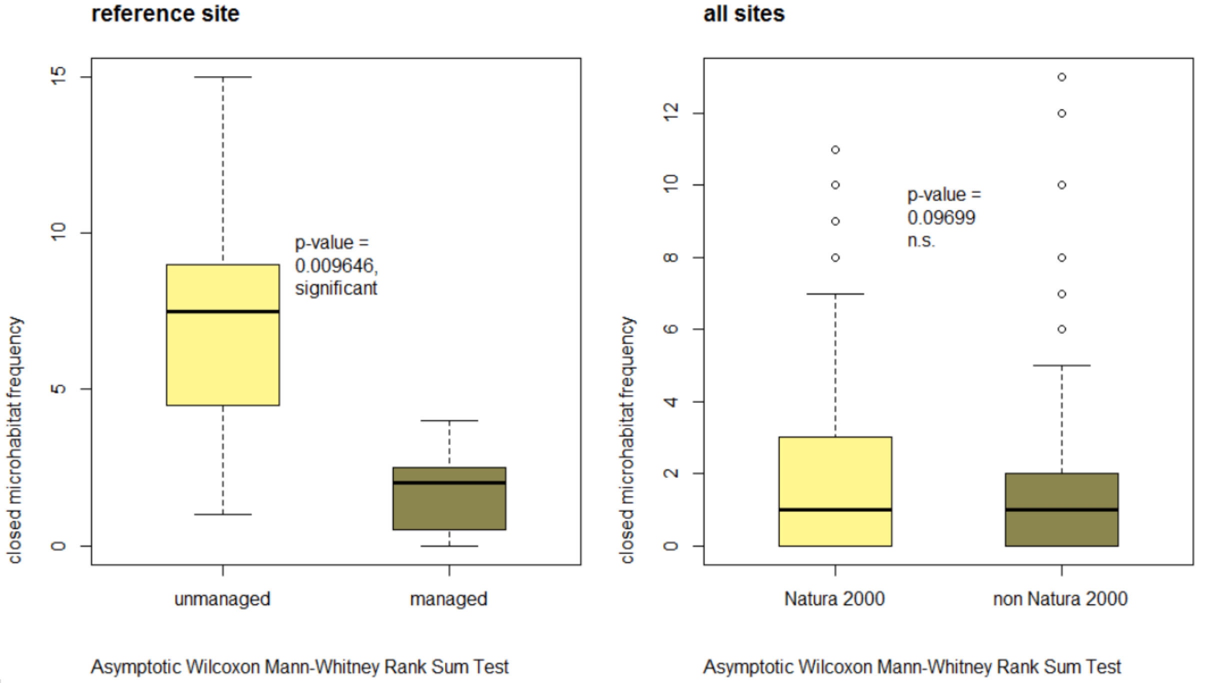

Figure 22. Closed microhabitats (Ref. site and Natura 2000 in total)

We also didn´t find some significant differences on the open microhabitats within the reference site as well as within the Natura 2000 stands. In both cases the frequency was slightly higher inside of the protected area (Figure 23). We couldn´t detect any significance according to open microhabitats even within each biogeographical region.

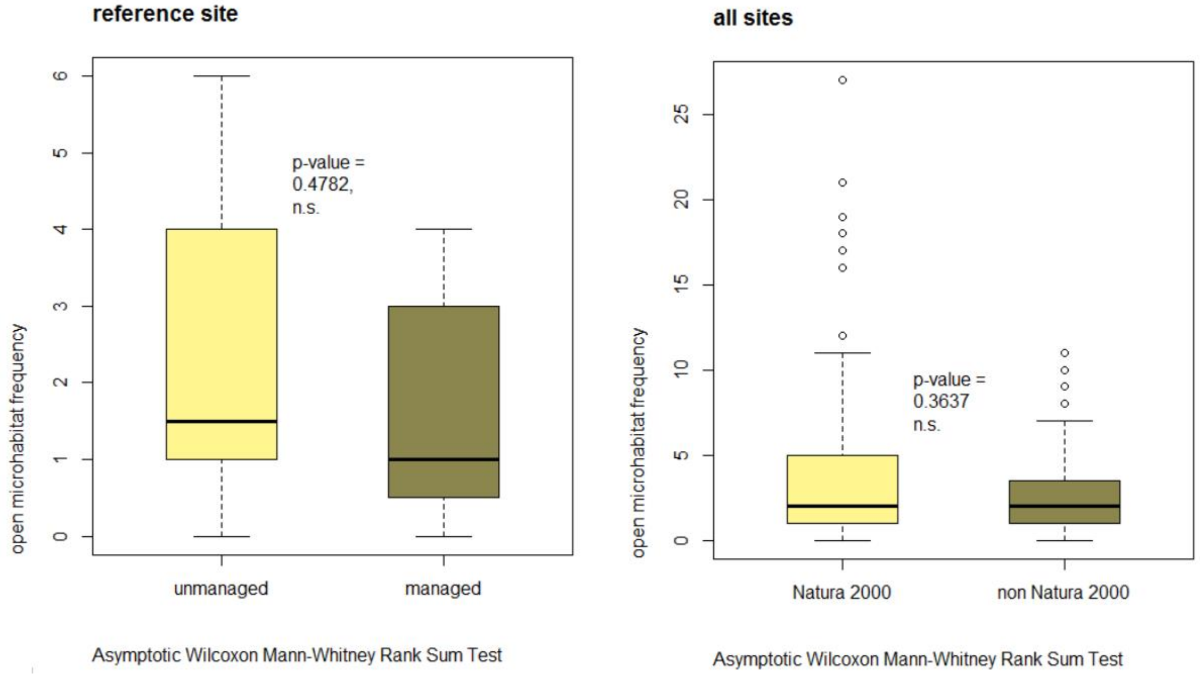

Figure 23. Open microhabitats, (Ref. site and Natura 2000 in total)

The crown breakage was higher within the unmanaged stand than managed stand. On the Natura 2000 sites the frequency of the crown breakages was slightly lower, but the difference was not significant (Figure 24).

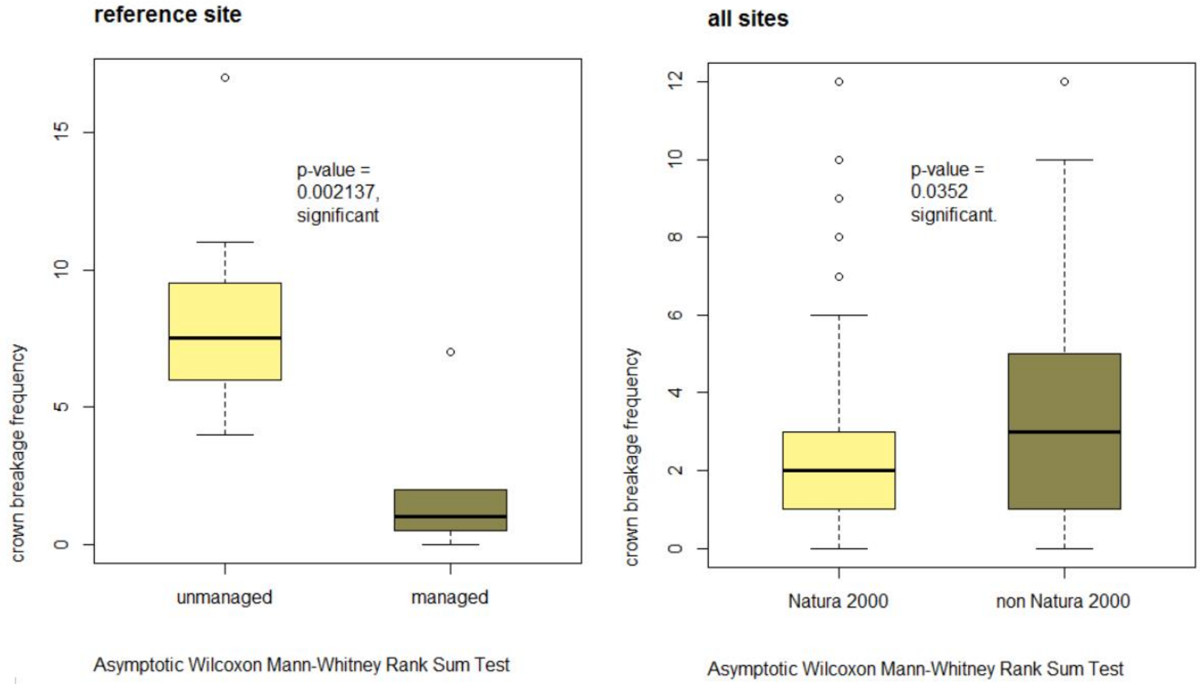

Figure 24. Crown breakage, (Ref. site and Natura 2000 in total)

Also the dead branches were more frequent within the unmanaged stand. At the same time the Natura 2000 paired sites show no significant difference (Figure 25).

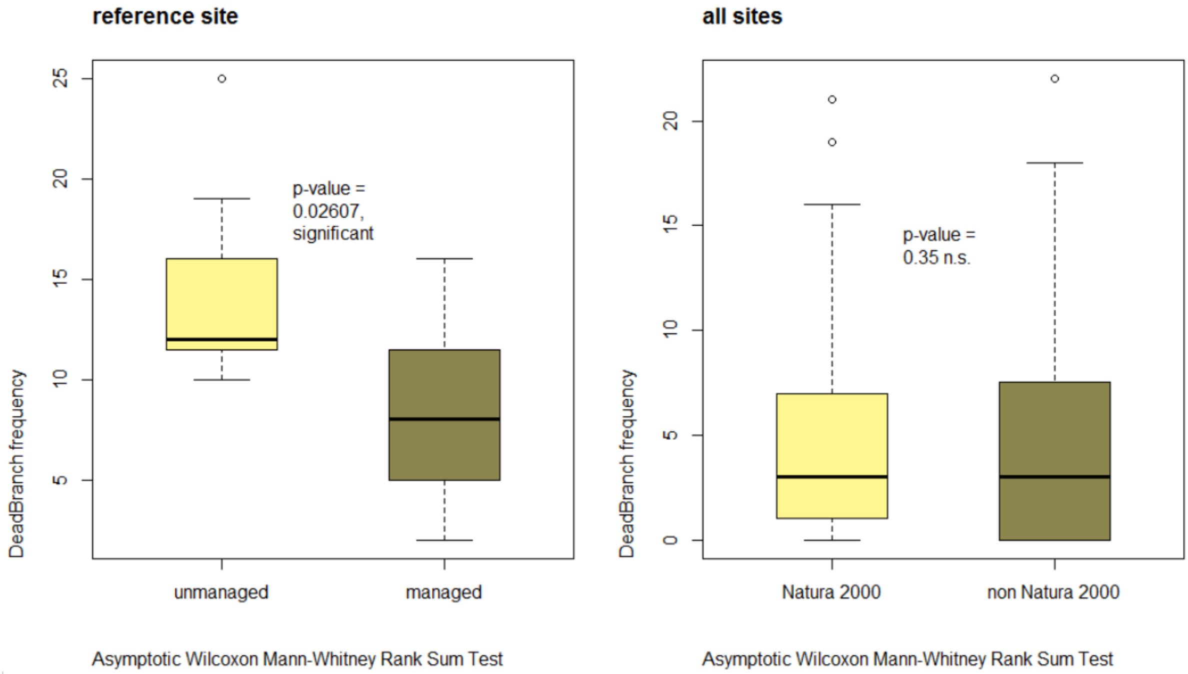

Figure 25. Dead branches, (Ref. site and Natura 2000 in total)

The bizarre growth was very seldom observed inside of the evaluation plots. Most of such observations were located within the Atlantic biogeographical region and eastern Austria. However we found no significant differences neither within the reference site nor regular study sites (Figure 26).

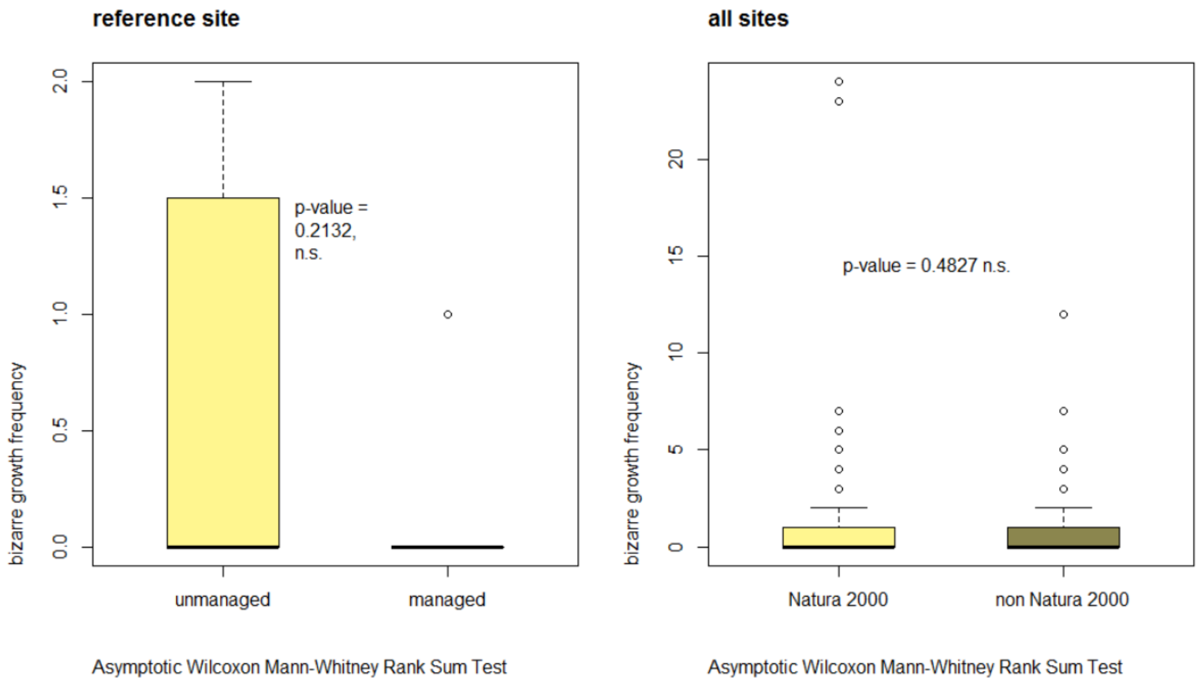

Figure 26. Bizarre growth, (Ref. site and Natura 2000 in total)

2.5.3 Effects of Natura 2000 on the microhabitats as ecological indicators

Different groups of microhabitats show different behavior of frequencies due to many external factors (chap. 2.5.2). We found that only closed microhabitats and dead branches reacting consistently on different management strategy within the used forest stands. Especially closed microhabitats indicated significant increase inside of the stands with longer protection history. This fact could be explained by the longer time period needed for natural genesis of the closed microhabitats. The frequency of other groups, within the used study sites, seems to be influenced by many external factors like climate, environmental events, landscape features etc.
To analyze the possible effects of Natura 2000 on the microhabitat frequency we applied bivariate and multivariate generalized linear models.
For the multivariate analysis we used several models, based on following blocks of parameters described under Statistical analyses:

1. Stand structure
2. Tree morphology and individual tree characteristics structure
3. Deadwood parameters

To see the general effect of Natura 2000 on the microhabitats we used the bivariate GLM described under Statistical analyses. To graphical presentation of detected effect we used the effect plot method from the R-package effects. Detailed results of modeled multivariate effects on all groups of microhabitats can be seen in Annex 2 to 7.

The bivariate model represents the most robust and general effects of Natura 2000 on microhabitat frequency. These effects were modeled based on recorded microhabitat frequencies only, without any additional impact factors. The bivariate effect of Natura 2000 indicates a general positive trend on the total microhabitat frequency (Figure 27). The effect is increasing into Natura 2000 direction (Figure 27). But the Natura 2000 effect was not significant inside of both the Mediterranean and the Continental biogeographical region (Figure 28). Only within the Atlantic biogeographical region the effect was highly significant (Figure 28).

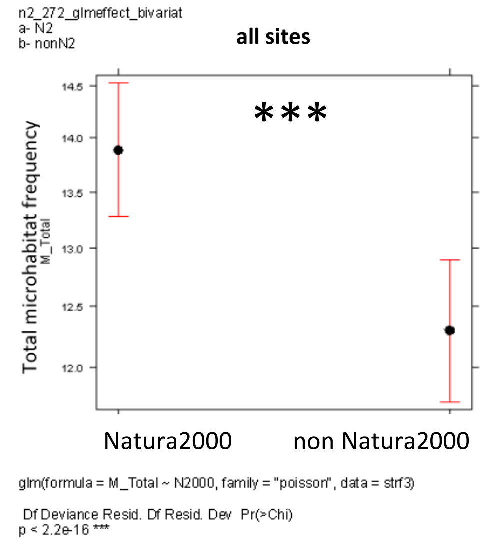

Figure 27. Total microhabitat frequency, bivariate Natura 2000 effect (all sites in total)

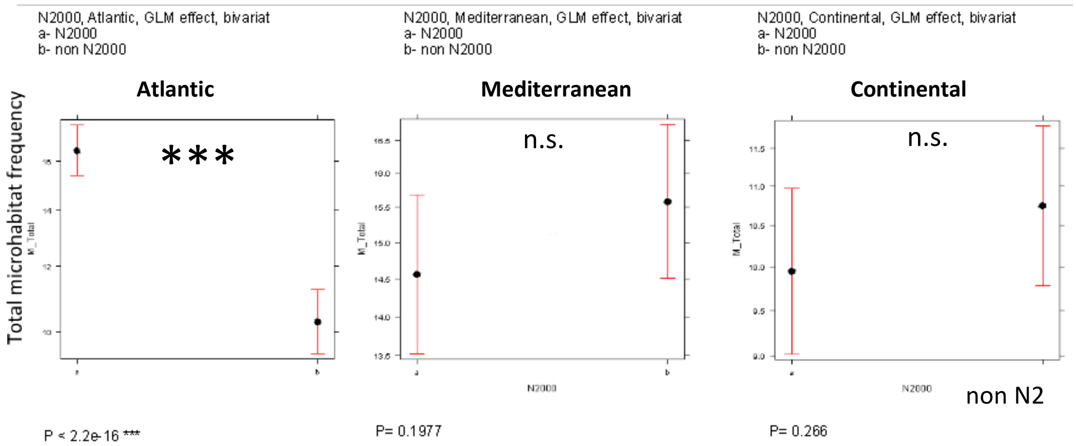

Figure 28. Total microhabitat frequency, bivariate Natura 2000 effect (single biogeographical region)

The similar situation like with total microhabitat frequency was detected on the closed microhabitat frequencies. The Natura 2000 effect on the frequency of the closed microhabitats was significant within all study sites together (Figure 29). But by applying the model on single biogeographical regions we detected a significant effect inside of the Atlantic biogeographical region only (Figure 30). The used GLM indicated no significance within the Mediterranean and Continental biogeographical regions (Figure 30).

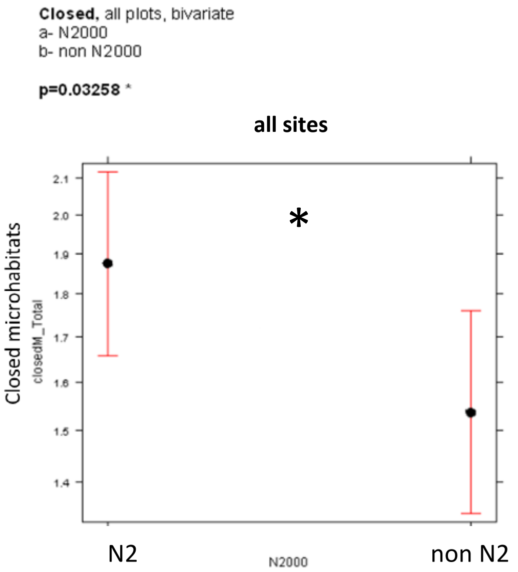

Figure 29. Closed microhabitats, bivariate Natura 2000 effect (all plots)

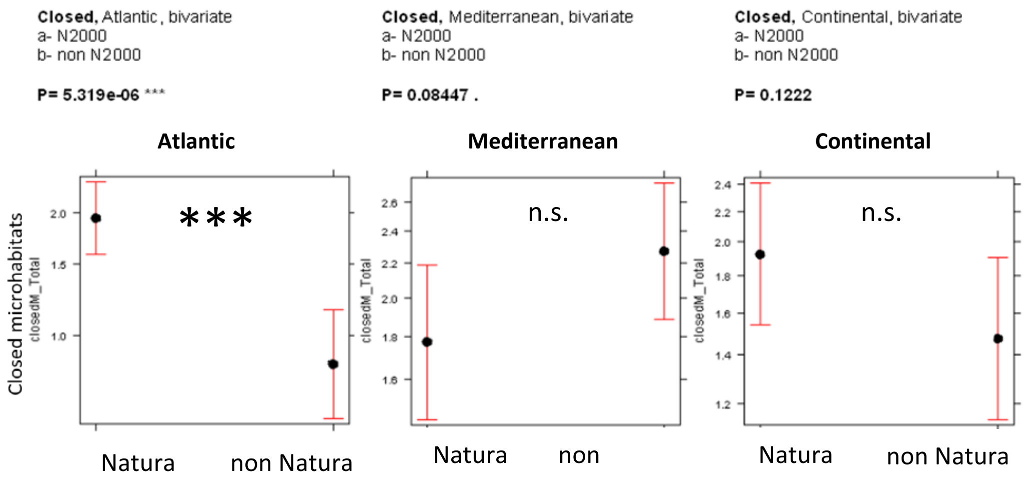

Figure 30. Closed microhabitats, bivariate Natura 2000 effect (each biogeographical region)

Contrary to the bivariate GLM results, the **multivariate effect of Natura 2000** is modeled in connection with three sections of additional impact factors (stand structure, tree growth and vertical structure, deadwood).

In connetion with **stand structure** the effect of Natura 2000 is only slightly significant on the total microhabitat frequency within the Continental and Mediterranean biogeographical region (see ANNEX 1, Figure 57). But Atlantic sites as well as all sites in total didn´t detect any significant effects in this context (see ANNEX1, Figure 57).

We detected a high significant Natura 2000 effect on closed microhabitats within the Medeterranean biogeoraphical region only. All other biogeographical regions as well as Natura 2000 sites in total didn´t show tangable Natura 2000 effect accoding to stand parameters (see ANNEX 1, Figure 58).

In connection with the **tree growth and the vertical structure** the modeled Natura 2000 effect is significant on the total microhabitat frequency, applied on all study sites together. But the single biogeographical regions don't have any tangible Natura 2000 effects in connection with the tree growth parameters (see ANNEX 1, Figure 59). The effect of Natura 2000 in connection with tree growth and vertical structure on closed microhabitat frequencies is significant in total but only because of the strong positive effect of Natura 2000 within the Continental biogeographic region (see attachment 1, Figure 60).

The GLM results of the **deadwood** section are very close to the results of the bivariate GLM (2.5.3.1) regarding total microhabitat frequency.We detected a significant effect on all sites in total. The effect within the Atlantic region is highly significant. But neither Mediterranean nor Continental biogeographical region indicate any significant GLM effects according to the deadwood (see ANNEX 1, Figure 61). The modeled effect of Natura 2000 combined with deadwood on closed microhabitats is similar to the results of the total microhabitat frequency. The modeled Natura 2000 effect is significant, calculated for all sites together. But if we take a look to the single biogeographical region – only the Atlantic region shows a significant effect (see ANNEX 1, Figure 62).

2.5.4 Spatial visualization of microhabitat frequencies with help of ordination routine.

2.5.4.1 Ordination results of the reference site (managed-unmanaged) regarding microhabitat frequencies.

We used this example to prove how reliable microhabitats as indicators really are. The presented ordination map of the reference site shows a clear differentiation between regular managed forest and long term unmanaged forest, which can be seen by plotted polygon areas of each stand (Figure 31).

The final length of gradient of the used data was 1.615; the chosen ordination method therefor is the principal component analysis (PCA). The location of stands within the reference site shows clear different concentration areas. Only 12.5% of the unmanaged plots are located inside of the intersection area with the regular managed plots. All microhabitat vectors are increasing into the direction of the unmanaged stand. Basal area and deadwood volume are significantly increasing into the direction of the unmanaged stand as well. "*Sociability of the F. sylvatica seeds"* and the "*bark defects due to management*" (see chapt..2.4.3 Stand structure) are significantly increasing into direction of the regular managed stand (Figure 31).

The significance range was calculated regarding Sachs (1992) as following:

$$\frac{1}{\sqrt{n}}$$

n- number of observations

According to this calculation all vectors which indicate R>0.250 are statistically significant (Table 12). The vectors of bizarre growth, crown breakage, dead branches, and closed microhabitats are more correlated with the axis one. Crown breakages, closed microhabitats and dead branches have the highest r-values on axis one.

Fungal trees and open microhabitats are mostly correlated with the axis 2. Further information to the plotted vectors provided by Table 12.

That means that we have two almost completely separated areas of managed and unmanaged stands with all groups of microhabitats indicating clear increasing into direction of unmanaged forest.

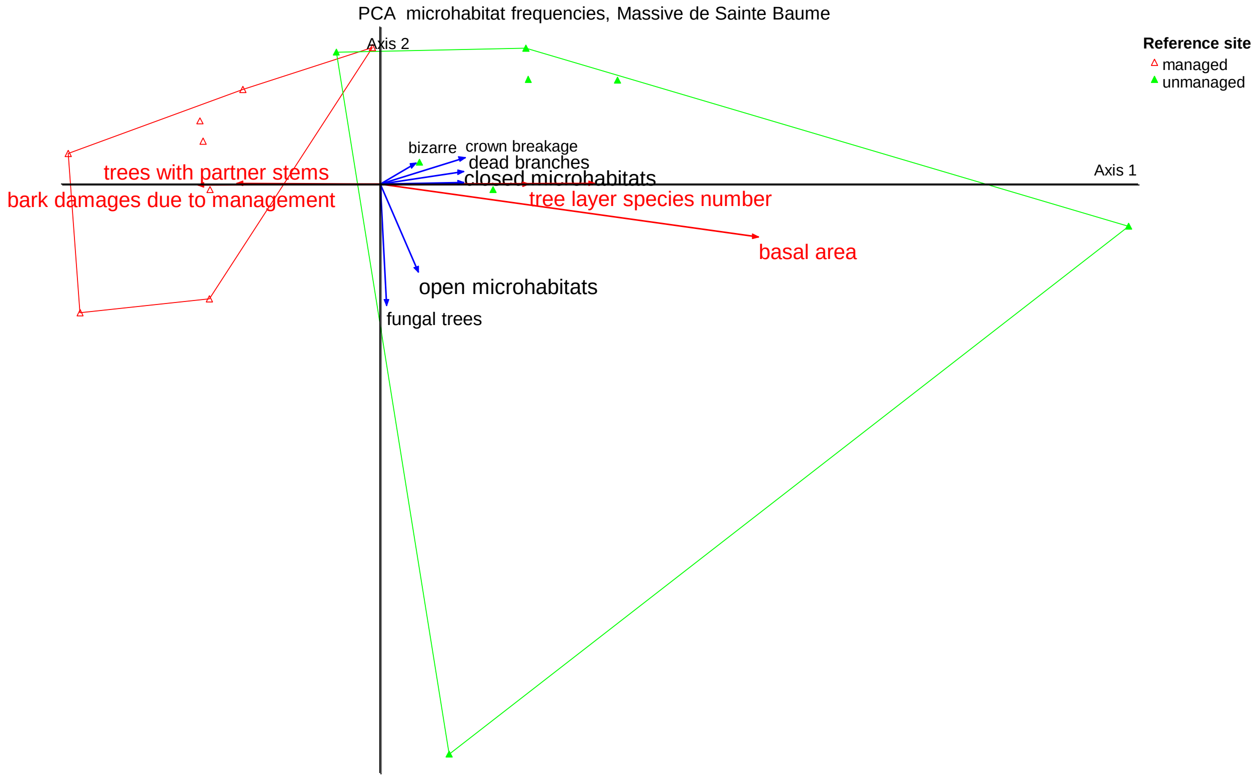

Figure 31. Ordination result for the reference site according to frequencies of the microhabitats

Table 12. Vector data for PCA of the reference site

		Axis 1		Axis 2	
parameter	**matrix**	**R1**	**tau1**	**R2**	**tau2**
closed microhabitats	main	0,901	0,678	-0,012	0,198
open microhabitats	main	0,413	0,103	-0,636	-0,74
dead branches	main	0,894	0,725	0,09	0,121
crown breakage	main	0,917	0,65	0,191	0,286
bizarre growth	main	0,388	0,253	0,152	0,051
fungal trees	main	0,071	0,118	-0,878	-0,354
top closure	second	0,04	-0,055	0,191	-0,219
bark damages due to management	second	-0,586	-0,571	-0,038	-0,133
tree layer species number	second	0,529	0,387	-0,012	0,009
trees with partner stems	second	-0,519	-0,455	0,042	-0,198
basal area	second	0,845	0,683	-0,318	-0,067

2.5.4.2 Ordination results of Natura2000 and non Natura2000 regarding microhabitat frequencies.

As mentioned in chapt.. 2.5.2, significant trends may occur due to the situation within one of the represented biogeographical regions. Ordination results of Natura 2000 and non Natura 2000 stands regarding the microhabitats indicate slightly different trends within each biogeographical region. But in contrast to the reference site no clear differentiation trends between Natura 2000 and non Natura 2000 stands could be detected.

The ordination of **all sites together** shows an almost completely overlapped area of Natura 2000 with non Natura 2000. In contrast to the reference site we find that the plotted area of non Natura 2000 is slightly bigger than Natura 2000. The ordination shows evenly scattered plots without clear statistically differentiation trends.
The collected frequencies of microhabitats detect the final length of gradient by 2.491 in total; therefore we used detrended correspondence analysis (DCA). As a result, we have got the ordination map with 4 vectors of parameters on it, projected from the second matrix. All these vectors (top closure, basal area, number of stems >20cm DBH, percentage of trees with partner stems) indicate increasing trends into the direction of closed microhabitats. Nevertheless, the ordination of Natura 2000 sites in total didn't show any significant difference between Natura 2000 and non Natura 2000 stands. The plot locations of both Natura 2000 and non Natura 2000 have been evenly distributed. Only 8.82% of non Natura 2000 plots and 2.22% of Natura 2000 plots were outside of the overlapping area (Figure 32).
Regarding to Sachs (1992) vectors with r>0.06 are significant (Table 13). For example top closure has a vector of r2 = 0.302 on the axis 2 and indicate a positive correlation trend with closed microhabitats as well as negative correlation with crown breakage, which is consequently. But also the structural parameters like basal area and number of stems seem to indicate a similar trend.

Only dead branches (r1 = -0.515) and open microhabitats (r1 = 0.531) are higher correlated to the axis 1 than the other groups of microhabitats. At the same time they are negative correlated to each other. All other groups of microhabitats are higher correlated to the axis 2 (Figure 32). That means no differentiation between Natura 2000 and non Natura 2000 is possible. As a consequence – no trends regarding Natura 2000 status can be indicated by using all study sites together.

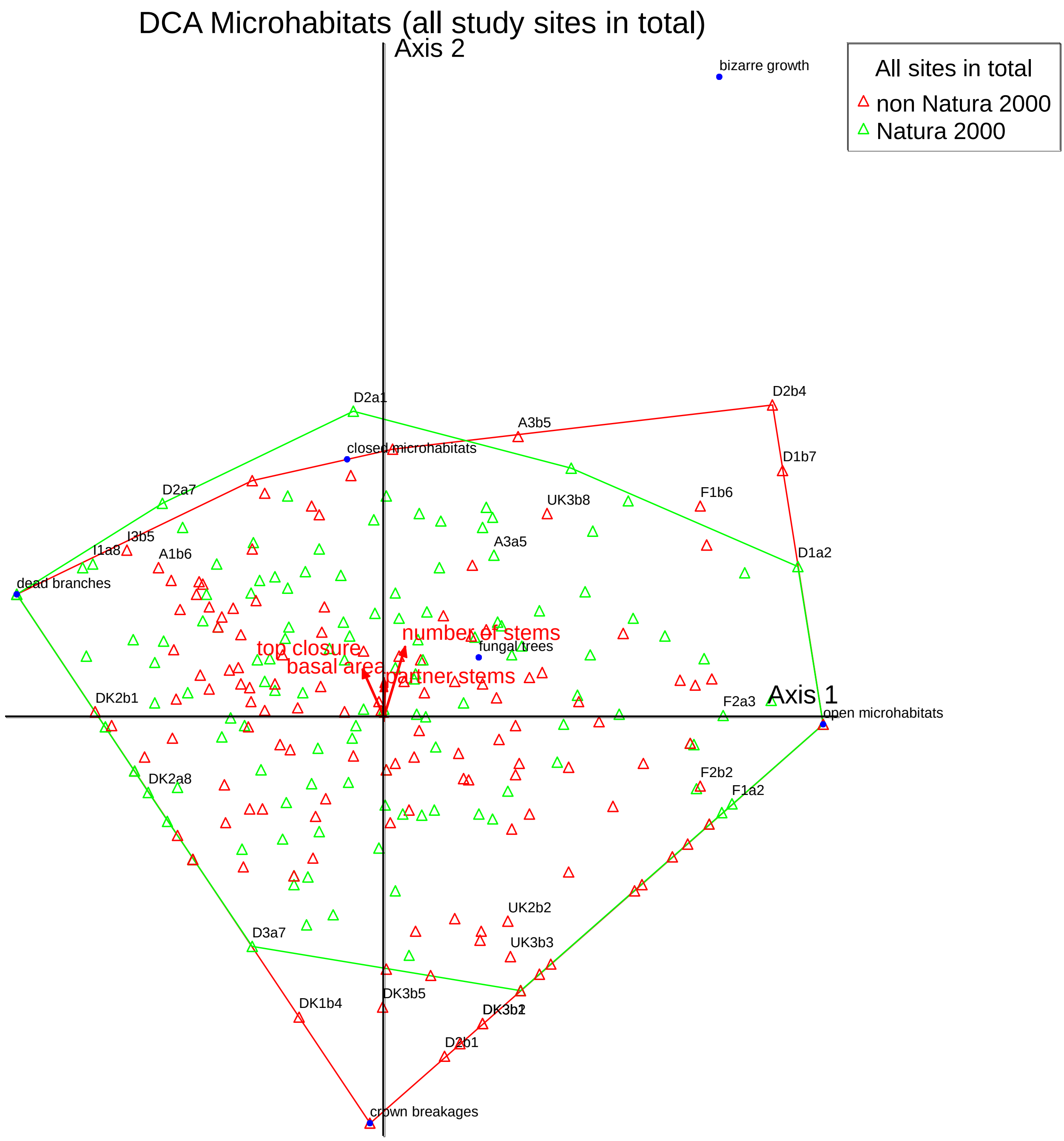

Figure 32. DCA ordination of all study sites in total regarding microhabitat frequencies

Table 13. DCA vectors of parameters for all sites

significance Range	0,061	Axis 1		Axis 2	
parameter	**matrix**	**R1**	**tau1**	**R2**	**tau2**
closed microhabitats	main	0,531	0,505	0,171	0,113
open microhabitats	main	-0,074	-0,024	0,394	0,37
dead branches	main	-0,518	-0,456	0,361	0,287
crown breakage	main	-0,05	-0,015	-0,47	-0,429
bizarre growth	main	0,184	0,166	0,388	0,427
fungal trees	main	0,04	0,04	0,091	0,021
top closure	second	-0,2	-0,116	0,302	0,236
sociability of beech seeds	second	0,1	0,67	-0,234	-0,177
maximum tree height	second	-0,167	-0,11	-0,025	-0,009
bark damages due to management	second	0,043	0,041	0,148	0,1
basal area	second	-0,02	-0,001	0,275	0,181
maximum DBH	second	-0,112	-0,09	0,006	0,006
number of tree stems	second	0,201	0,107	0,366	0,263
trees with partner stems (%)	second	0,037	0,002	0,26	0,192
tree layer species number	second	0,007	0,037	0,197	0,123

The used data for the **Atlantic biogeographical region** have the final length of the gradient of 2.155. The used method was the detrended correspondence analysis (DCA). The variation of Natura 2000 and non Natura 2000 plots shows a lightweight differentiation trend, but this trend still is statistically not significant. 8.32% of Natura 2000 and 52% of non Natura 2000 plots located outside of overlapping area (Figure 33). We found a slightly differentiation shift mostly on the axis two. But this trend is not clear. Calculated vector values have been listed in the Table 14. Top closure indicates increasing tendency into direction of closed microhabitats and decreasing into direction of the crown breakages. The number of stems and percentages of trees with partner stems are positive correlated to several groups of microhabitats, which are open, closed, bizarre growth and fungal trees. Other remarkable vector from the projected second matrix is the maximal tree height, which indicates a significant negative correlation to open microhabitats.

Open, closed microhabitats, bizarre growth and fungal trees are higher correlated to the axis 1. The open microhabitats have the top r1= 0.629 on the axis 1. The crown breakage and dead branches are higher correlated to the axis 2 and negative correlated to each other on the axis 2. That means we detected a low differentiation between Natura 2000 and non Natura 2000, but it is still not enough to see clear tendency of used microhabitats and structural parameters regarding Natura 2000 status.

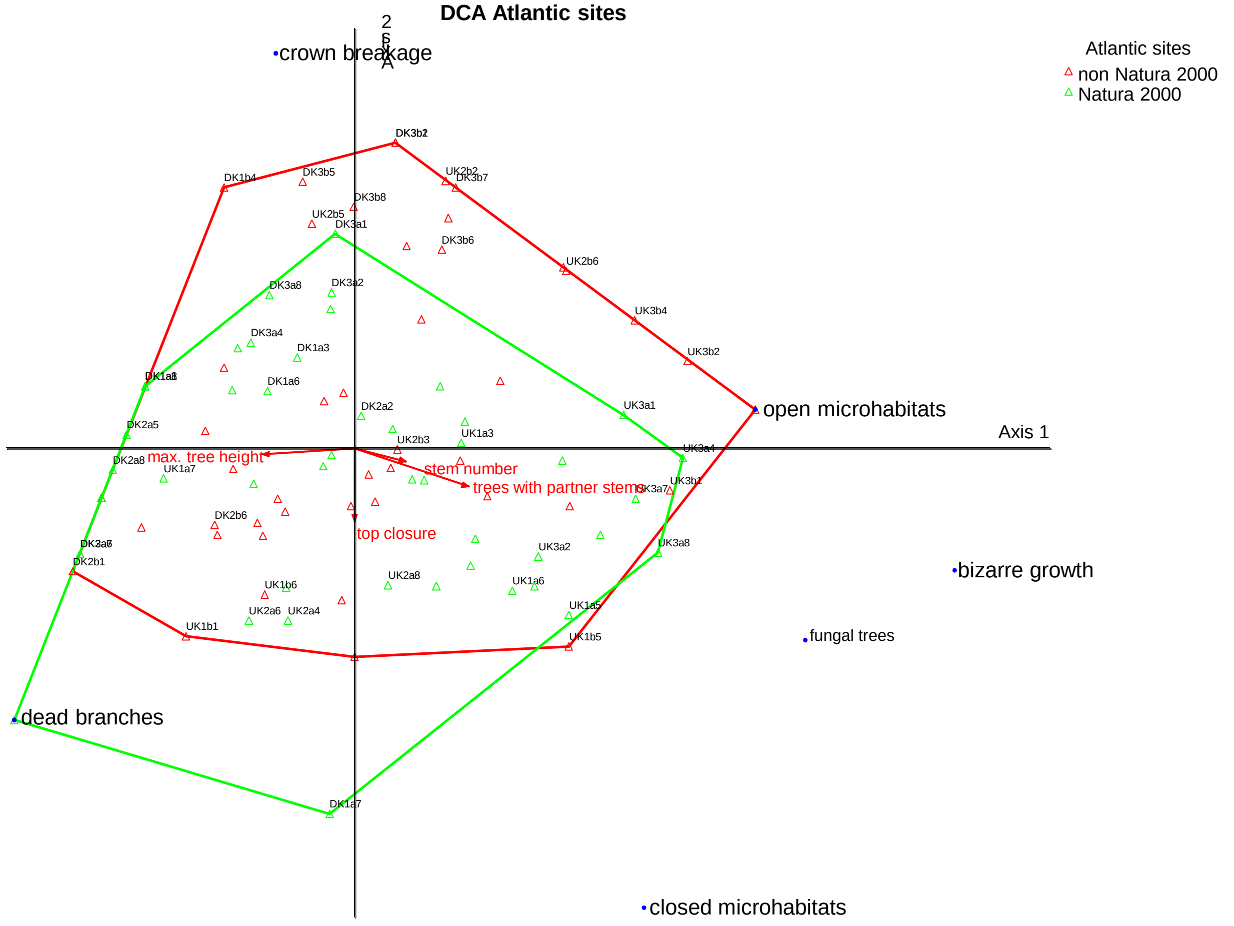

Figure 33. Ordination results for microhabitat groups within the Atlantic biogeographical region

Table 14. DCA vector values for Atlantic biogeographical region

significance range	0,10259784	Axis 1		Axis 2	
parameter	**matrix**	**R1**	**tau1**	**R2**	**tau2**
closed microhabitats	main	0,444	0,346	-0,398	-0,344
open microhabitats	main	0,615	0,619	-0,111	-0,051
dead branches	main	-0,2	-0,203	-0,513	-0,49
crown breakage	main	0,165	0,108	0,45	0,326
bizarre growth	main	0,428	0,366	-0,141	-0,192
fungal trees	main	0,273	0,219	-0,137	-0,125
top closure	second	0	-0,025	-0,395	-0,358
sociability of beech seeds	second	-0,225	-0,218	0,12	0,168
maximum tree height	second	-0,444	-0,303	-0,105	-0,045
bark damages due to management	second	0,251	0,2	0,188	0,138
basal area	second	0,137	0,053	-0,306	-0,245
maximum DBH	second	-0,166	-0,125	-0,223	-0,172
number of tree stems	second	0,331	0,139	-0,165	-0,124
trees with partner stems (%)	second	0,494	0,331	0,284	0,298
tree layer species number	second	0,296	0,262	-0,141	-0,105

The used data within the **Mediterranean biogeographical region** show the final length of gradient close to 2. The used method was the detrended correspondence analysis (DCA).

No clear differentiation trends between Natura 2000 and non Natura 2000 were detected. Around 33.28% of Natura 2000 plots and 2.08% of non Natura 2000 plots located outside of overlapping area (Figure 34). The most of Natura 2000 plots, which are not inside of overlapping area, are from the study sites of Massive de Saou (France) and Montagne de Lure (France) as well as the north side of the Mount Etna. The projected vectors have been listed in the Table 15. Here we found no significant vectors, which could have a correlation with closed microhabitats. Nevertheless, the number of stems indicates an increasing trend into direction to the bizarre growth and open microhabitats, as well as a negative correlation with dead branches. Two groups of microhabitats have a significant correlation to the axis one, which are dead branches and open microhabitats (Table 15). The crown breakages were evenly correlated to the both axes. The closed microhabitats were more significantly correlated to the axis 2. The bizarre growth and fungal trees didn´t have a significant correlation to axes one as well as two. We summarize no differentiation regarding Natura 2000 status within the Mediterranean biogeographic region.

DCA Mediterranean sites

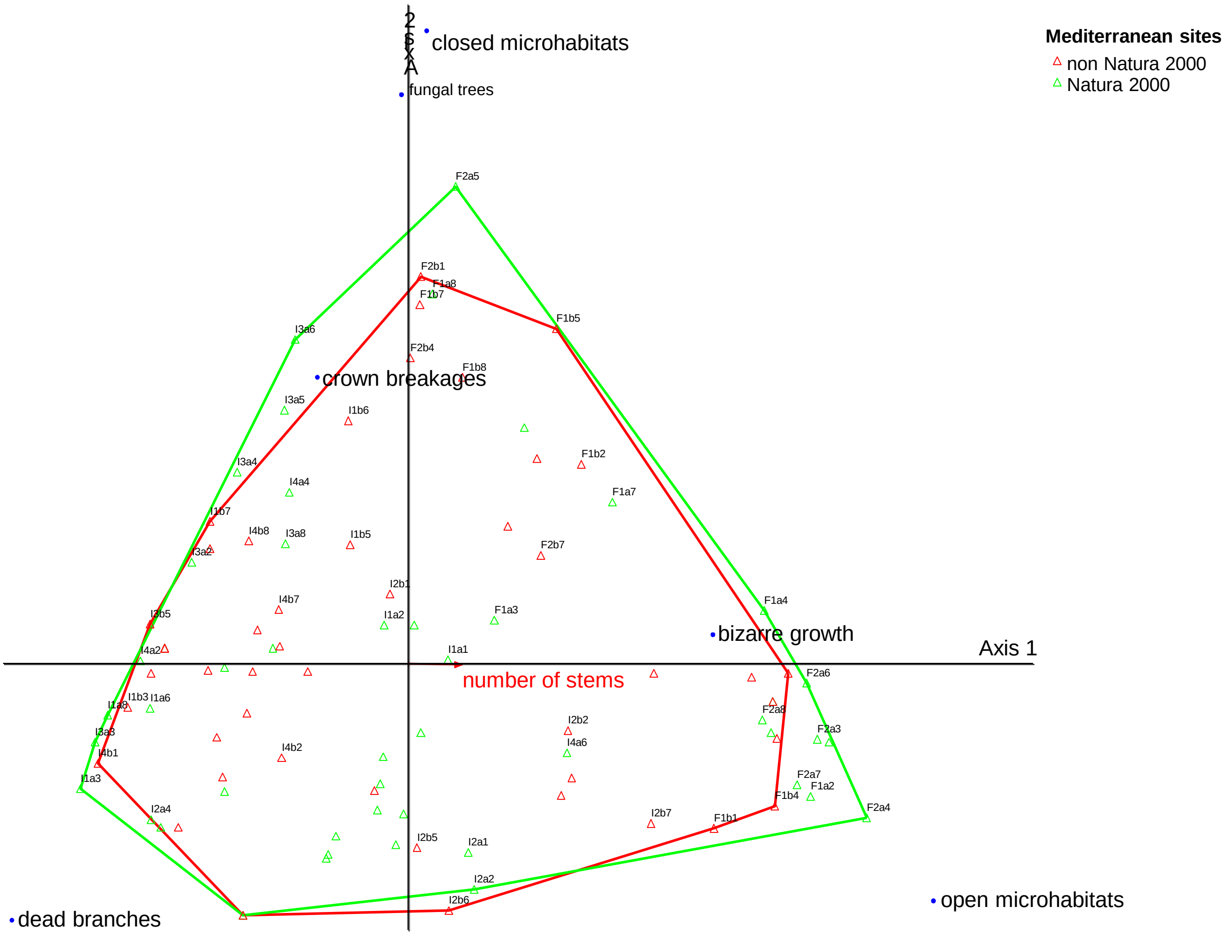

Figure 34. Ordination for Mediterranean sites

Table 15. DCA vector values for Mediterranean biogeographic region

significance range	0,10206207	Axis 1		Axis 2	
parameter	**matrix**	**R1**	**tau1**	**R2**	**tau2**
closed microhabitats	main	-0,108	0,024	0,535	0,519
open microhabitats	main	0,661	0,574	-0,448	-0,348
dead branches	main	-0,616	-0,494	-0,351	-0,251
crown breakage	main	-0,328	-0,234	0,311	0,26
bizarre growth	main	0,146	0,116	-0,062	0,006
fungal trees	main	-0,054	-0,016	0,165	0,107
top closure	second	-0,2	-0,073	-0,286	-0,278
sociability of beech seeds	second	0,188	0,14	0,249	0,179
maximum tree height	second	-0,223	-0,145	-0,252	-0,167
bark damages due to management	second	-0,144	-0,091	-0,084	-0,093
basal area	second	0,202	0,131	0,172	0,114
maximum DBH	second	0,118	0,093	0,286	0,167
number of tree stems	second	0,344	0,186	-0,041	-0,067
trees with partner stems (%)	second	0,026	0,036	-0,084	-0,034
tree layer species number	second	-0,019	-0,009	0,057	0,049

The data for the **Continental biogeographical region** shows the final length of gradient by 2,631. The used method was the detrended correspondence analysis (DCA). No clear differentiation trends were observed. Around 20% of the Natura 2000 plots and 27.5% of the non Natura 2000 plots are outside of the overlapping area (Figure 35).

5 significant vectors were detected on the axis 1 (r>0.102). The sociability of the F. sylvatica seeds indicates an increasing trend into the direction of crown breakages but decreasing into the direction of dead branches and closed microhabitats. The basal area, number of tree stems and top closure show the opposite trend.

Three groups of microhabitats were mostly correlated to the axis 1. The crown breakages are the one, which is strongly positive on the axis one. The dead branches and the closed microhabitats are strongly negative on the axis one. The bizarre growth and the open microhabitats were mostly correlated to the axis two (Table 16). That means that also no trends regarding Natura 2000 status can be detected within the Continental biogeographic region.

DCA Continental sites

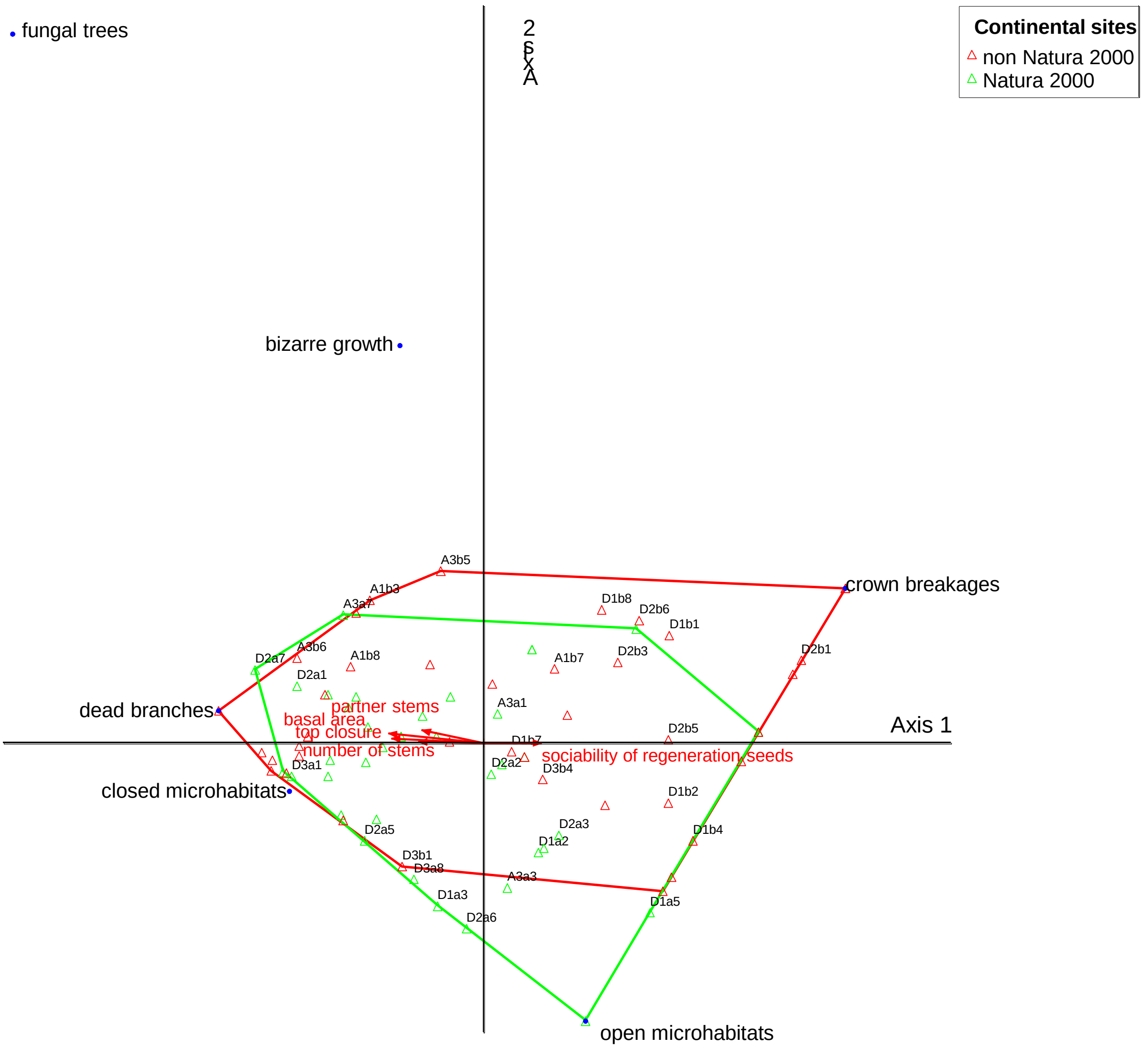

Figure 35. Ordination results for Continental sites

Table 16. DCA vector data for Continental biogeographical region

significance Range	0,11250879	Axis 1		Axis 2	
parameter	**matrix**	**R1**	**tau1**	**R2**	**tau2**
closed microhabitats	main	-0,546	-0,478	0,05	0,007
open microhabitats	main	0,129	0,147	-0,488	-0,432
dead branches	main	-0,646	-0,577	0,184	0,098
crown breakage	main	0,621	0,506	0,26	0,208
bizarre growth	main	-0,245	-0,191	0,423	0,378
fungal trees	main	-0,089	-0,069	0,166	0,139
top closure	second	-0,432	-0,344	0,088	0,031
sociability of beech seeds	second	0,343	0,247	-0,014	-0,018
maximum tree height	second	0,007	-0,013	0,198	0,114
bark damages due to management	second	-0,148	-0,088	-0,05	-0,052
basal area	second	-0,44	-0,303	0,139	0,106
maximum DBH	second	-0,137	-0,113	0,235	0,151
number of tree stems	second	-0,363	-0,234	0,054	0,058
trees with partner stems (%)	second	-0,354	-0,322	0,16	0,057
tree layer species number	second	-0,261	-0,179	0,095	0,072

2.5.5 Detecting classification possibilities for Natura 2000 – nonNATURA 2000 regarding microhabitats and deadwood.

For the Central European conditions the **deadwood** volume is the reliable indicator for the long sustainable development period of the forest stand (Lassauce et al. 2011), which is closely connected with the naturalness and natural biodiversity.
If the critical time scope for the long term indication of signs of recovery under Natura 2000 has already been reached and stands start getting more natural, so we´ll see the classification node, which separate Natura 2000 from non Natura 2000. To proof the test results as well as detected trends of the used ordinations we applied the recursive partitioning method (Hothorn & Hornik 1999), which is based, in our case, on classification models according to Natura 2000 status.
The classification analyses with help of the R-Package party-kit shows no detectible options for Natura 2000 partitioning according to the deadwood volume in total (Figure 36) as well as within the Continental and Mediterranean biogeographical regions (Figure 37). Nevertheless, the Atlantic biogeographical region indicates an outstanding position, compared with other biogeographical regions, according to the deadwood volume with the highly significant p-value for the partitioning regarding the Natura 2000 status (Figure 36).

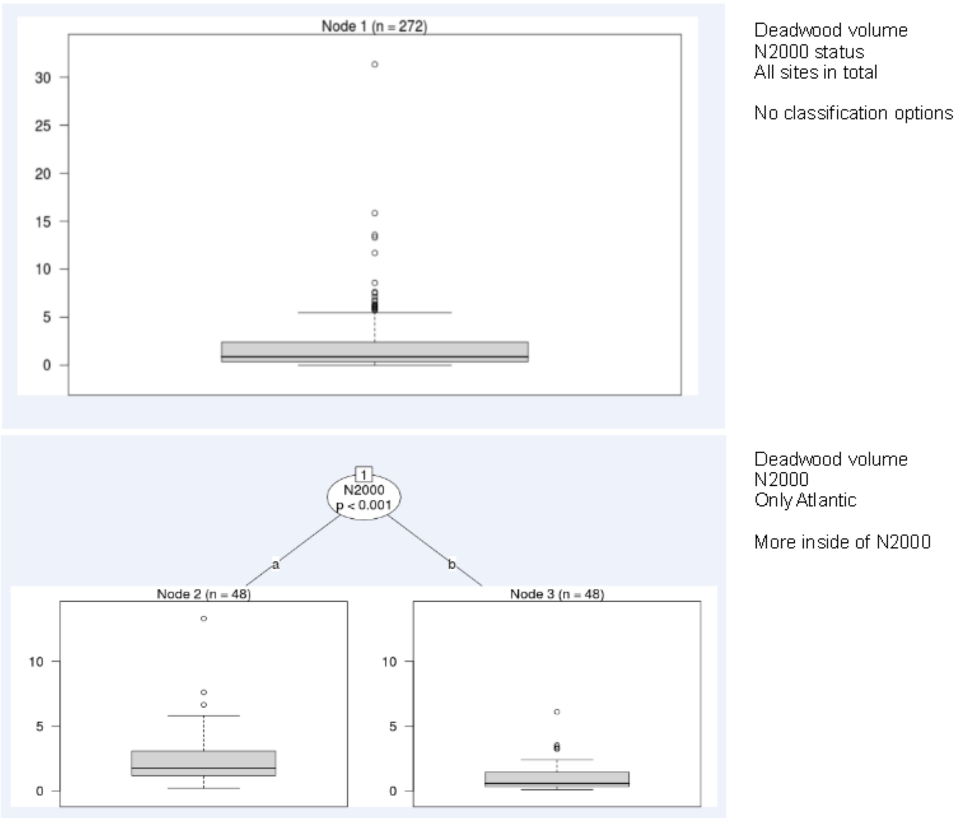

Figure 36. Natura 2000 partitioning according to the deadwood volume

Figure 37. Natura 2000 partitioning results for Continental and Mediterranean study sites

To proof the test results and detected ordination trends for used **groups of microhabitats**, we created classification models for each group of microhabitats. Detected classification options were defined by Natura 2000 status and tested for significance with help of Monte Carlo test routine. Fungal trees wasn´t used for classification models because of low number of data. We used 5 groups of microhabitats as well as the total microhabitat frequency. Total microhabitat frequency indicates the classification into Natura 2000 – non Natura 2000 inside of Atlantic biogeographical region only. The following 3 groups indicate significant classification option according Natura 2000 also within the Atlantic sites:

- closed microhabitats
- open microhabitats
- bizarre growth

Open microhabitats is the only one group, which indicate classification by applying also on all study sites in total. We found no classifications by Natura 2000 status for crown breakage and dead branches.

The results of the applied partitioning method for Natura 2000 sites according to the **total frequency of the microhabitats** confirm the results shown on deadwood volume (Figure 38, Figure 39). The analyses of all sites (Figure 38) as well as the Continental and Mediterranean sites (Figure 39) indicate no options for the classification into Natura 2000 - non Natura 2000. The Atlantic sites indicate a classification option with a statistically significant p-value (Figure 38).

The same result we could detect on the **closed microhabitats** (Figure 40, Figure 41). The open microhabitats indicate a statistically significant classification of all sites together (Figure 42, left diagram), but only due to the result of Atlantic sites (Figure 42, right diagram). Neither Mediterranean nor Continental sites indicate classification nodes (Figure 43).

Dead Branches as well as **crown breakages** show indifferent behavior to management within the evenly aged stands (Figure 44). As a consequence, we can´t detect any classification options regarding Natura 2000 status for those groups.

Bizarre growth makes the same result as the closed microhabitats and the deadwood (Figure 45). The significance of the Natura 2000 partitioning within the Atlantic biogeographical region is slightly lower but still significant. The all sites in total as well as Continental and Mediterranean sites have no significant classification options (Figure 46).

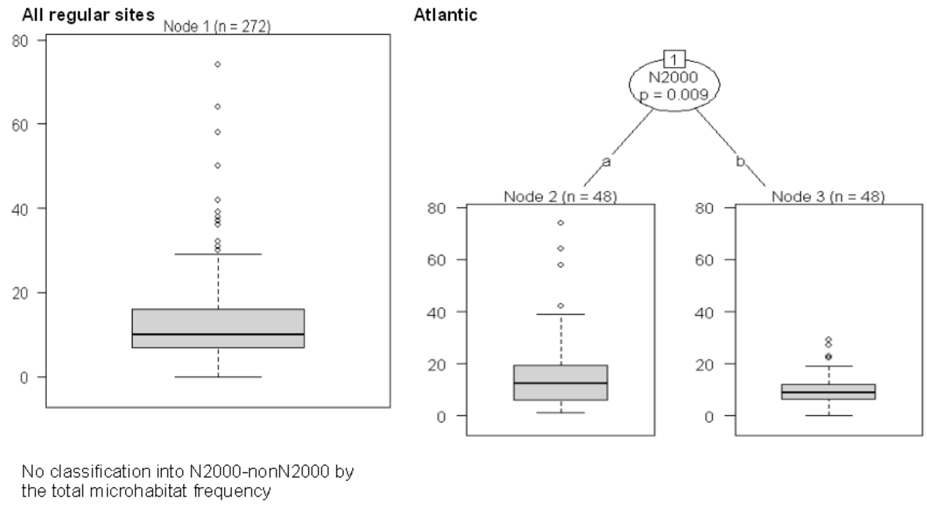

Figure 38. Natura 2000 partitioning based on the total microhabitat frequency:

All sites - left diagram

Atlantic sites only – right diagram

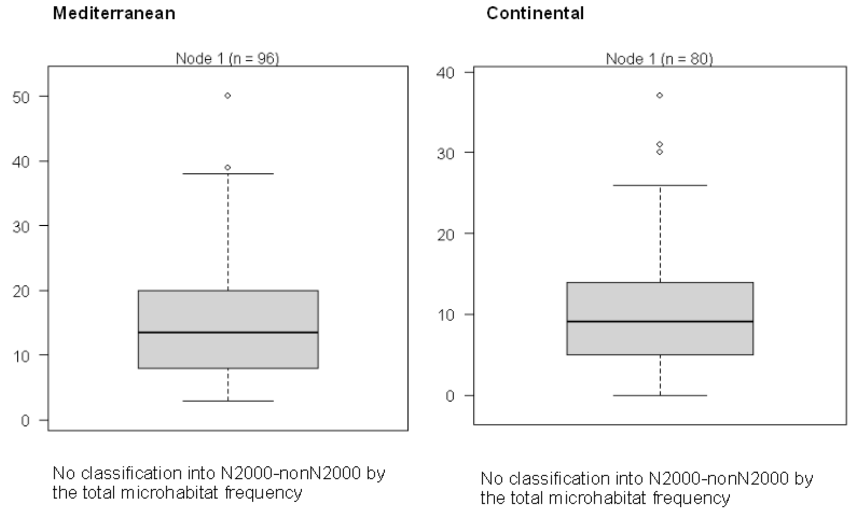

Figure 39. Natura 2000 partitioning based on the total microhabitat frequency:

Mediterranean sites – left diagram

Continental sites - right

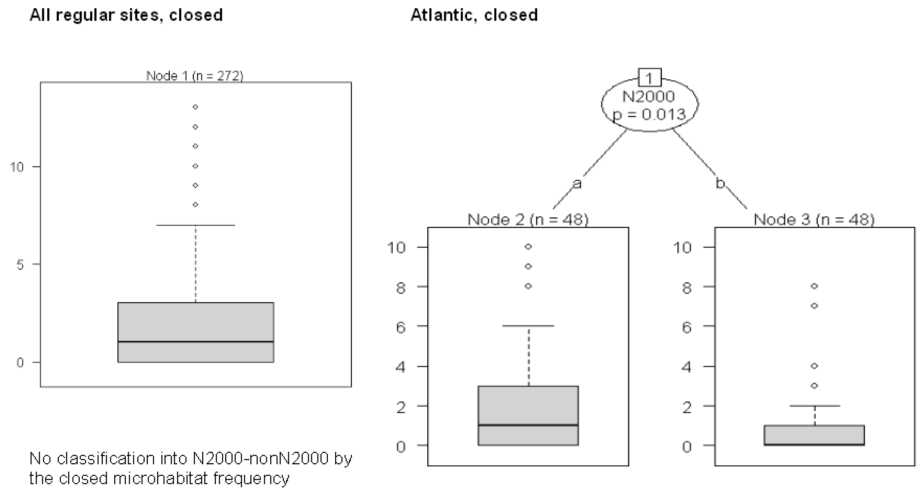

Figure 40. Natura 2000 partitioning based on closed microhabitats:

All sites – left diagram

Atlantic sites – right diagram

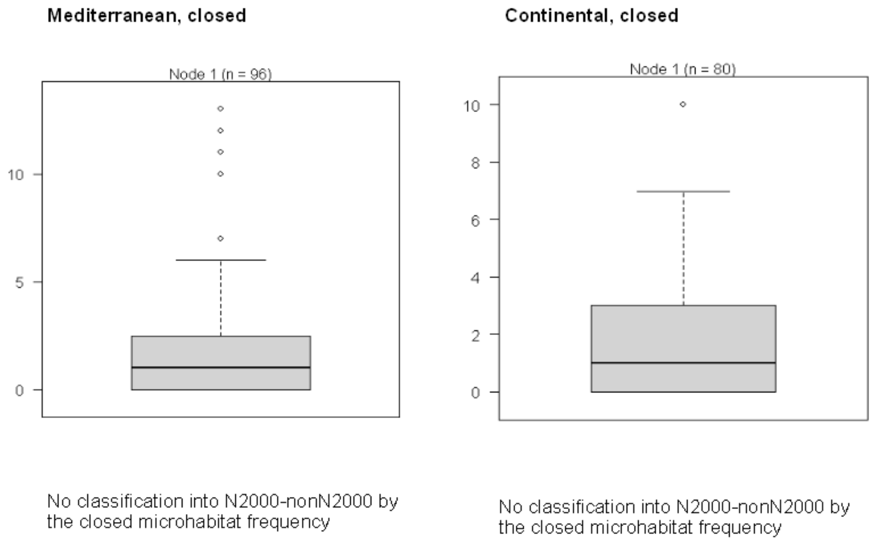

Figure 41. Natura 2000 partitioning based on closed microhabitats:

Mediterranean sites – left diagram

Continental sites – right diagram

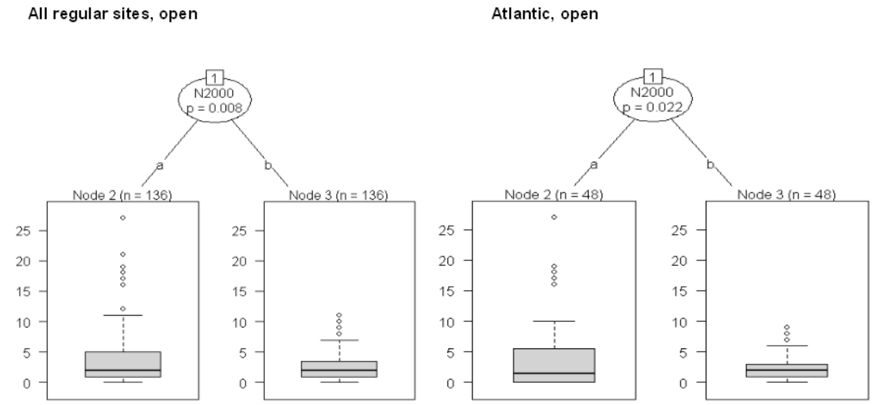

Figure 42. Natura 2000 partitioning based on open microhabitats

All sites – left diagram

Atlantic sites – right diagram

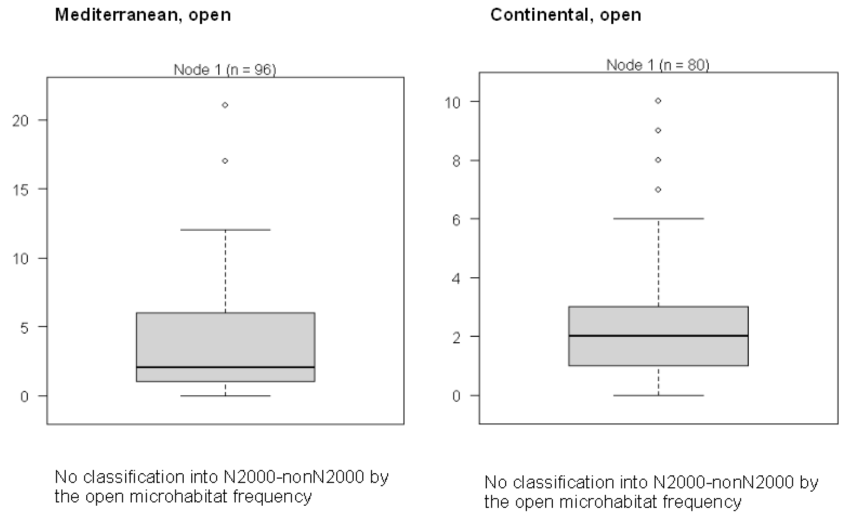

Figure 43. Natura 2000 partitioning based on open microhabitats

Mediterranean sites – left diagram

Continental sites – right diagram

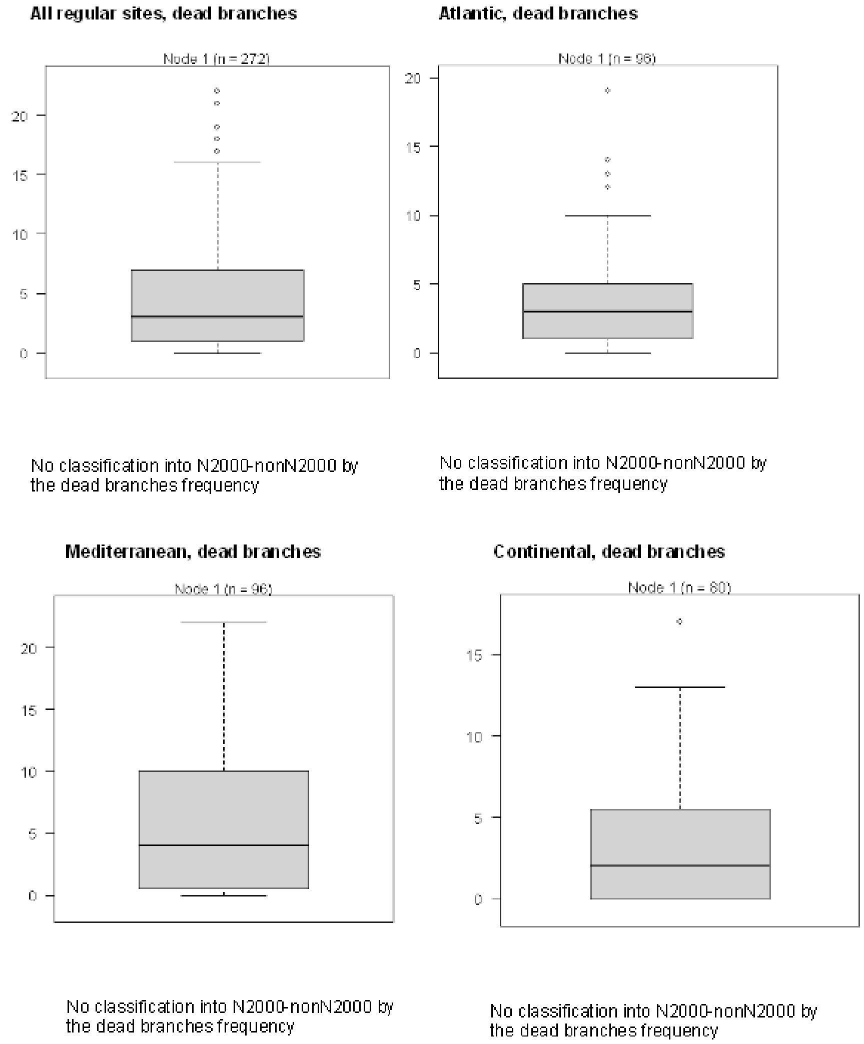

Figure 44. Natura 2000 partitioning based on dead branches of all sites in total and each biogeographical region

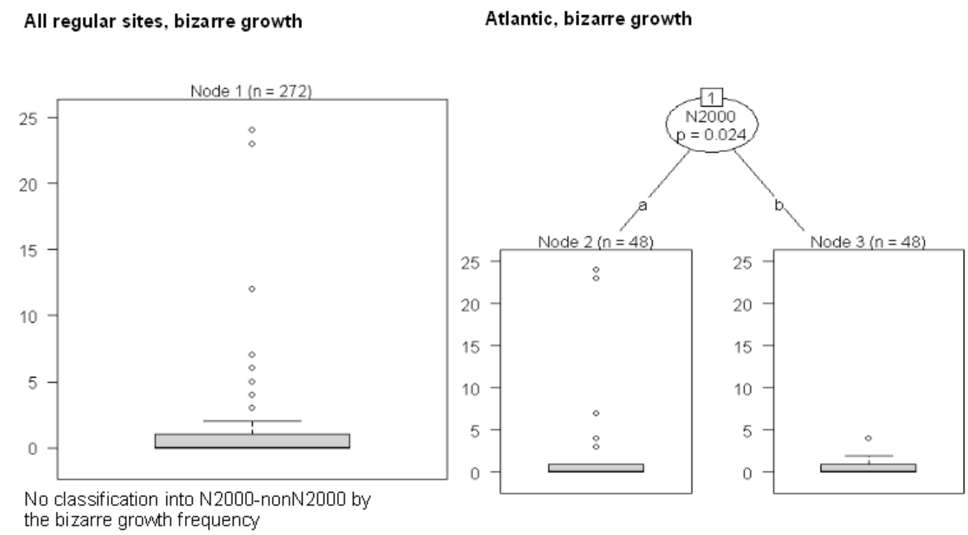

Figure 45. Natura 2000 partitioning based on the bizarre growth:

All sites – left diagram

Atlantic – right diagram

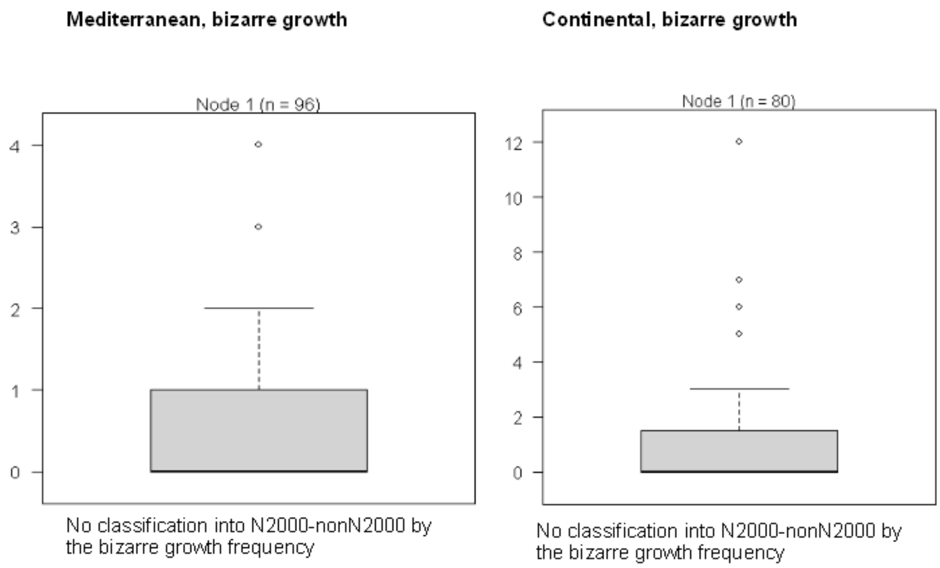

Figure 46. Natura 2000 partitioning based on the bizarre growth

Mediterranean sites – left diagram

Continental sites – right diagram

We summarize that also this clustering technic detects clear differentiation trends regarding Natura 2000 status within Atlantic biogeographical region only. Differentiation options regarding Natura 2000 status within Mediterranean and Continental biogeographical regions aren´t yet found.

2.6 Discussion

The structural conditions of the temperate broadleaved forests, including European beech forests, have been transformed by human activities stronger than any other forest biome (Hannah et al. 1995). New management strategies were needed to insure the future of these forests (Fischer & Lindenmayer 2007). A major objective of these strategies is to create biological 'legacies' (e.g., live residual trees, dead snags, and fallen logs) and heterogeneous stand structures that may help promote biological diversity, critical ecosystem functions, and resilience to disturbance (Christensen et al. 2005). Studies on managed forests, which encompass legacy trees and structural complexity suggest that these strategies can increase populations of sensitive species relative to conventionally managed forests (Hanson et al. 2012). Natura 2000 is such a strategy. Its main objective is to support the natural biodiversity by reversing the habitat loss (COMMISSION OF THE EUROPEAN COMMUNITIES 2009). However, an internationally accepted monitoring method as well as data of the structural parameters to assess the effectiveness of the Natura 2000 management is needed (Chape et al. 2005). Forest and land use monitoring systems are under development in Europe to link both the ecological and forest use data into the one information system (Jonsson et al. 2011).

Our research provides priority environmental data and results of the monitoring of the Natura 2000 effects on European beech forests according to the ecological indication. In this study we detected differences between the Natura 2000 and non Natura 2000 beech forest stands according to microhabitats, stand structure, tree growth and deadwood. These differences are, however, mainly restricted to the stands being under protection long before Natura 2000 had been implemented. Due to this fact, we couldn't confirm significant influences of the Natura 2000 strategy on the current conditions of the investigated European beech forests up to now. The management strategy of the forest stands, designated as Natura 2000 areas, on the current implementation phase often remains unchanged.

According to **Hypothesis *H1.1*** (see chapt. 2.2) we expected that *microhabitat diversity within the Natura 2000 is higher than outside*. But this couldn´t be statistically confirmed. No significant differences between Natura 2000 and non Natura 2000 in total were detected (Table 8). Generally we found that used diversity indexes and evenness of microhabitats slightly, but not significantly, increased within the Natura 2000 stands in comparison to non Natura 2000 stands. The number of microhabitat types is nearly the same inside of Natura 2000 as well as outside.

The comparison of the microhabitat diversity in single biogeographical regions confirms the outstanding position of the Atlantic Natura 2000 stands. The Atlantic biogeographical region indicates clearly higher microhabitat diversity within the Natura 2000 sites. Especially inverse Simpson Index and Evenness were highly significant. We detected a higher number of microhabitat types within these Natura 2000 stands, but the test result was less significant. Mediterranean as well as Continental forest stands don´t show significant differences between Natura 2000 and non Natura 2000 according to the microhabitat diversity. Generally, the diversity of microhabitats should be understood as an indicator for the long term development conditions within the forest (Fenton & Bergeron 2011). As has been mentioned, the development of the regular managed stands was dominated by the management interventions. On the other hand, the natural disturbance regime is getting the key factor for the forest development of the stands with low intervention level (Fischer et al. 2013). The results of the microhabitat frequencies should be understood as an indication of the intensity of those factors (Larrieu et al. 2011).

The frequency of the detected microhabitats was significantly higher within the unmanaged stand of the reference site (Table 7). But on the other hand, differences between Natura 2000 and non Natura 2000 were not detected. Nevertheless, we detected clear differences between Natura 2000 and non Natura 2000 within the Atlantic biogeographical region according to the frequency of dead branches as well as closed microhabitats. Further we found no differences between Natura 2000 and non Natura 2000 regarding the microhabitat frequency, which occur consistently across all biogeographical regions. That result was confirmed by the ordinations described under (2.5.4) as well as classification models (described under 2.5.5).

Hypothesis H1.2 (chapt. 2.2) expects that the individual tree structures will differ according to the forest management strategy. At the current stage, however, no significant difference regarding the current Natura 2000 management in total could be detected. We found that only one out of ten tested parameters of the vertical structure indicate significant differences between Natura 2000 and non Natura 2000 stands in total, which was mainly due to the situation within Atlantic sites. On the other hand, the reference site indicates significant differences on five out of nine tested parameters in comparison between managed and unmanaged stands according to the vertical structure (Table 9). Thus twisted growing trees, secondary shoots and the occurrence of Hedera helix were significantly higher within unmanaged stand. The Occurrence of the partner stems and the percentage of the partner stems per plot were significantly higher within the managed stand of the reference site.

The detected differences of the investigated stands according to the used vertical parameters seem to depend more on climatic differences and historical management than on the current management impact. Also the study sites with the similar management but located within the different climatic regions don’t indicate similar trends.

Nevertheless, spatial patterns in the horizontal distribution of structures, such as trees, snags, and logs significantly influence ecosystem functioning (Franklin et al. 2002).

Hypothesis (H1.3) (see chap. 2.2) points out that the structural diversity will differ according to management strategy. We detected some indicators on the stand level, which were significantly different according to Natura 2000 status. Especially the basal area and the minimal tree height of the top level differ according to management (Table 10). But this trend seems to be a specific characteristic of the continental biogeographical region. Neither Atlantic nor Mediterranean sites show any kind of significant differences according those parameters. On the other hand we have got significant results on eight out of ten parameters of the stand structure within the reference site; all of the detected differences there were highly significant (Table 10). Because of a such significant result of the reference site and just few cases of significance of the Natura 2000 paired sites, we came to the conclusion that the used parameters indicate differences according management but can be used as the long term indicator only.

The presented results indicate a specific situation within the Atlantic sites. A significant number of the British Natura 2000 sites have a long protection history, reaching far beyond the Natura 2000 implementation. Lady Park Wood is such an example. The management history of this Natura 2000 site is well documented in several publications (Peterken & Jones 1989; Peterken & Mountford 1996). Regarding this information the Lady Park Wood has been managed as a minimum intervention forest reserve for ecological research since 1944. At the same time the regular beech forests are often a part of the industrial reforestation program (Henwood, Oakley wood) and still be used mostly for wood production and touristic activities (White Stone Wood, Hen Wood). Other factors, which can explain the elevated level of open microhabitats is the F. sylvatica responses on drought stress due to single extreme climatic events like drought summer 1976, which changed the competition relationships between species in UK dramatically (Cavin et al. 2013), and grey squirrel damages on F. sylvatica (Mountford 1997). All these factors seem to be the key points for the outstanding position of the Atlantic Natura 2000 sites regarding the structural parameters as well as the significant classification results regarding the Natura 2000 status (see chapt. 2.5.5). Also the groups of microhabitats like closed microhabitats and dead branches, which mostly indicate a long term development processes, are increasing within the Natura 2000 sites only inside of the Atlantic biogeographical region (Table 7). The above finding suggests that the outstanding position of the Atlantic sites was mostly due to other influencing factors than the Natura 2000 effects. Especially long time of protection seems to be an important factor for development of differences between Natura 2000 and non Natura 2000 stands.

This conclusion was underlined especially by the diversity of microhabitats (Table 8). The analysis of microhabitat diversity indicated few differences of the microhabitat building processes within N200 and non Natura 2000 stands, responsible for the structural diversity as well. The paired study sites, which indicate significant differences of microhabitat diversity, were located in similar climate conditions, but under different management strategies. For this reason, we came to the conclusion that the stands outside of Natura 2000, which are still managed in a convention way, still be dominated by management interventions. Those Natura 2000 sites, which have been managed as minimum intervention forest reserves for a period starting long before implementation Natura 2000, indicate clear recovery as well as self-regulation processes in terms of the natural forest development. As a consequence, the natural disturbances regime is getting the dominant factor for the forest development (Fischer et al. 2013).

In the other cases no significant differences due to Natura 2000 management could be detected. On the stand level we found several parameters, which are slightly increasing within the Natura 2000 sites. Such process indicating parameters like top closure and sociability of F. sylvatica seeds were slightly higher within the Natura 2000 plots, but no level of significance could be detected.

The maximal BHD per plot was slightly greater within the Natura 2000, but the difference was not statistically significant. Also the average BHD per plot indicate no significant differences between Natura 2000 and non Natura 2000 stands (Table 10).

As already mentioned in chapter (2.1.2), the high level of the open microhabitats within the Atlantic sites can be explained by drought events like summer 1976 (Cavin et al. 2013). This may be particularly confirmed by the natural bark damages within the Atlantic study sites (Table 10). Here the frequency of the natural bark damages became higher within the Natura 2000 area. But Natura 2000 as well as non Natura 2000 sites has been suffered by the drought in the same way. However, within the commercially used stands outside of Natura 2000 the damaged trees were immediately removed. Inside of stands with low intensity of management the damaged and dying trees are still present (Ask & Carlsson 2000).

The development of the horizontal formation of trees as well as other important kinds of structures within the unmanaged forests depend mostly on the development time as well as the natural disturbances regime (Moravčík et al. 2010). Because of the long protection history, the investigated Atlantic Natura 2000 stands have a longer development period aside from management pressure. That can be underlined by the detected differences on closed microhabitats (Table 7). Generally the microhabitat frequencies were taken as a primary indicator of the structural development (Winter & Möller 2008). While the work with the microhabitat frequencies we analyzed the relationship between the groups of microhabitats and the natural legacy of the European beech forests, which until now shows no significant influence depending on Natura 2000 status. But the study sites, which have been protected far beyond Natura 2000, show significant structural differences according to the represent groups of microhabitats.

We found that the diversity of microhabitats shows differences on the forest structural development in a similar way as the microhabitats frequencies but even more continuously and needs a shorter period for the indicating of occurred changes as microhabitat frequencies. On the other hand, microhabitat frequencies indicate the intensity of the changes more clearly. This fact can be used in further research to detect and proof trends in the forest development. For example the number of microhabitat types, evenness and Inverse Simpson Index can be taken to proof the results on microhabitat frequencies (Table 8).

Also the general tendency within each biogeographical region was clarified by the microhabitat diversity (Table 8). Especially the Inverse Simpson Index of the Natura 2000 investigated Atlantic sites was significant higher than these outside of Natura 2000. At the same time the index of the Natura 2000 sites was slightly low within the

Mediterranean region and slightly higher within the Continental sites. In both cases no significance between Natura 2000 and non Natura 2000 was detected (Table 8).
Our results underline that the Natura 2000 process obviously is still too young to indicate a remarkable influence on the investigated beech forest stands. Nevertheless the essential evaluation concept and monitoring of the management effects still need to ensure the success of Natura 2000 strategy anywhere in Europe. As already mentioned, the groups of microhabitats in connection with the commonly structural parameters can be used as indicators not only for the biodiversity but also for the indication of the different management impacts on the forest ecosystem. The commonly used structural parameters alone can be often unreliable by comparison between the regular used stands and may be proofed by the microhabitats.
For example the basal area is highly correlated to the total microhabitat frequency. Basically it means: more wood - more microhabitats. And this definition can be confirmed by the modelled effect from the GLM according the total microhabitat frequency and closed microhabitats (Figure 47). At the same time we have found, that the mean DBH isn't a reliable parameter to compare the managed beech forests and correlate it to the microhabitats. Indeed, most of the managed stands get more and more similar until the harvest time (Kirby et al. 1991). The forest and wood industry aims at low forest structure and one age stand to get market-conform product as much and as quickly as possible (Knoke 2005).

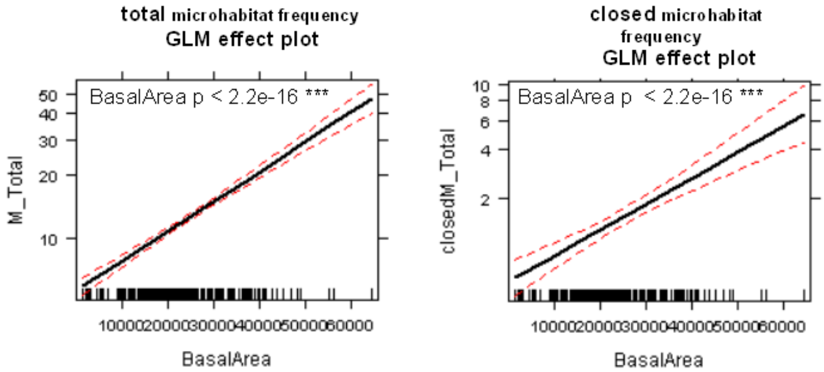

Figure 47. Closed microhabitats as well as total microhabitat frequency in relation to the basal area

In the regular case such stands have the lowest structural diversity and age diversity just before the harvesting, which, as a consequence, has a low amount of microhabitats (Figure 48).

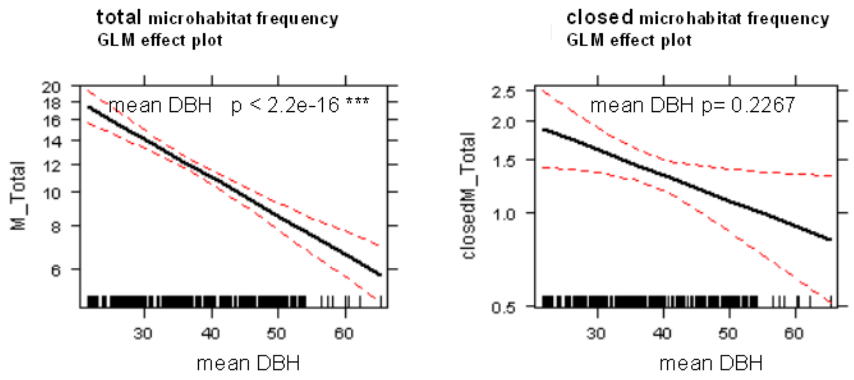

Figure 48. All microhabitats and closed microhabitats in relation to the mean DBH within the investigated normal used stands

The used GLM indicate a clear declination of the total microhabitat frequencies, starting by 20 cm average DBH per plot up to the top measured BHD mean around 66 cm (Figure 48). By applying this model on the closed microhabitats we found that the effect was not significant (p=0.2). As one can see in Figure 48, the still frequent measured biggest BHD mean per plot, located around 55 cm. But it shows a significant lower number of the microhabitats in total as the smallest measured DBH mean per plot, which is around 20 cm.

On the other side the maximum DBH, which is usually taken as an indicator to determine the development phase (Tabaku 2000) shows a positive correlation with the microhabitats in unmanaged low land beech forests in Germany (Winter & Möller 2008). The investigated normally used forests confirm that result only on closed microhabitats. But the relation between the microhabitats in total to maximum DBH seems to have an opposite direction regarding the microhabitats like shown at the GLM effect plot (Figure 49).

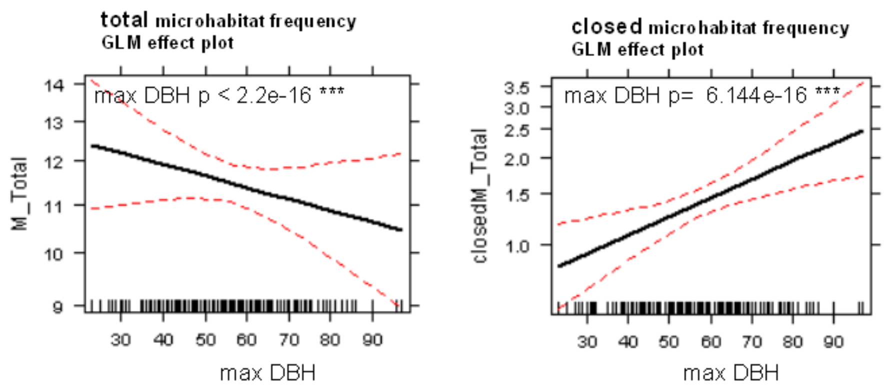

Figure 49. All microhabitats together and closed microhabitats in relation to the maximum DBH within the normal used stands

The frequencies of the bark defects were highly correlated with the total microhabitats frequency (Figure 50). All groups of microhabitats were closely correlated to the both groups of the bark defects (due to management and to nature). All microhabitat groups indicated the same trend according to the used GLM.

Especially effects on closed microhabitats, dead branches and bizarre growth were highly significant.

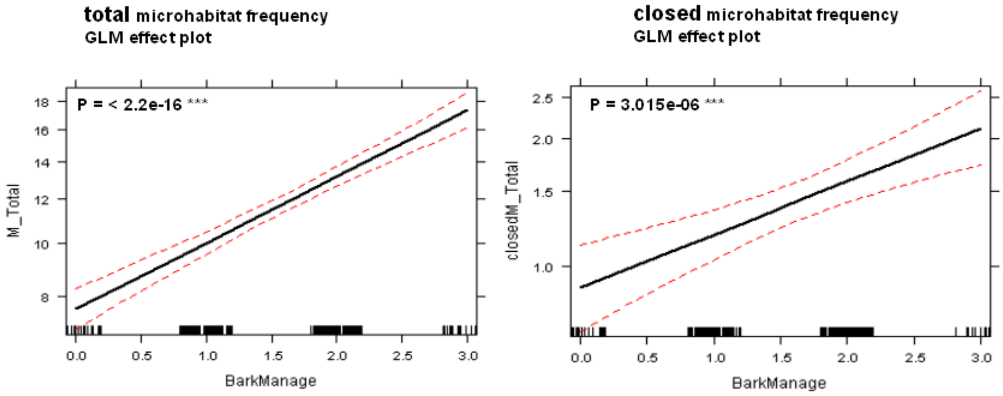

Figure 50. All microhabitats in total and closed microhabitats in relation to the bark damages due to management

For our study it was important to prepare and test a structural indicator based concept of parameters for the ecological assessment and special monitoring of the European beech forests regarding the ecological effects of Natura 2000 management. Our results underline the opinion, that the microhabitats can be suitable as a reliable indicator for the management influence of the European beech forest stands. But not every of investigated microhabitat types have the similar indication value. The tested “groups based concept” is easier to apply than the “single microhabitat concept” and shows that some groups of microhabitats can increase and other decrease through the intensification of the management pressure. We found that the closed microhabitats show the most reliable behavior regarding the natural legacy of the European beech forests, which mostly confirm the previously studies on microhabitats as indicators for the forest naturalness (Winter et al. 2010). Nevertheless, we found no consistently trends, which would indicate a Natura 2000 influence on investigated forest stands designated as Natura 2000 up to now.

2.7 Summary

The aim of this research was to investigate if Natura 2000 management has already a tangible effect on the structural conditions of the European beech forests and detect differences between the beech forests stands within and outside of Natura 2000 network. Here we assessed the tree growth, microhabitat frequencies, microhabitat diversity and deadwood volume within the forest stands. We used 17 paired study sites, containing one Natura 2000 and one non Natura 2000 stand each, within 6 west European countries to compare the stands regarding the mentioned parameters and to investigate if the effect of Natura 2000 can be detected in connection with the stand structure. The countries represented in our study are located within 3 biogeographical regions, which cover the main part of the European beech forest distribution: the *Atlantic* biogeographic region represented by British and Danish forests, the *Mediterranean* biogeographical region represented by France and Italy and the *Continental* biogeographical region represented by German and Austrian sites. In this way, the distribution of our study makes it possible to make a comparison between Natura 2000 and non Natura 2000 stands not only as a total dataset but also within each biogeographical region.

We hypothesized that the *Microhabitat diversity within the Natura 2000 is higher than outside*. But this couldn´t be statistically confirmed. No significant differences between Natura 2000 and non Natura 2000 in total were detected up to now. Nevertheless, all tested diversity indexes were significantly higher within Atlantic Natura 2000 stands compared with non Natura 2000.

We expected that *the individual tree structures (tree growth) will differ according to the Natura 2000 status*. At the current stage, however, no significant difference regarding the tree growth in connection with Natura 2000 impact could be detected.

Further we hypothesized that *the deadwood volume will differ according to Natura 2000 status.* This was again only the case within the Atlantic biogeographical region. Here we detected higher deadwood volume within the Natura 2000 stands. Such differences inside other biogeographical regions in connection with Natura 2000 weren´t statistically confirmed.

Based on our results and observations we summarized that the time since implementation of the Natura 2000 concept is still too short to develop consistently trends regarding structural features. Nevertheless, the outstanding position of the Atlantic biogeographical region indicates the effect of the protection history long before implementation of Natura 2000. Because of this fact it shouldn’t be understood as the actual effect of the Natura 2000 management but, however, it confirms the suitability of the collected structural parameters as a reliable long term indicators for the forest conditions and can be used for the further research.

3 Effect of Natura 2000 on the vegetation of European beech forests

3.1 Introduction

Botanical studies aim mostly on specific botanical and socio-ecological or phytosociological classifications. We designed this study to indicate tangible trends by comparing the species composition beech forests inside of Natura 2000 with comparable beech stands outside of Natura 2000 network, in terms to collect the data and to test the study concept for further scientific work.

The forest vegetation, its composition and pattern are influenced by many factors over its developmental history. That may include competitive interactions between trees, disturbances and differences in resources (North et al. 2004). In the cases like Asperulo-Fagetum beech forests, which became the main object of the current study, competition for light is a significant driver in young stand development between major disturbance events (Shugart & West 1980, Oliver 1981, Shugart 1984, Smith 1986, Oliver & Larson 1996) and continues to influence development in old-growth forests where localized disturbance creates gap-phase replacement (Runkle 1985, Canham 1988, Stewart 1989, Lertzmann 1992). Those gaps are often used by new species as an entry platform. The species diversity of the understory vegetation getting significantly higher within and around such gaps (Barbier et al. 2008).

Important accompanying species in old-growth beech forests include silver *fir Abies alba*, maples *Acer platanoides, A. pseudoplatanus*, hornbeam *Carpinus betulus*, ash *Fraxinus excelsior*, oaks *Quercus petraea, Q. robur*, Norway spruce *Picea abies* and lime *Tilia cordata* getting the possibility to reach the top layer (Korpel 1995, Peters 1997, Standovár & Kenderes 2003). Some of them were positively influenced other negatively by management and climate. In this part of our research we focus on the vegetation diversity and tried to identify the effect of Natura 2000 on it.

3.2 Hypotheses

As already mentioned (see chapt. 2.2.) we build our hypotheses on the basis of Natura 2000 objectives. Those objectives, to be precise, aim on protection of natural habitats and biodiversity. Especially the “protection of the natural biodiversity” is an essential point for our hypotheses and analyses in this chapter. However, in terms of vegetation ecology, the protection of species diversity and ecological wealth needs an understanding of natural processes and natural legacies of the ecosystem. In case of the beech forest habitat, it used to be the main object of the actual research, the same variation of diversity within the top and ground layer supposed to indicate different trends of ecological development (Noss 1999). Some modern studies of forest biodiversity show that the high species number alone is not necessarily a positive indicator in terms of naturalness (Standovár et al, 2006). One of the main drivers of the forest development is the light factor. Especially the understory vegetation within the European beech forests depends on it. Thus it is known, that the species diversity is limited mainly by this factor. In this way, the tendency into the direction of high biodiversity within the herb layer can be connected with management interventions or natural disturbances (Crozier & Boerner 1984). The same trend within the top layer can indicate natural recovery processes (Ihók et al. 2007). As a conclusion we have the following hypotheses:

H2.1- Plant diversity of Natura 2000 stands in the top layer as well as in the shrub layer is higher than in non-Natura 2000 stands
H2.2 - Plant diversity of Natura 2000 stands in the herb layer is lower than in non-Natura 2000 stands

3.3 Fieldwork design

The study includes the three main biogeographical regions, which are most important for the natural distribution of *Fagus sylvatica* beech forests in Western Europe: (i) Atlantic biogeographical region, (ii) Mediterranean biogeographical region and (iii) Continental biogeographical region (Figure 4, see chap. 2).
We used the same 17 study sites, which were described in chapter 2.3 of this dissertation (Table 1). Each study site contains two beech forest stands: one of them within the Natura 2000 network, the other outside. The paired stands were selected as close as possible to each other and with taking account the age characteristic, historical management as well as forest community and soil conditions. All stands were strongly dominated by European beech and contained low percentage of conifers within the top layer. We established 8 evaluation plots within each forest stand. Marginal areas, locations with conifers within the top layer as well as areas not dominated by beech were excluded from the selection. Collected parameters were developed with taking account of the important natural characteristics of the beech forests. We separated and specified vegetation parameters according to main vegetation layers, defined by the following classification:

- 0 to 1 m - herb layer
- 1 to 5 m - shrub layer
- 5 m up to the top height - tree layer

All vegetation data include a list of the species growing on the test site, coverage, vitality and classification of damages or defects. Additionally parameters like geographical coordinates, altitude, total canopy closure with foliage, total coverage of the ground vegetation and open substrate characteristics were collected to complete information about conditions on the test site.

3.4 Data and Analyses

3.4.1 Vegetation surveys

For our surveys on each plot we established evaluation circles (plots) with radius R=17.84 m. Almost all parameters were collected on the total plot area. For recording the herb layer species we used a subplot with the radius r=10 m using the same center point.

3.4.1.1 Plot parameters

We collect accompanying data and parameters on the plot level to perform actual analyzes and tests or to ensure the possibility to reproduce the data in further studies. The plot data are listed in Table 17.

Table 17. Plot parameters collected during vegetation surveys

plot parameters	description
coordinates	measured by Garmin Oregon 450t GPS device in decimal degree, WPS84
altitude	measured by Garmin Oregon 450t GPS device
slope	measured by Vertex Laser VL402 device, in degree
aspect	measured by Suunto KB-14/360/R/D Compass, in degree
total canopy closure with foliage	% canopy coverage of all present trees together
total coverage of the ground vegetation	% of the plot area covered by ground vegetation
coverage of the open substrate	% of the substrate not covered by ground vegetation: 1- organic 2- mineral soil 3- sand 4- fine core gravel 5- normal gravel 6- stones 7- blocks and monoliths

3.4.1.2 Parameters of vegetation layers

During summer field work activities in the time period from 20th June of 2011 to 30th September of 2013 we collected the main vegetation data of the three vegetation layers, described below. The Vegetation survey aims to focus on the late summer aspect, which starts during the second part of June within the Mediterranean region. Table 18 summarizes an overview over all analyzed vegetation parameters. The table contains information about the collected data of tree layer, shrub layer as well as herbal layer.

Tree layer parameters include species information, coverage, vitality and damages. Collected parameters of the **shrub layer** include information about species, coverage and found damages. The data of the **herb layer** were collected from the subplot with the r=10m.

Table 18. Parameters of vegetation layers

	vegetation layers		
parameters/samplings	**tree**	**shrub**	**herb**
plot radius (m)	17.84	17.84	10
species	botanic name	botanic name	botanic name
species coverage	% of the plot area covered by species	% of the plot area covered by species	% of the plot area covered by species
vitality of leaves	**1** - best vitality **2**- normal condition **3**- reduced vitality, loss of foliage less than 50 %, but recovery is still posible **4**- loss of foliage over 50 % **5**- advanced loss of foliage, recovery is extremely unlikely	**na**	**na**
most frequent kind of leafs demages	drying, insects, other	drying, insects, grazing animals, other	drying, insects, grazing animals, other
intensity of damages	**0** - no damages ; **1**- 5 to 10%; **2**- 10 to 30%; **3**- 30 to 50%; **4**- over 50%	**1** - no damages ; **1**- 5 to 10%; **2**- 10 to 30%; **3**- 30 to 50%; **4**- over 50%	**2** - no damages ; **1**- 5 to 10%; **2**- 10 to 30%; **3**- 30 to 50%; **4**- over 50%
plant vitality	**na**	**1** - best vitality **2**- normal condition **3**- bed condition but no signs of life threatening **4**- beginning of dying processes **5**- advanced dying, recovery is extremely unlikely	**2** - best vitality **2**- normal condition **3**- bed condition but no signs of life threatening **4**- beginning of dying processes **5**- advanced dying, recovery is extremely unlikely

* na- not analyzed

3.4.2 Data analysis and statistical tests

All statistical analyzes in this chapter are focused on following points:

- differences regarding plant diversity
- differences regarding plant composition and species coverage
- ordination of evaluation plots regarding the herb layer as a short time indicator
- modeling the generalized linear mixed effects of Natura 2000 on vegetation layers

The applied statistical tests of plant diversity parameters, tests of plant composition and species coverage as well as the modelling of generalized linear mixed effects were performed by using R version 2.15.2.

The applied ordinations were performed by using PcOrd version 6.0.

1.4.2.1 Differences

To detect the differences between selected Natura 2000 and non Natura 2000 stand we applied several non-parametrical tests. Mann-Whitney test was applied to see the differences regarding species diversity (Table 19). Following diversity parameters were prepared for tests on the plot level:

- inverse Simpson diversity index
- species number
- species evenness

Test results were provided in the form of the table of differences containing information regarding all sites together as well as each biogeographical region. The table was divided into 3 sections regarding vegetation layers. The tests of plant diversity were performed using following packages:

```
stats
Version: 2.15.2
Priority: base
Title: The R Stats Package
Author: R Core Team and contributors worldwide
Maintainer: R Core Team <R-core@r-project.org>
Description: R statistical functions
License: Part of R 2.15.2
```

To test the differences regarding species composition and coverage we performed a two-sample Wilcoxon rank sum test regarding species presence and mean coverage by using Natura 2000 and non Natura 2000 as two samples. To detect tangible differences regarding the species composition within and outside of Natura 2000 we used a comparison of species attendance as an indicator. To detect differences of coverage we used the average coverage of each found plant. The results were provided in form of the table containing significance codes regarding 3 vegetation layers within all biogeographical regions as well as according to all study sites together (Table 20). The tests were performed using package “stats” described above.

3.4.2.2 Ordinations of the ground vegetation

Ordination technics were used to create an overview “map” over all Natura 2000 and non Natura 2000 stands respectively together as well as each biogeographical region regarding the herb layer with taking account of environmental and structural parameters.
The herb layer has been chosen as the short term indicator to detect current development trends and tangible differences between Natura 2000 and non Natura 2000 stands.
Ordinations were performed by using PcOrd as aforementioned. We used the CCA method because of the better possibility for including and explanation of environmental and structural variables as well as indication of diversity parameters.
The first work matrix contains coverage of found species, which has been transformed by using power transformation (sqrt-transformed). The second matrix contains following additional variables:

- annual temperature
- annual precipitation
- climatic favorability index for *Fagus sylvatica*
- altitude
- basal area
- maximal DBH
- maximal tree height
- number of stems over 20 cm DBH
- sociability of beech regeneration seeds
- top closure
- *Hedera helix* on tree stems
- total microhabitat frequency
- closed microhabitat frequency
- frequency of bark defects
- total deadwood volume
- herb species number
- tree species number
- herb species evenness
- tree species evenness

3.4.2.3 Detection of Natura 2000 effects within the study sites

To define the actual effect of Natura 2000 on plant diversity and to estimate the influence of Natura 2000 on the plant diversity within each study site we fitted the generalized linear mixed model with following diversity parameters:

- species number
- inverse Simpson index
- evenness

The results have been provided in form of a table based on p-values of Natura 2000 effects on diversity parameters. The results have been divided into 3 sections regarding vegetation layers. The table includes information regarding Natura 2000 effects on the plant diversity within each study site.

The generalized linear mixed model has been fitted by maximum likelihood. Sites, biogeographical regions and countries were used as random variables. Following packages were used:

```
Package: lme4
Version: 1.0-4
Date: 2013-09-08
Title: Linear mixed-effects models using Eigen and S4
Maintainer: Ben Bolker <bbolker+lme4@gmail.com>
Author: Doug Bates, Ben Bolker, Martin Maechler and Steven Walker
Description: Fit linear and generalized linear mixed-effects models.
    The models and their components are represented using S4 classes and
    methods.  The core computational algorithms are implemented using the
    Eigen C++ library for numerical linear algebra and RcppEigen "glue".
Depends: R (>= 2.14.0), lattice, Matrix (>= 1.0), methods, stats
LinkingTo: Rcpp, RcppEigen
Imports: graphics, grid, splines, MASS, nlme, minqa(>= 1.1.15)
Suggests: boot, PKPDmodels, MEMSS, testthat, ggplot2, mlmRev, optimx
        (>= 2013.8.6), plyr, reshape, Rcpp (>= 0.10.1), RcppEigen (>=
        0.3.1.2)
License: GPL (>= 2)
URL: http://lme4.r-forge.r-project.org/
Packaged: 2013-09-21 07:50:15 UTC; ripley
NeedsCompilation: yes
Repository: CRAN
Date/Publication: 2013-09-21 10:00:40
Built: R 2.15.3; i386-w64-mingw32; 2013-10-03 05:02:09 UTC; windows
Archs: i386, x64
```

We used package “effect” to visualize Natura 2000 effects:

```
Package:     effects
Version:     2.3-0
Date:  2013/11/06
Depends:     lattice, grid, colorspace
Suggests:    nlme, lme4, MASS, nnet, poLCA
LazyLoad:    yes
LazyData:    yes
License:     GPL (>= 2)
URL:   http://www.r-project.org, http://socserv.socsci.mcmaster.ca/jfox/
```

3.5 Results

3.5.1 Differences between Natura 2000 and non Natura 2000 forest stands regarding species diversity

The common forest evaluation practices use to determine the tree species as a primary attribute of a forest ecosystem (Barbier et al. 2008). Indeed, understory vegetation is influenced by overstory composition and structural features (Barbier et al. 2008). Nevertheless, the natural development of understory and overstory vegetation uses to have an own dynamic (Dupouey et al. 2002). As has been mentioned in chap. 2.1, the structural development as well as the establishment of a constant natural tree layer composition needs a long development period to indicate a reaction on environmental and management factors. At the same time the understory vegetation is much more sensitive and show significant reaction already on short time events (Dupouey et al. 2002). By analyses of vegetation data we focused on plant diversity, species coverage and composition. To proof the differences between Natura 2000 and non Natura 2000 stands we distinguish between the tree layer vegetation and the herb layer vegetation as different classes of indicators (Barbier et al. 2008).
According to some diversity studies, the **species number** still is a reliable attribute to illustrate the current situation (Mölder et al. 2008). Figure 51 and Figure 52 visualize Natura 2000 and non Natura 2000 average species numbers of the forest stand within each biogeographical region. The proportion is illustrated in form of a bar chart. The green bars represent the species number within Natura 2000 stands, the red bars represent the species number outside of Natura 2000 stands.

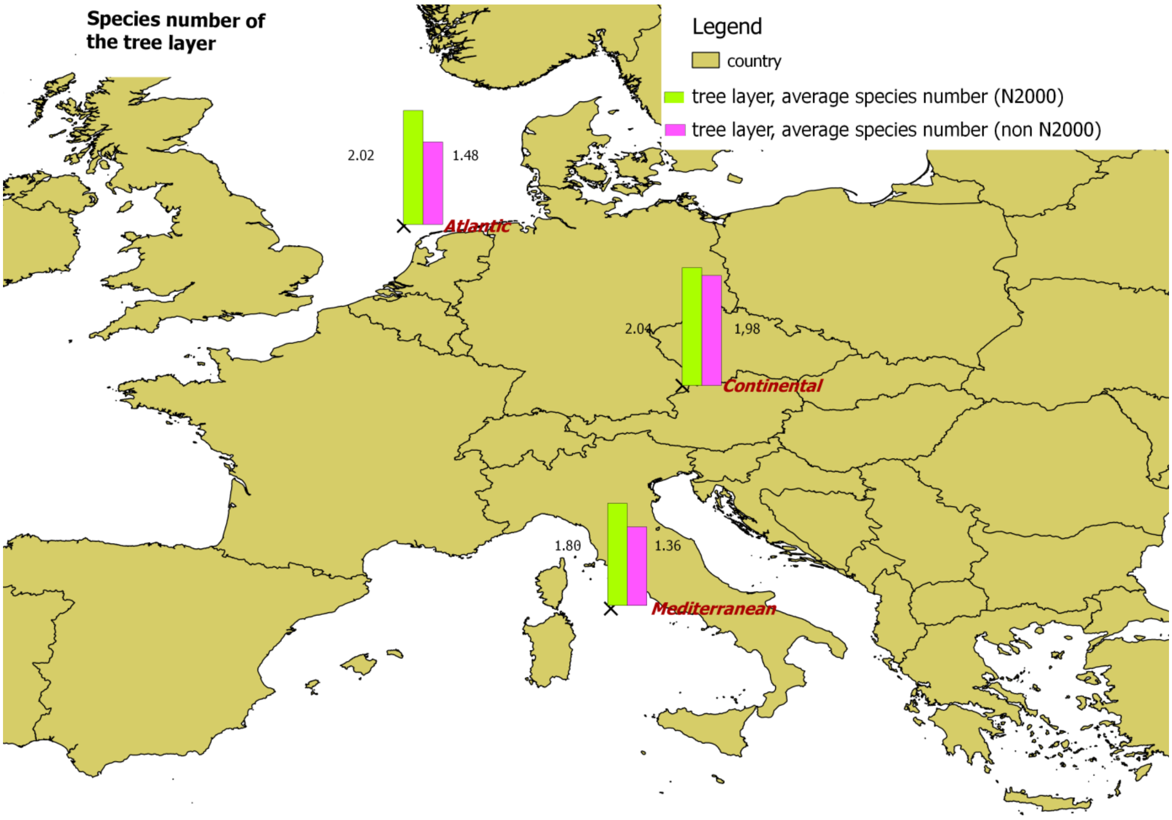

Figure 51. Average tree layer species numbers of Natura 2000 and non Natura 2000 stands within each biogeographical region

Wsssse [i] The **tree species number** is generally higher within the Natura 2000 stands (Figure 51). But we found this trend not in all biogeographical regions. Continental sites for example indicate no significant difference regarding this parameter. In contrast to the Continental sites, however, the Atlantic sites indicate a clear domination of Natura 2000 over non Natura 2000 regarding the tree species number.

Independently of it, the trends of the **herb species** number indicate the opposite direction (Figure 52). Especially the Atlantic biogeographical region indicates significantly more species within the understory vegetation of non Natura 2000. Nevertheless, other two biogeographical regions show no significant trends (Figure 52).

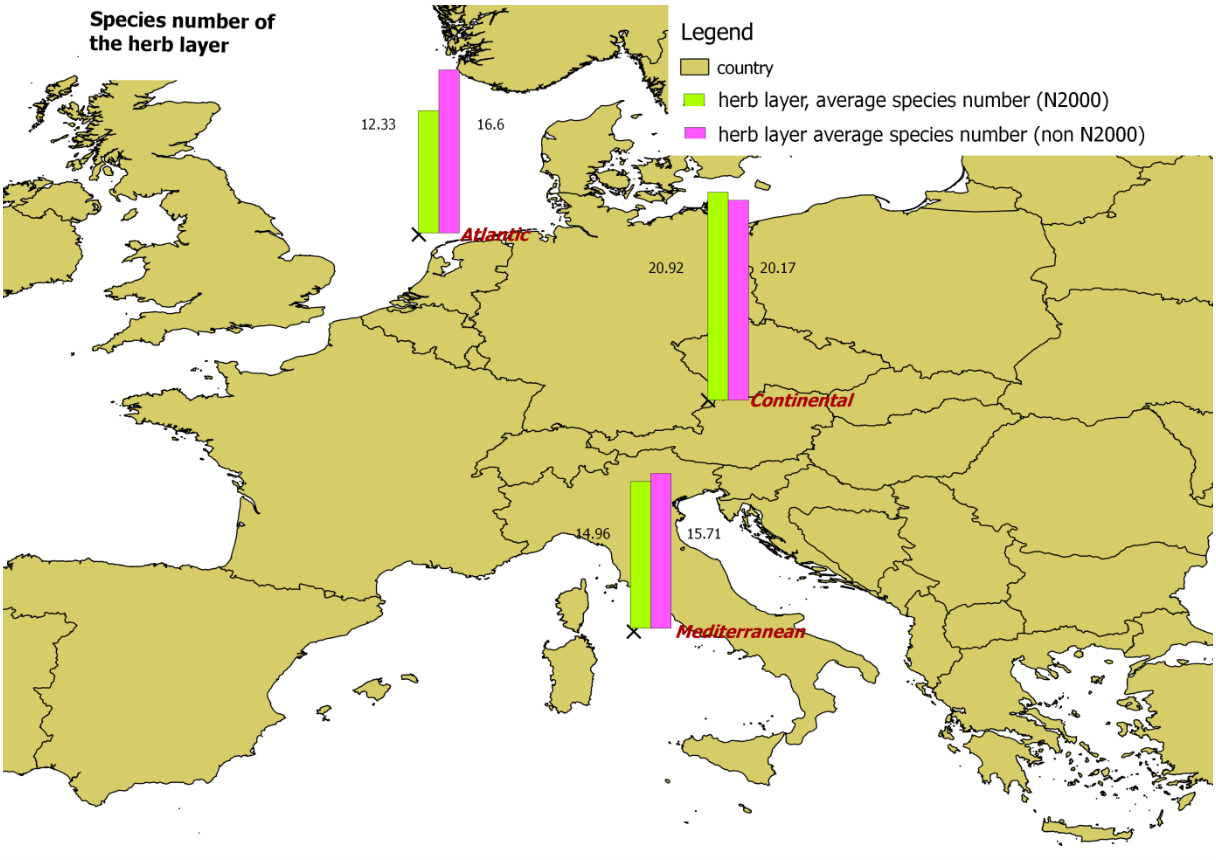

Figure 52. Average ground vegetation species numbers of Natura 2000 and non Natura 2000 stands within each biogeographical region

We found few significant differences between Natura 2000 and non Natura 2000 stands regarding **vascular plant diversity parameters**. Major diversity parameters choses for this task are known and commonly used for this kind of analyses. We provide the test results in form of the table of differences (Table 19). The differences between Natura 2000 and non Natura 2000 stands were tested by using the Mann-Whitney-Test routine. The result table illustrates the significance of the tested differences with help of the following classification regarding the p-value:

- *** > 0.001
- ** > 0.01
- * > 0.05
- ns - not significant

If the test result was significant, we used the arrow to show the trend of the difference: Arrow up indicates a higher value of Natura 2000, arrow down – lower value of Natura 2000. Vegetation layers were tested separately and these results build 3 own sections, starting by label "Layer" and marked by colors: "green" for herb layer, "blue" for shrub layer and "red" for tree layer.
We did not test the species composition or abundance in connection with the species diversity. The reference site was located in Massive de la Sainte Baume (southern France). This beech dominated forest stand has a very long protection history and is known as the oldest natural beech forest stand in the whole Western Europe. Inverse Simpson Index of the herb layer within and outside of Natura 2000 was only significant within the Mediterranean biogeographic region. The value is decreasing

into the direction of Natura 2000. The species number within the herb layer indicate only significance within the Atlantic stands and shows decreasing tendency within Natura 2000 compared with non Natura 2000 stands, but the evenness indicates the opposite trend (Table 19). No significant test results by comparison of Natura 2000 and non Natura 2000 forest stands could be found regarding the shrub layer. We detected more similarity of test results of the tree layer with the test results of the structural parameters (see chapt.2.5.2), which show a clear increasing tendency regarding all parameters of species diversity of Natura 2000 by testing all sites together. But the test results of every biogeographical region separately make clear that the test result on all study sites together was due to Atlantic sites only.

Table 19. Differences between Natura 2000 - non Natura 2000 regarding species diversity indexes

Layer:	**Herbs**								
parameters	**reference**		**all sites**		**Atlantic**		**Mediterranean**		**Continental**
	sign	trend	sign	trend	sign	trend	sign	trend	sign
inv.simpson	ns		ns		ns		*	↓	ns
spec.nr.	ns		ns		***	↓	ns		ns
eveness	ns		ns		**	↑	*	↓	ns
Layer:	**Shrub**								
parameters	**reference**		**all sites**		**Atlantic**		**Mediterranean**		**Continental**
	sign	trend	sign	trend	sign	trend	sign	trend	sign
inv.simpson	ns		ns		ns		ns		ns
spec.nr.	ns		ns		ns		ns		ns
eveness	ns		ns		ns		ns		ns
Layer:	**Tree**								
parameters	**reference**		**all sites**		**Atlantic**		**Mediterranean**		**Continental**
	sign	trend	sign	trend	sign	trend	sign	trend	sign
inv.simpson	***	↑	*	↑	**	↑	ns		ns
spec.nr.	**	↑	*	↑	**	↑	ns		ns
eveness	***	↑	*	↑	**	↑	ns		ns

The differences of both the species composition and the species coverage were tested between Natura 2000 and non Natura 2000 stands in total as well as within each biogeographical region (Table 20). The first part of the table shows test results of comparison between Natura 2000 and non Natura 2000 regarding the coverage of the present species. Here we compared coverage of the species have been found in both (Natura 2000 and non Natura 2000) forest stands. The species which were present only once within the stands (Natura 2000 or non Natura 2000) were exclude from this analysis. The trend arrow up - indicate an increased coverage inside of Natura 2000 compared with non Natura 2000. The arrow down shows the opposite tendency.

The second part of the table shows results regarding species composition by comparison Natura 2000 and non Natura 2000 stands. Here we compared basically name lists of present species. The trend arrow was used in context with number of present species. For example the arrow down means less species within Natura 2000.

The herbal layer indicates less coverage, less species as well as different species composition in comparison between Natura 2000 and non Natura 2000 in total. But this result was clearly due to Atlantic sites only. Neither Mediterranean nor Continental sites could confirm this tendency. The Mediterranean sites indicate even opposite trend regarding species coverage (Table 20).

The tree layer indicates the significant difference of species composition as well as tree species coverage between Natura 2000 and non Natura 2000 within the Atlantic biogeographical region only (Table 20). Neither Continental nor Mediterranean biogeographic region indicates some statistical significance of the tree layer. No case of significance was found regarding the shrub layer.

Table 20. Differences between Natura 2000 and non Natura 2000 regarding present species and species coverage

	differences between Natura 2000 and non Natura 2000 regarding species coverage							
	all sites		**Atlantic**		**Mediterranean**		**Continental**	
herblayer	**	↓	**	↓	**	↑	n.s.	
treelayer	n.s.		*	↑	n.s.		n.s.	
shrublayer	n.s.		n.s.		n.s.		n.s.	
	differences between N2 and non N2 regarding species composition							
	all sites		**Atlantic**		**Mediterranean**		**Continental**	
herblayer	**	↓	***	↓	n.s.		n.s.	
treelayer	n.s.		*	↑	n.s.		n.s.	
shrublayer	n.s.		n.s.		n.s.		n.s.	

Significance codes: '***' 0.001 '**' 0.01 '*' 0.05 ; (ns = not signif.)

3.5.2 Evaluation of the ground vegetation as an environmental indicator within Natura 2000 and non Natura 2000 forest stands

3.5.2.1 All sites overview over the herb layer of Natura 2000 and non Natura 2000 stands

The ordination map for all study sites together shows strongly overlapping areas of Natura 2000 and non Natura 2000 stands, which generally confirm the trends of the structural analysis (see chapt. 2): separation of Natura 2000 from non Natura 2000 forest stands occur only in few cases (Figure 53). At the first line it was the case by established plots of non Natura 2000 stand located within the Nebrodi National Park on Sicily, which are the warmest plots of the whole dataset (bottom area of the ordination map), as well as Natura 2000 plots from the North Slope of Mount Etna, which are the highest located and most southern plots of whole dataset. This both outstanding cases were certainly due not to the actual Natura 2000 effect but to the environmental impact as well as historical management and took place within the Mediterranean biogeographic region.

On this point we must notice, that the axis 2 separates the Mediterranean biogeographic region from the other two regions completely. The ordination map shows clearly that the biggest differences according to the ground vegetation occur inside of the Mediterranean biogeographic region.

In contrast to the Mediterranean plots (on the right side of axis 2), we can see very evenly scattered and close to each other positions of the Atlantic and Continental plots. Here we can´t see clear differentiation between Natura 2000 and non Natura 2000 from this perspective. The overlapping area between Atlantic and Continental sites seems to be also significantly big. By contrast the separation of Mediterranean sites from both other biogeographical regions is very clear to see in the ordination map (Figure 53). The presented ordination map was created taking account of several parametrical data. Some of them like species number of the ground vegetation or evenness of the tree species seem not to indicate clear trend vectors. Nevertheless, a significant number of parameters indicates trend vectors, which can be observe on the ordination map (Figure 53).

All in one the ordination result up to now indicates no significant influence of Natura 2000 management according to the understory vegetation of the beech forest stands. A certain differentiation between the single stands and geographical locations occurred due to environmental and historical factors.

The following parameters can be seen on the graph as vectors:

- beech regeneration seeds - regeneration seeds of *F. sylvatica*
- alt - altitude
- T_yr - annual temperature
- deadwood - deadwood volume
- BHDmax - maximum DBH
- Hmax - maximal height
- stems - number of stems over 20 cm DBH
- basal area
- top closure
- bark - bark defects due to management
- jherb - evenness of herb species
- spherb - species number within the tree layer
- microhabitats - total microhabitat frequency
- closed - frequency of the closed microhabitats
- Hedera helix - percentage of stems with *Hedera helix* on them

The most remarkable vectors are altitude, annual temperature, maximal tree height and sociability of *Fagus syvatica* regeneration seeds. Those vectors seem to indicate main trends within the ordination map. By closer observation of those main vectors, we found that sociability of regeneration seeds is strongly negative correlated to the annual temperature. This trend could be observed also in DCA maps of the microhabitat with projected parameters (see chapt. 2.5.4). In contrast to regeneration seeds (see description chapt. 3.4.1), the number of stems, total microhabitat frequency as well as the closed microhabitat frequency was strongly positive correlated to the annual temperature. Generally 50% of significant vectors increase into the direction of Atlantic and Continental sites and other 50 % into the direction of Mediterranean sites. The main part of the vectors increasing into the direction of Mediterranean sites is positive correlated with the annual Temperature.

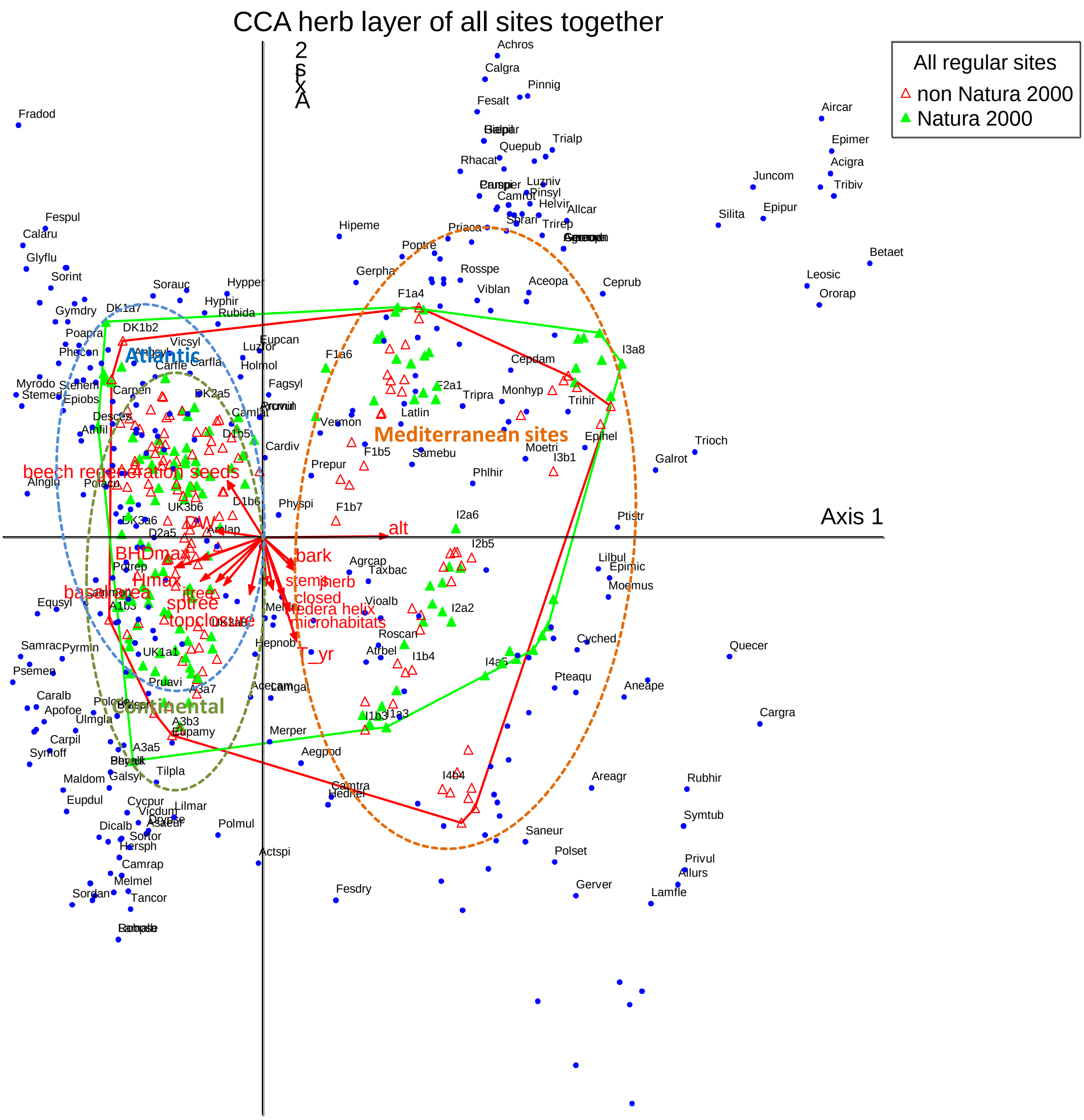

Figure 53. CCA ordination for all study sites together according to the ground vegetation

Description of the polygonal visualization and detected concentration areas:

Natura 2000 location area;

non Natura 2000 location area;

blue ellipse – concentration area of the Atlantic biogeographical region;

green ellipse – concentration area of the Continental biogeographic region;

brown ellipse – concentration area of the Mediterranean biogeographic region.

3.5.2.2 Herb layer of the Natura 2000 and non Natura 2000 stands in the Atlantic biogeographical region

The ordination map indicates no clear differentiation by Natura 2000 status (Figure 54). Also here we see an almost completely overlapping of Natura 2000 and non Natura 2000 plots. Mostly all plot locations on the ordination map are not grouped but scattered evenly. Generally, the main part of all Atlantic evaluation plots is located on the left of axis 2. Especially UK indicates only the one non Natura 2000 plot on the right side. Danish evaluation plots seem shifted more to the right. Nevertheless, they still are mostly on the right side as well.
All vectors are positive correlated with each other on the axis 1. The axis 2 indicates more differentiations between vectors. Also here we have got a negative correlation between annual temperature and sociability of regeneration seeds of the beech. In this case, the top closure is positive correlated to the regeneration seeds of *Fagus sylvatica*. The total number of microhabitats indicates a close positive correlation to the annual precipitation. The frequency of the closed microhabitats confirms this trend in general, but indicates even closer correlation to the altitude, *Hedera helix* presence on trees and evenness of the herb layer species.
The significance border of the vectors was calculated regarding Sachs (see chap. 2). The 12 following parameters can be seen on the ordination as vectors:

- T_yr - annual temperature
- P_yr - annual precipitation
- microhabitats - total microhabitat frequency
- closed - closed microhabitat frequency
- jherb - evenness of herb species
- jtree - evenness of tree species
- sptree - species number of the tree layer
- Hedera helix - presence of *Hedera helix* on tree stems
- stems - number of stems over 20 cm DBH
- top closure

Following parameters indicate no significant vectors within the Atlantic biogeographical region.

- BHDmax - maximum DBH
- basal area
- bark - bark defects due to management
- Hmax - maximal tree height
- spherb - species number of the ground vegetation

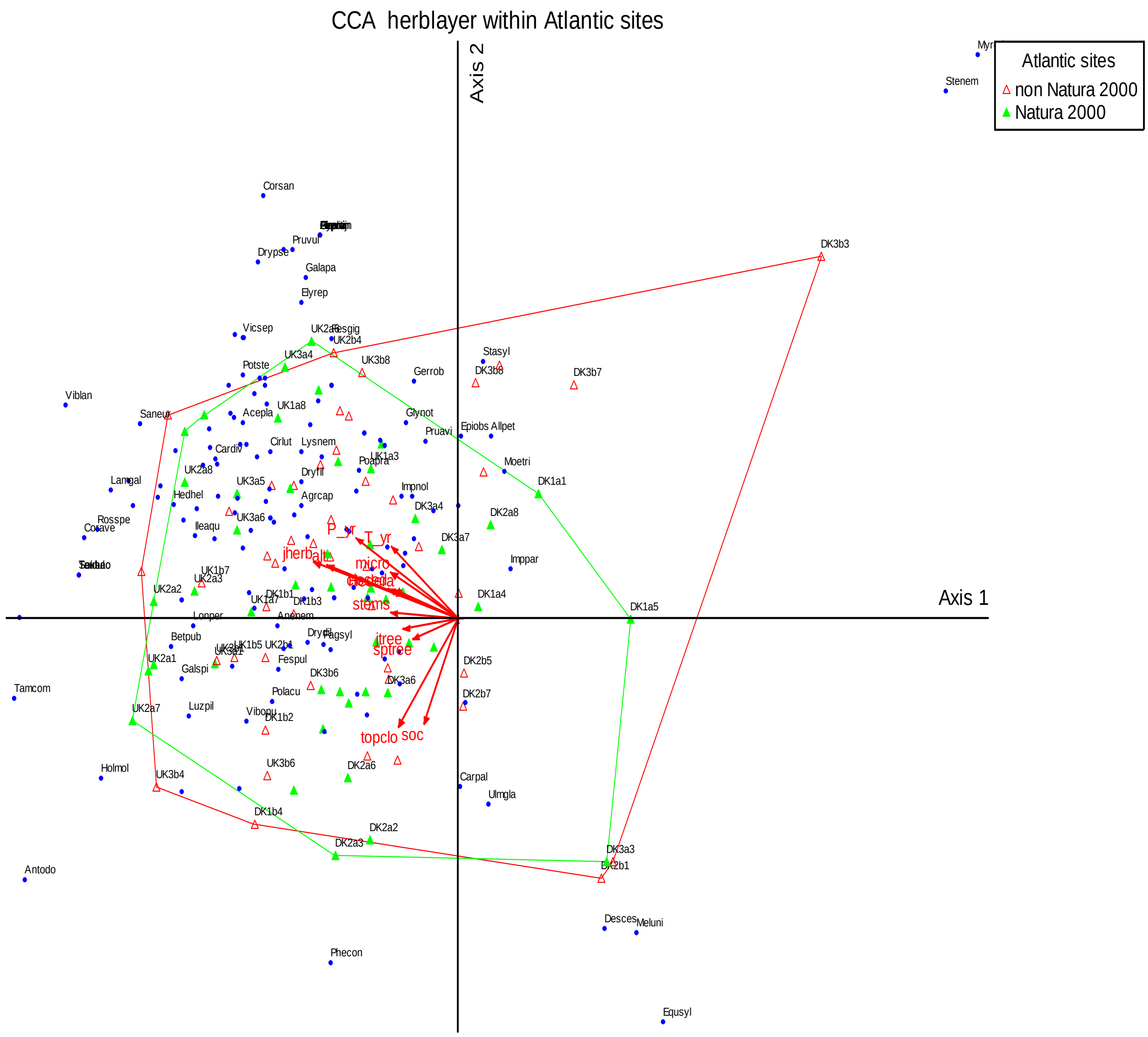

Figure 54. CCA ordination of Atlantic study sites according to the ground vegetation

Description of the polygonal visualization:

Natura 2000 location area;

non Natura 2000 location area;

No single concentration areas detected

3.5.2.3 Herb layer of the Natura 2000 and non Natura 2000 stands in the Mediterranean biogeographical region

As has been mentioned before, the Mediterranean biogeographic region is a special case, because most differences we found were due not to Natura 2000 status at all but seem mainly due to differences of the environmental factors between single sites concentrated within the Mediterranean biogeographic region. Generally the ordination detects no significant differentiation trends according to the Natura 2000 status. The most plot locations of Natura 2000 as well as non Natura 2000 mixed within the paired study sites and indicate significant overlapping areas. But in contrast to the situation within the both other biogeographical regions, here we see a clear separation trend of the paired study sites from each other by building separately located point clouds (Figure 55). This trend occurred especially due to the significant environmental differences between Italian study sites. The outstanding case is the warmest study site I4, located within the NP Nebrodi on Sicily (orange ellipse – Natura 2000 stand, orange dotted ellipse – non Natura 2000 stand). Here we see the clear separation of Natura 2000 plots (I4a) from the non Natura 2000 (I4b) due to the temperature. French study sites indicate no similar trends. Quite the opposite, here we see the one point cloud for all French sites, which is evenly scattered and shows no significant differentiation between the single sites (Figure 55, blue ellipse bottom right).

The vectors of used parameters from the second matrix clearly underline environmental factors like temperature, precipitation and altitude as the trend building elements within the ordination scale. All other visible vectors within Mediterranean biogeographical region in connection to the ground vegetation, seems to be influenced mainly by those 3 environmental elements. Following parameters indicated significant vectors within on the ordination scale within the Mediterranean biogeographic region:

- Hmax - maximal tree height
- BHDmax - maximum DBH
- basal area
- top closure
- stems - number of tree stems over 20 cm DBH
- Hedera helix on trees - *Hedera helix* on tree stems
- microhabitats - total microhabitat frequency
- bark - bark defects due to management
- Fagus regeneration seeds - beech regeneration seeds
- jherb - species evenness of the ground vegetation
- invherb - inverse Simpson diversity index of ground vegetation
- herb species - species number of ground vegetation
- deadwood - deadwood volume

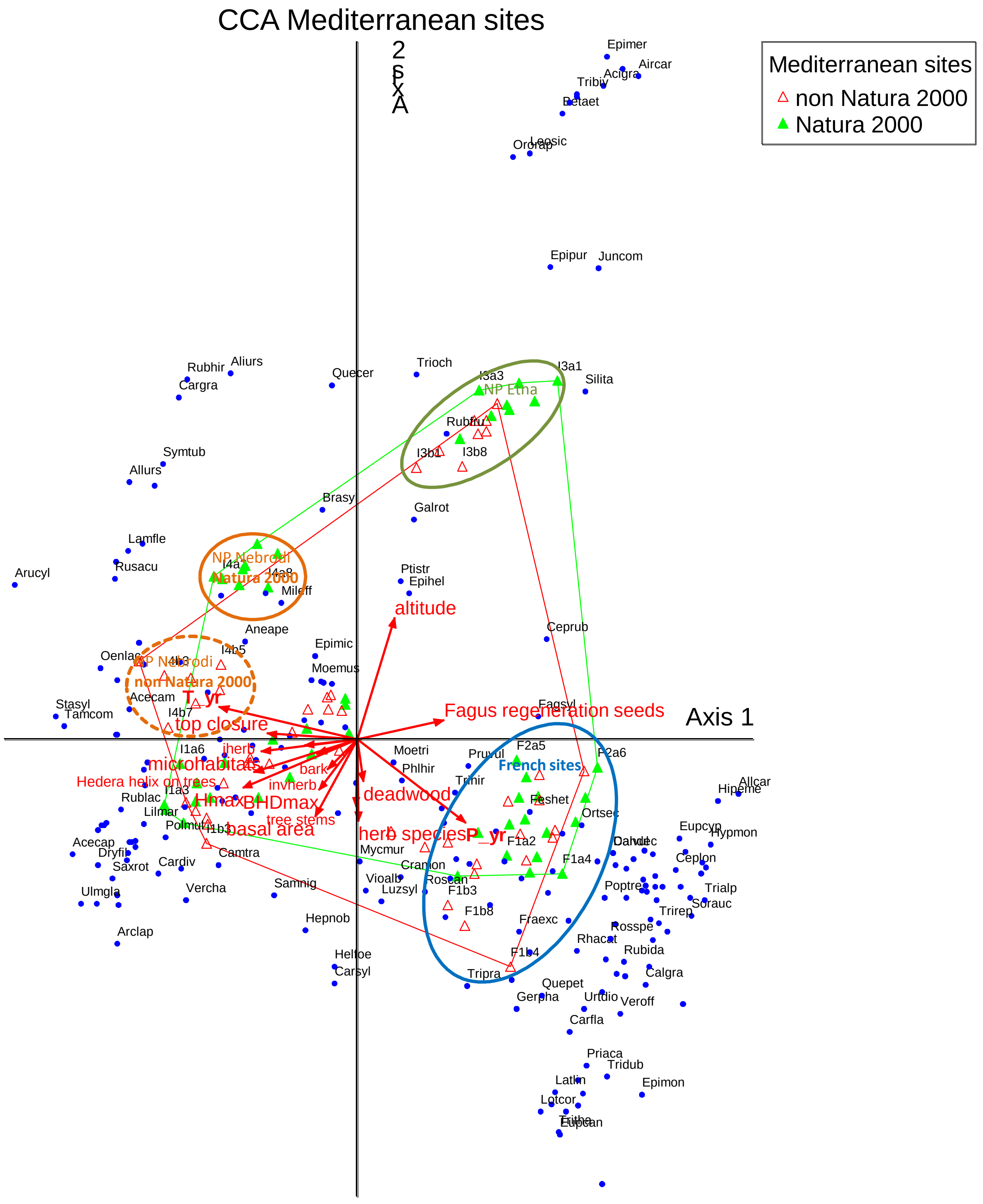

Figure 55. CCA ordination map of study sites within Mediterranean biogeographic region regarding ground vegetation

Description of the polygonal visualization and detected concentration areas:

Natura 2000 location area;

non Natura 2000 location area;

blue ellipse – concentration area of all french stands;

green ellipse – concentration area of sitands located in Ethna national park (I3);

brown ellipse, solid line – concentration area of Natura 2000 stand located in Nebrodi NP (I4a);

Brown ellipse, dotted line – consentration area of the non Natura 2000 stand located in Nebrodi NP(I4b).

3.5.2.4 Herb layer of the Natura 2000 and non Natura 2000 stands in the Continental biogeographical region

Continental sites are represented by Germany and Austria. The used ordination method sows no significant differentiation between Natura 2000 and non Natura 2000 stands (Figure 56). Just like all other ordinations of used Continental study sites also in this case the Natura 2000 area (green polygon) and non Natura 2000 (red polygon) build a big overlapping area, which generally confirms no significant differences regarding ground vegetation between Natura 2000 and non Natura 2000 stands.

The ordination map of all study sites together (Figure 53) shows a very close distribution of Atlantic and Continental sites and indicates some separation trend from the Mediterranean biogeographic region. Nevertheless, unlike Atlantic study sites, which build one, more or less, evenly scattered point cloud (Figure 54), the locations of the Continental plots indicate 3 concentration areas. Upon closer observation, however, we can see that German and Austrian study sites show different behavior (Figure 56). German evaluation plots located close to each other and build one point cloud. On the other side Austrian evaluation plots build two separately located point clouds, indicated by green ellipse (A1) and orange dotted ellipse (A3). A3 stand is located close to the eastern range of the *Fagus sylvatica* distribution area. The strongly dominant position, which *Fagus sylvatica* use to have within the European Continental biogeographical region, seems to be weakened at this point. Similar like in the case of Mediterranean biogeographic region we have here one study site as the Edge and two as Interior according to the current natural distribution of the European beech forests. The vectors of annual temperature as well as tree- and herb species numbers are increasing into the direction of this Austrian study sites. On the other side, the climatic favorability index, maximal tree height and sociability of beech regeneration seeds are increasing into the direction of the German sites, which is the opposite direction. Also the floristic composition indicates an increasing influence of the Pannonial floral province. Such species like *Cornus alba, Festuca drymeia, Dictamnus albus* are present only within the A3 stand. As well as the presence of other tree species within the top layer independent of the Natura 2000 status. The other Austrian sites, which located within the area with high precipitation rate, is situated much close to German stands, but still pretty clear separated. Most of structural parameters on the ordination map indicate the positive correlation to the annual precipitation. Especially the maximal tree height goes in the same direction. But also other important structural parameters like maximum DBH, basal area and the top closure seem to increase into the direction of A1 independent of the Natura 2000 status. Neverthless, the environmental favorability index for *Fagus sylvatica* seems to increase more into the direction of German sites. This can explain also the increasing of Fagus sylvatica regeneration seeds indicated by vector “soc”.

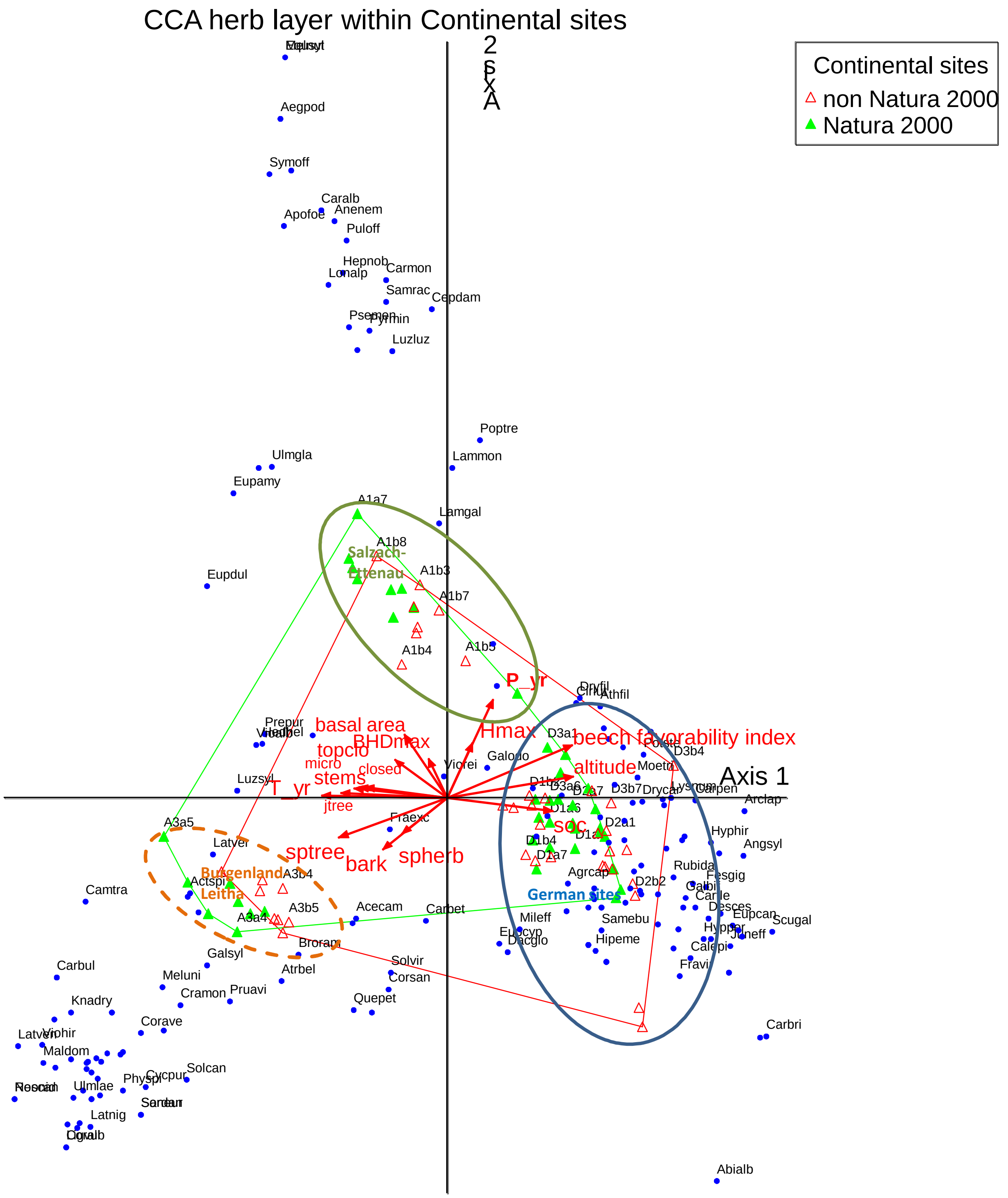

Figure 56. CCA ordination map of the continental sides regarding ground vegetation

Description of the polygonal visualization and detected concentration areas:

Natura 2000 location area;

non Natura 2000 location area;

blue ellipse – concentration area of all german stands;

green ellipse – concentration area of the Salzach –Ettenau site (A1);

brown ellipse, dotted line – consentration area of the Leitha site (A3).

Following vectors of parameters from the second matrix were shown on the ordination of Continental biogeographical region:

- P_yr - annual precipitation
- T_yr - annual temperature
- altitude
- beech favorability index - favorability index for *Fagus sylvatica*
- soc - sociability of beech regeneration seeds
- Hmax - maximal tree height
- BHDmax - maximal DBH
- topclo - top closure
- basal area
- bark - bark defects due to management
- stems - number of stems over 20 cm DBH
- mirco - total microhabitat frequency
- closed - closed microhabitat frequency
- sptree - tree species number
- spherb - species number of ground vegetation layer
- jtree - evenness of species within the tree layer
- jherb - evenness of species within the herb layer

3.5.3 Natura 2000 effects on the plant diversity

The modeled effect of Natura 2000 on the species diversity was analyzed by applying the generalized linear mixed model in connection with species number; inverse Simpson diversity index as well as evenness. The result summary of the modelled effects has been provided in form of tables 23 to 25, which contains significance codes of the p-values according to following classification:
0 '***' 0.001 '**' 0.01 '*' 0.05 'n.s.' 0.1 'n.s.' 1

The column "effect" indicates the exposition of the effect, which means positive (↑) or negative (↓) effect of Natura 2000. The found results were separated into 3 sections ordered regarding vegetation layers as following:

- tree layer
- herb layer
- shrub layer

On the current stage no significant effects of Natura 2000 on the **tree species** diversity were detected within the tree layer (Table 21, for site ID see Table 1).
In contrast to the tree layer, we found clearly significant effects of Natura 2000 on the species number of the **herb layer (**Table 22, for site ID see Table 1). The other used diversity parameters show no cases of significance. Table 22 shows results of the modelled effects. The applied model indicates a significant effect of Natura 2000 on the species number within the herb layer of 12 out of 17 study sites. 11 sites out of

the 12 sites with significant effect indicate a negative influence of species number within the herb layer by Natura 2000, which could be valued as a natural development trend. In contrast to non Natura 2000 stands, occurrence of certain tree species like *Betula* and *Populus* as well as grasses like *Bromus* spec., *Phleum* spec., *Dactylis* were usually missing within Natura 2000 stands (Table 22, for site ID see Table 1).

We found only one case of significance regarding the modelled Natura 2000 effect on the diversity of the **shrub layer**. Here we detect the effect also in connection with the species number. The other used diversity parameters show no cases of significance. The only one significant effect was detected within the most southern German study site located closed to Dießen am Ammersee (southern Bavaria). This outstanding result can be explained by historical background. As a consequence we observe high frequencies of Nitrogen-indicating species like Sumbucus nigra within the shrub layer of Natura 2000 stand. However, neither tree layer nor herb layer confirm these trends.

Table 21. GLMM results regarding the Natura 2000 effect on tree layer

tree layer	species number		inverse Simpson index		evenness	
Site ID	effect	significance	effect	significance	effect	significance
A1	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
A3	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
D1	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
D2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
D3	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
DK1	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
DK2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
DK3	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F1	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
I1	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
I2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
I3	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
I4	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
UK1	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
UK2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
UK3	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 22. GLMM results regarding Natura 2000 effects on herb layer diversity

herb layer	species number		inverse Simpson index		evenness	
site	effect	significance	effect	significance	effect	significance
A1	↑	**	n.s.	n.s.	n.s.	n.s.
A3	↓	*	n.s.	n.s.	n.s.	n.s.
D1	↓	*	n.s.	n.s.	n.s.	n.s.
D2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
D3	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
DK1	↓	***	n.s.	n.s.	n.s.	n.s.
DK2	↓	**	n.s.	n.s.	n.s.	n.s.
DK3	↓	**	n.s.	n.s.	n.s.	n.s.
F1	↓	**	n.s.	n.s.	n.s.	n.s.
F2	↓	**	n.s.	n.s.	n.s.	n.s.
I1	↓	**	n.s.	n.s.	n.s.	n.s.
I2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
I3	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
I4	↓	***	n.s.	n.s.	n.s.	n.s.
UK1	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
UK2	↓	***	n.s.	n.s.	n.s.	n.s.
UK3	↓	***	n.s.	n.s.	n.s.	n.s.

Table 23. GLMM results regarding Natura 2000 effects on shrub layer

shrub layer	species number		inverse Simpson index		evenness	
site	effect	significance	effect	significance	effect	significance
A1	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
A3	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
D1	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
D2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
D3	↑	*	n.s.	n.s.	n.s.	n.s.
DK1	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
DK2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
DK3	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F1	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
F2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
I1	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
I2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
I3	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
I4	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
UK1	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
UK2	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
UK3	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

3.6 Discussion

The environmental problematic of modern forest management focusing on loss of old forests, simplification of the forest structure, decreasing size of the forest areas and increased road buildings, all which have had negative effects on the native forest ecosystems (Noss 1999). These trends represent an important impulse to implementation of the Natura 2000 network (EU Commission, 2000). The number of studies about this matter increase since the implementation of Natura 2000. A part of these studies indicate the irreversible impact of former land management on forest soils and biodiversity (Dupouey et al. 2002). However, most other ecological studies about conservation strategies of the native forest biodiversity show that these trends can be reversed, or at least slowed, through better management (Noss 1999). Suitable data and methods are still needed to proof the question of the sustainability of European management and conservation strategies for beech forests on the international level.

Forestry today is characterized by low flexibility and low resilience due to the highly optimized harvesting of tree resources (Moen 2010). To assess the key changes in the forest development it is necessary to analyze conditions and composition of the tree layer precise and careful (Eilmann & Rigling 2012). We used the tree layer as a long time indicator to investigate the actual impact of Natura 2000 on the top layer vegetation within our study sites. Here we focus on far-reaching effects of the Natura 2000 management within the tree layer, which is not yet significant. This result was close to those observed by Zehetmair et al. (2014). Detected differences between Natura 2000 and non Natura 2000 are mostly indicating the long term conservation history or/and environmental impacts. So we found that those sites, which have been protected already long before Natura 2000 had been implemented, indicated higher percentage of important accompanying species (like *Q. petrea, Q. robur, F. excelsior, T. platyphyllos, T. cordata, A. pseudoplatanus, A. platanoides* etc) within the tree layer, that means in the same time higher natural biodiversity. Indeed, we expected higher biodiversity within the **tree layer** because of Natura 2000 effect (H3.1). But this main expectation cannot be yet confirmed by our investigation regarding all study sites.

Other case studies have shown that in undisturbed, unmanaged deciduous forests, species diversity of the herb layer at first decreases, while cover and species number of the shrub and herb layer increase (Schmidt 2007). To see the fine short time trend and indications of some recovery processes we focused on the **herb layer** as a short time indicator. Our results show, that the biggest differences of the herb layer within the Continental and Mediterranean sites occur not between Natura 2000 and non Natura 2000 stands but between site locations. Similar effects were observed by some dendro-climatological studies around Europe (Jump et al. 2010; Geßler et al. 2006; Hantley & Bertlein 2013). Especially sites on the edge of the European beech forests distribution within these biogeographical regions (Burgenland - Leitha, NP Etna, NP Nebrodi), which are located close to the edge of the beech forest distribution indicate separation trends due mainly to environmental factors. The only significant separation trend between Natura 2000 and non Natura 2000 can be seen on the ordination map of the Mediterranean biogeographical region (Figure 55). This ordination clearly recognized the reason of this separation, which is not the actual effect of Natura 2000 management but mainly the annual temperature (Figure 55, vector T_yr).

Also Atlantic sites have shown indication of the environmental variables like annual temperature and precipitation, which may influence the forest development upside the management strategy (see Figure 54, vectors P_yr and T_yr). But in contrast to Mediterranean as well as Continental biogeographical region, Atlantic sites show no such a significant differentiation driven by environmental variables or some other factors. However, the scattering of all Atlantic sites still is quite even, so we couldn´t clearly separate Danish from British sites (Figure 54). Nevertheless, we found clear effects on the herb layer in connection with Natura 2000 trough analyses with the help of generalized linear mixed models.

We hypothesized that the Natura 2000 would have a negative effect on species diversity of the **herb layer** (H3.2), which would confirm to the natural legacy of *Asperulo-Fagetum* beech forests by excluding of non-typical species (Mölder et al. 2008).

Our model detected 12 out of 17 study sites with significant effects. Only one case indicated a positive effect trend (see description chapt. 3.5.3) on the species number in connection with Natura 2000 status. This special case was found on the study site A1 (Austria) and may cause of the windfall within the Natura 2000 stand. All other detected cases of significance (Table 22) indicated a decreasing trend of the herb layer diversity within Natura 2000 stands. As has been mentioned, exactly such a trend has been hypothesized under H3.2 (chapt. 3.2). By analyzing of the modeled effects within each study site we determined 5 out of 6 Atlantic sites, 4 out of 6 Mediterranean sites and 3 out of 5 Continental sites with a significant Natura 2000 effect on the species number of the herb layer. In this way we can see that the herb layer may be able to indicate developmental changes earlier as the tree layer and is indeed suitable as a short time indicator in this context.

Nevertheless, not all detected significant differences between Natura 2000 and non Natura 2000 stands could be explained by the current effect of the Natura 2000 management only. Regarding our observations, especially within study sites, which use to be located close to the distribution edges, environmental events and the landscape features, represent an important impact factors for the biodiversity of the forest vegetation. Also abiotic gradients like elevation play an important role for forest dynamic (Bergmeier & Dimopoulos 2001). The soil biota effects on vegetation dynamic vary significantly among the elevation (Defossez et al. 2011). These aspects must be investigated to accurately represent and predict the effects of abiotic gradients like elevation on plant communities (Defossez et al. 2011). The mentioned factors cannot be evaluated as actual effects of Natura 2000 but seem often to be responsible for the dynamic changes within the ground vegetation. According to all mentioned we summarize that the developmental progress Natura 2000 strategy aims on, is not yet consistently occurred within all Natura 2000 sites. Nevertheless, this kind of progress has been successfully supported by Natura 2000 management in case of forest stands with a long conservation history.

3.7 Summary

This is the first comprehensive study of the effects of Natura 2000 on European beech forests encompassing three biogeographical regions, with emphasis on *Asperulo-Fagetum* beech forests. We provide a framework for assessment, results and data for future monitoring of Natura 2000 effects within different biogeographical regions. In this chapter we deal with vegetation indicators to detect tangible effects in connection with Natura 2000. We tested the differences between Natura 2000 and non Natura 2000 stands regarding species diversity within the three vegetation layers (tree, shrub and herb layer). By comparing of Natura 2000 and non Natura 2000 stands we found consistently differences of top layer (trees) diversity within the Atlantic biogeographical region only. Hereby all used diversity indexes of the tree layer indicate significant differences inside of Atlantic biogeographical region. Also the species number of the herb layer shows significant difference within the Atlantic biogeographical region only. But in the opposite of the tree layer, the herb layer indicates higher species number outside of Natura 2000. The tests of species composition and coverage confirmed these results as well. Additionally we found some reversible trends within the Mediterranean sites compared to the Atlantic biogeographical regions. For example we found that the herb species coverage was significantly lower inside of Natura 2000 within Atlantic biogeographical region but in the same time significantly higher within Mediterranean biogeographic region. No one of the tested parameters indicated some differences between Natura 2000 and non Natura 2000 within the Continental biogeographical region.

In terms of ecological legacy of the *European beech forests* we focused on the herb layer as a short time indicator and evaluated ordination maps of the current situation within the herb layer regarding Natura 2000 status using CCA ordination technique. We integrated environmental as well as structural variables to detect the main drivers for indicated trends and differences. The ordinations show no consistently separation trends between Natura 2000 and non Natura 2000 regarding the herb layer. The differences between single study sites are more significant than between Natura 2000 and paired non Natura 2000 stands. The ordination results show separation trends mostly between study sites within the Mediterranean and Continental biogeographical regions. Especially the marginal sites, located close to the edge of the beech forest distribution, were separated from the others independent of the Natura 2000 status. The ordination map of Atlantic sites shows a quite even mixed point cloud without any clear differentiation trends. Also Natura 2000 stands indicated a big overlap with non Natura 2000 stands. The environmental factors like temperature, precipitation and altitude seem to have a stronger influence on parameters like top closure and the species evenness of the herb layer within the Mediterranean as well as the Continental biogeographical region than the Atlantic biogeographical region.

We didn´t find any significant effects of Natura 2000 management within the tree layer and only one case of significance within the shrub layer. But we found significant effects on the species number within the herb layer in 12 out of 17 cases in connection with Natura 2000 status. Not all of these effects could be interpreted as an impact of Natura 2000. A big part of these effects should be explained by environmental impact as well as historical management (for example within most of the Atlantic sites). Nevertheless, the significant number of detected effects in connection with Natura 2000 could indicate starting recovery processes. The time since Natura 2000 implementation up to now is too short to show the clear impact of Natura 2000 management on the beech forest vegetation.

4 Final discussion

Natura 2000 became the main pan-European instrument for conservation and supporting of the natural biodiversity (Ibisch & Kreft 2008). European network for nature conservation, called Natura 2000, consisting of 'special protection areas' (SPAs) under the Birds Directive 79/409/EEC and the forthcoming 'special areas of conservation' (SACs) under the habitats directive (COMMISSION OF THE EUROPEAN COMMUNITIES, 2003). The pan-European biological and landscape diversity strategy (PEBLDS) was developed by the council of Europe and adopted at the Ministerial Conference in Sofia in 1995 (Council of Europe 1996). The main and most important aim of Natura 2000 is a long term protection of natural habitats and natural biodiversity in Europe with taking account on social as well as economic interests (Brocksieper & Woike 1999). Habitats and species for which Natura 2000 sites are designated must be maintained in a 'Favourable Conservation Status', which is defined in the Habitats Directive (Ostermann 1998).

Before we start discuss current effects of Natura 2000 on the European beech forests, so it's necessary to take a look on the historical background and needs of environmental conservation in Europe. Nature conservation became a part of the international European policy already at the beginning of this century (Jonsson et al. 2011). However, after the second war the nature conservation policy of European nations went into different directions (Jongman 1999). First of all, the non-government organizations started the reintegration process on the European level (Jonsson et al. 2011). The important step in this integration process was the creation of effective Pan-European instruments for the regulation and development of the sustainable nature conservation policy with the focus on problems like loss of old forests, simplification of the forest structure, decreasing size of the forest areas and increased road buildings within the forest ecosystems, all which have had negative effects on the native forests (Noss 1999). These trends are the reason to implementation of the Natura 2000 network (EU Commission, 2000). Natura 2000 became one of the main instruments in this context (Hettwer et al. 2009). The natural forest development itself is a long term process (Burrascano et al. 2008), which needs a consistently and objective oriented cooperation of all European governments (Luxmoore et al. 2008). The framework of Natura 2000 makes this kind of cooperation necessary. The presented study is a part of an international project, which links the policy and ecological science as well as transfer suggestions and experience to decision makers. Our study confirms that the protection of the remaining forests that have largely escaped the impact by human for 30 years or longer and came now under Natura 2000 management, indicate already now recovery tendencies (Jonsson et al. 2011). Especially within the Atlantic biogeographical region we find positive ecological indications regarding both structural and vegetation parameters. In contrast to most of Atlantic study sites, both Mediterranean and Continental sites show no consistently recovery processes up to now. Is the Natura 2000 beech forest management successful not everywhere in Europe? Is Natura 2000 really an effective instrument to support the natural biodiversity of the beech forests? Are previously management strategies more different as expected? Had the Natura 2000 management enough time to show the natural recovery of the European beech forests up to now? In this study we tried to look on these questions from different points of view.

Mainly because the European policy makers start to focus on these questions during last years, the number of studies about conservation of native forests in Europe increased significantly (COMMISSION OF THE EUROPEAN COMMUNITIES 2009). Up to now that fact can be viewed as positive impulse for the conservation strategy in whole Europe. In order to keep up with the development of the scientific knowledge we analyzed around 64 selected scientific articles of European studies alone about the related assessment strategies for forest conservation and support of the natural biodiversity. According to this research we could categorize mentioned studies in 3 general groups. The first of them are studies mainly focusing on the biodiversity as the ecological indicator (Chiarucci et al. 2008; Rondeux & Sanchez 2010; Lindenmayer et al. 2000; Humphrey & Watts 2004; Brunet et al. 2010). The other group of studies has the fragmentation of the habitat as the main factor (Fischer & Lindenmayer 2007; Fischer et al. 2013; Ask & Carlsson 2000; Harper et al. 2005; Jones-Walters & Čivić 2013; Petercord & Joachim 2006). And the last one dealing mainly with structural components like tree growth, microhabitats and deadwood as the key indicator (Nocentini 2009; Fakult 2002; Hanson et al. 2012; Kirby et al. 1991; Vuidot et al. 2011).

The framework of this dissertation allows combining our key points around the structural features (see chapt. 2) as well as vegetation parameters (see chapt.3). To our knowledge, it is the first scientifically reliable large-scaled approach for assessing the Natura 2000 effect on the European beech forests, in terms of the ecological indication of biodiversity on self-collected data. Additionally to the mentioned objects of our study we have to notice, that the actual research was designed in close cooperation with a number of other socio-ecological, dendro-genetic as well as zoological studies having a compatible study design and data structure (see www.befofu.org). Nevertheless, we must notice, that many important factors, which are influencing forest development within the Natura 2000 network are not sufficiently explained in our researches. One of the major problem in this matter is habitat fragmentation (Jones-Walters & Čivić 2013). In our opinion, the effect of Natura 2000 from this point of view is not enough described. The majority of the todays studies focuses on the biodiversity as an success indicator for the conservation strategy (Lindenmayer et al. 2000). Nevertheless, the landscape itself and the area covered by the habitat may influence the development of the biodiversity significantly (Granke & Kenter 2009). The results presented in this dissertation describe by far not all possible effects, which could be important to indicate the sustainability of Natura 2000 for the beech forests. However we see it as a contribution to sustaining the European forest management.

Regarding the mentioned influence on the beech forests we assume that the Natura 2000 effects still is highly inconsistent and can be restricted on the areas being managed as long time protected forests. Due to historical reasons almost all of the Natura 2000 beech forest stands, located within the Atlantic biogeographical region, were under protection long before Natura 2000 became implemented. Only here we

have observed significant differences of the forest management between Natura 2000 and non Natura 2000 stands. This impression was consistently confirmed by statistical analyzes on microhabitat diversity, tree growth, deadwood, plant composition and other indicators. Only here we find the differences between Natura 2000 and non Natura 2000 more significant than the differences between single study site locations. On the other hand, because of detected natural diversification of the habitat structure within such long term protected forests reserves like Lady Park wood in UC; we can speak about future effects of Natura 2000 on the local level. Continental sites show similar low differences between single study site locations, however, much lower differences regarding Natura 2000 status. For studied Continental forest stands we couldn´t find any consistent effects of Natura 2000 regarding collected parameters. The Mediterranean biogeographical region indicated the biggest differences between single site locations indifferent to the Natura 2000 status. After the analyzes of divers additional data, like temperature, precipitation, as well as climate favorability index for *Fagus sylvatica* (http://margins.ecoclimatology.com) and landscape features, we assumed that the differences of landscape and climate between the study sites here are significant higher than within Atlantic and Continental biogeographical region. At the same time, the management within and outside of Natura 2000 seems to be basically the same, or became shortly different. Generally it is known, that the difference in species richness between unmanaged and managed forests increased with time since abandonment and indicated a gradual recovery of biodiversity (Paillet et al. 2010). However, we cannot yet explain detected differences between Mediterranean Natura 2000 and non Natura 2000 stands by the effect of Natura 2000 or previously conservation strategy, as it is the case within the Atlantic biogeographical region. Nevertheless, we assumed that the climate conditions became the dominant factor influencing the beech forests. Especially plant diversity, tree growth and vertical structure vary according the climate gradient. The favorability index for *F. sylvatica* (http://margins.ecoclimatology.com), which proved to be useful to detect the possible effect of the climate conditions on beech and other tree species (Kölling et al. 2009), shows the biggest variability among Mediterranean study sites, than all over other biogeographical regions. Regarding all mentioned, we assumed that studied Mediterranean beech forests are influenced by climate and landscape conditions more than by any other factors up to now. The suitability of those trends was generally confirmed by accompanying zoological study on bets and saproxylic beetles (Zehetmair et al., in prep., 2014).
To summarize all mentioned, the time has not yet come to see or evaluate the success of Natura 2000 beech forest management. Nevertheless, differences of the previously management seem to have far-reaching influences on current forest conditions. So Natura 2000 stands with a long term low use traditions show under Natura 2000 already now trend of natural recovery. Otherwise, the stands, which became a protected area by implementation of Natura 2000, needs significantly longer time to make the natural processes visible for our assessments. An historical understanding is necessary to comprehend current relation between resource use and natural recovery (Moen 2010).

5 Abstract

In the context of the project we established a scientific case study aimed to analyze the possible effect of Natura 2000 on European Beech Forests within the three major biogeographical regions. UK and Denmark represent Atlantic biogeographical region. Germany and Austria the Continental biogeographical region and France and Italy are the Mediterranean biogeographical region. The actual research focused on *Asperula fagetum* beech forests, which announced in Annex I and listed under Natura 2000 habitat ID number – 9130. We established 16 reference plots as well as 272 evaluation plots within selected forest stands within and outside of Natura 2000, which can be used for further research work according to the collected data. We used structural as well as vegetation analyzes of all 272 research plots in total. Regarding the forest structure, we hypothesized that the microhabitat diversity within Natura 2000 is higher than outside, vertical structures and the tree growth will differ according to Natura 2000 status and finally the structural diversity will differ according to Natura 2000 status. Regarding the vegetation, we hypothesized that the plant diversity of the Natura 2000 stands in the top layer as well as in the shrub layer is higher than in non-Natura 2000 stands. In the same time the plant diversity of the Natura 2000 stands in the herb layer should be lower than in non-Natura 2000 stands, in terms of the natural aspect.

We tested differences between Natura 2000 and non Natura 2000 on structural parameters and microhabitat frequencies with help of asymptotic Man-Whitney rank sum test. We chose the microhabitats as consistently ecological indicator for further analyzes on collected structural data with help of the generalized linear models, detrended correspondence analyses and recursive classification models.

Vegetation parameters were analyzed in the similar way. We tested differences between Natura 2000 and non Natura 2000 stands regarding species diversity, species compositions as well as the species coverage within the tree, shrub and herb layers. Furthermore we used generalized linear mixed models to detect possible effects of Natura 2000 on the species diversity within each study site. And finally we applied DCA and CCA ordination methods to create the ordination map of the investigated beech forests within and outside of Natura 2000 network taking account of environmental factors and additional ecological parameters.

All applied analyses in general indicate up to now no consistent effects of Natura 2000, which could be found through all biogeographical regions. Our results show, that only those Natura 2000 sites, which have a protection history much longer than the implementation of Natura 2000 concept, indicate significant structural differences compared with the regular used stands. Such stands were mainly located within the Atlantic biogeographical region, cause of historical reasons.

Here we detected an outstanding position of the Atlantic Natura 2000 sites compared with non Natura 2000 sites on significant number of parameters. The diversity of all ecologically important groups of microhabitats, vertical structure diversity and deadwood volume were consistently higher within Atlantic Natura 2000 sites only. The stand parameters like DBH, basal area, number of stems and others indicate the same trend in our results. No consistently Natura 2000 effects were detected,

however, within the Mediterranean as well as Continental sites. The explanation of this result must be management interventions, which still are a dominant factor outside as well as inside of most Natura 2000 stands on the current stage. The time scope for the forest development is too short to make the possible effects of Natura 2000 ecologically significant.
Also the vegetation parameters could confirm structural trends according to the Natura 2000 status. Atlantic Natura 2000 sites indicated significant higher species diversity, top closure and tree species abundance within the tree layer. At the same time we detected significantly lower species diversity and species coverage within the herb layer of the Atlantic Natura 2000 stands only. Tree layer indicated no further significant differences between Natura 2000 and non Natura 2000 within other biogeographical regions.
In contrast to the Atlantic forest stands, we found that the species diversity of the ground vegetation within the Mediterranean biogeographical region was higher than non Natura 2000. That must be due to local environmental and other ecological features and not to the actual Natura 2000 effect. Applied CCA's of the ground vegetation in context with climate factors and environmental parameters compared our test results.
We did not find any significant differences regarding Natura 2000 status within the Continental biogeographical region. Nevertheless we found that the Continental sites are generally closer to the Atlantic sites in terms of the ecological forest conditions, structural features and species composition. Also positions of Continental and Atlantic sites were strongly overlapped in the ordination maps. Mediterranean sites indicate some few differences regarding Natura 2000 status, but show much more differences between single sites inside of the biogeographical region than between Natura 2000 and non Natura 2000 stands. That result was proofed and can be observed on applied ordinations.
In terms of our results we summarize that differences of microhabitat diversity between regular Natura 2000 and non Natura 2000 stands up to now are not significant. But the long term forest reserves indicate significant differences in comparison to the regular used stands. No influence of Natura 2000 on vertical structure could be yet detected. Structural diversity indicates no consistently influence of Natura 2000 on the current phase. The plant composition, species diversity and coverage indicate no significant influence by Natura 2000. Nevertheless we found slightly higher species diversity within the tree layer of Natura 2000 stands as well as slightly lower diversity within the herb layer of the Natura 2000 sites under long term protection, which indicate a natural development trend. Time since the implementation of Natura 2000 seems still too short to create significant general trends in both structure and plant species diversity up to now.

6 References

Ask, P. & Carlsson, M., 2000. Nature conservation and timber production in areas with fragmented ownership patterns. *Forest Policy and Economics*, 1(3-4), pp.209–223. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1389934100000162.

Barbier, S., Gosselin, F. & Balandier, P., 2008. Influence of tree species on understory vegetation diversity and mechanisms involved—A critical review for temperate and boreal forests. *Forest Ecology and Management*, 254(1), pp.1–15. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378112707007025 [Accessed October 18, 2013].

Bergmeier, E. & Dimopoulos, P., 2001. Fagus sylvatica forest vegetation in Greece : Syntaxonomy and gradient analysis. *Journal of Vegetation Science*, 12(1), pp.109–126. Available at: http://doi.wiley.com/10.2307/3236679.

Brocksieper, R. & Woike, M., 1999. Kriterien zur Auswahl der FFH- und Vogelschutzgebiete für das europäische Schutzgebietssystem FFH-Auswahlkriterien. *LÖBF-Mitteilungen*.

Brunet, J., Fritz, Ö. & Richnau, G., 2010. Biodiversity in European beech forests – a review with recommendations for sustainable forest management. , (Korpel 1995), pp.77–94.

Bugmann, H., 2013. Functional Types of Trees in Temperate and Boreal Forests : Classification and Testing Functional types of trees in temperate and boreal forests : classification and testing. *Journal of Vegetation Science*, 7(3), pp.359–370.

Burrascano, S., Lombardi, F. & Marchetti, M., 2008. Old-growth forest structure and deadwood: Are they indicators of plant species composition? A case study from central Italy. *Plant Biosystems An International Journal Dealing with all Aspects of Plant Biology*, 142(2), pp.313–323. Available at: http://www.tandfonline.com/doi/abs/10.1080/11263500802150613.

Cavin, L. et al., 2013. Extreme drought alters competitive dominance within and between tree species in a mixed forest stand D. Whitehead, ed. *Functional Ecology*, p.n/a–n/a. Available at: http://doi.wiley.com/10.1111/1365-2435.12126 [Accessed August 21, 2013].

Chape, S. et al., 2005. Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, 360(1454), pp.443–55. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1569446&tool=pmcentrez&rendertype=abstract [Accessed March 19, 2014].

Chiarucci, A., Bacaro, G. & Rocchini, D., 2008. Quantifying plant species diversity in a Natura 2000 network: Old ideas and new proposals. *Biological Conservation*, 141(10), pp.2608–2618. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0006320708002796 [Accessed November 1, 2012].

Christensen, M. et al., 2005. Dead wood in European beech (Fagus sylvatica) forest reserves. *Forest Ecology and Management*, 210(1-3), pp.267–282. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378112705001180 [Accessed November 3, 2012].

COMMISSION OF THE EUROPEAN COMMUNITIES, 2009. Composite Report on the Conservation Status of Habitat Types and Species as required under Article 17 of the Habitats Directive. , 358.

COMMISSION OF THE EUROPEAN COMMUNITIES, 2003. *Natura 2000 and forests " Challenges and opportunities " Interpretation guide*,

Crozier, C.R. & Boerner, R.E.J., 1984. Correlations of understory herb distribution patterns with microhabitats under different tree species in a mixed mesophytic forest. *Oecologia*, 62(3), pp.337–343. Available at: http://www.jstor.org/pss/4217326.

Defossez, E. et al., 2011. Do interactions between plant and soil biota change with elevation? A study on Fagus sylvatica. *Biology letters*, 7(5), pp.699–701. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3169063&tool=pmcentrez&rendertype=abstract [Accessed November 15, 2012].

Delhon, C. & Thiebault, S., 2005. The migration of beech (Fagus sylvatica L .) up the Rhone : the Mediterranean history of a " mountain " species. *Vegetation History and Archaeobotany*, 14, pp.119–132.

Dupouey, J.L. et al., 2002. IRREVERSIBLE IMPACT OF PAST LAND USE ON FOREST SOILS AND BIODIVERSITY. , 83(11), pp.2978–2984.

Eilmann, B. & Rigling, A., 2012. Tree-growth analyses to estimate tree species' drought tolerance. *Tree Physiology*, 32(2), pp.178–187. Available at: http://www.ncbi.nlm.nih.gov/pubmed/22363071.

Fakult, F., 2002. Growth of advanced European beech trees in the transformation phase in the southern Black Forest.

Fenton, N.J. & Bergeron, Y., 2011. Dynamic Old-Growth Forests ? A Case Study of Boreal Black Spruce Forest Bryophytes. , 45(October 2010), pp.983–994.

Fischer, A., Marshall, P. & Camp, A., 2013. Disturbances in deciduous temperate forest ecosystems of the northern hemisphere: their effects on both recent and future forest development. *Biodiversity and Conservation*, 22(9), pp.1863–1893. Available at: http://link.springer.com/10.1007/s10531-013-0525-1 [Accessed September 25, 2013].

Fischer, J. & Lindenmayer, D.B., 2007. Landscape modification and habitat fragmentation : a synthesis. , pp.265–280.

Fritz, Ö. & Heilmann-Clausen, J., 2010. Rot holes create key microhabitats for epiphytic lichens and bryophytes on beech (Fagus sylvatica). *Biological Conservation*, 143(4), pp.1008–1016. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0006320710000170 [Accessed June 21, 2013].

Geßler, A. et al., 2006. Potential risks for European beech (Fagus sylvatica L.) in a changing climate. *Trees*, 21(1), pp.1–11. Available at: http://www.springerlink.com/index/10.1007/s00468-006-0107-x [Accessed October 27, 2012].

Granke, O. & Kenter, B., 2009. Biodiversity assessment in forests - from genetic diversity to landscape diversity. , pp.1–3.

Gurnell, J., 1996. THE GREY SQUIRREL IN BRITAIN : PROBLEMS FOR MANAGEMENT. , 1937, pp.67–81.

Hannah, L., Carr, J.L. & Lankerani, A., 1995. Human disturbance and natural habitat: a biome level analysis of a global data set. *Biodiversity and Conservation*, 4(2), pp.128–155. Available at: http://link.springer.com/10.1007/BF00137781 [Accessed April 19, 2014].

Hanson, J.J. et al., 2012. Ecological forestry in an uneven-aged, late-successional forest: Simulated effects of contrasting treatments on structure and yield. *Forest Ecology and Management*, 270, pp.94–107. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378112712000278 [Accessed June 11, 2013].

Hantley B., Bertlein P.T., P.I.C., 2013. Climatic control of the distribution and abundance of beech (Fagus L .) in Europe and North America. , 16(6), pp.551–560.

Harper, K.A. et al., 2005. Edge Influence on Forest Structure and Composition in Fragmented Landscapes. , 19(3), pp.768–782.

Hettwer, C. et al., 2009. Berichtspflichten zur europäischen Fauna-Flora-Habitat-Richtlinie in Sachsen. , 2009, pp.36–59.

Hothorn, T. & Hornik, K., 1999. party : A Laboratory for Recursive Partytioning. , (1994).

Humphrey, J.W. & Watts, K., 2004. Biodiversity indicators for UK managed forests: development and implementation at different spatial scales. In M. Marchetti & T.-B. Larsson, eds. *Monitoring and indicators of forest biodiversity in Europe from ideas to operationality Proceedings of the EFIUFRO Conference 12 15 November 2003*. European Forest Institute, pp. 79–89.

Ibisch, P.L. & Kreft, S., 2008. Natura 2000 und Klimawandel. , pp.51–64.

Ihók, B.M. et al., 2007. Gap Regeneration Patterns in a Semi-natural Beech Forest Stand in Hungary. , 3, pp.31–45.

Imhoff, M.L. et al., 2004. Global patterns in human consumption of net primary production. , 429(June), pp.870–873.

Ishii, H. & Kadotani, T., 2006. Biomass and dynamics of attached dead branches in the canopy of 450-year-old Douglas-fir trees. , 389, pp.378–389.

JANTSCH, M.C. et al., 2014. How are plant species in Central European Beech (Fagus sylvatica) Forests affected by temperature changes? - Shift of potential suitable habitats under global warming. *Annali Botanica*, 4, pp.1–18.

Jones-Walters, L. & Čivić, K., 2013. European protected areas: Past, present and future. *Journal for Nature Conservation*, 21(2), pp.122–124. Available at: http://linkinghub.elsevier.com/retrieve/pii/S161713811200115X [Accessed July 23, 2013].

Jongman, R., 1999. BIOTOPKARTIERUNG U N D DIE PAN-EUROPÄISCHE STRATEGIE FÜR BIOLOGISCHE U N D L A N D S C H A F T L I C H E VIELFALT. *Sauteria*, 10, pp.129–144.

Jonsson, B.G. et al., 2011. Forest Naturalness in Northern Europe : Perspectives on Processes , Structures and. , 45(November), pp.807–821.

Jump, A.S., Cavin, L. & Hunter, P.D., 2010. Monitoring and managing responses to climate change at the retreating range edge of forest trees. *Journal of environmental monitoring : JEM*, 12(10), pp.1791–8. Available at: http://www.ncbi.nlm.nih.gov/pubmed/20818456 [Accessed August 27, 2013].

Kirby, K.J., Webster, S.D. & Antczak, A., 1991. Effects of forest management on stand structure and the quantity of fallen dead wood: some British and Polish examples. *Forest Ecology and Management*, 43(1-2), pp.167–174. Available at: http://dx.doi.org/10.1016/0378-1127(91)90083-8 [Accessed June 9, 2013].

Knoke, T., 2005. Timber harvesting versus forest reserves - producer prices for open-use areas in German beech forests (Fagus. , 52, pp.1–31.

Kölling, C. et al., 2009. Provisorische Klima-Risikokarten als Planungshilfe für den klimagerechten Waldumbau in Bayern Provisional climate-risk maps as a tool for climate adapted forest conversion in Bavaria. , pp.40–47.

Larrieu, L., Cabanettes, A. & Delarue, A., 2011. Impact of silviculture on dead wood and on the distribution and frequency of tree microhabitats in montane beech-fir forests of the Pyrenees. *European Journal of Forest Research*, 131(3), pp.773–786. Available at: http://www.springerlink.com/index/10.1007/s10342-011-0551-z.

Lassauce, A. et al., 2011. Deadwood as a surrogate for forest biodiversity: Meta-analysis of correlations between deadwood volume and species richness of saproxylic organisms. *Ecological Indicators*, 11(5), pp.1027–1039. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1470160X11000380.

Lindenmayer, D.B., Franklin, J.F. & Fischer, J., 2006. General management principles and a checklist of strategies to guide forest biodiversity conservation. *Biological Conservation*, 131(3), pp.433–445. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0006320706000814 [Accessed October 26, 2012].

Lindenmayer, D.B., Margules, C.R. & Botkin, D.B., 2000. Indicators of Biodiversity for Ecologically Sustainable Forest Management. *Conservation Biology*, 14(4), pp.941–950. Available at: http://doi.wiley.com/10.1046/j.1523-1739.2000.98533.x.

Lombardi, F. et al., 2008. Deadwood in Relation to Stand Management and Forest Type in Central Apennines (Molise, Italy). *Ecosystems*, 11(6), pp.882–894. Available at: http://www.springerlink.com/index/10.1007/s10021-008-9167-7.

Luxmoore, R.J. et al., 2008. Addressing multi-use issues in sustainable forest management with signal-transfer modeling. , 165(2002), pp.295–304.

McRoberts, R.E. et al., 2008. Large-scale spatial patterns of forest structural diversity. *Canadian Journal of Forest Research*, 38(3), pp.429–438. Available at: http://www.nrcresearchpress.com/doi/abs/10.1139/X07-154 [Accessed November 7, 2012].

Merganičová, K. & Merganič, J., 2007. Deadwood in Forest Ecosystems. , (1966).

Michel, A.K. & Winter, S., 2009. Tree microhabitat structures as indicators of biodiversity in Douglas-fir forests of different stand ages and management histories in the Pacific Northwest, U.S.A. *Forest Ecology and Management*, 257(6), pp.1453–1464. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378112708008761 [Accessed October 29, 2012].

Moen, J., 2010. Interlocking panarchies in multi-use boreal forests in Sweden. , 15(3).

Mölder, A., Bernhardt-Römermann, M. & Schmidt, W., 2008. Herb-layer diversity in deciduous forests: Raised by tree richness or beaten by beech? *Forest Ecology and Management*, 256(3), pp.272–281. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378112708003307 [Accessed October 18, 2013].

Moravčík, M. et al., 2010. Forest naturalness: criterion for decision support in designation and management of protected forest areas. *Environmental management*, 46(6), pp.908–19. Available at: http://www.ncbi.nlm.nih.gov/pubmed/20563808 [Accessed June 4, 2013].

Mountford, E., 1997. A decade of grey squirrel bark-stripping damage to beech in Lady Park Wood, [UK]. *Forestry*, 70(1), pp.17–29. Available at: http://forestry.oupjournals.org/cgi/doi/10.1093/forestry/70.1.17.

Mountford, E.P., 2002. Fallen dead wood levels in the near- natural beech forest at La Tillaie reserve , Fontainebleau , France. *Oxford Forestry Institute*, 75(2).

Müller, J., 2005. Waldstrukturen als Steuergröße für Artengemeinschaften in kollinen bis submontanen Buchenwäldern.

Nocentini, S., 2009. Structure and management of beech (Fagus sylvatica L.) forests in Italy. *iForest - Biogeosciences and Forestry*, 2(1), pp.105–113. Available at: http://www.sisef.it/iforest/?doi=10.3832/ifor0499-002 [Accessed November 3, 2012].

North, M. et al., 2004. Forest Stand Structure and Pattern of Fir and Mixed-Conifer Forests. , 50(780), pp.299–311.

Noss, R.F., 1999. Assessing and monitoring forest biodiversity: A suggested framework and indicators. *Forest Ecology and Management*, 115(2-3), pp.135–146. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378112798003946.

Ostermann, O., 1998. The need for management of nature conservation sites designated under Natura 2000. *Journal of Applied Ecology*, 35, pp.968–973.

Paillet, Y. et al., 2010. Biodiversity differences between managed and unmanaged forests: meta-analysis of species richness in Europe. *Conservation biology : the journal of the Society for Conservation Biology*, 24(1), pp.101–12. Available at: http://www.ncbi.nlm.nih.gov/pubmed/20121845 [Accessed November 7, 2012].

Petercord, R. & Joachim, B., 2006. Strategien zur sicherung von Buchenwäldern. *Forschungsanstalt für Waldökologie und Forstwissenschaft Rheinland-Pfalz*.

Pommerening, a., 2002. Approaches to quantifying forest structures. *Forestry*, 75(3), pp.305–324. Available at: http://forestry.oupjournals.org/cgi/doi/10.1093/forestry/75.3.305.

Rondeux, J. & Sanchez, C., 2010. Review of indicators and field methods for monitoring biodiversity within national forest inventories. Core variable: deadwood. *Environmental Monitoring and Assessment*, 164(1-4), pp.617–630. Available at: http://www.ncbi.nlm.nih.gov/pubmed/19415512.

Ryan, M.G., 2011. Tree responses to drought. *Tree Physiology*, 31(3), pp.237–239. Available at: http://www.ncbi.nlm.nih.gov/pubmed/21512097.

Schmidt, M., 2007. Vegetationsökologisches Monitoring in Naturwaldreservaten. , 78, pp.205–214.

Standovár, T. et al., 2006. Sensitivity of ground layer vegetation diversity descriptors in indicating forest naturalness. *Community Ecology*, 7(2), pp.199–209. Available at: http://www.akademiai.com/openurl.asp?genre=article&id=doi:10.1556/ComEc.7.2006.2.7 [Accessed May 31, 2013].

Travaglini, D. et al., 2007. ForestBIOTA data on deadwood monitoring in Europe. *Plant Biosystems An International Journal Dealing with all Aspects of Plant Biology*, 141(2), pp.222–230. Available at: http://www.tandfonline.com/doi/abs/10.1080/11263500701401778.

Vuidot, A. et al., 2011. Influence of tree characteristics and forest management on tree microhabitats. *Biological Conservation*, 144(1), pp.441–450. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0006320710004295.

Winter, S., 2005. Ermittlung von Struktur-Indikatoren zur Abschätzung des Einflusses forstlicher Bewirtschaftung auf die Biozönosen von Tiefland-Buchenwäldern. , (September).

Winter, S., 2010. Mikrohabitate und Phasenkartierung als Kern der Biodiversitätserfassung im Wald. , pp.38–40.

Winter, S., Fischer, H.S. & Fischer, A., 2010. Relative Quantitative Reference Approach for Naturalness Assessments of forests. *Forest Ecology and Management*, 259(8), pp.1624–1632. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378112710000599 [Accessed November 16, 2012].

Winter, S. & Möller, G.C., 2008. Microhabitats in lowland beech forests as monitoring tool for nature conservation. *Forest Ecology and Management*, 255(3-4), pp.1251–1261. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378112707008298 [Accessed December 3, 2012].

Zehetmair, T. et al., 2014. Poor effectiveness of Natura 2000 beech forests in protecting forest-dwelling bats. *in preparation*.

R version 2.15.2 (2012-10-26) -- "Trick or Treat" Copyright (C) 2012 The R Foundation for Statistical Computing ISBN 3-900051-07-0

McCune, B. and M. J. Mefford. 2011. PC-ORD. Multivariate Analysis of Ecological Data. Version 6.0 MjM Software, Gleneden Beach, Oregon, U.S.A.

QGIS-Version 2.0.1 – Dufour.

Copyright (C) 1989, 1991 Free Software Foundation, Inc., 51 Franklin Street, Fifth Floor, Boston, MA 02110-1301 USA

7 Table of figures

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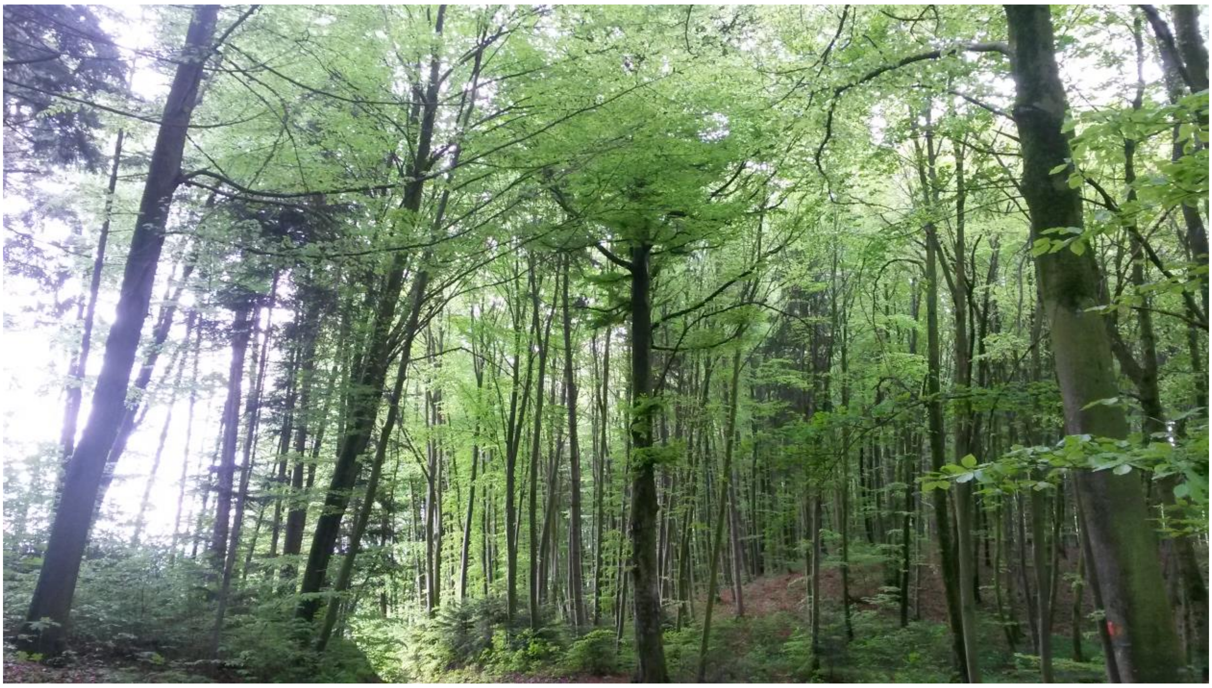
ANNEX



9 Annex

Explanation of abbriviations

Natura 2000 status
a – Natura 2000

b – non Natura 2000

Microhabitats
M_total – frequency of all microhabitats together

open – open microhabitats

closed – closed microhabitats

DeadBranch – dead branches

crownBr – crown breakages

bizarreGrowth – bizarre growing trees with microhabitats due to the tree growth

Stand level parameters
Hmax – maximal tree height

Hmin – lowest tree height of the tree layer

BHDmean – mean value (cm) of the stem diameter on the breast height

BHDmax – maximum diameter on the breast height

BasalArea – basal area in cm^3

sp_nr_tree – number of tree species within the tree layer

BarkManage – occurrences of bark defects due to human activities

BarkNature – occurances of bark defects due to nature

Tree growth
VitClas - tree vitality

Fper – percentage of forked stems

UpClas – uprightness of stems (see classification in chapt.. 2.4.4)

TWpres – occurrence of twisted stems

ShClas – intensity of secondary shoots on tree stems

LiPer – *Hedera helix* coverage of the tree stems

AllParPer – percentage of trees with partner stems

regClas – regularity of the stem diameter (see chapt.. 2.4.4)

Landscape and climate

altitudeW – altitude (m mN)

AspectDeg – aspect in degree

Slope – slope in degree

P_yr – annual precipitation

T_yr – annual temperature

Significance codes for P-values

```
< 0.0001 - '***'
< 0.001 - '**'
< 0.01 - '*'
< 0.05 - '.'
< 0.1 - ' '
Not significant - ns
```

Annex 1. Summary of Natura 2000 effects on microhabitat frequencies.

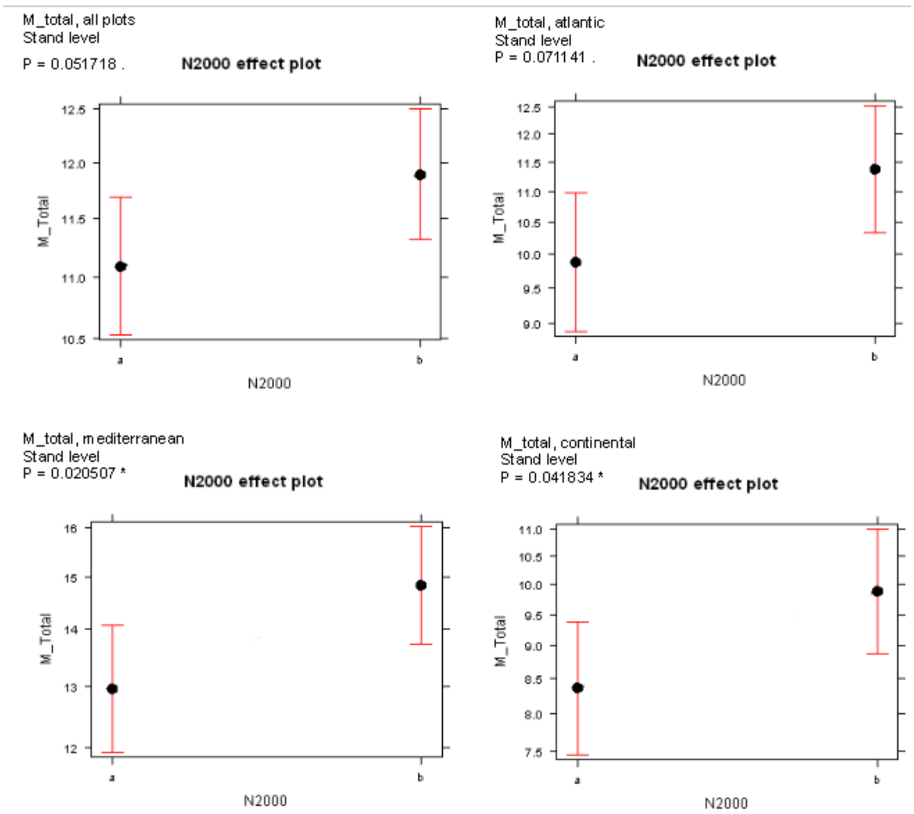


Figure 57. Multivariate effect of Natura 2000 on the total microhabitat frequency according to the stand structure

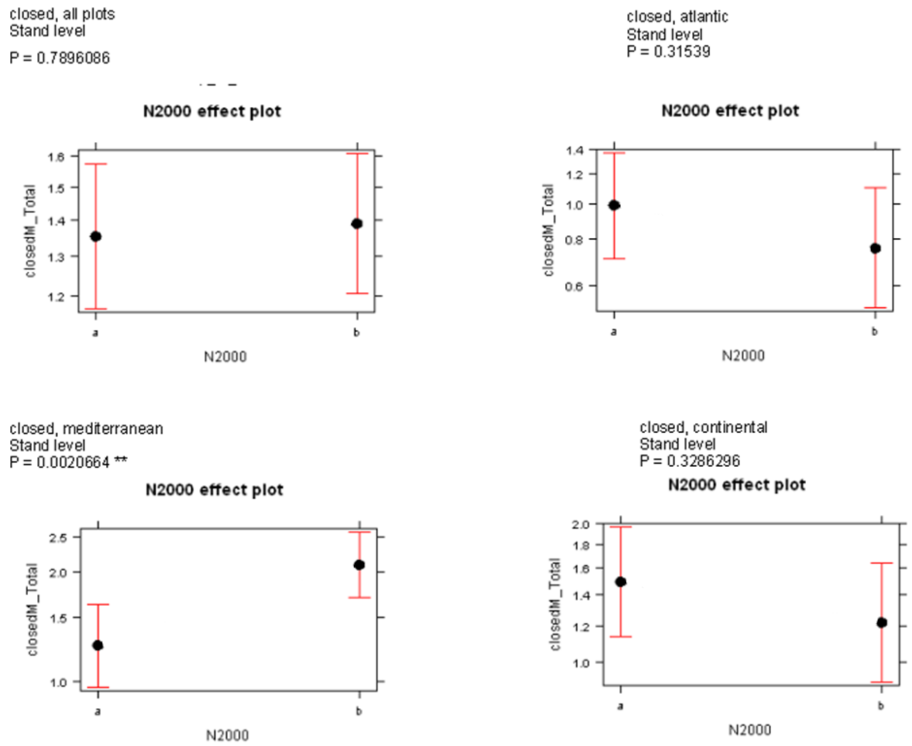


Figure 58. Multivariate effect of Natura 2000 on closed microhabitats according to the stand structure

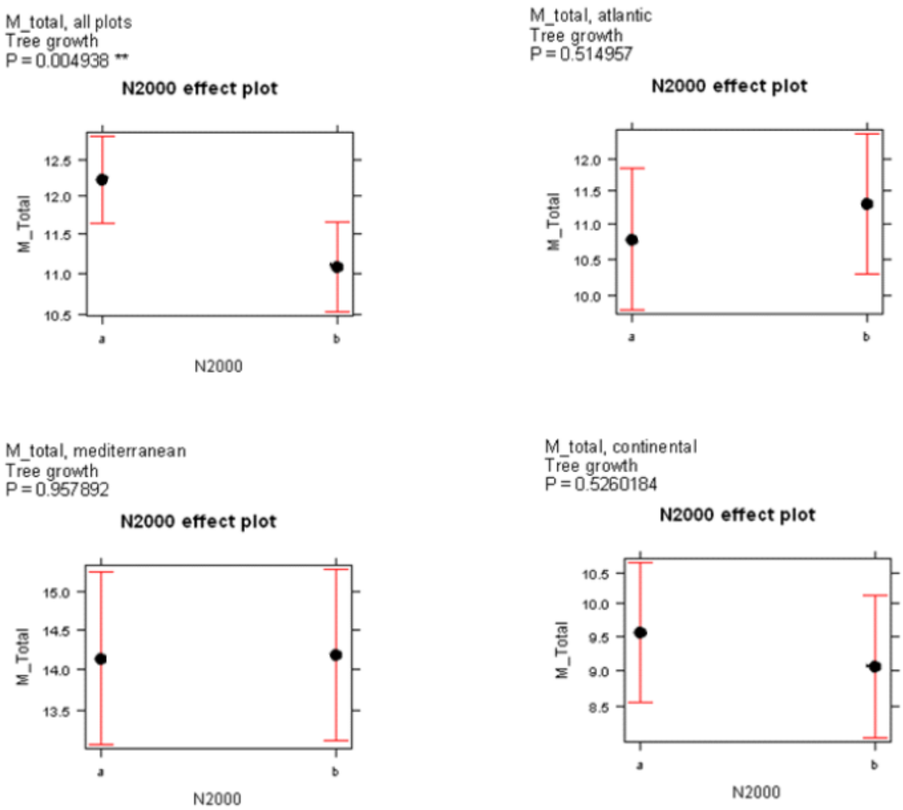


Figure 59. Multivariate Natura 2000 effect on total microhabitat frequency according to the tree growth and vertical structure

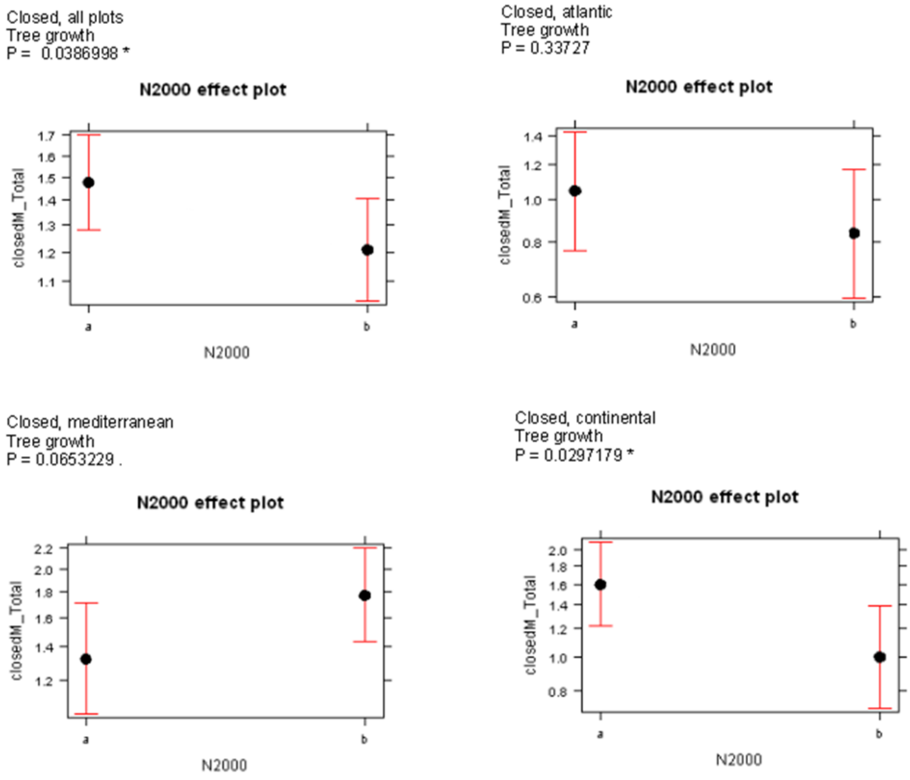


Figure 60. Multivariate Natura 2000 effect on closed microhabitats according to the tree growth and vertical structure

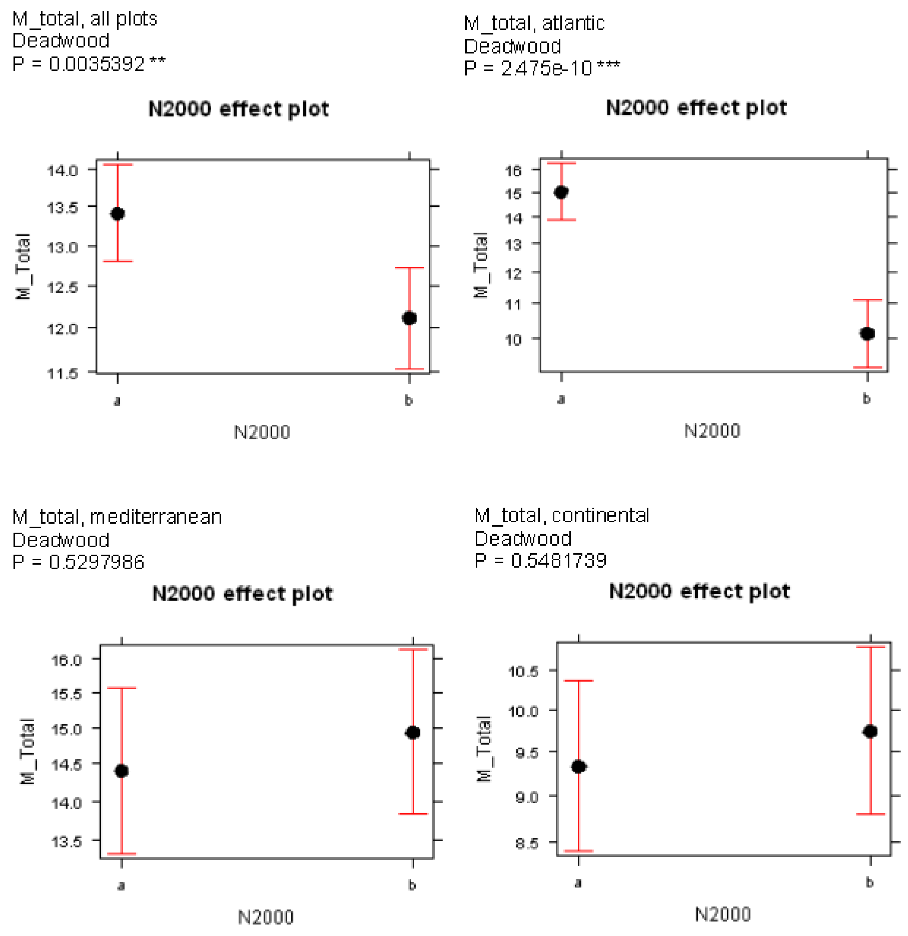


Figure 61. Multivariate Natura 2000 effects on the total microhabitat frequency according to the deadwood

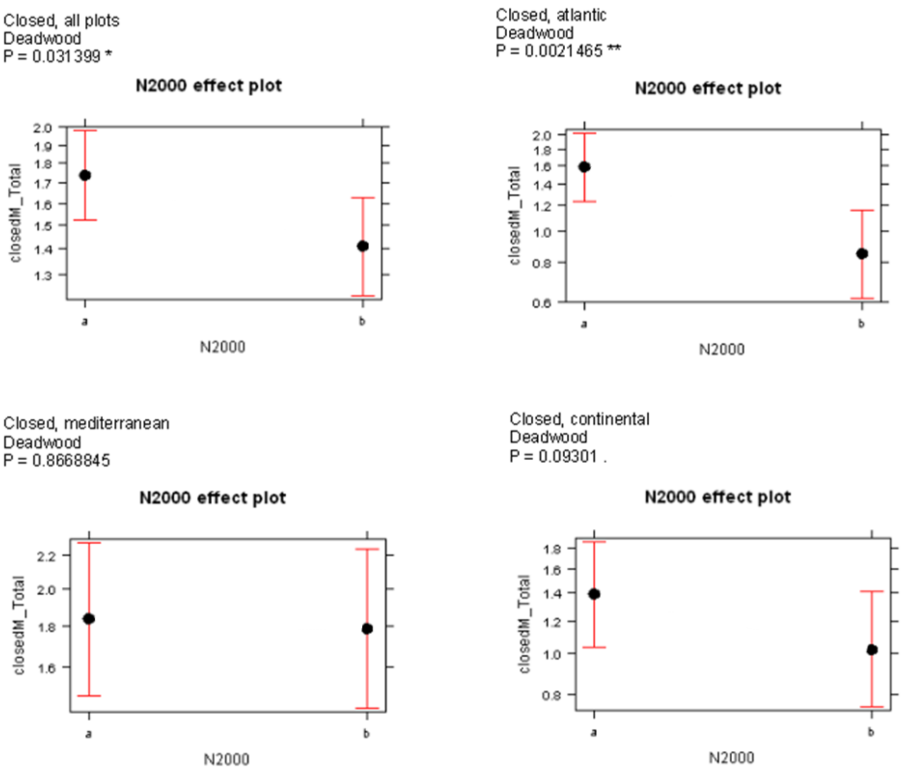


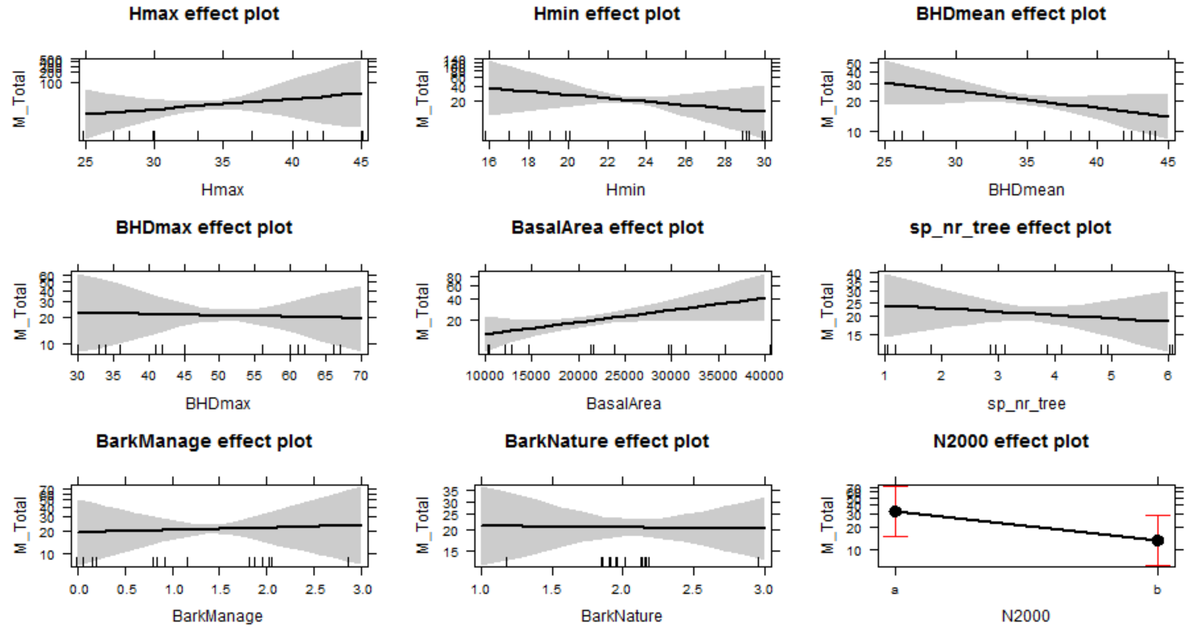
Figure 62. Multivariate Natura 2000 effects on the closed microhabitats according to the deadwood

Annex 2. Effects on microhabitats in total

Reference site – effect plots

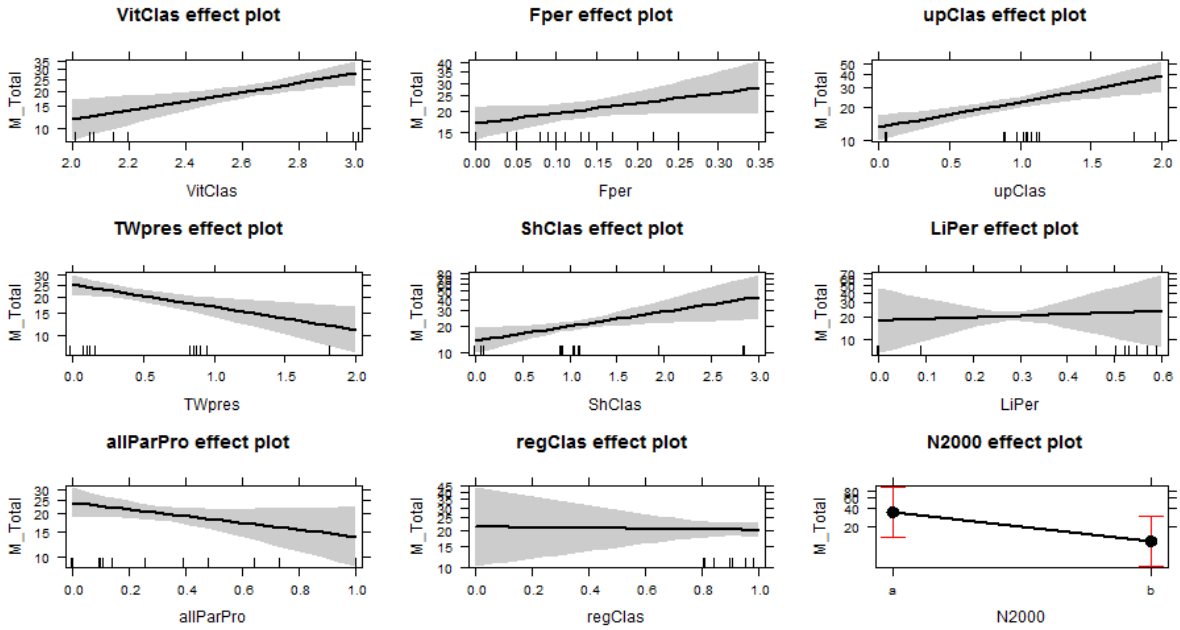
Reference site - effects of stand structure on the total microhabitat frequency

```
Hmax        ***
Hmin        ns
BHDmean     *
BHDmax      ns
BasalArea   ***
sp_nr_tree  ns
BarkManage  ns
BarkNature  ns
Natura 2000       ns
```



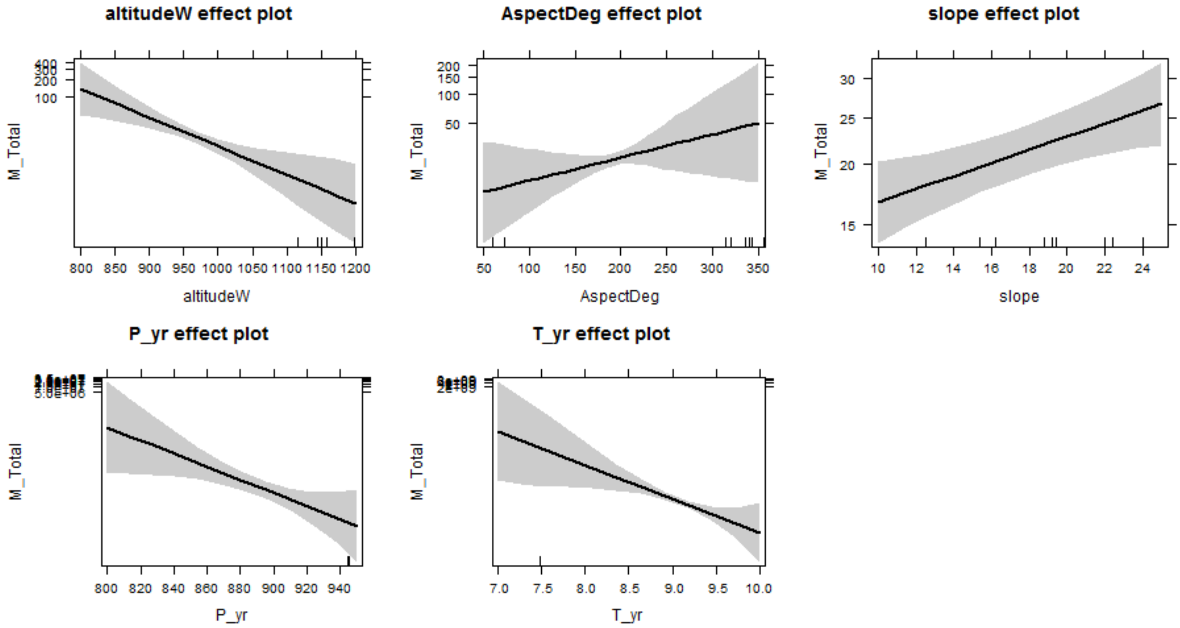
Reference Site - effects of tree morphology on the total microhabitat frequency

```
VitClas      ns
Fper         *
upClas       ns
TWpres       ***
ShClas       ns
LiPer        ***
allParPro    ns
regClas      ns
Natura 2000        ns
```



Reference Site - effects of the climate and landscape on the total microhabitat frequency

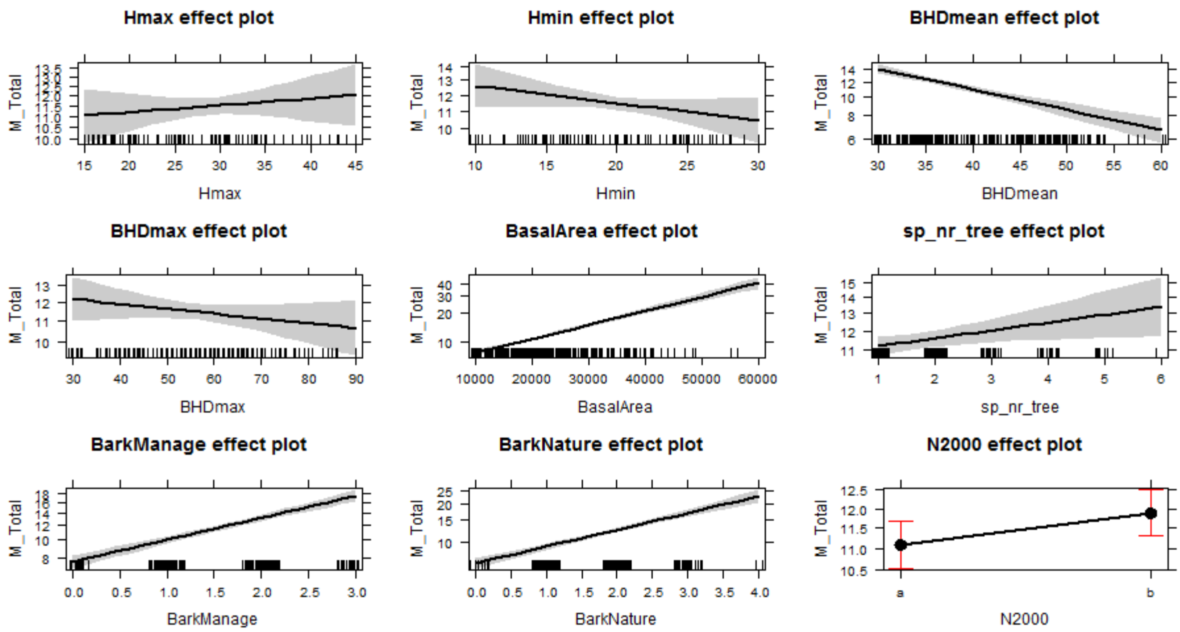
```
altitudeW   ***
AspectDeg   .
slope       **
P_yr        ns
T_yr        *
```



All sites - effect plots

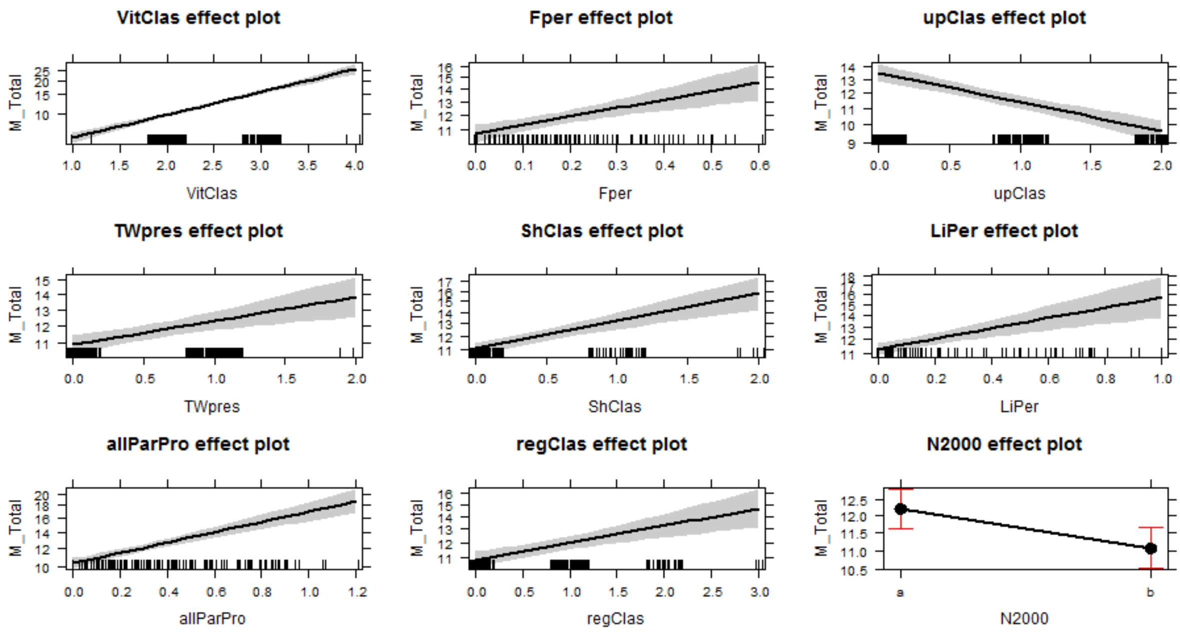
All sites - effects of stand structure on the total microhabitat frequency

```
Hmax         ***
Hmin         ***
BHDmean      ***
BHDmax       ***
BasalArea    ***
sp_nr_tree   **
BarkManage   ***
BarkNature   ***
Natura 2000       .
```



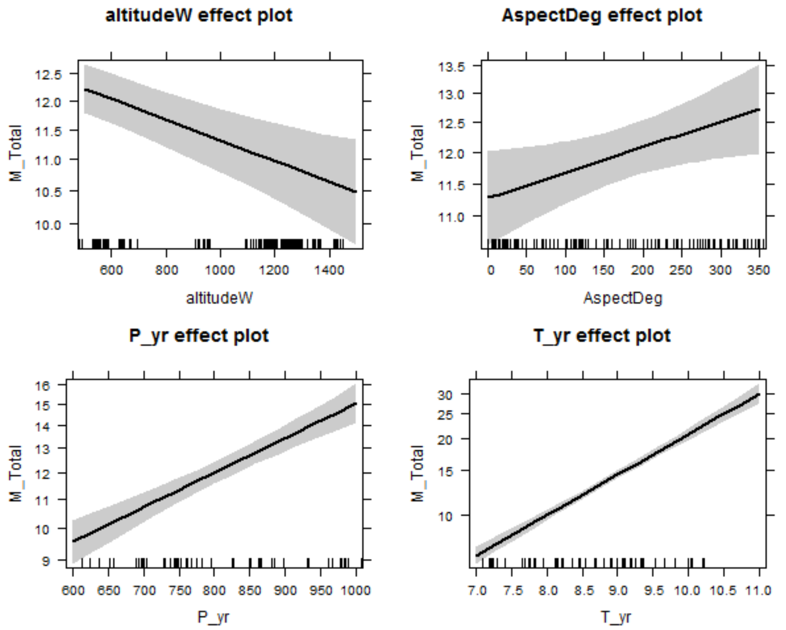
All sites - effects of tree morphology on the total microhabitat frequency

```
VitClas    ***
Fper       ***
upClas     ***
TWpres     ***
ShClas     ***
LiPer      ***
allParPro  ***
regClas    ***
Natura 2000      **
```



All sites - effects of the climate and landscape on the total microhabitat frequency

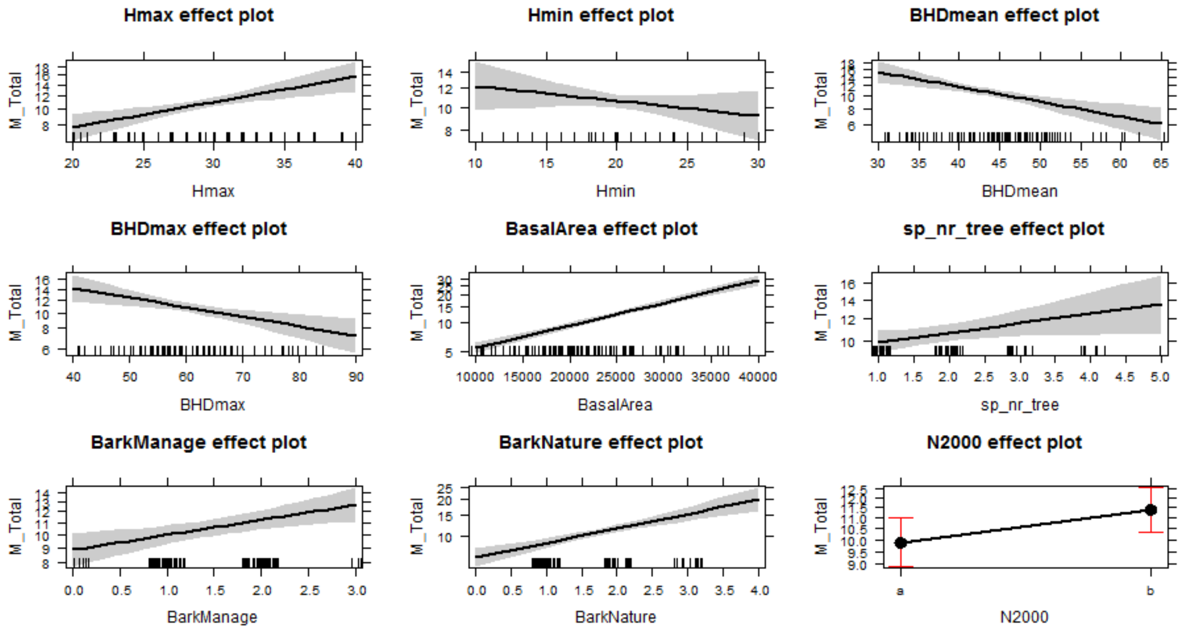
```
altitudeW  ***
AspectDeg  *
slope      ***
P_yr       .
T_yr       ***
```



Atlantic biogeographic region – effect plots

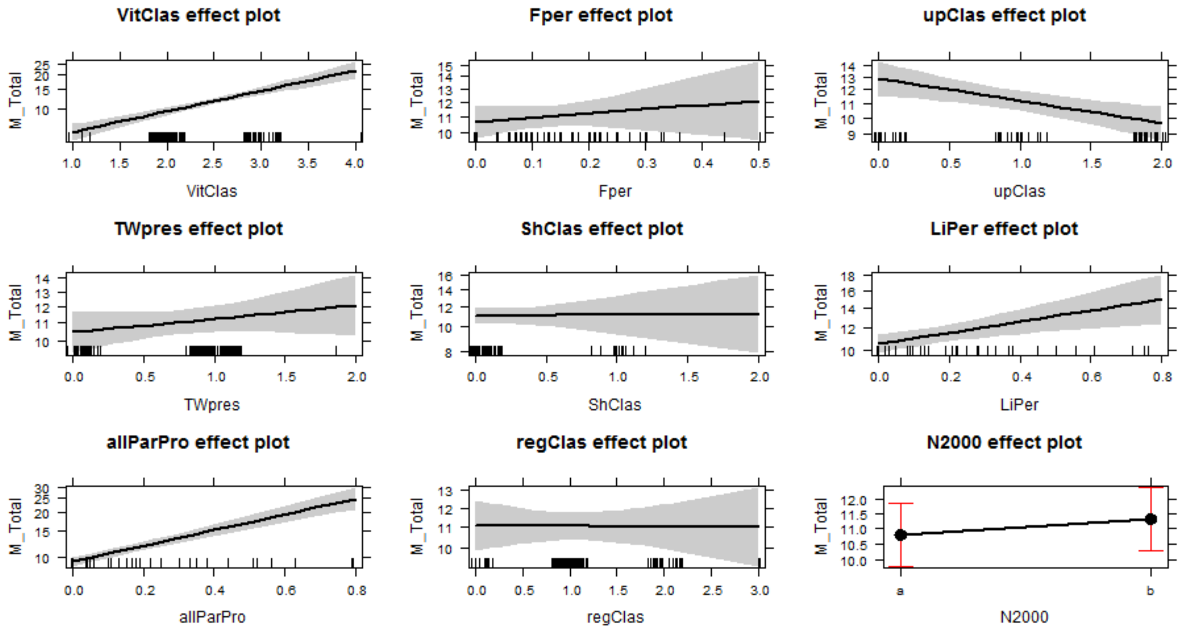
Atlantic biogeographic region - effects of stand structure on the total microhabitat frequency

```
Hmax         ***
Hmin         ***
BHDmean      ***
BHDmax       ***
BasalArea    ***
sp_nr_tree   **
BarkManage   **
BarkNature   ***
Natura 2000      .
```



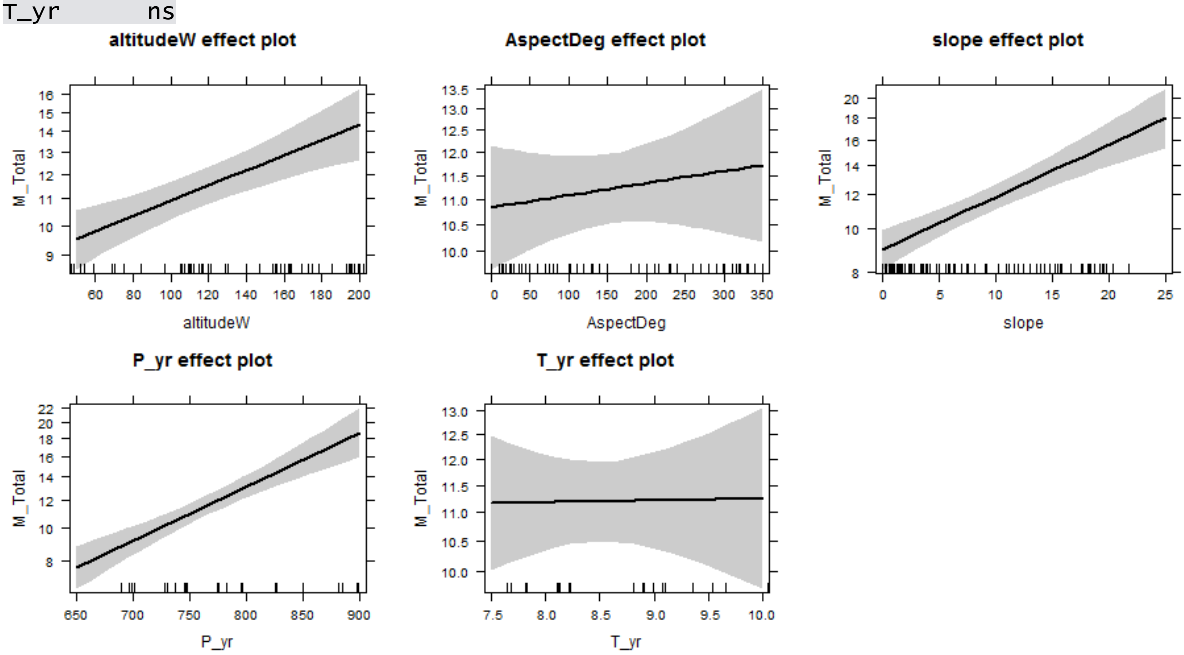
Atlantic biogeographic region - effects of tree morphology on the total microhabitat frequency

```
VitClas   ***
Fper      ns
upClas    ***
TWpres    **
ShClas    ns
LiPer     ns
allParPro ***
regClas   ns
Natura 2000     ns
```



Atlantic biogeographic region - effects of the climate and landscape on the total microhabitat frequency

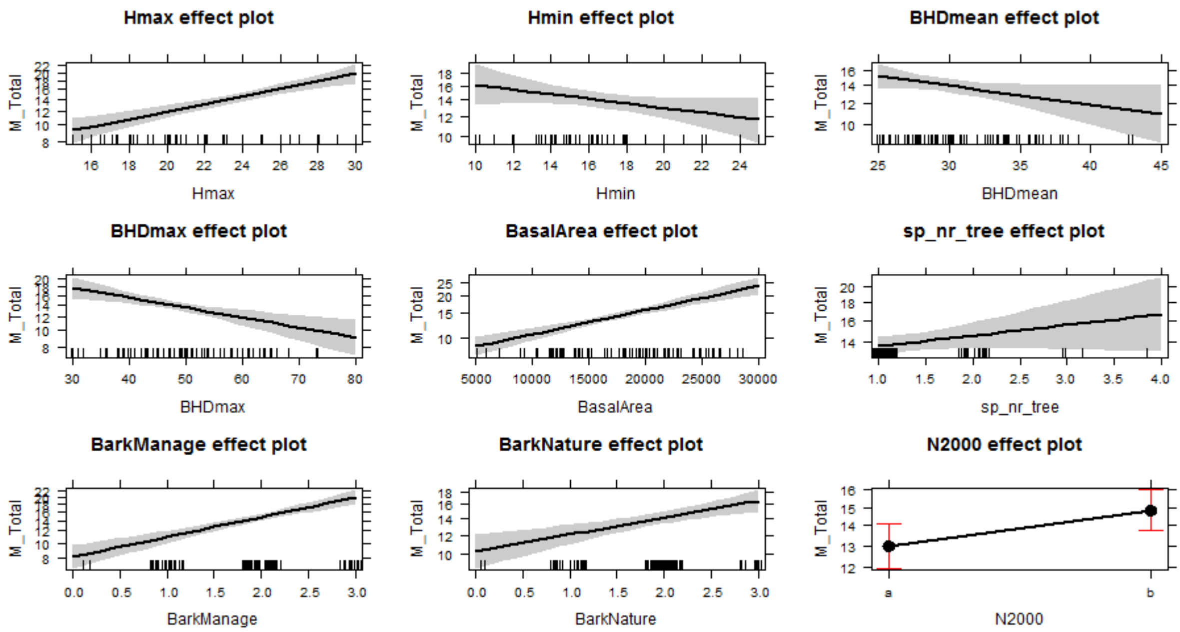
```
altitudeW ***
AspectDeg ns
slope     ***
P_yr      ***
T_yr      ns
```



Mediterranean biogeographic region – effect plots

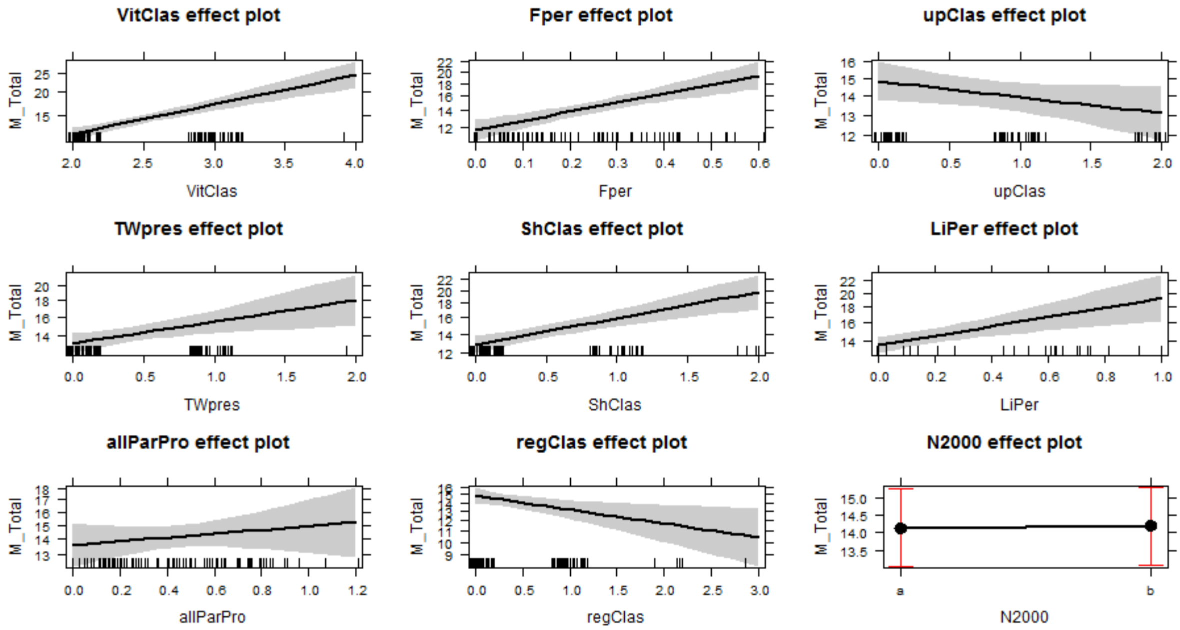
Mediterranean biogeographic region - effects of stand structure on the total microhabitat frequency

```
Hmax         ***
Hmin         .
BHDmean      ns
BHDmax       **
BasalArea    ***
sp_nr_tree   **
BarkManage   ***
BarkNature   ***
Natura 2000        *
```



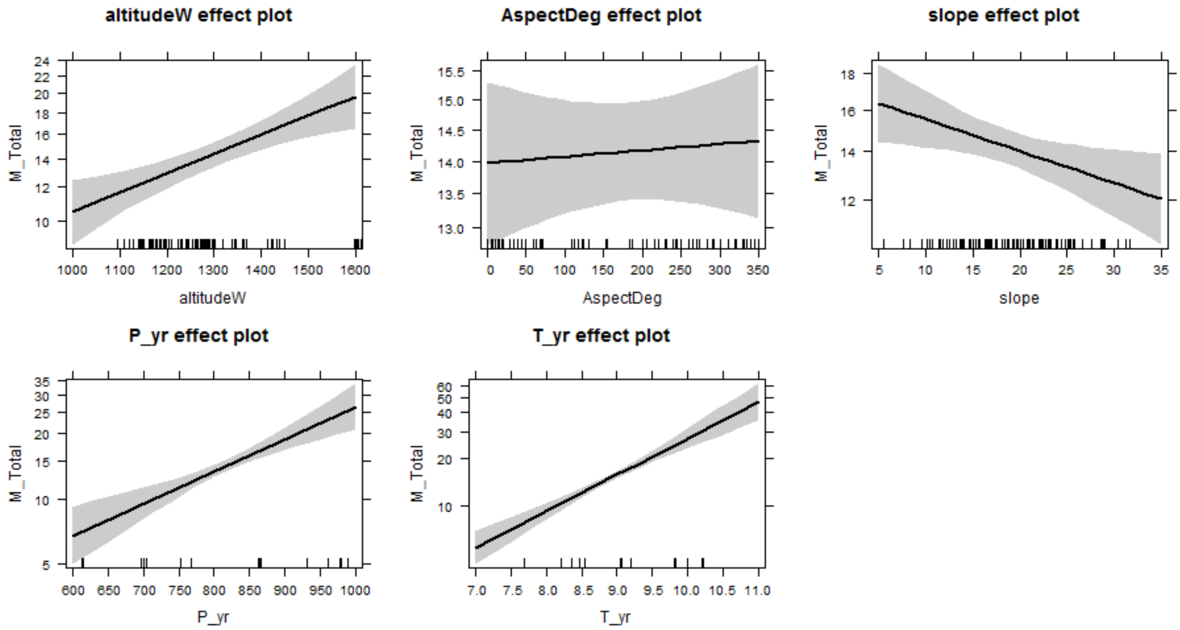
Mediterranean biogeographic region - effects of tree morphology on the total microhabitat frequency

```
VitClas    ***
Fper       ***
upClas     ***
TWpres     **
ShClas     ***
LiPer      **
allParPro ns
regClas    **
Natura 2000      ns
```



Mediterranean biogeographic region - effects of the climate and landscape on the total microhabitat frequency

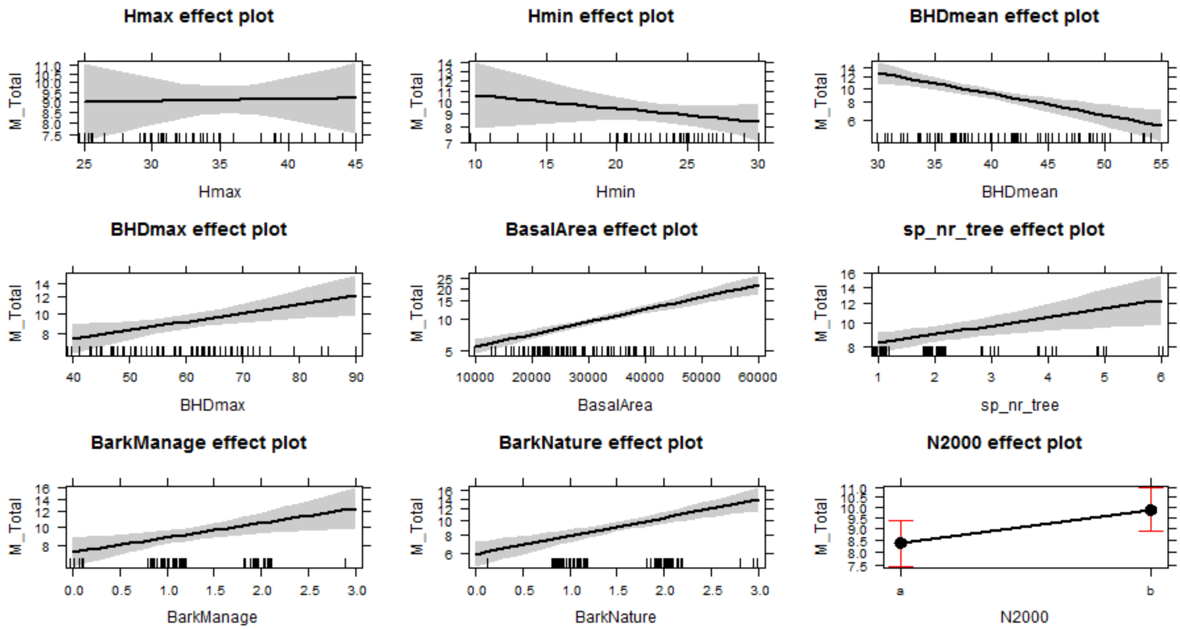
```
altitudeW    .
AspectDeg    *
slope        ns
P_yr         ***
T_yr         ***
```



Continental biogeographic region – effect plots

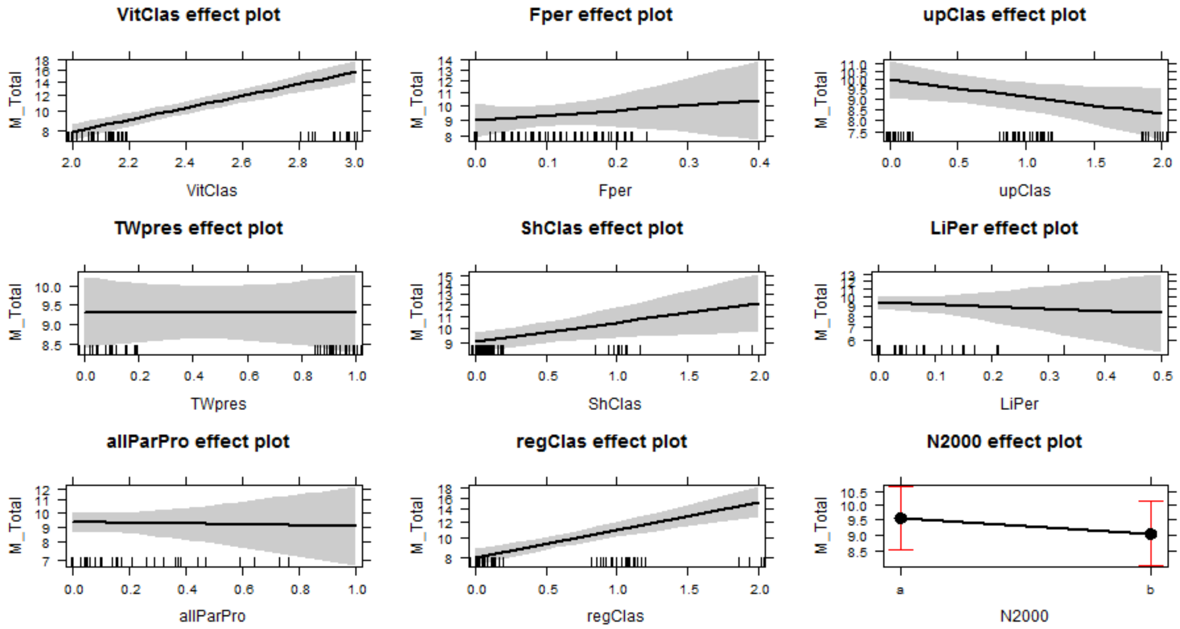
Continental biogeographic region - effects of stand structure on the total microhabitat frequency

```
Hmax          **
Hmin          ns
BHDmean       ***
BHDmax        ***
BasalArea     ***
sp_nr_tree    **
BarkManage    ***
BarkNature    ***
Natura 2000         *
```



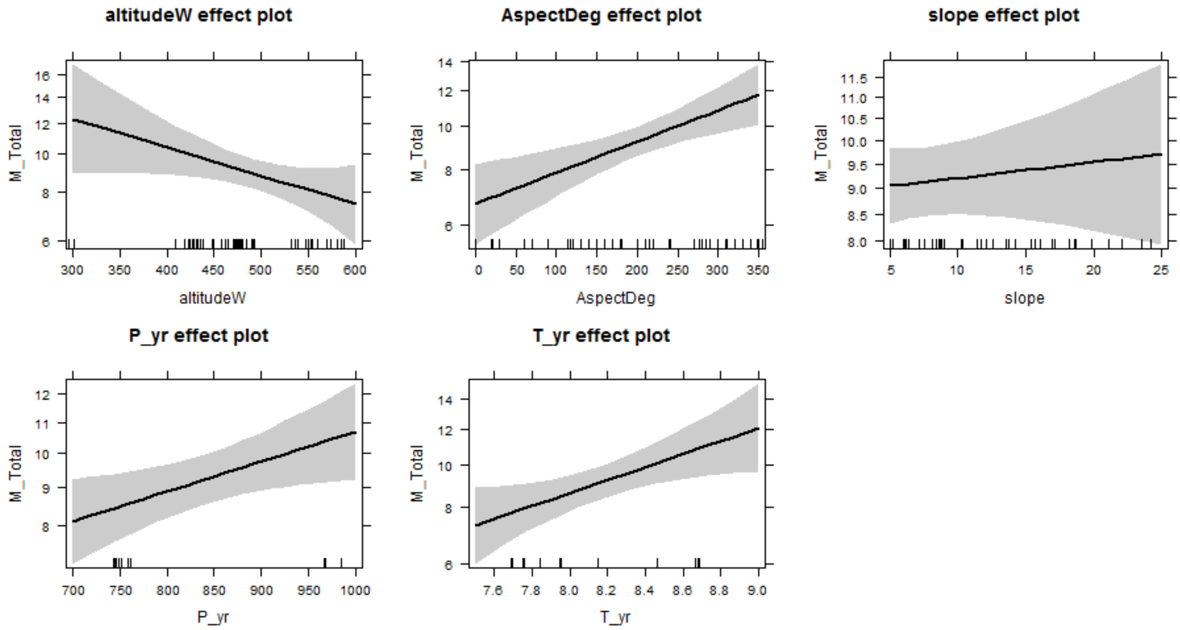
Continental biogeographic region - effects of tree morphology on the total microhabitat frequency

```
VitClas    ***
Fper       ***
upClas     **
TWpres     ns
ShClas     ***
LiPer      ns
allParPro ns
regClas    ***
Natura 2000      ns
```



Continental biogeographic region - effects of the climate and landscape on the total microhabitat frequency

```
altitudeW ***
AspectDeg ***
slope      ***
P_yr       ***
T_yr       *
```

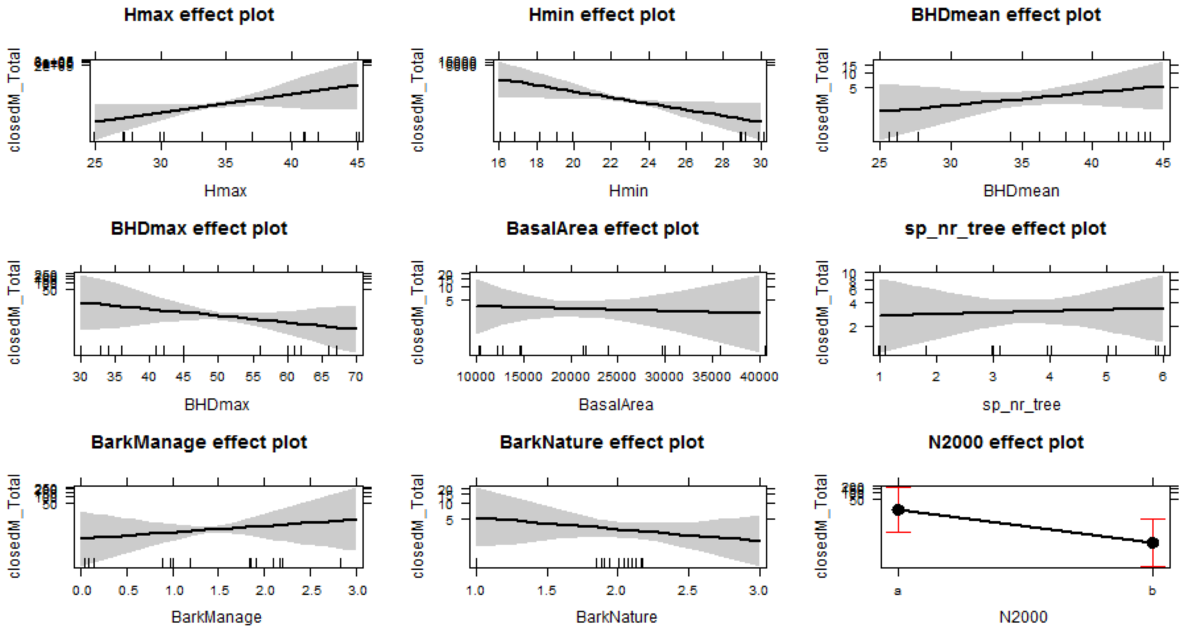


Annex 3. Effects on closed microhabitats

Reference site – effect plots

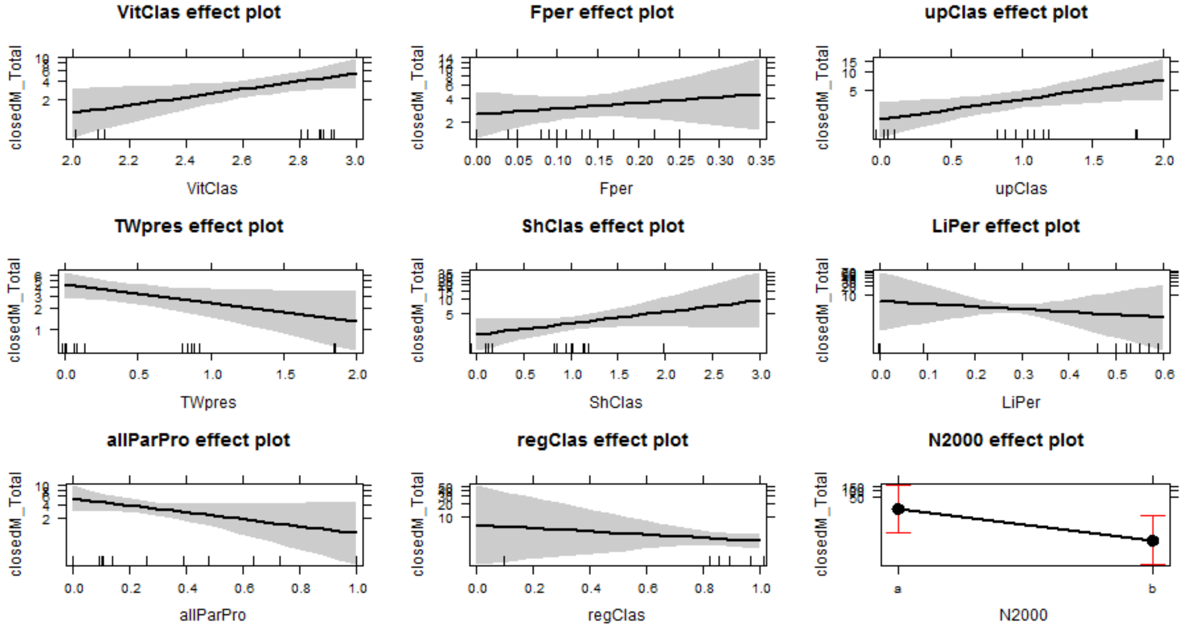
Reference site - effects of stand structure on closed microhabitats

```
Hmax        ***
Hmin        ns
BHDmean     **
BHDmax      ns
BasalArea   ns
sp_nr_tree  ns
BarkManage  ns
BarkNature  ns
Natura 2000       ns
```



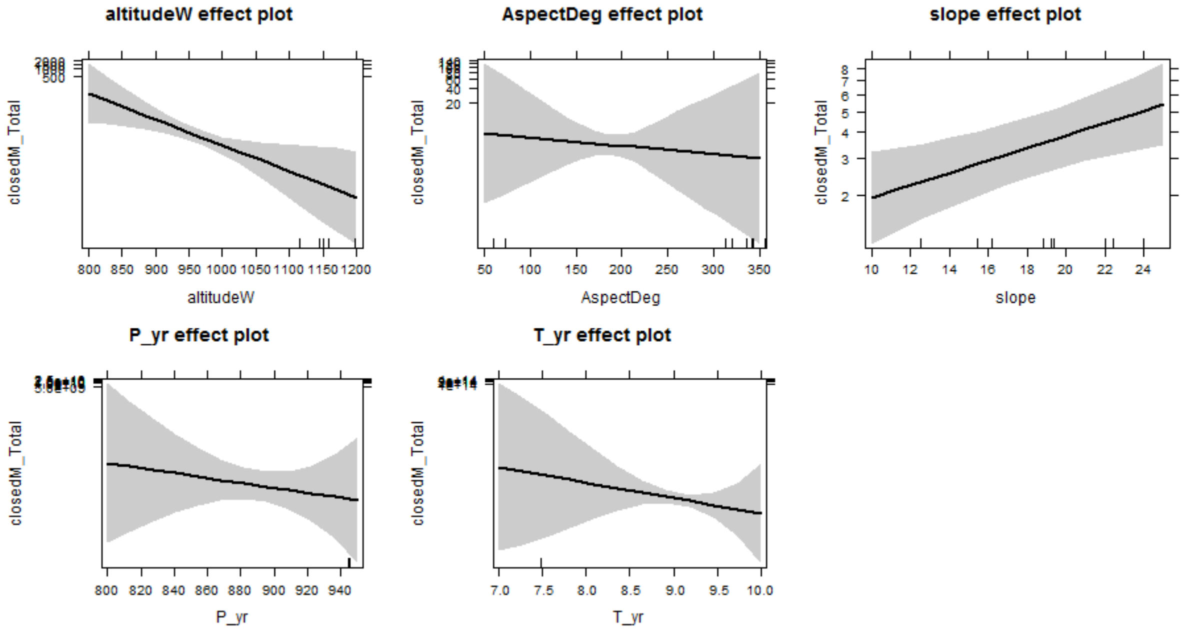
Reference Site - effects of tree morphology on closed microhabitats

```
VitClas       ns
Fper          ns
upClas        ns
TWpres        ***
ShClas        ns
LiPer         ***
allParPro     ns
regClas       ns
Natura 2000         ns
```



Reference Site - effects of the climate and landscape on closed microhabitats

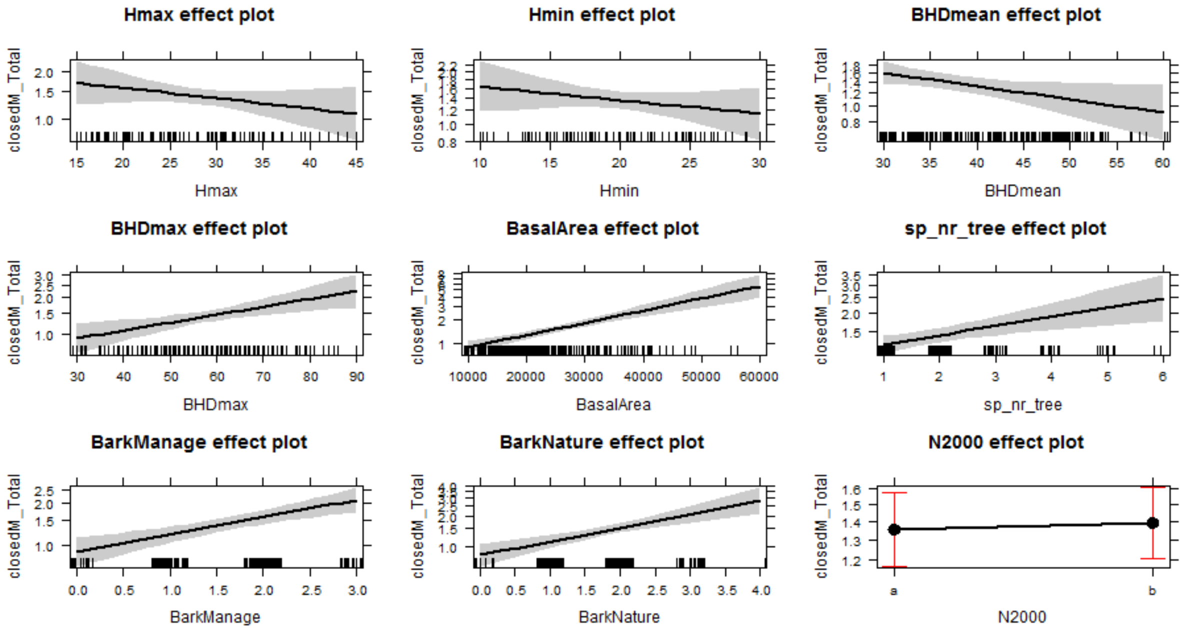
```
altitudeW   ***
AspectDeg   .
slope       **
P_yr        ns
T_yr        ns
```



All sites - effect plots

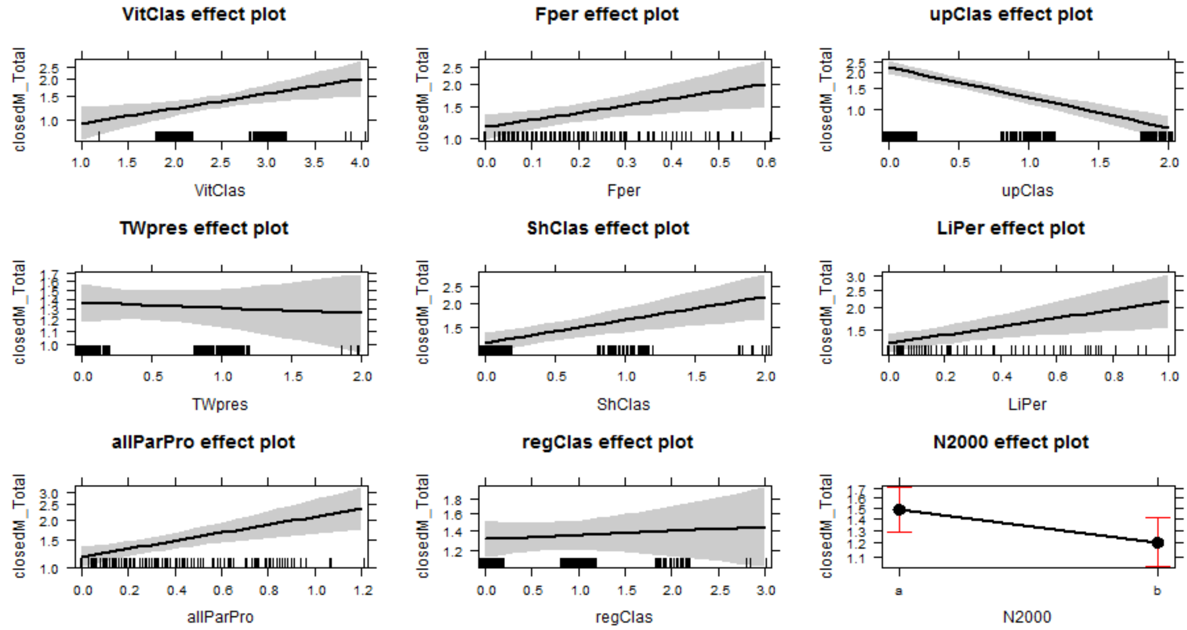
All sites - effects of stand structure on closed microhabitats

```
Hmax        **
Hmin        ***
BHDmean     ns
BHDmax      ***
BasalArea   ***
sp_nr_tree  ***
BarkManage  ***
BarkNature  ***
Natura 2000       ns
```



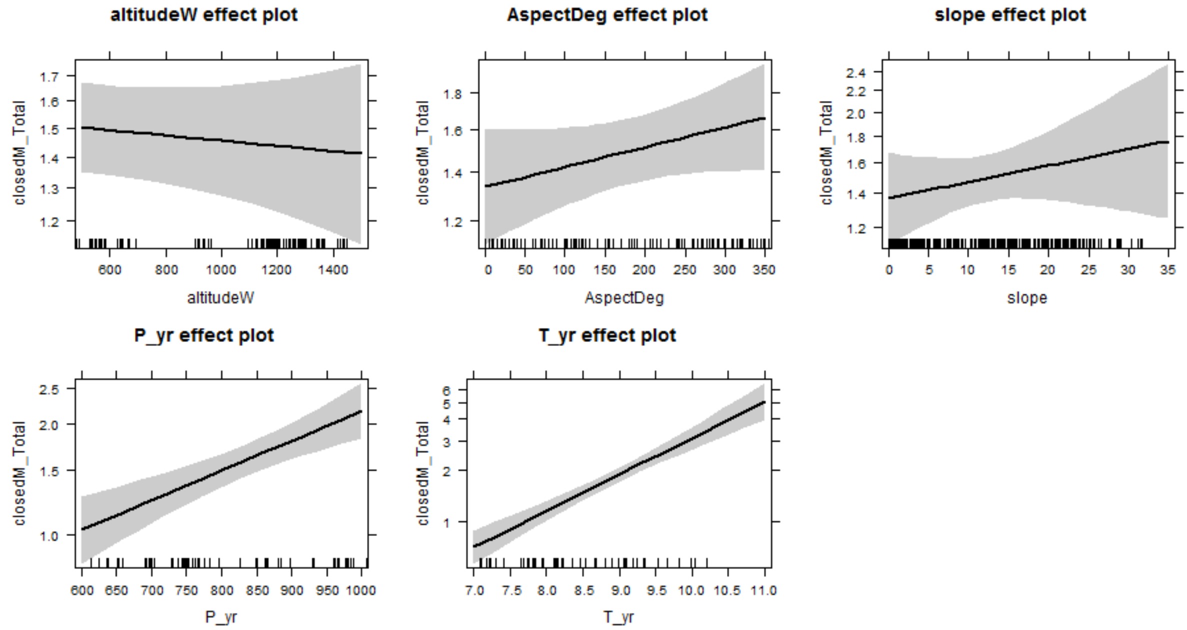
All sites - effects of tree morphology on closed microhabitats

```
VitClas    ***
Fper       ***
upClas     ***
TWpres     ns
ShClas     **
LiPer      **
allParPro ***
regClas    ns
Natura 2000      *
```



All sites - effects of the climate and landscape on closed microhabitats

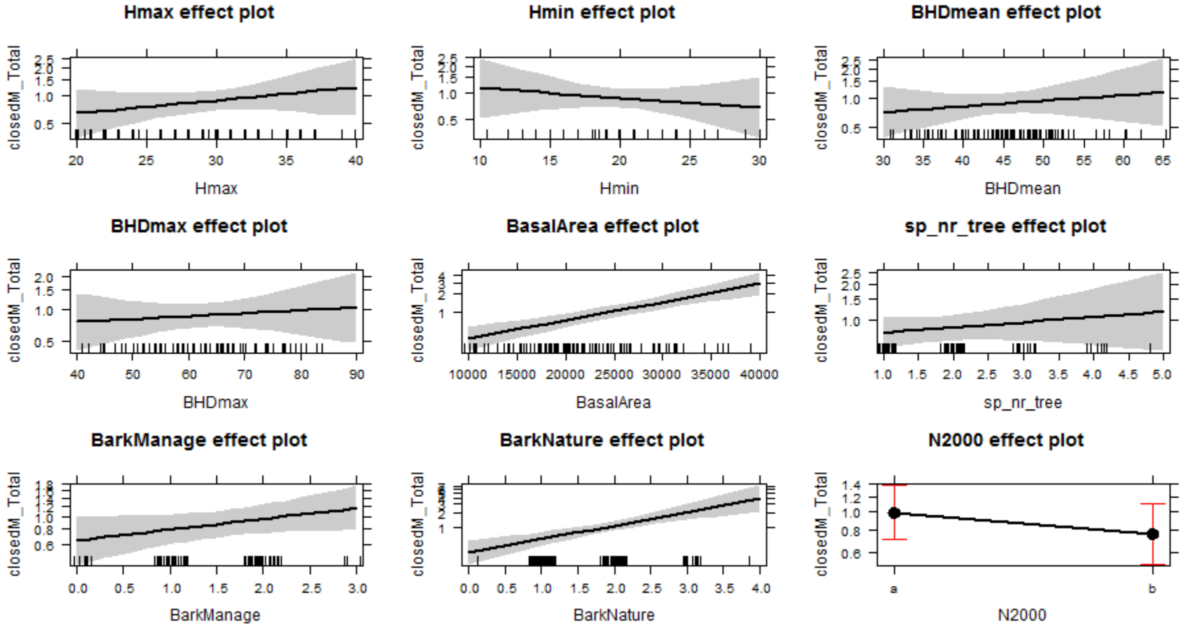
```
altitudeW     *
AspectDeg     ns
slope         ***
P_yr          ns
T_yr          ***
```



Atlantic biogeographic region – effect plots

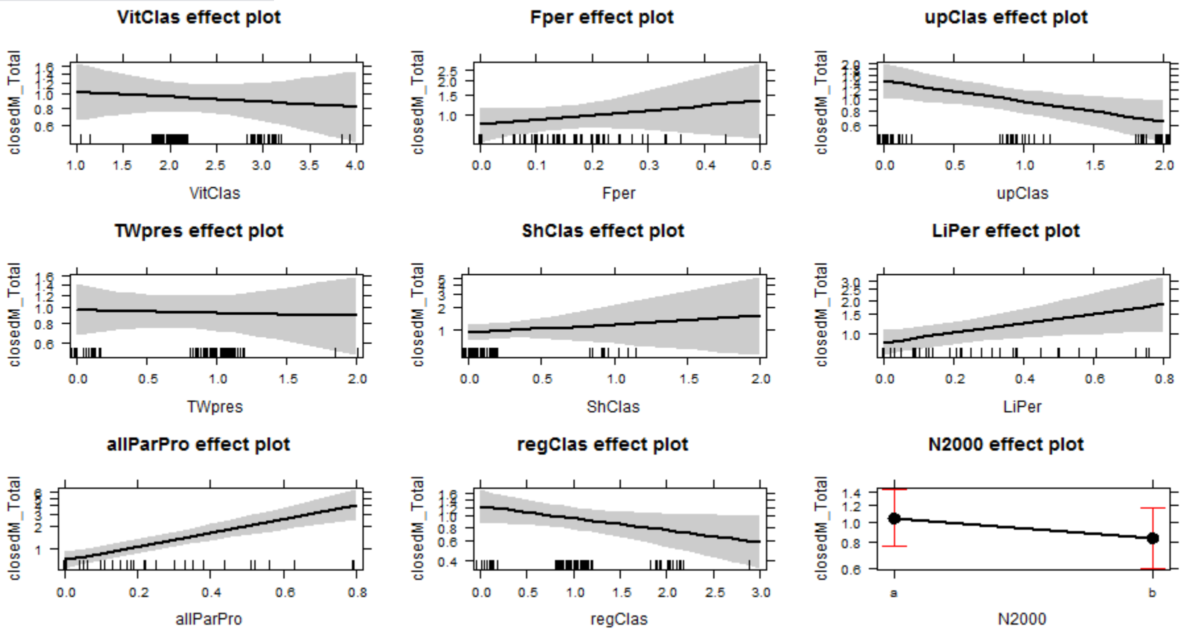
Atlantic biogeographic region - effects of stand structure on closed microhabitats

```
Hmax          *
Hmin          ***
BHDmean       *
BHDmax        ***
BasalArea     ***
sp_nr_tree    .
BarkManage    ns
BarkNature    ***
Natura 2000        ns
```



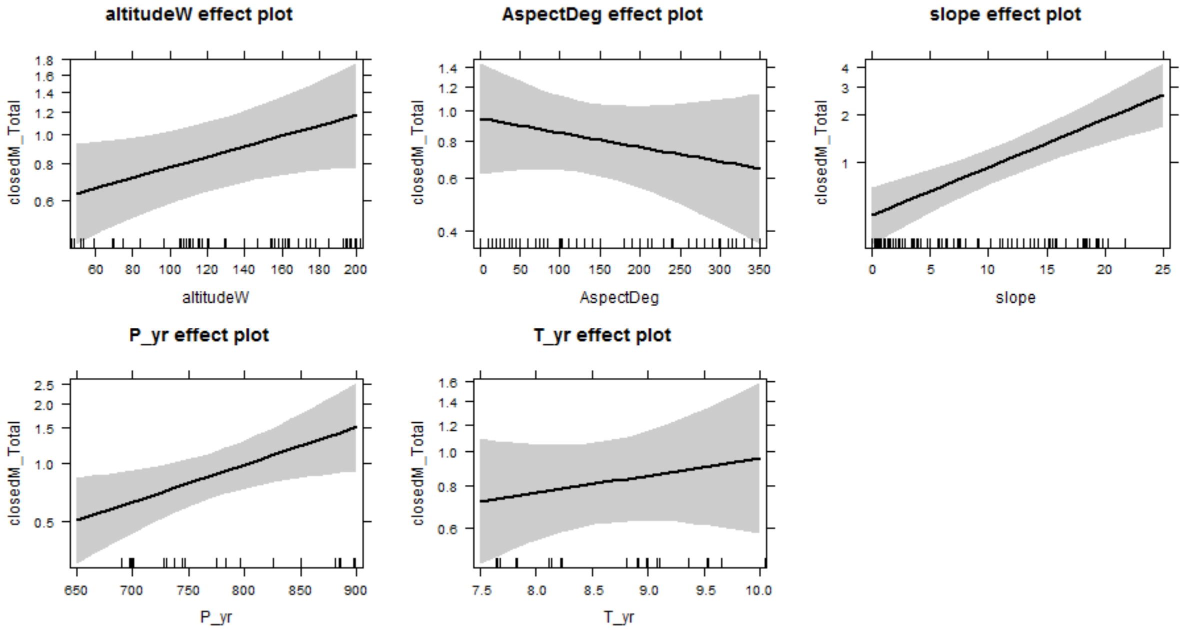
Atlantic biogeographic region - effects of tree morphology on closed microhabitats

```
VitClas     ***
Fper        ns
upClas      ***
TWpres      ns
ShClas      ns
LiPer       ns
allParPro   ***
regClas     .
Natura 2000      ns
```



Atlantic biogeographic region - effects of the climate and landscape on closed microhabitats

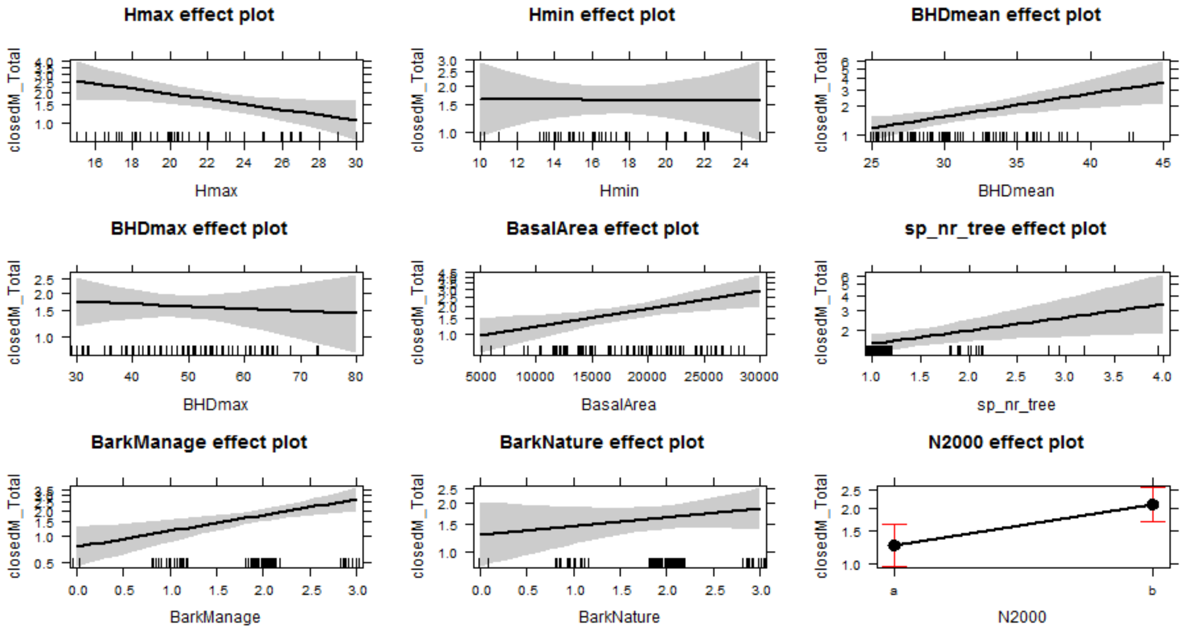
```
altitudeW   ***
AspectDeg   *
slope       ***
P_yr        **
T_yr        ns
```



Mediterranean biogeographic region – effect plots

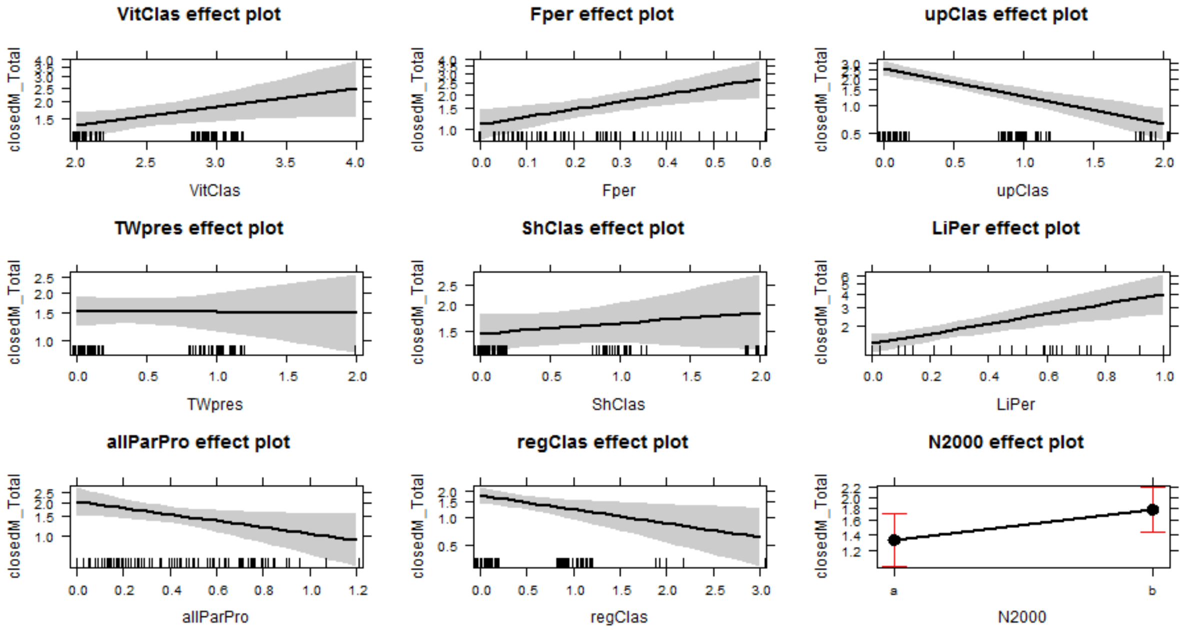
Mediterranean biogeographic region - effects of stand structure on closed microhabitats

```
Hmax        ns
Hmin        ns
BHDmean     ***
BHDmax      ***
BasalArea   *
sp_nr_tree  **
BarkManage  ***
BarkNature  ns
Natura 2000      **
```



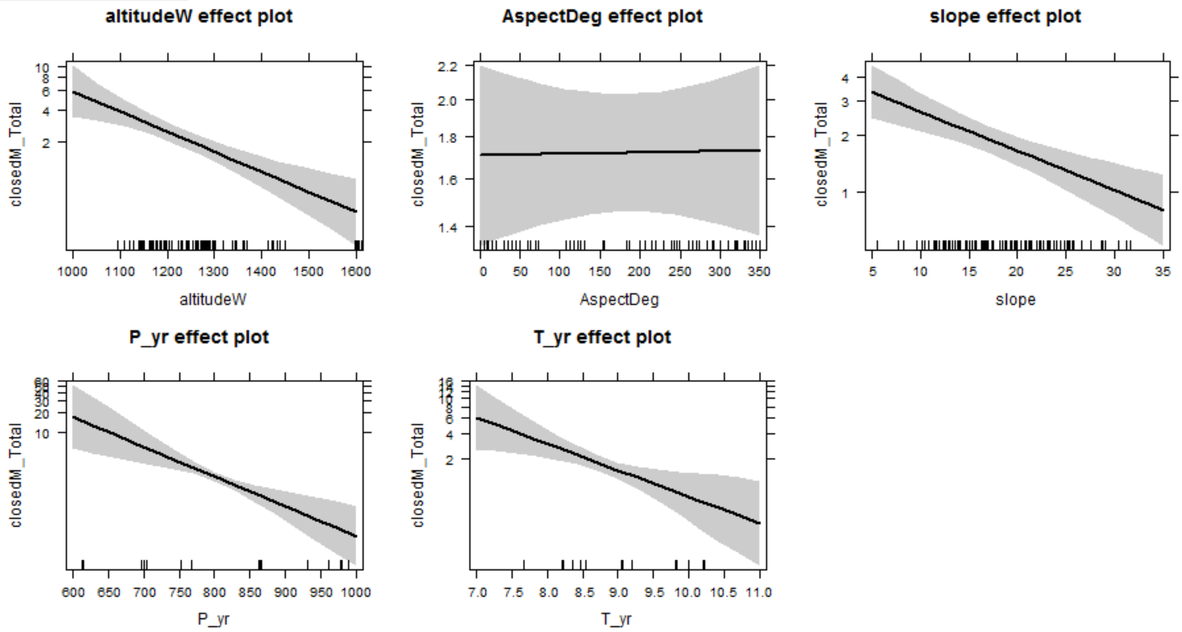
Mediterranean biogeographic region - effects of tree morphology on closed microhabitats

```
VitClas    *
Fper       ***
upClas     ***
TWpres     ns
ShClas     *
LiPer      ***
allParPro ns
regClas    **
Natura 2000      .
```



Mediterranean biogeographic region - effects of the climate and landscape on closed microhabitats

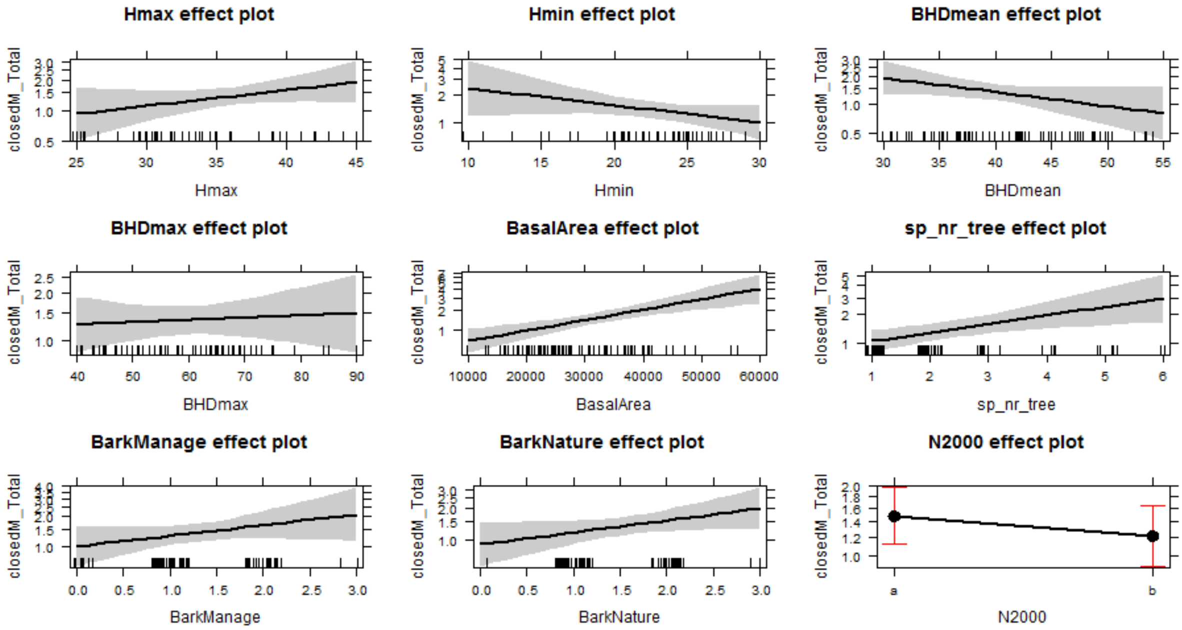
```
altitudeW   ns
AspectDeg   ns
slope       ***
P_yr        ***
T_yr        **
```



Continental biogeographic region – effect plots

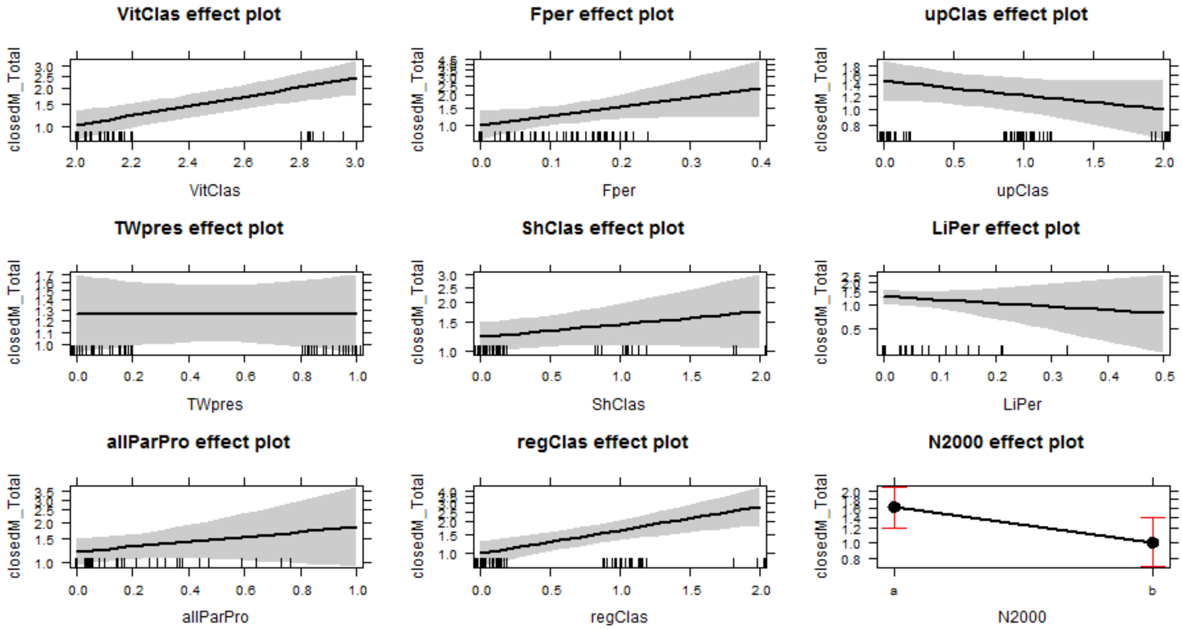
Continental biogeographic region - effects of stand structure on closed microhabitats

```
Hmax        ns
Hmin        ns
BHDmean     *
BHDmax      **
BasalArea   ***
sp_nr_tree  ***
BarkManage  *
BarkNature  *
Natura 2000       ns
```



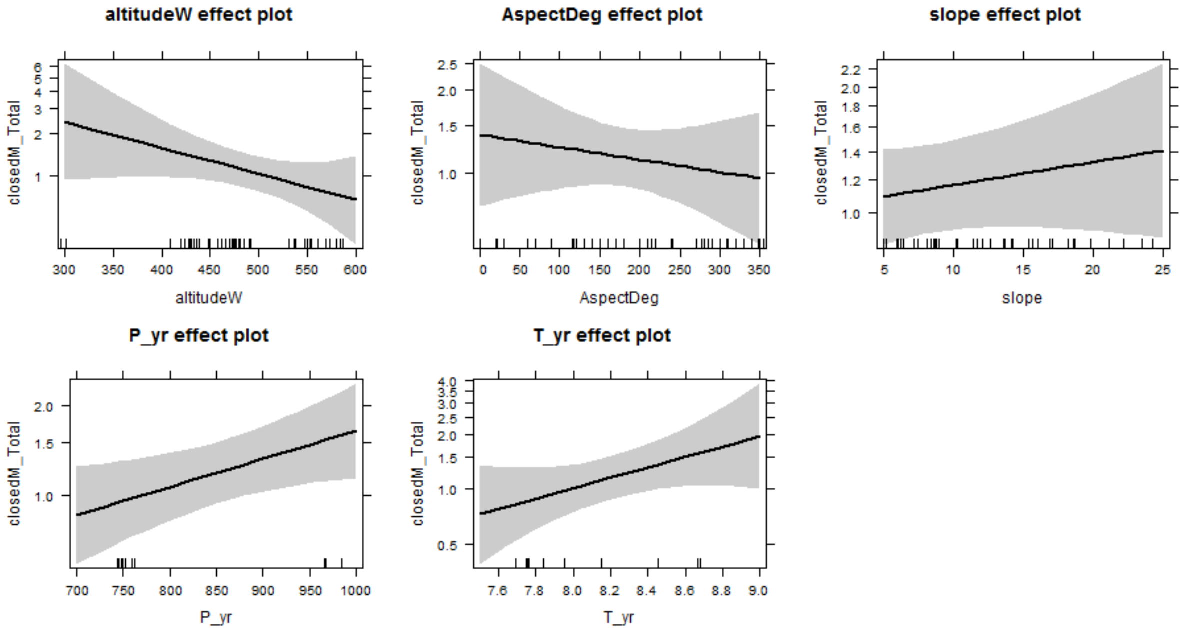
Continental biogeographic region - effects of tree morphology on closed microhabitats

VitClas	***
Fper	***
upClas	*
TWpres	ns
ShClas	.
LiPer	ns
allParPro	ns
regClas	***
Natura 2000	*



Continental biogeographic region - effects of the climate and landscape on closed microhabitats

altitudeW	***
AspectDeg	ns
slope	**
P_yr	***
T_yr	ns

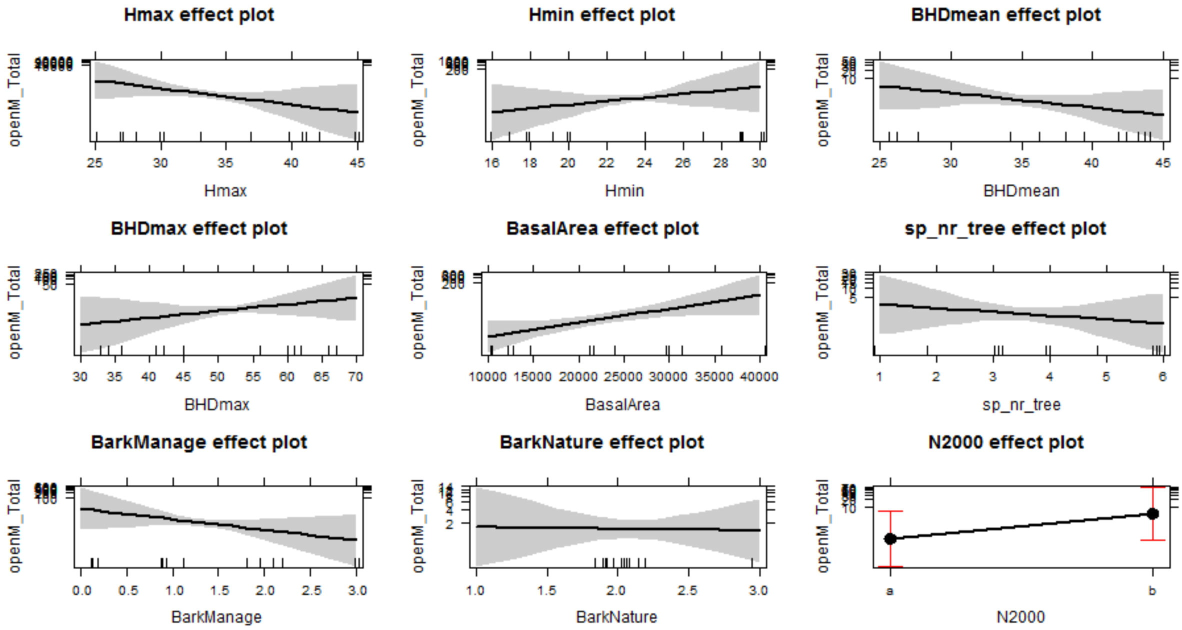


Annex 4. Effects on open microhabitats

Reference site – effect plots

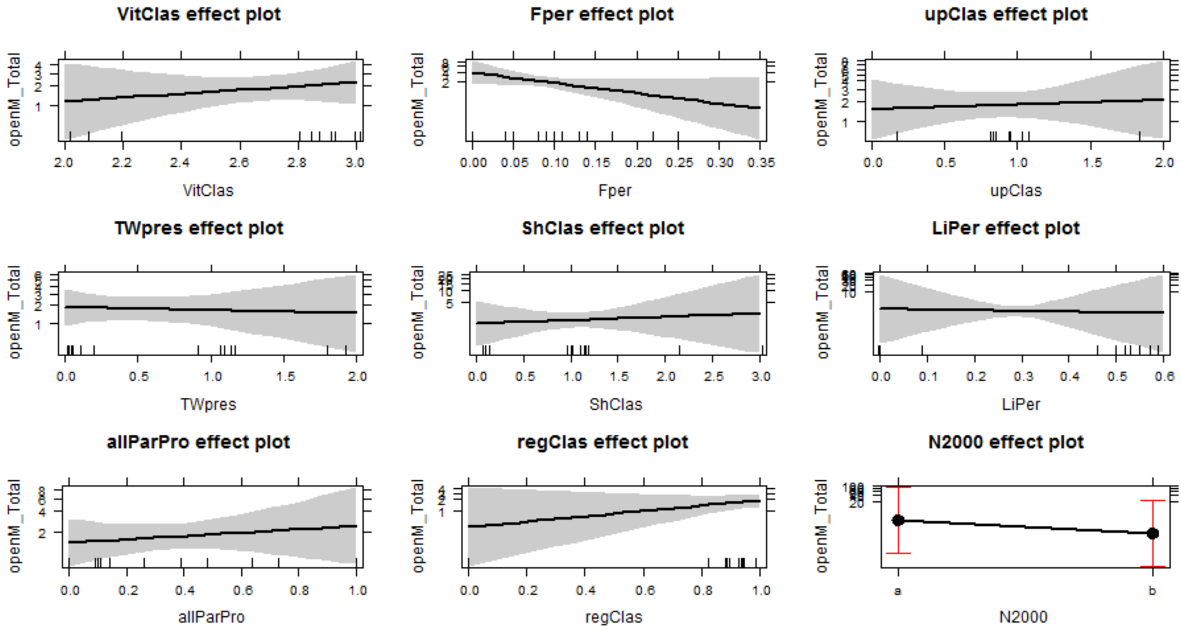
Reference site - effects of stand structure on open microhabitats

```
Hmax        ns
Hmin        ns
BHDmean     ns
BHDmax      ns
BasalArea   **
sp_nr_tree ns
BarkManage *
BarkNature ns
Natura 2000       ns
```



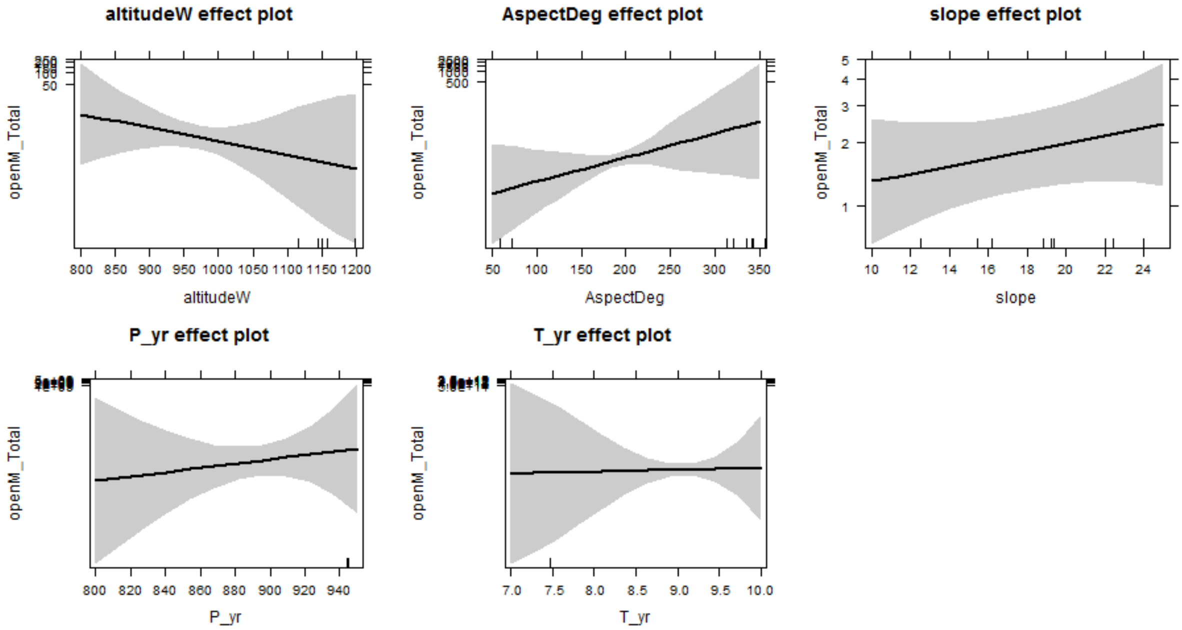
Reference Site - effects of tree morphology on open microhabitats

VitClas	ns
Fper	ns
upClas	ns
TWpres	ns
ShClas	ns
LiPer	ns
allParPro	ns
regClas	ns
Natura 2000	ns



Reference Site - effects of the climate and landscape on open microhabitats

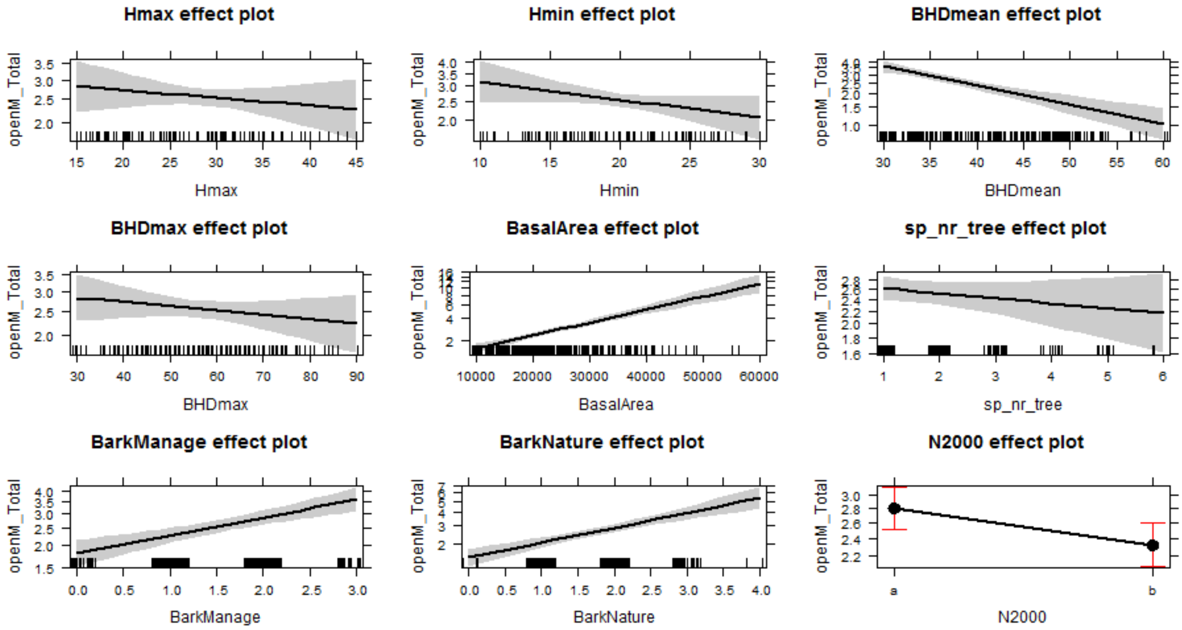
altitudeW	ns
AspectDeg	.
slope	ns
P_yr	.
T_yr	ns



All sites - effect plots

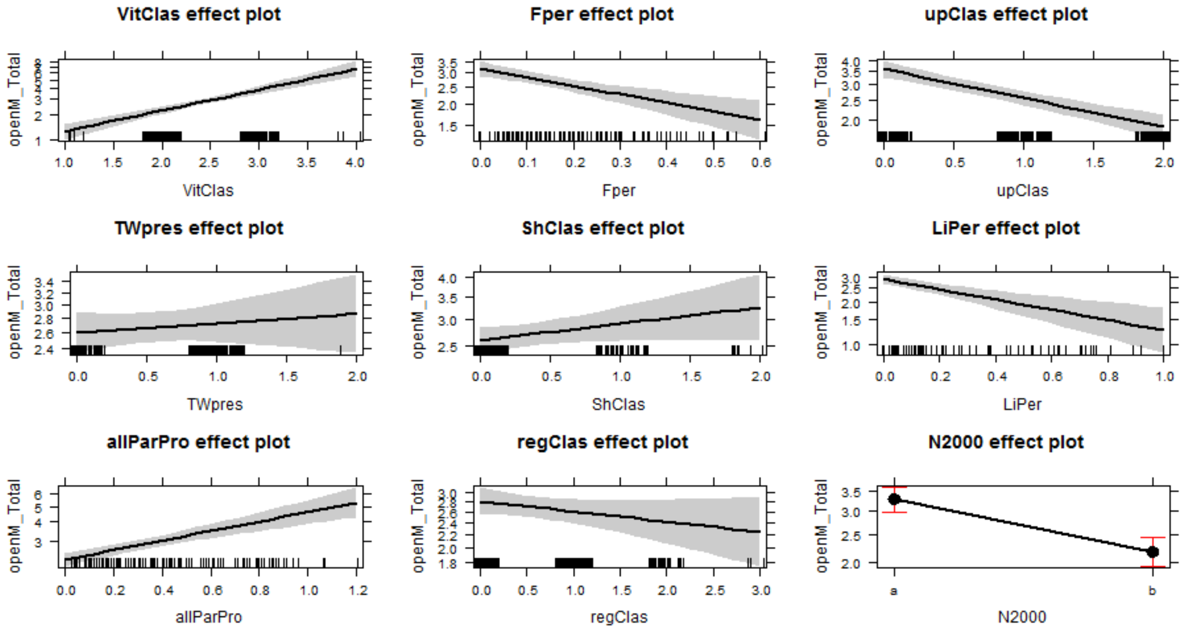
All sites - effects of stand structure on open microhabitats

```
Hmax        ***
Hmin        ***
BHDmean     ***
BHDmax      ***
BasalArea   ***
sp_nr_tree  ns
BarkManage  ***
BarkNature  ***
Natura 2000      *
```



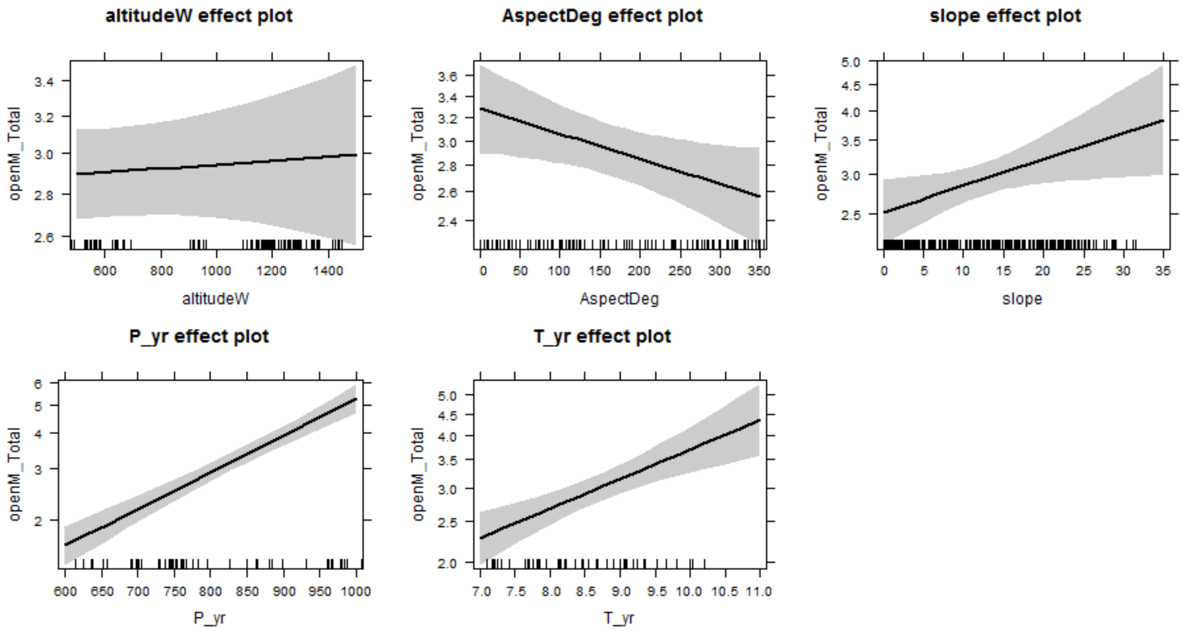
All sites - effects of tree morphology on open microhabitats

```
VitClas    ***
Fper       ***
upClas     ***
TWpres     ns
ShClas     ns
LiPer      ***
allParPro  ***
regClas    ns
Natura 2000      ***
```



All sites - effects of the climate and landscape on open microhabitats

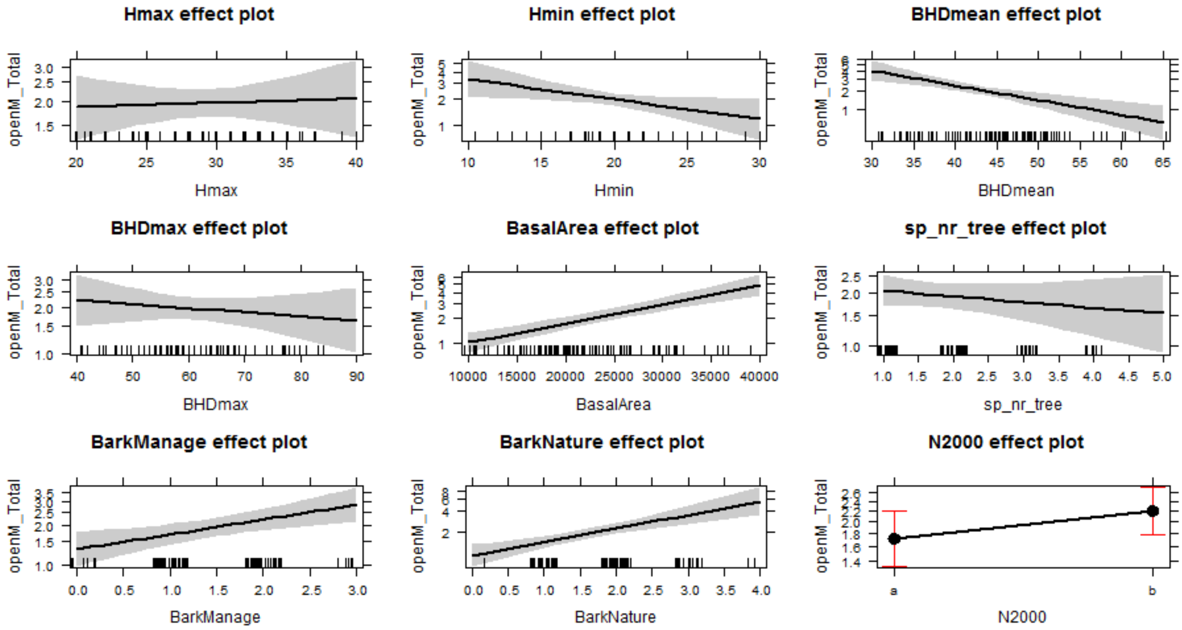
```
altitudeW  ***
AspectDeg  **
slope      ***
P_yr       ***
T_yr       ***
```



Atlantic biogeographic region – effect plots

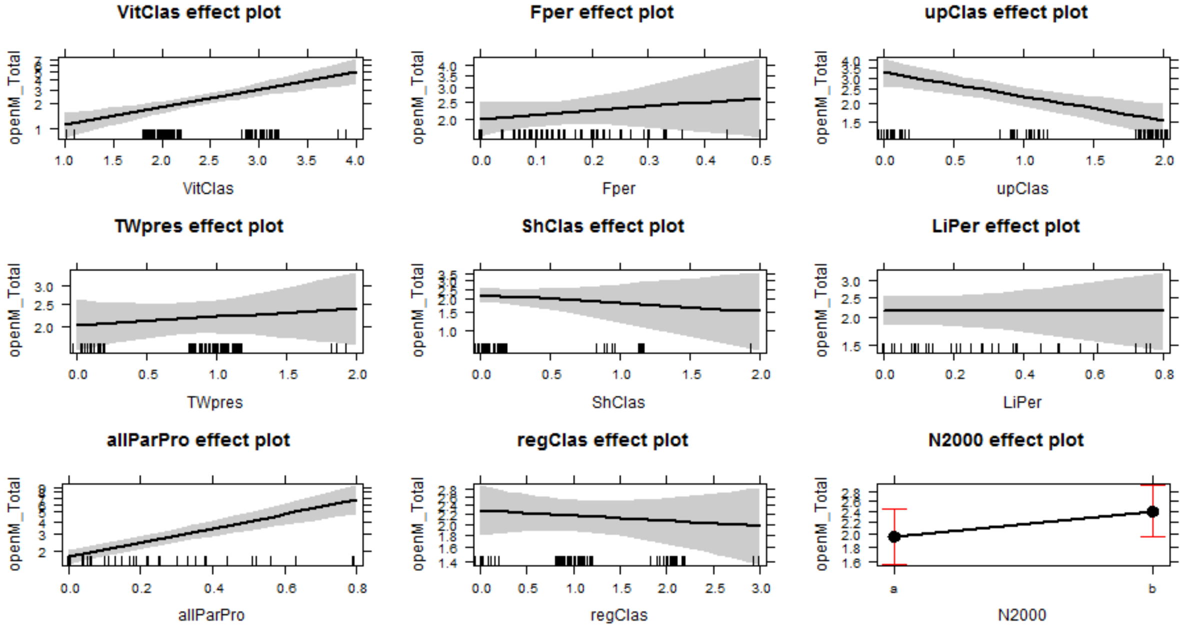
Atlantic biogeographic region - effects of stand structure on open microhabitats

```
Hmax        ***
Hmin        ***
BHDmean     ***
BHDmax      *
BasalArea   ***
sp_nr_tree  ns
BarkManage  **
BarkNature  ***
Natura 2000       ns
```



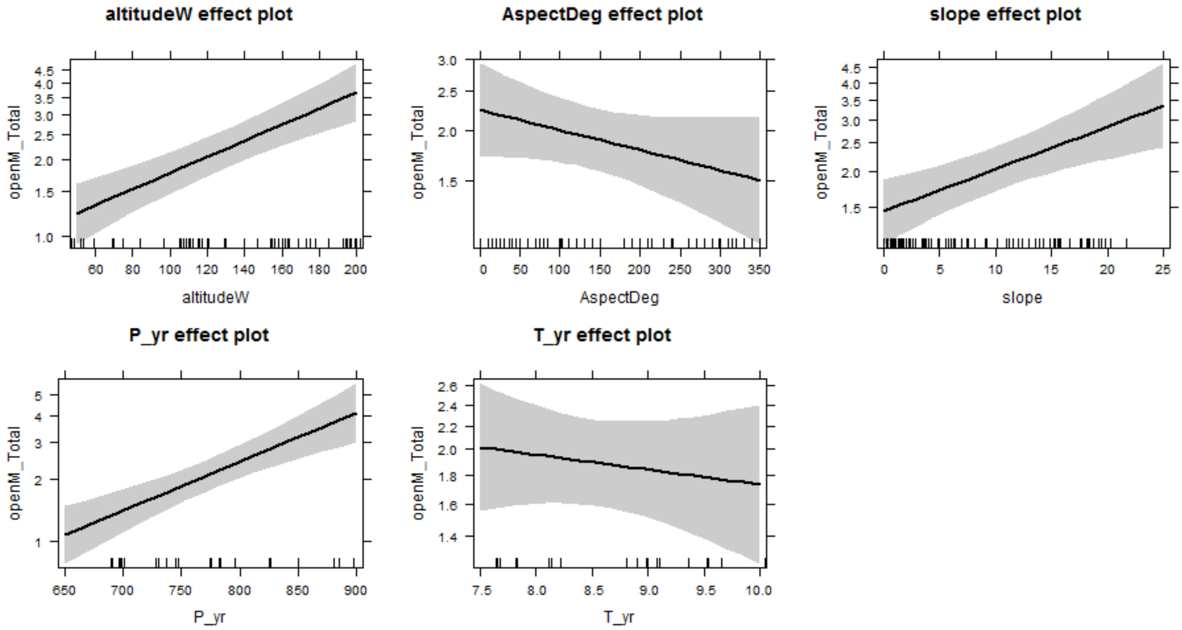
Atlantic biogeographic region - effects of tree morphology on open microhabitats

```
VitClas    ***
Fper       ns
upClas     ***
TWpres     *
ShClas     ns
LiPer      .
allParPro ***
regClas    ns
Natura 2000      ns
```



Atlantic biogeographic region - effects of the climate and landscape on open microhabitats

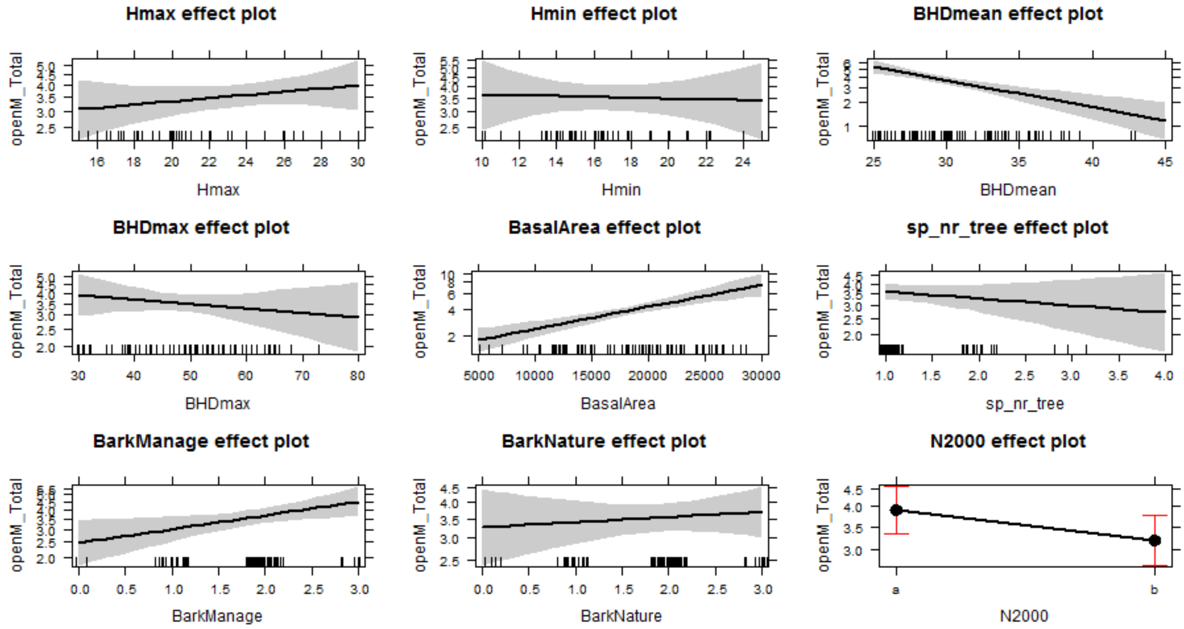
```
altitudeW ***
AspectDeg  **
slope      **
P_yr      ***
T_yr       ns
```



Mediterranean biogeographic region – effect plots

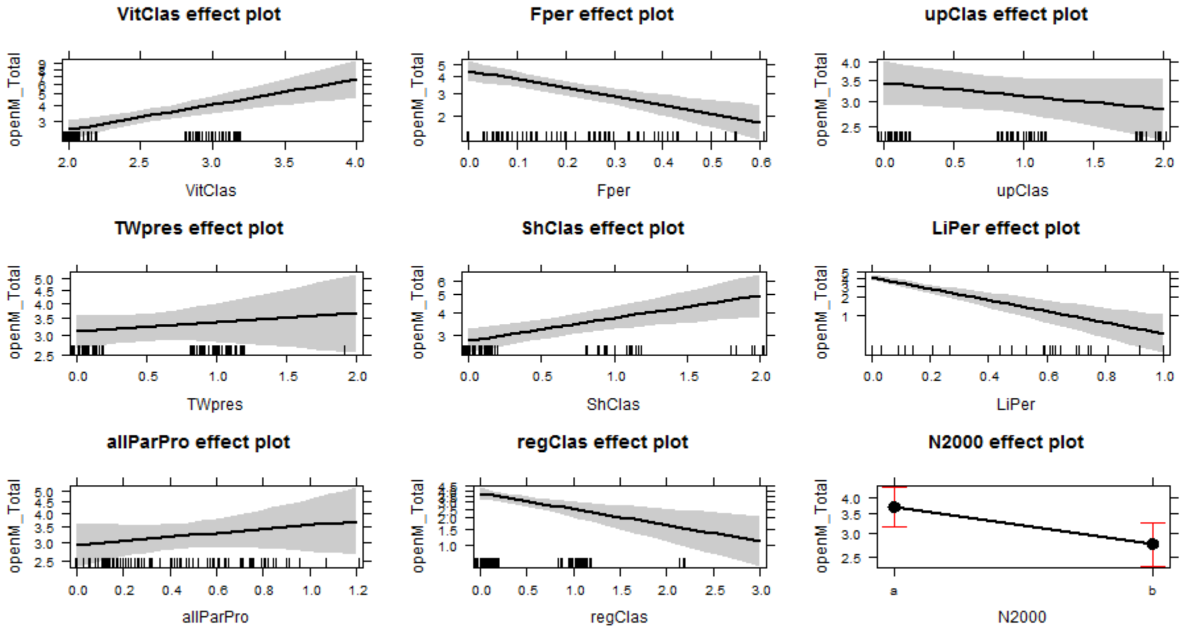
Mediterranean biogeographic region - effects of stand structure on open microhabitats

```
Hmax         ns
Hmin         ns
BHDmean      **
BHDmax       **
BasalArea   ***
sp_nr_tree   ns
BarkManage   **
BarkNature   ns
Natura 2000       .
```



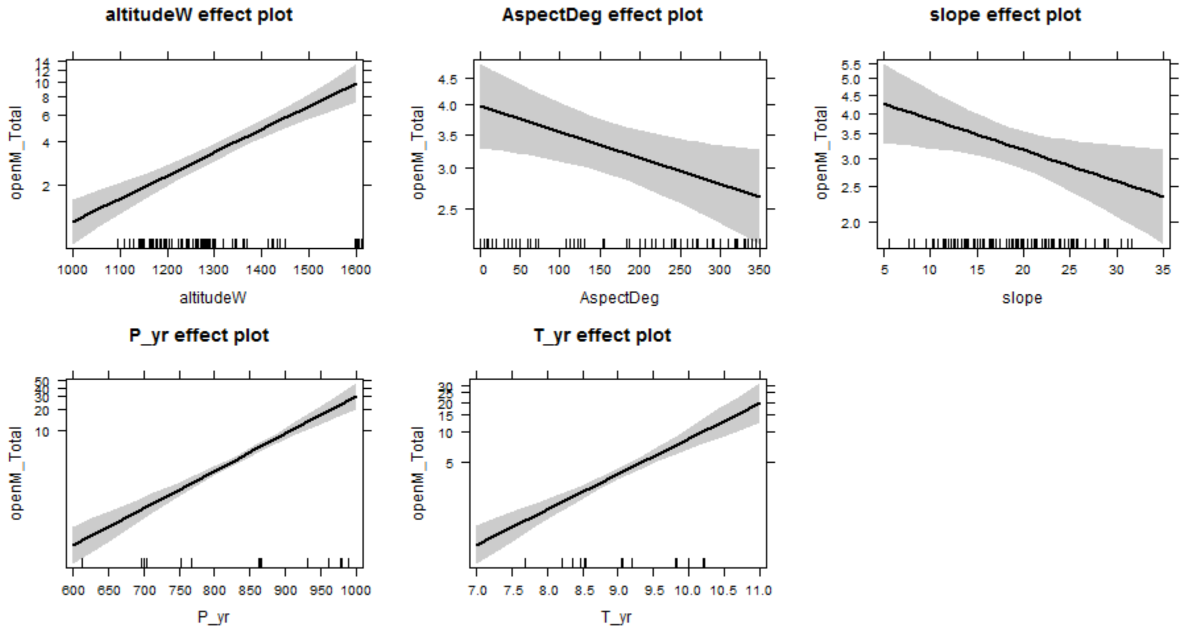
Mediterranean biogeographic region - effects of tree morphology on open microhabitats

```
VitClas    ns
Fper       ***
upClas     **
TWpres     ns
ShClas     ns
LiPer      ***
allParPro ns
regClas    ***
Natura 2000      **
```



Mediterranean biogeographic region - effects of the climate and landscape on open microhabitats

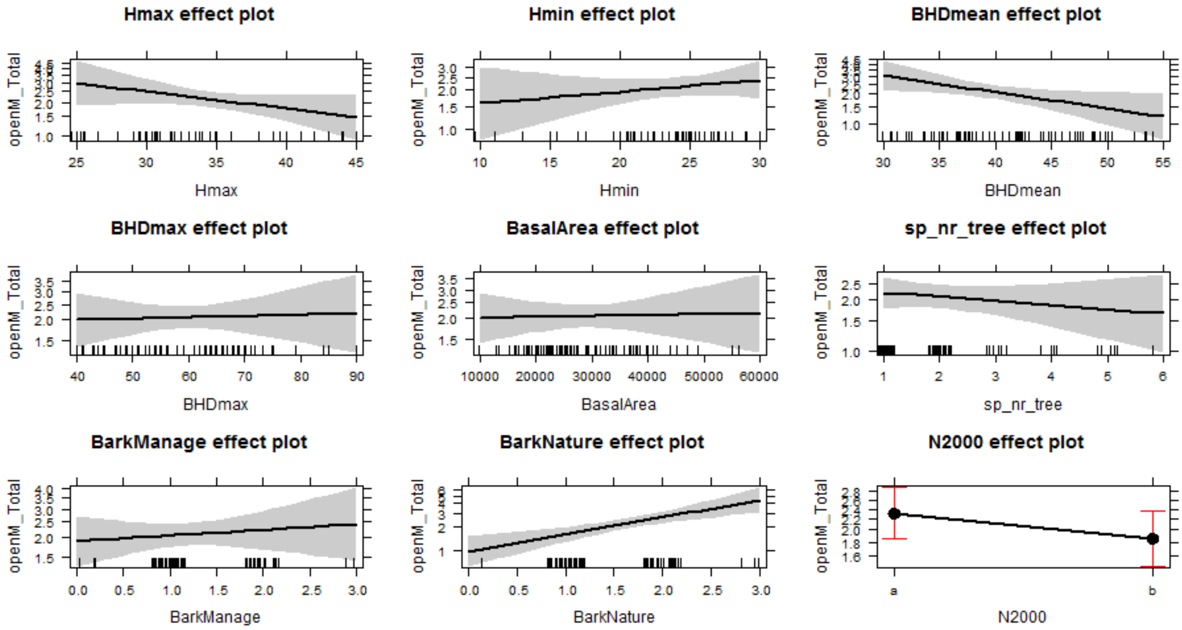
```
altitudeW    *
AspectDeg    ns
slope        *
P_yr       ***
T_yr       ***
```



Continental biogeographic region – effect plots

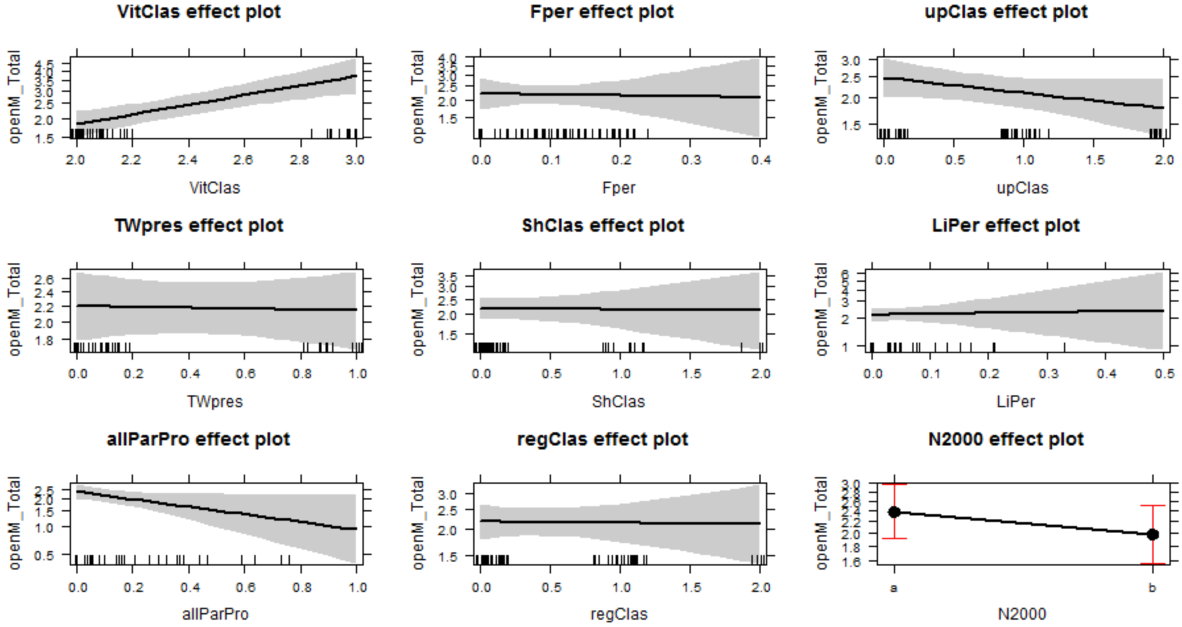
Continental biogeographic region - effects of stand structure on open microhabitats

```
Hmax        **
Hmin        ns
BHDmean     *
BHDmax      ns
BasalArea   ns
sp_nr_tree  ns
BarkManage  .
BarkNature ***
Natura 2000       ns
```



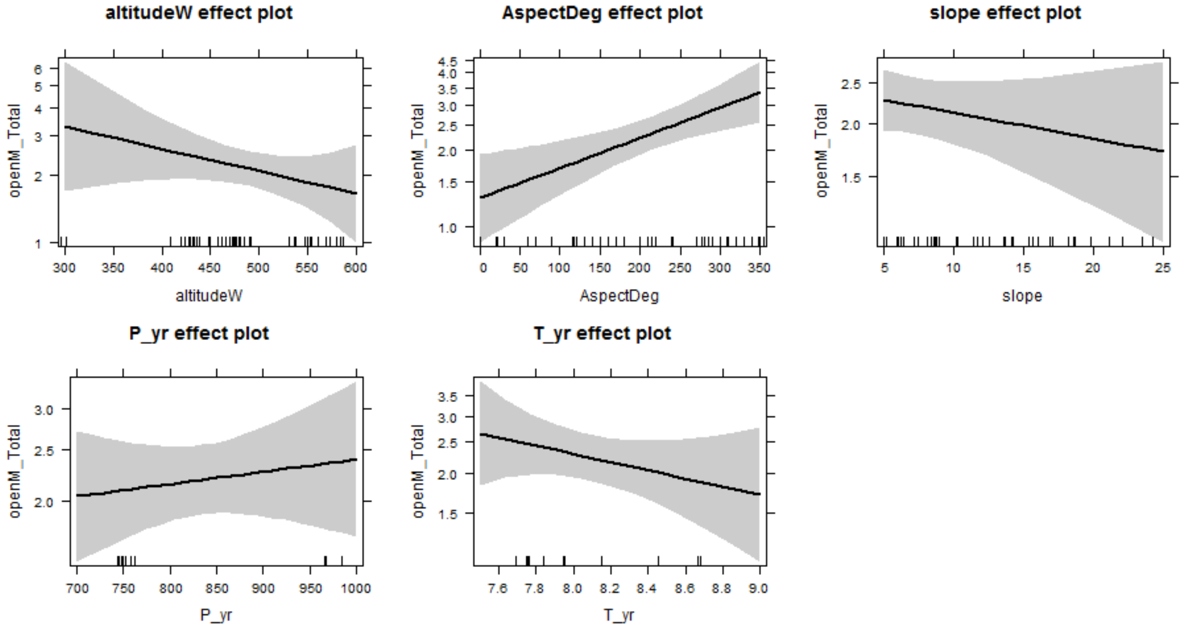
Continental biogeographic region - effects of tree morphology on open microhabitats

```
VitClas   ***
Fper      ns
upClas    ns
TWpres    ns
ShClas    ns
LiPer     ns
allParPro **
regClas   ns
Natura 2000    ns
```



Continental biogeographic region - effects of the climate and landscape on open microhabitats

```
altitudeW  .
AspectDeg **
slope     ns
P_yr      ns
T_yr      ns
```

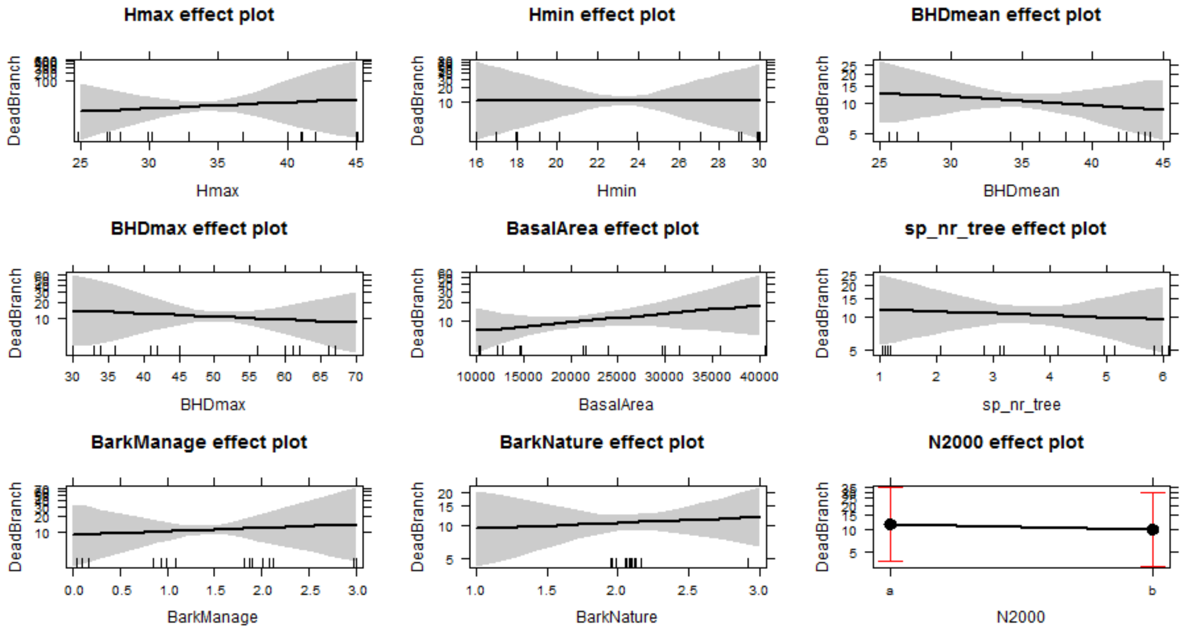


Annex 5. Effects on dead branches

Reference site – effect plots

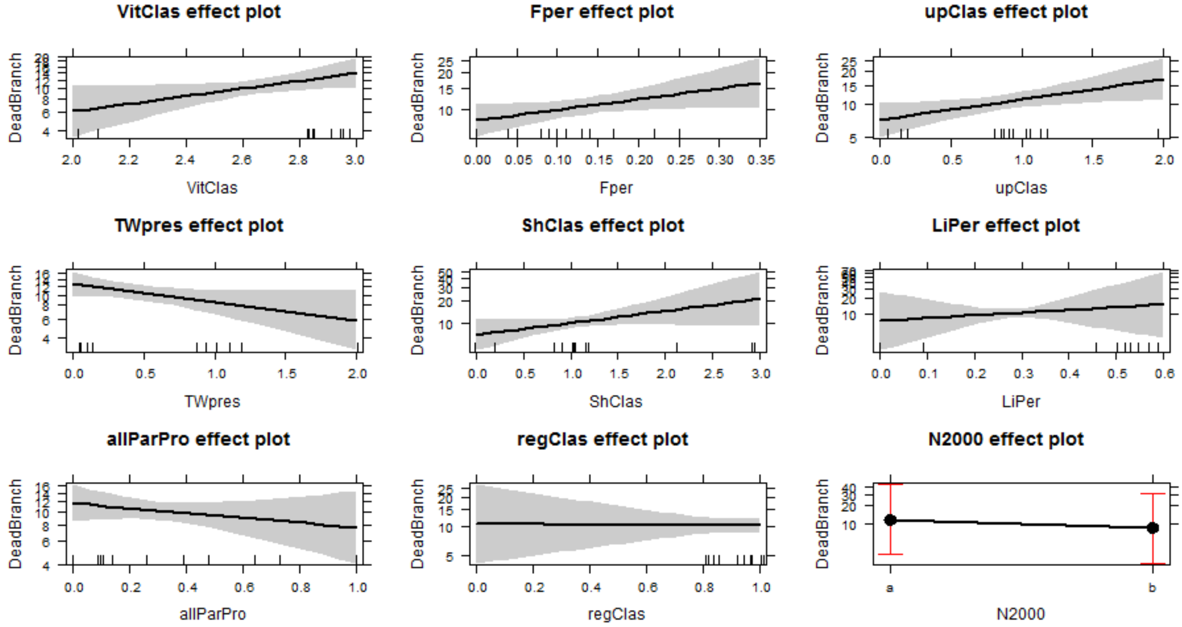
Reference site - effects of stand structure on dead branches

```
Hmax           ***
Hmin              ns
BHDmean           ns
BHDmax            ns
BasalArea         *
sp_nr_tree        ns
BarkManage        ns
BarkNature        ns
Natura 2000             ns
```



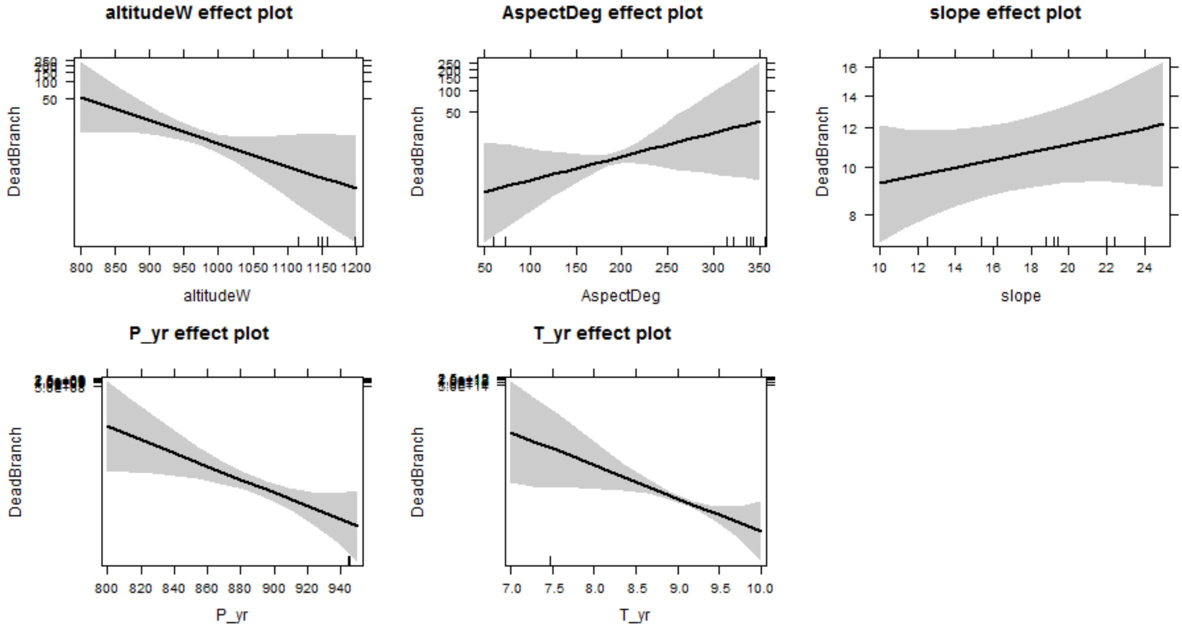
Reference Site - effects of tree morphology on dead branches

```
VitClas      ns
Fper         *
upClas       ns
TWpres       **
ShClas       ns
LiPer       ***
allParPro    ns
regClas      ns
Natura 2000        ns
```



Reference Site - effects of the climate and landscape on dead branches

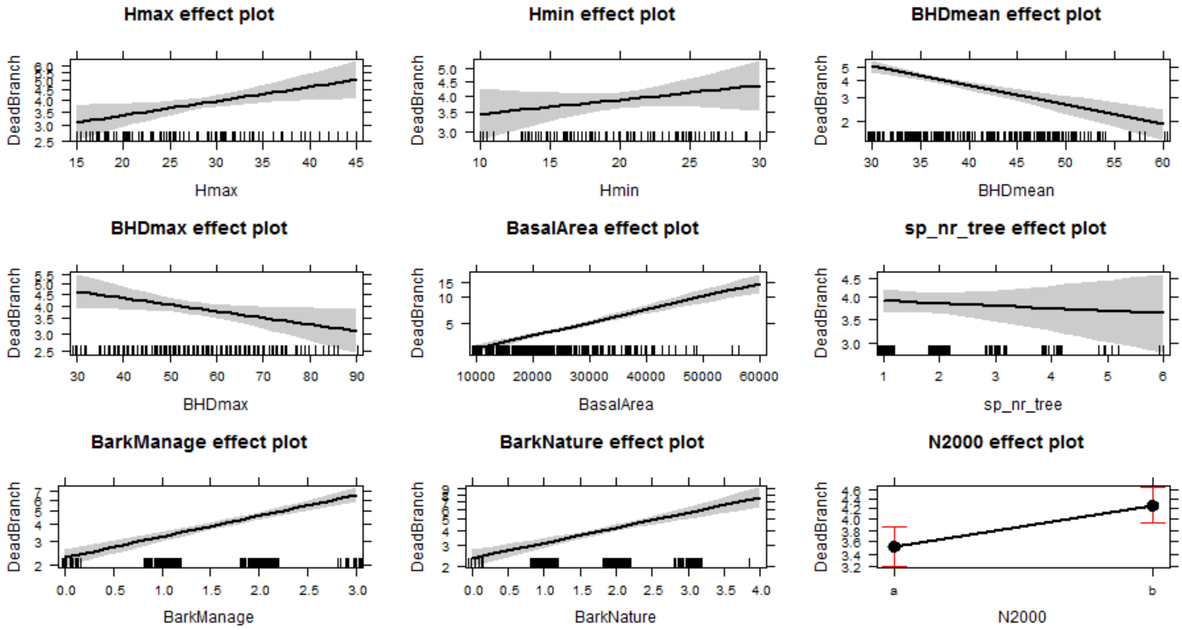
```
altitudeW ***
AspectDeg ns
slope     ns
P_yr      ns
T_yr      *
```



All sites - effect plots

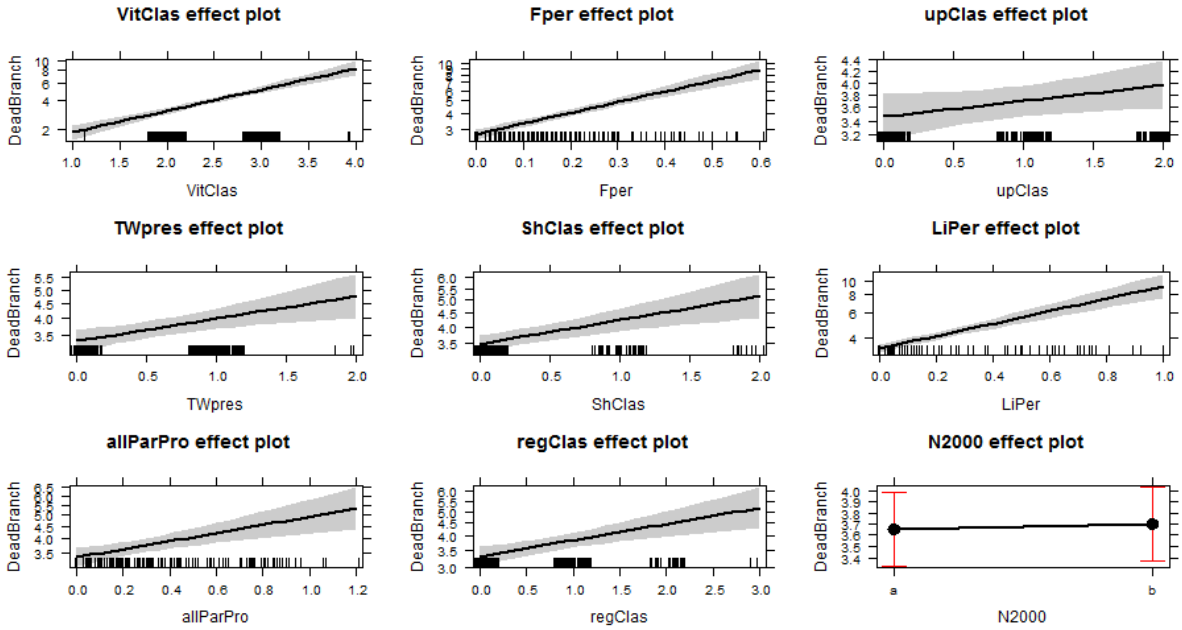
All sites - effects of stand structure on dead branches

```
Hmax         ns
Hmin         ns
BHDmean     ***
BHDmax      ***
BasalArea   ***
sp_nr_tree   ns
BarkManage  ***
BarkNature  ***
Natura 2000        **
```



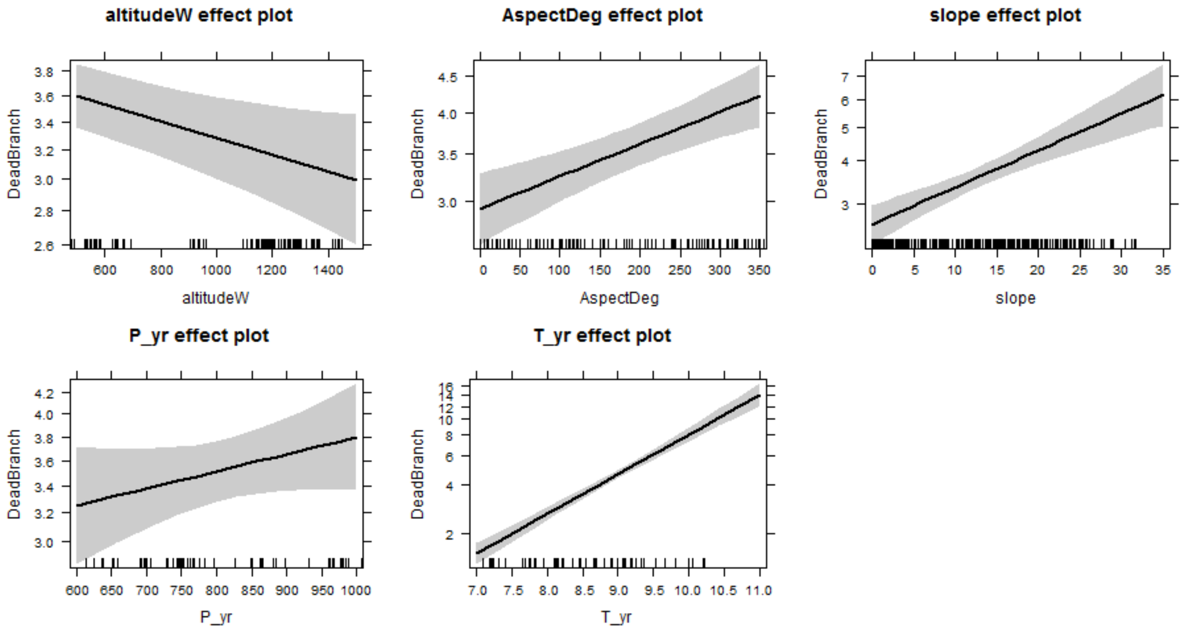
All sites - effects of tree morphology on dead branches

```
VitClas     ***
Fper        ***
upClas      ns
TWpres      ***
ShClas      ***
LiPer       ***
allParPro ***
regClas     ***
Natura 2000       ns
```



All sites - effects of the climate and landscape on dead branches

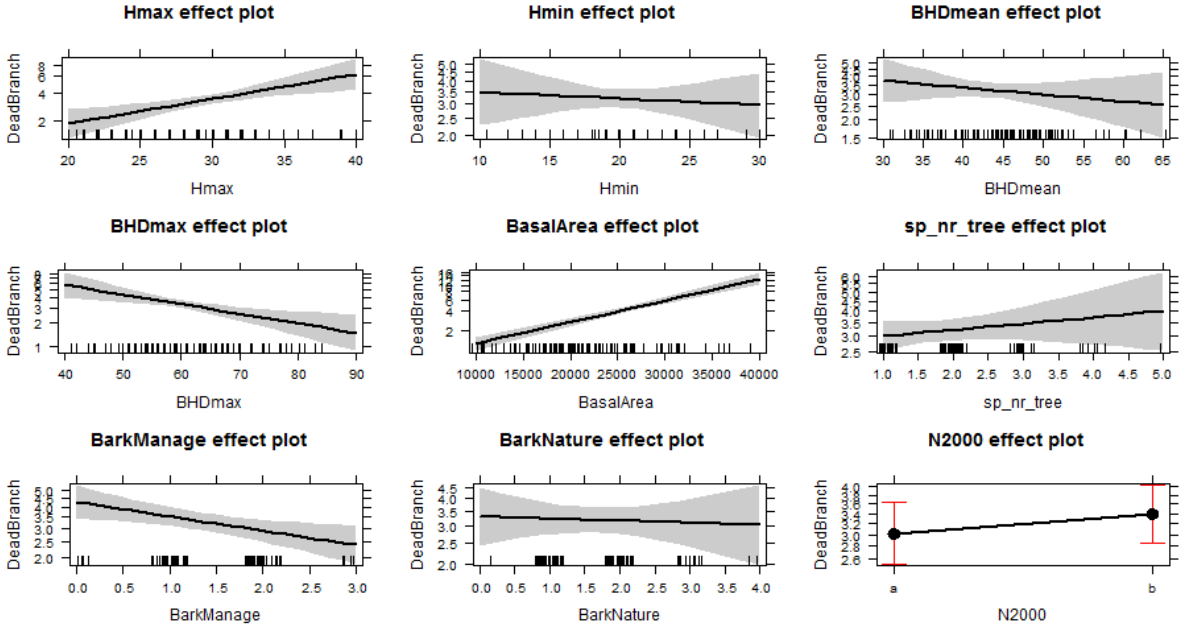
```
altitudeW ***
AspectDeg   ns
slope       ***
P_yr        ***
T_yr        ***
```



Atlantic biogeographic region – effect plots

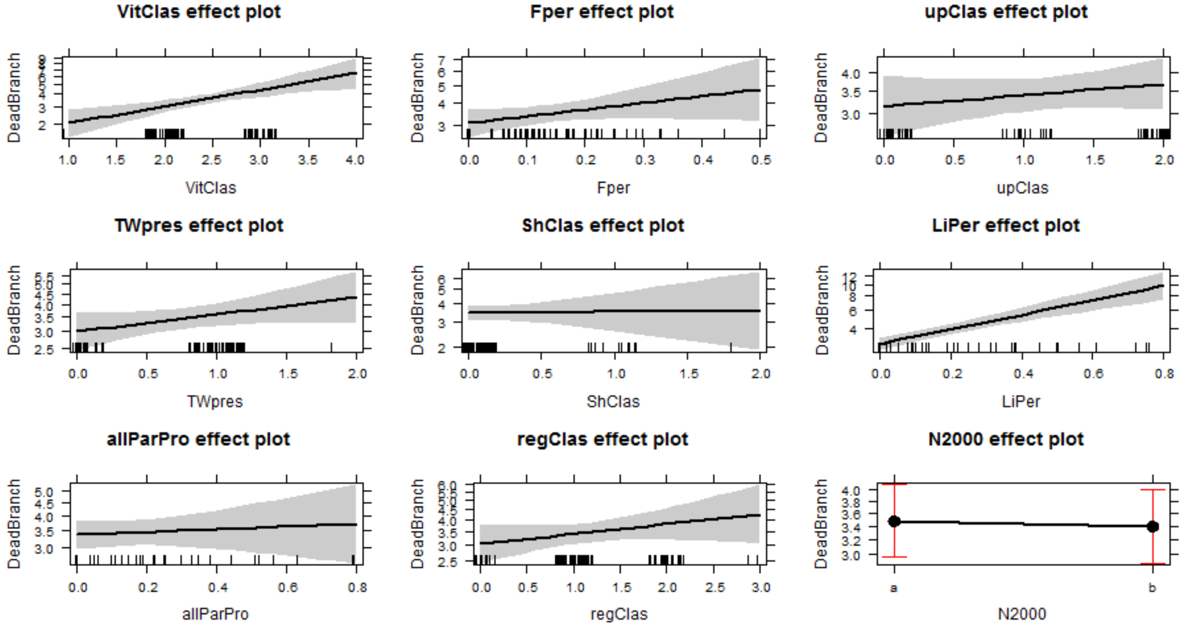
Atlantic biogeographic region - effects of stand structure on dead branches

```
Hmax         *
Hmin         .
BHDmean      ***
BHDmax       ns
BasalArea   ***
sp_nr_tree   ns
BarkManage   **
BarkNature   ns
Natura 2000        ns
```



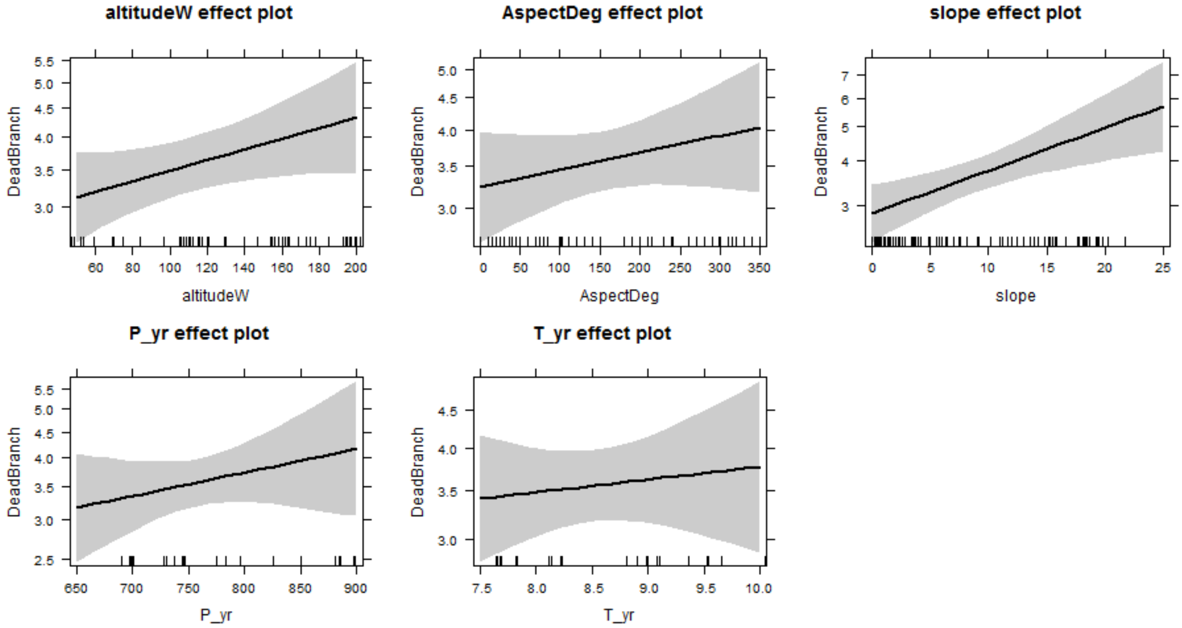
Atlantic biogeographic region - effects of tree morphology on dead branches

```
VitClas    ***
Fper        ns
upClas      *
TWpres      ns
ShClas      ns
LiPer      ***
allParPro   ns
regClas     ns
Natura 2000       ns
```



Atlantic biogeographic region - effects of the climate and landscape on dead branches

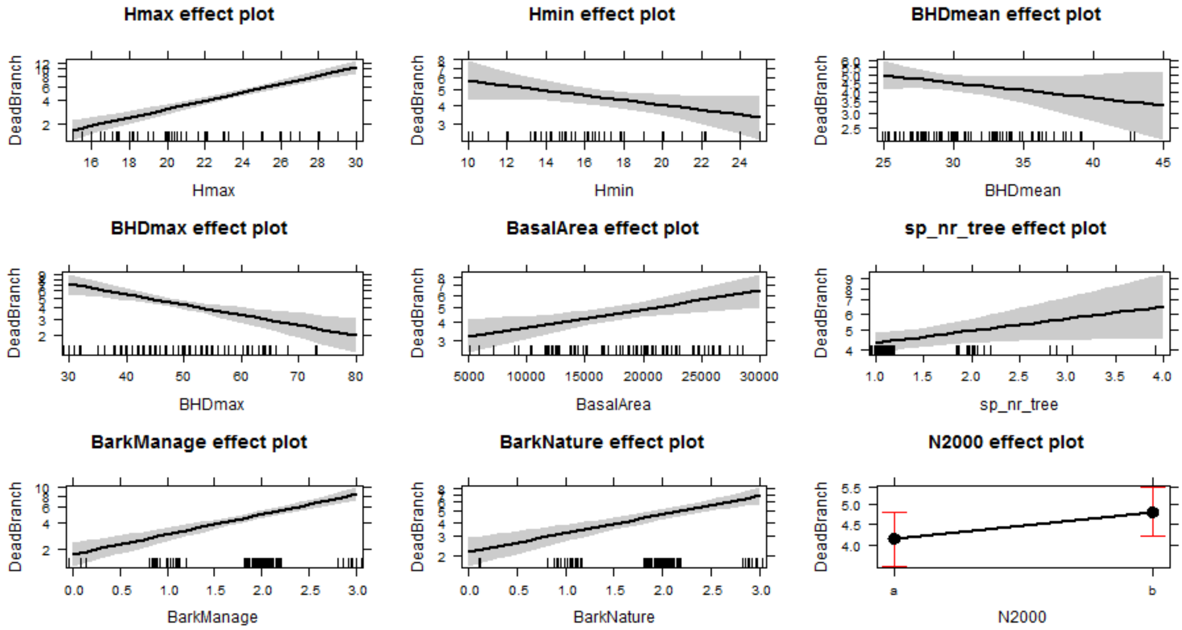
```
altitudeW ***
AspectDeg  ns
slope      ***
P_yr       ns
T_yr       ns
```



Mediterranean biogeographic region – effect plots

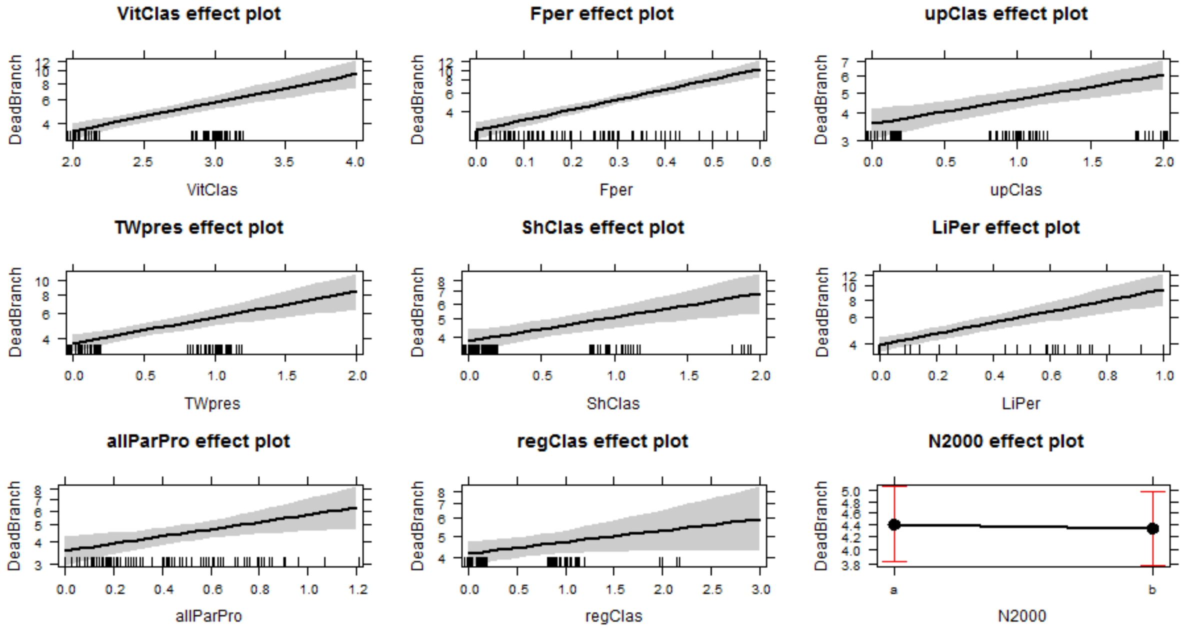
Mediterranean biogeographic region - effects of stand structure on dead branches

```
Hmax         ***
Hmin         ***
BHDmean      **
BHDmax       ns
BasalArea    ns
sp_nr_tree   ***
BarkManage   ***
BarkNature   ***
Natura 2000       ns
```



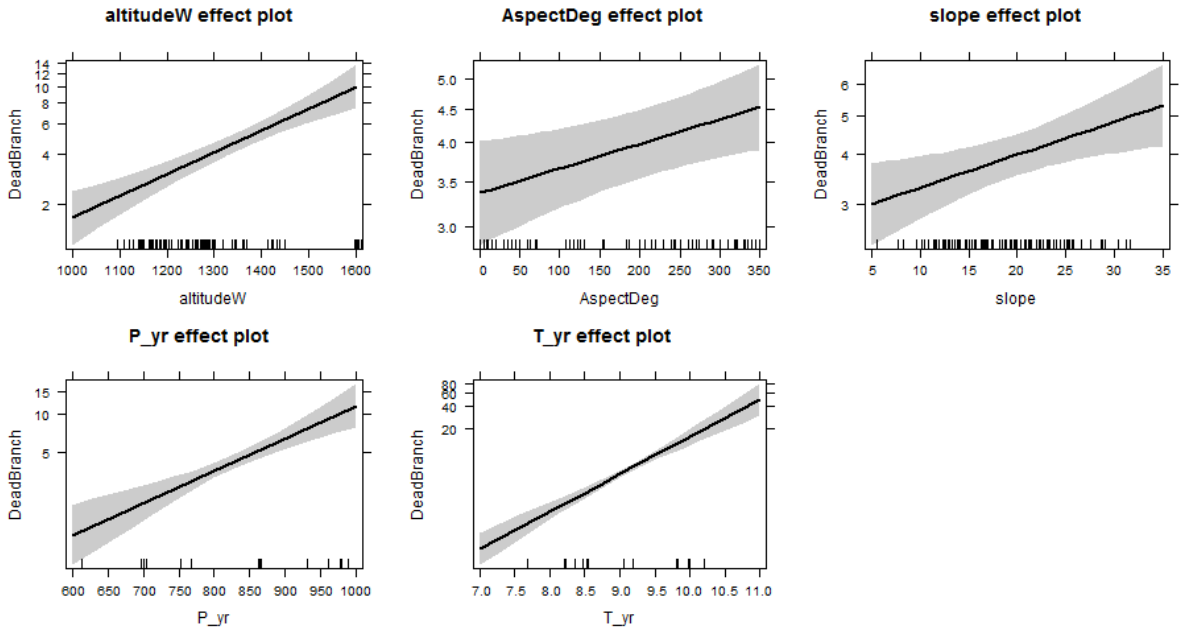
Mediterranean biogeographic region - effects of tree morphology on dead branches

```
VitClas     ***
Fper        ***
upClas        *
TWpres      ***
ShClas      ***
LiPer       ***
allParPro     *
regClas       .
Natura 2000        ns
```



Mediterranean biogeographic region - effects of the climate and landscape on dead branches

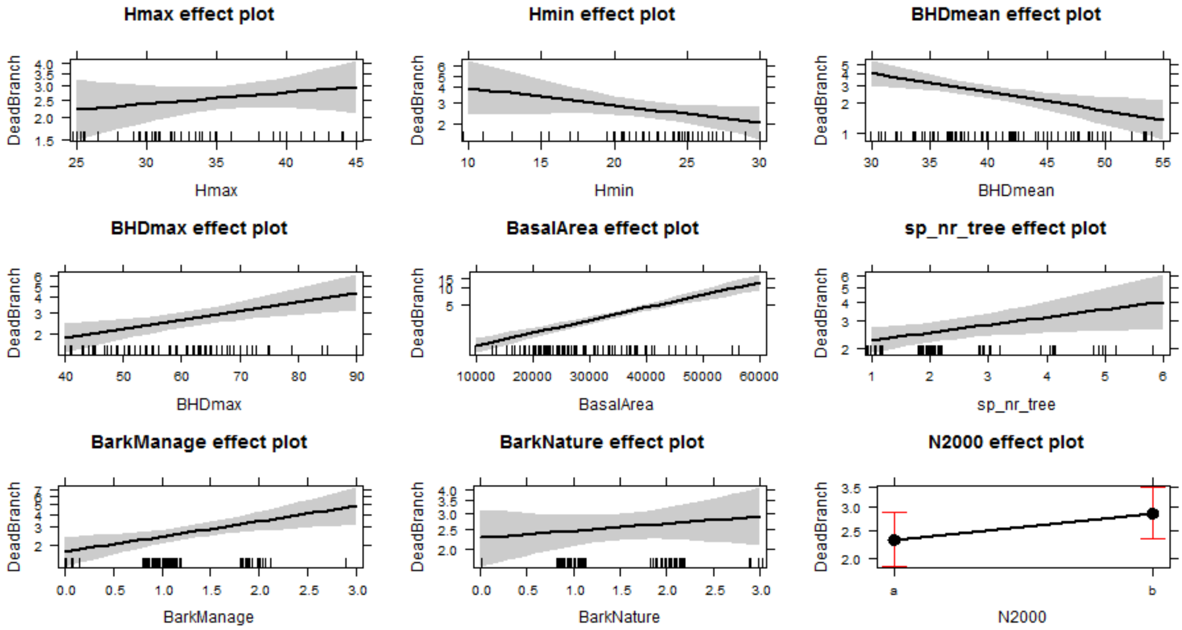
```
altitudeW     ns
AspectDeg      *
slope        ***
P_yr         ***
T_yr         ***
```



Continental biogeographic region – effect plots

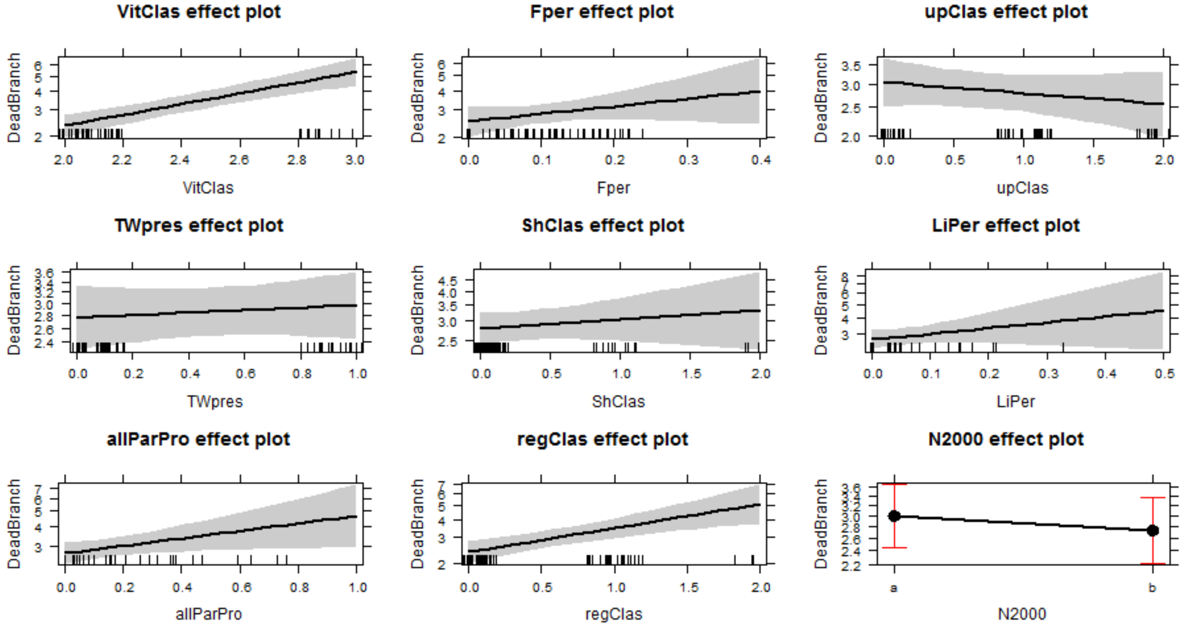
Continental biogeographic region - effects of stand structure on dead branches

```
Hmax        .
Hmin        ns
BHDmean     **
BHDmax      ***
BasalArea   ***
sp_nr_tree  **
BarkManage  ***
BarkNature  ns
Natura 2000      ns
```



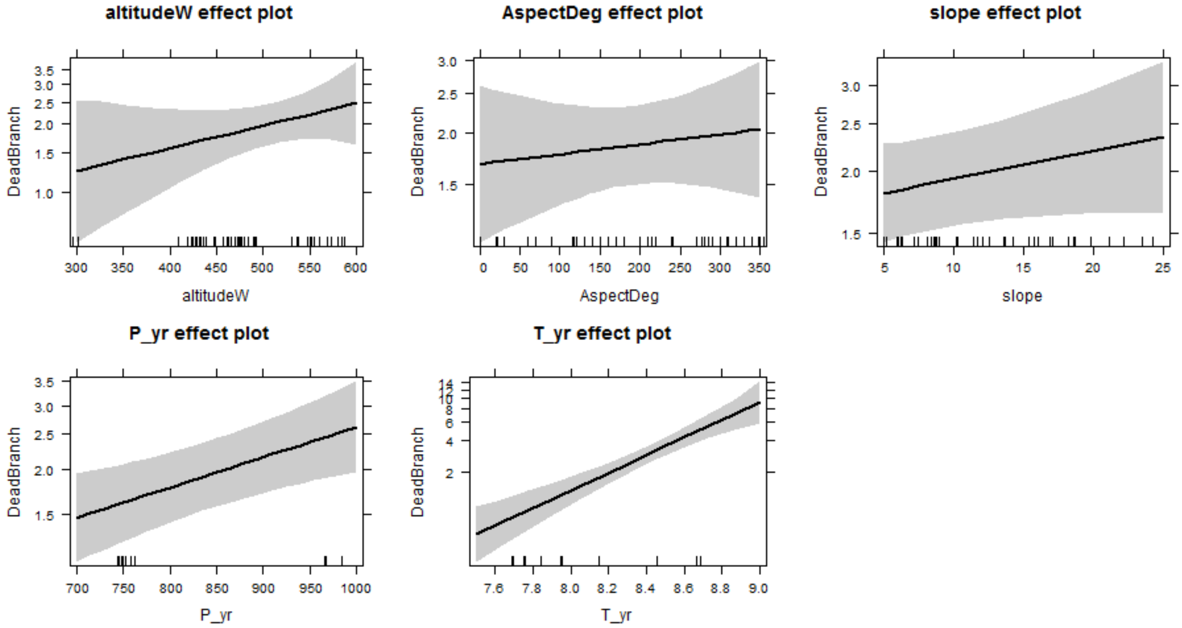
Continental biogeographic region - effects of tree morphology on dead branches

```
VitClas    ***
Fper       **
upClas     *
TWpres     ns
ShClas     *
LiPer      ns
allParPro  **
regClas    ***
Natura 2000      ns
```



Continental biogeographic region - effects of the climate and landscape on dead branches

```
altitudeW ***
AspectDeg    ns
slope      ***
P_yr       ***
T_yr       ***
```

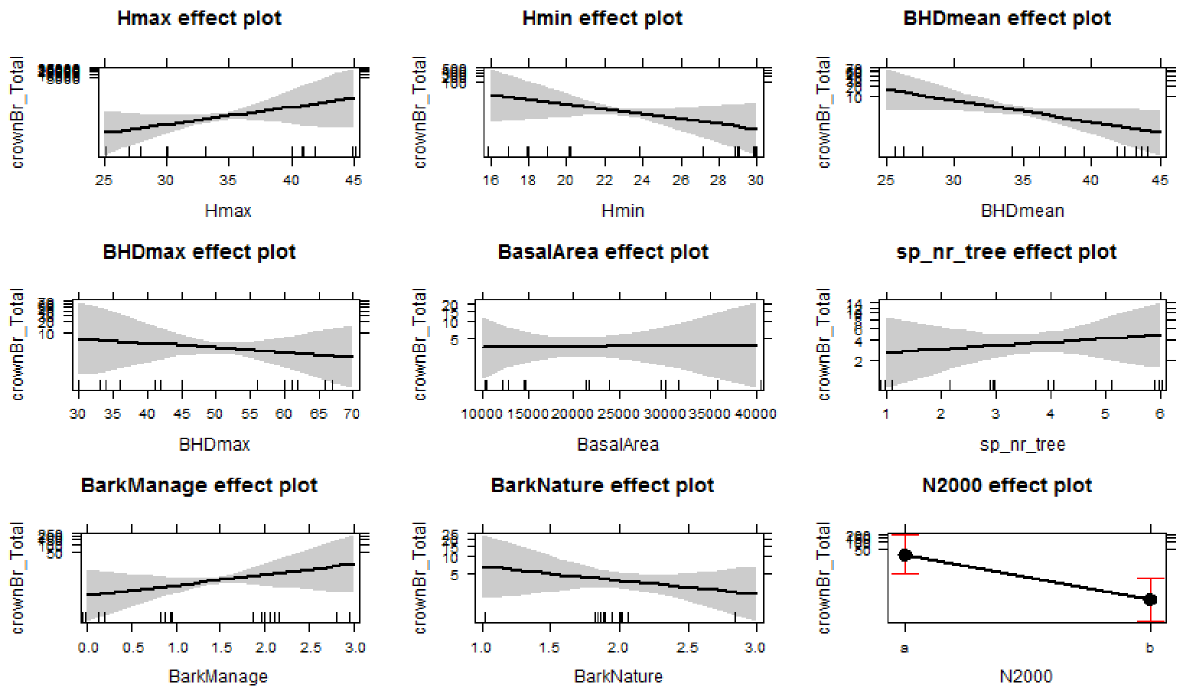


Annex 6. Effects on crown breakages

Reference site – effect plots

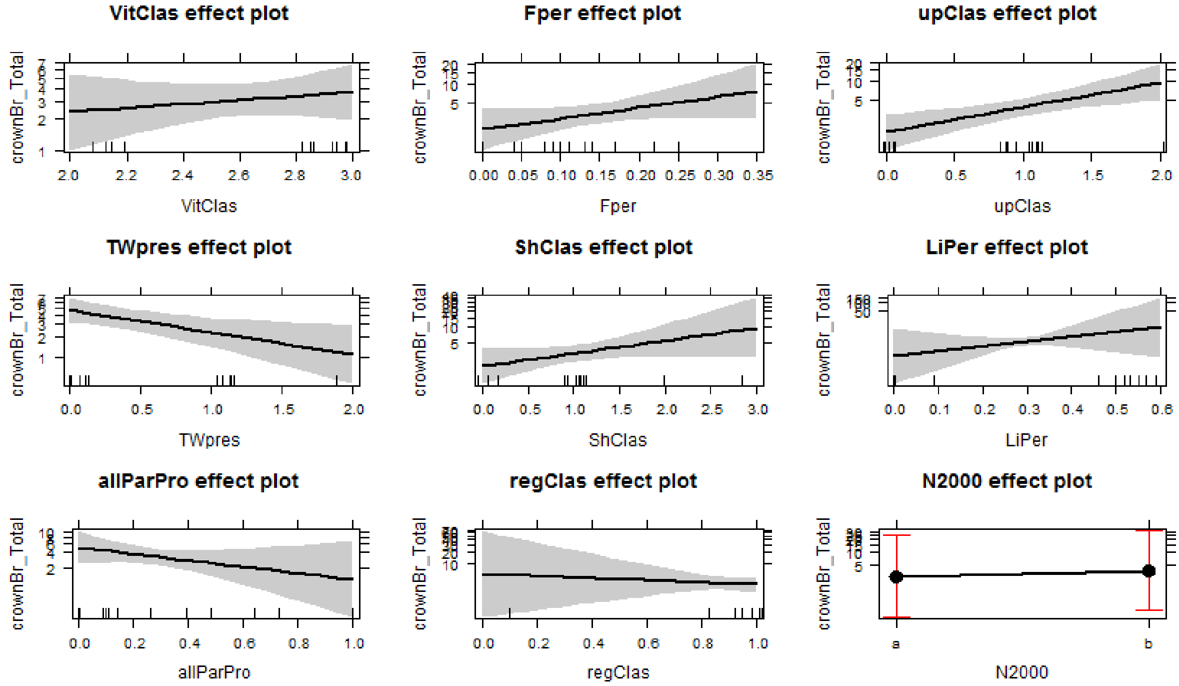
Reference site - effects of stand structure on crown breakages

```
Hmax         ***
Hmin         ns
BHDmean      ns
BHDmax       ns
BasalArea    **
sp_nr_tree   ns
BarkManage   ns
BarkNature   ns
Natura 2000       *
```



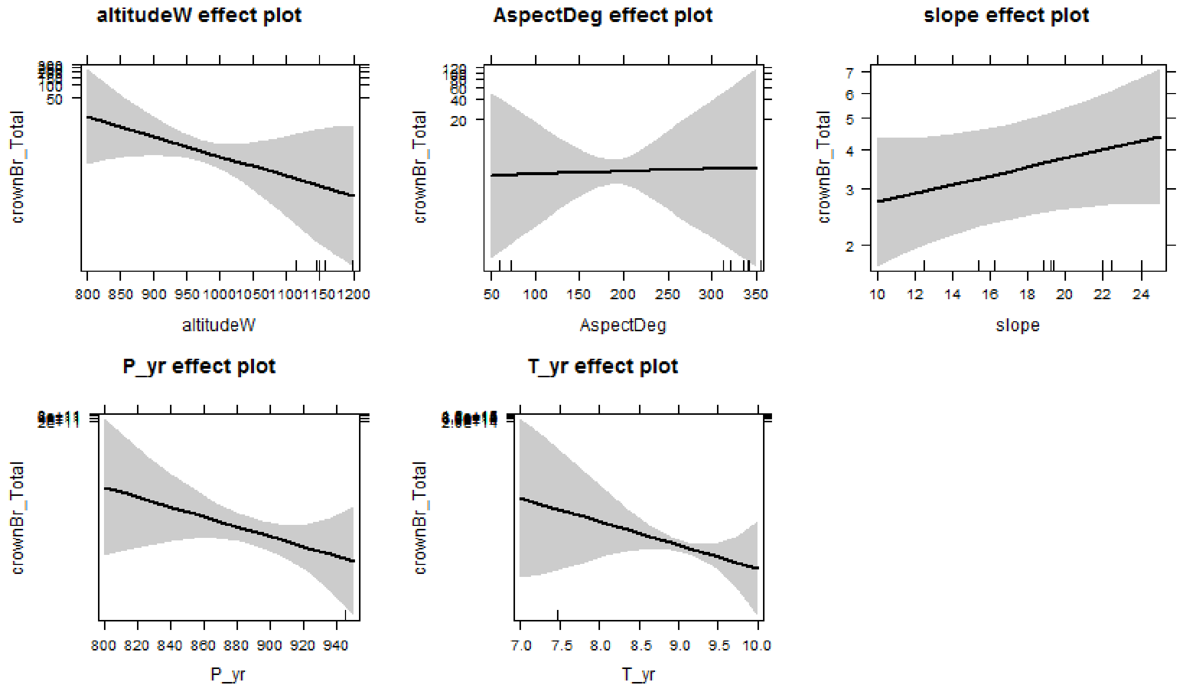
Reference Site - effects of tree morphology on crown breakages

VitClas	.
Fper	.
upClas	ns
TWpres	**
ShClas	ns
LiPer	***
allParPro	ns
regClas	ns
Natura 2000	ns



Reference Site - effects of the climate and landscape on crown breakages

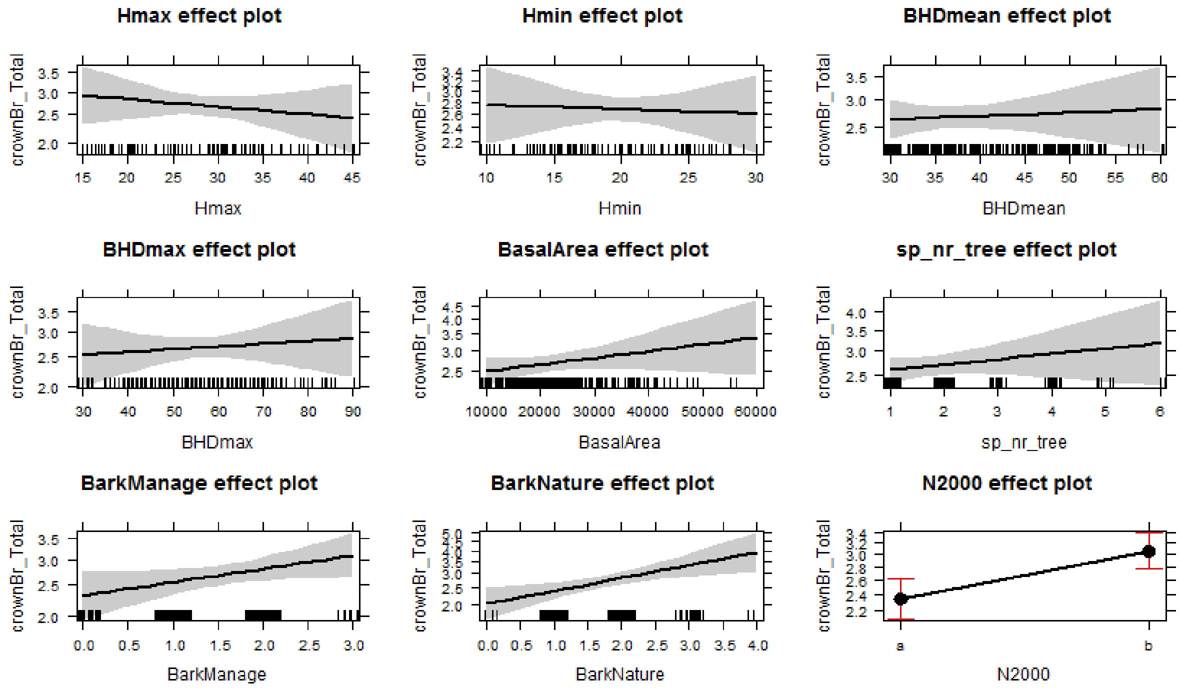
altitudeW	***
AspectDeg	ns
slope	*
P_yr	ns
T_yr	ns



All sites - effect plots

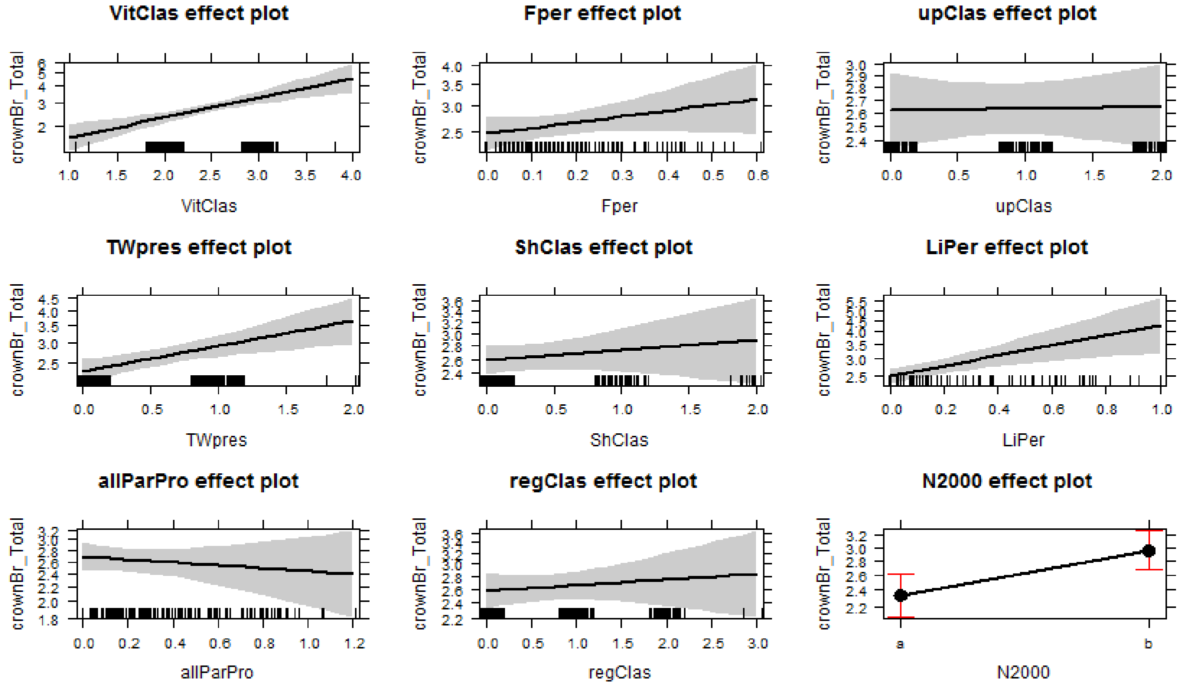
All sites - effects of stand structure on crown breakages

Hmax	ns
Hmin	.
BHDmean	ns
BHDmax	*
BasalArea	ns
sp_nr_tree	ns
BarkManage	*
BarkNature	*
Natura 2000	***



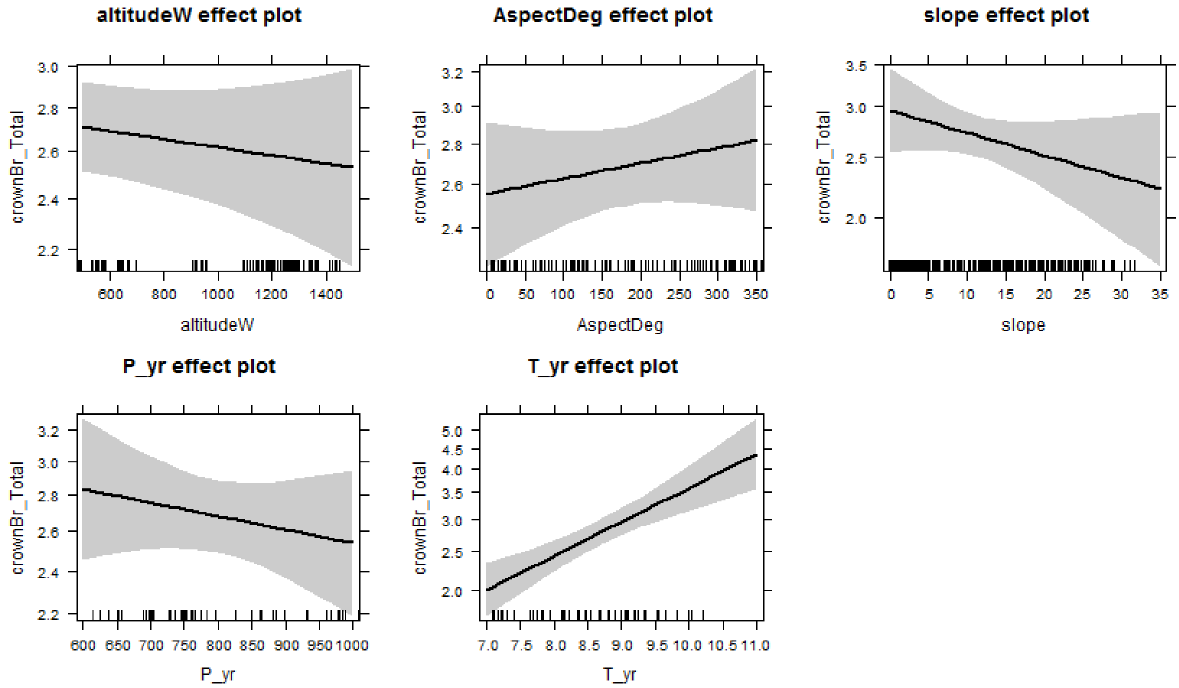
All sites - effects of tree morphology on crown breakages

```
VitClas      ***
Fper         ns
upClas       ns
TWpres       ***
ShClas       .
LiPer        **
allParPro    ns
regClas      ns
Natura 2000        **
```



All sites - effects of the climate and landscape on crown breakages

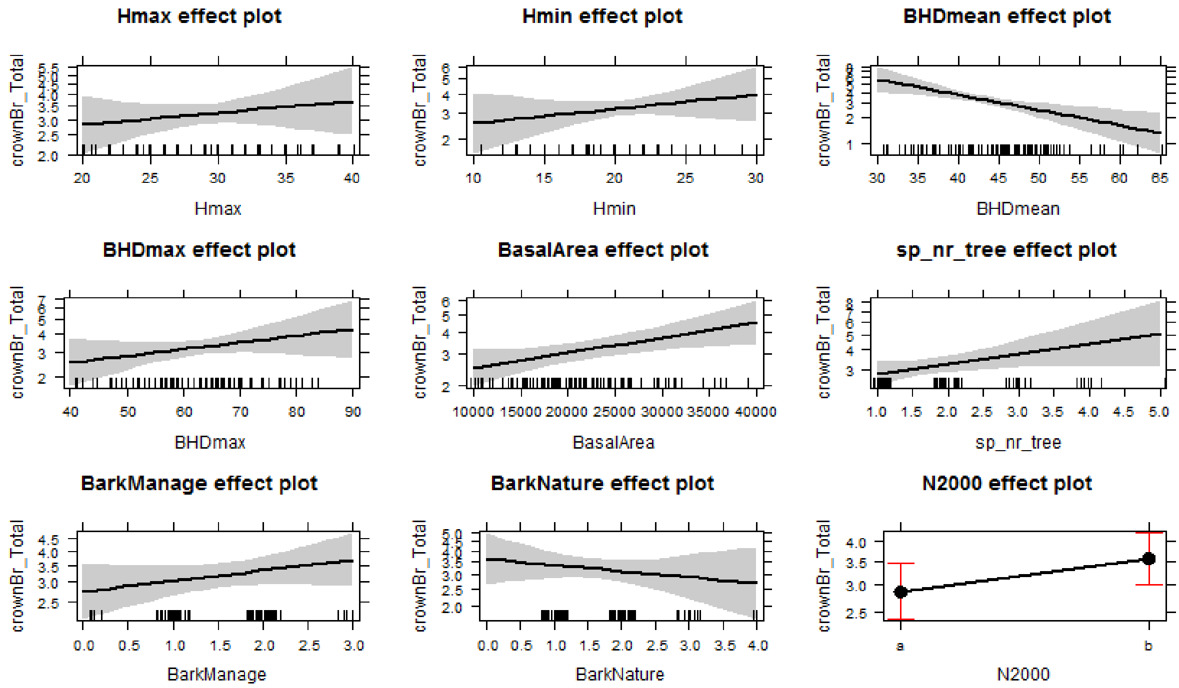
```
altitudeW    ns
AspectDeg    ns
slope        ns
P_yr         **
T_yr         ***
```



Atlantic biogeographic region – effect plots

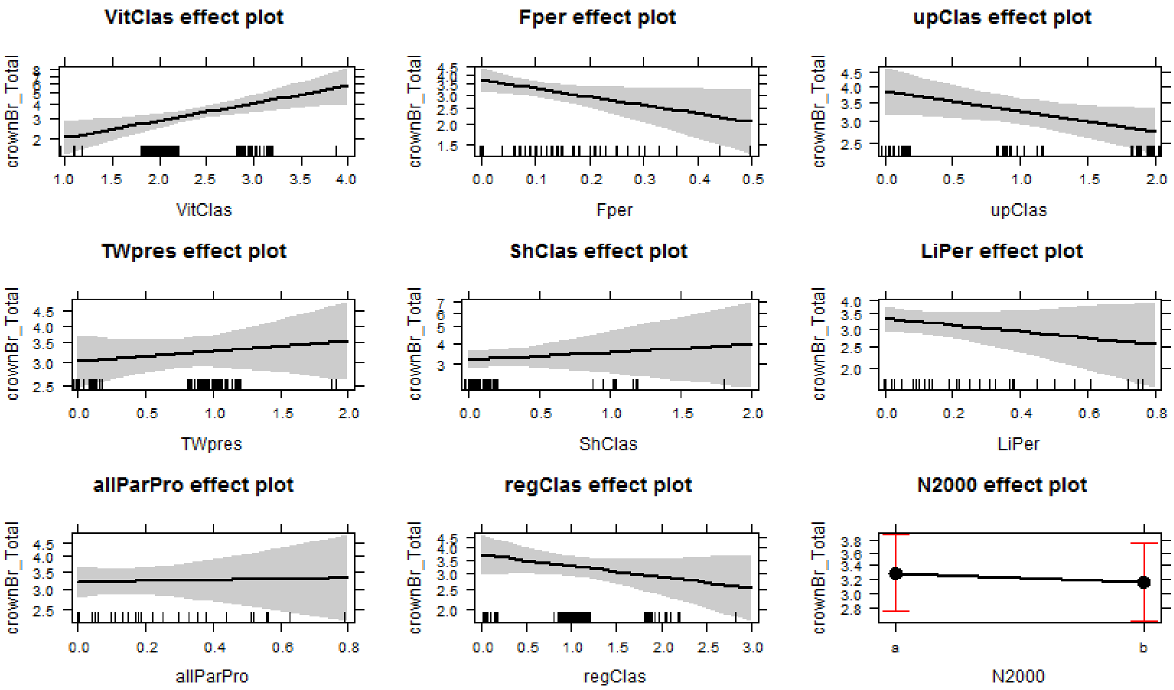
Atlantic biogeographic region - effects of stand structure on crown breakages

Hmax	ns
Hmin	*
BHDmean	***
BHDmax	*
BasalArea	*
sp_nr_tree	ns
BarkManage	ns
BarkNature	ns
Natura 2000	ns



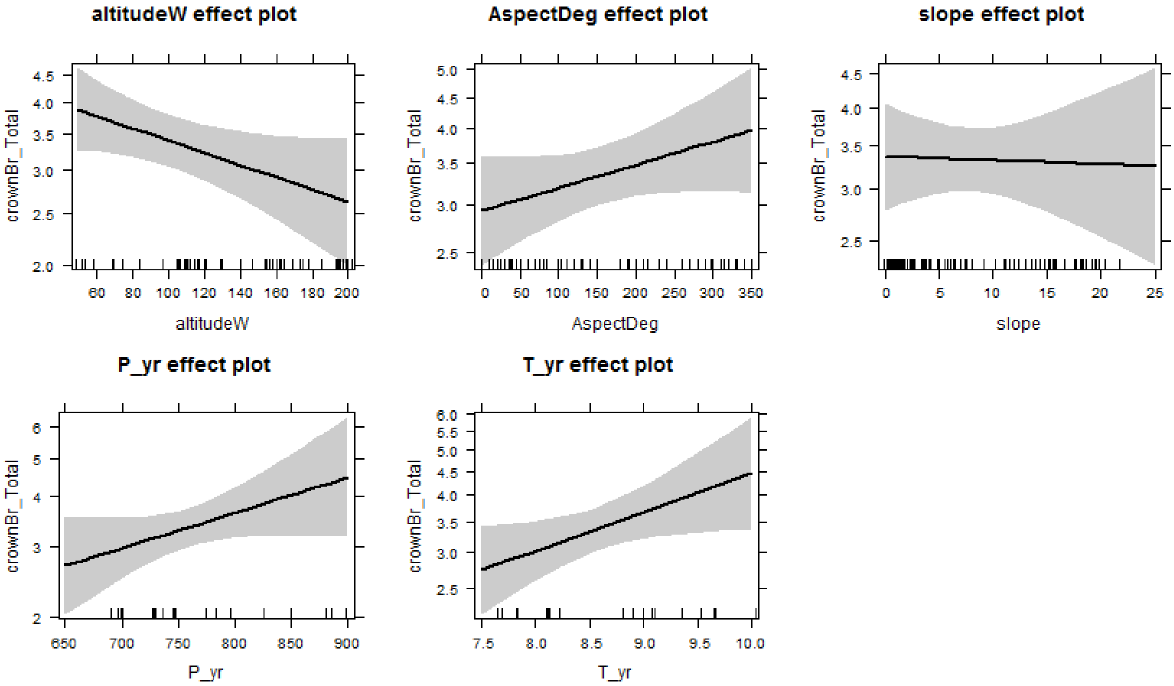
Atlantic biogeographic region - effects of tree morphology on crown breakages

VitClas	***
Fper	*
upClas	.
TWpres	ns
ShClas	ns
LiPer	ns
allParPro	ns
regClas	ns
Natura 2000	ns



Atlantic biogeographic region - effects of the climate and landscape on crown breakages

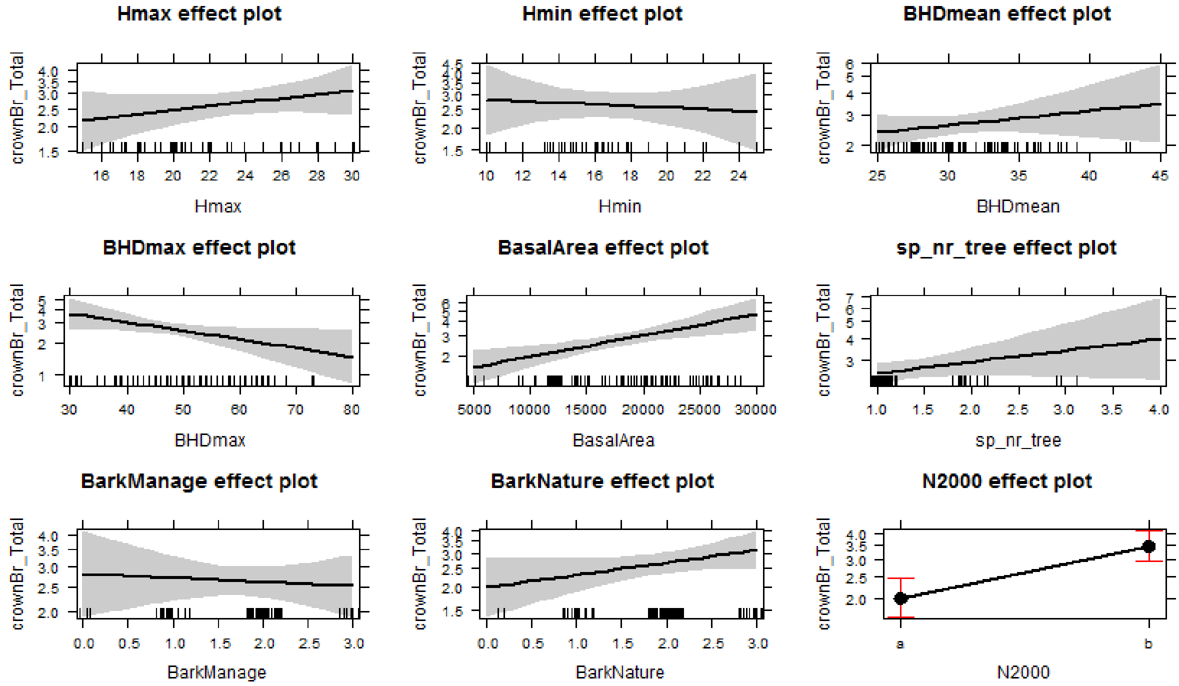
altitudeW	ns
AspectDeg	ns
slope	ns
P_yr	*
T_yr	*



Mediterranean biogeographic region – effect plots

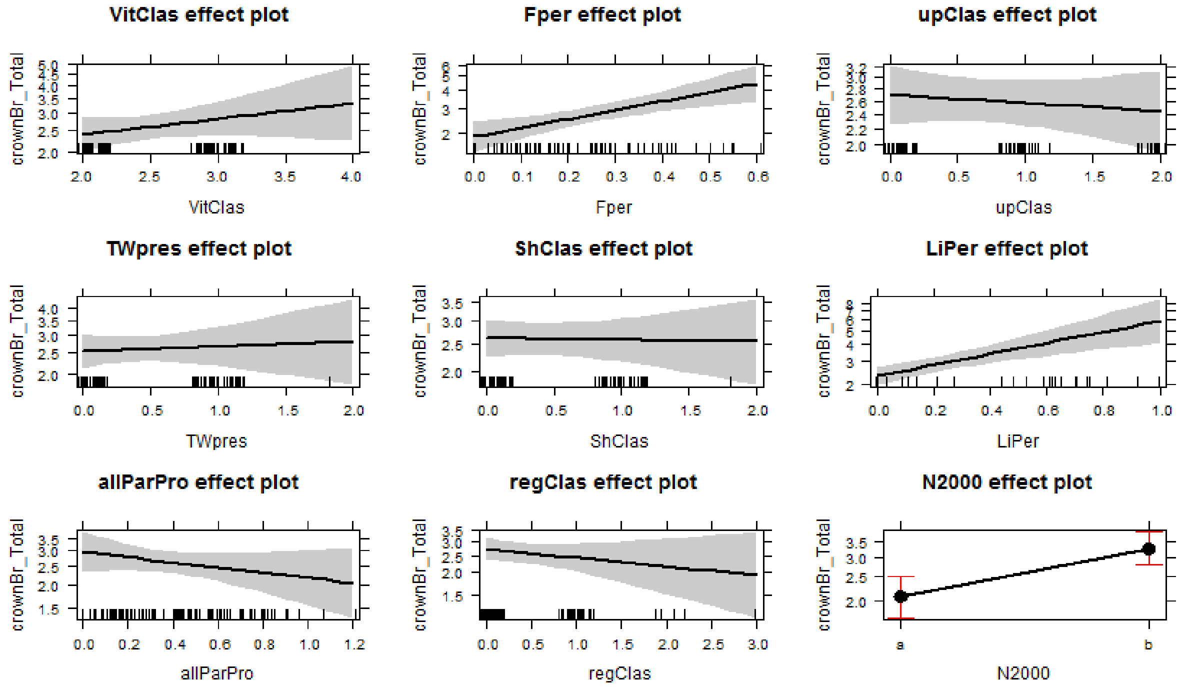
Mediterranean biogeographic region - effects of stand structure on crown breakages

```
Hmax         ***
Hmin         ns
BHDmean      ns
BHDmax       ns
BasalArea    *
sp_nr_tree   ns
BarkManage   ns
BarkNature   .
Natura 2000        ***
```



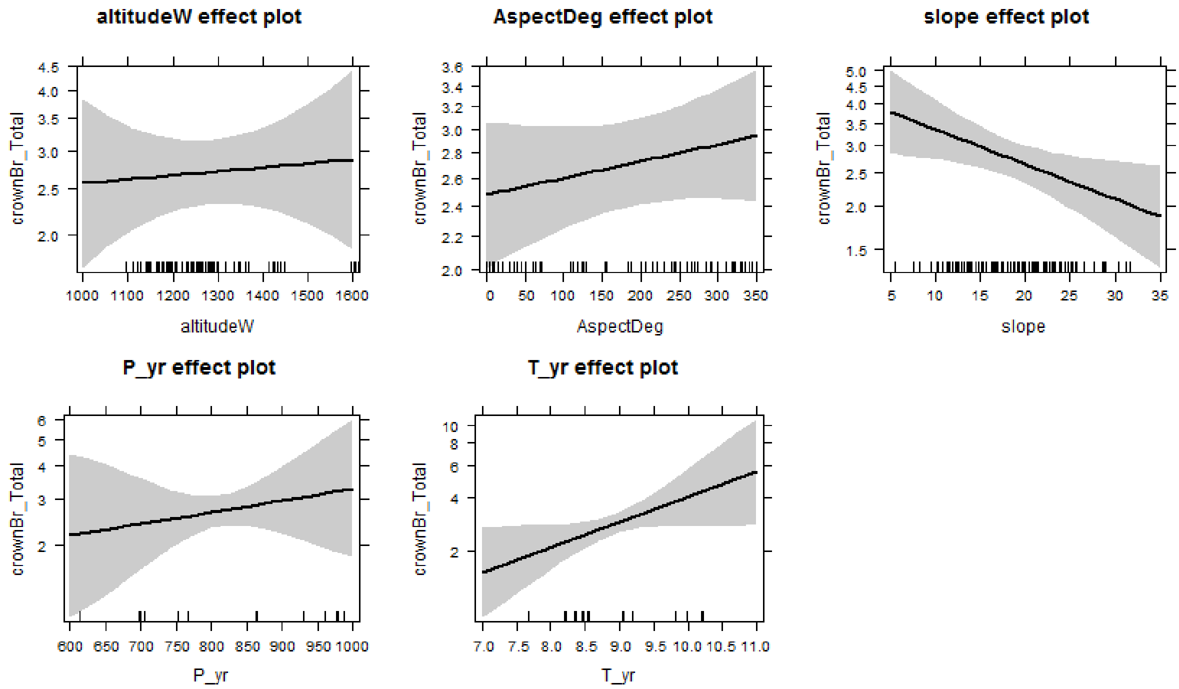
Mediterranean biogeographic region - effects of tree morphology on crown breakages

```
VitClas      *
Fper         ***
upClas       ns
TWpres       ns
ShClas       .
LiPer        ***
allParPro    ns
regClas      ns
Natura 2000        ***
```



Mediterranean biogeographic region - effects of the climate and landscape on crown breakages

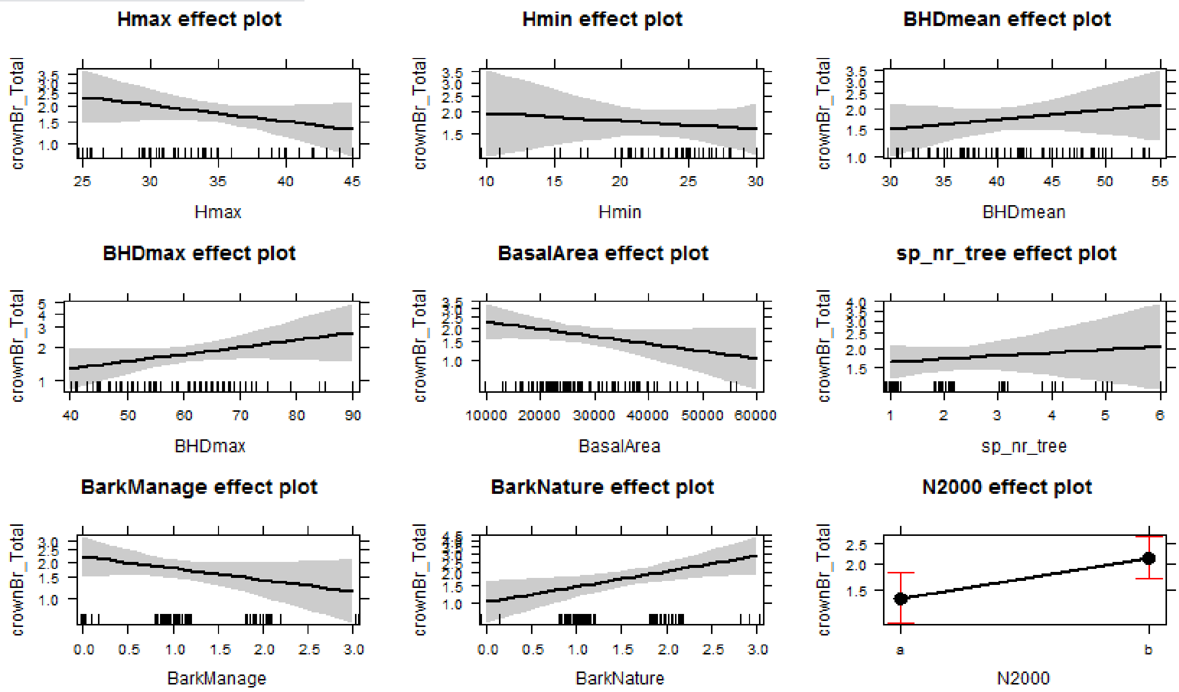
```
altitudeW    ns
AspectDeg    ns
slope        ns
P_yr         ***
T_yr         *
```



Continental biogeographic region – effect plots

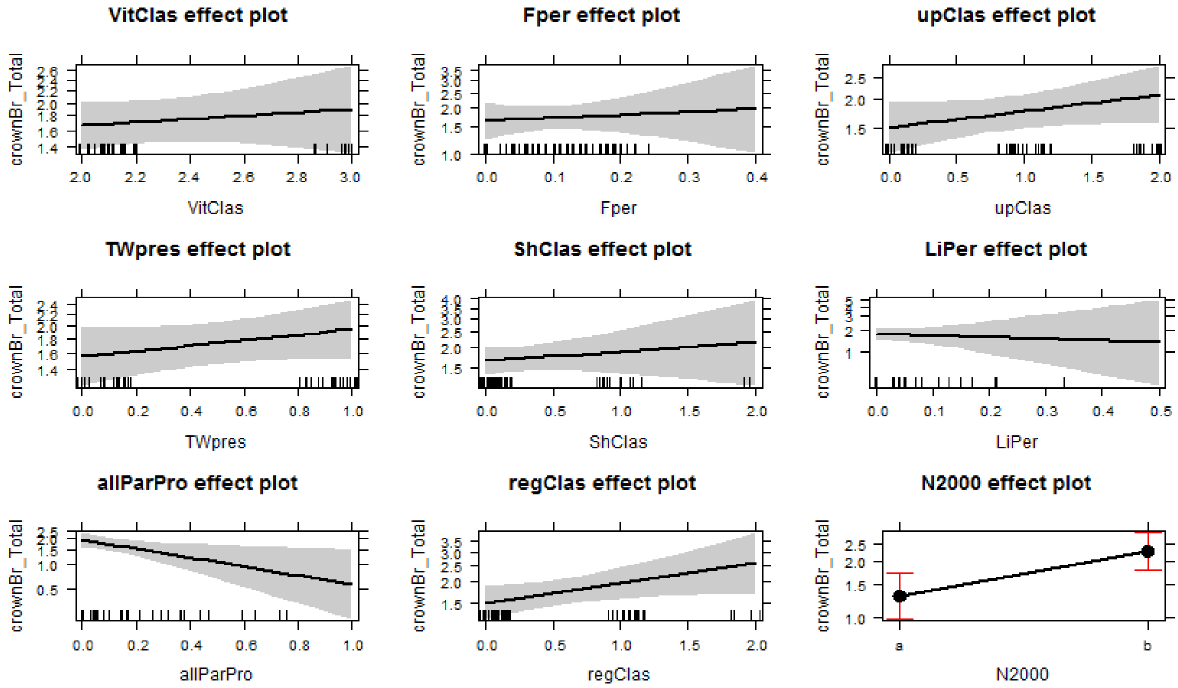
Continental biogeographic region - effects of stand structure on crown breakages

```
Hmax         ns
Hmin         .
BHDmean      .
BHDmax       ns
BasalArea    .
sp_nr_tree   ns
BarkManage   ns
BarkNature   *
Natura 2000        *
```



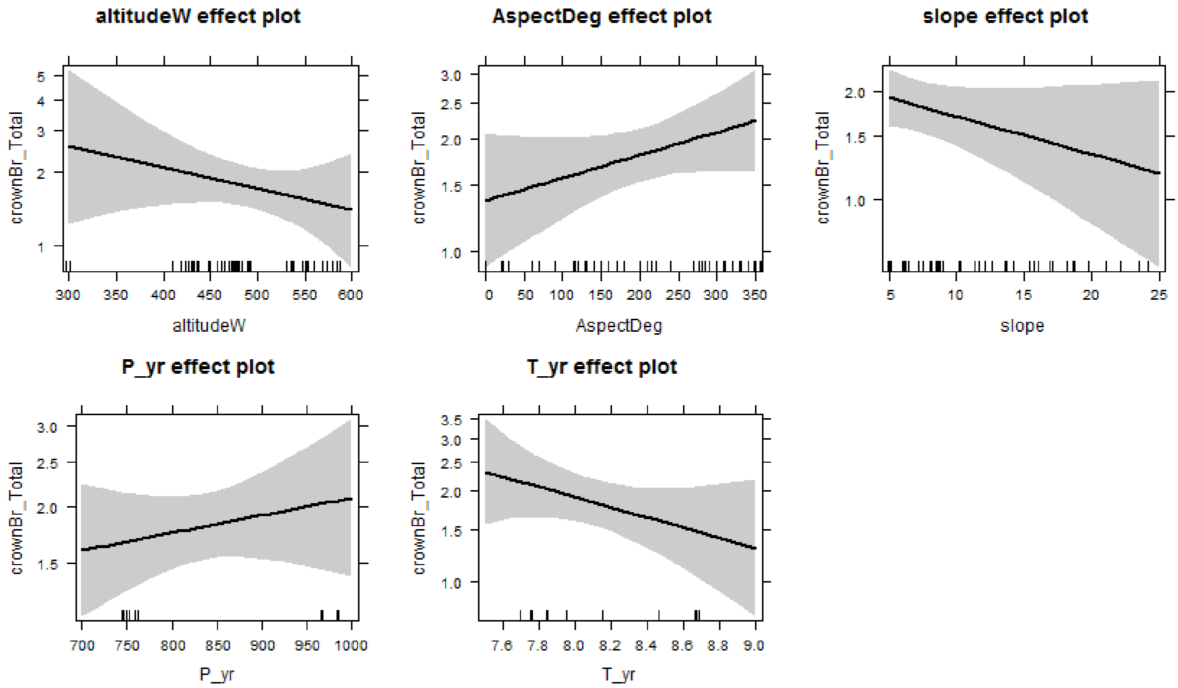
Continental biogeographic region - effects of tree morphology on crown breakages

VitClas	ns
Fper	ns
upClas	.
TWpres	ns
ShClas	ns
LiPer	ns
allParPro	.
regClas	.
Natura 2000	**



Continental biogeographic region - effects of the climate and landscape on crown breakages

altitudeW	ns
AspectDeg	.
slope	*
P_yr	ns
T_yr	ns



Annex 7. Effects on bizarre growth

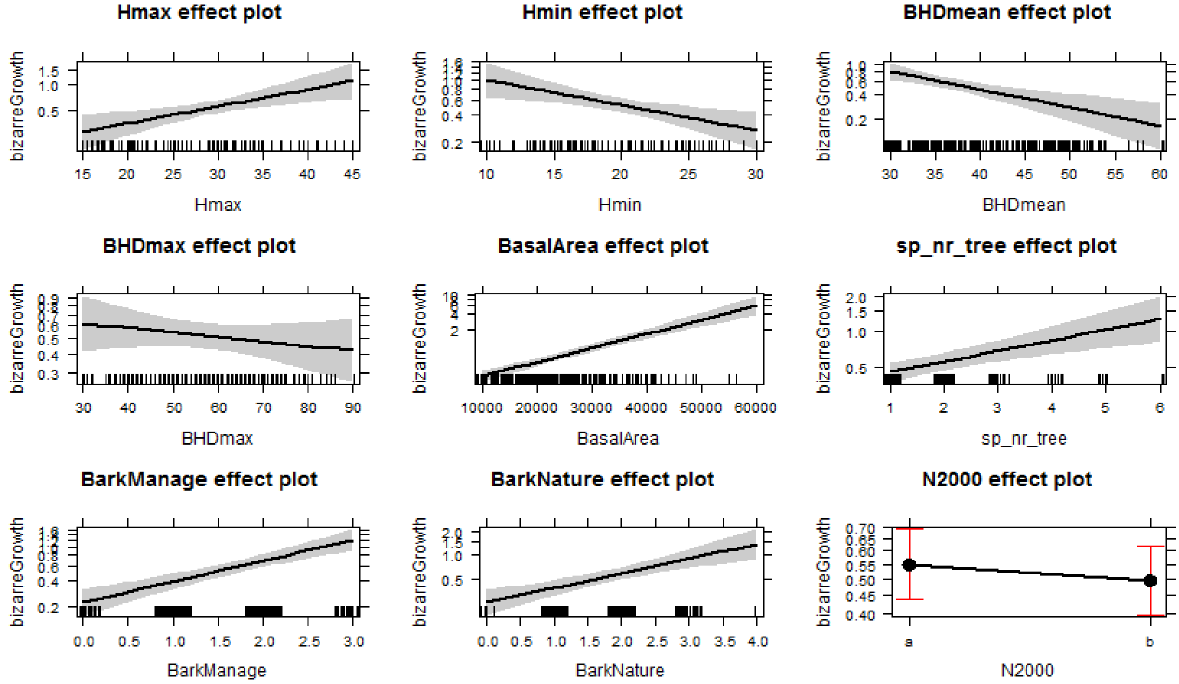
Reference site – effect plots

To less finds to model effects.

All sites - effect plots

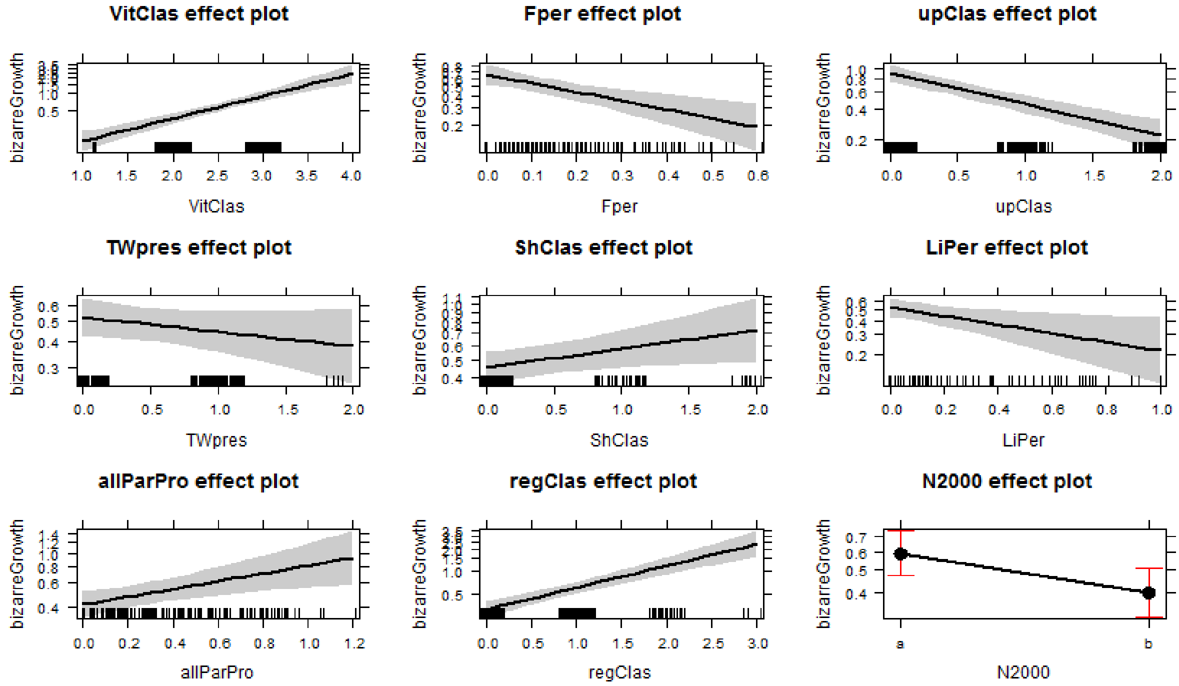
All sites - effects of stand structure on bizarre growth

```
Hmax           .
Hmin          ***
BHDmean       ***
BHDmax        ***
BasalArea     ***
sp_nr_tree    ***
BarkManage    ***
BarkNature    ***
Natura 2000         ns
```



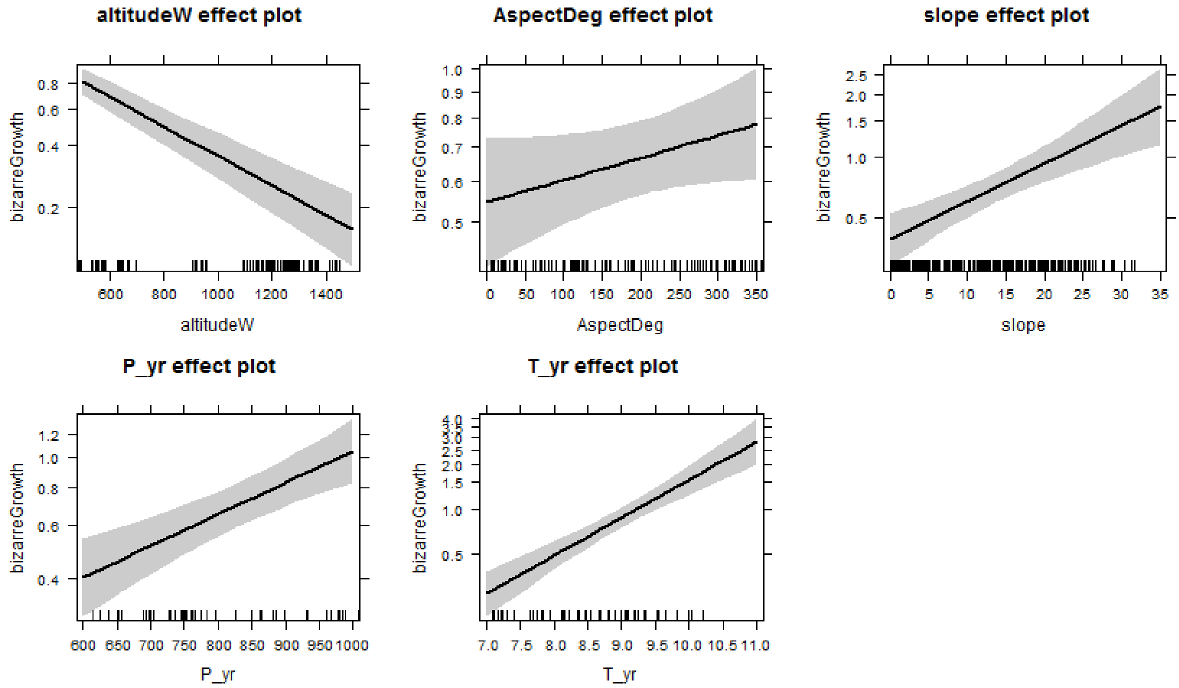
All sites - effects of tree morphology on bizarre growth

VitClas	***
Fper	***
upClas	***
TWpres	ns
ShClas	ns
LiPer	.
allParPro	**
regClas	***
Natura 2000	**



All sites - effects of the climate and landscape on bizarre growth

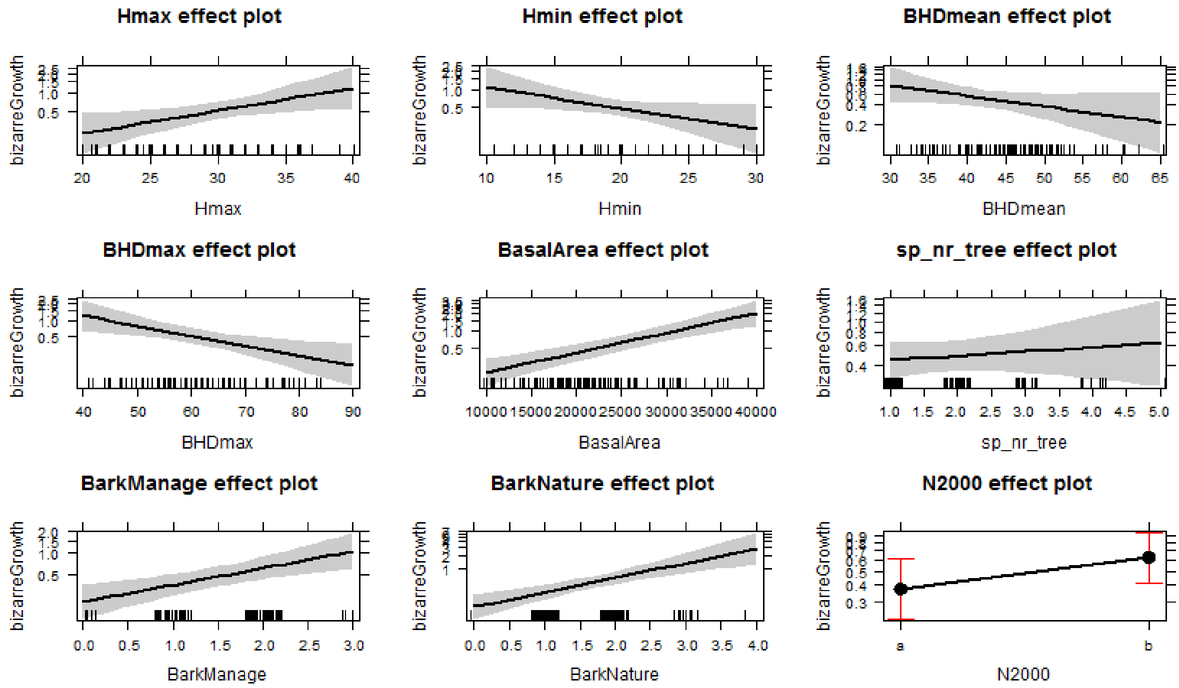
altitudeW	***
AspectDeg	ns
slope	***
P_yr	*
T_yr	***



Atlantic biogeographic region – effect plots

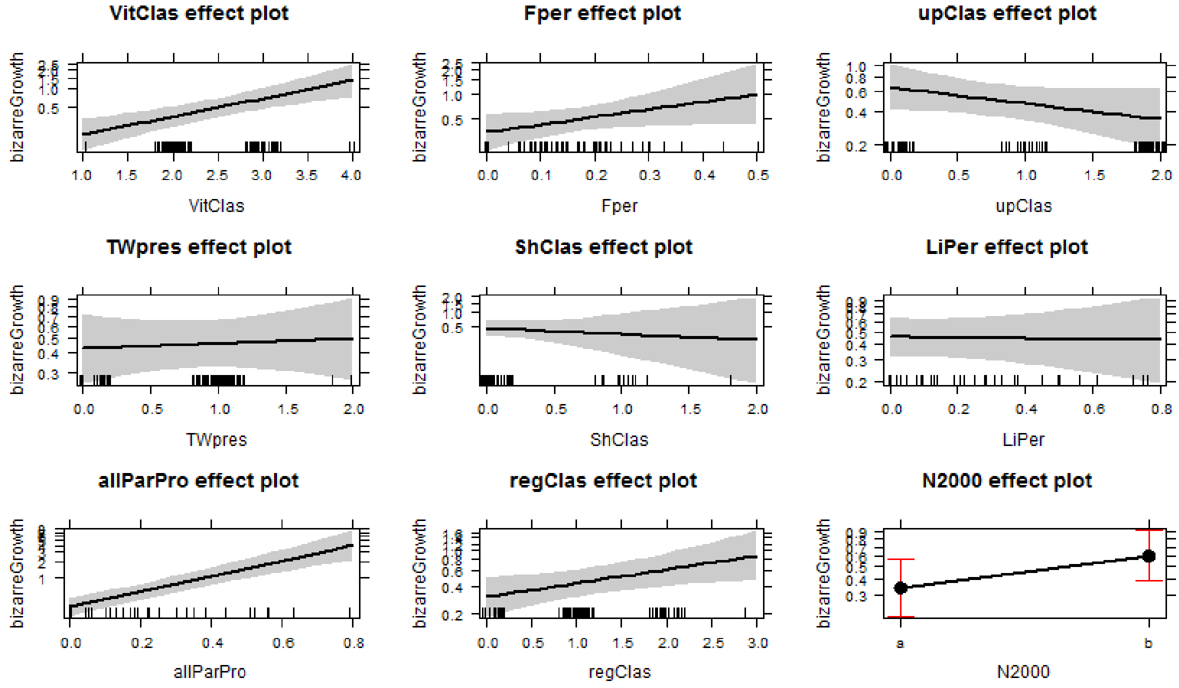
Atlantic biogeographic region - effects of stand structure on bizarre growth

Hmax	***
Hmin	***
BHDmean	***
BHDmax	ns
BasalArea	***
sp_nr_tree	**
BarkManage	**
BarkNature	***
Natura 2000	ns



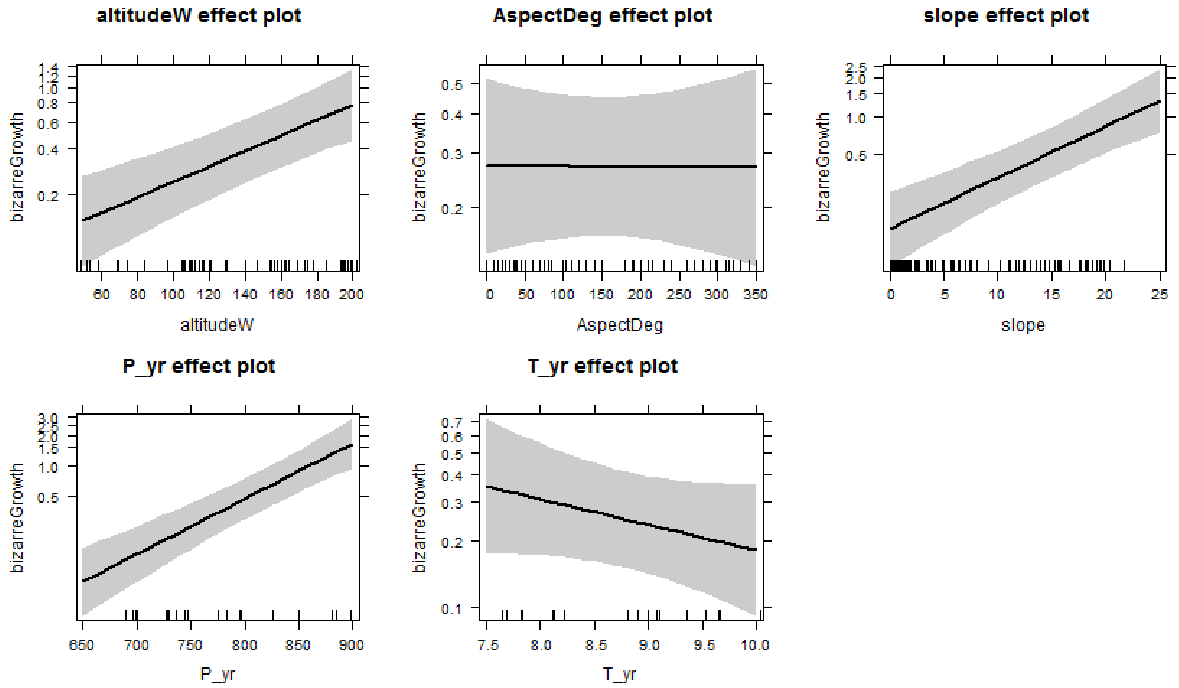
Atlantic biogeographic region - effects of tree morphology on bizarre growth

VitClas	***
Fper	ns
upClas	***
TWpres	*
ShClas	ns
LiPer	*
allParPro	***
regClas	*
Natura 2000	.



Atlantic biogeographic region - effects of the climate and landscape on bizarre growth

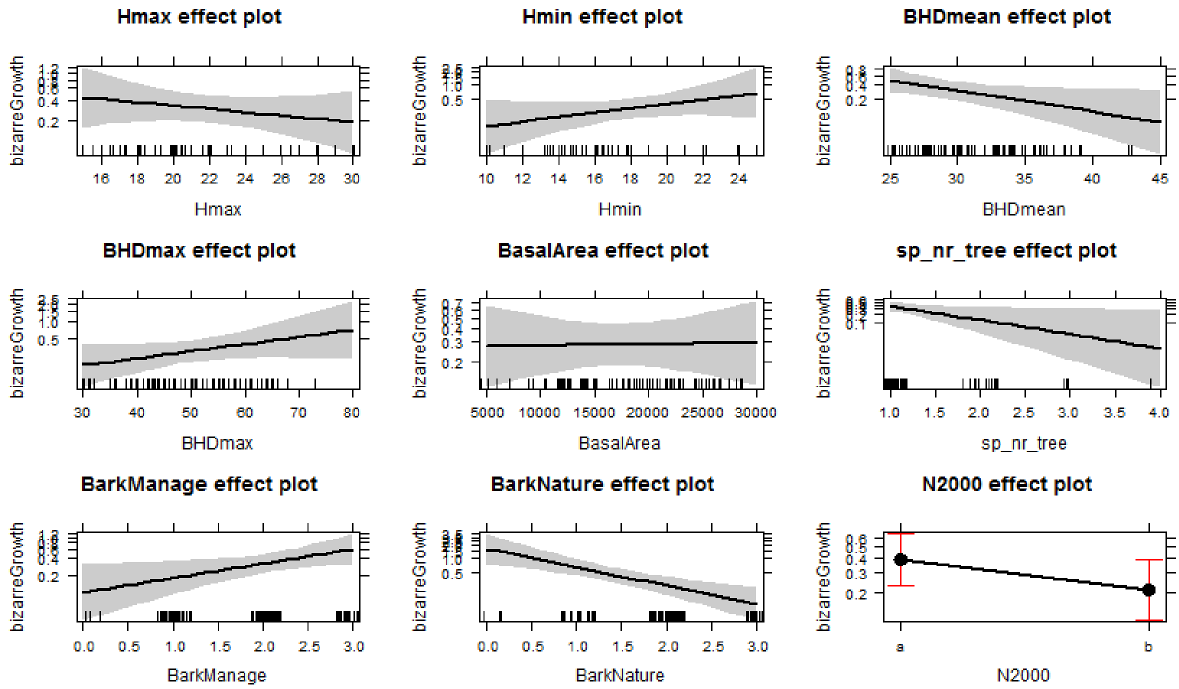
altitudeW	***
AspectDeg	ns
slope	***
P_yr	***
T_yr	ns



Mediterranean biogeographic region – effect plots

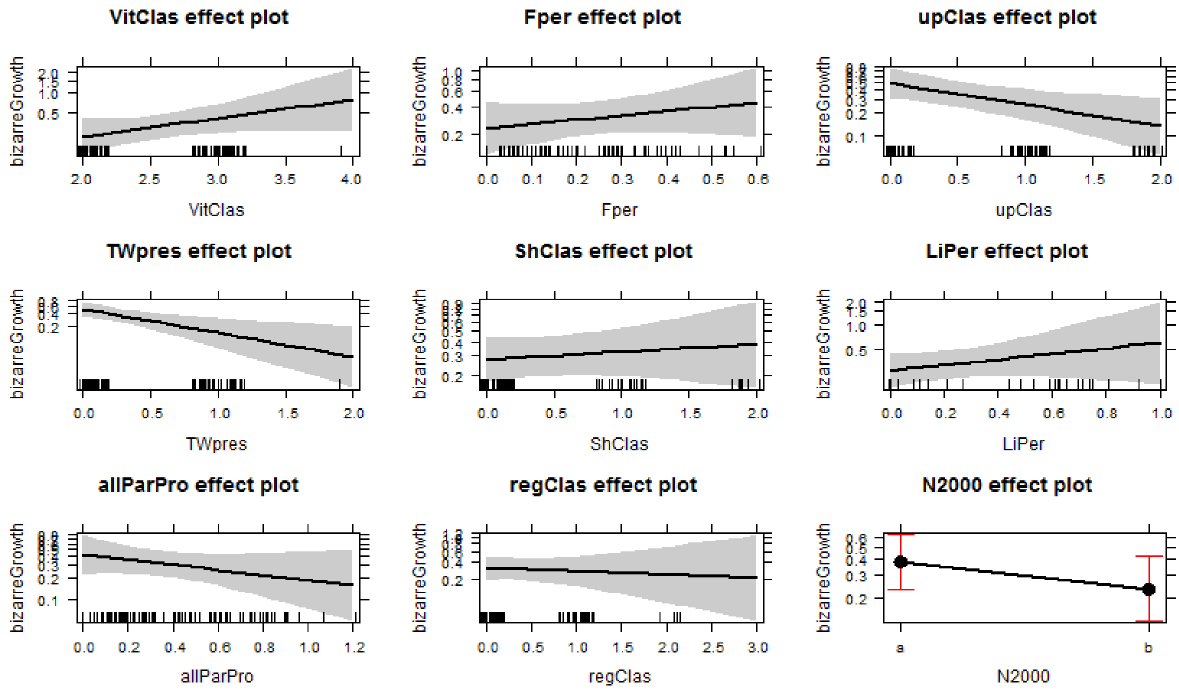
Mediterranean biogeographic region - effects of stand structure on bizarre growth

```
Hmax         ns
Hmin         ns
BHDmean      ns
BHDmax       .
BasalArea    ns
sp_nr_tree   *
BarkManage   ns
BarkNature   ***
Natura 2000        .
```



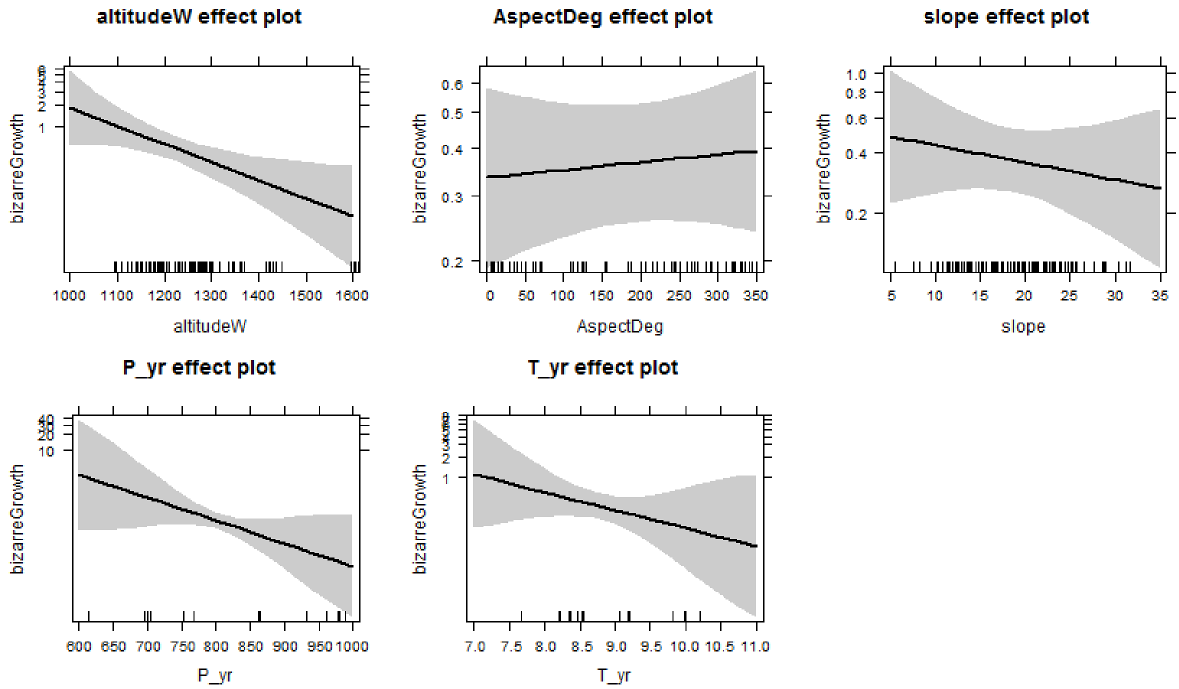
Mediterranean biogeographic region - effects of tree morphology on bizarre growth

```
VitClas      *
Fper         ns
upClas       *
TWpres       ***
ShClas       ns
LiPer        ns
allParPro    .
regClas      ns
Natura 2000        ns
```



Mediterranean biogeographic region - effects of the climate and landscape on bizarre growth

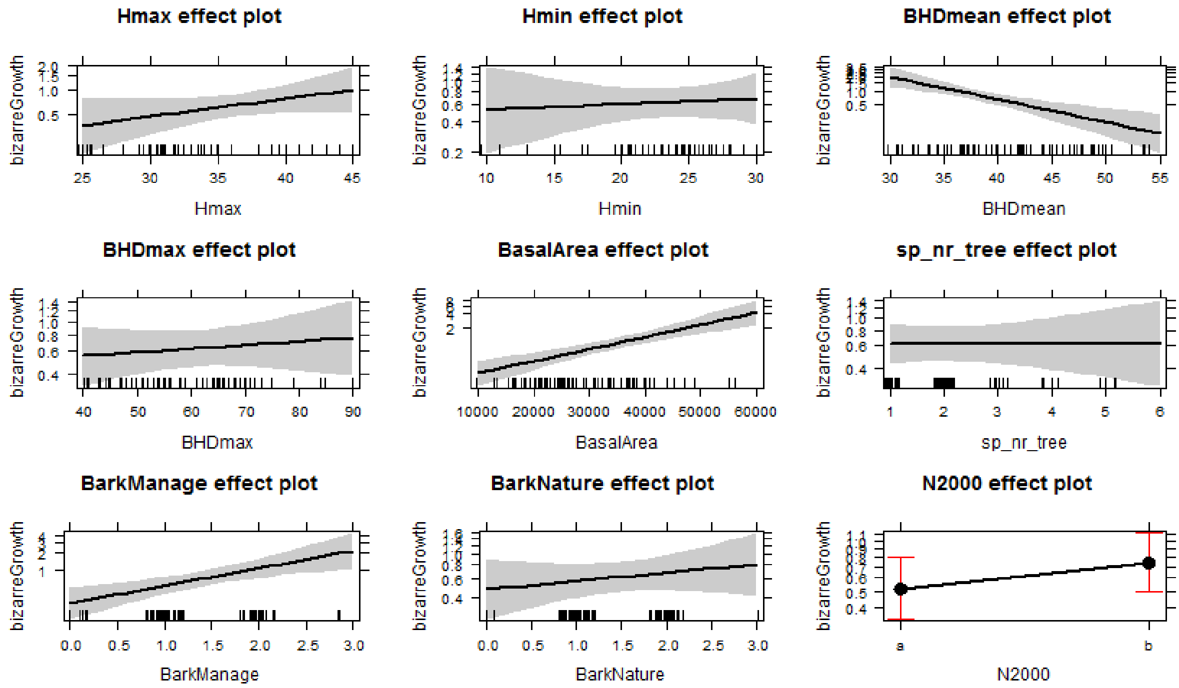
```
altitudeW    *
AspectDeg    ns
slope        ns
P_yr         **
T_yr         ns
```



Continental biogeographic region – effect plots

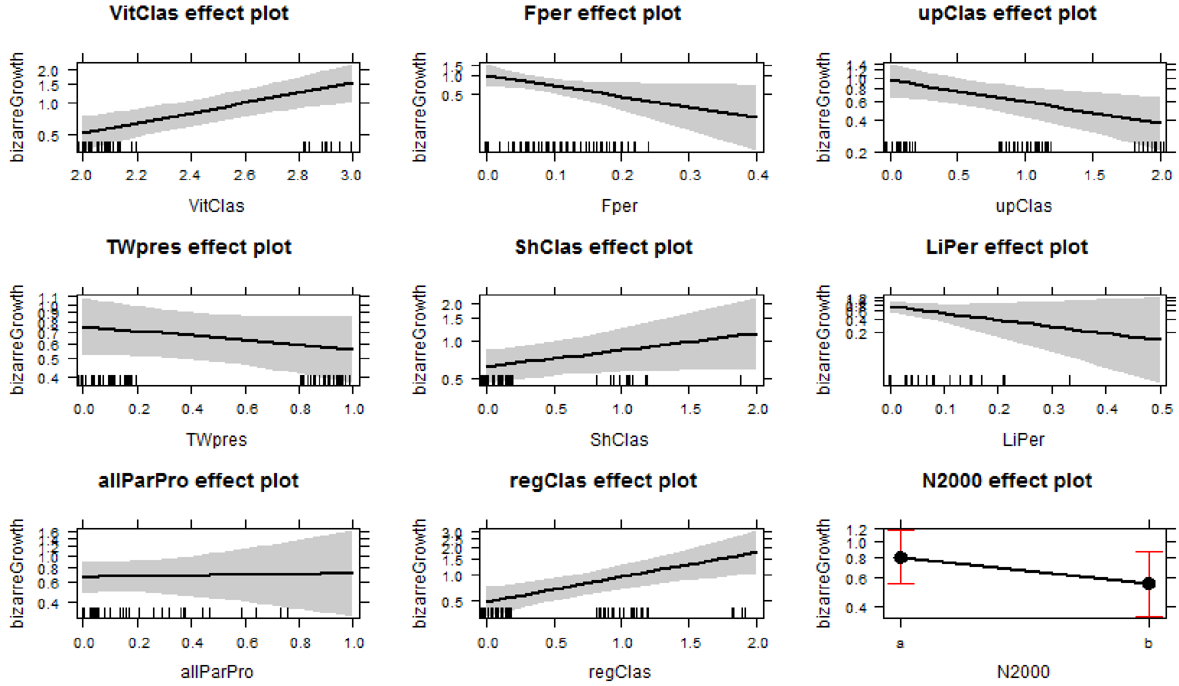
Continental biogeographic region - effects of stand structure on bizarre growth

```
Hmax          .
Hmin          ns
BHDmean       ***
BHDmax        **
BasalArea     ***
sp_nr_tree    ns
BarkManage    ***
BarkNature    ns
Natura 2000         ns
```



Continental biogeographic region - effects of tree morphology on bizarre growth

VitClas ***
Fper ns
upClas ***
TWpres *
ShClas **
LiPer ns
allParPro ns
regClas ***
Natura 2000 ns



Continental biogeographic region - effects of the climate and landscape on bizarre growth

altitudeW ***
AspectDeg ns
slope ns
P_yr ns
T_yr *