CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

# Introduction to Forest Protection

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# Foreword

Dear readers,

I hope that this textbook will help you with the study of the subject Forest Protection. At this point, I would like to write a few notes before your reading. I hope that they will help you successfully used this textbook.

Please, note that this textbook is focused primarily at commercial forestry and that most cases are from my country.

Most chapters are divided to the three sections separated by figures – (i) introduction, (ii) examples of scientific papers and (iii) questions for exam. I do not take references to other chapters, because I tried to make each chapter as self-contained.

An integral part of the textbook are examples of scientific articles. These articles deal (at least partly) with specific issues of particular chapter and are given to illustrate the chapter appropriately. I definitely recommend everyone to read original article and also related topics. Of course, the selected examples are dominated by papers from Europe and North America. This is due to the current state of knowledge of the problematic on planet Earth.

In this textbook is not a chapter devoted to damages to the plants due to nutrient deficiency. I find this topic rather as an issue of Plant Physiology.

I wish you pleasant reading.

**Jakub Horák**

In Prague August 26, 2014

## Acknowledgements

I am grateful to Karolína Lukášová for review and constructive comments, Dana Čížková, Vítězslava Pešková, Jaroslav Holuša and Marek Turčáni for the discussion.

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# Chapter 1: Introduction

Forest protection is a discipline of forestry that uses disparate methods to protect forests, which are threatened by abiotic and biotical threats. This discipline appears to be one of the most complex in forestry. Forest protection combines knowledge from forest ecology, entomology, botany, mycology, genetics, vertebratology and others derived from such disciplines like game management or phytopathology.

It depends on the place on Earth where we are, but there can be seen that while several factors are often and highly studied (e.g. causes and consequences of windstorms), some are in the focus of forest protection more ephemerally (e.g. pathogens) and some are still neglected (e.g. urban sprawl). In some countries (e.g. in Europe), several threats are continuously vanishing or even have nearly no influence, while in the others (e.g. in Africa) are of high significance – this is the case of unsustainable farming and logging. And last but not least, some disciplines are much more studied outside of forest protection – this is, for instance, the case of weeds that are mainly in the focus of botanists. Special example of this case are aliens (i.e. invasive organisms) that are one of the hottest topics of present scientific agenda.

One of the first questions that come to mind may be: Why are some forest ecosystems unstable and why is really necessary to protect forest? There are many factors that influence forest, but the most important thing is man. People affect forest from the very beginning of humankind. Even if, the strong influence on stability of forest occurred much earlier (e.g. due to the mining of precious metals), forest protection faced the biggest problems particularly since the beginning of the Industrial Revolution (at least in Europe and North America). If we focus on Central Europe, there may be clearly identified three main factors that have a major impact on forest ecosystems – (i) change in tree species composition, (ii) length of rotation period and (iii) change in forest cover.

## Historical vs. present tree species composition

The first and probably the most important factor is a significant change in the composition and distribution of most of the tree species. It is possible to see on illustrative figures (Figure 1.1.; 1.2.) what change has taken place within the Czech Republic with respect to the composition of forests regarding coniferous and deciduous trees and also in relation to particular tree species.

Change in species composition always leads naturally to the affectation of organisms linked to the forest. Each tree species historically occupied specific niche, and it is bound by a number of other organisms. An example is the Scots pine (*Pinus sylvestris*) that forms naturally sparse forest on nutrient poor soil substrates. If pine forest replaces native oaks (*Quercus* spp.) this will change trophic relationships – such as depletion of soil for soil organisms or reduction of food resources for large vertebrates. Thus, logically there is more pressure on just mentioned organisms. Soil organisms and large vertebrates as examples will seek other sources of food and possibly cause damage to forest. Another factor may be influencing of growth of pine forest on nutrient-rich substrates, this might increase the risk of pathogen attack. Of course, we can continue, but I kindly leave other considerations to the reader.

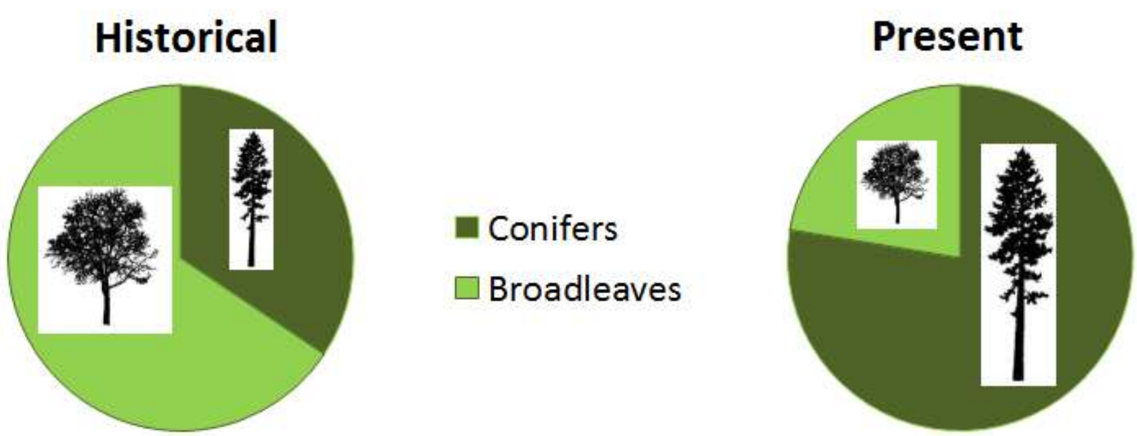


**Figure 1.1.** Pie diagrams illustrating the change between estimated historical (pre-human) and present composition of conifers (dark green) and broadleaves (light green) in the Czech Republic. Source: Živa (ziva.avcr.cz).

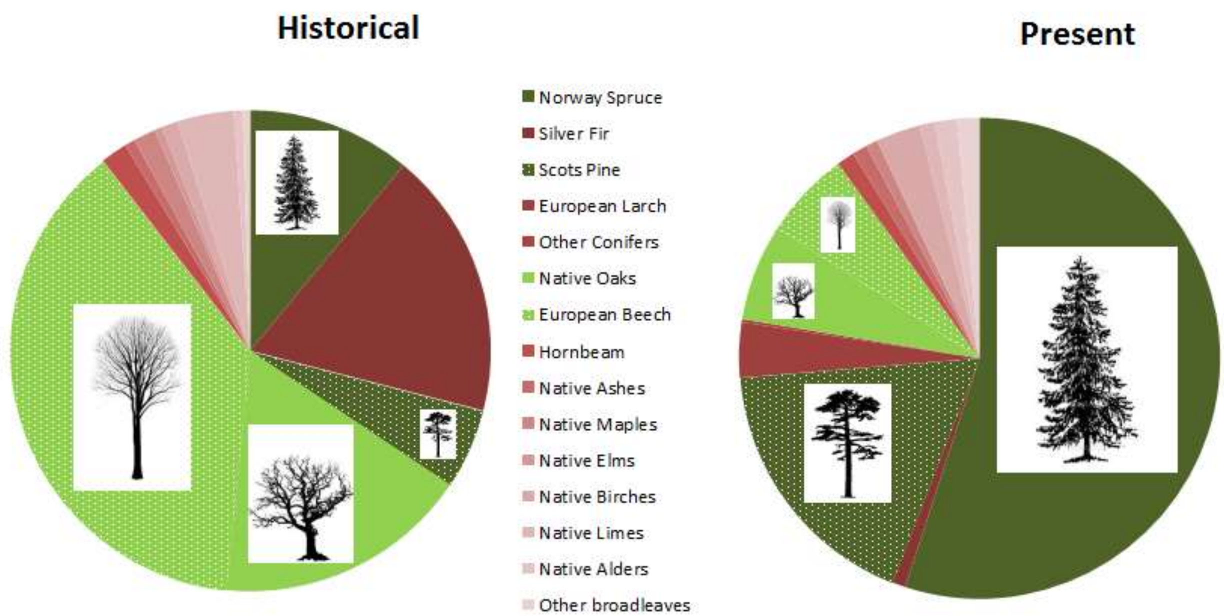


**Figure 1.2.** Pie diagrams illustrating the change between estimated historical (pre-human) and present composition of tree species in the Czech Republic. Tree species of main economic interest are dark green for conifers (Norway spruce and Scots Pine) and light green for broadleaves (native oaks and European Beech). Source: Živa (ziva.avcr.cz).

## Long rotation period

The second important driver of potential threats to the forests is a long rotation period of forest stands in most of Central Europe. For example, in the Czech Republic the minimum age for harvest of coniferous stands is 80 years and for deciduous stands exceeds 100 years.

This is a very long period during which it may happen a number of events that can threaten forests. Forest stands with dominance of the Norway spruce are an example. They are threatened from the establishment of forest stand till the final felling of forest stand by many biotic and abiotic factors as it is illustrated on Figure 1.3.

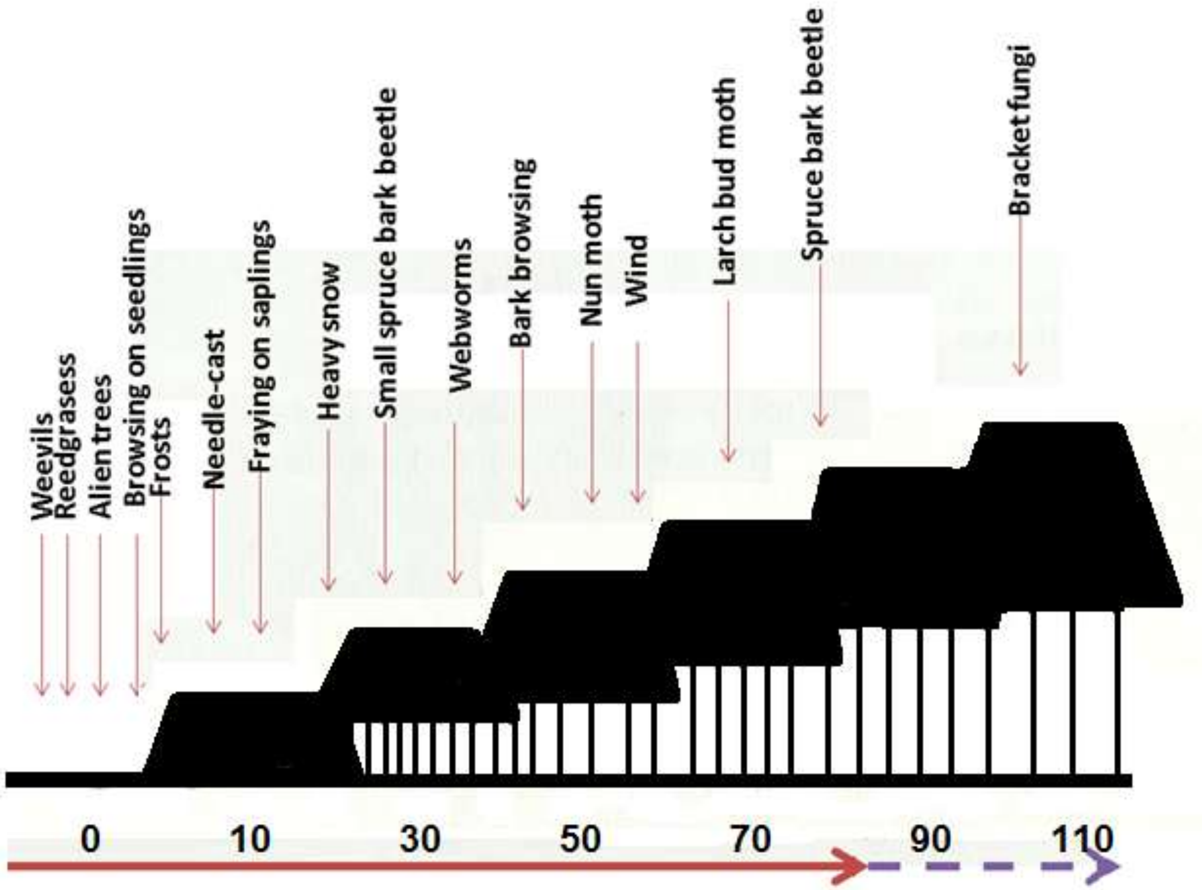


**Figure 1.3.** Norway spruce forest stand as an example of possible threats that might occur during the 80 year and longer rotation period.

## Expansion of forest cover

The third factor, which is still more and more important, is increasing area of forest cover. The forest cover may reach during tens of years one percent of total area of the Czech Republic, this is nearly 800 km².

This process is mainly due to two factors. The first is the spontaneous succession, such as in former military training areas, succession on marginal land or in protected areas left to the wilderness. The second, and probably more dangerous case, is artificial afforestation of the same land as mentioned above, but also afforestation of agricultural land. These artificially afforested sites are at high risk, because most of them are Norway spruce stands on nutrient-rich and highly compacted soils. Such stands are at high risk due to drought, pathogens and low resistance to the wind.

## The main threats to the forests in the central Europe

A major division of potentially harmful factors in forest protection to biotic and abiotic factors is already indicated by the above. The importance of potential threats is changing around the world, although the most important factor in Central Europe are strong winds. This threat is followed and often accompanied by insect outbreaks – most areas damaged by wind are further attacked by bark beetles.

As already noted above, the importance of abiotic factors may in different parts of the world vary greatly. Even if snow is of lower importance in the most of Central Europe, for example, avalanches in the Swiss Alps acquire considerable importance. Specifically, fires that are not so important in Central Europe are among the greatest threats to global forest protection, which goes hand in hand with climate change, and thus increasing drought. The other abiotic factors are, for example, frosts, floods and soil erosion.

Biotic factors are usually given more attention. The main reason is the greater possibility of prevention measures and remedies than in abiotic damaging agents. Again, it depends on the place where we are, but in Central Europe certainly act the most damages insects. In different parts of the world affect forest health also high numbers of wildlife and domestic livestock. The other important biotic factors are, e.g., weeds and fungi.

## Differences between forest stands and forest nurseries

Harmful factors in commercial forestry can be divided by place of action – those that cause losses in forest nurseries and forest stands. While the area of forest nurseries rather decreases (and thus the power of the threat of harmful agents), in forest stands occurs much more diversified ways of damage. Way of intervening in forest nurseries is much more intense and can perhaps be compared to agriculture, while in forest stands the number of interventions is greatly influenced mainly by their accessibility and also above mentioned long rotation period.

## Invasive organisms

Way of protecting the forest is also considerably influenced by a multitude of invasive organisms (e.g. black locust in Europe), but also those that are not aliens and spread extra-limitally (e.g. Norway spruce in Europe). While in the case of extra-limitally spreading organisms, we know about their biology usually at least something, the situation in aliens is considerably vitiated by the unavailability of information about their requirements or by shift in their requirements under the conditions of new distribution area.

## The main methods of forest protection

Finally, it is appropriate to mention distribution of the main curative ways to protect the forest. These are mainly mechanical protection (e.g. mowing) and chemical protection (e.g. pesticide use). Both approaches have advantages and disadvantages, but the main factor for their use will be primarily their efficiency and price. Nevertheless, biological control is presently one of the most promising methods in forest protection. There is also suitable to mention that each potential pest or pathogen must be assessed individually and accordingly the select measures.

# Chapter 2: Abiotic factors

Abiotic factors appear to be the most important threat to which forest is facing. They are often less predictable than biotics and measures against damage caused by abiotic factors is usually the long haul. The care for forest stands is one of the most important issues of silviculture.

Probably the most important factors are wind, water and fire. Strong winds are causes of windthrow or eolic (i.e. wind) erosion. Water comes in many forms. Water deficit induces damages caused by drought and longtime droughts are often causes of wildfires. On the other hand, high amounts of water might cause floods or water erosion. When water occurs in solid form it may cause snow and icybreakages or presented in the soil might cause heaving and snow in high elevations is the cause of avalanches. The other abiotic factors are for example frost or lightning storm. Nevertheless, there are many other abiotic factors that jeopardized forests, but their impact differs around the world (e.g. earthquakes).

Strong winds are the most important abiotic factors in temperate forests. These winds cause snapping, felling and uprooting of the trees, which is important for final losses on economic profit form forest stands. In this place would be good to mentioned that the care for forest stands from the early age is one of the most important issues in commercial plantation forests. It is indicated that high forests with trees with long crown and dense canopy are more resistant against the winds – of course it may seem that it contradicts. Thus, in this case foresters need to find some compromise – and the compromise probably will be more on the side of dense forests – because lower number of branches and higher number of trees per area means higher commercial success. One of the good measures against damages caused by strong winds seems to be also orientation of the shortest side of the clear-cut to the direction of prevailing winds.

Relatively low number of seedlings in sparse closure on clear cut is important measure against damages caused by heavy snows. Since this measure keep long crowns and thicker stems that are more resistant to the snapping by heavy snows or icy.

Another form of water that can cause serious damages in forests are hailstorm that are dangerous especially in vegetation season, because hailstones damage bark of younger twigs and opens them to the fungal pathogens. Leaves and needles are also damaged and hailstones may also cause damage to the blossoms or fruits. The protection against hails is relatively efficient only in agriculture – e.g. by using of nets that absorb the fall of hailstones.

The forest protection against avalanches is highly difficult and expensive. The main approach is regular control of potential avalanches during the winter. Snow retention structures like snow bridges, racks or nets are sometimes used above the timber line. It is sometimes indicated that reforestation of grasslands in high elevations might lead to the better stability of snow. On the other hand, in some cases when forest do not keep the avalanche, the mixture of snow and trees might cause higher damage and worsened the identification of persons or objects overwhelmed by an avalanche than avalanche with pure snow. Nevertheless most of the forests in the avalanche paths are mostly not clear-cut. Thus, one of the good measures is use of non-intensive silviculture and soft logging techniques in areas of high avalanche risk.

Late frosts in spring are one of the possible threats for young shoots of trees. Most native trees are relatively resistant to the frosts, although exotic fast growing trees might be sensitive to the frosts – like some eucalypts (e.g. *Eucalyptus gunni*). Many tree species from oceanic climate that are planted in conditions of continental climate are a very good example. The same problem might occur with trees from low latitudes that are planted in countries of high latitudes. Furthermore, very high frosts might cause damages to the wood even in mature trees – for example they can cause cracks on stems and limbs.

Floods are mostly not so important for forest ecosystems. However, it is dependent on the time of year when floods come, their duration and also configuration of terrain, where they occur. Drainages or drainage channels are one of the efficient measures in floodplain or moor forests. It is mentioned that the main damages caused by floods are outside of forests and they are caused by deforestation of large areas. In this case forests are highly efficient place of retention and retardation of floods. On the other hand, in some cases very strong floods with mixture of water, sludge and woody material might be worse than those with the pure water.

Erosion is caused by disparate factors. Heavy and long lasting rains waterlogged the soil, strong winds in the time of droughts blows away the top layer of soil. Furthermore, erosion is often caused by human activity in surrounding open landscape. Forests are one of the good barriers against erosion in landscape, although there are not so much forest protection measures against erosion inside the forest stands.

Droughts are one of the most hidden factors that are causing decline of forest trees. Even if this abiotic factor is wrongly guessable, it is highly probable that drought is at the beginning of many other damages to the forest. For instance, bark beetle outbreaks, fungal attacks or shortening of natural life span of the tree. Presently, there can be seen that many parts of the planet are threatened by desertification and forests are one of the good reservoirs of water. Nevertheless, there are only a limited number of measures that can be used inside the forests against droughts – one of them is irrigation in forest nurseries.

Droughts together with lightning storms are the main factors causing wildfires. However, fires are often caused by human. Forest protection against fires is sophisticated in boreal forests and special fire-fighting aircrafts are used. The main problem with fires is in areas with rugged topography, where aircraft cannot be used or its use is limited. In these areas fires require helicopters or the presence of firemen and in several cases some forest fires are badly accessible even with ground fire-fighting equipment. It is a problem in areas with sparse road networks.

Abiotic factors are most probably one of the most important abiotic threats around the world. Moreover, the forest protection against abiotic factors is highly divers and mostly dependent on the place where they occur.

**Figure 2.1**. Coniferous stands appear to be more susceptible to damages caused by strong winds. In this forest stand, mixed of Scots Pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*), Scots pines were relatively resistant to the wind storm, while Norway spruce trees were highly damaged, especially snapped.

## Examples:

**Example 2.1.** Nagel T.A., Diaci J. (2006) Intermediate wind disturbance in an old-growth beech-fir forest in southeastern Slovenia. ***Canadian Journal of Forest Research*** 36: 629-638.

Wind is one of the most important disturbance factors in central Europe. This abiotic factor cause uprooting and snapping of forest trees. The economic losses are highly connected with the number of snapped trees and, furthermore, with the time till the end of salvage cutting – since felled trees are often attacked by bark beetles.

Nagel & Diaci (2006) studied immediate effect of windstorms in an old-growth beech-fir forest in Slovenia. They selected two occasions – one storm was in 1983 and the second in 2004. The density and basal area of felled and broken trees was higher in 1983. They found that mid-sized and large trees were more prone to wind than small ones. Silver fir was more sensitive than the European beech, although the diameter of the tree was more important factor than tree species. With respect to the type of damages, large trees were more prone to snapping, while small trees were more felled – nevertheless, more trees were uprooted than snapped in total. Trees killed by wind showed clumped distribution, which resulted to gap dynamics in canopy. Authors concluded that wind storms occur in time intervals that are in coincidence or, furthermore, lower than is the lifespan of most central European tree species.

**Example 2.2.** Zhu J.J., Li X.F., Liu Z.G., Cao W., Gonda Y., Matsuzaki T. (2006) Factors affecting the snow and wind induced damage of a montane secondary forest in northeastern China. ***Silva Fennica*** 40: 37-51.

Many places in forests of China are left for natural succession. The secondary forests are highly affected by abiotic disturbances. Wind and snow breakages are mostly interconnected in mountainous areas. Snow is often causing avalanches, although when high amounts of snow are presented it can cause nearly the same damages as wind – e.g. uprooting and snapping.

Zhu et al. (2006) studied snow and wind induced disturbances in secondary forest in China. They were interested if main tree species in tree species composition differed in sensitivity to the type of damage. They found that main tree species were more damaged by both snow and wind. Slope and soil depth played important role during the disturbance. Dense stands were less affected by wind and snow-breakages. They also find that Manchurian Ash (*Fraxinus mandshurica*), Painted Maple (*Acer mono*), Manchurian Elm (*Ulmus lancinata*) and Mongolian Oak (*Quercus mongolica*) were the less susceptible tree species to the disturbances.

**Example 2.3.** Goulet F. (1995) Frost heaving of forest tree seedlings: a review. ***New Forests*** 9: 67-94.

Frosts might have highly different effects on forest trees. Probably the most known are those caused by late frosts to the shoots. Very high frosts might also cause damages to the stems, even of mature trees. Frost heaving of soil is the result of the formation of ice in the soil caused by freezing of segregate soil water. Ice lenses are growing and pushing upward. Seedlings are pushed out of the ground by ice sheet on the soil surface.

Goulet (1995) reviewed the knowledge about impact of frost, which cause heaving of the top soil layer. He found that the damages caused by frost heaving are difficult to control. The susceptibility of soils could be reasonably well improved using ameliorative measures – e.g. fertilizing, sowing or proper time planting of big seedlings. Modifying of soil using draining, shading and mulching seems to be useful especially in forest nurseries. He concluded that retaining of some natural vegetation also greatly reduce the damages caused by frozen soil.

**Example 2.4.** Bradshaw C.J., Sodhi N.S., Peh K.S.H., Brook B.W. (2007) Global evidence that deforestation amplifies flood risk and severity in the developing world. ***Global Change Biology*** 13: 2379-2395.

Floods are one of the most dangerous disturbances to human being and they often highly affect human populations. Floods inside the forests are also of some risks to the target tree species. They can, for example, cause wounds on stems or oxygen debt to the roots. However, the important fact is that high coverage of forests is good protection against floods.

Bradshaw et al. (2007) used data about flood frequencies from ten-year period from more than fifty developing countries. They found that flood frequency was highly correlated with the loss of natural forest cover. Thus, the cutting of natural forests led to the higher frequency of floods. This result is highlighted by the fact that nearly 100,000 people were killed and more than 300 million people lost their homes by flood and consequent events during the study period. Furthermore, economic damages exceed 1,000 billion USD. Authors concluded that reforestation may help to reduce the frequency of floods.

**Example 2.5.** Veblen T.T., Hadley K.S., Nel E.M., Kitzberger T., Reid M., Villalba R. (1994) Disturbance regime and disturbance interactions in a Rocky Mountain subalpine forest. ***Journal of Ecology*** 82: 125-135.

Forest fires are highly dangerous disturbances, because they threatened the human populations. The suppression of forest fires is much difficult in rugged terrain and during unsuitable climatic conditions – e.g. strong winds and long-term drought. Moreover, fires are predicted to be connected with other types of disturbances. On the other hand, several tree species like pines (*Pinus* spp.) are dependent on fires, because their cones are opened by high temperatures.

Veblen et al. (1994) studied the spatial and temporal patterns of fire, snow avalanches and, furthermore, bark beetle outbreaks in U.S.A. They used dendrochronological techniques to determine the time of disturbances. They found particular time periods from 15$^{th}$ century when major disturbances occurred. Results showed that since 17$^{th}$ century the studied area was most affected by fire followed by bark beetle and avalanches. At suitable places, avalanches occurred nearly annually. Fires have had approximately 200-year period frequency and bark beetles nearly 100-year period. They also find interactions among disturbance types. For instance, large avalanches improve the conditions for the spread of fire and both did not promote outbreaks of bark beetles till individual trees did not reach 70 years.

**Example 2.6.** Whicker J.J., Pinder J.E., Breshears D.D. (2006) Increased wind erosion from forest wildfire: implications for contaminant-related risks. ***Journal of Environmental Quality*** 35: 468-478.

As abiotic factors are mostly interconnected, it is also relatively conspicuous topic that one mostly followed the other. Fires often caused the immediate loss on vegetation cover. Even if, some species are fire dependent or more resistant to the fire heat, the vegetation cover is much lower in the next years after the wildfire. This is a potential risk, because topsoil without any vegetation layer is highly susceptible to the aeolian erosion (i.e. caused by wind). However, this relationship has been only poorly studied.

Whicker et al. (2006) studied the erosion caused by wind after forest fire. The study was done in New Mexico (U.S.A.) in ponderosa pine (*Pinus ponderosa*) forests. They studied wind-driven horizontal and vertical dust fluxes, metrics of transport related to wind erosion in unburned, moderately burned and severely burned (crown fire) sites. Dust flux was significantly greater in both types of burned areas. Due to delayed vegetation recovery in next dry years the elevated dust fluxes did not decrease during the next years in burned sites.

**Example 2.7.** Kramer M.G., Hansen A.J., Taper M.L., Kissinger E.J. (2001) Abiotic controls on long-term windthrow disturbance and temperate rain forest dynamics in southeast Alaska. ***Ecology*** 82: 2749-2768.

Wind is often causing two way dynamics – the first one is small scale disturbance that corresponded with gap dynamics. The second type is large scale disturbances with gaps of survived trees that are together with seed bank sources for future forest regeneration. As it is known, wind disturbance have some cycles and it is relatively hard to prevent against them. One of possibilities is discrimination between areas that are more susceptible to the large scale disturbances, or on the other hand, to the small gap dynamics.

Kramer et al. (2001) investigated the role of abiotic factors in patterns of windthrow in the pristine coastal temperate rain forests of southeast Alaska (U.S.A.). They were interested to which extent long-term patterns of windthrow can be predicted spatially at the landscape scale. Four abiotic factors – slope, altitude, soil stability and exposure to prevailing storm winds were used. Field data collected in areas most and least prone to windthrow suggest that structural and age characteristics, as well as forest development stages, vary with the probability of windthrow across the landscape. Authors concluded that small-scale disturbances predominate in areas least prone to windthrow, and large-scale disturbances are more common in most prone areas to windthrow.

**Example 2.8.** Krawchuk M.A., Cumming S.G., Flannigan M.D., Wein R.W. (2006) Biotic and abiotic regulation of lightning fire initiation in the mixedwood boreal forest. ***Ecology*** 87: 458-468.

Lightning is one of the important possibilities of cause of fire. Outside of boreal regions in temperate forests, lightning is mostly cause gap dynamics, because of death of one or a few more trees. The severity of lightning fire is indicated to be one of the dominant natural disturbances in mixed boreal forests in North America. Even if, lightning is common, it is still not well known which factors are causing the initiation of fire after lightning.

Krawchuk et al. (2006) quantified the independent effects of weather and composition of forests on initiation of fire caused by lightning in Canada. Forest composition tended to have higher impact than weather. Fire initiations were more frequent in conifer dominated woodlands and fewer incidences were in forests dominated by broadleaves and stands that were recently burned. Forest composition was stronger in years with more severe fire weather. Vegetation feedbacks might strongly regulate the disturbance dynamics.

**Figure 2.2**. Wildfires or fires induced by human are highly dangerous in densely populated areas. The suppression of fires in larger areas is relatively efficient by fire aircraft. However, the suppression in highly rugged topography is often unsuccessful and rains are often the only one possibility for expire of the fire.

## Questions for exam:

**Question 2.1.** Fires are potential threat to the commercial plantations of forest trees. When they are not suppressed, they can be a serious danger to the human settlements. In which areas are fires more dangerous?

**Question 2.2.** Wind is the most important abiotic threat in central Europe. Based on dendrochronological data, there seem to be a periods of windbreaks in Europe. What is the main consequence of wind break in spruce-dominated mountainous forests?

**Question 2.3.** Heavy snows cause tree breakages and avalanches in hilly and mountainous areas. Avalanches are more common in high mountains, but heavy snows might cause breaking of forest trees also in low altitudes. Which type of forest stands is the most susceptible to the damages caused by heavy snows?

**Question 2.4.** Frosts are one of the limiting factors for successful growth of trees of oceanic climate origin in continental areas. Frosts often damage shoots of broadleaved trees. Which type of abiotic threats is the most dangerous to the broadleaved forests in temperate climate?

**Question 2.5.** Floods appear to be presently more common due to the possible change in global climate. More recently, there is a rising body of knowledge that human alteration of landscape might be also one of the consequences of floods. What is the main global threat, with respect to forestry, that cause high severity of floods?

**Question 2.6.** Erosion is highly important in agricultural areas. However, forests on slopes are not safe against erosion. Erosion is often interconnected with other factors and might damage human settlements in relatively far areas. What is the main abiotic cause of erosion in flat dry areas of the world?

**Question 2.7.** Strong winds cause structural changes in forest and in many cases are able to destroy whole stands. Forest stands change immediately structure from vertical to horizontal. Why even small scale windbreaks may cause economic losses?

**Question 2.8.** Fires are quite common in areas with low amounts of rainfalls. The most important thing during wildfires is effort to reduce their area to a minimum. What are the main factors that are causing forest wildfires?

# Chapter 3: Weeds

Forest weeds are one of the most serious problems in forest protection. On the other hand, this topic appears to be one of the most neglected by literature. Good message is that this drawback could be relatively well substituted by knowledge from agriculture.

For those who like partitioning, we could divide forest protection against weeds into two areas: (i) forest nurseries and (ii) forest stands. Of course, each of these areas has its own problems and, furthermore, could be divided to other topics. If a bit generalization would be used, the protection in forest nurseries is quite similar to the agriculture – e.g. weeds and protection against them in beds of seedlings is highly similar to crop fields. Nevertheless, the protection against forest weeds in forest stands is highly specific discipline and with increasing age of stand is moving away from agriculture – i.e. the weed protection in clear-cut is more similar to agriculture than preparation of mature stand before cutting.

With respect to forest nurseries, there can be seen a growing tendency to replace artificial regeneration of natural regeneration. This trend has been causing the decline in area and number of forest nurseries – this is surely the case of central Europe. Not surprisingly, there can be clearly seen that nothing than commercial seedlings and saplings of target trees are welcome in forest nurseries. This is relatively simple, because all other plants are competing with target seedlings for natural sources like water or place in bed. The presence of weeds and their species composition depends also on the fact if target tree species are planted in beds outdoors or in greenhouses. Forest nurseries, on the other hand, are mostly better accessible and operated than forest stands, especially due to lower area, higher density of permanent roads, tracks and pavements and they are mostly also flat.

Forest stands are more complex issue than forest nurseries with respect to forest protection against weeds. As the stands grow from seedling to mature trees, forest protection has been differing. Furthermore, there is also different approach in forest protection within the first stages after harvest of the mature stand. This means that forest protection against weeds will be much more different in artificially forested sites than in forest stands where natural regeneration prevails. Of course, there are also differences between stands in mountainous areas or lowlands, between flat and sloppy stands or between stands on nutrient poor and rich soils – although, it is much more about plant ecology than about forest protection.

The second partitioning could be based on the main weed groups and especially some (i) grasses, (ii) shrubs and (iii) aliens (i.e. non-native organisms) could cause serious problems in forest protection. The main problem usually occurs, when some weed species found optimal or even supra-optimal conditions and start to dominate at the site – e.g. some moorgrasses (*Molinia* spp.) after the fire.

Most weeds of grasses in forest stands are perennial plants that combine vegetative reproduction and germination, although the vegetative reproduction appears to be one of the most successful characters for weed in forest stand. Illustrative example could be reedgrass (*Calamagrostis* spp.) in most parts of the northern hemisphere. On the other hand, grasses that are causing the highest economic losses in forest nurseries are annuals. In the northern hemisphere, there can be mentioned Annual Meadow-grass (*Poa annua*) and Cockspur (*Echinochloa crus-galli)*. Furthermore, these agricultural weeds are able to weed beds for many years, especially because they have more generations within the vegetation season.

In the case of shrubs in forest stands can be seen also some positive effect – like spiny shrubs' sheltering of seedlings and saplings against high game stocks. Although, some shrub species could slow down the artificial afforestation or change the species composition of target trees. An example is elderberry (*Sambucus* spp.) on highly nutrient soils, because this species is able to rapidly overgrown whole site from seeds and then again rapidly regenerate from stumps. Shrubs appear not to be so important in forest nurseries. Although, when the nursery is close to fruiting mature shrubs, beds could be weeded by seeds brought by birds or wind. The example could be willow (*Salix* spp.) or birch (*Betula* spp.) – and even if birches are not in most cases shrubs, the effect on seedlings could be the same as for shrubby wood plants.

The problem of aliens is highly discussed in recent and present literature and the combination of propagule pressure together with suitable conditions of climate and land use are mentioned as the leading factors that drive the spread of aliens. Some alien species could affect forest stands not quite directly, but their impact could be critical especially with respect to whole forest. For example, knotweeds (*Reynoutria* spp.) are able to cover whole understory and their shallow roots destabilize the forest soil against water erosion during floods. There are many aliens that could affect the effective cultivating of the seedlings in forest nurseries. Nevertheless, they will be the most important in forest nurseries that are using greenhouses.

The last partitioning will be based on approach used against the forest weeds: (i) mechanical and (ii) chemical. Both approaches have their own advantages and can be combined.

Probably the most used mechanical approach in present forest protection of forest stands is mowing. How one becomes more and more lazy, the brush-cutter or at least grass trimmer will be most probably the best selection for mowing in forest stands. One of the problems within the use of these devices is problem with forest workers, who are often not able to discriminate between weeds and broadleaved seedlings. Mowing is, furthermore, relatively expensive, because most of weeds need to be cut more times per year. Other approaches that can be included under the term mechanical approach are so called traditional forest management types: pasturing and haymaking. Even if, these management types were common and abundant in the past, presently the only space for them is in conservation areas or in other parts of the world than in central Europe. One of the possible approaches is also controlled fire. However, there rises a problem with adaptation of some forest weeds to burnt sites.

There are much more possibilities how to use mechanical devices in forest nurseries. Weeding of beds can be done using disparate machines or handmade. Mowing or other techniques are mostly used only for management of pavements etc.

Chemical forest protection against forest weeds in forest stands is presently mostly based on herbicides and total herbicides are prevailing. Nevertheless, several selective herbicides are becoming to be more important – especially, those against grasses. The area of clear cuts is often sprayed by total herbicides before afforestation. Although, there can rise a risk, especially when natural regeneration is present. Total herbicides, often called as arboricides are used in protection against alien trees – e.g. stumps of locust (*Robinia pseudoaccacia*) are smeared by liquid solution of herbicide and water immediately after tree cut. This can be also used in mature stand of tree species, which stumps show vigorous sprouting capacity and are not target in forest stand.

The chemical protection in forest nurseries has many options and both total and selective herbicides are used. Nevertheless, the use of herbicides in forest nurseries is not in its principle different to that in forest stands. Of course, there is not so big problem with weeds of woody plants and the target weed species are herbs. Often used approach is use of granulated herbicides against germinating weeds.

**Figure 3.1.** Reedgrass *Calamagrostis epigejos* in three-year old bark beetle gap in mixed oak-pine-spruce stand. Natural regeneration appears to be more successful toward the edges of gap, while inside is overgrown by tussocks of reedgrass.

## Examples:

**Example 3.1.** Lieffers V.J., MacDonald S.E., Hogg E.H. (1993) Ecology of and control strategies for *Calamagrostis canadensis* in boreal forest sites. ***Canadian Journal of Forest Research*** 23: 2070-2077.

Most reedgrasses can cause serious problem in forest protection. *Calamagrostis canadensis* is one of the most common forest grasses in North America. It is a perennial grass whose height reaches 1.5m when the plant is heading. From the perspective of forest protection of forest weeds is important that this grass is a palatable plant for grazing animals. This grass prefer humid and wet areas and is also able to colonize soils contaminated by pollution – e.g. by oil spills, which is important for forest ecological restoration. This grass outcompete many target forest tree species – especially, conifer seedlings are often suppressed in their growth.

Lieffers et al. (1993) studied the effect of this reedgrass on white spruce (*Picea glauca*) in boreal forests of North America. They found several important control strategies for *Calamagrostis canadensis*. When the grass is regularly distributed and abundant in the understory within whole forest stand before the logging, the grass will expand even when clones are sprayed by herbicides or/and deep burnt. The only chance for white spruce regeneration is use of larger seedlings that are planted on bare soil or mounds. This should be supplemented by herbicides or sheep grazing. One of the other possibilities is also shading by standards of mature trees. When the grass is not abundant in understory, the main possibility is avoiding of forest floor disturbance and burning.

**Example 3.2.** De Steven D. (1991) Experiments on mechanisms of tree establishment in old-field succession: seedling emergence. ***Ecology*** 72: 1066-1075.

Abandoned crop fields come under the succession toward forests. Herbs layer is one of the most limiting factors in tree succession. The situation in eastern part of U.S.A. is not much different to the other temperate parts of the world.

De Steven (1991) describes the experiment where six early successional tree species were sown. The Red Maple (*Acer rubrum*) is one of the most common and widespread deciduous trees of eastern North America. Loblolly pine (*Pinus taeda*) is the most common conifer species of tree in the United States and the second most common tree after red maple. White ash (*Fraxinus americana*) is a common broadleaved tree species in eastern North America. American sweetgum (*Liquidambar styraciflua*) is a deciduous tree, which prefers warm temperate areas of North and Central America. It is most common in hardwoods. Tulip tree (*Liriodendron tulipifera*) is common in eastern North America. It is fast growing and shade-intolerant tree. Winged Elm (*Ulmus alata*) is relatively small deciduous tree endemic to the south-eastern and central U.S.A. This pioneer is sun loving and often invades disturbed sites like are old fields. Not surprisingly, the highest mortality of all studied pioneer species was during the first growing season. Tulip tree was highly affected by the presence of herbs. Maple was only poor competitive and showed highest mortality, which was closing to 100% in plots with presence of herbs. Surprisingly, loblolly Pine grew well also in competition with herbs and showed the highest height of seedlings. Browsers were damaging all deciduous species except of tulip tree, but Elm was the most damaged.

**Example 3.3.** Timmins S.M., Williams P.A. (1991) Weed numbers in New Zealand's forest and scrub reserves. ***New Zealand Journal of Ecology*** 15: 153-162.

An invasion of alien weeds into the forests is one of the present hot topics and potential threats in forest protection against weeds. There are, of course, more studies dealing with the topic of invasion of alien weeds to forests. However, New Zealand is known to be an exercise book of influence of aliens to the ecosystems.

Timmins & Williams (1991) studied how numbers of weed species are related to disparate environmental factors. More than 200 sites were studied against 15 characteristics. The leading factor for increasing numbers of aliens was the distance to towns with 5,000 and more inhabitants, distance roads and railways, also level of human use, the shape and diversity of reserve. Most weeds were in narrow remnants on fertile soils with presence of clearings with high area of herbaceous vegetation and in remnants that were historically modified together with those close to towns with high level of human activity. One of the leading possibilities against the invasion of weeds is minimization of disturbances within forests.

**Example 3.4.** Standish R.J. (2002) Experimenting with methods to control *Tradescantia fluminensis*, an invasive weed of native forest remnants in New Zealand. ***New Zealand Journal of Ecology*** 26: 161-170.

Wandering Jew (*Tradescantia fluminensis*) is native plant to South America and is often used as an ornamental plant in Europe and in other continents. This perennial plant with white flowers has ground cover strategy and preferring moist and warm environments. Australia, New Zealand and southeastern states of the U.S.A. are the most affected by its invasion. The plant forms a dense mat in understory of forests and suppressed other herbs and natural regeneration of target tree species. Wandering Jew seems to be herbicide resistant and its vegetative parts are quickly regenerating elsewhere.

Standish (2002) studied this alien weed in New Zealand's forest remnants. For successful natural regeneration of forest there was needed to decrease the cover of this plant to 40% of total cover. Three methods were tested: herbicides, hand weeding and artificial shading. Herbicides and hand weeding were not successful, while artificial shading was the most effective method for the control of this weed. However, the shading needs to be for relatively long time – i.e. 17 months in this case. This is an example when herbicides failed in forest protection and manual protection is urgently needed.

**Example 3.5.** Dubois M.R., Chappelka A.H., Robbins E., Somers G., Baker K. (2000) Tree shelters and weed control: effects on protection, survival and growth of cherrybark oak seedlings planted on a cutover site. ***New Forests*** 20: 105-118.

All shrubs do not need to be forest weeds. In some cases (e.g. when high game stocks are presented), shrubs might play important role during the establishment of seedlings and their successful growth into mature trees. This approach might be also effective for admixed tree species or in game parks and pastured woodlands. Cherrybark oak (*Quercus pagoda*) is a tree with high importance due to timber quality. This species is native to southern U.S.A. and its acorns are important source of food for wild animals.

Dubois et al. (2000) studied the effect of protection of cherrybark oak against high game stocks using shrub sheltering and control of weeds by herbicides. They find that survival rate of cherry bark oak seedlings were highest when seedlings were sheltering by shrubs together with control of herb weeds. This was followed by sheltering, herbicide spraying. The control without sheltering and herbicides showed the lowest percentage of survival. Browsing was very high for herbicides and was very low for shrub sheltering and combination of sheltering and herbicides. The growing response of seedlings reflected by height was also highest when sheltering was presented and nearly the same result was for diameter and volume of stem of seedling of cherybark oak. Thus, natural sheltering by good weeds of shrubs could be of high importance in protection of seedlings.

**Example 3.6.** Hejcman M., Klaudisova M., Hejcmanova P., Pavlu V., Jones M. (2009) Expansion of *Calamagrostis villosa* in sub-alpine *Nardus stricta* grassland: Cessation of cutting management or high nitrogen deposition? ***Agriculture, Ecosystems & Environment*** 129: 91-96.

Reedgrasses are common in both forest and non-forest ecosystems. *Calamagrostis villosa* is mountainous grass native in Europe. This species is indicated to be associated with natural areas of the Norway spruce (*Picea abies*), but more recently this species is extra-limitally spreading and colonizing also lower altitudes and increasing its coverage in permanent grasslands. This grass could reach 1.5m height and very high vegetation cover, while using vegetative reproduction.

Hejcman et al. (2009) studied the expansion of this grass into permanent grasslands formerly dominated by matgrass (*Nardus stricta*) in the Czech Republic. Even if, this topic is not restricted to the forests, its results and conclusions might be successfully applied for forest protection. The main question was if the spread is caused by high nitrogen depositions in recent years or by cessation of traditional management like mowing for hay and pasturing. They used treatments that were fertilized, mowed, or mowed and fertilized. Species composition was influenced by mowing, while not by fertilizer. Cutting reduced the cover, biomass, height and tiller density of reedgrass. Density and cover of reedgrass was also highest when was fertilized in long-term perspective (six years). The recent expansion is most probably caused by abandonment of traditional management and also by increase in nitrogen availability in recent time.

**Example 3.7.** Brys R., Jacquemyn H., De Blust G. (2005) Fire increases aboveground biomass, seed production and recruitment success of *Molinia caerulea* in dry heathland. ***Acta Oecologica*** 28: 299-305.

Purple moor grass (*Molinia caerulea*) is relatively ecologically and genetically diversified grass native in Europe, west Asia and North Africa. This species likes low pH values. The grass can reach more than 2m in height and is common in heathlands, bogs and moorlands. Its tussocks are very dense and thus it is highly resistant to fires, it is also producing amounts of litter that is hardly decaying. Purple moor grass is recently increasing its abundances in most Europe.

Brys et al. (2005) studied this species in Belgium. It is predicted that increase in abundance of purple moor grass is caused by nitrogen deposition and different management with respect to historical. Fire increased the biomass, number of seeds and germination of the study grass. Furthermore, number of seeds was twice higher in burnt sites than in unburnt and this increased during following years. Seeds from burnt sites have also higher germination. These results indicated that burning can be relatively problematic management type against weeds.

**Figure 3.2.** Artificial regeneration of European beech, *Fagus sylvatica*, is successful in upper part under the canopy of oaks, while failed in lower part of a clear cut. Lower half of this clear cut looks more like grassland than forest stand.

## Questions for exam:

**Question 3.1.** Reedgrasses (*Calamagrostis* spp.) are one of the main forest weeds in the northern hemisphere. They are able to be abundant in clear cuts and cause the suppression or decline of target tree species. What is one of the most successful protection against reedgrass?

**Question 3.2.** Moorgrasses (*Molinia* spp.) are highly abundant on low nutrient soils with low pH values. They have very dense tussocks. What is one of the most successful protections against Moorgrasses?

**Question 3.3.** Alien (i.e. non-native) weeds and especially trees can cause serious losses for target tree species. What is one of the main factors during the process of spreading of alien (i.e. non-native) plants?

**Question 3.4.** Forest nurseries are producing seedlings and saplings for afforestation. The recent trend of preference for natural regeneration in forest stands is causing…

# Chapter 4: Phloeoxylophagous insects

This group of organisms in forest protection is mainly consisted of higher number of insect taxa – for instance, beetles (Coleoptera), hymenopterans (Hymenoptera) or flies (Diptera). However, beetles and namely bark and ambrosia beetles (Scolytinae and Platypodinae) appear to be the most important taxonomic groups. This topic and especially bark and ambrosia beetles are one of the highly studied problems – and not only in forest protection.

In this case, we could divide the forest protection with respect to the place where it is done. Here will be a bit difference in protection of (i) forest nurseries and (ii) forest stands.

Forest nurseries are mostly affected by insects damaging seedlings and saplings and control against them is not much different to forest stands, especially in initial stage of forest stands after clear-cut. In these cases, there are several organisms that might have more important impact on target tree species in forest nurseries than in forest stands. Beds in forest nurseries are often very dense monocultures. Thus, they are much more jeopardized by potential insect pests that are foraging on their bark, bast and wood. Several species are phytophages in their adult age, although their larvae are foraging of roots. An example might be *Melolontha* chafers – their larvae forage underground on roots of disparate tree species. Roots are also damaged by European mole cricket (*Gryllotalpa gryllotalpa*), which is one of the best known and conspicuous orthopteran forest pests. Other species that cause damages to seedlings are weevils (Curculionidae) that are foraging on seedlings – especially, those emerged from stumps in surrounding clear-cuts. Stems of saplings might be damaged by several species of bark beetles (e.g. *Scolytus* spp.) and ambrosia beetles (e.g. *Xyleborus* spp.). They are creating galleries under the bark of large saplings (bark beetles) or are able to create galleries inside the wood of relatively thin wood (ambrosia beetles). Both these processes mostly cause death to saplings that are dried or broken.

Forest stands with their very long rotation period have potential to host much higher diversity of potential pests. Stands of coniferous trees like Norway spruce (*Picea abies*) in Europe might be a good example – afforested clear-cut area is often affected by weevils (e.g. *Hylobius abietis*), then in pole stage stand they are affected by small bark beetles (e.g. *Pityogenes chalcographus*), then in premature and mature age by large bark beetles (e.g. *Ips typhographus*) and stocked timber or overmature trees might by attacked by ambrosia beetles (e.g. *Trypodendron lineatum*).

The phloeoxylophagous insects can be reasonably well divided into those that are attacking (i) bast (e.g. bark beetles of *Ips* spp.), (ii) wood (e.g. ambrosia beetles of *Xyleborus* spp.) or both bast and wood (many Cerambycidae). Their damages are different and also the dieback of trees is mostly much quicker in the case of bark beetles than ambrosia beetles. Bark beetles that are feeding in bast appear to be more important, because many species of them have in lower altitudes more than one generation per vegetation season and thus they are able to cause serious damages to the stands more times per year. It is also known that bark beetles are more important in boreal and temperate forests and their impact is replaced by ambrosia beetles when closing to Equator. In tropical forests bark and ambrosia beetles can have overlapped generations through the year. The impact of insects that are feeding in both bast and wood appears to be lower in temperate and boreal forests, although some alien species might have very high local impact on native ecosystems and also on target trees within harvested woodland landscapes. Presently several jewel beetles (Buprestidae) and longhorn beetles (Cerambycidae) are of high importance, e.g. in eastern states of the U.S.A. One of serious threats is also association of phloeoxylophagous insects with alien associates like in elm bark beetles and symbiotic fungi or association of some longhorns with nematodes.

The active forest protection against phloeoxylophages is mostly based on (i) chemical and (ii) mechanical approaches. (iii) Biological control is also, but marginally, used.

As an example of chemical protection in forest nurseries is use of pheromone traps – even if mostly un-effective. The mechanical approaches are, for instance, application of bark traps on weevils or burning of material that was attacked by pests. One of the important beetles in forest nurseries and clear-cuts is the pine weevil (*Hylobius abietis*) that is a pest that combines damages on bast and bark of seedlings. Forest stands have again more complex system in protection against phloeoxylophages. The main used approaches are pheromone baited traps and tree traps, or combination of them – like tripod logs with pheromone and furthermore, with application of contact insecticide. All these kinds of traps are often used for monitoring of actual population densities of phloeoxylophagous insects. Presently, there are highly selective pheromones for particular insect species. Releasing of natural enemies is an example for biological control against phloeoxylophages – Root-eating beetle *Rhizophagus grandis* (Monotomidae) was used against the great spruce bark beetle *Dendroctonus micans*.

All these systems have, of course their drawbacks like relatively short intervals of control of pheromone baited traps – because the trapping success of target insect species is lowering with rising time interval and number of non-target and often beneficial insects is rising. In the case of highly effective trap trees, should be mentioned need for early deactivation of this trap, which means peeling of the bark during the time of last larval stages or spraying by insecticides immediately before emerging of immature beetles. Tripods might be nonselective method – many beneficial insects are killed. And finally, biological control may fail due to poor adaptation of natural enemies.

At the end, there might be good to say that three phloeoxylophagous insects are indexed in the law of the Czech Republic as pests that might cause calamities in forests – *Ips typographus, Pityogenes chalcographus* and *Hylobius abietis.*

**Figure 4.1**. Last generation of the year of the Spruce Bark beetle (*Ips typographus*). Callow (immature) adults are mostly at the end of former larval galleries. Some part of them will overwinter under the bark, while majority will emerge and overwinter in forest soil.

## Examples:

**Example 4.1.** Karvemo S., Van Boeckel T.P., Gilbert M., Gregoire J.C., Schroeder M. (2014) Large-scale risk mapping of an eruptive bark beetle–Importance of forest susceptibility and beetle pressure. ***Forest Ecology and Management*** 318: 158-166.

Attacks by spruce bark beetle (*Ips typhographus*) on Norway spruce (*Picea abies*) forest stands can cause huge damage in Europe. This bark beetle is the most important pest beetle in Europe. Its population densities have increased during the recent years. Except of mountainous and boreal parts of its distribution (i.e. native distribution of Norway spruce), has this species more generations per season.

Karvemo et al. (2014) made the risk-rating models for damages caused by this bark beetle. They studied this species in temperate part of Sweden and used predictors like volume of Norway spruce and Birch wood volume per hectare, mean tree height, distance to the clear cuts, presence of bark beetle infestation spots and number of infestation spots in the neighborhood. They found that increasing volume of the Norway spruce was the only one significant predictor that positively influenced relative risks of infestation by the spruce bark beetle. They also found that the trees killed by the spruce bark beetle in managed forest landscapes are distributed in many small infestation spots.

**Example 4.2.** Lubojacky J., Holusa J. (2013) Comparison of lure-baited insecticide-treated tripod trap logs and lure-baited traps for control of *Ips duplicatus* (Coleoptera: Curculionidae). ***Journal of Pest Science*** 86: 483-489.

Double-spined bark beetle (*Ips duplicatus*) is presently spreading in Europe. The species has nearly the same requirements as most important pest of Norway spruce in Europe – *Ips typhographus*. With respect to forest protection against bark beetles, mostly two measures are used – pheromone baited traps or pheromone baited tripods that are treated by insecticide.

Even if, trap trees appears to be the most efficient, they bring relative risk when they are not debarked in the right time before new adults emerged.

Lubojacky & Holusa (2013) studied the difference between pheromone baited traps or pheromone baited tripods that are treated by insecticide. They found that commonly used pheromone traps were nearly three times more efficient in captures of the double-spined bark beetle. Furthermore, pheromone traps captured more females than males, while tripods lured and killed males and females in the same ratio. Both types of traps were more efficient during spring months than in summer. Moreover, tripods killed significantly higher number of beneficial and non-target insects than pheromone traps.

**Example 4.3.** Zas R., Sampedro L., Prada E., Lombardero M.J., Fernandez-Lopez J. (2006) Fertilization increases *Hylobius abietis* L. damage in *Pinus pinaster* Ait. seedlings. ***Forest Ecology and Management*** 222: 137-144.

Pine weevil (*Hylobius abietis*) has intricate ecology. Adults are feeding on bark of young stems and they are partly saproxylic in stumps. Larvae are feeding in fresh stumps and furthermore also in stems of young seedlings. Adults live for more years and preferred clear cuts with fresh stumps of conifers. One of the best measures in forest protection against this species is to leave the afforestation to the second year, when stumps are more decayed and thus not so attractive for the Pine weevil. Maritime pine (*Pinus pinaster*) is the most important forest tree species in Spanish Galicia. Fertilization is a commonly recommended for second-generation Maritime pine plantations.

Zas et al. (2006) studied damages caused by the Pine weevil in Maritime pine (*Pinus pinaster*) plantations in Spain. They found that fertilization (combinations of ammonium nitrate, calcium phosphate, potassium sulphate and magnesium sulphate) had a strong and significantly positive effect on pine weevil damage. The damage by the pine weevil was greater on fertilized plants. The loss on seedlings against unfertilized control was nearly four times higher.

Moreover, no significant effect of fertilization on growth of seedling of Maritime Pine was observed.

**Example 4.4.** Muller J., Bussler H., Gossner M., Rettelbach T., Duelli P. (2008) The European spruce bark beetle *Ips typographus* in a national park: from pest to keystone species. ***Biodiversity and Conservation*** 17: 2979-3001.

The spruce bark beetle (*I. typographus*) is considered as one of the major pests in European forests. On the other hand, it is known that if the areas with high nature conservation value are attacked by this beetle and are left for succession, the biodiversity often rapidly grows. The bark beetle surely have high potential as ecosystem engineer that is creating habitats for many other organisms and is also opening the canopy of high forests.

Muller at al. (2008) studied this bark beetle in Germany. They compared forests, gaps created by man and gaps created by spruce bark beetle. Species richness of three studied taxa – bugs (Heteroptera), bees and wasps (Hymenoptera) and saproxylic beetles (Coleoptera) was higher in gaps than in forests. Saproxylic beetles were more species rich in gaps created by bark beetle and the same result was reached for threatened species. Authors concluded that that *Ips typographus* fulfils the majority of criteria for a keystone species, particularly those that help to maintenance of biodiversity in forests.

**Example 4.5.** Bertheau C., Salle A., Rossi J.P., Bankhead-Dronnet S., Pineau X., Roux-Morabito G., Lieutier F. (2009) Colonisation of native and exotic conifers by indigenous bark beetles (Coleoptera: Scolytinae) in France. ***Forest Ecology and Management*** 258: 1619-1628.

Exotic trees are often planted as ornamental plants in non-forest habitats. The growth of some of them indicated that they have high potential for forestry and timber production. North American tree species Sitka spruce (*Picea sitchensis*), Eastern white pine (*Pinus strobus*), Grand fir (*Abies grandis*), Douglas fir (*Pseudotsuga menziesii*) and Western red cedar (*Thuja plicata*) are among them. In any case, exotic trees have some potential from the point of view of native organisms – and also potential pests including bark beetles.

Bertheau et al. (2009) studied colonization of three native conifers – Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*) and Silver fir (*Abies alba*) – and five above mentioned north-American conifers by native bark beetles. The study was done in France. The main aim of study was to estimate factors causing shift of bark beetles onto new host trees. While using window traps, they collected eighteen indigenous and furthermore two exotic bark beetles. Surprisingly, all exotic conifer species were colonized by indigenous bark beetles and no significant difference was observed between native and exotic tree species. They found that the ability of indigenous bark beetles to shift onto exotic conifers depend on host tree species, the presence of phylogenetically related native conifers and that of similar resources, in combination with insect host specificity.

**Example 4.6.** Boone C.K., Aukema B.H., Bohlmann J., Carroll A.L., Raffa K.F. (2011) Efficacy of tree defense physiology varies with bark beetle population density: a basis for positive feedback in eruptive species. ***Canadian Journal of Forest Research*** 41: 1174-1188.

Lodgepole pine (*Pinus contorta*) is a fire-dependent conifer that is widely distributed in western North America. This species has been planted also in other parts of the world. Mountain pine beetle (*Dendroctonus ponderosae*) is native in forests of North America. This species is associated with Blue stain fungus (*Grosmannia clavigera*). The mountain pine beetle outbreak recently destroyed wide areas of lodgepole pine forest.

Boone et al. (2011) studied in Canada potential factors in resistance of lodgepole pine to the bark beetle attack. They evaluated the ability of constitutive and inducible defenses to protect trees and restrict herbivore reproduction across disparate eruptive phases of outbreak. Host tree defenses were important only when mountain pine beetle populations were low. Trees of large diameter had more pronounced defenses. However, as populations increased, beetles selected increasingly larger, more resource-rich trees.

**Example 4.7.** Ayres M.P., Wilkens R.T., Ruel J.J., Lombardero M.J., Vallery E. (2000) Nitrogen budgets of phloem-feeding bark beetles with and without symbiotic fungi. ***Ecology*** 81: 2198-2210.

Many bark beetles (Scolytinae) have their own and sometimes species-specific fungal or bacterial (present research revealed also other organisms like mites, nematodes or protozoans etc.) associates. These associates often help them during the attack and killing of host trees. Some of them help them during the feeding and food digestion. On the other hand, host trees have many types of mechanism that help them against the insect attack.

Ayres et al. (2000) studied the influence of nitrogen in food on development of bark beetles with and without symbiotic fungi. They used loblolly pine (*Pinus taeda*) as a host tree and the southern pine beetle (*Dendroctonus frontalis*) with symbiotic fungi and eastern five-spined bark beetle (*Ips grandicollis*) without symbionts as its herbivores. The nitrogen content of plant tissue is rather low and low level of nitrogen as a part of a diet can limit the growth and reproduction of bark beetles. Phloem (bast) is very low in content of nitrogen and often contains poisonous substances. Mycangial fungi provide their benefits by concentrating dietary nitrogen for larvae. Trees with higher nitrogen content produced larger southern pine beetle adults. Non-mycangial bark beetles meet their nitrogen budgets through high consumption of unaltered phloem with low content of nitrogen.

**Example 4.8.** Mezei P., Grodzki W., Blazenec M., Jakus R. (2014) Factors influencing the wind-bark beetles’ disturbance system in the course of an *Ips typographus* outbreak in the Tatra Mountains. ***Forest Ecology and Management*** 312: 67-77.

Abiotic and biotic disturbances are often interconnected. Bark beetle outbreak that followed disturbance caused by windstorms is rather frequent. The amount of bark beetle salvage cuttings is rising in areas where the salvage cutting after windstorm failed or was delayed.

Mezei et al. (2014) studied factors that potentially influenced the interconnected system between wind and bark beetles. The study was done in mountainous area in Slovakia and Poland. The disturbance system (wind-bark beetle) was primarily influenced by forest stand factors (stand age and related changes in Norway spruce size and vitality). However, stand, site and solar radiation were the most important factors causing tree mortality in the epidemic phase.

**Figure 4.2**. The activity of Oak Pinhole borer (*Platypus cylindrus*) is highlighted by piles of fibrous frass that were handed out by adults during the creation of galleries in sapwood of oak stump. This borer has associated filamentous fungi that are distributed by adults in mycangia on their thorax and those fungi infested the oak wood and are diet for Oak Pinhole borer larvae.

## Questions for exam:

**Question 4.1.** Bark beetles might cause dieback of target forest trees in large areas of forests. In initial stage of outbreak, they mostly attack one or few weakened trees in one place of forest stand. If they kill the tree(s), they further spread to other areas of forest. What is the most used strategy of their spread at the forest stand level (< 10ha)?

**Question 4.2.** Bark beetles from genus *Ips* are one of the most important enemies for weakened conifer trees in Europe. These bark beetles are able to attack relatively healthy trees. What is their strategy with respect to feeding and creating of galleries?

**Question 4.3.** Clear-cut areas are highly attractive for many insect species and taxa. They offer high sun-exposure and high dimension dead wood in the form of stumps. What is the main group of insects that are causing damages on artificial seedlings in clear-cut areas?

**Question 4.4.** Ambrosia beetles (e.g. Platypodinae or genus *Xyleborus*) are mostly creating their galleries in sapwood of trees. Their adults have symbiotic fungi in their mycangia and these fungi are infesting beetle galleries. Fungi are known as ambrosia. Larvae are feeding on ambrosia and galleries get dark during the feeding process due to succession of fungal communities. The main impact of ambrosia beetles in forest protection occurs in…

**Question 4.5.** Sawflies (Hymenoptera) are one of the most important non-coleopteran (i.e. non-beetle) phloeoxylophages in forest protection. They have symbiotic fungi that helped them infest the tree and also during the feeding. Sawflies are species from…

**Question 4.6.** There are many species that are able to attack trees and feed under the bark. Early arriving phloeoxylophages are able to kill more or less healthy mature trees. Which groups of phloeoxylophages appears to be the most important with respect to commercial losses in forest protection?

**Question 4.7.** Bark and ambrosia beetles (Scolytinae and Platypodinae) are often associated with other organisms that help them to feed under the bark or in the wood. These associations are mostly beneficial to both taxa – beetles and associates, thus this relationship is called as symbiosis. Which organisms are the prevailing associates of bark and ambrosia beetles of subfamilies Scolytinae and Platypodinae?

**Question 4.8.** There are many ways how to protect forest stands against bark beetle attacks. Some of them are highly effective (e.g. trapping of high number of individuals), although some of them have several drawbacks (e.g. lowering efficiency during time period). What are the most effective methods in forest protection against bark beetles?

# Chapter 5: Defoliators and pests of seeds

Insect that is feeding on leaves, needles, fruits and seeds of forest trees is causing serious problems around the world. The most important representatives are lepidopteran caterpillars, some larvae of Sawflies (Symphyta: Hymenoptera) and adults and larvae of beetles. The other taxa are, of course, of importance, but excluding ungulates (that have their own chapter in this book) their damages have mostly only of local importance.

Insect harm trees from seedlings till the end of life of the tree. Many of them have highly synchronized development with their host plants. There are many potential pests that might limit growth of seedling of the trees – as several species that are not damaging leaves, but seeds and fruits of forest trees.

The main pests of seeds are butterflies (Lepidoptera) and beetles (Coleoptera). The larvae (and sometimes adults) of moths, weevils or wood-worms are feeding inside the seeds and fruits. Caterpillars of snout moths (Pyralidae) could be mentioned as an example – they are relatively common inside fruits or cones of forest trees and most of them are well recognizable due to presence of silk cocoons. Southern Pine Coneworm (*Dioryctria amatella*), known also as pitch moth is causing cone and shoot damages to the pines (*Pinus*) in North America. One of the most important beetle pests of seeds of broadleaved trees are weevils (Curculionidae) and wood worms (Anobiidae). Acorn weevil (*Curculio glandium*) has conspicuous adults due to their elongated snout (rostrum), which is longer in females than males and might reach more than one half of the length of an adult. Its larvae eat acorns from the inside.

Now back to the defoliators with the major impact on forest trees. In this case, the most important partitioning will be between defoliators on conifers and broadleaves. Broadleaved trees do not appear to be too sensitive to the activity of defoliators as conifer trees. The main reason is that they are able to restore their leaves from buds during vegetation season – although a bit different situation could be in the case of evergreen broadleaves that might be more sensitive. The main danger to the broadleaves lies in repetition of damages on leaves during vegetation season (e.g. defoliating moths and following leaf miners). The repetition of this damage can cause lower tree growth and fruiting. Furthermore, this situation may be worsened by damages on buds caused by several insect taxa – like caterpillars or e.g. adults of click beetles. Of course, there is also rising danger when several damages co-occur – like late frosts during spring time and defoliation. Caterpillars of the Gypsy moth *Lymantria dispar* are a good example of the defoliating free feeder, which is causing damages to the broadleaves in Europe and also as an alien in eastern North America.

Coniferous plantations are in possible threat nearly during the whole rotation period, but the most important time is approximately between 30 and 70 years. However, this is also highly dependent with climatic and geographic conditions. There are several taxa that are able to cause damages to the younger stands, but most of them are only an ephemeral problem. As an example may be mentioned is Pine Shoot Moth (*Rhyacionia buoliana*). This moth is causing damages or deformations to the buds and shots of pines and was introduced to whole America. The degree of damage to the forest stand, of course, depends on abundance of caterpillars. One of the first indications of high abundance before the needles are eaten or spun is amount of oval excrements on the forest ground. This can be perfectly measured when some light piece of cloth is attached on the forest ground. The second one option is glued strips around the stem that are catching flightless females. One of the most important defoliators in old continent is Nun moth *Lymantria monacha*. This species is able to kill healthy trees and several hectares of coniferous forest stands can be killed during a couple of years.

Seedlings and saplings in forest nurseries are also often in threat caused by defoliating insects. Especially, caterpillars or adults of weevils (e.g. *Otiorhynchus* spp.) are of high importance. However, the protection against them is much simple due to higher accessibility of forest nurseries. Pesticides (namely, insecticides) are one of the most used in the case of some species, although hand collecting as in agriculture for e.g. Colorado potato beetle (*Leptinotarsa decemlineata*) is also possible. Using of gloves is recommended in these cases, because caterpillars of some moths and especially their setae might cause allergic reactions. In this place it will be good to mentioned also aphids and similar insects that suck on the shoots of many tree species. This process weakens especially the seedlings and individual shoots and is able to kill them. The highest damages can be seen in forest nurseries.

Especially more recently, here are relatively many methods how to deal with high abundances of these pests. Probably the most efficient is spraying of some pesticide like pyrethroids – although here is a problem that this total insecticide kills all other insects (including beneficial organisms) presented on sprayed trees. The other are methods of biological control like using of inhibitors of development of caterpillars, use of more selective insecticides, use of fungal or bacterial pathogens – of which Gram-positive bacterium *Bacillus* *thuringiensis* is well known as abbreviation *Bt*- from agricultural (economic) plants. The use of nematodes (e.g. *Steinernema* or *Heterorhabditis*) appears to be also promising approach.

At the end of this introduction to the chapter of defoliators, it would be good to write that some defoliators insects are indexed in the law of the Czech Republic as pests that might cause calamities in forests – namely, Nun moth (*Lymantria monacha*), The Larch Tortrix (*Zeiraphera griseana*) and sawflies from genus *Cephalcia*.

**Figure 5.1**. Caterpillar of the Winter Moth (*Operophtera brumata*) crawling on the stem of oak. This species is abundant in Europe and its adults are active even in the depth of winter. Females are wingless. This species was introduced to the North America in 1930's. Species is well known from media (e.g. Boston Globe) due to its outbreaks in orchards in U.S.A.

## Examples:

**Example 5.1**. Peltonen M., Liebhold A.M., Bjornstad O.N., Williams D.W. (2002) Spatial synchrony in forest insect outbreaks: Roles of regional stochasticity and dispersal. ***Ecology*** 83: 3120-3129.

Population densities of forest defoliators mostly go through cycles – this means that very high population densities and thus high damages caused by defoliation activity by caterpillars are followed by decline in abundance and so on. Eastern spruce budworm (*Choristoneura fumiferana*) is mentioned to be one of the most destructive native insects in spruce and fir forests of the Eastern U.S.A. and Canada. Western spruce budworm (*Choristoneura occidentalis*) appears to be the most destructive defoliator of coniferous trees in Western part of North America. Larch bud moth (*Zeiraphera griseana*) is a coniferous defoliating moth that is native to the Europe. Forest Tent Caterpillar Moth (*Malacosoma disstria*) is a North American species that is distributed mainly in the eastern part of U.S.A. and Canada and defoliating deciduous trees. Gypsy moth (*Lymantria dispar*) is an alien pest in North America. It is one of the most destructive pests of hardwood trees.

Except of one bark beetle, Peltonen et al. (2002) studied five moths that cause damages to the forest by defoliation. Two of these species were studied in Canada (spruce budworm and forest tent caterpillar), two in U.S.A. (western spruce budworm and Gypsy moth) and one in Europe (larch bud moth). Even if temporal synchrony in several taxa is well known and studied, the situation in spatial synchrony was not well understood. Authors found that spatial synchrony was not directly associated with dispersal capabilities of particular species. The synchrony in outbreaks declined with geographical distance. Geographical variation in local population dynamics force synchrony to decline more rapidly with distance than the relationship with the environment.

**Example 5.2.** Raimondo S., Turcani M., Patocka J., Liebhold A.M. (2004) Interspecific synchrony among foliage-feeding forest Lepidoptera species and the potential role of generalist predators as synchronizing agents. ***Oikos*** 107: 462-470.

Oaks (*Quercus* spp.) in temperate zones are one of the most important commercial trees species, because their hardwood is very durable. There are more species of oaks in the Central Europe, while only two or three of them are of higher commercial importance. Native oaks were one of the most abundant tree species in this part of world before human intervention and thus taxa that is dependent on oaks belongs to the one of the richest around the world. Defoliating caterpillars have many types of strategies, while free-feeders and leaf-rollers are probably the most abundant in Slovakia.

Raimondo et al. (2004) studied the synchrony between sympatric populations of two or more species that are defoliators of oaks in Slovakia. They studied ten species of spring foliage feeding caterpillars sampled over a period of 25 consequent years. They found that nearly one third of interspecific pairs were synchronous and the highest correlation was among species exhibiting similar feeding strategies and thus morphologies.

**Example 5.3.** Payette S., Bhiry N., Delwaide A., Simard M. (2000) Origin of the lichen woodland at its southern range limit in eastern Canada: the catastrophic impact of insect defoliators and fire on the spruce-moss forest. ***Canadian Journal of Forest Research*** 30: 288-305.

So called lichen woodland is dominating forest type in boreal parts of Canada. The horizontal structure is highly homogeneous and is rather simple with two dominant strata – black spruce (*Picea mariana*) in sparse overstory and lichens in understory. This type of forest and its spatial structure is predicted to be highly driven by fires. Spruce budworm (*Choristoneura fumiferana*) and non-native European spruce sawfly (*Gilpinia hercyniae*) are one of the most common potential pests in lichen woodlands.

Payette et al. (2000) studied the dynamics of black spruce dominated sparse woodlands of boreal Canada. They tested the hypothesis that the lichen woodland is a regressive type of more humid spruce–moss forests that were affected by fire disturbances. Lichen spruce and spruce moss stands that grew under similar soil conditions were compared using tree size, tree ring patterns, and macrofossil analysis of organic soil. The most important result was that all the macrofossils of plants that were buried in the organic part under the charcoal layer corresponded to a moss forest and included head capsules of the spruce budworm or European spruce sawfly. Thus, defoliating activity of insects together with fires could degrade the forests – in this case from humid moss to sparse lichen woodland.

**Example 5.4.** Meigs G.W., Kennedy R.E., Cohen W.B. (2011) A Landsat time series approach to characterize bark beetle and defoliator impacts on tree mortality and surface fuels in conifer forests. ***Remote Sensing of Environment*** 115: 3707-3718.

As defoliators are important forest disturbance agents, mapping of their effects on mortality of trees and forests represents an important issue in forest protection. Remote sensing provides information about objects without making physical contact. The use of aerial sensor technologies to detect and classify objects on Earth is the major method. Most studies of remote sensing have focused on single species or single locations and not changes to the ground.

Except of the impact of bark beetle, Meigs et al. (2011) studied the impact of defoliation by western spruce budworm (*Choristoneura occidentalis*) in U.S.A. using remote sensing of forests. Many types of forests were studied ranging from mesic mixed-conifer to xeric lodgepole pine. They found that sites damaged by the western spruce budworm appeared to show a consistent temporal evolution of long-duration loss of vegetation followed by its recovery.

**Example 5.5.** Kyei-Poku G., Gauthier D., Van Frankenhuyzen K. (2008) Molecular data and phylogeny of *Nosema* infecting Lepidopteran forest defoliators in the genera *Choristoneura* and *Malacosoma*. ***Journal of Eukaryotic Microbiology*** 55: 51-58.

As defoliators are causing damages to the forest ecosystems, their population densities are naturally controlled by their enemies. Obligate intracellular parasite (or pathogen-they are presently listed as fungi, but they were formerly listed as primitive eukaryotes) species from genus *Nosema* are recently highly studied, especially that they can cause serious damages to the domestic bees. As mentioned above in this chapter spruce webworms (*Choristoneura* spp.) are causing serious damages to North American forests and especially coniferous are the most jeopardized, while forest tent caterpillar (*Malacosoma disstria*) is a defoliator of broadleaved forests.

Kyei-Poku et al. (2008) studied species from genus *Nosema* in five moth pests in U.S.A. Spruce budworm (*Choristoneura fumiferana*), jack pine budworm (*Choristoneura pinus*) and western spruce budworm (*Choristoneura occidentalis*) are defoliators of coniferous forests, and large aspen tortrix (*Choristoneura conflictana*) and forest tent caterpillar (*Malacosoma disstria*) are pestic agents to the broadleaved trees. These species were collected from various locations across North America. Authors found that each moth species tended to have its own species-specific *Nosema* species.

**Example 5.6.** Vanhanen H., Veteli T.O., Paivinen S., Kellomaki S., Niemela P. (2007) Climate change and range shifts in two insect defoliators: Gypsy moth and nun moth-a model study. ***Silva Fennica*** 41: 621-638.

The Nun Moth (*Lymantria monacha*) and the Gypsy moth (*Lymantria dispar*) are one of the most important defoliators of coniferous and broadleaved forests in the central Europe, respectively. Ongoing global change in climate might cause range shifts of many taxa and potential pests are not an exception. Ectothermic animals, like insects, are expected to shift their distribution ranges northwards toward presently less climatically suitable places in Northern Hemisphere.

Vanhanen et al. (2007) studied possible range shifts of Nun and Gypsy moths within the change in recent climatic scenario. They used life cycle requirements of particular species for modelling, because this measure reflects probability of a viable population to exist at a certain location. They modelled three degrees in increasing of temperatures. The possible climate warming shifted the northern boundary of the distribution area for both studied species by 700 km northward. Furthermore, the shift of southern distribution limit was retracted northwards by 100–900 km.

**Example 5.7.** Scriber J.M. (2004) Non-target impacts of forest defoliator management options: Decision for no spraying may have worse impacts on non-target Lepidoptera than *Bacillus thuringiensis* insecticides. ***Journal of Insect Conservation*** 8: 243-263.

Forest protection shifts from non-selective pesticides to still more and more selective matters. Even, if this shift appears to be highly environmentally friendly, there are several non-pestic and thus non-target taxa that might be very sensitive even to highly selective insecticides. Spraying of microbial pesticides such as those with strains of *Bacillus thuringiensis* is often mentioned as highly selective and influencing only lepidopteran pests. On the other hand, this insecticide might affect the whole Lepidoptera and thus also those that are under the threat from the nature conservation point of view.

Scriber (2004) described study from laboratory and field studies that were conducted to determine non-target impacts of *Bacillus thuringiensis* on native Lepidoptera in North America. He found that no spraying may have worse impacts on non-target Lepidoptera than insecticides with *Bacillus thuringiensis*. He further concluded that the important concept that must be maintained is that all pest management programs have some risk of negative non-target impacts.

**Example 5.8.** Holusa J., Kuras T. (2010) Diurnal behaviour of *Cephalcia lariciphila* (Hymenoptera: Pamphiliidae): Relation to climatic factors and significance for monitoring. ***European Journal of Forest Research*** 129: 243-248.

The Web-spinning Larch Sawfly (*Cephalcia lariciphila*) is a pest that defoliates European larch (*Larix decidua*) and could be regarded as its specialists. This species can also reach outbreak levels. Even when European larch is most probably non-native tree to the most of Europe, this tree is of high commercial importance due to quality of wood. Repeated defoliation of larches might result in a decrease of annual growth ring formation and trunk thickness and decrease might reach 70%.

Holusa & Kuras (2010) studied the day activity of this defoliating sawfly in the Czech Republic. The species start its activity during mid-April and last specimens flew at the beginning of June. Adult occurrence typically lasted about 20 days. The species diurnal activity was highly associated with temperature in interaction with humidity – adults were most active at 16 °C with 20% air humidity. The flight activity starts at 10 AM and ended at 5 PM.

**Figure 5.2.** Eggs hatched gregariously by the Vapourer (*Orgyia antiqua*) to the spruce twigs. This species is relatively opportunistic with respect to host trees, because can cause defoliation on both broadleaved and coniferous trees. Females of this abundant species have reduced wings and abundance of Vapourer is often correlated with other insect defoliators.

## Questions for exam:

**Question 5.1.** The activity of defoliators might cause dramatic changes in forest ecosystems and also commercial losses. Majority of defoliating insects in temperate forests are discriminating between coniferous and deciduous (broadleaved) trees. Which trees – conifers or broadleaves – are more sensitive to the defoliation?

**Question 5.2.** The species richness of caterpillars (larvae of Lepidoptera) depends on more factors in the conditions of temperate zone. The main ones are suitable climate, historical distribution of host tree or leaf palatability. Which tree species appears to be the most species rich on moths (Lepidoptera) in conditions of temperate central Europe?

**Question 5.3.** Many threats to the forests are highly interconnected. Interaction of two or more disturbance agents might cause hard change in spatial structure of the forest type and in some cases might cause its degradation. Which interacting factors appear to be the major disturbance threats in boreal forests?

**Question 5.4.** There are many techniques how to map the damages caused by insect pests. We could divide them easily to those that are done physically in forest stand (e.g. tree traps) and those that are done without physical contact (e.g. observation from airplane). What is one of the mostly used modern techniques made without physical contact, while mapping the distribution of damages caused by defoliators?

**Question 5.5.** Caterpillars (larvae of Lepidoptera) in many cases cause damages to the forest trees, because they reduce the photosynthetic activity of trees and, furthermore, they are able to kill trees. Their population densities are often reduced by natural enemies and the most well-known are those that are conspicuous (e.g. large carabid beetles) or well visible (e.g. woodpecker birds). There are several taxa that might highly influence the activity and also fecundity of many forest pests, even if they are not conspicuous. Obligate intracellular parasites from genus *Nosema* are from the point of view of taxonomy…

**Question 5.6.** There are many species of defoliators in central Europe. While many of them are of less importance, there are two lepidopteran taxa from the same genus (family of Tussock moths, Lymantriidae) that have caused many outbreaks in their native distribution area and at least in one case also in North America. One of them damages coniferous, while the second one broadleaved forest trees. What are these two most important defoliators of the central European forests?

**Question 5.7.** Forest protection uses many types of pesticides and insecticides are those that kill insects. One of the main problems is that many non-target species might be negatively affected. Thus, one of the solutions seems to be use of highly selective insecticides. What type of insecticides appears to be the most environmentally friendly against lepidopteran defoliators?

**Question 5.8.** The most important defoliators in forests are caterpillars of Lepidoptera. On the other hand, there are several other taxa that can cause damages to the leaves or needles of forest trees. Which taxa (except of Lepidoptera) appears to be important defoliator?

# Chapter 6: Fungi

Fungi, together with slime molds, are highly diversified taxa and their impact to the forestry is as diversified as their species richness. Furthermore, the importance of fungi is very high also after the timber harvest.

Fungi causing damages to the forests might be divided with respect to the manner of their impact on target tree species. Wood-decaying fungi, mainly conspicuous due to presence of fruiting bodies, are highly important in the last stages before the end of rotation period (i.e. harvest). Fungi that are causing losses in defoliation (leaves and needles) or seeds and fruits are the most important during the first stages of forest stand growth and also in forest nurseries.

The forest protection in forest nurseries might be in some cases very intensive with respect to the number of interventions (e.g. spraying of fungicides) and also with respect to amount of used chemicals. The protection against foliage damaging fungi is highly dependent on climate. For example, the damages caused by Red Band Needle tended to be higher after mild winters. In the case of forest nurseries, the forest protection is mostly based on spraying of fungicides. This approach appears to be relatively successful in forest nurseries, although its application possibility in forest stands is highly complicated regarding the accessibility.

Some potential pathogens like blister rusts could be named as those somewhere between. For example, the white pine blister rust (*Cronartium ribicola*) is first attacking leaves of currant (*Ribes*) species, which is not important from the point of view of commercial forestry, but its second host is the eastern white pine (*Pinus strobus*). This tree is important species from the point of view of forestry and timber industry. Furthermore, white pine blister rust is able to kill most of the other five needle pines. One of the good protection measures is removing of intermediate host plants.

The influence of wood-decaying fungi is, hence, important because of its occasional latency – this means that most damages could be hidden till the time of harvest. Of course, if the fungi do not fruit, there are some symptoms that could be used for detection of tree attacked by wood-decaying fungi. The symptoms are, for instance, enlargement of the base of stem or presence of resin on the stem. On the other hand, the symptoms might be highly variable with respect to the natural conditions of the forest stand.

The protection against defoliating agents is much simpler than against those that are attacking the wood. Since, most damages of inner wood are consequences of injuries (wounds) on stems of trees – the main protection against the wood decaying fungi is the use of considerate technologies during the forest operations.

**Figure 6.1**. Approximately three-years old stand of artificially planted Scots pine (*Pinus sylvestris*) seedlings. Needles on lower branches were attacked by Red Band Needle (*Mycosphaerella* (syn. *Dothistroma*) *pini*).

## Examples:

**Example 6.1.** Barnes I., Crous P.W., Wingfield B.D., Wingfield M.J. (2004) Multigene phylogenies reveal that red band needle blight of *Pinus* is caused by two distinct species of *Dothistroma*, *D. septosporum* and *D. pini*. ***Studies in Mycology*** 50: 551-566.

Red Band Needle (*Mycosphaerella* (syn. *Dothistroma*) *pini*) is a fungal pathogen causing needle cast of pine trees. Its attack often cause significant defoliation, decrease in growth and in some cases also death to the tree. This pathogen is most important in pure pine plantations and its importance decrease with rising height of a tree. High losses are often in plantations of Christmas trees.

Barnes et al. (2004) studied Red Band Needle using genetic analyses. They studied *Dothistroma septosporum*, which is a widely distributed pathogen of many pine species. They found that Red Band Needle is caused by two distinct species. One species (*Dothistroma septosporum*) is found worldwide, while the other (*Dothistroma pini*) is restricted to the North-Central U.S.A.

**Example 6.2.** Hood L.A., Swaine M.D., Mason P.A. (2004) The influence of spatial patterns of damping-off disease and arbuscular mycorrhizal colonization on tree seedling establishment in Ghanaian tropical forest soil. ***Journal of Ecology*** 92: 816-823.

*Milicia regia* from family Moraceae is a pioneer tree of West Africa. This species is threatened by habitat loss and logging, because it is important timber tree. It grows in the high forests and savanna and especially on well-drained soils. Strong and durable timber is known to be resistant to damages of wood-boring insects and fungal attacks.

Hood et al. (2004) used shade house experiments to examine the influence of light and soil source from beneath and away from conspecific adults on mortality and growth of seedlings of *Milicia regia*. They focused on fungal pathogens (damping-off of seedlings) and mycorrhizal colonization. The study was done in Africa, namely in Ghana. Application of fungicide reduced mortality in shaded, but not in exposed seedlings. Furthermore, in interaction with other studied factors, this study showed that Janzen-Connell spacing mechanisms of escape from the parent tree increases their survival rate.

**Example 6.3.** Wingfield M.J., Hammerbacher A., Ganley R.J., Steenkamp E.T., Gordon T.R., Wingfield B.D., Coutinho T. A. (2008) Pitch canker caused by *Fusarium circinatum* – a growing threat to pine plantations and forests worldwide. ***Australasian Plant Pathology*** 37: 319-334.

Pitch canker (*Fusarium circinatum*) is important pathogen of pines (*Pinus* spp.) worldwide. This pathogen is a serious threat to the commercial plantations of exotic pines. Like other species of genus *Fusarium*, it is the asexual reproductive state of the fungus and has a teleomorph – *Gibberella circinata*.

Wingfield et al. (2008) reviewed the status of this disease around the world. The most typical symptoms of the pathogen are large resinous cankers on trunks and lateral branches, although other parts as roots, shoots, female flowers and mature cones, seed and seedlings can also be affected. Thus, they found that symptoms of this disease differ with host species, geographical region and associated insects. This is highly important information and means that forest protection against this pathogen appears to be very difficult. The disease is frequently associated with reduced yields and high levels of tree mortality in certain areas.

**Example 6.4.** Brasier C.M., Buck K.W. (2001) Rapid evolutionary changes in a globally invading fungal pathogen (Dutch elm disease). ***Biological Invasions*** 3: 223-233.

Dutch elm disease (*Ophiostoma ulmi* and *Ophiostoma novo-ulmi*) caused two pandemics within the 20$^{th}$ century. This results in the death of mature elms (*Ulmus* spp.) across the northern hemisphere. This disease spreads using host bark beetles (mainly *Scolytus* spp.) that are feeding on elms. Formerly this was a symbiotic fungus that helps *Scolytus* species during feeding in bast of elms. However, this pathogen went through some ecological shift and starts to be highly destructive and killing pathogen of elms.

Brasier & Buck (2001) reviewed the knowledge about Dutch elm disease. *Ophiostoma ulmi* destroyed elms across Europe, North America and Southwest and Central Asia approximately during the period between World War I and II (1920s–1940s). *Ophiostoma novo-ulmi* followed the spread of the previous one and it has also spread as two distinct subspecies (*Ophiostoma novo-ulmi americana* and *Ophiostoma novo-ulmi novo-ulmi*). Nevertheless, this resulted in competitive interactions between these previously geographically isolated pathogens. This topic has been highly studied and a final conclusion appears to be still on the way.

**Example 6.5.** Vasiliauskas R. (2001) Damage to trees due to forestry operations and its pathological significance in temperate forests: a literature review. ***Forestry*** 74: 319-336.

Several species of bracket and other fungi attack wounds caused by logging operations quite quickly. Some bracket fungi are known to have highly dispersal spores. Any operation in forest is a potential threat due to wounds caused by forest operations like harvester travels, extraction of wood by horses and so on. The highest damages appear to be done during the clear cutting, because of presence of heavy duty technologies. On the other hand, while using mechanization there are also many potential threats to the younger stands, because any wound is potential habitat for wood-inhabiting fungal pathogens.

Vasiliauskas (2001) made review of recent knowledge about damages caused by operations in forest stands with respect to the pathological significance. He mentioned that trees in old stands are often damaged during selective logging using mechanization. Furthermore, damages are more significant when harvest occurs in summer months. The highest proportion of damages occurs during timber transportation from forest stand and most wounds can be found near the base of the tree. Wounds are mostly attacked by fungal pathogens and they cause significant financial losses due to decay of several meters of butt log.

**Example 6.6.** Dai Y.C., Cui B.K., Yuan H.S., Li B.D. (2007) Pathogenic wood-decaying fungi in China. ***Forest Pathology*** 37: 105-120.

Biological diversity of China still remains relatively unclear. The main problem is that China is one of the largest countries in the world. The knowledge about fungi species native to the China is of high importance, because many of them have become aliens in other parts of the world – and not only wood-decaying fungi.

Dai et al. (2007) surveyed wood-decaying fungi on living trees in China during twelve years. They found more than 100 species. More than 85% of found fungal species are known to cause white type of rot. The highest proportion of wood-decaying fungi were polypores from the Aphyllophorales (Basidiomycota).

**Example 6.7.** Vartiamaki H., Uotila A., Vasaitis R., Hantula J. (2008) Genetic diversity in Nordic and Baltic populations of *Chondrostereum purpureum*: a potential herbicide biocontrol agent. ***Forest Pathology*** 38: 381-393.

Silver leaf caused by pathogen *Chondrostereum purpureum* is a disease of trees. This fungus mostly attacks the rose family (Rosaceae) and especially fruit trees are the most exposed. Thus, form the first sight the importance for commercial forestry is not so high, although some fruit trees have highly expensive timber (e.g. Cherry trees). The disease after attack is progressive and for many individual trees fatal. It cause silver color of leaves and fruiting bodies are mostly in the places of wounds, because spores attack the sapwood. *Chondrostereum purpureum* has been reported to be a promising bioherbicide of weeds form the rose family that are sprouting from stumps (e.g. black cherry, *Prunus serotina*).

Vartiamaki et al. (2008) studied the diversity of genes of *Chondrostereum purpureum* in Finland and Lithuania. They were also interested in its potential as bioherbicide. Authors found that the genetic diversity of this species was very high, although the diversity within populations was low. They further concluded that due to this reason, the use of this species as biocontrol agent might bring a risk of introduction of non-indigenous genotypes. Especially, in the case when a highly pathogenic isolate of *Chondrostereum purpureum* will be used as a biocontrol agent.

**Example 6.8.** Norden B., Ryberg M., Gotmark F., Olausson B. (2004) Relative importance of coarse and fine woody debris for the diversity of wood-inhabiting fungi in temperate broadleaf forests. ***Biological Conservation*** 117: 1-10.

Fungi are not always pests and they can help to the foresters during the process of forest protection. For instance, some species are decaying stumps and harvest residuals (e.g. branches) and during this they also could improve nutrient status of the topsoil. Many species are also rare or threatened. There was a prediction that most species are at risk due to absence of coarse woody debris in the harvested forests.

Norden et al. (2004) studied the difference in number of fungal species between coarse and fine woody material. The study was done in temperate forests in southern Sweden. The species richness of studied fungi was, relatively surprisingly, higher for fine woody debris than for coarse woody debris. Furthermore, three thirds of ascomycetes were found on fine debris, exclusively. Thus, fine woody material is of high importance and furthermore many species of fungi are able to help with its decay and compete for it with potential pests (e.g. six-toothed spruce bark beetle *Pityogenes chalcographus*).

**Figure 6.2.** Pole stage stand of naturally regenerated exotic eastern white pine (*Pinus strobus*) in the Czech Republic. Many trees are attacked by white pine blister rust (*Cronartium ribicola*) and many of them were killed.

## Questions for exam:

**Question 6.1.** Many needle casts are causing decline to coniferous trees through the world. They reduce the photosynthetic activity of trees and cause decrease in their growth. Needle casts like Red Band Needle (*Dothistroma septosporum*) are threats to…

**Question 6.2.** There are many fungal pathogens that are not conspicuous such as bracket fungi. On the other hand, many of them are able to cause high commercial losses in forest nurseries. What is one of the main threats caused by complex of fungal pathogens in forest nurseries with respect to the losses on germinated seedlings?

**Question 6.3.** Species from genus *Fusarium* are filamentous fungi distributed in soil and in association with plants. Many species are harmless, although some species produce mycotoxins that affected human health. With respect to the forestry, several species of *Fusarium* fungi are pathogens of target forest trees. *Fusarium* fungi are causing…

**Question 6.4.** Like many other tree species, elms (*Ulmus* spp.) are often killed by association of bark beetles and their associated fungi. This disease was first found in Netherlands and then spread to the northern hemisphere. What is the name of this disease and organisms causing this disease?

**Question 6.5.** Forestry operations during harvest of timber can cause damages to the forest stands. More heavy duty technologies are used more damages could be expected. The main damages to the forest are due to wounds on stems of individual trees, especially in lower part of stem. What are the main organisms that attack wounds caused by forestry operations and which cause following decay of living wood?

**Question 6.6.** As wood is relatively nutrient poor substrate, fungi have disparate systems how to attack and consume the wood. We divide the rot caused by fungi to the three types: white (degrade all the structural wood components), brown (leave the lignin relatively unaltered) and soft (caused spongy consistency of wood). What is the dominant type of rot in temperate and tropical forests?

**Question 6.7.** Several organisms are used as biocontrol agents of forest pests and pathogens. Fungi are one of the promising organisms. What appears to be the main risk in their use as a bio-herbicides?

**Question 6.8.** Bracket (i.e. shelf) fungi have mostly highly visible fruiting bodies (conks). Because their main impact is inside the wood, the protection against them is prevention. In which age of forest stands are bracket fungi the most important from the perspective of forest protection?

# Chapter 7: Vertebrates

Vertebrates are one of the most conspicuous organisms that cause damages to the forest stands. Their body size varies from few centimeters and grams of small vertebrates like mice (*Mus* spp.) to withers height over than two meters and weight close to one ton in some bovines. Nevertheless, the body size does not need to be a correlate for amount of damages in forests.

The smallest vertebrates like voles (*Microtus* spp.) have highly fluctuating population densities and thus their total body size might outnumber the body size of some large ungulates. Also the damages caused by voles during the peak of their population densities might be higher than those caused by herd of wisents (*Bison bonasus*). Voles cause one of the greatest damages to the forest stands in the time when they go through the peak in population densities. They are the most harmful in afforested clear-cuts and on natural tree regeneration under the canopy of mature forest stands. They cause damages to the roots, because they severe seedlings. Moreover, they also damage bark of seedlings. This kind of damage is often caused also by hares (*Lepus* spp.) and rabbits (e.g. *Oryctolagus cuniculus*). Furthermore, small rodents like squirrels (*Sciurus* spp.) or dormouse (Gliridae) often forage on seeds of target tree species.

Beaver (*Castor* spp.) as rodent with large body size and the second largest rodent on Earth is able to cut down mature trees. Even if, there appears to be some preference of beavers to softwood broadleaved trees like poplars and aspens (*Populus* spp.) together with willows (*Salix* spp.), beavers cause also damages on all other target tree species during the building of their dams and homes. Their damages might be relatively dangerous within the woodlands that are close to human settlements, because beavers are able to cause local floods or falls of trees on the roads with higher intensity of transport. Forest protection against damage by beavers is considerably complicated in the European Union, because Eurasian beaver (*Castor fiber*) is protected by legislation.

Several species with medium-large body size like roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*) are mostly foraging within both forest and agricultural landscapes and, thus, their damages are sometimes season-dependent. This is, for example, the case of males of roe deer that fray on saplings during the time of marking of their territories. Hogs often grout in upper soil and uprooted seedlings and feed on seeds during the winter time.

Wild ungulates with large body like red deer (*Cervus elaphus*) cause nearly the same damages like other deer and moose (Cervidae), although it seems that they are more dependent on woodlands. The largest damages are mostly at the end of vegetation season, when they search for minerals and strip the bark of mature trees. This causes damages to the commercially important part of the tree – i.e. lower part of the stem. During the winter time they often browse on seedlings and feed on buds. In this place it will be good to write, that not only ungulates cause damages to the forest trees, because e.g. bears (*Ursus* spp.) sometimes damage trees – well known are damages caused by claws of male bears on endemic Pinsapo fir (*Abies pinsapo*) in Spain.

Many approaches against damages of ungulates are presently used. Except of human regulation of their population densities by shooting and natural regulation caused by factors like predation, there are several other relatively effective approaches. One of them is use of repellents, although it is indicated that especially wild boars often become accustomed to repellents. Relatively good way is alternation of different substances (e.g. smell and odor repellents).

During the time of protection against small rodents, poisonous traps were sometimes used. However, their impact on environment could be higher than commercial losses caused by small rodents and poisonous traps are prohibited in some states. Other mechanical approaches are for example the use of fences around the clear cuts – unfortunately, they are not so much effective against wild boars, hares and rabbits. Another option is individual tree protection, like tree guards – mostly plastic for broadleaves and wire for conifers. In this place, it would be good to write that there are many other possibilities how to protect target tree species against vertebrates, while some of which are country or site dependent or specific.

**Figure 7.1.** Silver fir (*Abies alba*), Scots pine (*Pinus sylvestris*) and European hornbeam (*Carpinus betulus*) naturally regenerated in the spruce bark beetle (*Ips typographus*) gap and under the canopy of Norway spruce (*Picea abies*) stand. Pine is damaged by fraying. Fir and hornbeam are browsed by roe deer (*Capreolus capreolus*) that reach high game stocks in rural agricultural-forest landscape of the Central Europe. Only regeneration of Norway spruce is left undamaged by high game stocks.

## Examples:

**Example 7.1.** Bratton S.P. (1975) The effect of the European wild boar, *Sus scrofa*, on gray beech forest in the Great Smoky Mountains. ***Ecology*** 56: 1356-1366.

Wild boars (*Sus scrofa*) are still increasing abundance in their former area, even if before no more than one century were close to extinction. This vertebrate was introduced during 1940s to the North America and colonizes many new places. The species surely has some impact on forests, however, its damages in forestry appears not to be as high as in agriculture. Moreover, this species might be a beneficial, because of its omnivorous diet, which part are also larvae of insect pests.

Bratton (1975) studied this species in Great Smoky Mountains National Park in U.S.A. His main aim was to find possible impact of this exotic species on native ecosystem. He measured canopy and understory in both hog occupied and hog free areas. The activity of wild boars had no significant impact on canopy species. Hog rooting was highest in places with high moisture and decreased toward dry sites. Rooting activity reduced species richness, but not the diversity, which showed relatively high values in disturbed plots.

**Example 7.2.** Motta R. (1996) Impact of wild ungulates on forest regeneration and tree composition of mountain forests in the Western Italian Alps. ***Forest Ecology and Management*** 88: 93-98.

Forests in Europe in less accessible areas are often damaged by high game stocks. The main types of damage are bark stripping on mature trees, which is lowering the outcomes from the timber, browsing on seedlings and saplings and fraying caused by antlers of males. Red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*) are one of the most important damaging ungulates in many parts of Europe.

Motta (1996) studied the impact of ungulates on forests in Italy (Europe). He focused on bark stripping, browsing and fraying. He found that the damages on forest regeneration occurred from approximately 10 % to nearly 80 %. The most sensitive tree species was silver fir (*A. alba*). Browsing and bark stripping was more selective than fraying, although there was a difference in fraying between red and roe deer. He also found that fraying caused high lethality under relatively low game stocks. Damages caused by browsing increases rapidly under high game stocks.

**Example 7.3.** Curtis P.D., Jensen P.G. (2004) Habitat features affecting beaver occupancy along roadsides in New York state. ***Journal of Wildlife Management*** 68: 278-287.

Beaver (*Castor* spp.) is known to be highly effective ecosystem engineer that is creating habitats for many other species. On the other hand, its activity could bring potential threat when closing to the human settlements and infrastructure. Beaver is able to cut trees of high dimensions and thus is able to cause local floods or closing of highly frequented roads.

Curtis & Jansen (2004) studied what habitat parameters are suitable for the presence of beaver. The study was done in U.S.A. The aim was to find implications for management suitable for presence of beaver and avoidance of damages to the roads. They found that with rising proportion of woody vegetation along roads there was also rising amount of damages caused by beaver. Thus, the main implication would be impractical – removal of trees along the roads, although this result might have some practical impact, especially, during establishment of new roads.

**Example 7.4.** Huitu O., Kiljunen N., Korpimaki E., Koskela E., Mappes T., Pietiainen H., Henttonen H. (2009) Density-dependent vole damage in silviculture and associated economic losses at a nationwide scale. ***Forest Ecology and Management*** 258: 1219-1224.

Small mammals as voles are able to cause damages to large areas of woodlands. Their damages are mostly correlated with cycles in their population densities. This means that in some years of lethal phases they are close to be rare, while in the time of the peak of their population densities it is nearly impossible to prevent forests against vole damages. Their damages are also important that they occur worldwide. Voles mostly forage of on roots, bark and seeds of target forest tree species, they also severe tree seedlings.

Huitu et al. (2009) studied impact of vole populations in the time, when population densities were highest for over fifteen years in Finland. They found that vole destroyed nearly 5 million tree seedlings with total cover of area of 2,600 hectares. Moreover, 80% of damages were on the commercially most important tree species – Norway spruce (*Picea abies*). Even if, it is hard to predict high population densities of voles in the future, they find that damages during the winter time were correlated with abundances in previous autumn. This might be an effective monitoring tool for damages caused by voles in forests.

**Figure 7.2.** Several forest tree species like European ash (*Fraxinus excelsior*) are able to outgrow the damages caused by browsing of wild ungulates. The main problem is that the most commercially important part of the stem (i.e. lower part) is deformed and these individuals will be cut before mature age or the yield in mature age will be significantly lower.

## Questions for exam:

**Question 7.1.** Larvae of some insect pests overwinter in the forest soil. It is very hard to kill them using any known mechanical or chemical approach. However, there are several natural enemies (e.g. fungi or bacteria) that are able to decrease the numbers of larvae in the soil. <u>What is one of the most efficient medium-large vertebrates that cause reduction of the number of pest larvae in the soil?</u>

**Question 7.2.** Large ungulates cause many types of damages in forests. These damages are mostly seasonally dependent. This means that e.g. seedlings are mostly not browsed during the summer months, when game has diversified supply of food. <u>What is the name for damages caused by antlers of males of deer?</u>

**Question 7.3.** Beaver (*Castor* spp.) is the second largest rodent in the world. This animal is highly dependent on aquatic environment and it needs woody plants for building of its dams, canals, and lodges (homes). <u>What kind of damages to the forest is caused by beaver?</u>

**Question 7.4.** Population densities of voles (*Microtus* spp.) are going through cycles. When these small rodents reach high abundance, they become serious pests for forest stands and forest nurseries. <u>Small mammals like voles cause the highest damages to the…</u>

# Chapter 8: Beneficial organisms

Many species appear to be potential threats for commercial success in forestry. On the other hand, many others are neutral, or even beneficial from point of view of forest protection. The most beneficial organisms in forest protection appear to be fungi and animals – particularly insect predators and parasitoids, pathogens, and predatory birds.

Beneficial organisms could be divided into those (i) that cause decline in population densities of pests or weeds and (ii) those that help forest protection with some particular problems. For example, parasitic (parasites and parasitoids) and predatory taxa that forage on insects, which cause damages to the forests are the example which belong to the first box. The same beneficial effect can have fungal pathogens of insects and weeds and last but not least also hunters with their impact on game stocks. Of course, in this case is the term beneficial organism a bit inappropriate. The second case are organisms that help to the forest protection in some particular cases – like saproxylic insects and fungi that cause decay of stumps and other woody debris. These organisms that are thus competitors of potential pests as large Pine Weevil (*Hylobius abietis*).

It is well known that birds and namely woodpeckers are predators of bark beetles and the same effect have other birds on phytophagous insects – especially on caterpillars. Nevertheless, bird predators are rather taxon (or species) unspecific – i.e. they are generalist predators. The same case is with the ground beetles (Carabidae) of which many species are more or less specialized. However, they are able to forage on more taxa in some cases. For instance, adults of genus *Calosoma* known as caterpillar hunters have the population density level highly interconnected with lepidopteran defoliators. As mentioned above, hunters are one of the ways how to reduce high game stocks. Nevertheless, in ecosystems that are more natural or semi-natural (like boreal parts of Asia and North America) there can be seen high impact of large predators (wolves, lynxes and bears) – some of which are more (lynx) or less (bear) specialized on prey. It is also known that generalist insect predators are more efficient in endophytic predation, while more specialized ones are exophytic predators (e.g. under the bark of a tree).

Specialized predators and parasitoids are one of the most beneficial organisms in forest protection. Population densities of their prey do not need to be the only one factor that influenced predators and parasitoids and thus it is often studied what are the other factors that influencing population densities of predators and parasitoids. One of the examples could be clerid beetle *Dermestoides sanguinicollis*, which is a predator specialized on oak wood-worm beetles (Anobiidae). This clerid beetle is, in conditions of central Europe, associated with sun-exposed trees, and thus its foraging success on wood worms is greatly decreased toward oaks in dense forests.

Both predators and parasitoids are mostly dependent on chemical communication and three main components are mentioned by authors – (i) communication within the same species (intraspecies), (ii) recognition of odors of trees damaged, weakened or even inhabited by prey and finally (iii) hacking of its prey communication. The most efficient and successful predators are able to communicate on more levels. Unfortunately, this may lead to very high specialization and thus these species need to be highly synchronized with prey. Example is clerid beetles (Cleridae) like *Thanasimus dubius*, whose adults are arriving on host tree before its prey (use of hacking of communication of its prey). They are also mentioned that they are able to smell the odor of damaged trees – nearly in the same way as in olfactory system of their prey. When prey is arriving and start to dwell into the bark, predatory clerids are calling the other individuals of the same species (intraspecific communication) that quickly arrive and kill bark beetles (exophytic predation). They mate and oviposit close to the entrance holes of bark beetles. Their larvae forage on larvae of bark beetles under the bark (endophytic predation).

In the case of predators is also questionable if the species is obligate predator (like Cleridae), facultative predator (like some larvae of click beetles (Elateridae) are predators, while adults are not) or opportunistic predators (like flat bark beetles (Cucujidae)). Very good example are forest ants (Formicidae). Some species are extremely greedy predators (some *Formica* species) that are able to clear the forest stand from other arthropods. Nevertheless, many other ant species are only facultative predators or opportunists. Even some of them, which have high body volume, which enabled them to prey on arthropods – this is the case of Carpenter ants (*Camponotus* spp.). They are foragers that typically eat parts of other dead insects or substances derived from other insects – like in some ant species that lick substances on aphids. Beetles, ants and birds are most probably the most efficient predators. Although, there are many others that are of importance – e.g. small mammals like some shrews (Soricidae), reptiles like lizards (Lacertidae), several flies (Diptera), wasps (Hymenoptera), bugs (Heteroptera), snakeflies (Raphidioptera) or dragonflies (Odonata).

Traditionally, parasites and parasitoids are referred primarily to organisms visible to the naked eye – so called macroparasites (not only insects, but e.g. helminthes or protozoans). Nevertheless, here are also many other microparasites like viruses and bacteria, which impact on pests and weeds could be high. Although, the present stage of knowledge is still rather low. An example could be fungi *Beaveria bassiana* (Clavicipitaceae), some of which strains are insect pathogens. The research on these fungi is in progress and this fungus was more or less successfully used against bark beetles or bugs (but mainly in laboratory). Contrary to *Beaveria bassiana*, relatively well known is bacteria *Bacilllus thuringiensis*. Some of its strains are recently used in forest protection and it is also well known as a part of *Bt*-economic plants. This bacteria has been often used against insect defoliators – like Gypsy moth (*Lymantria dispar*), which was introduced into North America in 1869 from Europe. Viral preparations are also used against lepidopterans.

In some cases it is hard to distinguish if it is parasitism or if better name is disease, pathogenity etc. Parasitism (at least the visible part of this process) is mostly restricted to the insects and hymenopterans and dipterans are probably the most efficient ones. Highly visible are also so called hemiparasites like mistletoes (*Viscum* and *Loranthus*) that are mostly interconnected with mature and overmature trees. Same as in predation on insects, parasitism starts on eggs and finishes on adults. There are known several species of trichogrammatid wasps (Trichogramma) that parasitize on eggs of bark beetles. Eulophid chalcid wasps like *Entedon* species are ovipositing into eggs and early instars of larvae of their prey. Pteromalid chalcid wasp *Rhopalicus tutela* is ectoparasitoid of larvae. There are also several species that are endoparasitoids of adults – like another pteromalid *Tomicobia seitneri*. Parasitoids seem to be rather species or taxa specific, while the errors in literature do not make final conclusions for species specificity so easy. One example of the species with rather nonspecific hosts is pteromalid wasp *Dendrosoter middendorfi.*

Last but not least group of beneficial organisms are dead wood dependent (saproxylic) organisms. If we exclude those that are potential pests and pathogens, we may find that there are many taxa that are potentially beneficial for forest ecosystems. Probably the most important saproxylic taxa are beetles (Coleoptera) and fungi. The others are Hymenoptera, lichens (lichenized fungi) and bryophytes (e.g. mosses). The present agenda on the research on saproxylic organisms indicate that they are beneficial and their impact is the most important in highly spatially (both horizontally and vertically) diversified environments.

**Figure 8.1.** Female of parasitic ichneumonid wasp *Dolichomitus mesocentrus* laying their eggs into some larva (probably longhorn) under the bark of the Black Alder (*Alnus glutinosa*).

## Examples:

**Example 8.1.** Aukema B.H., Raffa K.F. (2002) Relative effects of exophytic predation, endophytic predation, and intraspecific competition on a subcortical herbivore: consequences to the reproduction of *Ips pini* and *Thanasimus dubius*. ***Oecologia*** 133: 483-491.

As the abiotic disturbances and insect outbreaks appear to be more frequent in present years, the role of specialized predators on bark beetles is still much more studied. Pine Engraver Beetle (*Ips pini*) is a bark beetle native to North America. It kills weak and damaged trees of small diameters, although when reach high population densities its damages might become more important especially in pine plantation forests. *Thanasimus dubius* is a predatory clerid beetle specialized on bark beetles. Its adults are arriving before or with bark beetle adults and kill them immediately. Females of this clerid beetle are laying their eggs nearby the entrance holes of bark beetles and clerid larvae start with the predation inside of the galleries.

Aukema & Raffa (2002) studied the effect of exophytic and endophytic predation of *Thanasimus dubius* on Pine Engraver Beetle. They found that clerid adults and larvae can efficiently reduce the densities of *Ips pini*. Higher number of individuals of predators decreased the progeny and males of prey. However, when clerid adults increased the abundance on bark surface then the predation per adult decreased. Predation of larvae and adults of clerids on bark beetle was nearly the same, although adults ate nearly 20 times more prey than larvae.

**Example 8.2.** Edworthy A.B., Drever M.C., Martin K. (2011) Woodpeckers increase in abundance but maintain fecundity in response to an outbreak of mountain pine bark beetles. ***Forest Ecology and Management*** 261: 203-210.

Birds and especially woodpeckers are known as predators of bark beetles. They are mostly high efficient predators on insects that are able to forage even on prey inside the tree trunks. They are known to increase their abundances in the places where some forest disturbance occur and high densities of insect prey are presented. Although, their predation abilities are well known, there is question if they are also able to increase their fecundity during the time when food supply is increasing.

Edworthy et al. (2011) studied the fauna of temperate woodpeckers in British Columbia (U.S.A.) and relationship to the increasing number of prey after the mountain bark beetle (*Dendroctonus ponderosae*) outbreak. They have studied this problematic for 15 years. Six species of woodpeckers were evaluated: downy woodpecker (*Picoides pubescens*), hairy woodpecker (*Picoides villosus*), American three-toed woodpecker (*Picoides dorsalis*), pileated woodpecker (*Drycopus pileatus*), northern flicker (*Colaptes auratus*), and red-naped sapsucker (*Sphyrapicus nuchalis*). The number of individuals of woodpeckers increased during the years of bark beetle outbreaks. Even if, it is known that woodpeckers are relatively conservative in their fecundity, it was relatively surprising that despite the year-round multi-annual increase in food resources their annual fecundity was not increased – even when most of other bird species strongly increased their fecundity.

**Example 8.3.** Pettersson E.M., Birgersson G., Witzgall P. (2001) Synthetic attractants for the bark beetle parasitoid *Coeloides bostrichorum* Giraud (Hymenoptera: Braconidae). ***Naturwissenschaften*** 88: 88-91.

Parasitoids of potential pests are known to be efficient biological control. Ectoparasitoid wasp (*Coeloides bostrichorum*) is a parasitic species of late instars of coniferous bark beetle larvae and especially two most important spruce bark beetles in Europe – Spruce bark beetle (*Ips typographus*) and six-toothed bark beetle (*Pityogenes chalcographus*) – are its main hosts. It is known that this parasitoid species appears to be specialized. This species could be relatively abundant, although its ecology was poorly understood.

Pettersson et al. (2001) studied the host searching strategy of adults of *Coeloides bostrichorum* under the laboratory conditions. They found that oxygenated monoterpens were typical for bark beetle damaged trees, while monoterpene hydrocarbons were more typical for healthy trees of the Norway spruce (*Picea abies*). Parasitoid wasp was the most attracted by odours from spruce logs that contained late instar larvae of bark beetles. However, when fresh logs that were uninfested by bark beetles were baited by combination of suitable odours, adults of *Coeloides bostrichorum* were arriving on them. This reflected the situation that most predatory and parasitic taxa are highly dependent on chemical communication – and especially hacking of prey communication is one of the most important.

**Example 8.4.** Prikryl Z.B., Turcani M., Horak J. (2012) Sharing the same space: foraging behaviour of saproxylic beetles in relation to dietary components of morphologically similar larvae. ***Ecological Entomology*** 37: 117-123.

The larvae of flat bark beetles (Cucujidae) and fire colored beetles (Pyrochroidae) are often mentioned as predators of species living under the bark of trees, including bark beetles and other potential pests. The European flat bark beetle (*Cucujus cinnaberinus*) is red-listed by IUCN, while two fires colored beetles *Schizotus pectinicornis* and *Pyrochroa coccinea* are relatively common in central Europe. Mostly based on observations, several authors mentioned that their extremely flat bodies and environment predicted them to foraging on other insects. Nevertheless, observations of other beetle taxa associated with the microhabitats of flat bark beetles and fire colored beetles are only scarce.

Prikryl et al. (2012) studied larvae of these three potentially predatory taxa in the wild during more years. There were few significant differences in diet among the study species, but there were significant differences for the different dietary components in individual species. Guts of all three species included more plant and fungal material than animal. On the other hand, they observed significant differences among species and selection with respect to body size during the overwintering period – larvae swallowed more animal and less fungal material with increasing body size. The species seem to be only opportunistic foragers, varying their foraging capability according to seasonality and age. They probably generally foraged woody material infested by filamentous fungi (i.e. xylomycetophagy).

**Example 8.5.** Horak J., Vodka S., Kout J., Halda J.P., Bogusch P., Pech P. (2014) Biodiversity of most dead wood-dependent organisms in thermophilic temperate oak woodlands thrives on diversity of open landscape structures. ***Forest Ecology and Management*** 315: 80-85.

Dead wood dependent organisms are often known as saproxylics. These species are dependent at least in some part of their life on dead wood. Saproxylic organisms are decomposing the woody material that was left in forest and thus they are beneficial in forest protection – e.g. they forage inside the stumps, where compete with potential pests. On the other hand, many of potential pests are indexed also as saproxylics – like bark beetles. The most studied and well known taxa are beetles and fungi. Nevertheless, studies on comparison of more taxa were lacking.

Horak et al. (2014) studied four saproxylic taxa – beetles (Coleoptera), Aculeata Hymenoptera, fungi and lichens (i.e. lichenized fungi) in the woodland area of thermophilic deciduous woodland in the Czech Republic. They found that saproxylic organisms are the most positively influenced by rising diversity and openness in disparate landscape structures. Solitary trees, natural forest edges and sparse forest stands hosted higher biodiversity than closed canopy stands. Only fungi were not responding to studied landscape patches. Thus, most saproxylic organisms preferred high spatial heterogeneity of mature stands. Traditional forest management like wood pasturing, coppicing or its simulation like game keeping appears to be one solution to mitigate biodiversity loss.

**Figure 8.2**. Larva of some predatory clerid beetle (probably *Thanasimus formicarius*). Larvae of most clerids forage endophyticly on insects living under the bark, while adults are exophytic foragers on adults of bark beetles arriving on bark surface of attacked trees.

## Questions for exam:

**Question 8.1.** Clerid beetles are one of the most efficient insect predators of bark beetles. Both adults and larvae prey on all life stages of bark beetles. The predation of larvae of clerid *Thanasimus dubius* takes place…

**Question 8.2.** There are many bird species that prey on potential forest pests. Several of them are more specialized than the others – e.g. on caterpillars or on bark beetles. What are the most efficient bird predators specialized on bark beetles?

**Question 8.3.** Parasitoids kill their host, while parasites not. Although, parasites mostly caused damages to their inner organs – for example bark beetles are not able to reproduce after parasitism of *Tomicobia seitneri*. Adults of parasitoids mostly lay their eggs inside the body of their prey. What are one of the most important endophytic (i.e. under the bark) parasitoid taxa that forage on bark beetles?

**Question 8.4.** Forests are home for myriads of organisms. Many of them are beneficial, because they help to decompose the woody debris after the timber harvest. What is the name for beneficial organisms that help to decay the woody residuals?

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